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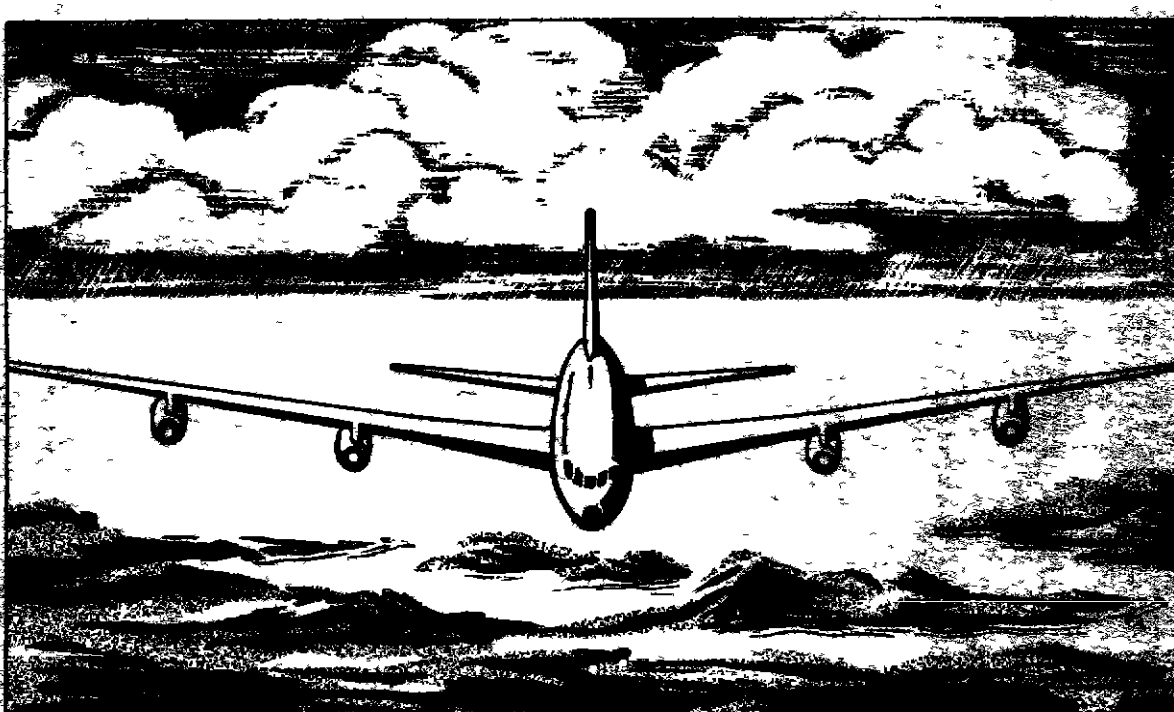

A REPORT ON

AIRPORT LIGHTING AND MARKING SYSTEMS

A Summary of Operational Tests and Human Factors, Report I of 3

Prepared for RESEARCH DIVISION
by HUMAN SCIENCES RESEARCH, INC.

MAY 1959

For sale by U S Department of Commerce
Business and Defense Services Administration Office of Technical Services,
Washington 25, D C

This report has been reviewed and is approved for distribution.

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Foreword

The attack on today's complex technological problems necessarily goes forward on a broad front, with specialists or experts concentrating on particular parts of the same problem An agency having responsibility for seeing that problem-solution proceeds systematically must develop some means of keeping abreast of over-all development and distributing information in useful form to those working on different aspects of the same problems

The Federal Aviation Agency (FAA) has as one of its areas of responsibility the problem of insuring effective airport marking and lighting This study was focused on bringing together available operational test data and human factors knowledge relevant to airport marking and lighting systems. This report represents a summary of our present state of knowledge from an operational viewpoint. At the same time, the report helps chart a course for future research and development required by existing and anticipated demands on airport marking and lighting systems

The authors express their appreciation to Dr H R Van Saun, FAA Project Manager, and Dr R. K. McKelvey, both of the Human Factors Branch, Operations Analysis Division, Bureau of Research and Development, for their many contributions during the study and in preparation of this report.

Mr. C. A Douglas and Mr. F C Breckenridge of the National Bureau of Standards provided invaluable guidance and technical information as consultants to the authors under a separate contractual agreement between the National Bureau of Standards and the Federal Aviation Agency

Several other persons of long acquaintance with airport marking and lighting willingly contributed their time and experience to the study Early discussions with these men provided the authors with an otherwise unavailable background in the operational and developmental status of airport marking and lighting. In addition, their assistance was invaluable in identifying and locating many of the important reports reviewed in the study. The authors acknowledge their indebtedness to these men.

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PREFACE

This report is one of three volumes* on airport marking and lighting systems prepared for the Federal Aviation Agency by Human Sciences Research, Inc. Its immediate purpose is to provide systematic guidance for operational installations that must proceed with new construction and cannot wait for the results of the Bureau of Research and Development research program. At the same time, the report contains theoretical analyses and reviews of operational requirements in support of the extensive Federal Aviation Agency research and development program It is also written to serve as a basic reference work on airport marking and lighting design principles. An outline of research and development requirements is included.

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* See footnote on following page

*The full series consists of:

Vol. I - Lybrand, W. A., Vaughan, W. S., Jr., and Robinson, J. P. Airport Marking and Lighting Systems: A Summary of Operational Tests and Human Factors. May 1959

Vol. II - Lybrand, W. A., Vaughan, W. S., Jr., and Robinson, J. P. Airport Marking and Lighting Systems: A Summary of Operational Tests and Human Factors: Selected Annotations and Bibliography. May 1959

Vol. III - Lybrand, W. A., Vaughan, W. S., Jr., and Robinson, J. P. Airport Marking and Lighting Systems: A Summary of Operational Tests and Human Factors: Condensed Report. (This is a special short version of Vol. I directed to the general non-technical reader).

Report Summary

The purposes of this study of airport marking and lighting were

- 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 applicable to the problems identified

Available operational test results from the beginning of the Landing Aids Experiment Station program at Arcata in 1946 to the Dow Air Force Base tests in 1958-9 were summarized and organized according to the system or component evaluated These are

Beacons	Threshold Lights
Angle of Approach Indicators	Runway Signs, Marks and Lights
Approach Lights	Taxiway Signs, Marks and Lights
Hazard Marks and Lights	

In order to identify problems requiring research and development, functions served by the airport marking and lighting (AML) system were examined in six selected flight modes

- Initial Approach (VFR)--including entry into traffic pattern
- Circling (VFR)--including downwind and base legs
- Final Approach (VFR and IFR)
- Flareout and Landing--including runway rollout
- Turnoff and Taxiing
- Takeoff.

The extent to which pilot information requirements in each flight mode are being satisfied by the AML system was examined initially on the basis of integration of available operational test data These data were supplemented by information from the following additional sources

Published studies and analyses of the pilot's tasks and recommended designs for airport marking and lighting systems by individuals (e g , Calvert), interested groups (e g , IATA), and agencies (e g , CAA)

Interviews with commercial and military pilots and with personnel engaged in marking and lighting research at both civilian and military agencies

A number of problems identified involved questions of limits of human capabilities and the fundamental nature of how a pilot sees and utilizes visual information reflecting his movement Human factors experimental research literature was reviewed for results relevant to solution of these problems

In general, current and anticipated inadequacies of airport marks and lights were found in each flight mode in terms of how well pilot information requirements are satisfied A few of the critical problems identified in this study, phrased in terms of functional requirements which the AML system does not completely satisfy, are

Initial Approach------- visual identification of active runway in day and night Visual Flight Rules (VFR) operations

Circling-------------- directional guidance during downwind and base leg in night and marginal day VFR operations

Final Approach------- height guidance under all operational conditions, region of guidance to be provided by approach lights for Instrument Flight Rules (IFR) operations, including optimal beam widths and intensity settings of approach light units and strobe-beacons

Flareout and Landing---	height guidance over the runway to touchdown in night and IFR operations, runway distance remaining information
Turnoff and Taxiing----	anticipatory identification information of high-speed turnoff exits, taxiway route identification for airport ground movement
Takeoff---------------	runway distance remaining information, directional guidance on runway during take-off run in night operations
Total AML System-----	a resolution of the apparent conflicts between standardization goals and economic realities and among differing requirements of military, commercial, and civil traffic

Many of the problems identified are the focal points of current research and development For others, analysis has progressed to the point where semi-operational or operational evaluations are in order Still others will require initiation of research and development in order to determine basic facts and data on which solutions can be based An outline identifying the areas in which further work is necessary is presented in the report

Technical discussions and analyses supporting the flight mode functional analysis are attached to the report as Technical Notes A catalogue of marking and lighting literature is presented in a separately bound Appendix In the Appendix, annotations and bibliographies of published materials reviewed during the study are organized in a form easily usable by airport design engineers and research personnel engaged in airport marking and lighting work

Table of Contents

List of Illustrations

Chapter I

Introduction

Background and Purposes

Background

The well-recognized heavy demands on all parts of the nation's air traffic control system are expected to increase at a continuing rapid rate Total Visual Flight Rules (VFR) aircraft operations forecast for 1963 are double those actually occurring in 1957 This rapid growth rate will be accompanied by a wider spread, or divergence, of aircraft performance characteristics in the traffic load, along with a higher general level of speed of aircraft movement These new factors tend to make air traffic control demands different in kind as well as heavier in number (GA34)

The airport marking and lighting (AML) system is an essential part of the over-all air traffic control system In this role, the AML system must provide timely and accurate visual guidance to pilots in order that air and ground traffic can be processed quickly, efficiently, and safely

A clear picture of the status and capability of the current AML system is required as a first step in programming and coordinating the research and development which will insure future effectiveness of this important link in the air traffic control system

Purposes

The underlying objective of this study 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 on AML sub-systems and components

To identify unresolved problem areas requiring immediate and future research and development

To review human factors research data relevant to the problem areas identified

Sources of Information

To achieve the study's purposes, information from many different sources was collected, sifted and integrated Because the study was based on these sources of information, they serve to define the study scope in terms of both the kinds of state-of-the-art information surveyed and the time period covered by the survey

Operational Tests

The term "operational test" covers evaluations made in an actual operating situation (as opposed to a laboratory or analytic evaluation) typically using flight data of one type or another The purpose of an operational test is to see how well an AML design actually does the job it is supposed to do Results of such tests represent fruitful sources of knowledge about the "in-being" status and capabilities of the AML system

All available reports on operational tests conducted from 1946 to the present were reviewed. This time period is defined by the beginning of the Landing Aids Experiment Station program at Arcata, California and the tests conducted on narrow-gauge runway lighting at Dow Air Force Base, Maine

Primary attention was given to tests which helped establish present National Standards and to more recent tests focused on filling recognized deficiencies in the AML system.[1]

Problem Areas

In order to identify unresolved problem areas, results of operational tests were supplemented by information on the AML system appearing in a variety of sources studies appearing in journals of scientific societies and associations, industry periodical articles and features, recommendations of national and international aviation groups, and reprints of speeches and discussions at conventions and meetings Again, all available literature in this category appearing between 1946 and the present was reviewed for the study.

Information from these sources was augmented by interviews with commercial and military pilots and with personnel engaged in on-going research and development activities

Human Factors Data

Using professionally recognized handbooks of human factors data as starting points, results of experimental research on human capabilities involved in AML problem areas were reviewed Generally speaking,

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[1] During the course of surveying operational test results, the authors necessarily touched upon many other accounts of endeavors in the history of airport marking and lighting An historical account was beyond the scope of our study, however Such a history does not exist in writing, to our knowledge The authors found Mr. F C Breckenridge and Mr. C A. Douglas of the National Bureau of Standards well-versed in the exciting and interesting events surrounding the developmental progress of airport marking and lighting It is hoped that these gentlemen can be persuaded to find the time to prepare an historical account of this colorful part of national aviation history.

research studies of the last decade were focused on, but results of earlier studies were included when appropriate In addition to "applied" human factors studies on AML related problems, research reviewed included reports in professional journals covering aviation medicine, applied experimental psychology, and experimental human physiology

Key Ideas Used in Study

It became obvious early in the study that a consistent way of looking at the AML system was required in order to meaningfully handle the different kinds of information contained in the sources used A number of key ideas were formulated which established a foundation for much of what was done in the study and is contained in this report These basic concepts may not be readily apparent or explicitly stated in the body of the report Three are briefly presented here to give the reader a context, or frame of reference, for placing the chapters following in perspective The interested reader is referred to Technical Note 1 for additional discussion of the underlying approach used in the study

A Continuing AML Need Assumed

Because electronic navigational aids for all-weather flying are being developed, the viewpoint has been expressed that contact flight is on its way out However, it was assumed in this study that pilots will use information provided by the AML system for some time to come, particularly in flights under good weather conditions and in the final stages of poor weather approaches and landings Even with the most advanced electronic navigational equipment envisioned as an aid to pilots and air traffic controllers, the viewpoint taken in this study was that the AML system probably will be indispensable as a cross-check reference for the pilot on equipment functioning and as a back-up system for use if equipment fails

From both short-range and long-range viewpoints, it was assumed desirable for AML to present all visual information required to successfully perform airport ground-reference contact flight tasks

AML Viewed as a Single Design

A system may be defined as a set of interacting parts having a central functional purpose In this study, airport marks and lights were considered to be parts of a single airport marking and lighting system The central purpose of the system was considered to be presentation of required visual information (visual guidance) to pilots A distinction is made in this definition between structures (parts) and functions (purposes). A survey of the state-of-the-art must consider both aspects of the AML system

Organizing Operational Test Data Structures can be used as a starting point and information about them organized according to the extent to which they satisfy all design requirements This was the approach utilized in bringing together the results of operational tests In this way, attention was given not only to design requirements stemming from the guidance functions of the AML system, but to other design characteristics and requirements as well, such as installation and maintenance In this sense then, the survey of operational tests was comprehensive with respect to what we know about AML system hardware

Identifying Critical Unresolved Problems The central purpose of the AML system provided a practical and sound way of identifying the most critical unresolved problems From this viewpoint, primary design requirements for structures stem directly from the visual guidance function of the system All other requirements are secondary in the sense that, even if satisfied by the system or its parts, they are meaningful only if the primary requirements are being met For identifying critical unresolved problems, pilot information requirements during terminal flight modes were used to organize information concerning the extent to which the AML system is achieving its central purpose

The Pilot as a Design Constant

It is becoming more and more obvious that scientific and technological advances in machine design are taxing man's control capabilities to their fullest In order to adequately realize the benefit of these advances, control of machines must be tailored to human capabilities The basic characteristics and capabilities of man are not likely to change and can be viewed as a design constant in man-machine developments This viewpoint was used as a basis for selecting and organizing human factors research data relevant to unresolved problems It was recognized that basic data from other related sciences and disciplines (e g , aeronautical engineering, physical optics, illumination engineering, meteorology) will contribute to solution of many airport marking and lighting problems However, survey of relevant information in these areas was beyond the scope of the present study

Organization of the Report

Chapter II (Pages 9-68) presents an integration of operational test results The chapter concludes with a brief commentary on what has been learned at a general methodological level about the conduct of operational tests, a summary picture of a typical current airport marking and lighting installation, and a review of on-going operational tests

The extent to which airport marking and lighting systems are satisfying pilot-aircraft control information requirements in the various flight modes is analyzed in Chapter III(Pages 69-136) This includes human factors knowledge about human capabilities relevant to marking and lighting problems identified

An outline of problem areas in which further research or development is necessary is presented as Chapter IV (Pages 137-141)

A series of Technical Notes (1 through 6) follows the main body of the report These are technically oriented discussions and analyses of assumptions, concepts, information and problems underlying much of the analysis of AML functions in flight modes (Chapter III).

Throughout the report, references are indicated by code numbers in parentheses at the end of paragraphs (e g., AL10). These code numbers refer to annotations and bibliographical entries which are contained in the Appendix. The Appendix has been bound separately so that it may more conveniently serve as a catalogue of airport marking and lighting information.

Chapter 2

Operational Test Results from Arcata to Dow

Test results are summarized and grouped in sections according to the kind of marking or lighting systems or components operationally evaluated Results are discussed in the following order

Beacons

Angle of Approach Indicators

Approach Lights

Threshold Lights

Runway Signs, Marks and Lights

Taxiway Signs, Marks and Lights

Hazard Marks and Lights

The information presented in each section is organized around four main topics

Design Requirements Used as Standards A combined discussion and list of requirements is presented first These represent the standards against which marking and lighting units were designed or evaluated. Unfortunately, this facet of operational tests was inconsistently reported in the literature although it is a most critical bit of information. The sections of this chapter, being based on what has appeared in the literature, reflect such inconsistencies, both in concept and terminology

Designs Tested Commonly accepted names, or labels, of the specific hardware systems tested are listed next

Summary of Test Results In this part of each section, the systems or components tested are described Test data and conclusions from the reports reviewed are included

Component Development Information. The last part of each section summarizes the developmental status of components involved in the systems discussed, as reflected in published reports of tests or evaluations conducted on the components. In order to focus the reader's attention on the component and relevant data, manufacturer's names have been omitted from this discussion, and all others throughout the report. Perusal of the references in the Appendix will frequently reveal the manufacturer involved, in other instances, the referenced report will have to be examined

References to published materials containing the data or information discussed are placed in parentheses at the end of paragraphs in order not to interfere with the reader's continuity of thought. Numbers in the parentheses identify annotations and bibliography entries in the separately bound Appendix.

A brief commentary on operational tests and a summary picture of the present status of airport marking and lighting are presented in the final section of the chapter

Beacons

Design Requirements Used as Standards

Location and Identification of Airport

The pilot needs a distinctive signal which will clearly locate and identify the airport from as great a distance as possible To be useful, an initial identification device

(1) should be visible and identifiable from a distance of 30 miles at altitudes of 25,000 to 30,000 feet when visibility is "unlimited",

(2) should not produce glare to pilots during any of their airport operations [2]

Location and Identification of Active Runway

Generally speaking, the greater the distance from the airport that the pilot locates and identifies an active runway, the more efficiently he can plan and execute his entry into the traffic pattern and approach Minimum acceptable visual range for recognizing the duty runway in unlimited visibility conditions is 3 miles for civil operations, and 5 miles for military operations Included in the category of visual aids serving this function have been all lights which will help the pilot orient his aircraft to the runway during downwind, base, and final legs in good visibility

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[2] The reader is referred to GA9-A which provided much of the information for this section, and which represents the most comprehensive and competent treatise found on the subject The report contains very thorough intensity distribution requirements analyses for visual landing aids (other than approach lights) as well as summary statements, reflecting the latest thinking of its author, on equipment components and patterns designed to meet the requirements.

During a circling approach, the pilot should know·

(1) distance from runway and runway centerline orientation so that downwind leg can be flown parallel to and at desired distance from runway,

(2) location of threshold, distance from threshold and orientation of runway centerline during turn from downwind leg to base leg, on base leg, during turn from base leg to final approach

When making a straight-in approach or on final approach the pilot should know

(1) location of and distance from the threshold,

(2) location and orientation of the runway centerline [3]

Designs Tested

(1) Single beacons

(2) Turntables of beacons at 1000 and 2000 feet from threshold on extended runway centerline.

(3) Rotating beacons (170 degrees coverage) at threshold corners of runway.

(4) Condenser discharge lights with baffle (30 degrees coverage) at threshold corners of runway.

(5) Counter-rotating beacons at threshold corners of runway.

(6) Circling guidance lights along edges of runway.

Summary of Test Results

Single Beacons

Present civil beacons emit 12 flashes per minute, alternately green and white. Beacons at military airports emit a dual white and single green flash. (See Figure 1.) (S3)

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[3] Douglas, et al., op. cit.

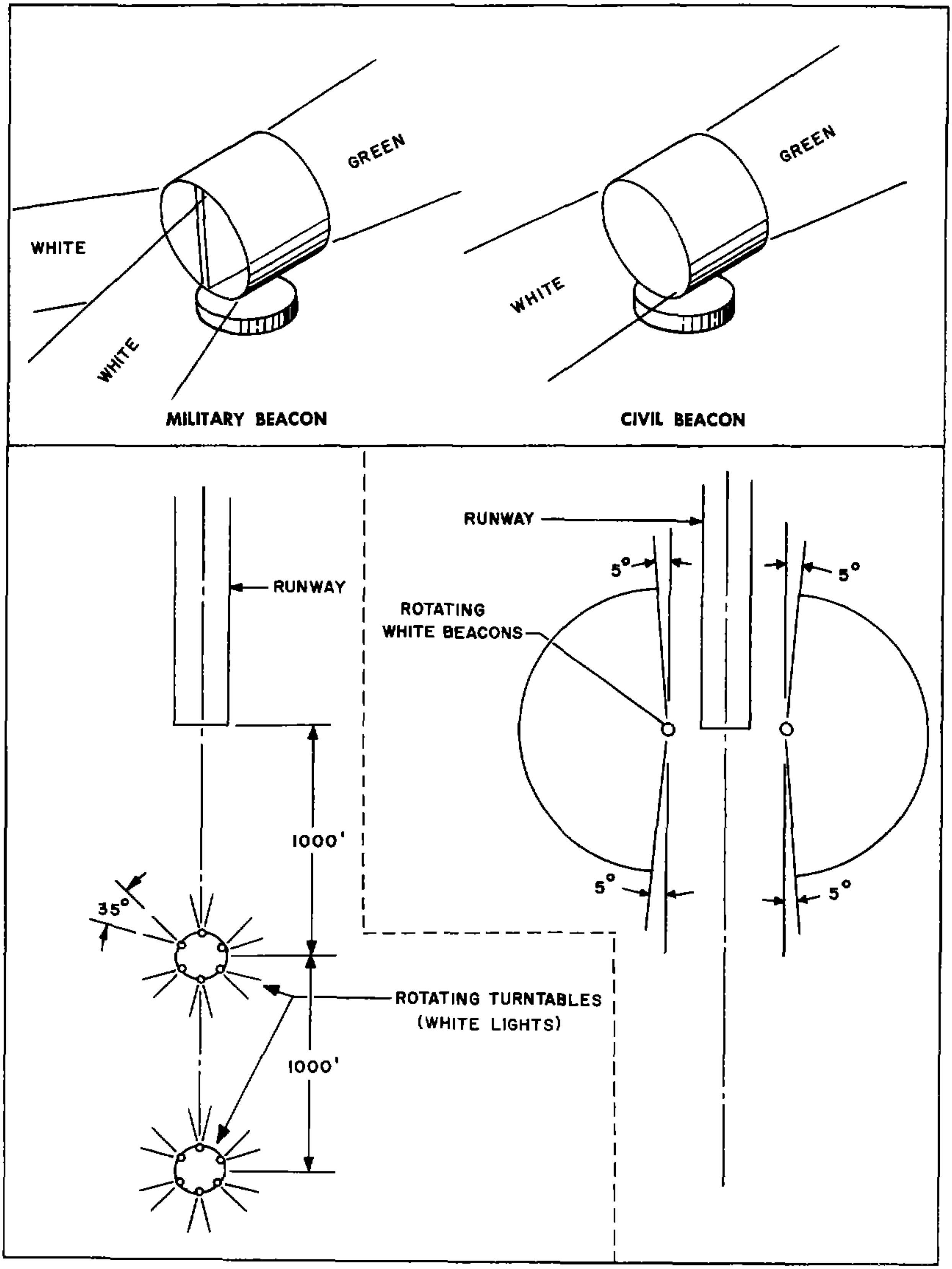

GREEN
WHITE
WHITE
MILITARY BEACON
GREEN
WHITE
CIVIL BEACON
RUNWAY
1000'
35°
ROTATING TURNTABLES
(WHITE LIGHTS)
1000'
RUNWAY
5°
5°
ROTATING
WHITE BEACONS
5°
5°

Figure 1

Relatively little change in design of airport beacons can be reported for the past 25 years. In 1957, however, a new 1200-watt, 115-volt lamp with larger vertical coverage was operationally tested in airport beacons at Wright-Patterson Air Force Base (AFB). The development was aimed toward more adequate servicing of jet aircraft Beacons with these new lamps were reported to have much better visibility characteristics than the standard beacon for aircraft operating above 15,000 feet This modified beacon was visible from aircraft flying at altitudes up to 40,000 feet close to the airport (6 to 20 nautical miles) while the beacon utilizing the standard lamp was not visible at these ranges It is felt that, with this new lamp, present beacons have attained maximum visibility characteristics short of a complete and costly re-design of the fixture. At this time, the advantages to be gained by such a design development program seem negligible (C20, C36)

Approach-Beacons (Turntables of Beacons)

This system utilizes steady-burning incandescent approach lights arranged on a turntable which rotates to give the appearance of a flashing light These lights are placed on the extended runway centerline to provide guidance and runway identification for straight-in and instrument approaches, as well as circling approaches, in visibilities as low as 1 mile (B3)

In 1948, turntables with ten lights, developed by the National Bureau of Standards (NBS), were flight tested at Patuxent River Naval Air Station (NAS) by the Navy Pilots reported that units positioned 1000 and 2000 feet from threshold as in Figure 1 provided sufficient directional guidance for landing under VFR conditions (B3)

During the past few years, NBS has been experimenting with and testing this concept at Arcata Optimum positioning of units appears to be at 1000 and 2000 feet from threshold, optimum flash rate about 72 per minute, and optimum flash duration from 0 3 to 0 4 seconds. Six beacons on each turntable are used instead of ten Test pilots again have found the system very useful and have indicated that it provides adequate guidance for most approaches Service test installations at El Toro, California and Oceana, Virginia are currently anticipated (B3)

Runway Identification Lights (Rotating Beacons)

It was found at Wright Air Development Center (WADC) in 1956 and 1957 that rotating beacons, giving 360 degrees coverage and located as in Figure 1, assisted pilots in locating the active runway when inbound to an airfield, but had adverse effects on pilots during ground operations The lights have recently been baffled to overcome this shortcoming, but no evaluative reports on this modified assembly were located It was not intended that the lights operate without shielding, they were designed for 170 degrees coverage The negative evaluation during ground operations apparently was a function solely of the operational test situation in which the lights were not baffled It appears that the modified beacons soon will be service tested at Norfolk, Virginia [4] (B2, C43)

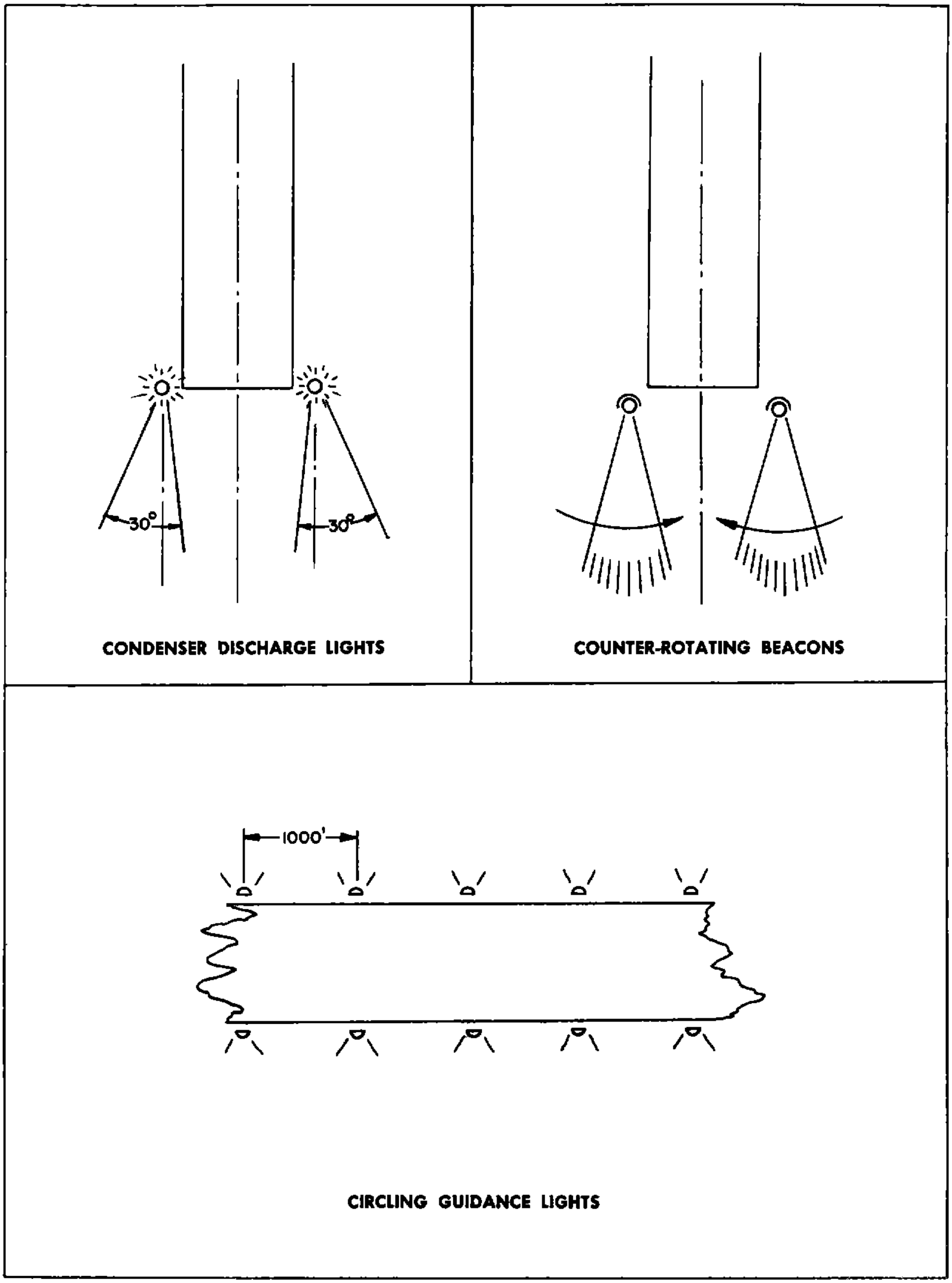
Runway-End Identifiers (Condenser Discharge Lights)

In 1958, WADC tested condenser discharge lights positioned as in Figure 2 for use as runway-end identifiers Use of a baffle to effect partial cutoff 1000 feet from threshold, along with other adjustments to the fixture, eliminated glare and made the lights suitable for use These lights give fairly wide vertical coverage and were reported to be of great assistance to pilots in determining their position with respect to the runway (B1)

Counter-rotating Beacons

The principle of counter-rotating beacons involves use of a pair of identical projectors, one projector located on each side of the runway threshold (see Figure 2) Projectors are synchronized to rotate at the

[4] Personal communication between the authors and Mr R Hartz, Navy Department


30°
30°
CONDENSER DISCHARGE LIGHTS
COUNTER-ROTATING BEACONS
1000'
CIRCLING GUIDANCE LIGHTS
Figure 2

same speed in opposite directions, and are so timed that both beams are along the approach axis at the same time interval For a pilot on the axis of the approach system, the flashing lights appear synchronized If he is off course to either side, the lights appear to flash separately and to jump toward the axis, thereby giving a corrective indication

In 1952, this system was service tested by the Civil Aeronautics Administration (CAA), Technical Development Center (TDC) at Indianapolis Airport, with the units located 3500 feet apart laterally at the threshold It was concluded that the beacons would facilitate circling approaches and final approaches by furnishing accurate on-course indication [5]

In an operational test at Weir Cook Airport, Indianapolis, in 1955, the beacons were installed in conjunction with threshold bars At that time, the system was considered to be of potential value, but no further conclusions or recommendations were made (TL1)

CAA (now Federal Aviation Agency, FAA), which first proposed the system, apparently has abandoned the idea This is evidently the result of reports of difficulty in pilot interpretation and problems of maintaining synchronization of the two beacons [6]

Circling Guidance Lights

In 1954, TDC tested a controllable-beam runway light which was designed to approximate an ideal candlepower distribution previously determined from an analysis of runway light requirements For experimental purposes, 1200 feet of these lights were installed at General Mitchell Field, Milwaukee, Wisconsin Flight testing of these lights

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[5] Pearson, H J C. Experimental counter-rotating marker beacon Indianapolis Civil Aeronautics Administration, 1952 (Report No 160)

[6] Personal communication between the authors and Mr Orrin Farris, FAA

showed that, while the lights did not entirely satisfy theoretical requirements, they did give satisfactory guidance for straight-in and circling approaches (C17)

Further evaluation of these units was continued by TDC at Milwaukee through 1957 It was concluded, with minor reservations, that under minimum weather conditions for circling approaches the lights gave adequate circling and straight-in guidance (C18)

In 1955, NBS further studied the problem of developing special lights, to be used in combination with runway lights, which would provide guidance to pilots during circling approaches Theoretical intensity-distribution requirements were determined by a study of approach patterns used by aircraft, as indicated in technical orders and pilot interviews [7]

An arrangement of three light units which approximated the required candlepower distribution was found These units were placed every 1000 feet along the runway edges as shown in Figure 2 The system was tested by WADC in 1956 and 1957 A limited amount of assistance to a pilot in the traffic pattern was reported However, the lights tended to blend with highway and runway lights in this test In 1957, the units were tested again in conjunction with runway identification lights Although 8 of the 12 test pilots claimed that the circling guidance lights were helpful, the report did not recommend their adoption as an Air Force Standard (B2)

The International Civil Aviation Organization (ICAO) recommended in 1958 the use of circling guidance lights at airports where such guidance is unavailable from other lights or landmarks (S1)

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[7] Douglas, et al , op cit

Component Development Information

Incandescent lamps currently used in airport beacons are satisfactory for almost all purposes, however, short-arc lamps, currently used in some searchlights, and mercury-arc lamps might be used where sources of higher brightness are desired (C3, C30)

A single light fixture has recently been developed to replace the three-light fixture used in circling guidance lights The light approximates the intensity distribution recommended by NBS [8]

[8] Personal communication between the authors and Mr C A Douglas, NBS.

Angle of Approach Indicators

Design Requirements Used as Standards

In good visibility conditions, advantages gained through use of 3000-foot approach configurations are greatly offset by the comparative high cost of installing and supplying power to such configurations on every duty runway Nevertheless, a number of experts feel that some approach guidance must be made available to the pilot under marginal and good VFR conditions

Angle of approach indicators should·

(1) indicate significant deviations from the ideal glide slope to the pilot,

(2) be compatible with runway and threshold lighting systems,

(3) be simply and unequivocably interpreted,

(4) allow for safe ground and air movement at the airport (GA6, GA8)

Designs Tested

(1) Split-filter beacons

(2) Lighted or painted double-bar systems

(3) Mirror landing systems

(4) Multiple beacons

Summary of Test Results

Split-filter Beacons

The most notable of these are the "tri-color system" and the new British Royal Aircraft Establishment (RAE) system which uses two colors red and white

The tri-color system (Figure 3) was developed around 1946 and shows a yellow light to the pilot when flying too high, a red light when flying too low, and a green light if on the correct glide path. The signal beams in some units are flashed to prevent confusion with other lights (AA2, GA7, GA22)

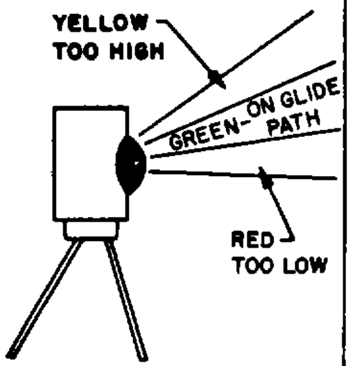
Student pilots of the U S Navy and Marine Corps tested the tri-color system in 1952 and found it extremely useful A few systems were installed at various air bases although interest in the system waned In a recent operational test at Blackebush Airport in England, practically all test pilots found the lights a valuable visual aid to approach and landing (GA22)

Results of tests conducted on two different tri-color systems at WADC in 1958, however, were not as promising One unit was found to have poor color definition, that is, a blending of colors occurred between the on-course and off-course indications Moreover, another unit, which did have sensitive color definition, gave either on-course (green) or off-course (red or yellow) signals, but did not indicate tendency of the aircraft to go off-course These units were rejected since they could furnish no information on rate of displacement from the glide path A combination of two of the latter units side by side was tried, but the rate indications were reported to be confusing (The evaluation rationale appears somewhat circular--one can not have a continuous rate-indication and discrete go-no go color indications at the same time from the same unit) Actually, WADC reported that none of the angle-of-approach indicators tested (which included all proposed indicators to date) were entirely satisfactory and adaptable for use with all types of aircraft, especially today's high performance aircraft For example, the B-47 and F-100 aircraft experienced difficulty because of the long, very flat approach angle necessary with these aircraft during final stages of the approach (AA2)

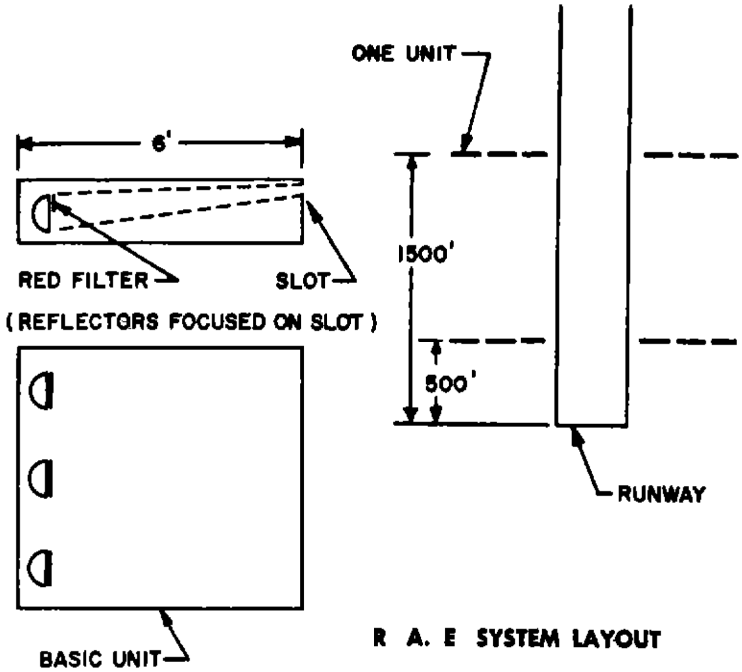
In England also, there is dissatisfaction with the tri-color system Opinion has been expressed that the main reason why the tri-color indicator has not proved very successful in improving safety is that the sectors narrow as the aircraft gets close to the runway At a certain point, the pilot receives an indication that he is too high or too low when in fact he is not The pilot, therefore, has to ignore the indicator just when he is in most need of it The unit also is small and could be inadvertently misaligned and physically upset Another reason for the less than complete success of the tri-color indicator may be that all light sectors tend to become amber because of condensation on the lens or diffusion in radiation fog This is potentially dangerous because amber is a fly-down indication (GA7)

It has been suggested that these disadvantages can be removed by using a two-color indicator Units which emit red and white beams separated by a narrow pink sector warn the pilot when he is beginning to pass from one sector to another In this RAE system, 12 light units are used to form two pairs of wing bars located as shown in Figure 3 Light beams are set so that when the pilot's head is within the ideal glide path "channel" he sees the nearer bar white and the furthermost bar red If the pilot goes high, the furthermost bar turns first pink and then white, and if he goes low, the nearer bar turns first pink and then red (See Figure 3) (GA7)

This new system theoretically can be used all the way to touchdown and is reported to be accurate to 5 miles It is inexpensive and easy to maintain It is claimed that, when this red-white system fails, it fails because it is unrecognizable and, therefore, does not lull the pilot into a false sense of security or give him an incorrect indication (GA7, GA8)



TRI-COLOR SYSTEM LIGHT CODING



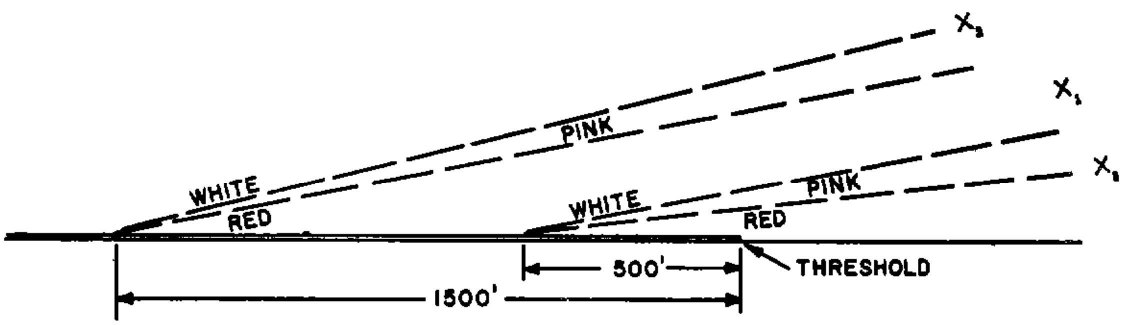
R A. E SYSTEM LAYOUT

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 3

Flight tests results in England have been reported as very promising A bi-color system, differing somewhat from the British system was tested by WADC in 1958 Distance between the units was reduced to 500 feet to improve the system on the basis of early test results Some confusion in differentiating the lights from runway lights was reported and the pink sector was not visible to some pilots The system as tested was judged unacceptable for these reasons and also because it did not give a satisfactory indication of rate of glide slope displacement However, WADC used fewer light units than called for by the British design and the system was operated at intensities considerably lower than those for which it was designed [9] (AA2)

Flight tests were conducted in Australia in November of 1958 on the RAE system and the Australian Double-bar System discussed next Objective flight path data gathered during these tests showed no significant differences in height deviations from an ideal 2-3/4 degree glide slope for the two systems With both systems, precision increased as range decreased All test pilots considered the approach aids either necessary or desirable in night conditions encountered, but only 3 of the 12 pilots preferred the RAE system to the double-bar system (AA4)

Lighted or Painted Double-bar Systems

Two or three horizontal bars, painted or lighted, are displaced laterally on both sides of the runway and longitudinally along the runway such that, when the pilot is on the ideal glide slope, the bars form a continuous line

The principle of the system was first suggested in England in 1945 and flight tested in 1954 At that time, the system was considered too dangerous at long ranges, unless made so large as to be an obstruction on the airport (AA9)

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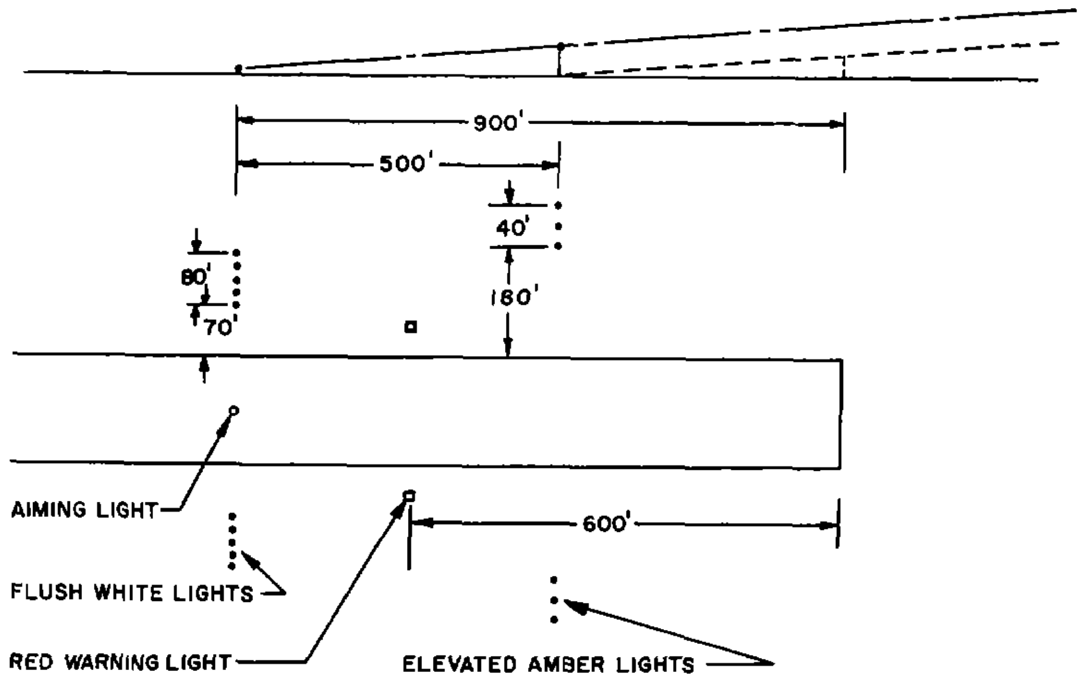
[9] Mr C A Douglas, NBS, to Mr E S Calvert, RAE, Personal communication February, 1959

In 1957, a lighted double-bar ground aid labeled the Precision Visual Glidepath (PVG) system was developed in Australia The aid uses 10 flush white lights and 6 elevated yellow lights positioned as in Figure 4 In addition, a beacon, shielded to give off red light when the pilot is approaching at an angle of less than 1 9 degrees, is employed as a safety check When the pilot is approaching on the ideal glide slope, the yellow and white lights form a continuous horizontal line When the pilot is above or below this slope, the bars of white lights rise above or dip below the bars of yellow lights, respectively (See Figure 4) The Australian system also includes a depressable, low-powered "aiming point" light located in the center of the runway, 900 feet from threshold There has been some European support for an aiming light of this sort and it has been used there independent of a glide slope indicator (AA10)

Preliminary flight results in Australia in 1957 showed that with this two-bar system, oscillations of the glide path are significantly reduced when compared with approaches using runway lights alone (AA3)

In England, current opinion is that, at distances greater than 5 miles, the sensitivity of the system for detecting deviations from the ideal glide slope is extremely inadequate Moreover, at these distances, some English investigators claim that an insensitive on-course indication can result in an altitude deviation of possibly 1000 feet (There is as yet no agreement on the maximum range at which glide slope indicators should be effective) The PVG system also is thought to be particularly susceptible to the effects of atmospheric and windshield refraction Finally, it has been pointed out that the system disappears from the pilot's field of vision at approximately 200 feet from the threshold One needs to temper these criticisms by consideration of the unique "flat-land" conditions existing to a very large extent in Australia, there can be little doubt of some positive utility under such conditions

AUSTRALIAN DOUBLE-BAR POSITIONING



AUSTRALIAN DOUBLE-BAR CODING

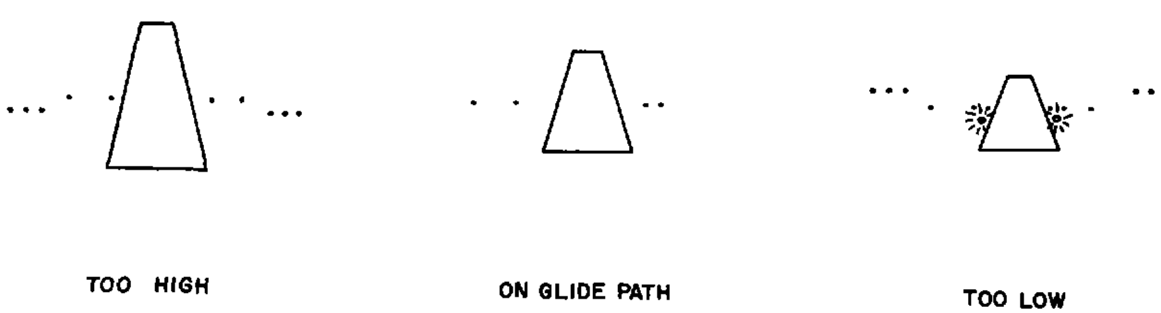


Figure 4

WADC tested a double-bar system using red and white bars 100 feet apart along the runway in its 1958 operational evaluation of angle of approach indicators It was determined that the system gave intelligent information only at distances of less than 1-1/2 to 2-1/2 miles, thus substantiating the "long distance" limitation pointed out in England None of the systems tested was found completely satisfactory for fighter and bomber aircraft However, after consideration of economy, adaptability to weather conditions and range of guidance, the two-bar system was recommended for Air Force installation wherever the requirement for glide slope information for transport-type aircraft exists (AA2)

Nine of twelve Australian test pilots who took part in an experimental test in Australia late in 1958 preferred the double-bar indicator to the RAE bi-color indicator Objective data gathered from this experiment indicated no statistically significant differences between the two systems (AA4)

Working on the same principle as the Australian system, POMOLA (Poor Man's Optical Landing Aid) was developed in this country in early 1957 The system uses either two or three billboards, each with a 6-inch lateral stripe across the middle When the pilot is on the ideal glide slope, the lateral stripes form a continuous line No operational test information is available on the system Its obvious advantage is that it is quite inexpensive (AA11)

Mirror Landing Systems

The Mirror Landing System was originally designed by the British and now is widely used on British and United States angled-deck aircraft carriers The system works on the principle illustrated in Figure 5 When on course, the reflected amber light source (the "meatball") will appear in the center of the mirror If slightly high or low, the meatball will appear above or below the green datum bars, respectively However, with a large displacement from the ideal glide slope, the pilot does not receive any signal (AA8)

As of April 1957, use of the Navy Mirror Landing System had reportedly reduced the landing accident rate on carriers from 3 to 2 per thousand (AA7)

In 1957, the Air Force tested the Navy Mirror Landing System at Atlantic City NAS Results showed that it provided satisfactory indication of glide slope during clear weather and that it increased the pilot's ability to make a spot landing More extensive testing was carried out at WADC in 1958. The system was found to be of definite assistance to pilots of transport-type aircraft Although it provided somewhat better glide path information than the two-bar system under optimal conditions, the scarcity of (and thus expense of) optically perfect mirrors and their susceptibility to loss of guidance in cold, moist weather made the system less desirable than the two-bar system. (AA1)

An "Interim Mirror System" developed when suitable mirrors were unavailable (dubbed the "mirror system without a mirror") was also tested by WADC. Many improvements were made on the installation, but it was still considered inferior to the regular mirror or two-bar systems (AA2)

Multiple Beacons

A pair of airway beacons, equipped with red and green filters were mounted side by side at Weir Cook Airport, Indianapolis in 1954 The zone covered in common by their beams was tested to determine whether the area where the colors balanced to produce a white light was usable as a glide path indication Results showed that a pattern usable for that purpose could not be produced (C28)

Component Development Information

Contained in above discussions.

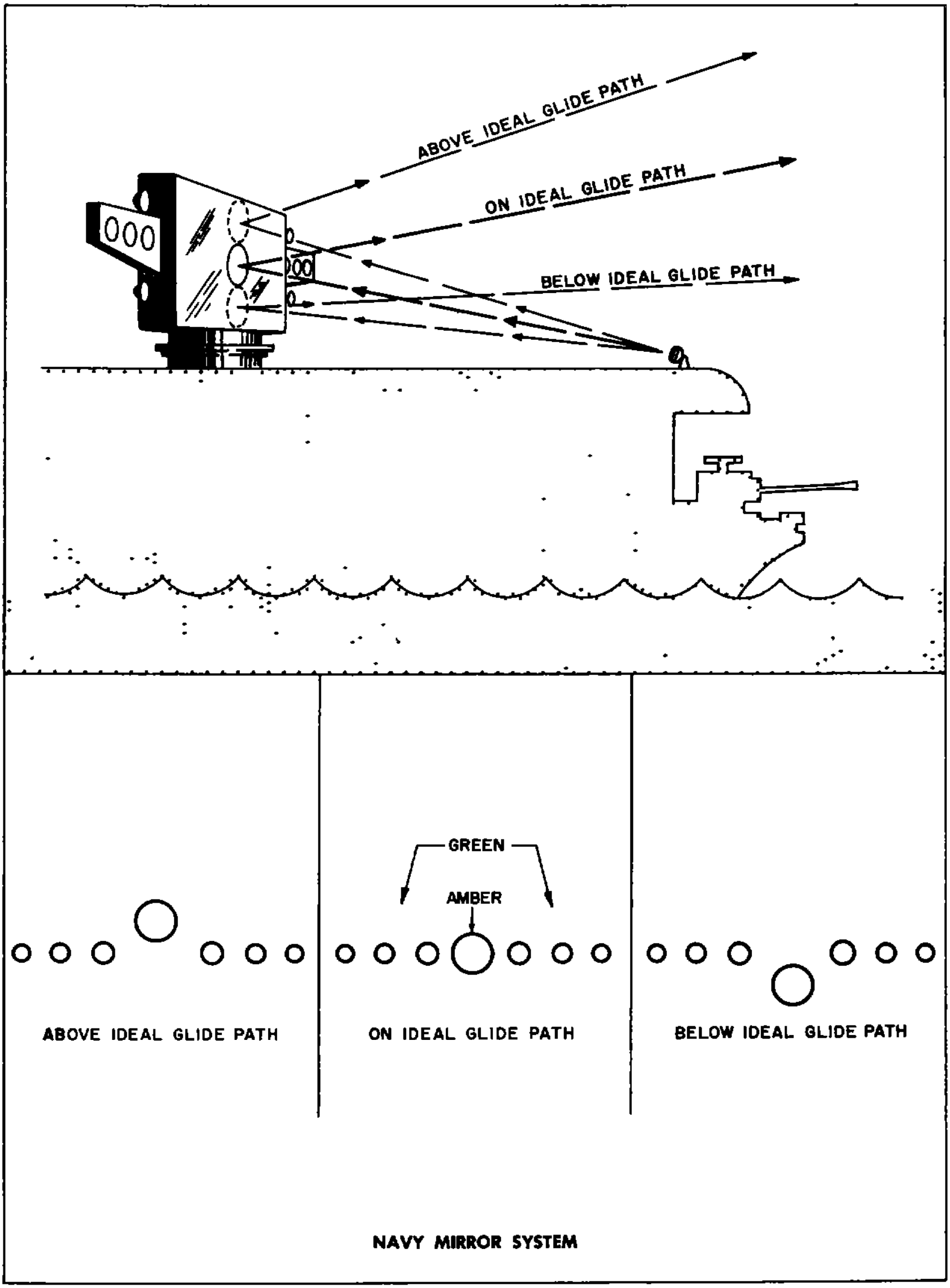

ABOVE IDEAL GLIDE PATH
ON IDEAL GLIDE PATH
BELOW IDEAL GLIDE PATH
GREEN
AMBER
ABOVE IDEAL GLIDE PATH
ON IDEAL GLIDE PATH
BELOW IDEAL GLIDE PATH
NAVY MIRROR SYSTEM

Figure 5

Approach Lights

Design Requirements Used as Standards

Instrument Landing Systems (ILS) or Ground Controlled Approach (GCA) systems typically bring the pilot to a distance of 1/4 to 1/2 mile from the runway threshold Somewhere between this point and the threshold, transition from instrument to visual approach takes place The pilot is aided in his visual approach by patterns of lights in the approach area designed to give attitude and flight path information

The following information should be given the pilot with little or no interpretation required.

(1) Distance from threshold

(2) Height above runway level (elevation, altitude)

(3) Displacement from runway centerline (alignment).

(4) Angle of bank

(5) Aircraft heading with respect to runway axis

The following information should be given the pilot but requires a time element for interpretation

(6) Direction of ground track.

(7) Rate of descent

(8) Rate of roll.

The following requirements also should be satisfied by an approach lighting system.

(9) Immediate recognition and guidance

(10) Lack of confusion with other lights.

(11) High fog penetration.

(12) Little or no loss of guidance when certain lights in the system are obliterated or out of order

(13) Minimal glare and blinding effects.

(14) Relatively low installation and maintenance costs.

(15) Clear definition of end of approach lights

(16) Usefulness within limits of various cockpit visibility restrictions.

(17) Beam coverage of individual units such that vertical and horizontal beam coverage encompasses the required region of guidance (AL1, GA22)

Designs Tested

(1) Centerline system

(2) Slope-Line system.

(3) Calvert (RAE) system

(4) Navy Composite system

(5) Two Parallel-Row or Multi-Row systems

(6) Single Row system

(7) Overrun configurations

Summary of Test Results

Centerline System

The centerline system (Figure 6) was first installed in this country around 1948 The Air Line Pilot's Association (ALPA) was instrumental in getting this installation after a series of experimental developments at Newark Airport aimed at determing an optimal configuration The line of steady-burning bar lights (each 14 feet in length) is designed to provide the pilot with a definite line fix for displacement guidance A 100-foot transverse bar at 1000 feet from threshold is provided for estimating distance from threshold Height guidance can be derived from three physical elements in the configuration (1) the apparent length of 14-foot bars, (2) the apparent distance between successive units (standardized at 100 feet), and (3) the apparent distance between individual lights in the same bar The bars, being oriented perpendicular to the extended runway

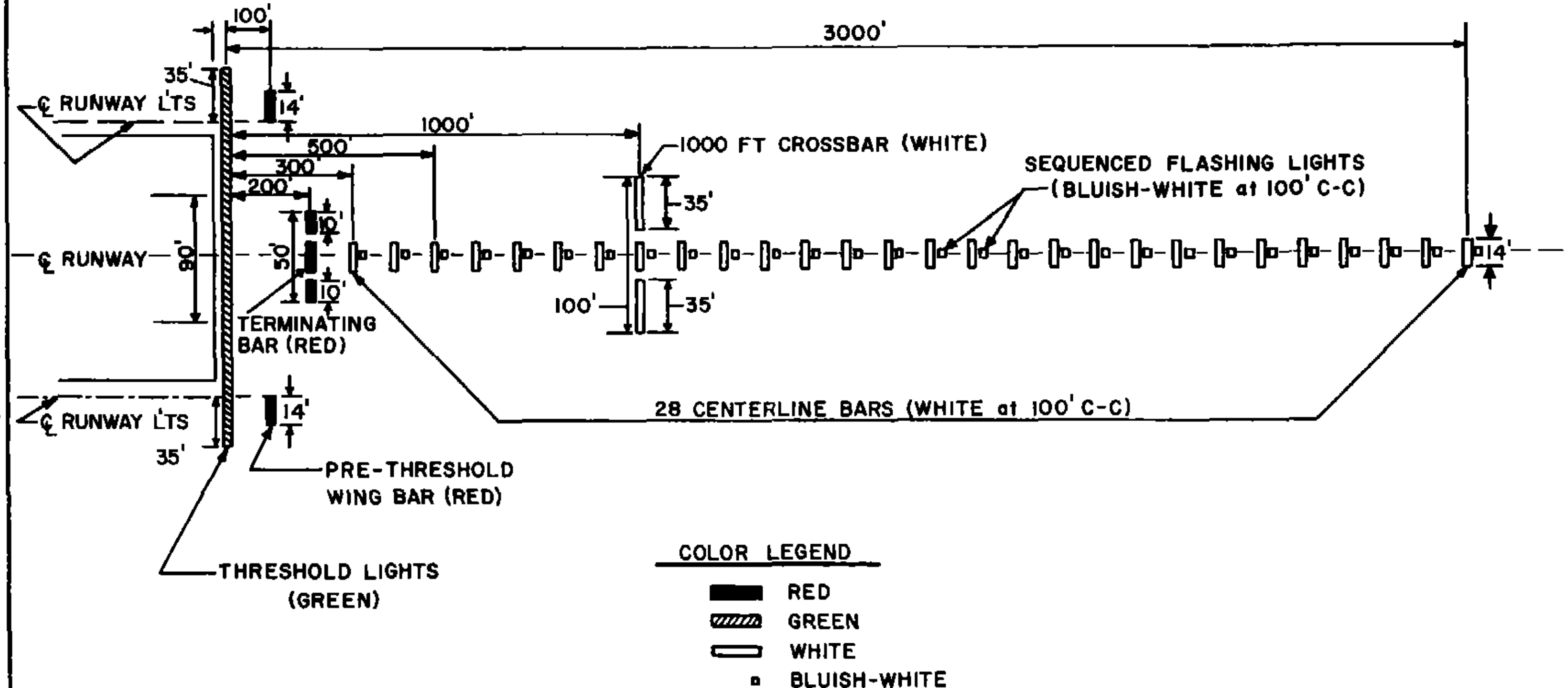


Figure 6

CENTERLINE APPROACH SYSTEM — NATIONAL STANDARD centerline, are designed to provide the horizontal referents necessary for roll guidance Perspective views of on-course and off-course positions are shown in Figure 7. Two of the system's main advantages frequently cited are simplicity and lack of optical pitfalls. (AL16, AL17, AL24, AL28, S2, S10, GA13)

The centerline was tested at Landing Aids Experiment Station, Arcata, California (LAES) in 1949 with the long transverse bar located at 600 rather than 1000 feet from threshold and with ten light units on each bar instead of five In low visibility tests, height and distance-to-threshold guidance were rated inadequate by most test pilots Roll guidance generally was rated adequate, but under minimum visibility conditions was reported as somewhat inadequate (AL1)

Support for the system became progressively stronger The system was operationally tested at Newark in 1951 Although no written report on the results could be found, verbal reports from those familiar with the installation indicate that favorable results were obtained [10]

In 1952, CAA, ALPA, and Air Transport Association (ATA) representatives wrote a joint report favoring the centerline system Navy and Air Force representatives dissented because of their particular requirements for a clear underrun area, the structural peculiarity of military aircraft, and military approach procedures in use The centerline system at that time was considered the easiest system for pilots to interpret and all desired guidance elements apparently were obtainable with the system (GA13, AL27)

In 1956 at McGhee-Tyson Field, the centerline system was found suitable for all aircraft except certain fighters The addition of an underrun configuration was thought necessary to accommodate these aircraft.

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[10] Douglas, op. cit.

Limited testing using clear centerline lights indicated glare and reflection were more prevalent than when red lights were used (AL7)

An experimental installation designed to settle the controversy between civil and military authorities was tested at March AFB in 1957. The 1000 feet of 14-foot centerline bars within the underrun area were installed with flush open-grid units Included in the system were flashing condenser discharge lights (discussed under Component Developments). The following conclusions regarding the system were reached the pilot is capable of determining at a safe distance out that he is properly aligned with the runway, added confidence is given the pilot, with the mental hazard of a minimum weather approach considerably reduced, there is a tendency to prevent the pilot from landing short of the runway, since the lights provide a positive reference for depth perception The flush centerline lights reportedly gave excellent flareout assistance Additional transverse bars and extended edge lighting did not significantly improve the system's reported effectiveness for most types of aircraft (AL2)

The centerline system was adopted as the national standard in a paper of the Air Coordinating Committee on April 24, 1958 (S2)

There is some feeling that not enough low visibility flights were made at March AFB to warrant the adoption of the centerline system as the national standard It is argued that under conditions of restricted visibility, no distance-to-threshold indication is available until the 1000-foot bar can be seen Some experts also doubt whether the 14-foot transverse bars are long enough to provide adequate roll guidance, though others feel that they are adequate (AL17, AL23, GA22, M18)

Slopeline System

The slopeline system was the unofficial American standard between 1949 and 1953 It is composed of two rows of lights, each row being composed of bars set at a 45-degree angle to the ground surface as shown in Figure 8 When viewed on course, the slope-line lights merge

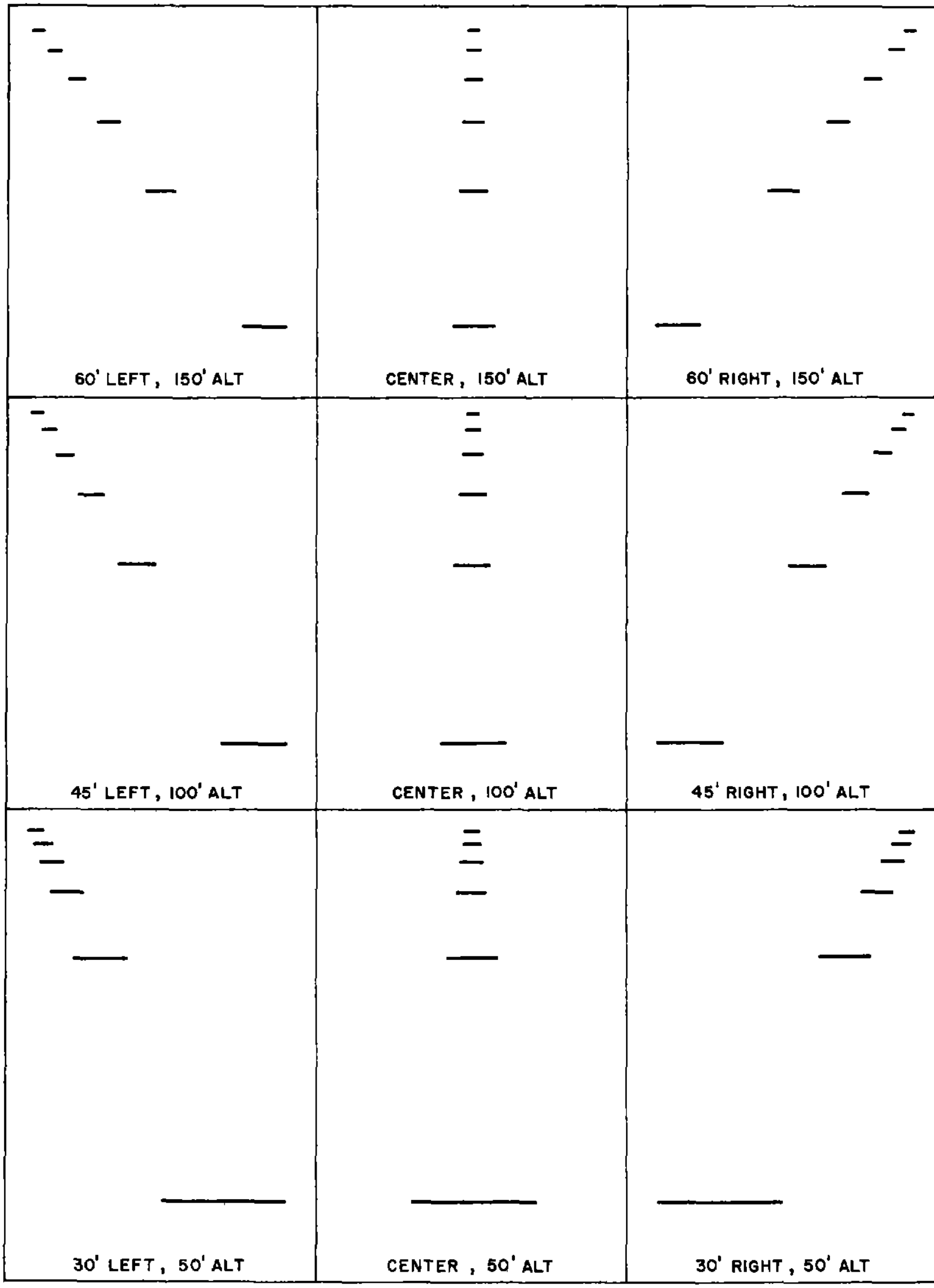


Figure 7 **PERSPECTIVE VIEWS — CENTERLINE APPROACH SYSTEM**

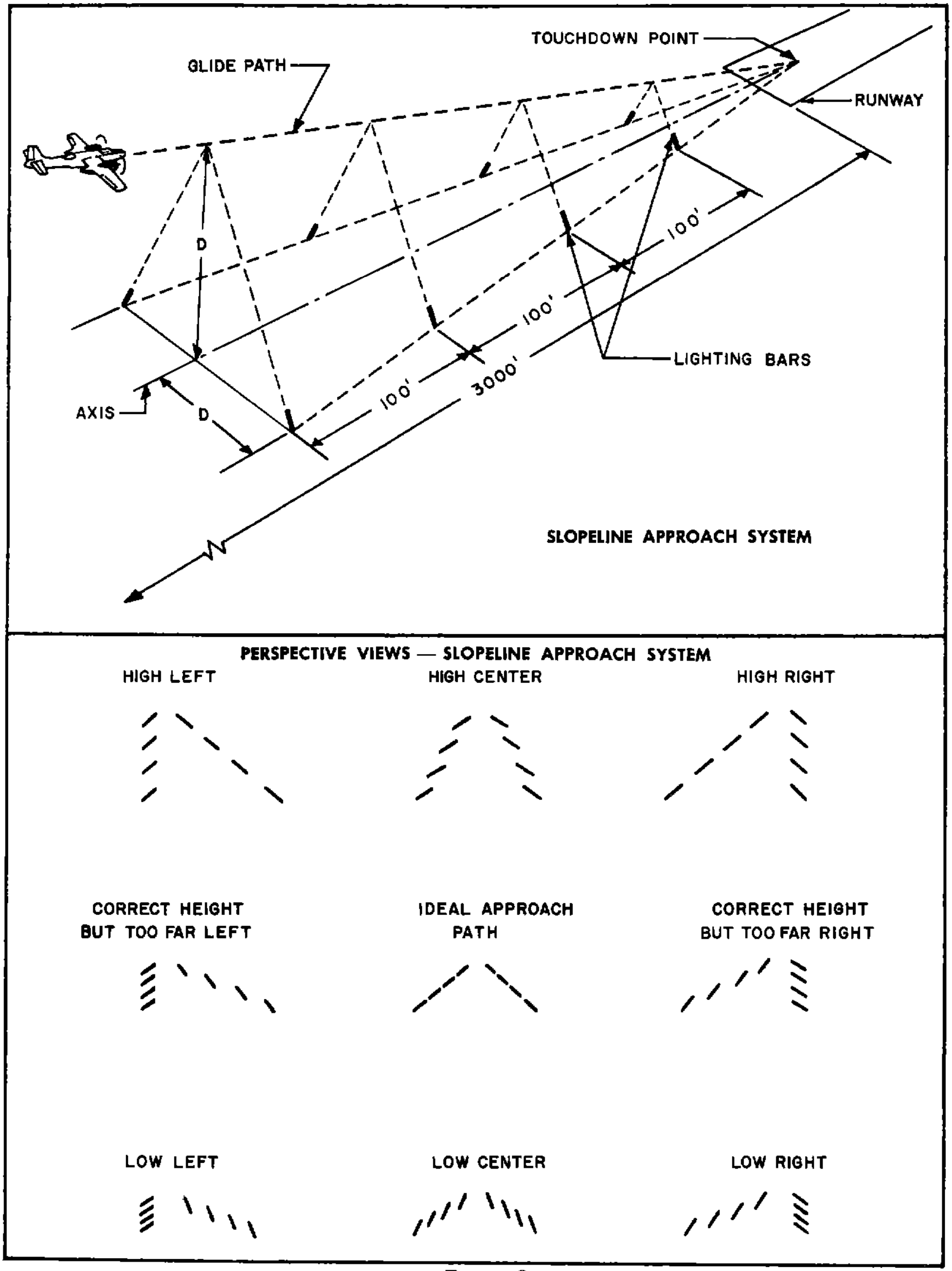

TOUCHDOWN POINT
GLIDE PATH
RUNWAY
D
100'
100'
100'
3000'
LIGHTING BARS
AXIS
D
SLOPELINE APPROACH SYSTEM
PERSPECTIVE VIEWS — SLOPELINE APPROACH SYSTEM
HIGH LEFT
HIGH CENTER
HIGH RIGHT
CORRECT HEIGHT BUT TOO FAR LEFT
IDEAL APPROACH PATH
CORRECT HEIGHT BUT TOO FAR RIGHT
LOW LEFT
LOW CENTER
LOW RIGHT

Figure 8

into two continuous lines of lights aimed at the point of touchdown Figure 8 also shows perspective views of the system for on-course and various off-course approaches. (AL26, AL30, GA22)

In 1948 and 1949 at LAES, the slopeline system was reported to be the most acceptable of approach systems tested In 1949, the addition of transverse bars every 1000 yards was incorporated into the system and did improve roll and distance-to-threshold guidance The conclusion of the experimenters at LAES was that the slopeline system excelled in providing good elevation alignment and directional guidance On the basis of these results, the slopeline was adopted as the nominal national standard in 1949 (AL1)

In 1950, however, CAA withdrew support for the slopeline, noting that a survey of airports showed that terrain problems made it impractical to install the system at half the airports surveyed (AL13)

In 1951, operational evaluations of the centerline, Calvert, slopeline, and French systems (discussed in a subsequent paragraph) were conducted, the centerline evaluation taking place at Newark, the others at the Patuxent River NAS, Maryland At Patuxent, the Calvert system was judged to be slightly better than the slopeline, although glidepath indication with the slopeline was judged to be excellent There was some feeling that because of the nature of roll and distance guidance elements in the slopeline system, an untrained pilot in an off-course indication might possibly suffer the effects of vertigo A combination of the slopeline system and the Calvert system was recommended (see Navy Composite System, Figure 9, discussed in a subsequent paragraph) (AL10, AL24)

In 1952, apparently on the basis of the Newark and Patuxent tests, the majority opinion of a five-man civil and military committee held that while the slopeline system provided the most complete information under good visibility conditions, it was confusing and difficult to interpret in poor visibility Roll information was reported as intermittent at visibilities less than 1000 feet, an undesirable factor if any alignment or direction correction is necessary (AL27, AL28, GA13, GA22)

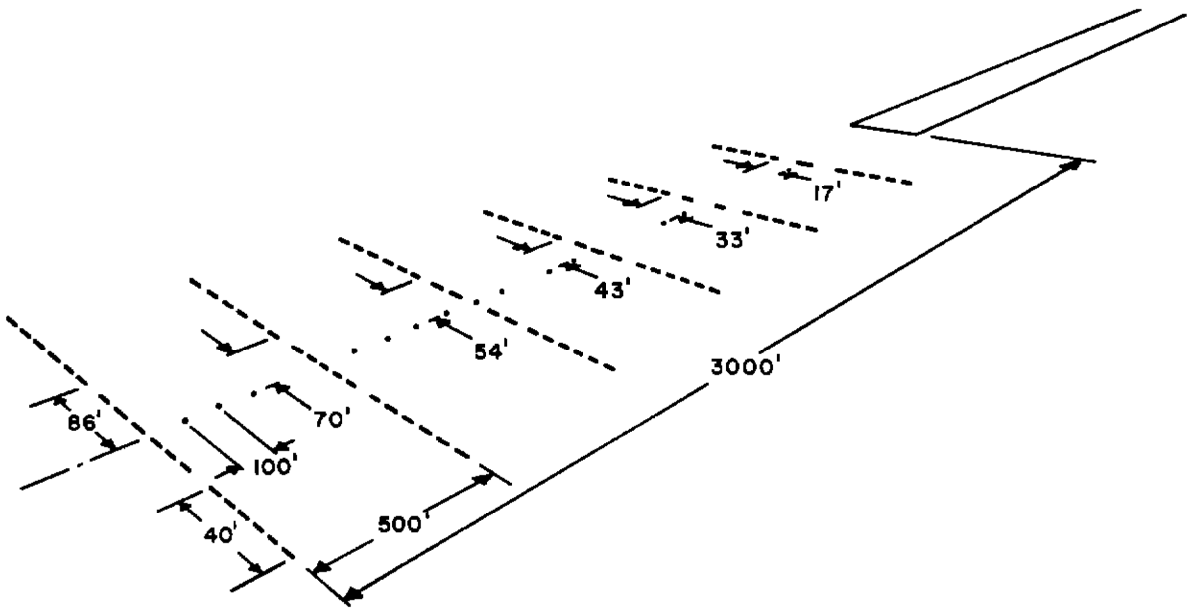
As the system was used more extensively, it was thought to have several dangerous traps for the pilot who was tired, distracted, or out of practice ATA and ALPA, who never really accepted the system, held that the slopelines were misleading and required too much interpretation to achieve both vertical and lateral control Certain optical illusions were also reported with the system Under certain atmospheric conditions, some pilots were led to believe they were too high and approaching nose down At other times, an uphill appearance of the runway was noted (AL23, AL31)

In 1954, the last proponent of the slopeline system, the Navy, reported that its own Composite System, utilizing some slopeline units, was found superior to the slopeline system in operational tests at Patuxent River NAS. (AL6)

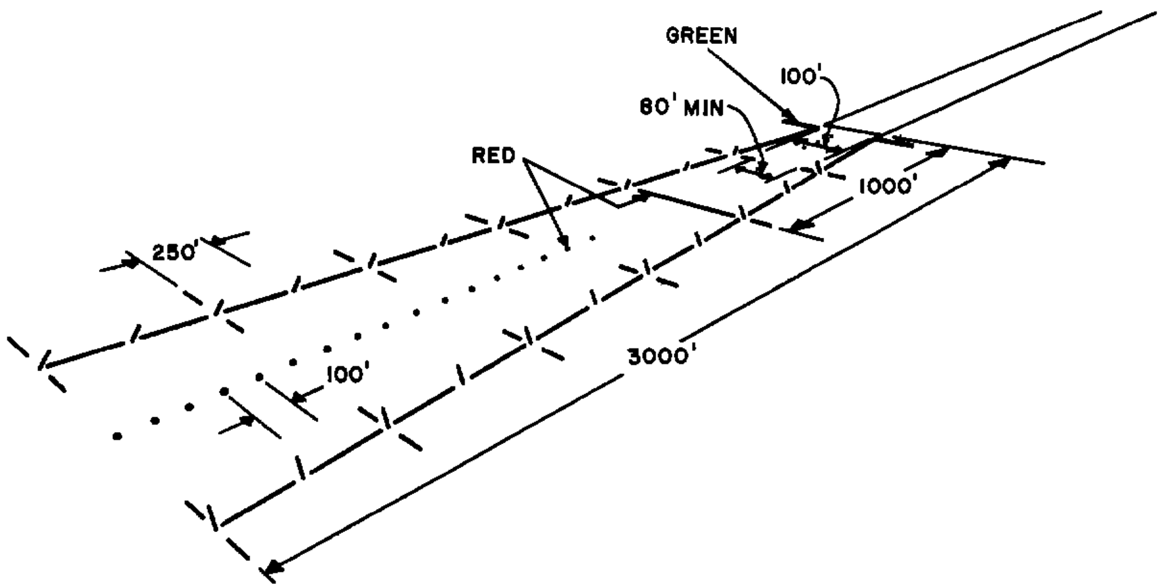
Calvert System

In 1946, Mr. E S Calvert of the Royal Aircraft Establishment attempted to ascertain the visual and mental methods by which a pilot lands an aircraft He then analytically assessed the comparative value of different systems of lighting both rationally and empirically, rationally by the use of perspective diagrams, and empirically by the use of a visual simulator

Calvert's analysis led to the development of the two-coordinate system which bears his name The system is illustrated in Figure 9 This pattern consists of two basic elements--a line of lights leading to the runway threshold, and transverse bars of lights The greatest asset of the Calvert pattern cited is its simplicity and over-all visibility in the sense that a pilot has a single line to follow and can keep his aircraft level or can bank and turn using the horizontal bars.



CALVERT (R A E) APPROACH SYSTEM



NAVY COMPOSITE APPROACH SYSTEM

Figure 9

Moreover, a line and crossbar pattern supposedly gives a realistic impression of the ground plane Height and distance-to-threshold indications are generally more difficult to determine (AL16, AL17)

The system was operationally tested at LAES in 1948 and 1949 In general, roll and direction guidance were rated excellent Some pilots had difficulty in identifying distance-from-threshold coding, however, certain modifications of the system were suggested to improve this feature Elevation guidance was thought to have been presented in spurts, without continuity, and was rated as only moderately effective (AL1, AL3)

Tests at Patuxent River in 1951 found the Calvert system slightly better than the slope-line system Roll, distance, and alignment guidance were reported easily and instantly interpretable, and no danger of undershooting was reported The system was reported to be only partially effective in marginal weather conditions where sudden corrections in aircraft maneuvers were required while "between" crossbars (AL24, GA13)

No other tests on the system have been conducted in the United States, although it has found widespread use in Europe and Japan A variant of the Calvert system, using shorter transverse bars, was installed at Schiphol Airport in the Netherlands in 1956 However, no operational evaluation data were found on this system

The Calvert system is quite similar to the centerline system in matters of simplicity and information presentation, however, it is generally concluded in the United States that, compared to the centerline system, roll and elevation guidance are absent for too long a time to allow for smooth corrective procedures (AL16, AL17, GA22)

Navy Composite System

The United States Navy has developed an approach configuration based upon experimentation and consideration of the unique requirements of Navy flying The Navy configuration, as shown in Figure 9, provides a

3000-foot center row of red lights, clear light transverse bars every 500 feet, a red bar at 1000 feet, and slope-line units every 250 feet providing a funnel to the runway

When the pilot views this system exactly on a 3-degree glide slope, he sees three straight lines of clear lights leading to the touch-down point If he is below the proper glide path, the outside lines will appear to be bars that stick up above the line of lights If he is above the proper glide path, the bars will angle inboard or below the line

In operational tests at Patuxent NAS in 1954, flight evaluations during both good and poor visibility conditions indicated that the Navy system gave optimum guidance for all types of aircraft A study of pilot comments indicated that the system may not be yielding unequivocal guidance For example, some pilots claimed that the centerline system was not needed, others said transverse bars were not necessary Both commercial aviation and Air Force spokesmen have criticized the Navy system on the grounds that it is confusing (AL22, AL32, GA22)

Two Parallel-Row Type Systems or Multi-Row Systems

Most of these systems are considered obsolete today as they provide only direction guidance adequately The addition of transverse bars adds roll and possibly distance-to-threshold guidance, but poor elevation guidance seems to be inherent in the system (AL21, AL25, GA22)

In 1946, some experts felt that a "funnel system" (Figure 10) would be better than the dual-row systems previously proposed, namely two parallel rows along the extended edges of the runway and two diverging rows ending at the runway corners Tests at LAES in 1946 and 1947 showed that the system had major inadequacies including a misleading perspective appearance when both rows were visible, necessity for sharp correction near the threshold when approach was made along one of the rows, inability to see both of the widely divergent rows when at the outer end, lack of differentiation of one row from the other There was also a great danger, as there

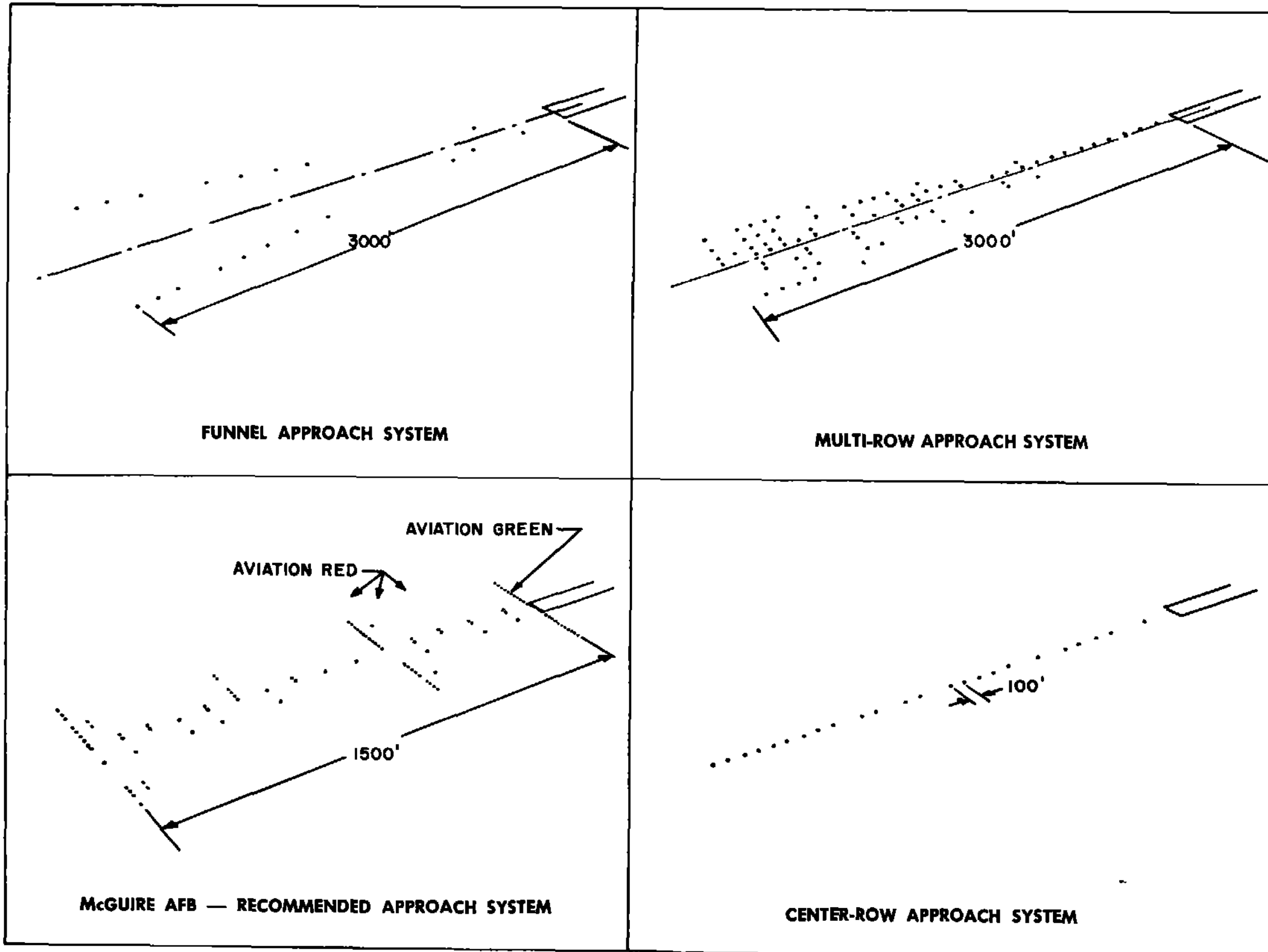

3000'
FUNNEL APPROACH SYSTEM
3000'
MULTI-ROW APPROACH SYSTEM
AVIATION GREEN
AVIATION RED
1500'
McGUIRE AFB — RECOMMENDED APPROACH SYSTEM
100'
CENTER-ROW APPROACH SYSTEM

Figure 10

is in any two-row system, that the pilot tended to mistake the approach lights for runway lights This fact alone was deemed sufficient to render these systems unsuitable for use (AL1)

In 1947, LAES reported that a multi-row system (Figure 10) was superior to the funnel system In 1948, however, LAES reported this system to be far inferior to the slope-line system Multi-row systems confused the pilot as to which row was sighted first Also, when drift conditions were present, the guidance elements were difficult to interpret (AL1, AL3)

In 1955 several patterns incorporating extended runway edge lighting, both with and without transverse bars, were tested at McGuire AFB and Atlantic City NAS A 1500-foot system (Figure 10) using dual-row extended edge lighting on the left, and single-row lighting on the right, with pairs of transverse bars every 500 feet, was chosen as the most suitable No apparent action was initiated, however, on the basis of this study In 1957, essentially the same pattern was tested at March AFB and was found less desirable than the centerline system (AL2, AL5)

Single-Row Systems

The earliest approach lighting system was a single row of lights leading through the approach area to the runway threshold A typical single-row system, the center-row system, is shown in Figure 10 It was judged as providing adequate runway centerline guidance, but yielding little altitude guidance Only when combined with a clearly-defined horizon did the single-row system provide adequate roll guidance When the horizon was obscured by low visiblity, pilots were unable to make judgments consistently regarding differentiation between displacement, bank, and roll indications (AL21, GA22)

Because of the above reasons, single-row systems were generally abandoned after the war although some modified ones are still in use, as at Oakland, California A single-row system using krypton flashing lights was tested at LAES during the 1948 and 1949 seasons While identification and direction guidance were reported as very good, other guidance elements were reported inadequate (AL1, AL3)

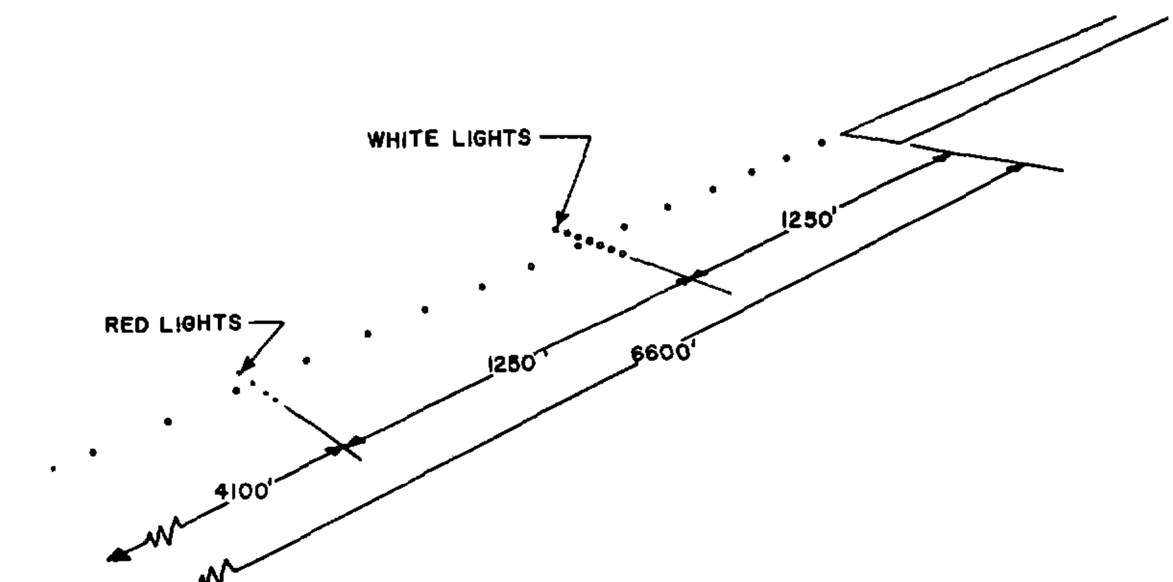
An Air Force operational test at McGuire AFB in 1955 included a 1500-foot center-row system Although no comments were made about the system, it was reported as inferior to a system of extended edge lights with transverse bars (AL5)

The French system (Figure 11), developed primarily to aid French mail pilots, provides a row of single lights for 6600 feet along the left extended runway edge, with a red transverse bar at 2500 feet from threshold and a white transverse bar at 1250 feet from threshold The length of the system, and position and number of transverse bars, have apparently varied according to where the system was installed. A 3000-foot French configuration was operationally tested at Patuxent NAS in 1951 Both French pilots and the United States pilots who flew the system at Patuxent have reported that information about runway centerline location is difficult to extract and that perspective is difficult to interpret unless a large portion of the system can be seen In addition, the single left-hand row can be confused for runway edge lights in low visibility conditions (AL24, GA22)

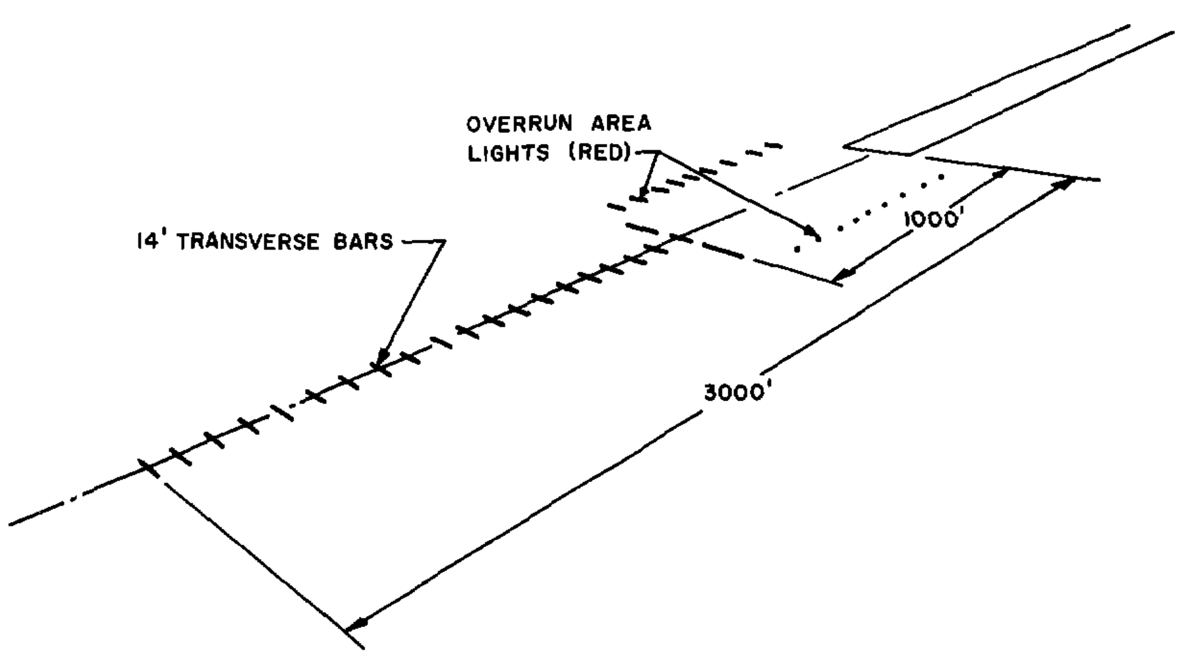
Overrun Configurations

Because of the relative instability of its aircraft at low speeds, the Air Force does not permit obstructions of any kind in the final 1000 feet before the runway threshold In order to meet this requirement, certain "overrun" configurations were developed to replace the final 1000 feet of lights in approach configurations

LAES tested three of these systems (Figure 12) in conjunction with the slope-line approach system It was concluded that, in general, primary 3000-foot configurations were weakened considerably when modified with a dissimilar 1000-foot parallel row over-run section This



FRENCH APPROACH SYSTEM



CONFIGURATION B OVERRUN SYSTEM

Figure 11

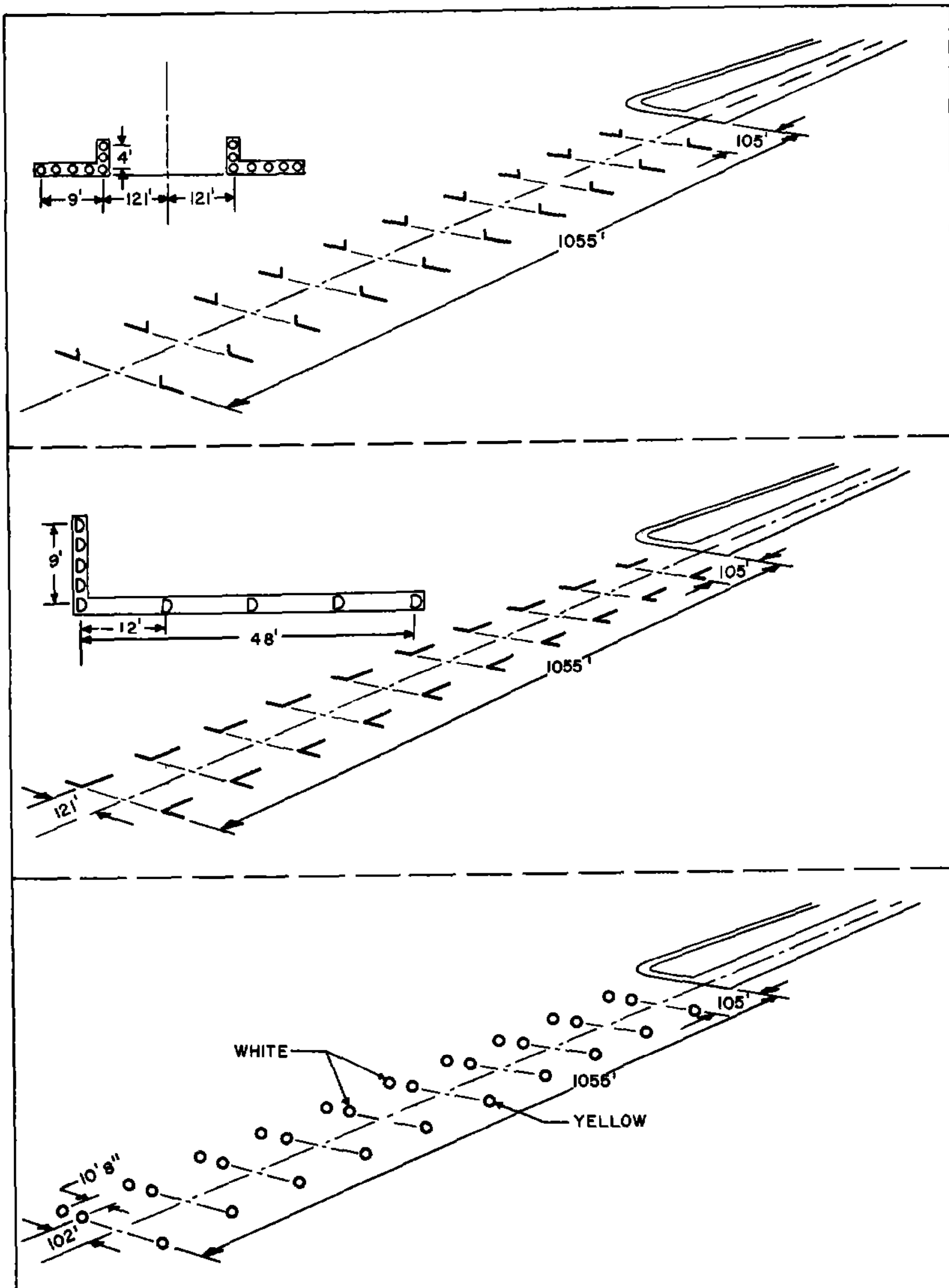


Figure 12 **OVERRUN CONFIGURATIONS TESTED AT ARCATA**

dissimilarity in some cases caused the pilot to mistake the over-run area for the runway (AL1)

In an operational test program at McGhee-Tyson Field in 1956, the centerline system, with special over-run modifications, was reported to provide adequate guidance for all aircraft tested, except certain fighter aircraft with poor forward cockpit visibility To accommodate these aircraft, an over-run configuration (final 1000 feet before threshold), consisting of a triple row of red lights on the left, and a single row of red lights on the right (along extended runway edges) was tested and found optimal Another over-run configuration with the typical centerline lights in the final 1000 feet (Figure 11) removed, reportedly made the total centerline system inadequate and confusing. Provision was then made for the final 1000 feet of centerline lights to be mounted on frangible supports to comply with Air Force regulations (AL7)

Flush, semi-flush, and frangible-top flush lights have been developed which can be installed in the final 1000 feet of approach systems These flush units were included in a test configuration at March AFB and found acceptable by all pilots who took part in the test (AL2)

In this latter evaluation, transverse bars in the over-run area were found to assist in providing ground reference to fighter aircraft pilots under VFR or high ceiling conditions

Component Development Information

Approach Light Lamps

At the present time, civil airfields using the centerline system are changing over to approach-light lamps already in use at most military fields These lights appear to have a satisfactory intensity distribution as well as a wider vertical beam spread [11]

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[11] Douglas, op cit

NBS recently recommended that present approach-light lamp groups be replaced on the basis of accumulated time of full-intensity operation rather than waiting for individual lamps to burn out (C8)

Condenser Discharge Lamps

On the theory that success of low visibility landings may be directly related to the timeliness of transition from instrument to visual flight during approach, sequenced flashing condenser discharge lights have been used with 3000-foot approach systems to facilitate early identification of the approach path in poor visibility conditions The use of flashing lights to provide early positive identification of an approach area has long been thought to be an excellent visual aid Service use of sequenced flashing lights during the Berlin Airlift was favorably received While the row of condenser discharge lights apparently provides directional guidance in addition to identification, it does not provide adequate attitude guidance (AL1, AL3)

The lights were used in the March AFB experimental installation with the centerline system A single condenser discharge unit was placed directly in front of each 14-foot bar in the approach system They were synchronized to discharge successively, beginning with the unit furthermost from the runway A complete cycle is flashed twice each second, with the resulting effect resembling a brilliant ball of light moving toward the runway at a speed of 3600 miles per hour The apparent high intensity of the lights, coupled with their characteristic of apparent motion, effectively attracts the pilot's visual attention All pilots who took part in the tests at March AFB agreed that the flashers were an ideal identification device The flashing lights could be seen at a distance of approximately three times that of reported visibility (AL2, GA22, GA31)

Some pilots said the units caused a distracting glare just prior to the aircraft passing over the threshold, although it is claimed by the manufacturers that a pilot familiar with the system will experience little or no glare At March AFB, recommended practice was to turn off the lights at 1 mile from threshold when visibility was 1 mile or more It has been suggested that the units be installed every 200 or 300 feet instead of 100 feet, or that the lights not be installed in the final 1000 feet of approach lighting to cut down the effects of glare [12] (AL2)

It is the feeling among some experts that success of condenser discharge lamps is directly related to the relatively poor vertical coverage afforded by the narrow-beamed lights formerly used in approach systems A new wider-beam incandescent approach lamp is now being used, and it is possible that the difference between the effective range of approach lights and condenser discharge lights will be significantly reduced (GA8, TV10)

There also is a feeling among some pilots that the condenser discharge lamps, when used with the narrow-beamed approach lights, over-emphasize the directional guidance, and thereby eclipse to some extent the value of centerline crossbars in providing roll guidance (AL17, GA8)

FAA has recommended that condenser discharge lamps be used with the centerline approach system (S2)

Flush, Semi-Flush, and Frangible-Top Lights

Lights have been developed to meet the following requirements.

(1) They must be capable of operating under severe environmental conditions such as snow, ice, blowing sand, etc

(2) They must be capable of being installed in the pavement surface and of being readily maintained

(3) They must be capable of being run over by aircraft, snow plows, and other vehicles without damage to lights or vehicles

[12] Personal communications among Capt W W Braznell, Capt E A Cuttrell, Capt D S Little, Capt R C Robson, all of American Airlines, Capt P E Bressey, BOAC, and Mr E S Calvert, RAE April to June, 1957

(4) They must not set up harmful oscillations or undue stresses in aircraft which taxi over them

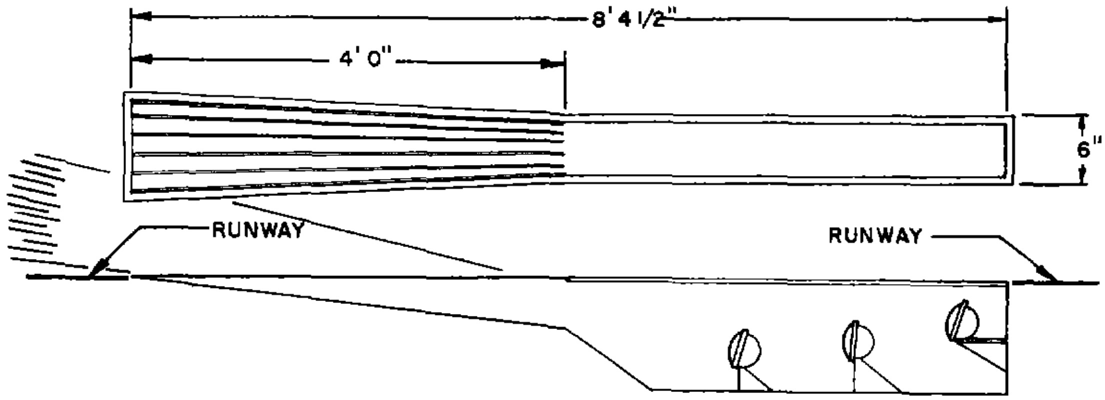
(5) They must have suitable intensity and beam spread so they can be seen by pilots from required distances and angles under all weather conditions

Three general types of lights have been developed to be used in over-run or runway surfaces open-grid (flush), prismatic (semi-flush), and expendable (frangible) top Illustrations of typical units are shown in Figure 13 Open-grid units were found satisfactory at the March AFB tests Recent work, however, has indicated that while the lights are structurally satisfactory, they give relatively poor horizontal light coverage and are quite expensive to install [13] (AL2)

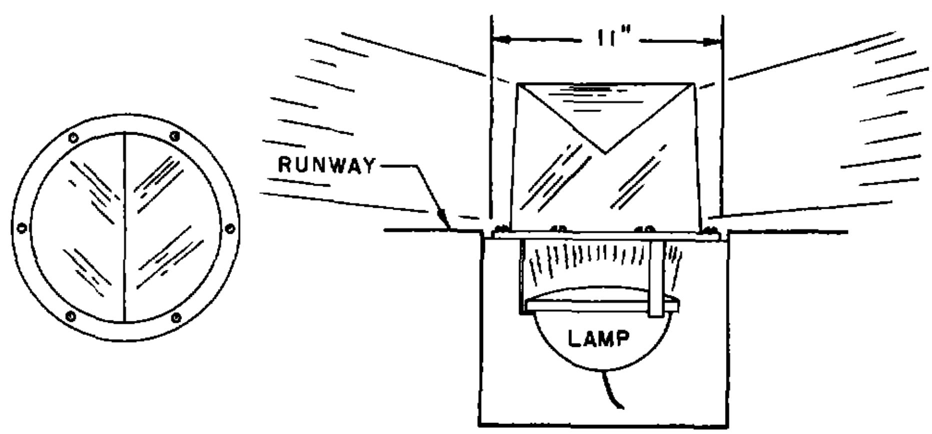
Of the lights tested by NBS, WADC, and NASA, the expendable-top light gave by far the best candlepower distribution and had the longest visual range This light also has the advantage of not being subject to obliteration due to weather conditions, but it would be incompatible with current snow-plowing procedures and jet-runway cleanliness requirements if the top were broken The candlepower distribution of one of the prismatic units also exceeded requirements, but it was not as satisfactory as the expendable-top unit This prismatic light will not cause damage to, or be damaged by, snow plows The recent development of a tubular quartz lamp is expected to improve the performance of these latter units (C9, C11, C13, C23, C24, C29, C33-35, C37-39, C46, C51)

Development of a flush "pancake" light has recently been initiated by FAA for use in its experimental program at the National Aviation Facilities Experimental Center (NAFEC), Atlantic City

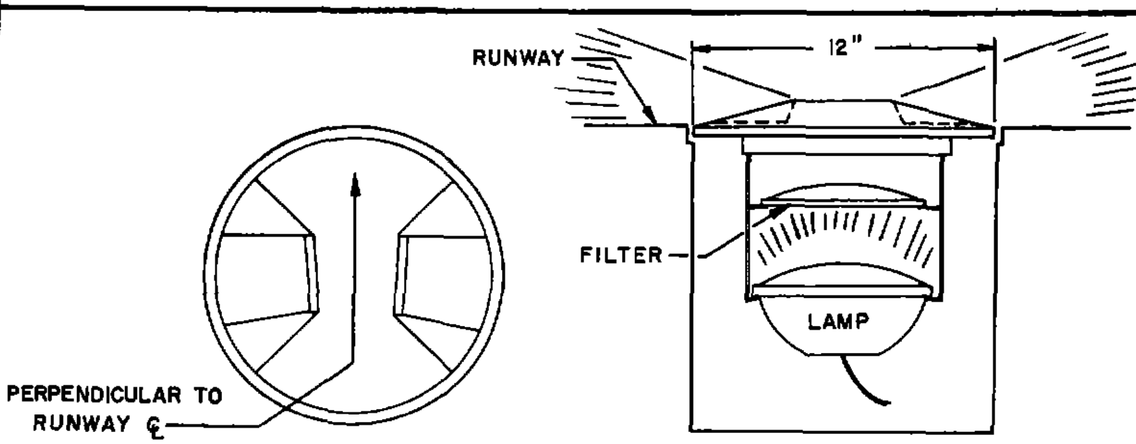
[13] Personal communication between the authors and Mr R C Herner, FAA



OPEN-GRID FLUSH LIGHT



EXPENDABLE-TOP FLUSH LIGHT



PRISMATIC FLUSH LIGHT

Figure 13

Threshold Lights

Design Requirements Used as Standards

Threshold lights define the end of the runway for a pilot on his final approach Threshold lights are used with runway lights, with both operating independently of approach configurations Using threshold lights and runway lights, the pilot should be able to clearly perceive the prescribed landing area Threshold lights are green, by international agreement

Threshold lights and lighting patterns should meet the following requirements

(1) Define the end of the runway simply and unmistakably

(2) Remain visible to an approaching pilot for several seconds prior to touchdown

(3) Present no potential danger to landing aircraft

(4) Produce little or no glare

(5) Be compatible with approach and runway lighting systems (TL1, TL3)

Designs Tested

(1) A continuous row of lights, or two bars of light placed symmetrically on the threshold (with or without red wingbars)

(2) Runway zone markers

Summary of Test Results

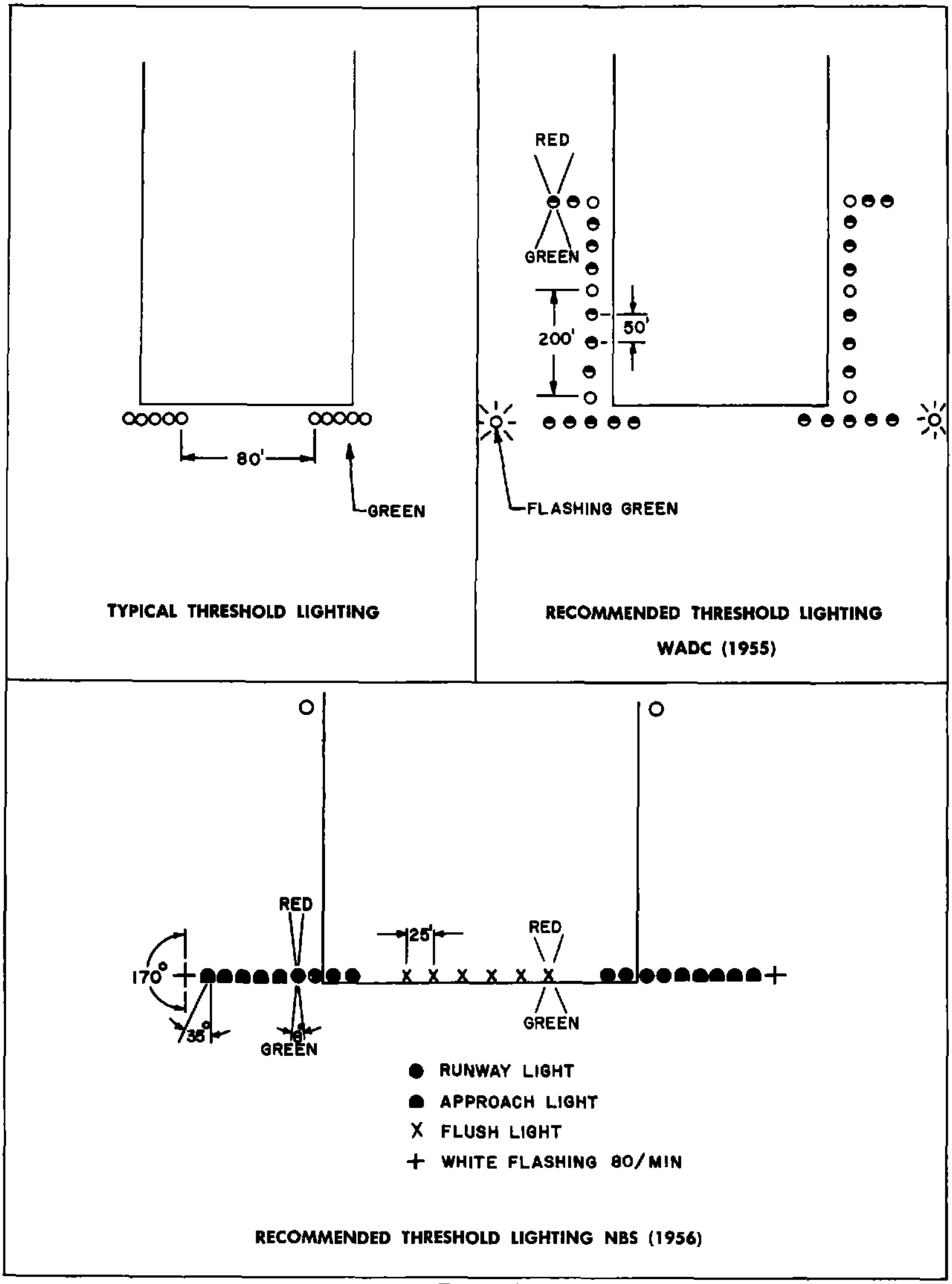
Row or Bars of Lights on Threshold

The present national standard for threshold lights, when installed with the centerline approach system, calls for a row of green lights perpendicular to the runway centerline Light units are to be placed at 5 to 10 foot intervals, extending completely across the runway and 35 feet beyond each edge The use of flush units in threshold lighting is preferred, but not mandatory, except for an 80-foot gap centered on the runway where safety considerations require their use Five red pre-threshold warning light bars are located as shown in Figure 6 (S2)

On runways with no approach configuration, the national standard calls for a minimum of eight lights in a row placed symmetrically with respect to the runway centerline Elevated lights are used at most airports In these instances, a 75-foot gap must exist in the middle for safety reasons A threshold system for a typical civil airport is shown in Figure 14 The main difficulty encountered with threshold lights is loss of effective intensity through color-coding Green filters reduce the effective intensity of lamps to approximately 1/5 of their original intensity Also, when lights are operated at less than 100% output, lamps are subject to a reddening effect, further decreasing effective intensity Because of these defects, a considerable number of pilots have complained for many years about the lack of conspicuousness of threshold lights (AL2, R6, S1, S26)

Whether or not threshold lights need to be extended entirely across the end of the runway to increase conspicuousness is still debated It has been strongly suggested that lights should extend outboard of the runway lights to accommodate fighter aircraft having relatively unstable low-speed handling characteristics and with poor forward cockpit visibility (due to nose-high landing attitude) In 1955, WADC tested six basic threshold patterns The most effective pattern was that shown in Figure 14 This pattern incorporated split-filter threshold lights which showed green at the near end of the runway to an approaching pilot, and red at the far end of the runway to a pilot taking off A full row of flush lights across the threshold was thought to warrant serious consideration whenever serviceable flush units became available (TL1, AL2)

Results of a combined theoretical-operational study by NBS and TDC in 1956 gave rise to the threshold configuration also shown in



80'
GREEN
TYPICAL THRESHOLD LIGHTING
RED
GREEN
200'
50'
FLASHING GREEN
RECOMMENDED THRESHOLD LIGHTING
WADC (1955)
RED
25'
RED
170°
35°
GREEN
GREEN
RUNWAY LIGHT
APPROACH LIGHT
X FLUSH LIGHT
+ WHITE FLASHING 80/MIN
RECOMMENDED THRESHOLD LIGHTING NBS (1956)

Figure 14

Figure 14 The recommendation was made that some of the lights should show red to aircraft taking off as well as green to landing aircraft, as in the design mentioned in the previous paragraph Spacing of lights within the bars was varied to determine the effect of spacing on effectiveness There was no noticeable difference in linearity of appearance of the bars when 2 5-foot and 5-foot spacings were used At distances of greater than 1 mile, however, the effective intensity of the bar with 2 5-foot spacing was twice that of the bar with 5-foot spacing. A spacing of 5 to 8 feet ultimately was thought to be satisfactory.[14]

In the May 1956 International Federation of Air Line Pilots Associations (IFALPA) Technical Meeting, a simple line of lights across the threshold was reported as inadequate Some favorable comment was received on a proposed "sleeve" of green lights which would not only extend across the threshold, but along the runway edges for 100 to 200 feet As part of the same proposal, a triple row of green lights, instead of the single row, was recommended in order to emphasize the threshold It was generally agreed that some green threshold lights should be placed along the sides of the runway and that these could serve to indicate length of runway remaining as well as marking the threshold (AL16)

Runway Zone Markers

The extension of the threshold lighting concept to one of definition of the landing area has been suggested, as indicated in the preceding paragraphs. Proponents point out that such a lighting system could also be used to indicate runway remaining for both landings and takeoffs (TL2)

A study conducted by the Air Force School of Aviation Medicine (SAM) in 1949 concluded that a flush system of red-green lamps in the initial 1500 feet of the runway, at each end of the runway, would be helpful To a pilot beginning takeoff or landing, the lights would show red

[14] Douglas, et al , op cit

in the final 1500 feet of the runway This is the same principle that has been recommended by WADC (see Figure 14) except that in the SAM design, zone marking would be accomplished by flush lights rather than edge lighting (M23, TL1)

The principle of zone marking was used at LAES in 1949 The initial 1500-foot zone on each end of the runway was marked at 200-foot intervals with bi-directional red-green satellite lights positioned outside of regular runway lights Pilots reported that the red lights were readily identified, but that the green lights lacked conspicuousness It was recommended that the lights be moved inside the runway lights and that a more transparent green filter be developed (AL1)

In a joint TDC-WADC test at Weir-Cook Airport, Indianapolis, in 1954, spacings of the red-green satellites were varied to find the most suitable pattern. A pattern utilizing a pair of satellites positioned outside runway lights every 400 feet for 2000 feet was recommended Of 29 answering test pilots, 15 recommended that the system be adopted as a national standard (TL2)

The national standard for runway lighting established in 1955, however, does not require installation of runway zone markings, and few airports have such a system Some recent pilot opinion has indicated a need for distance-along-the-runway information visible to the landing pilot airborne over the runway The primary problem in color-coding such information is that the most appropriate length of the warning zone will vary markedly according to type of aircraft Airborne pilots ordinarily can not use the present runway distance markers discussed in other sections below [15]

Runway zone marking also was favored at the 1956 IFALPA Technical Meeting, primarily for indicating runway distance-to-go A warning light, or light bar, was recommended for installation 600 feet before

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[15] Personal communication to Capt J Gill from Capt P. D Parkinson, both of Eastern Air Lines, 5 December 1958

the end of the runway A pre-warning light was to be installed 1200 feet before the warning light--thus, the last 1800 feet of the runway would be "zoned" (AL16)

At Gatwick Airport in England, location of the threshold was emphasized recently by "wingbars" of green lights located perpendicular to and outside of the runway lights At a distance of 1000 feet along the runway from threshold, there were similar white, high-intensity "wingbar" lights The purpose of these "wingbars" was to help the pilot judge his angle of descent and to touch down between the two sets of differently-colored lights. (TL4)

Component Development Information

Apparently little can be done to overcome the approximate 80% decrease in output due to addition of green filters on threshold lights. It would be possible to have a separate power supply so that threshold lights could be operated at higher intensity than runway lights (threshold and runway lights are currently operated and controlled on the same circuit). However, even if there are separate power supplies, the effective intensity of threshold lights, compared to runway lights, will always be low when runway lights are operated at full intensity.[16] (C1)

For threshold systems to extend completely across the runway, safety considerations require the use of flush lights. For this purpose, flush lights must meet the requirements cited in the section on over-run lighting, plus the following additional one.

(6) They must supply adequate candlepower with a green filter throughout the region in which they are to be seen.

It was found at WADC that the expendable-top light had almost twice the effective intensity when used uni-directionally, as when used

[16] Douglas, op cit

bi-directionally As a threshold light, it is also more susceptible to contact with aircraft and snow plows, and although the cost of replacing the plastic tops is very small, continual replacing and cleaning up could become rather expensive and time-consuming (C24)

Open-grid type units again have the disadvantages of comparatively narrow horizontal beam spread and high unit cost, although they do provide sufficient vertical coverage. United States units are uni-directional only, but a Danish version of the Elfaka open-grid light reportedly is bi-directional and is installed at Copenhagen

Prismatic lights can provide bi-directional beams, meet photometric requirements, and are not as affected by aircraft and snow plows, although they are more susceptible to being rendered ineffective by snow than the open-grid units or expendable top units (C24)

Runway Signs, Marks and Lights

Design Requirements Used as Standards

In final landing procedures, the pilot typically focuses his attention on his intended touch-down area When his view of the threshold lights is cut off by cockpit restrictions and a nose-high landing attitude, the pilot must rely entirely on whatever he can see along the runway itself to land his aircraft He may make use of his aircraft landing lights to highlight whatever is available for guidance Once he has actually touched down, the pilot must use some runway directional information to guide his roll-out. (GA22)

The primary function of runway lights is to define limits of the ground area on which an aircraft can safely operate. The runway lighting system should meet the following requirements

(1) Provide positive unambiguous identification of the runway

(2) Outline the runway

(3) Distinguish between touchdown, intermediate, and caution or warning zones of the runway

(4) Be compatible with high-intensity approach lighting.

(5) Maintain effectiveness in a wide range of conditions

(6) Be compatible with normal aircraft and airport operational procedures (e. g., cause shocks to landing aircraft or interfere with snow removal).

(7) Be relatively inexpensive to install and maintain.

The following information should be given the pilot with little interpretation required

(8) Height and distance-along-the-runway

(9) Displacement from runway centerline (alignment)

(10) Attitude. (AL1)

Designs Tested

(1) Runway edge lighting
(2) Patterns of flush lights within the runway surface
(3) Runway edge floodlighting
(4) Painted markers and runway distance markers.

Summary of Test Results

Runway Edge Lighting

The national standard since 1955 calls for straight lines of runway lights on each side of the runway, defining the lateral limits of the runway Longitudinal spacing of the lights may not exceed 200 feet, and spacing must be uniform along the runway (S18, S26)

Edge-lighting systems (Figure 15) have been in use for the past 13 years and today, with few exceptions, are installed at all United States airports And also practically without exception, pilots have complained about the lack of elevation guidance provided by edge lighting after passing over the threshold in low visibility conditions. The effect of passing from the approach lights to the runway-edge lights has been likened to entering a "black hole" since, when the pilot is at altitudes below 100 feet, the edge lights are outside the area of the pilot's attention and the more sensitive areas of his eye The relatively higher effective intensity of approach lights also aggravates the "black hole" condition by affecting the pilot's dark adaptation The distance between the threshold and touchdown point has also been dubbed the "hold off and hope" area (M4, M9, M19)

It seems to be a general opinion that edge lighting alone is hardly the optimal runway lighting system Its main advantage over other

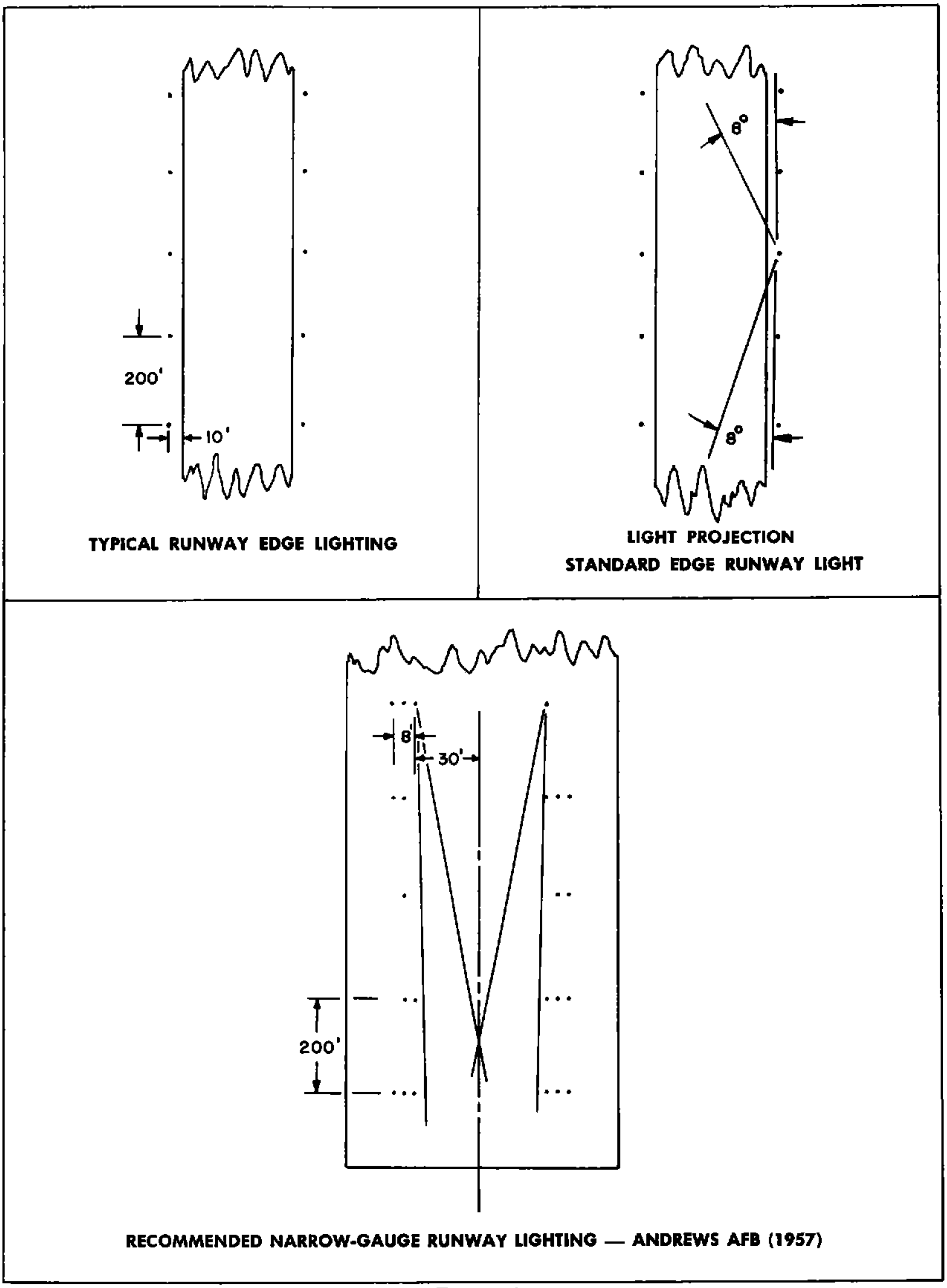
200'
10'
TYPICAL RUNWAY EDGE LIGHTING
8°
8°
LIGHT PROJECTION
STANDARD EDGE RUNWAY LIGHT
8'
30'
200'
RECOMMENDED NARROW-GAUGE RUNWAY LIGHTING — ANDREWS AFB (1957)

Figure 15

proposed systems is largely in the matter of relative economy of installation and maintenance

<u>Patterns of Flush Lights Within the Runway Surface</u>

For the past few years, flush lights have received much support as the potential solution to the "black hole" problem Proponents argue that a pattern of light units within the runway surface, having standardized lateral and longitudinal spacing, would offer accurate height guidance The apparently increasing separation of rows of linear bars and closing of the distance between units within a row at a familiar rate as the pilot descends should permit precise height judgments It has been recognized that a system accomplishing these objectives would entail a rather large expense, for not only are the light units themselves costly, but existing runways would have to be torn up for their installation (GA33, M9)

The first attempt to illuminate the middle of the runway with flush lights was at Schipol Airport, Amsterdam in 1956 A row of lights imbedded in the pavement on either side of the runway centerline, using the open-grid housing units first developed in the Netherlands (GA22)

In 1957, at Soesterberg Airport, Netherlands, four British pilots took part in brief flight tests on an extension of the Calvert approach system into the runway with the use of grid-type flush units Although far from ideal in providing visual guidance during final flareout and landing, the provision of a pattern within the runway was generally considered to be a great improvement over runway edge lighting Vastly improved height guidance was reported (R4)

Fixtures which simulated the light output of open-grid units were placed on a test runway at Andrews AFB, Maryland, in 1957 (The regular open-grid fixtures were not used because of the expense involved and because the arrangement used allowed spacing of the lights to be varied) Optimum spacing of the lights recommended are shown in Figure 15 Light units were toed in so that their main beams intersected the runway centerline 700 feet from parallel units There was some feeling, however, that a 200-foot spacing might at times fail to provide necessary guidance When visible throughout the landing maneuver, narrow-gauge lighting, as the system was labeled, was considered effective in sharpening directional guidance and providing roll guidance during flare and landing, but it apparently did not provide adequate height guidance for touchdown However, there was not complete agreement on this last conclusion among personnel who conducted or participated in the tests It was agreed by all that not enough low visibility flights were made to warrant more than tentative conclusions (AL4, R1, R9, GA47)

Edge floodlighting was also installed at Andrews AFB and it was reasoned that an optimum runway system might combine runway illumination for touchdown with a simplified narrow-gauge or centerline pattern for supplementary guidance during flareout Such a system has advantages of economy of installation on existing runways over the proposed narrow-gauge system In limited tests, however, a centerline row of flush point sources of light was found to produce surface roughness at the most heavily traveled areas on the runway This would have undesirable structural effects on certain aircraft (R1, R9)

In England, the use of a 75-foot gauge (distance between parallel units, symmetrically placed on each side of the centerline) with a longitudinal spacing of 250 feet over a runway distance 3000 feet long has been suggested by the Air Ministry This particular spacing has been criticized by researchers in both England and the United States It has been suggested in England that, on a theoretical level at least, the best configuration for elimination of the "black hole" might be a centerline pattern, but this might confuse a pilot when used with the centerline approach system. (TL4, GA2)

In a joint meeting on August 15, 1957 called by CAA to discuss the Andrews AFB tests, government and industry officials present agreed that the length of the narrow-gauge system should be about 3000 feet to form a landing mat for accommodating pilots who might fly the system only a few times a year This length was also recommended at the IATA Technical Conference at Amsterdam in November 1955. A simple centerline of lights to continue past this landing mat also has been suggested [17] (R9, GA33)

Operational tests of a narrow-gauge system using open-grid light units at Dow AFB were in the final stages in February 1959 Formal analysis of results were not completed, but military pilot opinion was considered to be very favorable The narrow-gauge system was being evaluated by the military from the standpoint of its part in an all-weather (down to 0-0) recovery system for bomber and fighter aircraft. Preliminary analysis of results allowed a tentative conclusion that, during the period from twilight to dawn, an aircraft correctly lined up with the runway centerline by GCA or ILS could land safely in any type of weather. Of particular interest was the tentative finding that a 200-foot longitudinal spacing between units was considered by pilots only to be "brighter" than a 200-foot spacing, guidance differences between the two spacings were not reported as significant by pilots [18]

Patterns of the pancake low-intensity units under development at FAA and the open-grid units will be operationally tested in the near future at NAFEC.

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[17] Braznell, et al , op cit.

[18] Personal communication between the authors and Dr H. C. Coleman, Air Proving Ground Center, Eglin AFB, Florida.

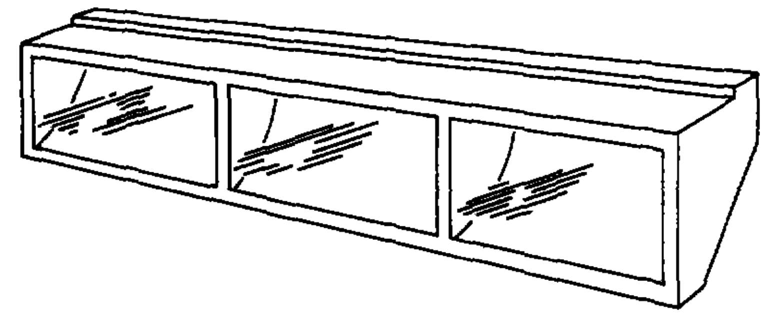
Runway Edge Floodlighting

The use of floodlighting in conjunction with flush runway lights was mentioned in the preceding section Floodlighting is the earliest known form of airport lighting A floodlighting unit has recently been developed which houses high output lamps in a specially designed luminaire (Figure 16) The purpose of these luminaires is to cast light at a grazing angle across the runway to vividly bring out runway texture One aspect of floodlighting considered encouraging is that the pilot receives guidance from more nearly the same visual stimuli he uses under good visibility daylight conditions. Suggested luminaire spacing is every 9 feet beginning 200 feet from threshold and continuing for about 1400 feet on both sides of the runway. With such a system, some proponents claim that there would be no need for threshold lights currently in use (R11, C31)

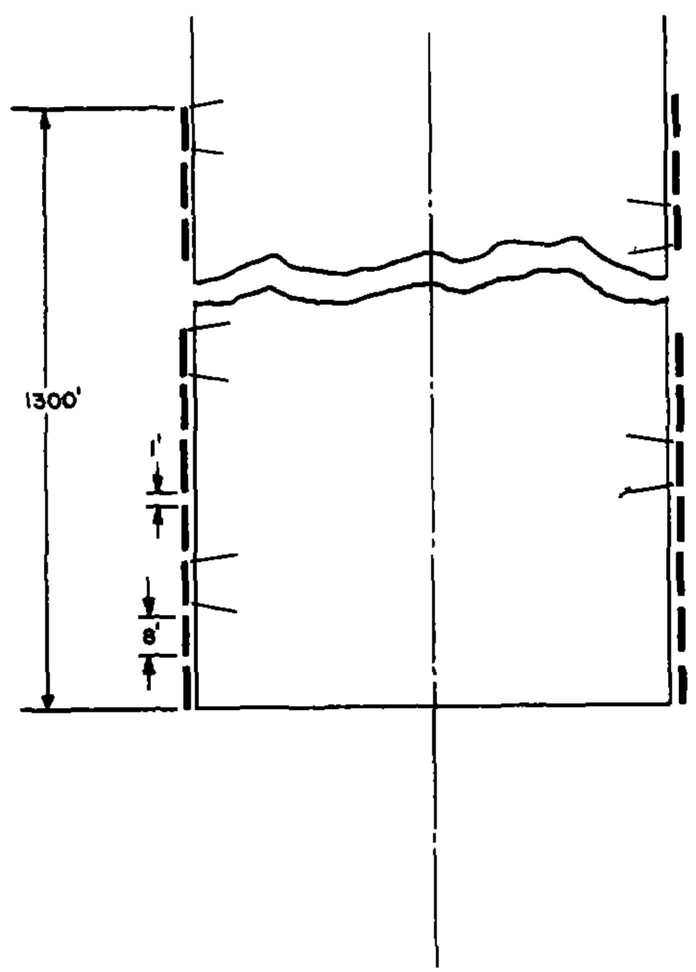
Luminaires were installed at the recommended spacing from 500 feet to 1215 feet from threshold at Andrews AFB and operationally tested in 1957. The system reportedly gave adequate directional, pitch, and roll guidance Conflicting reports, however, were received on whether or not the lights were adequate in providing altitude information and avoiding glare The general feeling apparently was that the luminaires were adequate, or with some minor adjustments could become adequate. These lights were relatively expensive to operate, interfered with snow removal, were subject to wind, hail, and jet blasts, presented a continuous obstruction along the edges of the runway, and could not be used at intersections. In addition, runway markings were not sufficiently visible, "texture" apparently being obtained only from the runway surface itself.[19] (AL4, R1, R9, GA22)

Recently, floodlighting units were installed along 1300 feet of a runway at Washington National Airport (this was not CAA-recommended operational length, but test installation length). Under ceiling conditions of

[19] Braznell, et al , op. cit.



LUMINAIRE



FLOODLIGHTING PROJECTION — WASHINGTON NATIONAL AIRPORT (1959)

Figure 16

200 feet or more, and 3/4 mile or more visibility, most pilots have found the lights useful New markings of masonry and beaded traffic paint were placed in the touch-down area On October 23, 1958, all pilots who noticed the markings were favorably impressed Some glare effects were reported On November 15, 1958, under low fog conditions, a number of missed approaches occurred, although it is not clear to what extent glare from the floodlights was a contributing factor Preliminary results show that floodlighting is less effective on blacktop than on concrete, but that white runway markings improve their effectiveness on blacktop surfaces [20, 21]

Some modification of fixtures to effect more illumination at the center of the runway and less glare at the edges is being accomplished on the Washington installation Reports on the initial system indicate that distribution of light across the runway was inadequate In addition, the luminaire has been re-designed by the manufacturer to effect increased lamp life Floodlighting probably will be tested in the near future at NAFEC.

Painted Markings and Runway Distance Markers

The value of painted runway markings has long been recognized There has been some question, however, as to what and how much information the marking should encode Even today, all airports do not strictly adhere to national standards (AL1)

The early system of runway markings (ANC system in Figure 17) was used by the Air Force, Navy, and CAA. Runway length was indicated by 50-foot painted stripes at the threshold, with each stripe signifying 1000 feet of runway length. With these earlier markings there

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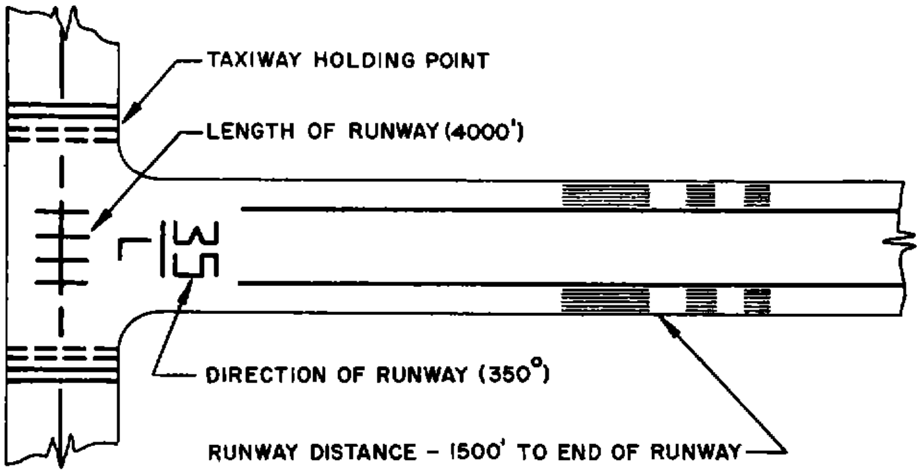
[20] R F. Gates, FAA Memorandum to files, dated 29 October 1958

[21] Gill to Parkinson, op. cit

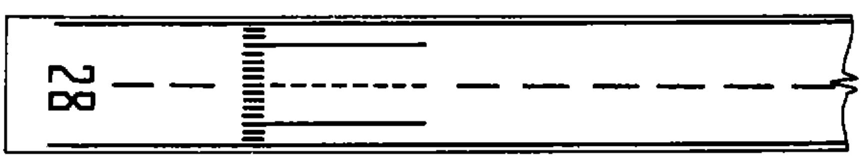
was no painted centerline, longitudinal stripes were painted on the runway, parallel to and 15 feet on each side of the runway center, to provide direction guidance They began and ended 25 feet from the runway number designations at each end of the runway The markings appearing as a series of broken stripes down the runway from the approach end (see Figure 17) were intended as distance markers and were positioned 1500 feet from the ends of the runway (R12)

Recent Navy runway markings are illustrated in Figure 17 There is lack of a requirement for the familiar runway length symbols at the threshold Runway centerline marking is formed for the most part by a broken line having 120-foot dashes and 80-foot spaces In addition to the centerline, there are two longitudinal stripes, located 72 feet to each side of the centerline Both the centerline stripes and side stripes are 2 feet wide A new item is a landing area marking (simulating a carrier deck), starting at a minimum of 500 feet from the runway threshold It consists of the following a series of stripes 30 feet long, 2 feet wide, with all stripes running parallel to the runway, forming the near edge of the area, a centerline stripe broken into 30-foot dashes and 20-foot spaces for a distance along the runway of 530 feet, two stripes placed 40 feet on either side of the centerline, also extending 530 feet down the runway (R12)

With some slight differences, the current national standards (as of 1953) follow the ICAO recommended systems and suggestions made by Sperry Three categories of runways and their markings are illustrated in Figure 18. Most prominent features of the "all-weather" marking style are the groups of longitudinal stripes along the first 2000 feet of runway. These groups are 500 feet apart and can serve to indicate the position of the aircraft along the runway. The eight bars indicating the threshold area are 12 feet wide and extend a minimum of 150 feet down the runway. In each category, the centerline is the same, 120-foot dashes and 80-foot spaces Width of the centerline is at least 3 feet, and in some instances,

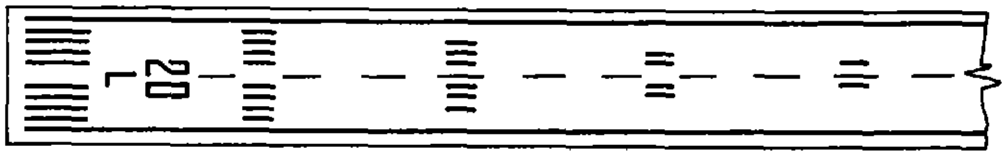


ANC RUNWAY MARKINGS

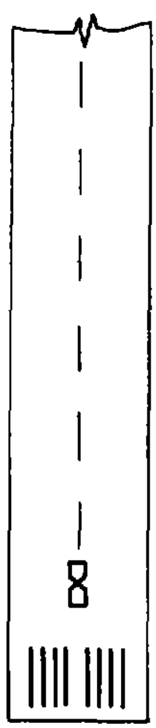


NAVY RUNWAY MARKINGS

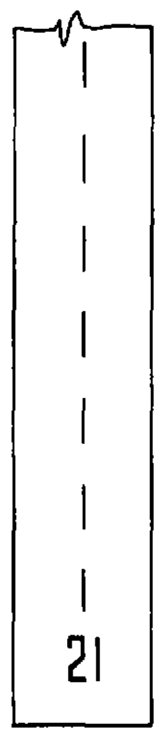
Figure 17



ALL-WEATHER RUNWAY MARKINGS — NATIONAL STANDARD



VFR RUNWAY MARKINGS
NATIONAL STANDARD



INSTRUMENT RUNWAY MARKINGS
NATIONAL STANDARD

Figure 18

widths up to 10 feet are being used Runway side stripes 3 feet wide and 70 feet from either side of the centerline are included in the all-weather markings (R12, S6)

Air Force runways have additional touch-down zone markings in the form of 3-foot wide stripes placed across the runway, one 2000 feet from either end of the runway. There is also a runway midpoint marker consisting of two stripes, 2 feet wide, extending across the runway (R12, S6)

Runway distance markers have been developed to help the pilot determine his exact longitudinal position along the runway. These signs are being used to give information on amount of runway remaining (or used) Pilots generally have expressed a preference for the signs to be on both sides of the runway, and for information on runway remaining rather than runway used The signs generally have been 4 to 5 feet square and have been positioned from 25 feet to 215 feet from the side of the runway (R2, R3, C21)

In a two-year (1955-1957) study of runway distance markers by WADC, eleven different types of signs were tested The following characteristics of signs were varied size, height above ground, color of numeral (white and black), color of the background (white, black, or orange), height of numeral, distance from runway, and construction The recommended sign and its characteristics are shown in Figure 19 The sign would be lighted with a 75-watt lamp for nighttime use (C21)

In the WADC evaluation of runway distance markers, some pilots expressed a need for a visual indication of take-off acceleration check point. This check point would be marked 3000 feet from threshold by a 3-foot wide stripe painted completely across the runway A flashing light was suggested to aid night identification of this point No operational evaluation of these proposals has been conducted (R3)

In September of 1957, signs using two types of orange background paint were tested at Arcata by NBS for the Navy. A black numeral on an international orange marker was found to be best of the combinations tested, in terms of recognition distance Optimal levels of nighttime illumination and location of the lamps also were determined (R5)

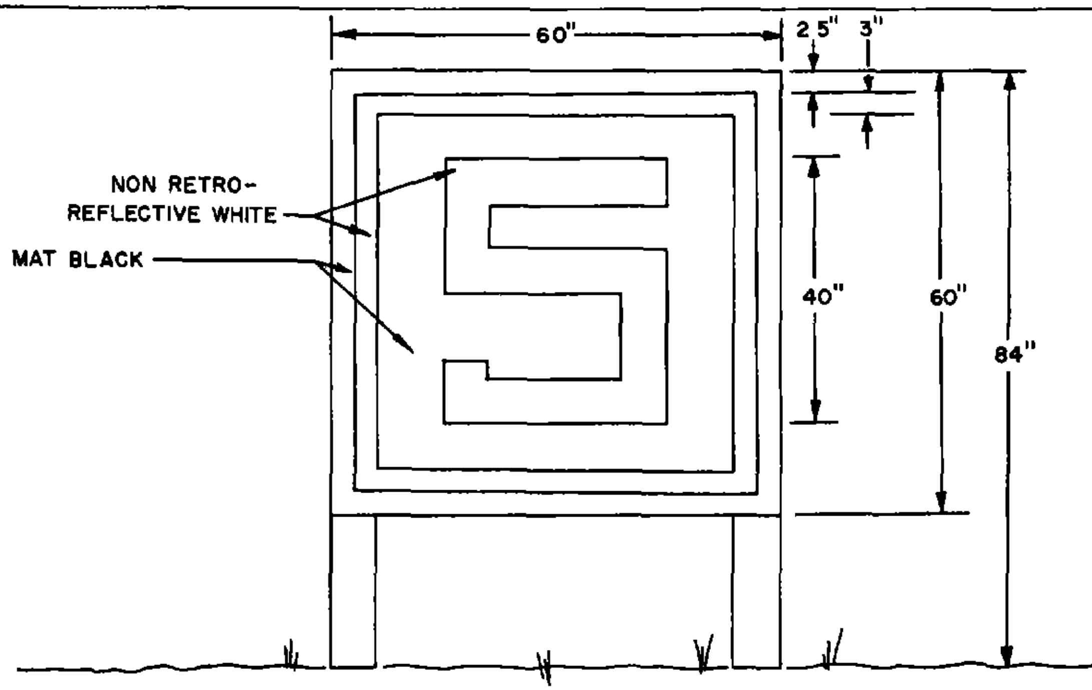
The main problem with runway distance markers is that the further they are moved into the pilot's normal field of vision, the greater hazard they become to aircraft Internally-illuminated signs have generally been so large as to be a hazard WADC reports that electroluminescent panels have been found inferior to, and more expensive than, externally-illuminated signs, although development of an improved electroluminescent panel has recently been reported (AA5, C41, C43)

Component Development Information

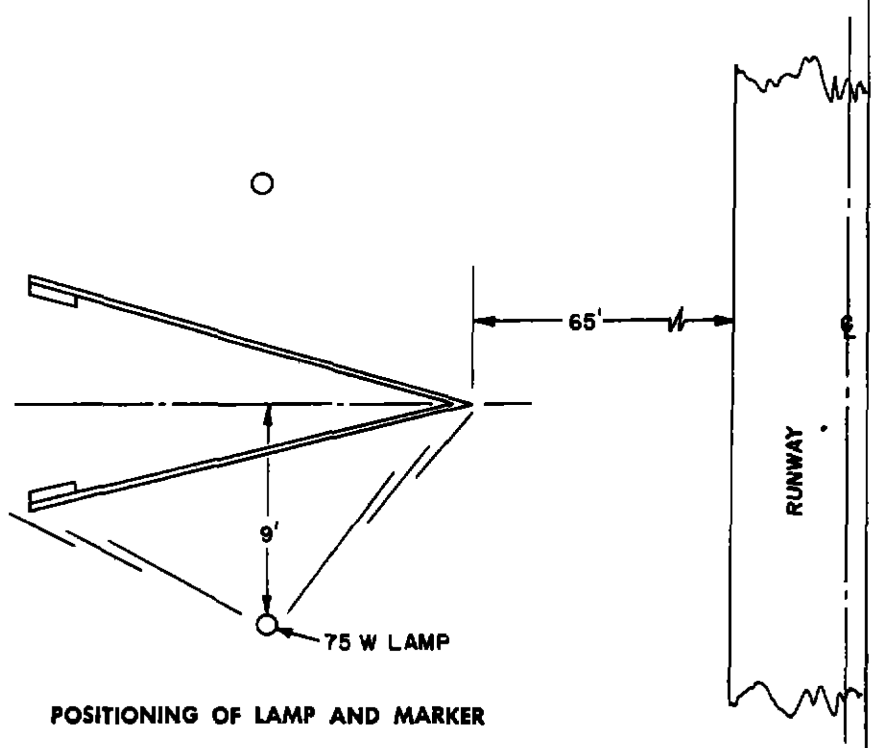
Present high-intensity runway edge lights distribute light as in Figure 15 Their output is generally adequate Present medium-intensity runway lights are reportedly inadequate (C4, C17, C18, C54, C55)

Lights to be used in the runway surface must fulfill the same requirements stated in the section on overrun lighting Again, three types of units are available flush, semi-flush, and frangible-top The open-grid and prismatic flush lights presently appear to be the best units available. A prismatic light which would afford full 360-degree coverage had been found to lack sufficient candlepower. (C23, C35)

Both the operational tests at Andrews AFB and laboratory tests at WADC seem to indicate that the open-grid type light is deficient in horizontal beam coverage Early tentative results from Dow AFB seem to confirm this, although stated somewhat differently Results of tests on prismatic lights to date appear promising. It is anticipated that these units will soon be tested at NAFEC, Atlantic City



RUNWAY DISTANCE MARKER — WADC (1957)



POSITIONING OF LAMP AND MARKER

Figure 19

Runway marking materials are evaluated in terms of the following performance characteristics

(1) Reflectance at required viewing angles.

(2) Capability to withstand normal weathering and abrasion.

(3) A coefficient of friction roughly equivalent to that of the surrounding pavement

(4) Resistance to molten rubber depositing

No one paint has been found optimal in meeting all or most of these requirements. Eight different types of paint were applied to the main runway at Washington National Airport and their performance evaluated both with and without floodlights Testing was not completed as of February, 1959 Few clear-cut preliminary results have been evident It does appear, however, that except for use with floodlighting, retro-reflective paints are best Also, due to the relatively large amount of rubber deposited at the center of the runway in the touch-down zone, the cheapest retro-reflective paint available may turn out to be the wisest solution for centerline markings in this zone (C1, C7, C25-27)

The use of new marking materials (reflex-reflective, self-luminous) on runway distance signs may increase the conspicuousness of the numerals, but the fact that the signs must be placed outside the pilot's normal field of vision is still the main reason for their lack of acceptance. (C2, C41, C50)

It may be, however, that runway distance signs are only an interim measure. It has been suggested that it might be optimal to encode this type of information for the pilot through some sort of an electronic or mechanical device linked to the aircraft, since the pilot has little time to search for these signs while landing or taking off [22]

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[22] Douglas, op cit

Taxiway Signs, Marks and Lights

Design Requirements Used as Standards

The great number of aircraft taking off and landing at today's airports makes it almost impossible for landing aircraft to come to a complete stop on runways. Thus, airports are being designed to link runways with parking aprons The sooner an aircraft can turn off a runway onto a taxiway, the greater will be the total volume of traffic which can be handled by the airport. Basically, taxiway signs, marks, and lights should simply and unequivocally define direction to the airport destination of each unit of ground traffic

The design of runway turnoffs and taxiway marks and lights should meet the following requirements.

(1) Provide an integrated system of visual aids to allow rapid aircraft movement between the runway and the parking apron.

(2) Allow aircraft to leave runway at as high and safe a speed as possible

(3) Unmistakably distinguish taxiways from runways.

(4) Provide identification of turnoffs and taxiways with sufficient lead-time to the pilot

(5) Provide identification of taxiway-runway intersections with sufficient lead-time

(6) Be visible under night and low visibility conditions

(7) Be visible despite cockpit visibility restrictions (GA22)

Designs Tested

(1) Edge lighting

(2) Centerline lighting

(3) Painted markings

(4) Taxiway signs

Summary of Test Results

Edge Lighting

A line of aviation-blue lights is used on each side of the taxiway, with uniform longitudinal spacing of not more than 200 feet to define the lateral limits and direction of the taxiway There is some feeling that closer spacing and lower intensity of these point sources of lights may be desirable (AL1, GA22)

Edge lighting was tested at McClellan AFB in 1958 in conjunction with a study of high-speed turnoffs Although the best guidance was provided by a centerline plus edge lighting pattern, the guidance provided by edge lights alone with any spacing tested was sufficiently adequate to permit the pilot to negotiate the turn without serious difficulty (TW2)

Centerline Lighting

It has recently been argued that optimum guidance would be obtained from a centerline system which gives a clear and unmistakable path to follow along the runway and taxiway At McClellan AFB, however, centerline lighting alone was found to leave something to be desired for high-speed turnoffs Lack of edge lighting caused pilots to be uncertain about amount of lateral space available to make a correction when the aircraft was displaced from the centerline Since the tests were limited in scope, only tentative conclusions were reached. It was recommended that experimental installations be set up to more fully explore centerline systems (TW2, GA22)

Centerline systems have been used in Europe Spacing of lights usually is not more than 80 feet on straight sections, with decreased spacing at curves and intersections By international agreement, these lights are green to prevent confusion with blue edge lighting systems (GA22)

An experimental centerline system was installed at a runway turnoff at Indianapolis in 1958 No formal evaluation reports are available

Painted Markings

The national standard for taxiway markings, as of 1953, requires a single continuous yellow stripe along the centerline of the taxiway Where a taxiway intersects a runway, the taxiway centerline should be curved into the runway centerline (S25)

At McClellan AFB, the most effective daytime guidance was obtained from a 1-foot wide, yellow, reflectorized stripe on the centerline Some feeling was expressed that the stripe should be wider (TW2)

Taxiway Signs

As the network of runways and taxiways at modern airports has become more complex, a more efficient method of guiding the pilot to his airport destination has become a necessity in both day and night operations At airports with control towers, signs have been used to supplement the controller's instructions and to aid the pilot in complying with these instructions

A 1952 Navy Department study on taxiway marking and lighting favored use of internally-lighted black signs with translucent yellow letters and symbols The reasons for this recommendation were maximum contrast with other airfield light and objects and maximum legibility, especially under low visibility conditions The present national standard spells out both of these requirements, in addition to standardized size, shape, lettering, and location Work done at TDC, Indianapolis, in 1952 on taxiway guidance systems apparently helped in establishment of these standards (TW1, TW3, C19, C47, C48, S8, S9, S12)

Taxiway sign systems consist basically of two sign types destination signs, which indicate the direction to taxi to a particular destination on the airport, and intersection signs, which identify intersecting taxiways and runways. Typical destination and intersection signs are illustrated in Figure 20

Component Development Information

A new gaseous-tube type of edge taxiway light, somewhat similar to one found adequate at LAES in 1949 has been experimentally developed by the Port of New York Authority and has been installed at Idlewild Airport. These lights appear more desirable visually than the point sources of light units currently used on taxiways. Verbal reports from Idlewild indicate that the light meets all visual requirements, however, some breakage of the units has been reported.[23] (C12)

Requirements for flush centerline taxiway lights are the same as those stated in the section on over-run flush lights, with the following addition

(6) They must supply adequate candlepower with a blue or green filter.

Two types of light units have been proposed for use in centerline taxiway systems. One is a round, gradually-shaped dome type light, the other a fluorescent bar type. A light which could be taped on the runway was used in the tests at McClellan AFB, however, these lights were considered suitable for interim use only. The pancake light being developed by FAA probably will be suitable for taxiway guidance (AA5, TW2, C38, C39, C40)

WADC reported that the dome-shaped light has met all requirements for its intended application No operational results are yet available on the fluorescent bar type light, but it is anticipated that light output may not be sufficient at required viewing angles. (C40)

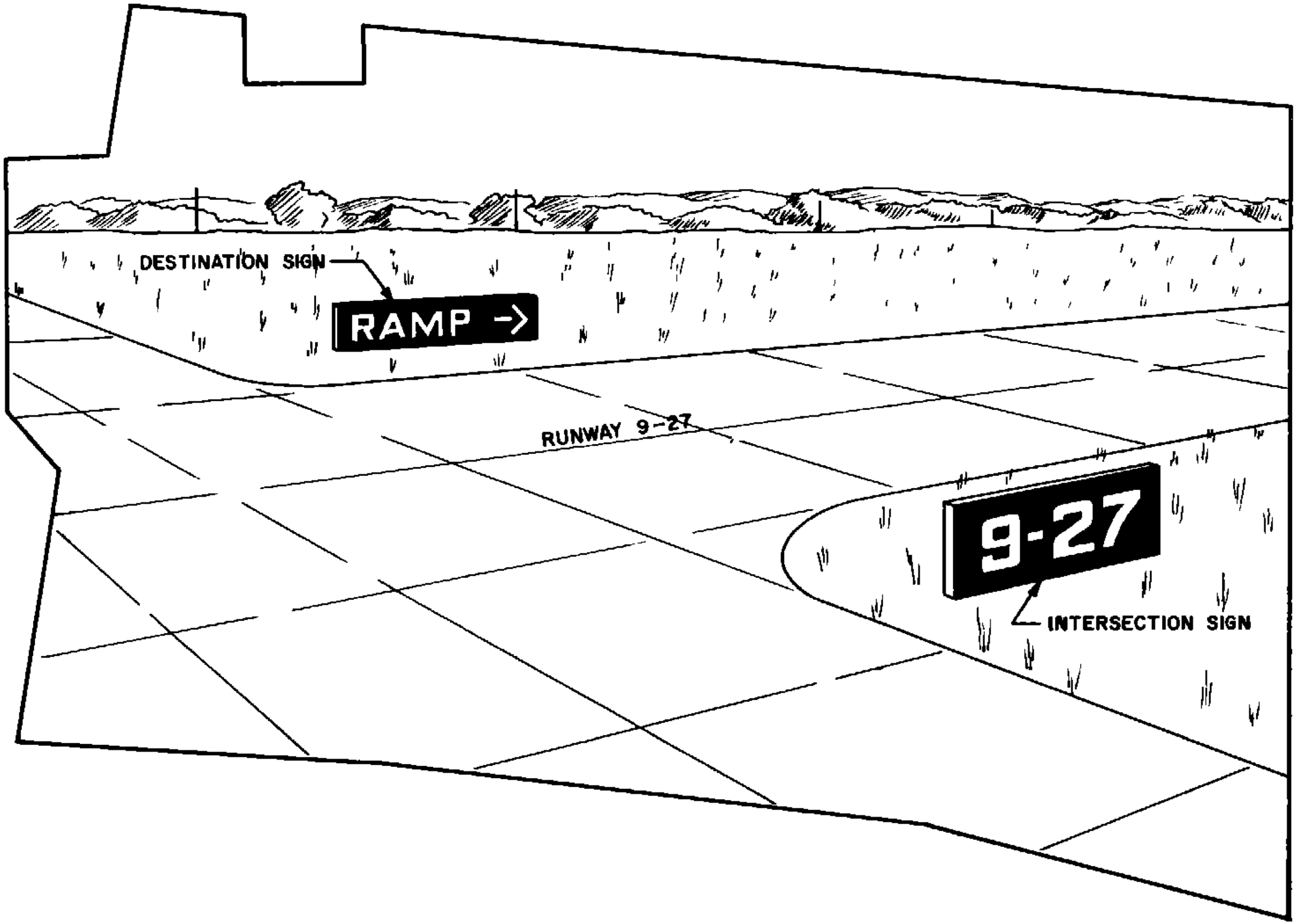
[23] Douglas, op cit

Hazard Marks and Lights

A study from 1954 to 1956 on marking of television towers, conducted by the Air Coordinating Committee, established certain specifications. Since 1956, however, little work has been done to develop lights which will meet these specifications Lights now being used to mark hazards and obstructions are apparently satisfactory for night use, but far from ideal for daylight and twilight conditions Steady-burning red lights are used to mark obstructions, the more hazardous of these being marked by red lights flashed approximately 40 times per minute Marking specifications call for alternate red and white painting (H2)

Battery-powered hazard markers have been developed for isolated hazards or emergency areas on the airport itself (H1)

There is a dearth of operational test evidence on hazard marking and lighting



TYPICAL TAXIWAY SIGNS

Figure 20

General Commentary on Operational Testing

The operational studies reviewed utilized a wide range of evaluation and testing practices At best, operational testing is difficult, time-consuming and expensive Safety and economy stakes remain high, however, making it most compelling that methods and procedures be used which accurately and reliably reflect the effectiveness of a proposed marking or lighting design

From the standpoint of economical and sound testing procedures, the survey has pointed up the need for more careful attention in the future to certain aspects of operational testing, which are discussed in this section

Economy of Testing

An operational testing program frequently can collect more than one type of data at little increase in cost or time An objective for each test should be to collect as much data as can reasonably be gathered without interfering with sound data collection procedures This principle has two general applications testing a proposed design's effectiveness against more than its primary function, gathering information that will be useful beyond the rejection or acceptance of a particular design

As an example of testing a proposed design's effectiveness against more than one criterion runway lighting can be evaluated not only for its primary utility during flareout and landing, but also its secondary utility in providing guidance during the final stages of approach and takeoff In most instances, test runs will be made with aircraft taking off from the same field at which landing evaluations are being made

The above comments should be interpreted with some caution In some instances, testing situations can be set up to produce a glut of data which would ultimately be stored, unanalyzed, and unuseful. Operationally meaningful hypotheses should be set up before testing, as should data reduction and analysis plans All data collected should contribute to the acceptance or rejection of specific hypotheses of one sort or another

Operational tests are frequently conducted on prototype equipment The pilots participating in the tests should be made aware that they are not seeing "the polished brass" Researchers must be careful to evaluate comments in light of this tendency Just as importantly, researchers must be cautious in interpreting results, frequently a concept or pattern received a negative report which was attributed to the pattern or concept, when it appears likely that another variable, such as effective intensity, was the major determinant of the negative report

The high cost of operational testing demands that testing programs be set up to maximize within practical limitations the information collected in a test In addition to providing information that can be used to reject or accept a proposed design, operational tests can be set up to generate feedback information for equipment designers Thus, test results can be used to specify a set of functional design requirements which, even if they are not met by the hardware operationally tested, can be used to help design future equipment which will be acceptable

Objective Testing Standards

Pilot "output" and "input" performance measures are both essential Operational testing without one or the other does not provide the firm overall basis required for recommendations which necessarily involve many lives and large expenditures of money

Instrumentation is required which allows an objective record to be made of attitude and flight path profiles during testing In the long run, these performance "output" measures--flight path deviations, attitude variations, landing impact force, actual point of touchdown, etc -- represent one of the two primary criteria These measures are obtainable and have been used at such places as National Aeronautics and Space Administration Ames Research Center and Air Force Flight Testing Center, Edwards AFB Use of such measures has been sporadic and incomplete in airport marking and lighting operational tests

Subjective reports of pilot opinion are one type of "input" measure and have been used almost exclusively in operational tests Certainly one must take account of the "tranquility of spirit" referred to frequently as one important requirement for an airport marking and lighting design But pilot "input" must be defined more broadly to include all types of pilot effort and strain Opinion collection instruments can be refined in light of the knowledge which has accumulated in recent years on removing or accounting for bias and other such factors in opinion measurement Specially designed information collection instruments can be used by trained observers for on-the-spot-in-flight record taking (for other than single-place fighter aircraft) as another measure of pilot "input"

Comprehensiveness of Test Design

Operational testing procedures must guard against systematic biases and chance results Output and input measures can be expected to vary with aircraft performance characteristics and structural factors such as cockpit visibility, pilot training and experience, both general and specific, auxiliary aids (electronic or others), weather conditions, and many other factors

It is virtually impossible to test all possible combinations of all factors However, a systematic testing program can focus on the values of factors that bracket the range of values that the factor can take For example, aircraft representative of particular extreme ranges of control characteristics might be used, instead of aircraft representative of all control characteristics Caution must be exercised so that test pilots are representative of the pilots who will use the system, continued use of the same test pilots can lead to biased results due to their unusual familiarity with the system being tested In addition, of course, inherently unsafe conditions can not be routinely programmed as a part of the testing program But a factorial design approach, as opposed to random or functional approaches, would insure that test designs are comprehensive

Operational testing in the past has been characterized in general by use of a relatively small number of pilots and only a few combinations of the many factors which potentially affect test results

The Proper Role of Operational Tests

The cost of operational testing in the future can be expected to be higher due to projected increases in complexities of aircraft and operations Care must be taken to see that as much preliminary screening of design proposals as is possible has been accomplished before the operational test stage is reached The use of semi-operational screening techniques, such as simulators with visual presentations, should be increased These screens can weed out designs that appear to be sound on the drawing board, but which have serious deficiencies in the operational situation

In the past, a number of operational tests have been conducted on designs which were still being drastically modified during the testing program It is most difficult to justify the use of operational tests as a routine experimental design procedure Operational tests properly should be considered as the last step before service installation In this role, operational tests are viewed as a proving grounds for designs which have passed thorough analytic and semi-operational evaluations

Current Status of A M L Installations and Ongoing Operational Tests

The preceding sections have ranged over what "has been", what "is" and what "may be" in airport marking and lighting operational tests As a summing up, it may be useful to shift this emphasis A picture of what is likely to be actually installed today at a "typical" heavy traffic airport is described in this section, along with a review of operational tests currently underway

Typical Airport Marking and Lighting Installations

Installation of airport marking and lighting systems at service airports has not immediately followed operational tests demonstrating a system's or component's effectiveness There has been a built-in time lag due to budgetary limitations and attempts to resolve different opinions of interested groups Above all, there has been a phenomenal rate of increase in air traffic and in operations under night and poor visibility conditions These factors have tended to widen the gap between what could be done, what had to be done, and what needed to be done The rapid development of high-performance aircraft (which also increased the divergence of total aircraft performance characteristics that must be handled by a common system) has outmoded some systems before they were in widespread use The net result of all these conditions has been an irregular installation of marking and lighting systems, making it difficult to find more than a few airports with the same over-all system Needless to say, this situation has been the source of widespread demands for standardization

From a practical standpoint, one of the most significant contributions that can be made to the airport marking and lighting system program is a reduction in the time required between introduction of a design concept and its acceptance or rejection The centerline approach system was first introduced in 1948 It was not made the national standard until 1958 Transmissometers, used to measure atmospheric transmissivity, are just now getting into full use, but have been developed since 1949 A reduction in lead time can be expected through the use of more objective operational testing procedures recommended in the preceding sections, inasmuch as data should help resolve differences in opinion

One can expect to find the following at today's "typical" heavy traffic airport.

Beacon Alternate green and white flashes, 12 per minute (Dual white flashes at military airports)

Approach Lights. On instrument approach runways, and used only in poor visibility conditions short left-hand single red rows, extended runway edge white rows, or white centerline approach systems. There were 14 national standard (NS1a) centerline systems in operation in June 1957, a total of 89 were planned for installation through 1962 Sequenced flashing lights were programmed for 36 centerline systems by the end of 1958, a total of 83 of the 235 centerline systems planned through 1962 are to have sequenced flashing lights. (GA34)

Threshold Lights A continuous or split row of aviation-green lights extending across the end of the runway

Runway Marks White centerline painted in 120-foot stripes with 80-foot spacing White runway number just beyond threshold Eight threshold lines extending 150 feet down the runway Other markings vary considerably from airport to airport

Runway Lights White runway edge lights extending along both sides of the runway.

Taxiway Marks Yellow continuous centerline

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

Runway and Taxiway Signs Vary considerably from airport to airport

Ongoing Operational Tests

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

Beacons. The usefulness of beacons as visual aids for locating and identifying the active runway is being actively explored The more promising of these appear to be approach-beacons recently tested at Arcata and soon to be further evaluated at El Toro, California, and Oceana, Virginia, runway-end identifiers (170-degree coverage) soon to be service tested at Norfolk

Runway Lights. This is currently the area of most activity The flush narrow-gauge system testing at Dow AFB is approaching an end A narrow-gauge system is being installed on a runway at Idlewild. Floodlighting is being tested at Washington National Airport. Both narrow-gauge high intensity, "pancake" medium intensity, and floodlighting systems will be further evaluated at NAFEC, Atlantic City Centerline "button-lights" for runway roll-out guidance were also included in the Dow AFB installations and will be further tested at NAFEC

Runway Marking Materials Experiments and tests of runway marking materials, including retro-reflective paints, are currently under way at Washington National Airport

Taxiway Lights New edge lights are being service tested at Idlewild Centerline (flush) taxiway lights are being evaluated at Indianapolis and probably will be further tested at NAFEC, Atlantic City

Chapter 3

Flight Mode Analysis of AML Functions

The survey of operational test results presented in the preceding chapter was organized around hardware systems and components. In this chapter, focus shifts to functions served by the AML system. The analysis is presented by flight modes, which are logically related portions of the pilot's tasks in air and ground movement involving use of the AML system Modes are discussed in the following order

Initial Approach (VFR)--including entry into traffic pattern

Circling (VFR)--including downwind and base legs

Final Approach--VFR and IFR.

Flareout and Landing--including runway rollout.

Turnoff and Taxiing

Takeoff

A brief discussion on total AML system functioning is presented last

Explanation of Mode Analysis Parts

The analysis for each mode consists of the following parts

General Pilot Task Description. Brief statements are made regarding those parts of the pilot's task involving the AML system These statements are not meant to cover all of the pilot's tasks in the flight mode For example, his systems' management tasks (e g , hydraulic, oil systems) and aircraft configuration tasks (e g , operation of flaps, spoilers, landing gears, speed brakes) are not included These tasks have implications for the AML system to the extent that they place time-sharing demands on the pilot, which in turn place a general requirement on the AML system to provide easily and quickly interpretable information to the pilot Our focus in this part of the analysis is to find what information must be presented and how this might be best accomplished

To the extent possible, task statements have been made as broad as possible in order to cover different variants of the task introduced by different types of aircraft and operating procedures The statements are based on literature describing the pilot's tasks analytically and interviews with commercial and military pilots The interested reader is referred to Technical Note 2 for a general technical analysis of the nature of the pilot's task formulated during the present study

Information Pilot Requires from AML System. Statements in this part of the analysis form the standard against which the adequacy of the AML system was evaluated in this study The information requirements were formulated on the basis of a distillation and synthesis of all operational test and analytic literature, as well as interviews with commercial and military pilots Following logically from task descriptions, the listing is restricted to information the pilot typically receives from sources external to the cockpit The interested reader is referred to Technical Notes 3 and 4 for a general analysis of the basic information requirements for flight control and the kinds of basic visual cues typically utilized as sources of information

Inasmuch as information requirements represent the keystone of the analysis, these statements of information requirements have been phrased, not in terms of characteristics of the AML system or other sources of information, but rather in terms of the information content the pilot requires To get this information, he will frequently need to make judgments based on what he sees, but it is the information which he requires, not some particular visual cue. Thus, distance to the threshold is listed as the requirement and not visual definition of the threshold The latter is too restrictive in the sense that it refers to an external visual cue that may some day not be required as a basis for the pilot to make a distance judgment Distance to the threshold might conceivably be given to him by another source of information, such as the indicator provided with Distance Measuring Equipment (DME) displays One can see how phrasing functional requirements in terms of external visual cues places restrictions on imaginative research and development

The preceding discussion leads into another critical distinction which must be kept in mind throughout the entire chapter The light reflected or emitted from an object at once typically gives the pilot information about the nature of the object, i e , identification of what it is, and information about the relationship of the pilot to the object, i e , guidance for flight control Some patterns of marks and lights provide these two kinds of information better or more poorly than other patterns. Each type of information is important to the pilot at various times There has been a tendency during the historical development of the AML system to focus on the identification function of light and to accept the relationship function as given and dependent upon the "natural" ability of pilots [24]

A final point regarding information requirements is related to both of the preceding considerations There are three general ways in which the AML system can provide guidance to the pilot

(1) The AML system can highlight "natural" visual characteristics or provide substitutes to help the pilot make better judgments Outlining the edges of the runway so that they are more easily seen helps the pilot make better distance and height judgments on the basis of apparent changes in the size and shape of the runway. This has been the conventional approach to airport marking and lighting

[24] Because judgments are involved, accidents involving faulty judgments are frequently attributed to pilot error The implication is plain that the pilot should have done better, that it was within his capabilities to have done better While this labeling is true to the extent that a poor judgment may have been involved, the important point is that the poor judgment, in the absolute sense, may have been the best one that the pilot could have made, given the visual cues provided him and the limits of his "natural" ability Better ways to do the former, and recognition of the latter, should lower the accident rate and go far toward reducing the accidents currently labeled as pilot error The interested reader is referred to Technical Note 5 for a discussion of the implications of accident data for AML systems design

(2) The AML system can change the nature of the judgment the pilot has to make by providing him with a more easily interpreted visual signal incorporating standard and error information The angle of approach indicators represent developments of this type It is easier for the pilot to make a judgment about being on, or off, course on the basis of color discrimination or separation of two visible bars of light than to have to integrate height and distance judgments and to compare his final judgment about his glide slope against a standard of what it should be stored in his memory

(3) A third option is for the AML system to provide control information directly by visual means. This has not been attempted to date It is similar in concept to the steering information of flight director cockpit displays and to many functions performed by the Navy Carrier Landing Signal Officer (LSO).

The statements of information requirements in this chapter have been formulated in such a way that they will be most useful for research and development in the first two options listed above, but also serve as useful anchors for research and development within the third option

Again, requirements have been formulated for the general case in the sense that a particular operating procedure used by a particular aviation group (such as private aircraft owners) that requires special information has not been included These kinds of considerations are treated in the Discussion under each flight mode as appropriate

Finally, it should be noted that this part of the analysis does not list requirements other than those based on the pilot's information needs, nor does it include statements about what the AML system should not do It is recognized that such factors as cost, ease of installation and maintenance, and safety are important criteria Also, it is critical that the AML system should not interfere with snow removal procedures or equipment, produce glare, or in other ways be incompatible with other requirements and considerations Focus in the analysis is on what the AML system should do positively for the pilot

Existing AML System Sources of Information. There are two categories in this part of the analysis The first category, Designed for Requirements, lists those AML systems and components which have been developed specifically to meet one or more of the flight mode information requirements The category includes the present national standard and prior systems still in existence. Other Visible Sources, the second category, lists those characteristics of visible objects which are present in the operational situation to some degree and which can be used as a source of information by the pilot, although not specifically developed or designed for that purpose

"Sources of Information", as used in the title of this part, refers to an object, or its characteristic, which provides the pilot with a visible basis (cue) for making the visual-perceptual judgments involved in controlling his aircraft

Relevant AML Components Under Development This part lists those AML systems or components which are being designed or evaluated specifically to meet one or more of the flight mode information requirements Information for this part of the analysis came from the operational test and analytic literature, as well as from interviews with personnel engaged in on-going research in civilian and military agencies.

Summary of Reported Pilot Problems In this part of the analysis, problems currently being experienced by pilots using the existing AML system are presented briefly Problems were identified through interviews with commercial and military pilots This part serves to supplement and highlight the operational test evidence on the AML system presented in Chapter II.

Discussion Each flight mode information requirement is discussed in terms of how well the existing AML system is meeting that requirement Problems reported by pilots and identified in operational tests on the existing system are used as focal points of the discussion. Possible solutions to the problems are discussed in light of operational test evidence on AML system components under development, applicable human factors research data, and suggestions made by interested aviation groups

Recommended Research and Development. The final part of each flight mode analysis lists research and development projects which seem compelling on the basis of the flight mode analysis Generally speaking, the projects recommended fall into three categories basic analytic studies or development of components, semi-operational evaluations, operational or service tests

It should be noted that recommendations for research and development are made primarily from a pilot information requirements viewpoint Each suggestion is phrased in terms of its objective from that viewpoint. The listing is not meant to spell out the research or development project in detail. It is assumed that relevant reports contained in the Technical Appendix to this report would be reviewed as a matter of course by those planning any of the research projects in detail

Initial Approach (VFR)

General Pilot Task Description

Locate airport and fly toward it

Locate duty runway and fly to traffic pattern entry point

Information Pilot Requires from AML System

Identification of airport

Identification and orientation of duty runway

Existing AML System Sources of Information

Designed for Requirements

Beacons

Other Visible Sources

Characteristics of Airport--Day

(1) Color or brightness contrast between airport area and surrounding area

(2) Contrast in terrain features between airport area and surrounding area (relative absence or presence of man-made structures, such as buildings, and natural features, such as hills and trees)

(3) Color or brightness contrast between runway and surrounding airport area

(4) Runway markings

(5) Presence of buildings typically associated with airports (e g , hangars, tower)

Characteristics of Airport--Night

(1) Threshold and runway edge lights

(2) Illumination of hangars and other airport buildings

(3) Contrast in lighting between airport and surrounding area

Relevant AML Components Under Development

Approach beacons on extended runway centerline

Runway identification lights (170-degree coverage) at threshold corners of runway

Runway-end identifiers (30-degree coverage) at threshold corners of runway.

Circling guidance lights along edges of runway.

Summary of Reported Pilot Problems

It is difficult to identify some airports during both day and night operations because they are not distinct from their surrounding areas Present civil beacons are frequently indistinguishable from flashing lights of supermarkets, drive-in restaurants and similar advertising signs in a city

Identification of the duty runway is very difficult, both in day and night operations In the day, black-top runways blend with surrounding terrain. At night, runway lights and other airport lights blend with city street and parking lights as, for example, at Chicago Midway

Discussion

The new beacon lamp tested at Wright-Patterson AFB should increase the maximum distance and altitude at which beacons are visible, if installed at civil airports (C36)

It is apparent from discussions with pilots and researchers, however, that at certain airports, the present beacon alone does not provide sufficient airport identification information It is doubtful whether further re-design and development of beacons themselves would help, because the problem seems to be less one of beacon conspicuousness than airport area conspicuousness During day operations, there does not seem to be enough color or brightness contrast between the airport area and the surrounding area at a number of airports At night, the beacon and other airport lights are "imbedded" among city lights at some airports No operational evidence was found which conflicted with pilot reports of this problem

The same problem seems to exist with identification of the duty runway During the day, there is frequently insufficient contrast between runways and surrounding airport terrain One study shows that in many cases, instrument-measured contrasts of runway surfaces to the surrounding area were less than 0 05, which is commonly accepted as the contrast threshold applicable to service conditions When one considers that glare and windshield diffraction can even further reduce the contrast figure, the basis for reported pilot problems in runway identification is clear Even with the best contrast measured (white concrete against dark earth), the runway in day haze was not visible until the measuring aircraft had approached to within a 1/2 mile when meteorological visibility was reported to be 1 mile (TV16)

At night, threshold and runway lights are not very useful, particularly at city-area airports Their beams are directed so that maximum intensity falls along the approach path and runway centerline, respectively, thus, even in non-city areas, the utility of these lights to pilots of aircraft in any other location is minimal In city areas, these lights are again "imbedded" and difficult to detect in off-axis approaches because of low intensity settings (to prevent excessive glare when the pilot is in the main beam)

What tends to solve the runway identification problem at night may solve the airport identification problem also. Looking at runway identification for the moment, the use of either approach beacons or runway identification lights (or both) in night operations would form, with the airport beacon, a pattern of flashing lights From a human factors standpoint, this pattern of flashing lights would be more easily detected by pilots, whether or not "imbedded" in city lights at night, than is the airport beacon alone. Because of narrow beam width, the proposed condenser discharge lamps at the threshold corners of the runway are not as satisfactory as the approach beacons or runway identification lights (HF47)

During day operations, contrasts between runway and surrounding terrain, already demonstrated to be inadequate alone at many airports, would be supplemented if the approach beacons and runway identification lights are used. At night, particularly when thought of in combination with circling guidance lights (see next section), the total pattern of flashing lights should readily identify the duty runway for pilots in the initial approach When considered in combination with the airport beacon, the same patterning of flashing lights should readily identify the airport without the necessity of relying on the inherent contrast between the airport area and surrounding terrain (At longer distances, this inherent contrast is not readily visible in the first place due to the apparent bluish hazing by atmospheric transmissivity conditions) It should be recognized that lights in general will be useful during day VFR operations when visibility conditions are marginal (e g., haze, dawn, twilight), in bright daylight, the effective intensity required to overcome surround brightness would be most difficult to attain

Although colored lights could be used to code identification information, the loss of effective intensity due to color filters makes a solution of this sort prohibitive in cost In addition, there are no significant haze or fog-penetrating differences among the colored lights For this reason, all of the suggested designs use white lights (TV15, TV33)

Of course, operating high-intensity approach lights with strobe-beacons in day VFR conditions might accomplish the same result, and has been suggested From another consideration, namely, gaining familiarity with the approach light system during final approach and thus increasing transfer of training to night and IFR operations, this solution is preferred. But for purposes of initial approach, this would be a fairly costly solution and would be useful only where installed on IFR runways The use of approach beacons and/or runway identification lights is relatively inexpensive

Pilots frequently have circumvented the airport area and runway identification problem by learning the relationship of other landmarks to the airport and runway At Melbourne, Australia, for example, an area of white sandy beach bordering a fairly large water inlet adjoins the airport area. Pilots use the "white beach" as their airport identification cue The same kind of process is used by pilots for identifying (and thus orienting their aircraft to) the duty runway

If it is considered too costly to operate lights as described in preceding paragraphs during day operations, or if intensity settings feasible are not adequate, pilot practices point to an alternate solution. Airport buildings could be painted so as to provide maximum contrast with buildings and terrain in the surrounding area for airport identification. There would be no "operating" costs, as such, with such a solution, but initial cost and maintenance might introduce serious cost problems

Recommended Research and Development

It is recommended that operational tests be conducted on the National Bureau of Standards (NBS)-developed approach beacons and runway identification lights These designs should be tested both against each other and in combination In both instances, they should be tested alone and with circling guidance lights.

It is further recommended that the tests be concerned with the effectiveness of the designs in providing both airport and duty runway identification during both day and night operations For this reason, if tested at the National Aviation Facilities Experimental Center (NAFEC), and found acceptable, the designs should be subjected to an early service test at a city-area airport, such as Chicago Midway, before being finally accepted. It is not considered necessary to use a wide variety of test aircraft, effectiveness of the identification (and thus location) function of the AML system would not be expected to vary significantly because of different aircraft performance characteristics

Circling (VFR)

General Pilot Task Description

Fly downwind leg parallel to and at prescribed distance from duty runway

Initiate, maintain, and roll out of base leg so that resulting position is aligned with extended runway centerline at proper altitude for initiating approach

Information Pilot Requires from AML System

Changes and rates of change in

- Orientation to duty runway during downwind and base legs
- Distance from runway edges during downwind leg.
- Distance from threshold during base leg

Existing AML System Sources of Information

Designed for Requirements

(1) Runway lights

(2) Threshold lights

(3) Runway markings

Other Visible Sources

Characteristics of Airport--Day

Color and brightness contrast between runway and surrounding area

Characteristics of Airport--Night

Miscellaneous airport lights (e. g , ramp lights) having a known relationship to duty runway

Relevant AML Components Under Development

Circling guidance lights along edges of runway

Approach beacons on extended runway centerline.

Runway identification lights (170-degree coverage) at threshold corners of runway

Condenser discharge lights with baffle (30-degree coverage) at threshold corners of runway

Summary of Reported Pilot Problems

Pilot problems during this mode are closely related to those reported for the Initial Approach mode. At many airports, the lack of brightness contrast between the runway and surrounding airport terrain leads to a lack of definition of the runway during day operations Inasmuch as pilots typically "trail" the runway edge with some referent on their aircraft (e g , wing tip, side window structure) for directional guidance, this lack of definition leads to an irregular downwind flight path and forces the base leg to be "tighter" or "looser" than the pilot desires. Distance judgments are based on apparent size and shape of the runway, and lack of definition of the runway edges makes this judgment more difficult With blurred edges, actual distances are likely to be overestimated, leading to "tight" downwind and base legs (HF19, HF36, HF37)

During night operations, runway lights are reported by pilots to be of minimal directional or distance guidance assistance during the downwind leg because of having narrow beam widths and being "imbedded" in city and airport lights The same irregular downwind flight path results

The green threshold lights do not serve effectively as "anchors" for judging when to initiate and roll out of the base leg, probably because of narrow beam widths. This leads to missing the extended runway centerline on the first roll-out attempt and the necessity for making flight path corrections during the early part of the approach when corrective maneuvers should be decreasing A recent fatal airline accident was attributed to a stall condition resulting from a violent corrective maneuver after the aircraft had "overshot" the runway centerline rolling out of the base leg.

Discussion

There is no operational test evidence on the existing AML system for this mode because no component now in use has been designed specifically for guidance within this mode

The operational test evidence with respect to developmental circling guidance lights has been favorable in all cases The only major deficiency found has been, again, that the lights tended to get lost among city lights in urban-area airports, although testing conditions were not optimal when these observations were made This result, however, is an identification problem primarily and may be resolved when circling guidance lights are used in conjunction with approach beacons and/or runway identification lights The pattern probably would be visually compelling enough to identify the runway guidance lights

Another possible solution would be a shorter spacing (1000 feet has been used in operational tests) between lights. This would provide a more continuous indication of the runway edge, with the "line" as a whole being easier to detect

From a human factors viewpoint, either of the above solutions would be more desirable than increasing the unit intensity of the 1000-foot spacing arrangement. The problem is primarily one of pattern detection, in this case, the runway edge pattern. Brighter lights would not be expected to be significantly easier to detect from among competing lights in which they are "imbedded", unless perception of a pattern is enhanced It probably would be prohibitive in cost to accomplish this pattern improvement by increases in light intensity alone

By the same reasoning, increasing the beam widths of the circling guidance lights would not be expected to increase their detectability under "imbedded" conditions Such an increase might increase the "region of guidance" which such lights could service. The minimum beam width required should be based on servicing typical entrance points on the downwind leg to the point at which the base leg is typically initiated To the extent that more lights would be visible from a given point on downwind leg, then pattern perception would be enhanced and directional guidance improved

Again, the operation of high-intensity approach lights with strobe-beacons might solve the downwind and base-leg guidance problems in day VFR operations, but their use is difficult to justify economically In addition, day use of strobes has been reported to be disturbing by pilots in the final approach stage

The above analysis applies primarily to night operations, but circling guidance lights also would provide guidance during the downwind leg in marginal VFR day operations as well Combined with the turntables of beacons and/or threshold beacons, it is probable that adequate guidance during the entire circling mode would be available

The 3-foot side stripes (70 feet to either side of centerline) currently specified in the national standard for all-weather runways might be used on all runways to increase the conspicuousness of the runway shape in good VFR day operations. For this marking solution, it would seem that the turntables of beacons, threshold beacons, or some such similar runway identifier would be required to aid the pilot to <u>locate</u> the duty runway edge in marginal VFR day conditions. The adequacy of any such runway markings is open to question, however, particularly during minimum VFR conditions, because of the large slant range (distance) between the pilot and runway--1/2 to 2 1/2 miles--during the downwind and base legs But paint is relatively inexpensive and the width of stripes could be increased in order to increase their conspicuousness Serious consideration should be given to more liberal use of paint for edge stripes, a relatively unused portion of the runway is involved, thus maintenance would not be as large a problem as it is with centerline stripes and markings on heavily-used portions of the runway. High color contrast with each airport's runway surface and surrounding terrain should be a guide for selecting colors, standardization of color is less important than high contrast. Such contour outlining would be useful in the initial approach mode, as well as the circling mode, by assisting the pilot in locating runways

Pilot practices at airports where circling guidance is poor, due to either poor runway-airport contrast or low visibility, afford some interesting insights. At Baltimore Friendship International, for example, the orientation of Runway 15 to the Calvert distillery complex has led to the (visual) use of the distillery for directional guidance during the downwind and base legs--the "Calvert Distillery Approach" At New York LaGuardia, the "Rikers Island Approach" to the main north-south runway is so-named because of the use of the island itself, and a tall tower and prison buildings on the island, as directional cues during the base leg In short, pilots make heavy use of tall buildings, water towers, and other conspicuous <u>non-airport</u> cues for required guidance

The basis for the use of these non-airport cues is probably broader than the inadequacy of runway-airport contrast Although no human factors research data are available, it seems reasonable to believe that flying a straight path in a given direction is easier when the visual cue being used is along the path of movement, rather than off to the side In the former instance, a flight path can be gun-sighted on a target, in the latter, continual parallel judgments must be made, typically on the basis of the apparent size, shape, and edge of the runway and the apparent position of the runway edge with respect to some part of the aircraft's structure.

The analysis in the preceding paragraphs suggests that markers, perhaps lights, patterns of lights, or cleared areas with paint for contrast, strategically placed on the extended downwind path ahead of the pilot might provide downwind leg directional guidance by serving as targets. This could lead to an increase in VFR traffic acceptance rate at high-density airports at which a variety of performance characteristics are involved in the air traffic load Slower aircraft would fly a tight pattern and faster aircraft a loose pattern, both patterns being set by the "targets" ahead of the pilot during the downwind leg. This is similar in principle to the final approach entry technique used by controllers for IFR traffic, aircraft are brought on to the final approach heading at various distances from the runway Presumably, this technique would still involve rotating turntables or threshold beacons for base leg guidance. The problem of target lights being "imbedded", and thus difficult to identify and locate, would need to be considered carefully. Also, day use of lights probably would be restricted to marginal VFR conditions, in good daylight conditions, lights would be difficult to detect.

Recommended Research and Development

It is recommended that operational tests be conducted on the runway circling guidance lights of the single-fixture type developed recently by NBS Special attention should be given to determining optimal distance between units and optimal beam width settings

It is further recommended that these tests be conducted in conjunction with the recommended operational tests on use of approach beacons and runway identification lights for Initial Approach mode guidance As in that instance, if found acceptable at NAFEC, the lights should be subjected to an early service test at a city-area airport before final acceptance Consideration should be given in the testing to using different traffic pattern techniques

It is further recommended that an analytic feasibility study be made of downwind leg "markers" such as described in the Discussion Special attention should be given to utilizing different-sized traffic patterns, perhaps at different altitudes, for different classes of aircraft as a means for increasing airport acceptance rates of VFR traffic

Final Approach

General Pilot Task Description

Initiate descent at proper distance from runway to set up an optimal approach angle to flare-out point.

Maintain proper attitude and air speed in order to maintain optimal approach angle and rate of closure with runway.

Reduce power at proper distance for optimal touch-down air speed

Information Pilot Requires from AML System

Identification of duty runway approach area.

Distance to threshold when threshold not visible.

Changes and rates of change in

- Distance between intersection of glide path with runway and aircraft--closure (a function of elevation (height), sink rate, and ground speed).
- Attitude of aircraft--pitch, roll, and heading-line of flight coordination.
- Glide path (direction of flight path).
  - Displacement laterally from extended runway centerline.
  - Displacement vertically from optimum approach angle with runway--glide slope (a function of elevation).

Existing AML System Sources of Information

<u>Designed for Requirements</u>

IFR Approaches

(1) Configuration "A" Approach System, with sequenced strobebeacons.

(2) Short single row of red lights on extended left edge of runway

(3) Rows of white lights on extended edges of runway.

(4) Threshold lights (green)

(5) Runway edge lights (white).

VFR Day Approaches

(1) Runway markings

Threshold marks

Centerline stripe

Side stripes

(2) Navy Mirror Landing System--Aircraft Carrier Approaches.

VFR Night Approaches

(1) Approach lights, where installed on IFR runways.

(2) Threshold lights.

(3) Runway edge lights

(4) Navy Mirror Landing System--Aircraft Carrier Approaches

<u>Other Visible Sources</u>

IFR Approaches

Depends upon meteorological visibility conditions Ground lights and texture can be the only sources present in minimum visibility conditions. As visibility increases, more of the sources listed below for VFR flights become useful

VFR Day Approaches

(1) Color or brightness contrast between runway and surrounding terrain.

(2) Approach area ground texture (e.g., small shrubs, trees)

(3) Runway surface texture, including tire marks

VFR Night Approaches

(1) Taxiway lights.

(2) Approach area ground texture if landing lights are used.

(3) Miscellaneous airport lights having known relationship to duty runway

Relevant AML Components Under Development

Angle of approach indicators

(1) Two-color split beacons

(2) Double-bar.

Flush lights in runway surface.

Floodlighting of runway surface.

Approach beacons on extended runway centerline.

Summary of Reported Pilot Problems

IFR Approaches

The most persistent problem mentioned in pilot interviews centered around intensity of approach lighting, including strobebeacons. Glare and very high background brightness during latter portions of the approach have been frequently experienced, particularly in rainy or snowy conditions. This glare and high background brightness ruined dark adaptation and led to later problems during flareout and landing.

Some pilots expressed a desire for having approach light intensities dimmed and strobebeacons cut off after initial contact Others felt that dimming lights led to another problem. These latter pilots believed they were using apparent brightness of the approach light bars as a cue to height judgments. According to this line of thinking, a dimming of lights would lead to a visual perception of an increase in height when in fact such an increase would not have occurred

VFR Approaches--Day and Night

At a number of airports, the lack of distinct landmarks makes distance judgments difficult This in turn affects proper initiation of the final approach and the maintaining of optimal glide path. Raleigh-Durham and Savannah were mentioned as typical of airports where this condition exists

Irregular terrain in the approach area increases the difficulty of making elevation judgments, with resultant effects on maintaining an optimal glide path and landing at the proper place on the runway The Wilkes-Barre airport represents an example of this type of problem. Related to this, Binghampton, New York, Arcata, California and Charlestown, West Virginia airports were mentioned by airline pilots as examples of airports on-a-hill, making above-runway elevation judgments most difficult

Discussion

Without a doubt, guidance during the final approach flight mode has commanded more research, development, study and comment during the last two decades than any other function of the airport marking and lighting system This primarily can be accounted for by two factors an increase in night and poor-weather flying, and the criticality of errors of judgment during this phase with higher-performance aircraft

In the discussion that follows, IFR and VFR approaches are treated separately, although basically the pilot's information requirements are the same This is necessary because the differences in visibility conditions place quite different requirements on the positioning and intensity of marks and lights for the two types of approaches As might be expected, marking and lighting problems turn out to be quite different for the most part. Because Configuration "A" with sequenced strobebeacons is the current national standard, the discussion on IFR approaches uses that pattern as a starting point.

IFR Approaches

One of the more critical problems in designing lighting systems for the IFR final approach flight mode concerns positioning light units correctly and operating them at proper intensities. The pilot must see enough lights, at a distance far enough away from the GCA or ILS intended touch-down point, to give him time to properly use the visual information provided by the lights. Much attention has been given this problem by national and international pilot and transport groups, as well as researchers.

The approach area boundaries in which the pilot should receive required information has been labeled the "region of guidance" and its dimensions generally determine positioning and intensity of approach lights. Determination of the region of guidance is based on

(1) ILS or GCA accuracy
(2) Aircraft and pilot response time characteristics for making corrective maneuvers.
(3) Aircraft landing procedures
(4) Cockpit visibility restrictions.

These determinants of positioning and intensity of approach lights, as well as considerations of transmissivity measurement, are discussed more fully in Technical Note 6 Although the primary concern of this analysis is more in the direction of optimal visual cue patterns, the subject of positioning and intensity was considered quite critical. It is included as a Technical Note in order for the report to provide comprehensive coverage of airport marking and lighting problems.

The Use of Strobebeacons

The use of sequenced strobebeacons with Configuration "A" approach lights is still a subject of national and international debate United States pilots consistently report a preference for strobebeacons The issue seems to be centered on the attention-getting value of strobebeacons in low visibility conditions, since most pilots interviewed discounted their value for providing directional guidance (displacement laterally from extended runway centerline) after transition from instrument to visual flight control is made It will be recalled from the summary of reported pilot problems that a number of pilots expressed a desire to have strobebeacons turned off after visual contact is made. The 14-foot approach light bars are evidently quite satisfactory for lateral displacement guidance, and most pilots interviewed prefer to use them instead of the sequenced strobebeacons

It has been suggested that pilots feel strobebeacons are more conspicuous than approach lights because of differences in beam width and angle at which the highest intensity of approach-light beams are set While the observations about beam width and direction may be valid, the weight of human factors evidence favors flashing lights over steady lights as attention-getters when factors such as beam width and intensity are controlled This advantage of flashing lights apparently is greater at low contrast levels (between the light and its background) and when the location of the lights in the visual field is not known beforehand These latter two factors are typically present in the operational IFR situation (FL2-FL6)

In light of these considerations, the use of strobebeacons seems to be justified for providing approach area identification information and direction-to-go to the approach area. Their placement at each approach-light bar for runway centerline alignment guidance is more debatable One possible kind of solution that might be explored is to place strobebeacons in the outer region of the approach light system only (e g., the first 1000 or 1500 feet) Their attention-getting value would be utilized, but they would not be distracting or affect dark adaptation, during the latter stages of the final approach mode. It is likely that special dimming or cut-off practices would not be required in this instance Needless to say, reduction in the number of strobebeacons must be carefully evaluated to see that there is no significant loss of their attention-getting value (See Figure 21.)

Approach Light Intensity

Pilot problems with the intensity of approach lights obviously can not be handled in the same way as suggested in the preceding section for strobebeacons There have been three general solutions suggested for this problem

(1) Have the tower dim the lights at the request of the pilot

(2) Give the pilot cockpit control over approach light intensity, so that he may dim them himself

(3) Set the inner portions of the approach light system at a lower intensity than the outer portions. (TV4)

With respect to the first solution, the tower operator already has a fairly heavy work load, as does the pilot when considering the second solution Thus, both suggestions build in opportunities for errors, not only with respect to setting the intensities, but in other tasks being performed on a time-sharing basis In addition, both suggestions would involve a conflict in heavy traffic conditions when a pilot in the final stages of the approach would want the lights dim, but the next pilot, trying to gain visual contact, would want the lights at maximum intensity Furthermore, the comment of one of the pilots interviewed that dimming might produce illusions of change in height is well taken here.

The third suggestion for having different portions of the system at different intensities introduces fewer operational problems and appears least costly There is a possibility that series of "steps" might be perceived by the pilot which would affect his height judgment, this can be investigated quite easily on the NAFEC simulator. The use of wider light unit beams in the outer approach area and a system of separate intensity controls for the different sections also have been suggested The controls would be geared more precisely to prevailing transmissivity conditions These latter developments would further tend to reduce approach light glare and discomfort now experienced by pilots in the inner portions of the approach light system (See Figure 21.) (TV4)

Distance to Threshold Information

With Configuration "A", the first unequivocal information on distance remaining is provided by the 100-foot crossbar of lights positioned 1000 feet from the threshold It seems apparent that unmistakable identity of this point in the approach area must be preserved, since it is variously referred to as the "zero error" point and, in Configuration "A", as the "decision bar" By this, it is meant that beyond this point, the pilot is committed to land with higher-performance aircraft and, if not in a condition to do so at this point, he should initiate a go-around immediately to avoid a probable accident The decision bar also represents a go-no go anticipatory signal for initiating the flare-out procedure. Thus any scheme for providing distance information must not destroy easy identification of this point (GA17)

An additional constraint on providing approach distance remaining information is that color coding probably is not useful because of high power cost and poor penetration in low visibility conditions (TV15, TV33)

IFR FINAL APPROACH

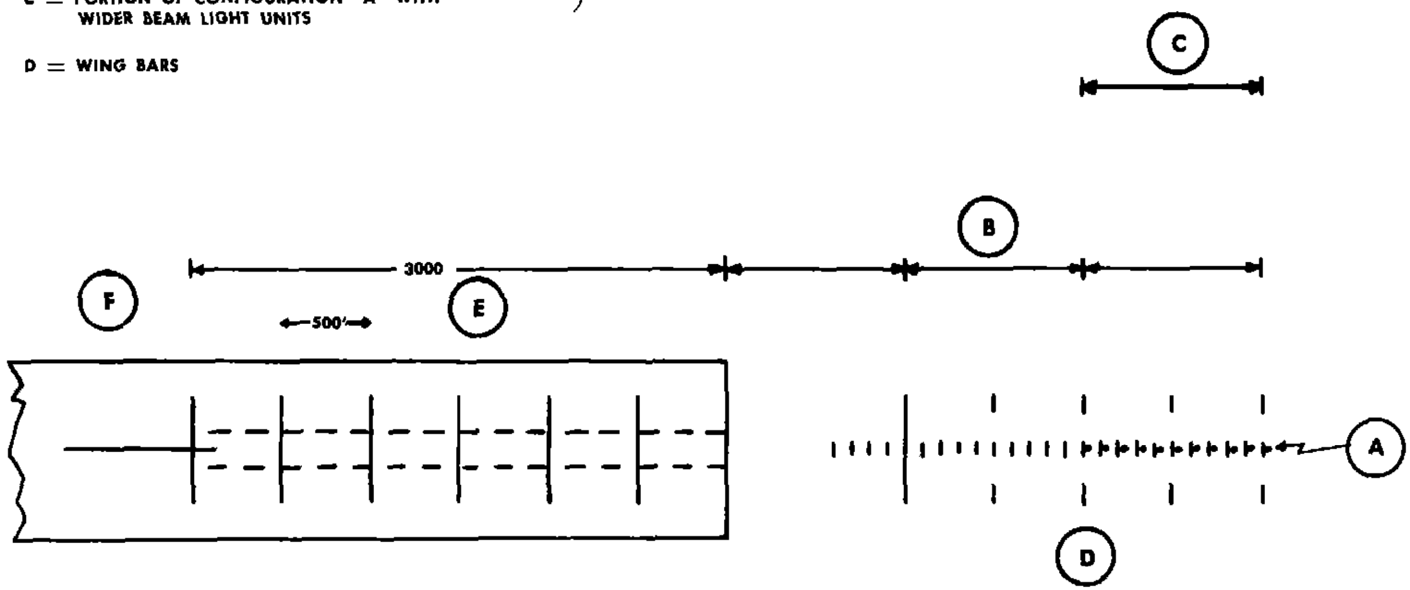
A = USE OF STROBEBEACONS IN OUTER 1000' ONLY OF CONFIGURATION "A'

B = PORTIONS OF CONFIGURATION A AT DIFFERENTIAL INTENSITIES (BRIGHTEST IN OUTER PORTION)

C = PORTION OF CONFIGURATION 'A" WITH WIDER BEAM LIGHT UNITS

D = WING BARS

LENGTH OF PORTIONS IN A B C MAY BE 1500'



FLAREOUT AND LANDING

E = LATERAL ARRAYS OF FLUSH LIGHTS OR MARKINGS FOR DEFINITION OF GROUND PLANE AND ROLL GUIDANCE (WITH NARROW GUAGE OR SINGLE CENTERLINE)

(WITH NARROW GAUGE OR SINGLE CENTERLINE)

F = CENTERLINE OF FLUSH BUTTON LIGHTS FOR ROLLOUT GUIDANCE

SCHEMATIC ONLY

NOT TO SCALE

SUMMARY OF SELECTED R & D RECOMMENDATIONS

Figure 21

Within the preceding constraints, the problems of providing approach distance remaining information are as follows deciding what specific distance information needs to be provided, and determining the best way of providing it.

Both of the above problems will require solutions that compromise some of the many considerations involved. It has been estimated that the pilot needs to see a source of information at a minimum of 600 to 800 feet (depending on height) in front of him if the information is to do him any good, and approach lights are positioned and operated at intensities designed to meet this requirement. Thus, if the pilot is to have distance information provided to him at every instant after making visual contact, the light encoding the information should not be spaced farther apart than 600 to 800 feet for use in minimum IFR conditions. On the other hand, it seems likely that as more distance points are encoded, discrimination time required of the pilot will increase And, the less "unmistakably identifiable" will be the decision bar (GA6, M9)

Using the same basic reasoning which leads to the use of the 1000-foot decision bar, it might be most helpful to the pilot to have anticipatory-type distance information at 2000 feet from the threshold Depending upon his exact approach speed, he would know that he is 3 to 4 seconds from the decision bar and must make flight corrections and adjustments in that time in order to achieve the flight condition he wants at the "zero error" point, or decision bar

The way in which distance-to-go information might be presented to the pilot is related to the proposed solution to intensity-setting problems previously discussed The use of strobebeacons in the outer portion only of the approach area was suggested in a preceding section. Also, operating the approach lights at different intensities in the outer and inner portions was mentioned. Whatever the length of the outer portion (e g , 1000 or 1500 feet), the two suggestions can be combined so that the same portion of the approach lights is involved in both If this instance, the point at which the strobebeacons stop and the intensity of the approach lights changes would provide positive, easily interpreted distance-to-go information at the 2000-foot (or 1500-foot) point. One important virtue of the combined suggestion is obvious--economy A reduction in installation and operating costs would be realized for strobebeacons, while the cost of installing the differential intensity control system would be offset to a large extent by reduced operating costs

The combined suggestion would need to be evaluated carefully to insure that visual contact could be maintained without strobebeacons in the inner portions of the approach lights in minimum IFR conditions When thinking in terms of all-weather recovery capability for military aircraft, it might be that the strobebeacons should extend to the decision bar, further enhancing its identification along with identification of the entire approach area It is here assumed that one of the developments in runway lighting now under consideration would be visible for guidance from the point in the approach at which the decision bar can no longer be seen (See Figure 21)

Glide Path and Attitude Information

Operational test results and pilot preferences clearly indicate that Configuration "A" provides adequate guidance to the pilot in terms of his lateral displacement from the extended runway centerline Also, there is no evidence that pitch guidance is inadequate

Some pilots report confusion when making the transition from instrument to visual flight when the ILS or GCA has built in a heading-line of flight coordination setting to compensate for crosswinds In addition, wind shear, for which GCA or ILS corrects, can create serious problems of this type However, this type of problem should not be considered a fault of the AML system It is difficult to conceive of ways in which any system of marks and lights would compensate for these conditions Rather, the solution to this problem should be sought in improved procedures Accurate reporting of wind direction and velocity to the approaching pilot, as well as relayed reports of pilots who have previously landing on the heading-line of flight compensation they discovered at breakout, should alert the pilot to what he can expect to see at breakout Evidence with respect to roll, glide slope, and distance closure guidance provided by Configuration "A" is not as clear-cut.

When the 1000-foot crossbar is visible, it apparently provides adequate roll guidance But assuming that the pilot makes contact with the outermost bar and that low visibility conditions limits his forward visual range to 1000 feet, there will be a period of 6 to 8 seconds after he makes his transition to visual control when he must get his roll guidance from the 14-foot approach lights. Two interrelated cues are reportedly used noting whether or not the individual bars are parallel to some part of the aircraft structure having a known relationship to the aircraft's roll axis (e g , bottom of windscreen), noting whether or not the array of visible 14-foot bars is perpendicular to that part of the aircraft structure The latter judgment is dependent to a great extent upon the first, since a single row of lights (independent of appearance of lateral length) would yield no differentiation between certain bank attitudes, altitudes, and lateral displacements. (M18)

Some pilots participating in operational tests on Configuration "A" have reported that roll guidance is somewhat inadequate in the minimum visibility conditions assumed in the preceding paragraph. However, published comments by airline pilots have consistently maintained that roll guidance is adequate, no pilots interviewed mentioned roll guidance as a problem (AL1, GA31, GA46)

On the other hand, lack of conscious awareness of a problem is not always a good criterion to use for saying it does not exist Among other things, it is certain that pilots also are using internal body cues induced by gravity in making the roll attitude judgment. But in a moving aircraft which produces artificial g forces, these can not be relied upon solely Human factors evidence shows that when a conflict occurs between visual indications of body orientation and internal sensations, a compromise judgment somewhere between the two indications is reached. When the visual indications are not very, very compelling, the judgment tends to favor the internal body cues. Thus, to the extent that pilots may be basing their judgments about roll guidance adequacy of the 14-foot roll bars on internal body cues, the adequacy of roll guidance being provided visually by Configuration "A" deserves further investigation. (PV1-PV15)

Additional support for further investigating roll guidance adequacy comes from a geometrical analysis check performed in this study. Assuming a 15-degree downward visibility (larger than is available in most aircraft), a 3-degree glide slope, and a speed of 150 miles per hour, the apparent size at the windscreen of the 14-foot approach light bar varies between .27 of an inch and 2 inches during the outer portions of the approach. No human factors data bear directly on this problem but, rationally at least, it would seem to be most difficult to make a judgment about whether or not a line segment .27 of an inch is parallel to another line (bottom outline of windscreen), particularly when the two lines are relatively far apart on the windscreen. The problem is further complicated by the fact that the pilot's eye would need to be focused at the windscreen or on the approach-light bar, with one or the other being out of focus.

The problem seems most suitable for simulator investigation at NAFEC, inasmuch as varying gravity cues would be eliminated as an influencing factor in the judgments. In terms of cockpit visibility limits, the approach attitude of some military aircraft, the typical lateral displacement errors associated with ILS and GCA landings, and the importance of not interfering with the integrity of the 1000-foot bar, one suggested pattern would be white wing bars at 1500, 2000, 2500, and 3000 feet from the threshold. The optimal length of the wing bars and distance from the centerline could be determined in the simulator From the 1000-foot bar on in, roll guidance can be obtained from the 1000-foot bar, the pre-threshold bars, threshold lights, the 14-foot flush centerline lights (altitude is low enough to make their apparent size on the windscreen quite large) and patterns of flushlights in the runway surface (if installed because of flareout and landing mode considerations) (See Figure 21)

Glide slope and distance-closure guidance problems are closely related. Their solutions require more analytic understanding of how these judgments are made by pilots

During the final approach, after visual contact is made, photographs of pilots' eye movements show that most pilots visually shift their attention between visual landmarks outside the cockpit and the cockpit display Depending upon the type of aircraft involved, the films show that the pilot time-shares his attention so that for 60 to 85% of the time he is looking outside of the cockpit and for the remaining time he is looking at two cockpit displays--air speed and vertical speed. Of the time spent looking at the cockpit displays, the air speed indicator receives the greater proportion of his attention (A1, M5, M28)

The pilot visually integrates this cockpit display information with the information he receives from outside of the cockpit to make final judgments about his angle of approach and rate of closure with the surface Before discussing how the pilot utilizes the visual cues outside the cockpit, a brief word should be said about an ancillary development that might help ease some of the difficulties of the pilot during final approach.

Human factors data show that it takes approximately 2 seconds to complete the shift cycle, that is, focusing on an object at some distance, then focusing on the cockpit display and reading an indication, then re-focusing to the distant object During the shift time, the pilot may be restricted to making any judgments required on the basis of "fuzzy" visual impressions of whatever visual cues outside of the cockpit he may be using. It may be possible to project an image of the air speed and vertical speed indicators on the windscreen The projection could be a virtual image focused at infinity, such as the reticles and aiming dots used in military aircraft gun sights, thus requiring no, or very small, shifts in the pilot's line of sight and eye accommodation and convergence. Apparently, even further advances in projecting virtual images have recently occurred and are being considered for use in orbital and space vehicles. WADC has sponsored some feasibility research by Minneapolis-Honeywell on a visual landing aid sight system similar in concept Lane and Cummings in Australia and Calvert in England have made similar suggestions As with gun sights, intensity controls could be provided the pilot. The optimal location for the projection would need to be determined by simulator tests (M5, RT4)

We are suggesting here that many of the pilot's demands for having AML information positioned ahead of them may be more a function of problems in shifting focus rather than sensitivity areas of the eye With air speed and vertical speed more easily monitored, and assuming for the moment accurate information is provided on glide slope and lateral displacement from the extended runway centerline, the pilot's over-all task would be made much less difficult

Given improvements along the lines suggested above, it would be expected that the pilot would reach the decision bar, or point of "zero error", with greater tranquility of spirit, as well as with fewer flight path adjustments that may be caused by loss of guidance while checking cockpit displays.

With respect to glide slope information, accident statistics show that about 80% of landing accidents are made in conditions with visibilities 2 miles or greater, and ceilings 400 feet or higher (this is not a rate difference, but a total number difference) The utility of an acceptable angle of approach indicator, even for a large number of IFR approaches, seems obvious The important positive feature of an angle of approach indicator is that it eliminates the necessity of the pilot making elevation judgments on the basis of "enhanced" natural cues, a process that seems basically most difficult from a human factors standpoint, probably because man is not normally called upon to make such judgments If the pilot is on the correct glide slope, as determined by the indicator, his height must be correct (within error limits of indicator), if his air speed is optimal, his rate of closure must be correct (MS5, MS6)

It is difficult to differentiate, on a human factors basis, the relative merits of the various angle of approach indicators under development Those indicators which utilize white lights would seem preferable to those which use colored lights because of power and transmissivity penetration considerations Also, the closer to touchdown the indicator continues to provide information, the more preferable it would be to others. Finally, the indicator that provides information from one location in the visual field would seem preferable to those that require looking at more than one location to make a judgment It should be feasible to check out the various indicators in the approach and landing simulator at NAFEC, if modified The cost of providing the simulator with such an evaluation capability would be more than justified by reduction in the cost of operational tests and, to the extent that a successful indicator emerges, expected reduction in accident rate

Angle of approach indicators probably would not be useful until the flareout and landing mode, if then, in minimum visibility conditions. Thus, the pilot would be in the same position in which he finds himself at present with respect to angle of approach and distance closure judgments. It is commonly accepted that these judgments are made on the basis of visual impressions of the ground plane Those visual characteristics of the ground plane which are believed to provide the basis for the judgments are apparent distance between approach light bars, apparent size of the approach light bars, apparent expansion of the visual field (e g , streamer pattern theory) Changes and rates of change in apparent size and shape are actually specific cases of the expansion pattern theory (GA3, GA4, GA11, GA12, HF6)

It seems apparent from the perspective views of the centerline system (Figure 7 in Chapter II) that the greatest differences in size of, and interval between, approach light bars occur with those lights nearest to the aircraft. This may account for the tendency of some pilots to drop below the ILS or GCA-initiated glide slope and "come in on top" of the lights As a routine practice, this is somewhat less than optimal, particularly at airports where approach area terrain texture is poor (e g , over water, airports located on a hilltop, etc)

No direct human factors evidence is available on what kinds of visual characteristics allow the best height judgments which are basic to angle of approach estimations Rectangles have the highest amount of shape constancy, that is, a rectangular figure is recognized as a rectangle, regardless of the orientation of the rectangle to the observer This would suggest that patterns that have regular rectilinear characteristics with respect to the airport surface may be the best for giving impressions of the ground plane This suggestion concurs with the recommendations of IATA and ICAO study groups on airport marking and lighting that equal spacing of major lateral elements in the approach and landing area would be best It also may account for the poor acceptance of the slope-line system which attempted to encode elevation information from a series of ground plane structures which were not regular or rectilinear with respect to the airport surface (GA16, [illegible], [illegible], HF54)

In terms of improving elevation guidance in the final approach, then, the following possibilities emerge from a human factors standpoint. Use wing bars every 500 feet, as suggested for improving roll guidance, to make the visual impression of the ground plane more compelling In terms of the regular rectilinearity requirement, the outside edge of each pair of wing bars could be located 50 feet from the centerline to match the outside edges of the decision bar. When considering patterns of flush lights within the runway surface, lateral arrays spaced at 500-foot intervals along the runway should be seriously considered in addition to runway longitudinal axis arrays (See Figure 21.) Floodlighting the runway surface probably would not help much during the final approach mode in minimum visibility conditions On the other hand, flush lights, being point sources, would have better transmissivity penetration characteristics and a portion of them might be visible during the final parts of the approach (dependent upon intensity and vertical angle along which their maximum intensity is directed).

The above suggestions also can be expected to improve distance closure judgments during final approach because more elements would be visible in the expansion (or streamer) pattern No direct evidence is available, but it is reasonable to assume that the entire visual field does not need to be seen as expanding in order to make a rate of expansion judgment However, it may also be reasonably assumed that, up to a point, better judgments might be made with more visible elements in the expansion pattern This basic question deserves further human factors research effort

Simulator study of the wing bar design already has been suggested with respect to improving roll guidance The experimental program could also include evaluation of how well the wing bars aid angle of approach and distance closure judgments

It should be noted that wing bars can not be justifiably objected to on the basis of being outside of the sensitive portion of the pilot's eye during the final approach mode Their linearity would be quite compelling with peripheral vision alone, even if the pilot chose not to make the small angular shifts in line of sight required to center his visual attention on them The question of retinal sensitivity is discussed more fully under the flareout and landing mode

VFR Approaches

Accident statistics support the contention that the major guidance problems in both day and night approaches are concerned with angle of approach and distance closure judgments VFR problems with angle of approach and distance closure differ from those in IFR approaches in that the existing AML system sources of information in VFR approaches are located nearer the intended touch-down point--runway markings, threshold lights, and runway edge lights

The use of an angle of approach indicator and windscreen projections of the air speed and vertical speed indicators has been suggested in the discussion on IFR approaches Their use for both day and night final approaches seems as well justified, although for somewhat different reasons which are discussed next

Calvert, Gibson, and Hochberg and Smith have put forward theories of aircraft control based on a geometric analysis of the landing situation The several theories lead to the same kinds of conclusions with respect to use of the X-spot--the point in the pilot's visual field which is the center of an apparent radial expansion pattern--and with respect to the use of rate of expansion of this pattern Essentially, both theories suggest that the X-spot can be used as a source of information for control of the angle of approach and that the rate of expansion can be used for distance closure judgments More recently, Calvert has modified his position somewhat to take account of inherently difficult height judgments in the final approach situation because of the angle of regard of the ground plane, and has recommended the use of an angle of approach indicator on this basis (GA1, GA3, GA4, GA6, GA7, GA11, GA12, M6, HF6, HF9)

The rationale for use of an angle of approach indicator from a human factors standpoint is even more basic. The concept of an X-spot requires that a relatively small area of the visual field (the X-spot) be discriminated by the pilot as not moving, while the area surrounding it expands The best estimate of the human's lower limit for detecting movement indicates that an object must be moving at a minimum rate of 2 to 4 minutes of arc per second (measured at the eye) in order to be detected These data were collected under ideal laboratory conditions, when operational conditions, such as a bouncing aircraft, windscreen distortion, and time-sharing attention with other tasks are considered, it seems apparent that the lower limit for the pilot surely must be somewhat higher (VA1-VA25)

However, even using this laboratory-determined figure, a geometric analysis of the pilot's visual field when 4000 feet from touchdown on a 3-degree glide slope (intersecting the runway 1000 feet from threshold) and flying at 150 miles per hour shows that the X-spot is in fact quite a large area shaped much like a cigar lying symmetrically on the runway centerline This "lane of no perceptible movement" extends between points on the runway 500 feet and 1600 feet from the threshold, being approximately 150 feet wide for the most part The intended touchdown point is not located in the longitudinal middle of the lane, but is roughly at the 1/3 point from the threshold end of the lane (See Figure 22)

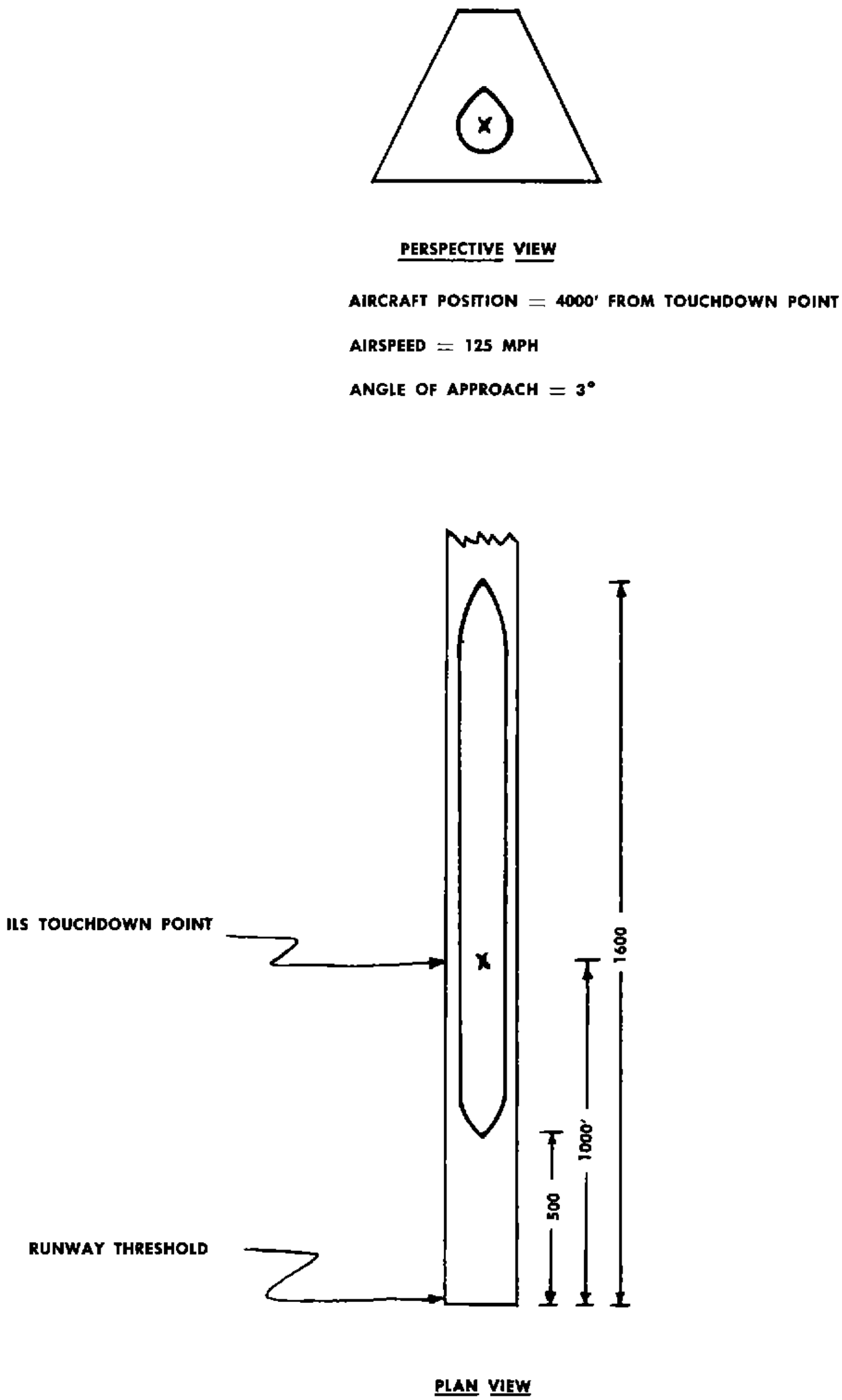
Even when the surface which is being approached is perpendicular to the line of sight and movement of the observer, evidence in the laboratory suggests that errors on the order of 5 degrees of visual arc in locating the intersection point may be the best humans can do [25] The hypothesis, then, that the X-spot is , in fact, an area of some extent and not a point--or even a small area--seems fairly compelling.

Of course, as the pilot gets closer to the intended touch-down point, the lane will reduce in size The important point, however, is the obvious difficulty of placing the so-called X-spot on the intended touch-down point in order to adjust glide slope or to intersect the surface at that point, as some have suggested It seems that such control could not be feasible until very close to the runway, probably closer than the flareout distance Characteristic glide slope oscillations during final approach, as shown in photographic recordings of the approaches, are understandable on the basis of this hypothesis Only the one geometric analysis was conducted in this study for illustrative purposes to get at the problem, the analysis should be continued to touchdown using various air speeds

The implication of the preceding discussion is clear It is unlikely that any system of runway markings, runway edge lights, or patterns of flush lights will significantly improve angle of approach and distance closure judgments during the early parts of the final approach. Their utility would seem to be confined primarily to the flareout and landing mode The value of an angle of approach indicator and windscreen projections of air speed and vertical speed indicators in the final approach mode seems more apparent in light of these considerations

It might be pointed out that the pilot can make height judgments on the basis of objects in the approach area and thus indirectly make angle of approach judgments This judgment is exceedingly difficult at night, over water, or over irregular terrain For VFR day approaches

[25] Personal communication between the authors and Dr W. Carel, General Electric Advanced Electronics Research Center



LANE OF NO PERCEPTIBLE MOVEMENT

Figure 22

over fairly flat terrain, a suggestion concerning objects not typically considered in the province of the airport design engineer might be useful Lateral rows of shrubs, trees, or other foliage might be placed at 500-foot intervals from 1000 to 3000 feet from the threshold, with a centerline of shrubs extending for the same distance. (This suggestion is similar in concept to the line of oil barrels used in the bay at Nantucket) Selection of good hardy shrubs that do not mature to too large a height would make operating costs minimal However, this suggestion should only be implemented as an auxiliary aid to the pilot, not as a substitute for an angle of approach indicator. Needless to say, the shrubs, if placed as suggested, would give the pilot distance-to-go information as well as height guidance

Recommended Research and Development

Research should be conducted to collect the following data related to determining the AML system region of guidance required by higher-performance aircraft

(1) The lateral and vertical displacement errors at visual contact of ILS, GCA, and Flight Director guided instrument approaches.

(2) The minimum flight path correction times for various lateral displacements at various altitudes (within final approach ranges) of newer high-performance aircraft in order to set the outer lateral boundaries, of most maneuverable conventional commercial carriers to set the inner lateral boundaries.

The data would be used for determining positioning, intensity, beam width, and maximum-intensity angle setting for light units utilized in providing guidance for the visual portion of IFR final approaches The data would be applicable to runway lighting design as well as approach lighting

Basic human factors research is required to determine

(1) Accuracy of distance closure judgments made on basis of seeing only certain portions of an expanding visual field and as a function of the number and arrangement of elements in the visual field Stimulus conditions should be selected on the basis of fields of view provided by different types of cockpit designs, the kinds of light pattern variants feasible for the AML system, and viewing angles approximating the final approach glide slope.

(2) Dimensions of the "lane of no perceptible movement" during final approach to touchdown.

Results of both studies would have applicability to the flareout and landing mode as well as the final approach mode.

A feasibility study should be conducted on techniques for windscreen projection, with image focus at infinity, of air speed and vertical speed indicators Recent work conducted at WADC can be used as a starting point. Again, the technique is applicable to the flareout and landing mode as well as the final approach mode

Semi-operational tests of angle of approach indicators and suggested wing bar additions to Configuration "A" should be conducted on the landing and approach simulator at NAFEC, if feasible If not possible, then operational tests should be conducted at the NAFEC facility.

The suggested use of strobebeacons in the outer portion only of the approach light system, differential intensity of the 14-foot light bars in the outer and inner portions, differential beam width settings of the 14-foot light bars in the outer and inner portions, and variable intensity control of each portion should be operationally tested at NAFEC.

Flareout and Landing

General Pilot Task Description

Rotate aircraft to pitch attitude for landing at proper distance from intended touch-down point so that rate of descent is zero at touchdown.

Align heading with longitudinal axis of runway before touchdown.

Keep wings parallel to runway surface (zero roll attitude).

After touchdown, keep rollout on some prescribed path (typically middle of runway) aligned with longitudinal axis of runway.

Brake aircraft rollout in order to be at optimal ground speed for turnoff.

Information Pilot Requires from AML System

Identification of safe landing area on runway.

Changes and rates of change in

- Distance between aircraft and intersection of glide path with runway--closure (a function of elevation, sink rate, and ground speed).
- Attitude of aircraft--pitch, roll, and heading--runway axis coordination.
- Glide path (direction of flight path)
  - Displacement laterally from runway centerline.
  - Displacement vertically from optimum approach angle with runway--glide slope (a function of elevation).
- Displacement of ground track on rollout from runway longitudinal axis.

Runway length remaining.

Identification of duty runway exits--prescribed and optional.

Existing AML System Sources of Information

Designed for Requirements

IFR Approaches

(1) Threshold lights (green).

(2) Runway edge lights (white).

(3) Runway markings.

(4) Runway distance markers.

(5) Runway exit signs, runway and taxiway identification and intersection signs.

(6) Taxiway edge lights (blue).

VFR Day Approaches

(1) Runway markings

Threshold marks.

Centerline stripe, including exit stripes.

Side stripes.

Distance markings.

(2) Navy Mirror Landing System--Aircraft Carrier Approaches.

(3) Runway distance markers (signs).

(4) Runway exit signs, runway and taxiway intersection signs.

VFR Night Approaches

(1) Threshold lights.

(2) Runway edge lights.

(3) Runway markings (as listed under VFR Day Approaches) for use by pilots in aircraft having landing lights.

(4) Navy Mirror Landing System--Aircraft Carrier Approaches.

(5) Runway distance markers.

(6) Runway exit signs, runway and taxiway intersection signs.

(7) Taxiway edge lights.

Other Visible Sources

IFR Approaches

Depends upon meteorological visibility conditions. Runway surface texture can be the only source present in minimum visibility conditions. As visibility increases, more of the sources listed below for VFR flights become useful.

VFR Day Approaches

(1) Color or brightness contrast between runway and runway exit surfaces, and surrounding terrain.

(2) Runway surface texture, including tire marks.

VFR Night Approaches

(1) Taxiway lights.

(2) Runway surface texture, including tire marks, if landing lights are used.

Relevant AML Components Under Development

Angle of approach indicators

(1) Two-color split beacons.

(2) Double-bar.

Flush lights in runway and taxiway surface.

Floodlighting of runway surface.

Runway zone lighting.

Summary of Reported Pilot Problems

The most consistently reported problem was the difficulty in making elevation judgments. The problem was reported as especially acute on the wider runways, on black-top runways--particularly those with inadequate runway markings--on rainy or snowy days even with good runway markings, and at night, when, in IFR approaches, the well-known "black hole" condition exists. Lining up with the longitudinal axis of the runway under the same conditions was also reported by a number of pilots as a most difficult task.

Runway distance remaining information after touchdown is the next most pressing need according to the pilots interviewed. Runway distance markers were reported to be difficult to read in marginal visibility conditions and at night because they are located outside of the pilot's primary focus of attention.

Discussion

The AML system function currently receiving the most research, development, and evaluation effort is guidance during the flareout and landing mode. This attention is due mostly to an increase in awareness of the "black hole" problem in IFR and night approaches, which occurred with installation of high-intensity approach lights.

IFR Approaches

The suggestions in the previous section on the final approach mode regarding lower intensity settings of lights and removal of strobebeacons in the inner portion of the approach light system should help alleviate the "black hole" problem. To the extent that the strobebeacons and the approach lights have been affecting the dark adaptation level of the eyes, the suggestions will reduce the total light flux reaching the pilot's eyes. Human factors data show that night visual sensitivity is dependent upon adaptation to all stray light falling on the retina, not just light from sources in the line of sight. Effects on adaptation of a steady light, or lights flashing within a 3-second time interval (the strobebeacons fall within these bounds) are essentially the same. (RT1, FL1)

But maintaining good dark adaptation is not a complete solution to the "black hole" problem, even if such could be achieved. The guidance problems associated with flareout are essentially the same as those identified for the final approach mode. Angle of approach, particularly the elevation component, distance closure, alignment with the longitudinal runway, and roll guidance apparently are lacking in minimum IFR visibility conditions.

Angle of approach indicators may be useful for the initial few seconds of the flareout part of the mode for maintaining a constant angle of approach. However, the pilot can be expected to quickly focus his attention on the runway surface, rather than outside the edges of the runway, as he gets closer to touchdown, at this point, the angle of approach indicators lose their utility. In any event, he is committed to a given angle at this point. Whatever use the pilot can make of runway edge lights is affected by this same shift in attention.

The pilot's critical problem is deciding when to initiate the flareout. Since this point will vary with different aircraft, it is difficult to imagine a go-no go signal (such as the decision bar represents for some types of aircraft regarding go-around) that could be used. It would be a most desirable feature, if feasible. But there appears to be a basic conflict between the need for presenting continuous information about the flight path, and the need for a discrete signal for a special action, when both sources of information must come from the same source.

It appears likely, then, that the pilot will have to make his flareout decision on the basis of elevation and distance closure judgments obtained from visual impressions of the ground plane. This brings the AML design problem back to a consideration of what visual characteristics provide the best visual impressions of the ground plane.

As pointed out in the final approach mode discussion, regular rectilinear patterns appear best from a human factors viewpoint.

When considering patterns of flush lights in the runway surface, this would mean providing lateral arrays of light bars as well as lights running along the longitudinal axis. When considering floodlighting, runway markings should have lateral stripes as well as longitudinal stripes.

On a rational basis, patterns of flush lights appear more suitable than floodlighting a marking pattern. In the first instance, flush lights with suitably wide beams properly angled would be visible during much of the final approach (except in 0-0 weather), as well as after the decision bar has been reached and the flareout mode begun. It is questionable whether runway markings illuminated by floodlights would be as visible. Perhaps more importantly, there is no firm evidence of a significant breakthrough on development of a runway paint or other material that would maintain good reflectance characteristics in rainy weather. Finally, because of the determinants of dark adaptation discussed in a preceding paragraph, floodlighting would have more of an undesirable effect on dark adaptation levels of the pilot's eyes than would patterns of flush lights.

The point often made about floodlighting regarding reproduction of so-called "natural" cues for the pilot (those that he uses in VFR conditions) should not be considered a virtue uncritically. As discussed in a preceding section, most landing accidents occur in visibility conditions far above IFR minimums. The "natural" capabilities of the pilot regarding elevation and distance closure judgments are limited as discussed in the section on the final approach mode.

However, operational tests are programmed at NAFEC to compare the merits of the two systems and the rational reasoning presented here should only be considered a commentary pending the outcome of these tests.

Whether considering patterns of flush lights or floodlighting with runway markings, the lateral arrays suggested in a preceding section should be spaced at regular intervals down the runway, probably for the first 3000-4000 feet, depending on the length of the runway and requirements of heaviest traffic units. A 500-foot spacing conforming to the spacing suggested for the approach-light bars would provide a consistent, regular frame of reference for the pilot in both the approach area and the runway. The requirement of identifying the safe landing area can be met by either patterns of flush lights or runway floodlighting.

For the early portions of the flareout part of the mode, the lateral arrays would provide visual field elements for the apparent expansion pattern, thus assisting distance closure judgments. The width of the lateral arrays would be dependent upon the dimensions of the "lane of no perceptible movement." A significant portion of the arrays obviously would need to be located outside of the lane. In addition, the lateral arrays would provide roll guidance to touchdown.

Height judgments when the pilot is closer to the surface and is looking between the 500-foot lateral arrays would be based on the apparent size and separation of the light units in the light bars forming the longitudinal array, or arrays, providing directional guidance It appears that two longitudinal arrays (instead of one) should be used in order to clearly differentiate the landing area from the approach area, although the low-intensity lights under FAA development, when used in a single centerline longitudinal array, may appear quite different (narrower) than the broader lane of approach lights Also, there is the further problem that a centerline array would always have a large portion in the "lane of no perceptible movement," depending upon aircraft. Unless landing to the side, the centerline array would not be visible to pilots of some aircraft, due to cockpit visibility restrictions. This consideration would seem to indicate that the gauge of the longitudinal arrays (distance between arrays) should be kept relatively narrow. On the other hand, the arrays need to be far enough apart to allow distance closure judgments on the basis of rate of apparent expansion of these elements of the visual field. The best gauge needs to be determined through simulator studies.

With respect to runway markings for use with floodlighting (but also useful for VFR approaches), very wide lateral stripes could be used to mark the 500-foot intervals, with smaller checkerboard or cross-hatching stripes used in between. As with the flush lighting, it is suggested that this patterning extend for the first 3000-4000 feet of the runway.

It should be noted that skill in flareout, even with an optimal lighting or marking structuring of the ground plane, will have to be dependent upon practice. It is difficult to envision, for the near future, an AML system or component that will provide guidance in this mode by other means than providing a visual impression of the ground plane. Given this situation, the pilot who must flare out on the basis of these cues must become familiar enough with them through actual landings to have stored in his memory a good standard for knowing when the visual picture he sees appears "right" and when it appears "wrong"

One other consideration with respect to flush lights is important. The beam width of individual light units should be wide enough to provide guidance to touchdown regardless of reasonable flight path displacement errors that can occur. Although it might be useful to have beam widths set so that one section of the lights "disappears" if the aircraft is laterally off course, this design is somewhat inadequate from other guidance considerations. When the lights appear "off" the pilot loses a great deal of roll, angle of approach, and distance closure guidance. Thus, the merits of use of flush lights with such narrow beams seems more than offset by its disadvantages.

For landing rollout, the centerline array of flush "button" lights tested at San Francisco and Dow AFB yielded favorable results, although limited, and led to the development of the low-intensity centerline lighting concept which has been suggested as an alternative to the narrow-gauge concept The use of "button" lights for rollout guidance beyond the 3000- or 4000-foot point on the runway deserves semi-operational or operational testing.

With respect to the requirement for runway length remaining information, it may be that the rollout button lights may alleviate current problems to some extent. If runway distance markers meeting military specifications are used, showing runway length remaining, it may be that the pilot will find it easier to use them because he will have come by his directional guidance somewhat easier, thus reducing his time-sharing load

The requirement for identification of runway exits is discussed in the turnoff and taxiing mode

VFR Approaches

The suggestions made in the discussion on the final approach mode with respect to an angle of approach indicator and windscreen projections of air speed and vertical speed indicators should assist the pilot in the same way during the initial seconds of this mode. As the pilot gets closer to the runway surface, the runway markings suggested in the preceding section for IFR approaches would provide angle of approach, roll, and rate of closure guidance. Using the same pattern on all runways has the advantage of building in pilot practice with the patterns. Increased skill with the pattern that would be expected to result should prove useful in IFR approaches and night VFR approaches.

Alignment with the longitudinal axis of the runway in VFR night landings was reported as a serious problem by pilots, both while in the air and after touchdown. Consideration might be given to use of flush button lights on the centerline of the runway, starting 3000-4000 feet down the runway (as suggested for IFR operation), or perhaps overlapping some with the narrow-gauge a centerline lighting in the first part of the runway.

Use of the proposed runway markings and button lights would effectively define runway zones for the pilot. For this reason, it would not be necessary to consider extending colored lights down the sides of the runway to define a "sleeve"--appearing red on takeoff, and green on landing. Using the markings and the button lamps has the further advantage of maintaining the color integrity of the threshold. If the button lights are used for night VFR operations, it would tend to free more of the pilot's time to attend to properly constructed runway distance markers.

The visual acuity of different parts of the eye has been used as a justification for suggesting that the AML system sources of information during the flareout and landing mode should be located near the center of the runway. Suggestions of this nature have been made regarding placement of flush lights and runway distance markings. The rationale for such suggestions refers to the "stare" period of pilots believed to occur during the last few seconds prior to touchdown, and the fact that vision for fine detail during this period is located within a small visual angle subtending the fovea--the most sensitive part of the eye. (GA47, M9, HF16)

Human factors data show that when the eyes are light adapted, vision just 5 degrees to either side of the line of sight is 1/2 as acute as it is at 0 degree (straight ahead), it is 1/10 as acute at 10 degrees. In terms of the absolute size of objects in a non-dynamic situation, an object 1 minute of arc can be seen straight ahead, while at 10 degrees off center an object needs to be 10 minutes of arc to be seen. It should be recognized that this advantage is lost when the eyes are dark adapted. Visual acuity is poorer generally, with there being very little difference between the acuity of different parts of the retina. In terms of sensitivity to light, the retinal area just outside of the fovea (about 4 degrees off center) seems to be the most sensitive in night vision. (MS3, HF2, HF16)

The patterns of flush lights and runway markings suggested herein will be in the area of maximum sensitivity during the final few seconds before touchdown. However, the pilot may be making his closure judgments on the basis of the apparent motion of elements in the peripheral portions of his eyes (more than 5 degrees off center) because of lack of apparent motion in the "lane of no perceptible movement" As was suggested, simulator tests are required to see just how far apart the longitudinal arrays of light bars should be on the runway

While the pilot may be staring during the final few seconds before touchdown, there is no evidence that he does on the landing rollout and on takeoff The difficulty of reading runway distance markers may be partially tied up with poor directional guidance, as briefly suggested in a preceding paragraph, but also with the time required to shift focus, not line of sight. If the w k screen projections previously suggested are developed and button lights are used for better defining directional guidance, the pilot can keep his eyes focused at infinity outside of the cockpit for most of his landing rollout (and takeoff). It can be expected that he would find runway dis a ice markers ar d intersection signs somewhat easier to read under these conditions.

In summary, the important implications of human factors data for positioning of flush lights and runway distance markers are the following.

(1) Areas of differential retinal sensitivity (and thus shifts in line of sight) probably are less related to pilot demands for "centered" positioning of AML information sources than

   a poor alignment guidance--if this guidance is improved, the pilot won't have to work as hard at getting alignment information, thus freeing more of his attention,

   b. decreased acuity during shifts in focus (accommodation and convergence) and time required to shift focus,

c. the so-called "stare" period as a matter of attention habit built in by factors a and b. above

(2) Rate information must come from peripheral portions of the visual field--outside of the "lane of no perceptible movement".

(3) Use of windshield projections of air speed and vertical descent rates and the herein recommended patterns of flush lights and runway markings should help alleviate the problems of obtaining information from runway distance markers and improve rate of closure judgments.

Recommended Research and Development

AML system design requirements in this flight mode support the following research and development projects previously recommended in the section on the final approach mode

(1) Feasibility study of windscreen projections of air speed and vertical speed indicators

(2) Research to gather region of guidance data to touchdown

(3) Basic human factors research on the dimensions of the "lane of no perceptible movement"

(4) Operational tests of use of strobebeacons in outer portion of approach system only, and differential intensity of approach light bars in inner and outer regions

(5) Simulator studies of angle of approach indicators (if feasible--if not, operational tests at NAFEC)

Different patterns of flush lights and runway markings should be semi-operationally evaluated through simulator studies at NAFEC if feasible Special attention should be given to providing lateral as well as longitudinal visual arrays along the runway With respect to longitudinal arrays of flush lights, low intensity single centerline systems and high intensity lane systems can be compared and optimal gauge settings for the lane system determined.

AML design needs for this mode also support the operational tests programmed for NAFEC on floodlighting and flushlighting systems.

Further operational tests at NAFEC of a centerline system of flush button lights for providing directional guidance during landing roll-out and takeoff seem indicated, particularly with respect to the extent to which such a system aids utilization of runway distance markers.

Turnoff and Taxiing

General Pilot Task Description

Turn off at optimal ground speed at prescribed (or optional) runway exit

Guide turnoff through path (typically the middle) aligned with longitudinal axis of exit extended onto runway.

Guide ground movement at optimal ground speed through path on taxiway (typically the middle) aligned with longitudinal axis of taxiway

Information Pilot Requires from AML System

Identification of duty runway exits

Identification of safe taxiing and parking areas and taxiways

Changes and rates of change in

Displacement of ground track from longitudinal axis of taxiway

Distance of aircraft structures from limits of safe taxiing and parking area.

Taxi route information, particularly at intersections.

Existing AML System Sources of Information

<u>Designed for Requirements</u>

(1) Runway edge lights (white)

(2) Runway markings.

Centerline stripes, including exit stripes

(3) Taxiway edge lights (blue)

(4) Taxiway markings

Centerline stripes

(5) Runway distance markers (signs)

(6) Runway exit signs, runway and taxiway identification and intersection signs.

Other Visible Sources

Color, brightness, and texture contrast between taxiway surface and surrounding terrain

Relevant AML Components Under Development

Flush lights in runway and taxiway surface

Summary of Reported Pilot Problems

Identification and location of runway exits is reported to be very difficult at night when the view from the cockpit has been likened to looking at a "maze of blue lights" at the larger airports The linearity of the taxiway edge lighting is not seen until the turnoff is actually reached--too late to make the turn safely Thus, some pilots expressed a need for anticipatory information about location of the exit, particularly if high-speed turnoffs are expected to become routine

Once on the taxiway at the larger airports, whether coming from the runway or after leaving the parking area, pilots report that it is extremely difficult to find their way to their airport destination.

Idlewild and LaGuardia at New York were mentioned as examples of airports where runway exit and taxiway routes are overwhelmingly confusing to the newcomer, and often time-consuming and difficult for the pilot who uses the airport only occasionally

Discussion

Identification (and thus location) of runway exits at night and in poor visibility is a problem that may require solution combining a number of marking and lighting techniques with different operating procedures.

A recent operational study of runway exits at McClellan AFB suggests that a line of flush button lights be used, with the line of lights curving from the centerline of the runway through the middle of the exit and extending down the centerline of taxiways in order to define what has been termed "linear contours". Exits and taxiways are currently marked with a similarly-designed centerstripe which also, by specification, curves into the runway centerline. Thus, the suggested pattern of flush button lights would be familiar to the pilot and its introduction should not lead to any serious re-training problem Centerlines are in use at Gatwick and London, England, Gatwick also uses retro-reflective edge lighting Results of the McClellan AFB study indicate that taxiway edge lights are required to define the lateral limits of the safe taxiing surface

Color coding techniques might well be used along the edge of the runway to identify the runway exit From a human factors viewpoint, the problem seems to be primarily one of discrimination, the pattern of white runway edge lights is not sufficiently broken, from a visual standpoint, at runway exits Specially-colored lights, perhaps flashing to increase their conspicuousness, could be used at the exit corners to make the exits easily discriminable The pilot would not need to perceive the linearity of blue taxiway lights to select two runway edge lights between which he should taxi.

A third technique that might be helpful for providing anticipatory information is to assign identification numbers to runway exits based on runway length remaining The pilot typically is checking on runway length remaining during his landing rollout and it would be relatively easy for him to use this information as anticipatory signals for a runway exit whose location is keyed into the system The fact that more than one exit at an airport would have the same number would be of little concern The pilot only uses one runway at a time, for briefing or other purposes, the runway designation can be affixed to the exit number. A pilot who frequently uses the airport would rapidly become familiar with exit designations for major runways, the itinerant pilot could be quickly and easily given the designation as part of his landing instructions

Ground traffic guidance is largely handled by the tower through radio instructions But, as one pilot interviewed indicated, the message "use Taxiway S" leaves the pilot with a somewhat helpless feeling when he does not know where "Taxiway S" is located

A recent study by Franklin Institute Laboratories exploring the potential use of various sign techniques for reducing the amount of radio communication needed to control departing ground traffic, provides some useful insights Lack of a simple confirmatory process was identified as a major reason why signs can not be expected to replace voice communications completely (GA27)

However, the study suggested that use of highway-type signs and use of intersection traffic lights would reduce tower communications considerably. It was recommended that highway-type signs, reflectorized or floodlighted, should be ample in number with relatively simple redundant text, rather than tricky abbreviations. This would alleviate the pilot's problem of finding and staying on "Taxiway S". The tower would have simple manual control of the intersection traffic lights in order to control movement of traffic over prescribed routes. The suggestions above are applicable to both incoming and outgoing traffic

Recommended Research and Development

Further operational tests of the flush button lights for exit and taxiway guidance are in order These should be done in conjunction with the runway centerline rollout guidance tests recommended in the flareout and landing mode discussion. At the same time, it would be relatively inexpensive to evaluate an exit designation system based on runway length remaining and the exit light color-coding suggested above.

Operational testing of highway-type signs and intersection traffic lights should be conducted, and evaluation based not only on a reduction of radio communications but also on measures of improved guidance.

Takeoff

General Pilot Task Description

Position aircraft at prescribed optimal distance (typically the middle) from sides of duty runway, as close to threshold as necessary.

Initiate and maintain take-off ground roll through path on runway aligned with longitudinal axis of runway

Break ground at prescribed air speed, its safe feasibility having been determined on the basis of runway length remaining during ground roll

Initiate and maintain optimal angle of attack for climbout

Information Pilot Requires from AML System

Distance of initial aircraft position from runway edges and threshold

Runway length remaining

Changes and rates of change in

- Displacement of ground track on take-off roll from runway longitudinal axis
- Attitude of aircraft--pitch, roll, and heading-line of flight coordination

Existing AML System Sources of Information

Designed for Requirements

(1) Runway edge lights (white)

(2) Threshold lights (green)

(3) Runway markings

Centerline stripe

Side stripes

Distance markings

(4) Runway distance markers (signs)

Other Visible Sources

Color, brightness, or texture contrast between runway surface and surrounding terrain

Relevant AML Components Under Development evelopment

Flush lights in runway surface

Floodlighting of runway surface.

Runway zone lighting

Summary of Reported Pilot Problems

A number of pilots pointed out that runway distance remaining information needs to be presented by some means other than by runway distance markers It is especially critical during low-visibility takeoffs when the end of the runway can not be seen Pilot objections to the runway distance markers are the same as those presented for the flareout and landing mode the signs are located outside of the focus of attention

Staying aligned with the longitudinal axis of the runway during take-off roll was reported as a problem on wide runways when the take-off roll is located close to one side Even when the aircraft is located in the middle, the centerline stripe is difficult to see in rainy or snowy weather

Discussion

The problem of presenting runway distance remaining information on takeoff is the same as discussed in the flareout and landing mode With a windscreen projection of air speed, with image focus at infinity, effectiveness of the present system of runway distance markers would be expected to improve

It has been suggested that an acceleration check-point should be marked on the runway surface. However, adequate runway distance remaining information, combined with the air speed projection, should alleviate the need for this.

The centerline system of flush button lights in the middle sections of the runway should improve directional guidance on rollout at night and in poor visibility conditions For day takeoffs, consideration might be given to using a thin "pencil" stripe located halfway between the wide centerline and edge stripes on all runways. The stripes would extend for the same length as the button lights and depending upon results of the runway marking research suggested in the flareout and landing mode, might be an integral part of a cross-hatch system in the first 3-4000 feet of each end of the runway As recommended in the circling guidance mode, wide edge stripes might prove useful on all runways. The pencil stripe would assist pilots taking off on one side of the runway or the other.

Recommended Research and Development

Research and development projects previously recommended cover the distance remaining problem during takeoff Evaluation of the flush button lights should include takeoff criteria.

The simulator studies recommended for studying runway marking of the landing mat can include evaluation of thin [illegible] stripes for providing additional directional guidance during takeoff

Comments on Overall AML System Functions

The nature and amount of traffic at an airport is the principal determinant of the kind of AML system required and justifiable In this functional analysis, focus has been placed on the heavy-duty general aviation airport (commercial, military, civil traffic). Suggestions for future research and development have been directed toward an AML system for this type of airport It is hoped, however, that some of the relatively less expensive components, particularly angle of approach indicators and runway end identifiers, might be suitable for common use, much like the beacon, at small civil airports.

Necessarily, our analysis has not treated every particular need of all potential aviation groups using a general aviation facility. For example, small civil airports largely servicing light private planes and helioports require considerations which were beyond the scope of this project's efforts. It may be that the special performance characteristics of some military or private aircraft require particular additional components. The recommendations do envision, however, a common core system, unmodifiable in the sense that what is provided would not be changed so that different kinds of visual judgments are required of the pilot for the same control task (e g , using a left-hand row, then a centerline row at successive airports for approach guidance)

It has been suggested many times that standardization is a vital need However, because of the varying needs of different aviation groups, the standardization principle applied uncritically would be extremely expensive and some group would always be quite unsatisfied Without a doubt, some aspects of the AML system should be, and to some extent are, standardized Thus, green color-coding of threshold lights is internationally standardized But, not all airports require all possible AML capabilities, standardization is not an applicable principle across the board

Compatibility has been suggested as a comparison principle and was used as one basis for the recommendations made. In its operational sense, compatibility primarily means the following an AML component, designed for the special use of one aviation group, can be included at a heavy-duty, general aviation airport, provided that its functioning does not interfere with the functioning of other components installed and provided that its functioning is critical to the safe performance of the aviation traffic for which it was designed. With some guidance requirements, this may mean that some redundant information is presented (e g , more than one source of roll guidance) in an absolute sense. But, for any given aircraft, only one of the sources may be useful because of factors such as cockpit cut-off restrictions, etc. At a general level, compatibility means the avoidance of requiring the pilot to use, as <u>his only alternative</u>, fundamentally different visual cues to make his required judgments (e g., left-hand row vs centerline row for alignment guidance).

Working within the framework of the common core system envisioned, research should be conducted to determine the specific traffic needs for an AML system, both current and anticipated, at each type of airport if such data are not presently available This would involve analysis of the nature and volume of traffic, current and projected, at each airport. A large amount of the survey might be conducted by means of questionnaires

Concomitant with this, a study to determine what parts of the AML system should meet the standardization principle and which should be considered from a compatibility viewpoint should be conducted Criteria of compatibility need to be developed for application to particular designs suggested for use by various aviation activities

A merging of the results of the two studies would yield a blueprint for systematically improving national AML system facilities at a pace consistent with the projected increase in use of these facilities

Chapter 4

Outline of Recommended Research and Development

In the vast literature on airport marking and lighting, almost every possible solution to problems has been suggested at one time or another This is probably true of the recommendations listed in the following outline, a recap of those presented in the different sections of Chapter III. The integrating characteristic of the list developed in this study is that it is based on a frame of reference composed of

(1) Pilot information requirements

(2) Results of operational tests.

(3) Data on basic human capabilities.

One category of recommendations is based on the assumption that a visual simulator study capability will be available for research and development purposes Such a capability for the United States was recommended for studying airport marking and lighting problems as long ago as 1948 It can be justified not only on grounds of flexibility and economy, both very obvious, but also for the need to get closer to the operational situation in studying the human factors involved in airport marking and lighting The basic need is for a variable characteristic simulator--one in which certain factors can be controlled and manipulated and from which one can get performance measurements Its design requirements are, in many respects, quite different from a simulator developed for training purposes It is hoped that an adequate simulator capability will be made available to those charged with the responsibility of conducting research and development on airport marking and lighting. (M13)

As indicated in the commentary on operational tests presented at the end of Chapter II, operational test procedures have varied considerably during the last decade There is a pressing need for development of comprehensive standardized operational measures of AML design effectiveness. Such measures must not only include pilot opinion, a very critical measure of "input", but also analytic, objective flight control performance measures which will provide feedback information for further development as well as testing of a particular design Measures of installation cost, power requirements, compatibility with airport operating procedures (e. g., snow removal) would need to be included A general formula for comparing increase in effectiveness, and thus accident reduction, to general cost needs to be developed.

Such measures would provide a standard for evaluation, rather than forcing dependence on the pilot's prior experience as the only criterion. A pilot who has lived through many landings in the "black hole" can be expected to react favorably to any improvement in guidance in that area But the aim from a research and development point of view should be to do the best job possible--and the improvement in guidance favorably received by the pilot, because previously he had none, is not sufficient evidence, by itself, that the improvement is the best that can be achieved.

Relying solely upon pilot opinion is tenuous because of the natural inclination of pilots to trust what they are accustomed to using more than innovations. A good case in point is the distance separating runway edge lights and the reported experience of pilots at Dow AFB with separation of the flush runway light bars Attempts to change the spacing of runway edge lights by 20 feet have met with almost universal rejection on the part of the pilots Yet, it was difficult for pilots to detect 100-foot changes in the spacing of the flush lights at Dow AFB. The answer is not found in differences in absolute value of guidance received, nor in basic human capabilities, but rather in experience.

As the ultimate users, pilots must be satisfied that an AML system does a good job of providing guidance. It behooves the researcher to recognize this and demonstrate to the pilot that he is working for the pilot's best interests, even when he is not using pilot opinion as his sole standard during research and development.

Summary Outline

Research and Development Recommendations

Basic Analytic Studies—Development of Components

For Circling Guidance

Analytic feasibility study of downwind leg "markers"

For Final Approach and Flareout and Landing Guidance

Determination of optimal region of guidance

(1) Lateral and vertical displacement from prescribed flight path at visual contact for various types of electronically-guided approaches.

(2) Minimum flight path correction times, at final approach altitudes, of representative range of aircraft

Determination of human capabilities for making rate-of-closure judgments

Determination of dimensions of "lane of no perceptible movement".

Feasibility study on techniques of projecting air speed and vertical speed displays on windscreens, with image focused at infinity.

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 criteria of AML system component compatibility

Determination of which AML system components should be standardized and which should be viewed from a compatibility criterion

Development of comprehensive, standardized operational measures of AML design effectiveness, including both objective performance (output) and pilot opinion (input) measures

Semi-Operational (Simulator) Evaluations

For Final Approach Guidance

Wing bar additions to Configuration "A"

Angle of approach indicators (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 Chapter III for recommended patterns)

Operational and Service Testing

For Initial Approach and Circling Guidance

Approach beacons

Runway identification lights

Circling guidance lights

For Final Approach Guidance

Strobebeacons in outer 1000 (or 1500) feet only of Configuration "A".

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 Configuration "A".

For Flareout and Landing Guidance

Initial testing of relative merits of flush lighting (high intensity and low intensity) vs floodlighting with specially marked runways

For Turnoff and Taxiing Guidance

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

Highway-type signs and intersection traffic lights

TECHNICAL NOTES

INTRODUCTION

A study which attempts to present an integrated, state-of-the-art description of research results related to airport marking and lighting (AML) initially must develop a general conceptualization of the domain The conceptualization must be sufficiently broad in scope to identify primary areas of knowledge which have an important bearing on AML. It also must be sufficiently structured to indicate how these relevant areas of knowledge relate to AML.

Such a basic structuring of the problem area is required at an early stage in the study so that the critical domains of information can be adequately sampled A more specific structuring then is required to place in proper perspective the knowledge contained in a general source of information such as human factors Within the general area of human factors, certain types of studies, such as reaction time or perception of motion, have greater relevance than others to AML problems The relevant information is important in particular ways Eventually conceptualization of the AML problem area must become developed in sufficient detail to permit application of results of specific studies to critical AML problems

TECHNICAL NOTE 1

AML AS SYSTEM DESIGN
AND
RESEARCH AND DEVELOPMENT PROBLEMS

AML as System Design
and
Research and Development Problems

AML as a System Design Problem

In this study, the airport marking and lighting (AML) problem was approached from the point of view of the system designer The designer's problem consists of deciding how to arrange the photometric properties available to him into a pattern which will maximally aid pilots in the performance of their tasks. At the same time, the demands of operational use must be considered in terms of fabrication, power supply, maintenance, and safety limitations on design options The wide range of alternatives theoretically or potentially available to the designer are significantly reduced by the practical considerations involved in landing aircraft, maintaining runways, and other requirements placed upon airport facilities, as well as the level of current technical development in lighting equipment. After accounting for such restrictions, there remains considerable latitude for decision, and the AML system designer should have guiderules to aid him in discriminating between particularly good and particularly poor design options. The basic conceptualization of the present study developed out of a consideration of how this AML System Designer's Handbook might be structured if it existed, or how it might be developed to be of maximum use

Guidance for design of an optimal AML system stems from the purpose it is intended to serve. Since the effectiveness of any given AML system is ultimately evaluated in terms of the degree to which its purposes are achieved, an analysis of AML design objectives provides a fundamental basis for the development of design principles or guiderules Basically, the function of marks and lights is to provide pilots with information required for successful control of aircraft during final flight phases and ground movement. The objective of an AML system is to provide this information to pilots in a form that is immediately identifiable and easily interpreted under the range of atmospheric conditions encountered.

While the current state of the fabrication art and related installation and maintenance considerations represent one class of restrictions on the design of AML systems at a given point in time, advances in engineering technology tend to overcome these limitations.

On the other hand, the basic information required by the pilot in the performance of his landing task and the basic capabilities of pilots which largely determine guiderules for deciding how best to provide the information are much less subject to change

In summary, three kinds of design guidance information are needed by the AML system designer first, knowledge of the information which is required by the pilot in his task performance, second, the basic capabilities of pilots within whose limitations the system designer must work, and third, the AML equipment available to implement theoretical or potential design options.

AML as a Research and Development Problem

The concept of an AML System Designer's Handbook would include an up-to-the-moment account of knowledge applicable to design decisions As technological and scientific advances extend this body of knowledge, improved guiderules can be provided the design engineer. Furthermore, as new developments in airframe design occur, extended and perhaps qualitatively different requirements will be placed on the AML system. The system may be required to provide information more quickly at longer ranges and at increased levels of accuracy. Should landing techniques change qualitatively in the future, new kinds of information may be required by tomorrow's pilot

As the frontiers of knowledge are extended in the fields of meteorology, physical optics, and optics, new sources of radiant energy and new forms of transmission will be at the disposal of the designer as additional design options. As research in visual/perception functioning advances, more detailed knowledge will be available as to how best to provide optimum patterns for interpretation by pilots

Ongoing work by illuminating, mechanical, and electrical engineers will continue to remove old barriers to the implementation of potential design options

These examples but brush the surface of the role and challenges of research and development in progress toward the solution of AML design problems

TECHNICAL NOTE 2

THE NATURE OF THE PILOT'S TASK

The Nature of the Pilot's Task

The fundamental desgin decisions of the AML system planner concern identification of information which patterns of marks and lights should encode, and selection of means by which such information is to be encoded and displayed The first problem is one of determining the kinds and amounts of information to display that will allow the pilot to perform his task without overloading him with redundant, useless, or confusing information The second problem is one of determining, from among all possible options, that encoding option which is most compatible with the relatively invariant visual perceptual and motor-response properties of the pilot

An approach to the solution of the design problem must be based on a detailed analysis of the pilot's task in controlling an aircraft by visual reference Such an analysis should first identify the human functions involved in task performance The next step should focus on the question "How well does the human perform these functions under task-related conditions?" As a subsequent step, human performance differences in critical functions then must be related to differences in AML design options to evaluate various solutions. The optimal solution will be that system which compensates best for the human's "weaknesses" and takes maximum advantage of his "strengths".

The pilot's tasks, when viewed in the context of the aircraft as a man-machine system, are generally those of system sensor, evaluator, and controller. Assuming conditions of contact flight, the pilot as a sensor requires information which indicates the aircraft's response to the combined effect of external conditions and control inputs. As the system's evaluator, the pilot acts as an error detecting device Sensory inputs from the ongoing situation are continually compared to some ideal pattern of "how things should look" As controller, the pilot functions as an error nulling device, making control inputs which are designed to bring about the eventual matching of actual sensory inputs and the ideal specified by the pilot's training and experience.

Basically, the pilot is performing a compensatory tracking task. He is attempting to maintain a desired degree of relationship between some index of optimal aircraft movement and the actual movement of the aircraft he controls. The nature of this task, however, is far more complex than any two-dimensional tracking task characteristically experienced by humans such as steering a bicycle or driving an automobile. In automobile driving, for example, the path of the vehicle is essentially in exact correspondence with the heading of the vehicle. No necessary correspondence of this sort holds in the control of an aircraft's flight path. The method of controlling associated with the two types of tasks is even more dissimilar. Turning the steering wheel of an automobile establishes the turn radius for the vehicle. When the turn has progressed to the satisfaction of the driver, he "straightens" the wheel and the turn is ended. In the aircraft, however, the pilot must introduce a rate of change in some rotational axis, for example, pitch This change in rotational tendency eventually, but not immediately, brings about a desired change in the aircraft's pitch position. Thus, the pilot must anticipate the time delay required for the given rate of change of pitch to bring about the desired pitch position and then reduce the control change to zero. He must further anticipate the amount of change in location in altitude, which the new pitch position will bring about through time, in order to begin introducing a counter-rotation in pitch rate that will produce a leveling off at the new altitude desired. Again, he must anticipate effects and return the counter-rotation to zero.

A desired change in location of the aircraft requires a four-step control procedure as follows

Introduce a rate of change in rotation which eventually changes the aircraft's attitude

Reduce the change to zero while desired attitude change is being achieved

Introduce a counter-rotational change which eventually changes the aircraft's attitude in the direction of a return to normal attitude at the desired location

Reduce the change to zero while desired attitude change is being achieved

As the system's controller, the pilot directly manipulates four basic elements thrust and rate of change of rotation about the three principal axes of the aircraft Manipulation of these controls first brings about changes and rates of changes in the attitude of the aircraft with respect to the surface of the earth Eventually, changes and rates of changes in the aircraft's location occur with respect to some point on the earth's surface. In his role as sensor, therefore, the pilot potentially can employ whatever visual stimuli of the earth's surface and objects on it which are present in his visual field as cues to changes and rates of changes in his aircraft's location Since changes in attitude are predictive of changes in location, the pilot who "knows his aircraft"; i e., has experience with the control lags and aerodynamic functions of the aircraft, can make good use of information about his attitude and rates of change in attitude as cues to his future location When performing as the system's evaluator or comparator, the experienced pilot can time-sample information about his present location and attitude to confirm or deny his expectations of where he should be at that time and, further, to predict his future location. To extrapolate his future position, the pilot is required to integrate location information through time and in combination with his present attitude and control settings.

Present location and, more importantly, future location must be evaluated in terms of the degree to which this actual and projected actual location conforms to the pilot's ideal flight path. When significant deviations occur, the pilot must estimate which control adjustments and in what degree now will effect the desired change in future location. As the pilot approaches the threshold in the landing mode, it becomes increasingly critical that he also estimate whether a given correction in future location can be effected by present control manipulations soon enough to conduct a successful landing.

At a general level of description, the basic ingredients of information required for the pilot to function as comparator are these

Knowledge of the ideal flight path and of the visual cues that serve as an indicant of the achievement of an ideal flight path. (The pattern of visual cues which indicate the anticipated flight path has been referred to as pilot visual "expectancies".)

Information about the present location of his aircraft.

Information as to the present relationship between actual and ideal location, and projections of this relationship into the immediate future.

The pilot's task has been conceptualized as a sensor-comparator-controller link in a closed loop man-machine system (see Figure 1). From this frame of reference, the following sequence of events describes one cycle of the continuous compensatory tracking task performed by the pilot

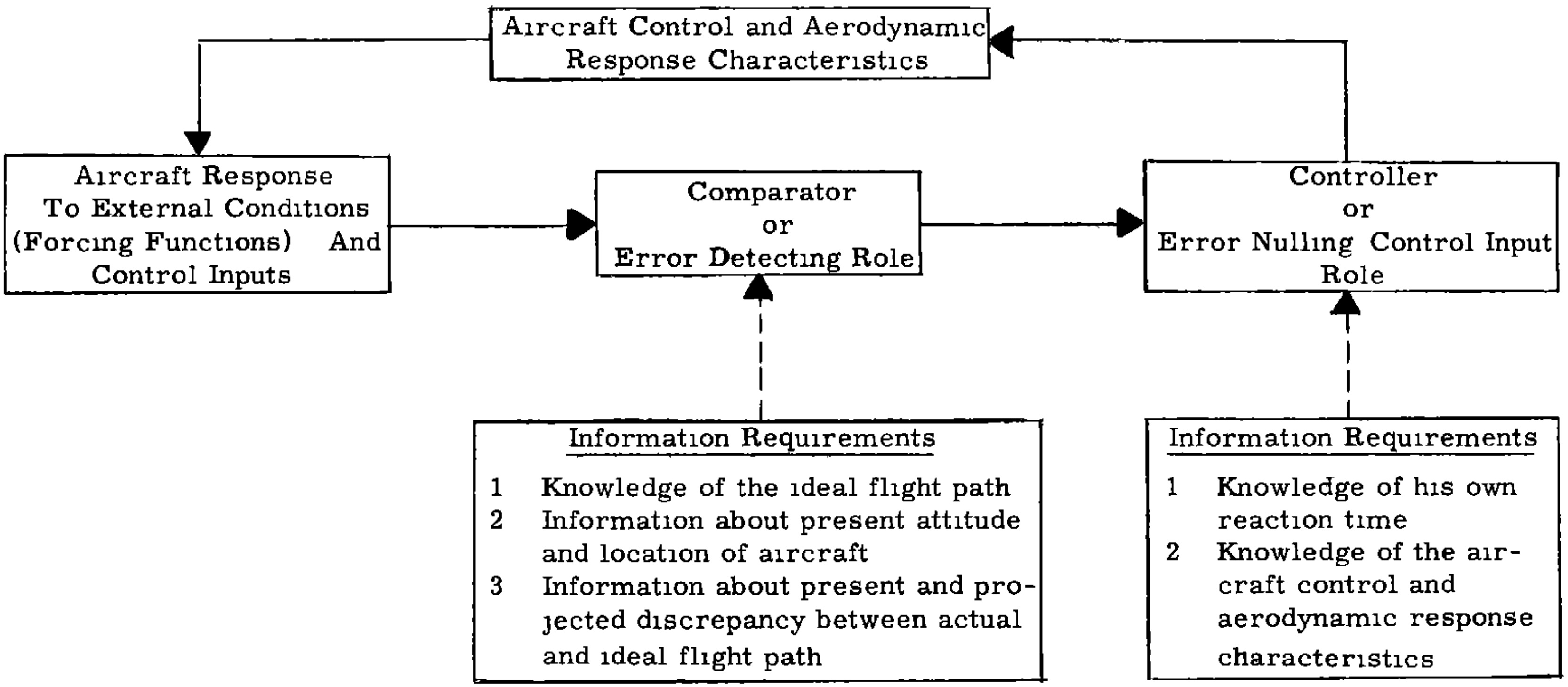
In response to a required change in the flight program, such as a transition from downwind to base leg, the pilot introduces an appropriate set of control inputs, i. e., thrust and rotation changes.

Following a control response lag and then an aerodynamic lag, the attitude of the aircraft changes in one or more rotational dimensions, i. e., roll, pitch, and yaw, accompanied by a change in the aircraft's thrust component

The changed aircraft attitude and thrust results in a change in flight path.

Figure 1

Generalized Aircraft Control System and Pilot Information Requirements



On the basis of visual stimuli from the external environment accompanying the system changes, the pilot makes an estimate of his aircraft's actual attitude and flight path Subsequently, the pilot performs a comparison between his actual attitude or location, and the ideal flight path he intended to bring about at that time through his control inputs.

The direction and magnitude of the discrepancy between his actual path, as estimated from the visual cues available, and the ideal or standard, based on a stored-in-the-pilot's-memory expectancy of how the visual world "should look", forms the basis for new control inputs

TECHNICAL NOTE 3

INFORMATION REQUIREMENTS DERIVED FROM ANALYSIS OF THE PILOT'S TASK

Information Requirements Derived from Analysis of the Pilot's Task

Based on the abstract description of the pilot's control task presented in the preceding Technical Note, information required by the pilot is that which denies or confirms correspondence of an ideal or standard flight path with the actual path achieved. This statement implies the presence of a standard and a means for perceiving it (or recalling it from memory), an index of actual performance, and a means by which the two can be compared to permit estimates of magnitude and direction of errors.

What, then, are the ways in which the pilot can be in error and how can the nature of these errors be "displayed" to him by airport marking and lighting systems? At a basic level, flight error can occur in two aspects of aircraft performance location and attitude.* The present location of the aircraft can be in error with respect to location prescribed by an ideal flight path. The present attitude of the aircraft can be in error with respect to the ideal attitude required to bring about future correspondence with the ideal flight path. Since the flight control of an aircraft occurs under dynamic conditions only, the basic information requirements are as follows·

Attitude control information requirements.

> Changes and rates of changes in pitch and roll with respect to the earth's surface.
>
> Changes and rates of changes in heading with respect to the aircraft's previous direction of flight.

---

* Attitude is used here in its broad sense covering pitch, roll, and heading-line of flight coordination.

Location control information requirements.

> Changes and rates of changes in direction of movement over the earth's surface with respect to a task-related point or area on the earth's surface (e. g., the duty runway).
>
> Changes and rates of changes in altitude with respect to the earth's surface.

The means by which error in attitude or location is "displayed" through marking and lighting systems potentially may take one of several forms. Cues to information requirements present in real world objects may be highlighted--an enhancement of natural cues--as visual stimulus inputs to the pilot. On the basis of apparent changes in the cues produced by control inputs, the pilot can estimate his current attitude or location. This estimate is then compared to ideal attitude and location values stored in the pilot's memory and an error estimate results. This has been the conventional approach to airport marking and lighting design.

Part of the pilot's integration requirements can be reduced through the use of a partially integrated display. This class of display encodes information about the ideal as well as the actual and may provide the pilot with an indication of magnitude as well as direction of his error. Examples of this display type are found in the several angle-of-approach indicators that have been developed.

A fully integrated display would program the response of the pilot as a result of present location error. As yet, no airport marking and lighting design has achieved this level of display sophistication. The carrier Landing Signal Officer (LSO) who projects future location of the aircraft as a result of its present location and signals corrective control action to the pilot is an example of visually encoding control commands. Another example is the flight director concept utilized in certain cockpit displays in which guidance on "where to steer" is presented.

Visual Cues to Required Information

Basic Properties of the Visual Field

The visual field is contained within the angle defined by the array of light, reflected or emitted from physical objects, which enters the eye. Brightness differential (intensity) among elements of this array of light is basic to seeing a physical object. A surface is seen when the brightness differential of small elements is uniform or regular over the entire visual field, or patches of it. This property of the visual field is optical texture. Contour is seen when there is an extended sharp break in brightness differential. If the contour is closed, a form is seen. Color tends to increase contrast. (HF1, HF2, HF6, HF7, HF13, HF17)

When an observer is in motion, his forward visual field "expands" from a "zero point" in the visual field at which he will collide with a surface or object if he maintains that instantaneous direction of motion. The elements of the field expand radially from this "zero point" at a rate related to the speed of movement and the distance from the observer to the objects reflecting or emitting the array of light entering his eyes The movement of elements or "rate of flow" in the observer's visual field is directly related to both the direction in which he is looking and the direction in which he is moving. This fundamental property of <u>motion perspective</u> is basically a geometrical transformation, with both variants and invariants, between the objects emitting or reflecting light and the light entering the eyes. Familiar objects are not necessary to give a perception of movement, unfamiliar textured projections have been utilized to give a compelling impression of movement through space (GA1, GA3, GA4, GA11, GA12, M6, HF6)

Correlated with the fundamental property of motion perspective, familiar objects, or classes of objects (e. g., trees, houses) will change in size, shape, interposition, light reflectance (shading), and aspect (perspective view) in the visual field. (GA11, HF6)

Visual Field Properties Related to Required Information

Unfortunately, there is no one-to-one relationship between information requirements and properties of the external visual field A given visual property can yield more than one type of information, the same type of information can be gotten from many different visual properties. The following discussion relates the basic properties of the visual field to the primary classes of information required by the pilot.

Pitch and Roll

Texture gradients provide information about the slant of the surface with respect to the pilot. The texture elements of a receding surface appear closer together at the far end of the surface and farther apart at the surface location nearest the pilot. When texture elements are equally spaced in the center of the visual field, and appear more closely spaced in the periphery, the surface plane is oriented 90 degrees to the pilot's line of vision. Because roll and pitch information derived from texture gradients is dependent upon position of the pilot's head, it can only be used by an observer if his line of sight is coincident with the aircraft reference axis of interest.

Contours on the earth's surface, particularly the horizon, are used with reference to some structural aspect of the aircraft for roll and pitch orientation. When using visual contours other than the horizon, the relationship of the contour to the horizon must have been learned previously. In each instance, however, the aircraft structure is used as an index for aligning the aircraft in some relationship with the horizon or other contour such as may be provided by marks and lights.

The orientation of natural and man-made surface structures, ordinarily built up at a 90-degree angle to the earth's surface, also provides a basis for judgments about roll. In this instance, alignment is made vertically with the constructed structure and the pilot assumes that the surface is in its expected relationship to the object.

Heading-Line of Flight Coordination

Perhaps the most useful heading-line of flight coordination information comes from the direction of visual pattern flow "under" or "over" the windscreen. If the line of flight coincides with the fore-aft axis, the flow will be aligned with the axis To the extent that the fore-aft axis of the vehicle is not oriented with the direction of movement, the flow will appear slanted in one direction or another with respect to the fore-aft axis or some structural index of the axis such as a windscreen support. To the extent that particular objects (e. g., approach lights) are learned to be associated with direction of movement, their position in the visual field (assuming for the moment that line of sight and the fore-aft axis of the vehicle are coincident) and flow "under" or "over" the pilot yields reliable heading-line of flight coordination information.

Elevation (Height)

The apparent relative size of familiar objects is probably the most commonly used source of both distance and elevation information. Apparent relative internal length between adjacent runway lights, and apparent relative brightness also can be used as cues to height above ground level, providing that the pilot has had sufficient prior experience with the particular stimuli involved.

Rate of Closure

Apparent movement velocity of visual field elements (rate of pattern expansion) is a function not only of speed of movement, but slant range to the object or surface as well. As might be expected, changes in the apparent relative size and shape of a task-related object (e. g., runway) along the projected direction of movement are frequently utilized by the pilot as the source of information of elevation and distance changes. Again, some structure of the aircraft (e. g., windshield or nose structure) can be used as an index for estimating the critical apparent size of the familiar object being used as the source of control decision information.

Direction of Movement

Researchers have singled out the "zero point" of the visual field expansion pattern as the most direct source of information of movement direction. By positioning the "zero point" on the object or the surface area toward which movement is desired (e. g., touch-down point), the pilot presumably has very reliable information about his direction of movement. While the "zero point" concept is sound geometrically, recent studies suggest that it may not be easily picked out by the pilot unless he is very close to the surface or object. At further distances, there is a large number of elements in an area which move at a rate slower than the typical pilot's capability to detect movement (See Chapter III) Errors in location of the "zero point" averaging about 5 degrees visual angle have been obtained in the laboratory.*

When the direction referent is not in the projected movement path, or is out of visual range (e. g., downwind leg of landing pattern) then extended contours of natural or man-made structures (such as rivers or landing strips) having a known spatial relationship to the direction referent

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* Personal communication between the authors and Mr. W. J. Carel, General Electric Advanced Electronics Center.

can be used as directional guides. Typically, some aircraft structure will be used as an index for "tracing" the directional referent or to align movement along a surface contour such as a runway centerline.

TECHNICAL NOTE 4

SPECIAL ANALYSIS

THE INFORMATION REQUIRED FOR THE VISUAL CONTROL OF AIRCRAFT LANDINGS

By

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The Information Required for the Visual Control of Aircraft Landings

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In order to land an aircraft, the movements of the controls have to be in a very exact relationship to the information the pilot receives through his sense organs But just what is this "information"? What is the best way to specify it? What parts of it are essential and what merely incidental? Are some aspects of it more trustworthy than others? It is clear at least that, among all the different sensory channels, the optical is more important than the others Consequently this paper will be concerned entirely with vision But the same questions have to be asked about the optical input as about the others The light which enters the eyes must somehow contain most of the information which a pilot uses, and the question is how to describe and classify it.

Visual stimuli or sensations are usually described as cues for the perception of objects and of space The cues for space perception have been classified and listed as an explanation of how we see the depth of objects It is assumed that if the pilot can see all the objects of the earth at their proper distances he can then learn to make the necessary responses for landing The accepted list of the cues for depth, however, comes from a long history of special problems in psychology and philpsophy instead of from a direct consideration of the problem of landing It is better to make a fresh start In the following account, therefore, the classical description of visual sensations and the theory of visual perception will be omitted We are interested only in the optical information necessary for flying

I. <u>The Field of View of a Pilot</u> Without going into all the complexities of optics and of binocular vision, it can be safely asserted that a man sees his environment only because light, travelling in straight lines, converges from all directions to the position of the man's head. The rays of light must not be diffused (e. g by fog) or intercepted (by an opaque barrier) and, of course, the environment must be illuminated if the rays of light are to exist at all. The man can move his eyes and his head so that he can explore this complete field of view if he needs to, in a few seconds of time. At any one moment of time he can take in roughly a hemisphere of rays, but he can register fine detail only in a very slender cone of rays at the center of the hemisphere So he moves his eyes, or looks around, in order to see the complete field. The focussing and fixation of the eyes on either stationary or moving details of this array, the formation of retinal images, the excitation of the mosaic of cells, and the use made of the slight disparity between the two retinal images--all these are simply mechanisms by means of which the information in the field of view is picked up

What, then, is the particular field of view of a pilot like? Considering only the hemisphere in front, which he can take in without having to turn his head, the upper sector is made up of light coming from the environment through the windshield, the lower sector is made up of light coming from the cockpit and the instruments. Now the information in the upper sector is of a quite different sort from that in the lower sector, that is, from the instruments. The former may be called <u>natural</u> information, whereas the latter is <u>coded</u> information The pattern of the light coming from the world depends only on the shape of the world, whereas the pattern of the light coming from the instruments depends on the way they were designed, and on the codes adopted for instrument reading The remainder of the paper will be concerned mainly with natural information, that is, with light coming directly from the physical environment to the pilot's eye.

The question, then, is this. What are the stimuli or cues, or whatever one wants to call them, which are contained in the array of light-rays from the sky and the earth, and which provide the information necessary for the performance of landing?

II. What Does the Pilot Need to See? Before attempting to answer this question in the exact language of optics, it would be well to ask a preliminary question in commonsense language what does the pilot need to see in order to make a successful landing? Admittedly, different pilots emphasize different things when asked about this, but they might agree on the following general statement

First, the pilot needs to see the layout of the earth. This comprises the overall layout of the terrain, that of the airfield, and that of the runway, in a sort of descending order. This assertion will be expanded a little later on

Second, the pilot needs to see at all times where he is going relative to this layout This means the momentary direction of flight, or the point of aim, relative to the terrain, the airfield, and the runway Obviously he needs to see this so that he can control where he is going.

Third, in the final approach the pilot needs to foresee the moment of impact with the ground for the present direction of flight. He needs to see this, of course, so that he can avoid the impact He does so in a fixed wing aircraft by changing the direction of flight, i. e. levelling off, and in a rotary wing aircraft by decreasing speed We here assume that the "foreseeing" of collision is in fact a kind of "seeing", and the evidence for this psychological assumption will be given

If these three types of perception are possible, a landing can be made In the most general sense, all one needs to do in order to get to a certain place is to see it in relation to other places, to see where one is going at any given moment, and to avert collisions. These are the essentials Other kinds of perception are of course important, but they are supplementary A knowledge of altitude, groundspeed, air speed, heading, wind-direction, glide angle, angle of attack, etc , are very helpful, it is better to have redundant than insufficient information. Of these supplementary kinds of knowledge some are given by instruments (e. g. air speed and heading) some are given by combinations of stimuli (e g. angle of attack or altitude), and some are equivalent to the former (e. g. glide angle to the direction of flight). But the former kinds of perception are the fundamental ones for locomotion. And they are given directly in the light from the earth to the eye, as can be shown.

The layout of the earth is given by the overall pattern and sub-patterns of the light--by the "optical texture" in the field of view. The momentary direction of flight is given by the position of the focus of radial expansion in this textured array. And the degree to which collision is imminent is given by the relative rate of expansion of the pattern surrounding this focus These three assertions will be taken up in order.

III. The Information for Perceiving the Layout of the Earth. The pilot needs to see the country at large, and the parts of it, and the details within these parts. He needs to pay attention only to the parts and details which are significant for his job, it is true, but he needs to see the whole. Now, the terrain, the airfield, and the runway are at different levels of size Taking all these shapes together at the different levels of size, the result is an enormously complicated physical structure. Nevertheless, however complicated it may be, the complete structure is represented exactly in the light which comes to the pilot's position in space, at least in clear daylight. The light is textured, as it were, just as the ground is textured, and it is formed as the countryside is formed Mathematically speaking, the physical structure is projected to a station point in the air The kind of projection is not that of a blueprint, it is a perspective projection, but it is nonetheless exact and the physical structure of the earth is no less well specified by it As modern geometry has demonstrated, the essentials of a structure or a form are unaltered or invariant from one projection to another This is the information on which the perception of the earth is based.

When the flier loses altitude, the optical structure is magnified The enlargement or expansion increases as the eye approaches the earth Any given form in the structure keeps its geometrical identity, the difference is that forms previously too small to be registered by an eye now become visible, and other forms previously visible get too large to see all at one time During a let-down and landing, the pilot is oriented first to the airfield in its surroundings, a little later to the runway in the airfield, and still later to the landing spot on the runway. The corresponding optical form gets big enough for the eye to pick up at just about the time when the perceiver needs to pay attention to the object, and eventually gets too big for the eye to pick up after it is too late to pay attention to the object

It is as if the human eye had on the one hand, a certain acuity for registering small forms in the over-all structure of light (if they are not too small) and, on the other hand, a kind of sensitivity to large forms in the structure of light (if they are not too large). The forms of intermediate size are registered by the optical system, and any one of them can be attended to if it is sufficiently interesting. The psychological basis of "paying attention" and "arousing interest" is still a mystery to psychologists, but that need not concern us here We are only interested in describing the potential information about the face of the earth which comes to the eye And it is now evident that this consists of a sort of hierarchy of forms within forms This is what the visual system is adapted to register The hierarchy of forms is related to the actual face of the earth by what mathematicians would call a perspective or projective transformation The laws of this relationship are the laws of perspective geometry, although they have to be referred not to a flat picture-plane, as the books on perspective do, but to a hemispherical optic array.

IV. Optical Transformations and Motion Perspective. We must now consider an important fact, not often emphasized in treatises on visual perception. When a man moves, the patchwork of forms changes In the course of the maneuvers preparatory to landing, each of the forms referred to above undergoes a continuous series of projective transformations The form representing a patch of forest, that representing the airfield itself, of the runway, of any particular building, and of any one of the windows in the building--each is continually changing. A rectangular object, for example, is represented over time by a continuous family of trapezoidal forms, of which the rectangle itself is only one member Another way of putting this is to say that there are differential motions over the whole field of view, that is, motions of all the parts of all the forms They arise, of course, because the pilot is moving and his point of view is moving Consequently, there is a different parallax, as the astronomers say, for each of the different elements of the earth's texture at different distances from the observer A transformation can be analyzed as a set of differential motions of the points which make up the form.

Now in the study of perception it has been considered very difficult to explain why a trapezodial form should lead to the perception of a rectangular object. The usual answer is that there has to be depth perception for the object And this means that we must take into account all the traditional cues or clues for depth before we can understand the puzzle But the whole puzzle can be bypassed if we take a new approach to the problem of space perception and make a simple, if unfamiliar, assumption. Let us suppose that the principal stimulus for the perception of an object is not its projected form but its family of transformations--more exactly the mathematical invariant of its family. Strange as this hypothesis may seem at first, it clarifies the old puzzle The invariant property of the time-series constitutes information about the object, the variant property of the time-series constitutes information about locomotion, that is, about the change of position of the observer relative to the object This formula will explain both object perception and the perception of one's own motion in space at the same time

If now we consider all the forms in an array of light to a moving point of view, it is evident that there are subfamilies and superfamilies of continuous transformations in the total array. They are all interlocked geometrically. Now the fact is that for any given super-transformation, there is one and only one movement of the point of view in space which will correspond to it Strange as it may seem, the transformation specifies the movement of the observer The total array yields information not only about the unchanging face of the earth but also about the changing point of view of the observer himself

Considering these families analytically, as a set of differential motions of points over the greater part of the whole field of view, one can describe them in terms of angular coordinates In this analysis, the forms as such disappear as it were and leave only the motions of their elements The result is what the writer has called "motion perspective", that is, the set of the parallax motions of all elements on the face of the earth as projected to an observer moving relative to the earth A mathematical statement of the law of motion perspective was derived and published by the author and his collaborators a few years ago It says that the momentary angular velocity of any point projected from the surface of the earth is a function of two constants and three variables The formula makes it possible to plot the pattern of velocities as vectors on a hemispherical array around the head of the flier This pattern will be the same whether the flier be an airplane pilot, a bird, or an insect Such a plot has very interesting characteristics, which differ for different circumstances of aerial locomotion Several of these plots are shown in the paper referred to The pattern of velocities is more easily visualized, however, if less conveniently specified, on a plane, that is, by a picture The direction and speed of each optical velocity can be represented by a vector. Such pictures can be found in the writer's volume of research on aviation psychology or in his book on visual perception. Three of them are reproduced here.

In general, the over-all pattern of velocities in the total spherical field of view is one of centrifugal flow from a focus in the direction of locomotion and centripetal flow to a focus in the direction opposite to locomotion One can observe the latter from the rear end of a train The magnitude of any velocity in the field vanishes at the optical horizon. Hence the angular velocity of any point in the array is an inverse indicator of the distance away of the corresponding element of the earth's surface It is a clue to the distance of the object, in classical terms, but this way of considering optical information is laborious and clumsy. A perceiver does not have to see all the velocities in his field of view, one at a time, and then put them together Instead, his eyes register the pattern of velocities, that is, the gradients of optical flow and the parameters of optical transformation. These indicate the actual layout of the environment in important respects. And, as a bonus, the flow pattern also tells the perceiver important facts about his own locomotion

V The Information for Seeing Where One is Going In addition to seeing the face of the earth, we suggested, the flier must be able to see where he is going relative to the face of the earth. Only so can he choose where to go. The point of aim at any time during locomotion is given, in the pattern of optical velocities described above, by its focus The center or origin of the centrifugal flow of the elements is the direction of one's movement In level flight, this is on the horizon, in a glide or dive it is at some angle down from the horizon The form within which this center falls represents that feature of the earth toward which the pilot is heading Assuming that he can

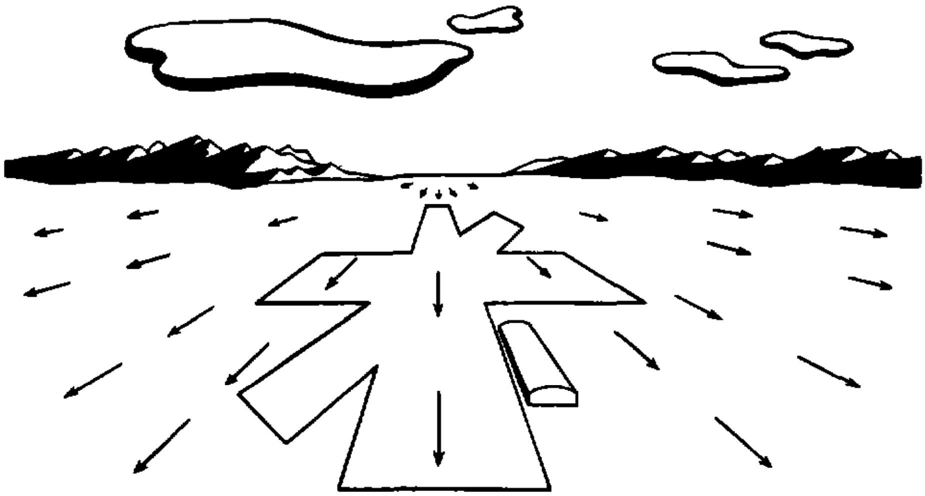

FIGURE 1 Motion Perspective in the Visual Field Ahead

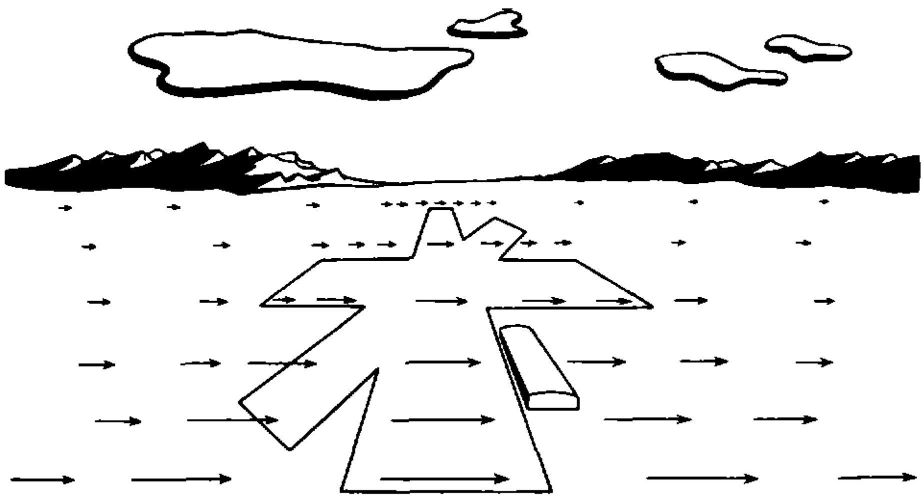

FIGURE 2 Motion Perspective in the Visual Field Looking to the Right

If the arrows are reversed, this becomes the visual field looking to the left

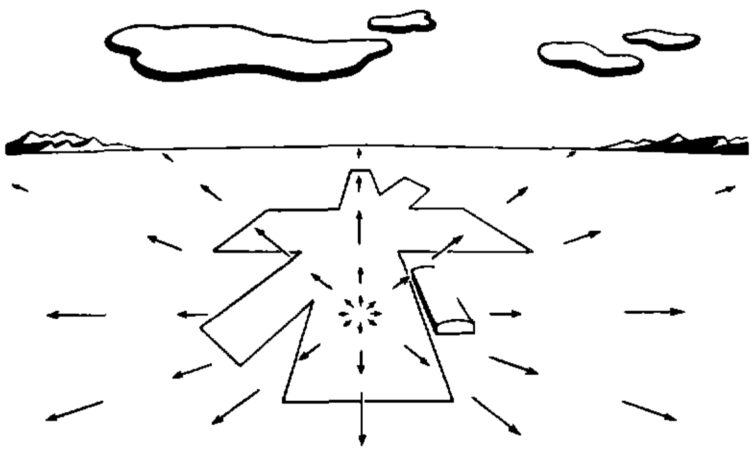

FIGURE 3 Gradients of Deformation during a Landing Glide

identify a city, an airfield, or the upwind end of a runway from its (changing) form, all he needs to do in order to get there by the shortest path is to keep the focus of flow on that form. If he turns, the focus sweeps over the features of the earth, if he dives the focus moves downward from the horizon to a new feature of the earth. This point of aim is given unmistakeably in the field of view, it is a point of no optical velocity and, moreover, the vectors of all the velocities in the field point exactly away from it It is always there to be seen, whether or not it is attended to

As every flier knows, the axis of the aircraft is no indicator of the direction of flight The angle of attack and the angle of "crabbing" in a cross-wind are variable But the focus of flow is an indicator of the direction of flight, and a perfectly reliable one. Moreover, it is directly visible The ability to see the point of aim relative to the ground, rather than to conceive it or to infer it, is important to pilots, for it is trustworthy information. This fact explains the dissatisfaction pilots feel for all blind landing systems mediated predominantly or wholly by instruments.

One does not have to look directly at the focus on the ground in order to apprehend it, since all vectors in the field of view, wherever one looks, radiate outward from the focus and line up with it In the customary round-about approach to an airfield necessitated by traffic, wind and other considerations, the cone of light rays coming through the side window instead of the front may receive the most attention This is the case, for example, during the downwind leg. But this picture is just a part of the whole melon-shaped pattern of optical velocities in the total flow of the face of the earth. And all velocities point to the pole of the melon. The whole pattern can be visualized by combining the pictures shown.

During the final approach, of course, the focus must be watched with care so as to keep it just above the line representing the near edge of the runway Here is the case where vision for details is necessary If the focus is too high there is danger of overshooting the runway, if too low, of undershooting As this situation approaches its climax, there is less and less time for looking around. The pilot begins to anticipate the touchdown.

VI. The Information Needed to Foresee the Moment of Impact. Collision with the ground, in a fixed wing aircraft, is avoided by levelling off. This consists physically of changing the direction of the path until it is tangent to the ground. It is quite a trick, however, and there is a danger of levelling off either too late, which results in immediate impact, or too soon, which results in eventual impact The direction of flight, or the point of aim, must be altered by just the right angular amount and over just such a period of time that the wheels touch when the path is parallel to the ground. In terms of motion perspective, this means that the focus of flow must be shifted upward from the beginning of the runway to the horizon of the earth, and must coincide with the horizon at that moment when the wheels touch. The shift is easy enough, it is accomplished by pulling back on the stick What is difficult is the timing of the performance The information for pulling out of the glide is contained in the pattern of vectors relative to the horizon. Is there also information in it for the timing of the pullout?

The answer is yes. In the mathematical statement of the law of motion perspective referred to, it can be shown that the pattern at any moment of time gives the time remaining before collision with the earth, for the speed and heading of that moment. An attempt will be made to put this fact into ordinary language

When approaching any object or patch of surface at a constant speed, the visual angle intercepted at the eye increases. It reaches 180° when the eye touches the surface. This is the angular size of the object. The increase of size per unit of time is accelerated as the distance of the object lessens Visually, it seems to "loom" in front of the perceiver as he gets closer. When this happens, he blinks, or dodges, or ducks. The effect can be demonstrated experimentally with a harmless shadow on a translucent screen in front of his face Now it is easy to prove that the relative increase of size per unit of time is inversely proportional to the length of time remaining before collision. If a silhouette increases in diameter 10 per cent per sec., collision is 10 seconds in the future. If it increases 50 per cent per sec , collision is two seconds off And if it increases 100 per cent per sec , collision is one second off This rule holds whatever the absolute physical size of the object or the absolute angular size of its projection may be Calling the shortness of time before collision the degree to which collision is imminent, we may now assert the law that the rate of increase of relative size, the rate of magnification, is an exact indicator of the imminence of collision

Note that the rate of magnification is not simply one event which signals a future event, in the same way that a dinner bell enables us to expect dinner. It is more than a "cue" or a "signal". Collision is continuously foreseeable, and its closeness in time is literally visible if the rate can be registered by the eye. It is possible to say that the pilot can theoretically perceive at all times the moment of impact during his final approach to a landing Foreseeing of this sort is more like seeing than it is like expecting or predicting

The continuous change in the rate of magnification of the runway or of its details is, therefore, information by which the pilot can time the performance of levelling off. He does not have to know the width of the runway in yards or his altitude above the ground in feet in order to do so. In short, he does not have to depend on an estimate of depth or distance based on the traditional cues, although he may, of course, make such an estimate There is one reservation which must be made, however, in the application of the foregoing theory. The pilot does not land on his own feet, but on wheels, which may be 10 or 20 feet above the surface of the runway, depending on the airplane he is flying. He has to know where his wheels are, as a sort of extension of his own body Or, to put it in another way, he has to know what the absolute perspective of a runway looks like when the wheels are on the ground In short, he must know the airplane

In the case of a vertical helicopter landing, the performance is simpler The pilot has only to slow down his rate of approach to the ground so as to just to cancel the magnification in the field of view when the landing gear touches. The operation of decelerating as one approaches an object is one at which we all have had considerable practice in everyday life--whenever, in fact, we wish to get close to something or someone without colliding with it.

It is worth noting, incidentally, that birds and insects make successful landings on various surfaces of the world, and have done so for millions of years longer than man has. Some creatures land by hovering, and some by gliding, or by both The information they need for landing is the same as a man needs Their eyes differ but the light entering the eyes is the same for them as it is for us Presumably the rules for success are also essentially the same

VII. The Special Character of Continuous Feedback Information. The pilot needs to see three things, the earth, his point of aim, and his future moment of impact. The latter two depend on the first In other words, he cannot see the point of aim or foresee the moment of impact except in relation to the earth But not only that, these two differ in still another way. The information for point of aim and moment of impact depend on motion in the light, the information about the face of the earth depends on what remains constant in the light despite motion. There are invariants of the energy input as well as continuous variations of the input, or transformations of pattern. The fact to note is that the transformations are produced by locomotion and also serve to control locomotion The invariants are simply a constant background of information. The transformations are examples of continuous feedback information.

The focus of centrifugal flow shifts when the flier turns, and thus serves to control the turn. The rate of magnification increases as the flier approaches and thus serves to control the approach These two are "cues" for perception or "stimuli" for behavior only in a special sense of those terms, inasmuch as their action is circular

The invariant properties of an optic array, on the other hand, provide cues or stimuli in a more familiar sense These enable the perceiver to respond to permanent objects, large or small, in the world The flier, of course, must have cues for both the world and for his flight, but the analysis of the cues must be different for the two kinds The one is environment-produced stimulation The other is response-produced stimulation The traditional analysis of the cues for depth perception fails to make this distinction, and thereby loses much of its relevance to aviation

The commonsense theory which says that if the pilot can see the earth he can land the airplane is not enough It fails to explain <u>how</u> he can land the airplane The information which specifies locomotion and provides for its control is necessary for that The pilot may be unaware of this kind of information and quite unable to say how he uses it It is apt to be registered unconsciously. In learning to use it, practice is more important for the novice than verbal instruction This would be expected, since the words available to describe the motions and transformations which occur in his field of view are difficult and unfamiliar, as may have been noted

VIII <u>The Information Required for Low Visibility Landings</u> We have said that the pilot needs to be able to register the over-all pattern and subpatterns in the light, the position of the focus of radial expansion in this over-all pattern, and the relative rate of expansion of the pattern around this focus

This structure, the patchwork of color-differences and intensity differences in the light, obviously depends on the presence of light. The countryside, the airport, and the runway must either be illuminated by the sun or lighted by artificial sources. More exactly, they must be sufficiently illuminated or sufficiently lighted to fix these surfaces in perception and to define at all times the position of the pilot relative to them The question of just what is sufficient information in the way of patterns and transformations of light is an extremely complicated and difficult one

At night, it is possible, of course, to supplement natural light with artificial light, either "direct" lighting by luminous sources imbedded in a surface or "indirect" lighting which sends reflected light from the surface In either case the important parts of the structure of the earth, although not the whole of it, can be represented in the light to the pilot's position in space. The greatest difficulty arises when the airspace is filled with haze or fog. The light is then said to be "diffused" and the pattern at the eye is said to be "veiled" or "blurred" and to lose "contrast". In the extreme case of a diffusing substance in front of the eyes (e. g spectacles of frosted glass), there is no pattern in the entering light at all, and the perceiver might as well be blind In cases of partial diffusion of light, only one thing is certain· the information about the external world is reduced.

No one seems to know, at present, a good way to measure the loss of information produced by the diffusing or blurring of light or by reducing its contrast. In practical aviation, "visibility" has a definite meaning. But it is measured only by a rule-of-thumb method, that is, by measuring the distance at which objects are detectable through haze or fog. The kind of information we are considering, it should be remembered, is what we have called natural. There are newly developed methods for measuring coded information, as in speech communication, but they do not seem to be appropriate for the quantification of the information about the world which is carried by light. Information theory has not yet been successfully applied to this problem, and it may be that a different mathematical procedure is required.

The problem of defining optical information cuts across several different sciences, psychology, visual physiology, optics, physics, and illuminating engineering. A great deal of research has been carried out which is more or less relevant to the problem but not centered on it--work on visibility, visual detection, visual contrast or brightness discrimination, visual contour perception, visual acuity in relation to illumination, form perception, surface perception, brightness constancy, and perhaps still more The problem of the definiteness of an optic array should not be confused, of course, with the problem of the definition or clarity of a retinal image. The latter depends not only on illumination and diffusion in the air but also on the anatomical condition of the eye, with which we are not here concerned.

The practical problem for flying at night or with fog or both is how to mark and illuminate airports and runways in such a way that the light reaching the pilot carries at least the essential information for landing the aircraft According to the present analysis, the essential information consists of a "sufficient" degree of patterning of the light--sufficient to carry the geometrical invariants and the transformations of pattern which enable the pilot to see a surface and to control his flight relative to the surface But we do not know what degree of patterning is sufficient for this purpose, and we are not even sure how to define "patterning". Various systems of airport marking and lighting can be designed, but they will be based on guesswork until these basic questions are clarified.

Part II Recommendations for Research on Airport Marking and Lighting

The reason for the present confusion about airport marking and lighting systems is simply that we do not know enough about how light enables us to see things. The accepted theories of perception have hindered rather than helped by concentrating on the stale philosophical question of how the mind constructs a picture of the outer world, or if not the mind, then the brain. The theories and experiments of physics and optics have been concerned with light, but not with the kind which makes visual perception possible. The visual physiologists have concentrated on the cells in the retina of the eye but not on the way the whole system works. The only remedy for this situation is basic research.

Experimental work is needed in at least three areas, first, studies of the patterning of light projected to a station point in an environment, second, research on motions or continuous transformations in such an optical array, and third, an effort to find a method for quantifying the information carried by the array under unfavorable conditions In each of these areas, cooperation is required between physics on the one hand and psychology on the other. The light has to be manipulated and controlled, and then its effect on a perceiver or a pilot has to be determined.

Studies of the Patterning of Light. This area includes a great variety of experiments on vision which have been treated as separate problems but not as parts of an over-all problem--experiments on acuity, form-perception, brightness-discrimination, contrast, etc. This diversity is illustrated by the different terms used in the present paper to describe the information-carrying capacity of light structure, texture, form, pattern, or a "patchwork" of intensity differences and wavelength differences. Some experiments in the area which seem to be especially relevant to airport lighting and marking are as follows

1. Research to determine the stimulus conditions for the perception of a surface This involves experiments on optical margins and textures. It is related to older work on film-colors vs. surface-colors, on the figure-

ground phenomenon, on the constancy of surface-color under varying illumination, on brightness contrast, and on the relation between acuity and illumination

2 Further experiments on the optical conditions producing sharp contours in perception (e. g. Mach bands) and the conditions producing a shadowy transition or penumbra

3 Further experiments of the type now performed on visibility, visual detection, and several kinds of visual acuity targets.

4 Research to determine how the variables of natural objects and luminous sources do in fact determine an optic array This is a new and uncoordinated field of study which the writer has called "ecological optics". It involves studies of illumination, reflectance, the directionally reflecting properties of surfaces, and the geometry of perspective

Further Studies on Continuous Transformations or Differential Motions in an Optic Array There are few existing experiments in this area except those from Cornell University carried out recently under contract with the Office of Naval Research Most of the early experiments on visual motion are not relevant. Some projects that would be profitable are as follows

1 A further mathematical study of motion perspective or the generalized formula for the parallactic motions of points on the surface of the earth. Also the application of this method to the analysis of particular arrays encountered during aircraft landings This method should be compared to that advocated by Calvert in England for analyzing the apparent motions in the field of view during an approach glide

2. Psychophysical experiments in which the variations in perception aroused by variations of optical transformation are determined This involves the producing and controlling of artifical arrays such as those from displays, simulators, motion picture screens, or shadow-projectors Research in this field has been handicapped up to the present by the difficulty and

expense of wide-screen presentation.

3 The construction of optical simulators, intended wholly for research rather than for training, for the study of two abstract control mechanisms in a human operator steering and making contact without collision

Discovery of Methods of Quantifying the Information in Optical Structure The information in ordinary visual stimulation has to do with the places, objects, and events of an environment, and with the activity of getting about in the environment It is not coded information as the information in speech sounds and written symbols is As the Gestalt psychologists have emphasized, there is great danger in trying to find elements or units in visual forms and patterns But units of some kind are necessary for quantification, and the question is whether appropriate ones can be discovered which do not do violence to the facts of perception

An exploratory collaboration between a perceptual psychologist and a mathematician might be useful in attacking this problem.

There are various ways of blurring, weakening, impoverishing, reducing, or otherwise attenuating visual patterns. Many of them have been tried experimentally in psychological laboratories, and they occur naturally when fog or darkness intervenes. Efforts should be made to measure the reduction of information in these experiments.

There have been recent efforts to define "regular" as compared to "irregular" visual patterns in a mathematical way, and to discover what difference this makes for perception The regular are superior to the irregular stimuli by several criteria But regularity is by no means a simple mathematical variable and further work is necessary to clarify the concept The only thorough going discussion so far published of the possible ways of conceiving the amount of information in a pattern undergoing continuous magnification is that of Hochberg and Smith, and even this treatment is confined to small patterns with a limited number of elements

TECHNICAL NOTE 5

IMPLICATIONS OF ACCIDENT AND PILOT REACTION TIME DATA FOR AML DESIGN

Implications of Accident and Pilot Reaction Time Data for AML Design

Accident analyses are one source of insight into problems associated with pilot control of an aircraft having implications for airport marking and lighting design. A summary of accident statistics presented in the reports reviewed in this present study indicates that a majority of military and commercial aircraft accidents occur where visibility and weather are far above minimal conditions, although there is not much difference in accident rate between VFR and IFR conditions. However, the majority of accidents occurred when

the pilot is in final flight phases associated with landing his aircraft,

he has transitioned to visual contact as the information source for flight control,

it is night, and

visibility is greater than 2 miles

In a recent speech, the Director of Flight Safety in the Air Force reported the following concerning 235 cases of major undershoot accidents.

All except four (4) occurred in VFR operations

All except 15 occurred with visibility greater than three (3) miles

The data on which these conclusions are based have been gathered over a period of several years. The experiences of both the United States and United Kingdom military and commercial aircraft are included (GA6, GA8, A2-A10)

This description of the conditions associated with the major percentage of accidents suggests that the accident problem is not solely a matter of poor visibility, or other performance-degrading conditions. Rather, there appears to be a basic failure in the information-response system which links the airport marking and lighting system with the pilot. (GA8)

Approach speed, sink rate, and aircraft response lag to pilot control inputs (throttle, flight controls), all combine to place a time demand on performance of the pilot's task. As these dimensions of aircraft performance have increased through recent years, increased demands have been placed on the pilot's reaction time. A basic problem appears to be the fact that, while increasing aircraft performance characteristics are placing heavier reaction time requirements on the pilot, these response characteristics of the pilot remain relatively fixed As aircraft-generated response requirements approach the upper bounds of pilot performance, and pilot "band width" is used to capacity, the probability of linkage failure, somewhat erroneously termed "pilot error", increases (GA8)

Assuming a continuing increase in approach speeds and sink rates of aircraft, and continued use of the pilot as principal controller of such aircraft, there is a consequent necessity to compensate for the relatively fixed upper limits of the pilot. In this context, the requirement for improved airport marking and lighting systems is paramount. The information utilized by the pilot in the landing phase must be provided at a time and level of clarity concomitant with the demands of the landing task. The pilot soon will be unable to compensate for airport marking and lighting systems which provide him visual information which is either inadequate or ambiguous in the sense that it takes the pilot a relatively long time to interpret and react successfully. (A1, A4)

With the increasing demands of high-performance aircraft in mind, consider the information processing time requirements of the pilot as described by Zeller

> Whatever the information encoded by the airport marking and lighting system, the light falling on the retina must be transmitted to the brain. <u>30 milliseconds to 3/10 of a second.</u>
>
> The stimulus pattern must be recognized. <u>1/2 second.</u>

The stimulus pattern must be interpreted and a decision reached as to the appropriate response indicated by the interpreted information 1 - 2 seconds

The decision must be translated into a control response. 1/10 - 5/10 second.

The control responses, in turn, affect aircraft control surfaces and eventually an aerodynamic response of the aircraft occurs.

Each of the first four steps must be performed in visual contact flight and each step implies a function or process of the pilot which is relatively fixed by his physiology, musculature, etc. Total time required by the first four steps thus appears to be somewhere between 1.5 and 3 seconds. Jenks also has estimated this time to be about 3 seconds. However, it may be that this time is shorter if the pilot is "set" for a stimulus which, when seen, triggers off a sequenced response. (A4, M7)

For all five steps, total time has been estimated by Jenks to be on the order of 7 seconds Cornell Aeronautical Laboratory also has estimated total lag time for the first five steps to be about 7 seconds. In this calculation, the following breakdown was used

Time for pilot to receive and assimilate command 1 second.

Time to advance throttle. 1/2 second

Time to move stick. 1/2 second

Time to develop power, coincident with aircraft response time 5.0 seconds (GA45)

Empirical data specifically collected to measure pilot-aircraft response lag time in the final approach mode have not been systematically collected. However, data on total time required for various corrective maneuvers have been collected in the United States and in England. Although more directly to the point with respect to airport marking and lighting systems, the English data do not allow extrapolation to new types of aircraft. (GA8)

A summarization of accident statistics in terms of implications for airport marking and lighting design indicates the following

> The pilot's task in the landing phase imposes the most stringent time requirements for information on the airport marking and lighting design.
>
> The airport marking and lighting design which provides information needed by the pilot in performance of the landing task must be guided by the nature of information requirements in poor visibility conditions
>
> The most critical information items that must be represented in airport marking and lighting design seem to be rate of closure with the surface and projected point of closure with the surface. (A1)

TECHNICAL NOTE 6

DETERMINANTS OF INTENSITY AND POSITIONING OF APPROACH AND RUNWAY LIGHTING

Determinants of Intensity and Positioning of Approach and Runway Lighting

While many approach lighting configurations to aid the pilot in poor visibility conditions have been designed and tested, only a few have been adaptable to the wide variety of operational conditions under which the system must function

To make possible provision of information to the pilot on his position in relation to the runway and the point at which he has to aim to make his touchdown, a sufficiently long segment of the approach and runway lights must be visible during the approach and landing This segment must not only be seen when the aircraft approaches the runway along the proper glide path, but also when it follows a path that deviates from the proper one

This Technical Note is concerned with a discussion of operational conditions which determine specific values of two fundamental design characteristics of approach lights, namely, positioning and intensity

Position at Point of Transition from Instruments to Visual Contact

This variable is, of course, highly correlated with atmospheric conditions The poorer the atmospheric transmission, the closer to threshold the pilot will be before seeing a given set of approach or runway lights. Assuming a more-or-less linear glide path, this implies that for each instrument approach, values of the following factors will vary widely regarding the point at which the pilot initially obtains visual guidance.

Height

Distance from threshold

Horizontal and lateral displacement from proper glide path.

Heading.

Rate of change of each of the factors listed above

A recent report from an ICAO meeting in Montreal gives the following data on lateral displacements at 4000 feet from threshold The data bracket 95% of instrument approaches with the electronic aids and approach speeds listed. (M30)

	145 mph	175 mph
ILS automatic approach	110 feet	140 feet
ILS flight director	220 feet	280 feet
GCA	250 feet	-------
ILS crosspointer	440 feet	560 feet

Some data have been compiled both in the United States and England on the possibility of a successful landing with transport class aircraft as a function of horizontal departures from the extended runway axis (TV1, TV11)

Small errors in heading at greater distances from threshold are usually unimportant, but this factor becomes very important if heading errors become significantly large at distances closer to the runway

In judging the relative importance of lateral and vertical displacements, it has been said that lateral deviations result in missed aproaches while vertical errors cause accidents.

It is realized that information on rates of change of the four basic factors is critical also Once precise information on the momentary value of the four factors is complete, it would seem advisable to study the much more intricate effects of their rates of change.

Aircraft and Pilot Response Characteristics

It has been estimated that approximately 3 seconds are required by the pilot in the approach zone to appraise his situation, apply the necessary correction, and observe that the correction is taking place. This value can vary several tenths of a second either way, according to the individual pilot and conditions When only edge runway lights can be seen, it has been estimated that the comparable time for this action is 6 to 9 seconds. (GA22, M7, M9, M19)

It has been estimated by Jenks that the time needed by an aircraft to show a measurable departure from track after a turn has been initiated is between 4.5 and 7 seconds. The time then required to spot a displacement and complete a corrective maneuver is at least 9 to 11 seconds, although the time may be slightly shorter for very small displacement errors. Calvert reports that tests conducted by the RAE in 1955-56 showed that the time taken to correct a given displacement was nearly the same for each of a wide variety of tested aircraft (mostly propeller driven). The following values were given for the minimum time required to correct (in one maneuver) the lateral displacements given below. (TV1, M8)

Lateral displacement	Minimum time to correct
40	10
100	12.5
200	15
330	17.5
500	20.0

It should be noted that due to the unstable aerodynamic characteristics of aircraft at lower speeds required for landing, maintenance of an absolutely straight-line flight is practically impossible unless the pilot can "gun-sight" the aircraft toward a certain point. As can be imagined, the task of properly correcting misalignments is a much more complicated task. The aircraft does not respond to minute turns or corrections at the instant of application. The mass of the aircraft continues along a ballistic path without significant deviations until the corrective forces become of sufficient quantity to deflect the mass in the desired direction (M8)

For the reasons described in the preceding paragraph, the pilot will often over-correct or under-correct since he is estimating the future effects of his control input. He does not have immediate feedback due to aerodynamic lags. (It may be that "quickened" indications, showing where the aircraft will be at some future point in time, would be a useful developmental program.) Thus, it is seldom that a pilot can correct a large displacement in one maneuver Instead, the aircraft follows a more oscillatory track with the oscillations getting progressively smaller. This track holds not only for lateral and vertical displacements, but also for oscillations of the aircraft around its own axis as well In addition, it has been reported from England that during the correction of a lateral error in poor visibility conditions, visual guidance in the vertical plane from approach and runway lights is practically non-existent. (GA7, GA15)

Aircraft Landing Procedures

The particular aerodynamic characteristics of each type of aircraft will primarily determine the airspeed and the type of approach which the aircraft should follow for the safest possible landing.

The FAA requires that landings be made at 1 3 times the stalling speed for all approaches. For a typical modern commercial aircraft, this speed is approximately 130 to 140 miles per hour. This figure may vary between 120 and 210 miles per hour for other large aircraft

Civil and military transport aircraft will usually try to follow a linear glide path at an angle of approximately 2 1/2 degrees This angle may vary from 1 5 to 3.6 degrees. (GA15)

Groundspeed will, of course, be the determining factor in how much time the pilot has available to spot an error, make the required correction, and still land the aircraft Under the following conditions, the pilot will have 4800 feet remaining to his touch-down point.

Cockpit cutoff of 15 degrees

Pilot obtaining visual guidance to make glide-path corrections needed at the point at which the outermost bar of the 3000-foot approach configuration is cut off by the structure of the aircraft

A straight-in approach path 2 1/2 degrees above the horizontal with intersection at a point 1000 feet down the runway.

In the above situation, the maximum time remaining for various groundspeeds would be

120 mph (176 ft/sec)	27.3 seconds
150 mph (220 ft/sec)	21.8 seconds
180 mph (264 ft/sec)	18 2 seconds
210 mph (308 ft/sec)	15.6 seconds

(GA22)

As has been discussed previously, at distances closer to touchdown, maintaining a proper glide path becomes much more critical According to Calvert, the time required to make a lateral correction (excluding "slipping") of only 40 feet requires 10 seconds It can be seen that as the approach speeds of aircraft increase, the problem of performing these necessary corrections in the allotted time approaches the limit of what the human pilot can be expected to do (TV1)

Cockpit Visibility Restrictions

The structure of present commercial aircraft is such that only about 15 degrees (measured from the aircraft longitudinal axis) of downward view is available to the pilot Some military aircraft have as much as 5 to 8 degrees less downward view available. Some of these aircraft, however, have a slimmer fuselage which allows greater side vision. It is possible that in some future military aircraft, forward visibility may be reduced to as low as 5 degrees. (GA7, TV1)

In England, the RAE has collected some valuable data from flight tests and experiments on the kinematic sumulator about cockpit cut-off angle effects on aircraft landing procedures. From these studies, guidance requirements of visual aids for aircraft with from 5 to 20 degrees of cut-off angle have been established. Although the results are much too complicated for our present discussion, it is recommended that the interested reader become familiar with them. (TV1)

The prevalent feeling today is that cockpit cutoff does not become an important factor until the threshold is reached, except under very poor visibility conditions. The cutoff consideration is important, however, in military jet flare-out procedures. In some modern high-performance aircraft, the forward visibility cutoff is above the horizon.

Runway Width and Length

The dimensions of the runway define the tolerance limits within which the pilot must touch down. The adequacy of these limits varies according to the type of aircraft being considered. (TV1)

Longitudinally, higher-speed aircraft require more runway to complete the touch-down and roll-out maneuver. Runways ranging from 3000 to 13,000 feet in length have been constructed. Most of today's civil runways fall into the 5900 to 8000-foot class Present feeling seems to be that for future aircraft, at least an 8400-foot all-weather runway will be required. Most military (and NATO) runways conform to this standard (M30)

The amount of lateral tolerance is mainly a function of aircraft size and heading at point of touchdown (This last factor varies from landing to landing.) Runways may differ in width from 150 to 300 feet. The 150 and 200-foot widths are most common, wider runways are being used where there is more military traffic

Atmospheric Conditions

For approach lights, the most intense part of the light beams should ideally be directed at the pilot at the most distant point from which he will view the light during the operational maneuver. Conversely, he should be in the less intense portions of the light beam as he approaches it to prevent glare. (TV2, TV3, TV4, TV5, M11)

Approach lights have been developed which can meet these requirements when visibility is unrestricted, but when the weather becomes a little "soupy", the problem of meeting the requirements becomes almost impossible Under these weather conditions, the character of the atmosphere is seldom homogeneous so the probability that the pilot will be precisely in the peak of the beam of the approach light when the light is first seen is very low. Not only is the atmosphere non-homogeneous, but its character varies considerably according to position and time. (TV5)

The non-homogeneous conditions of the atmosphere in such instances often results in the following

intermittent loss of guidance,

some glare (as a result of trying to make all lights visible), and

difficulty in informing pilot what his visual contact height and range will be.

Rain, snow, and other forms of precipitation further intensify the problem, especially by causing distortion on the windshield (M17)

The character of the atmosphere is not the sole determinant of when the pilot can expect to make visual contact with the approach lights. Background brightness is also an important consideration. The least favorable conditions for observing approach lights is considered to be daytime fog, when approach lights have little contrast with the atmospheric hue (TV2, TV24)

Increasing the intensity of approach lights will increase their visual range. There is a point, however, at which this principle becomes impractical. For example, when day visibility is 1/16 of a mile, a 10,000 candlepower light can be seen for a distance of approximately 1100 feet while a 100,000 candlepower light can be seen only for a distance of about 1300 feet. (C16)

Size of the light source also influences the visual range of approach lights. For a given intensity, the source of smallest size will give the farthest visual range. However, for a given candlepower per unit area, the light of largest size will give the greatest visibility. Shape of the light, or groups of lights, has some effect on visual range. Single sources of light are usually kept as circular as possible. There seems to be little effect due to the shape of a group of lights, provided the number of units is kept constant. It should be noted, however, that at greater distances from threshold the individual lights, grouped as (for example) in the bars of the centerline system, have an additive effect in providing increased visual range. (TV2, TV35, M27)

For lights of equivalent intensity, the influence of light color on visibility is negligible. However, the addition of any colored filter to a light source will significantly reduce the visual range of the light. For this reason, clear lights are usually used in approach and runway lights. (C42, TV32, TV33)

A flashing light of given effective intensity is generally more conspicuous than a steady-burning light of an equal intensity. However, the two will have an equal visual range. With a given amount of energy, the flashing light with the shortest flash duration will have the greatest visual range. Continuation of this principle becomes impractical at time intervals of less than 0.01 seconds. Peak candlepower and frequency of flash also influence the conspicuity of flashing lights. (TV10, TV40)

Visibility Measurement

The accurate reporting of atmospheric conditions is a prominent factor in landing an aircraft for two reasons. Primarily, it allows ground personnel to determine whether the pilot should follow an instrument or visual approach, or should not approach at all. If an instrument approach is recommended, ground personnel can use information on visibility conditions to judge the proper brightness control setting on approach lights which allow the pilot to see the required number of lights at a required time and will avoid glare at distances closer to threshold. An automatic brightness control device has been developed by NBS which varies the brightness settings of the approach and runway lights according to transmissometer readings, and sky-brightness measurements. (TV7)

In addition, the pilot uses visibility information as an indication of how many lights he can expect to see at a certain point in time or space, and how these lights will appear through the particular atmospheric conditions which exist.

Two pieces of equipment have been predominantly used to measure visibility conditions. the transmissometer and the ceilometer The transmissometer measures the transmission of the atmosphere, determining the amount of light which is received at a certain horizontal distance from a light source of given intensity. The ceilometer measures cloud height by measuring the angle of light reflected by clouds from a light source at a given point.

The LAES Final Report for 1949 reported mixed results after using a combination of fixed-beam ceilometers and transmissometers. This feeling, however, apparently was not shared by a great many of the meteorological personnel connected with the tests. In November 1948, LAES recommended further developmental and research work with the equipment.* Tests were continued at National Airport which ultimately led to the testing by Sperry discussed next.

In a flight test program jointly carried out by the Air Navigation Development Board and Sperry Gyroscope Company at Idlewild and MacArthur Fields from 1951 to 1954, it was concluded that the combination of a rotating-beam ceilometer and transmissometer provided a satisfactory method for remotely measuring routine weather conditons in the runway approach zone. Supplementary photometric data were thought to be required for the optimum interpretation of these weather observations. (TV11, TV14)

Subsequent data gathered by the same organizations from 1955 to 1956 essentially supported this conclusion. Satisfactory equipment and techniques which supplemented the transmissometer and ceilometer information were found. An alternate method, however, was proposed for evaluating fog-smoke-haze weather conditions, because it was thought that the assumption of a homogeneous atmosphere (basic to transmissometer and ceilometer measurement) could not be justified for these conditions. (TV12)

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* Stocher, G H. Preliminary plan for an objective system of reporting ceiling and visibility in adverse weather conditions. Arcata, California Landing Aids Experiment Station, Meteorology Department, 16 November 1948

Operational experience soon indicated that the proposed alternate system, although giving satisfactory results, was much too cumbersome and expensive for general use A simplified evaluation system was tested at Newark Airport in 1957 and comparisons of computed altitudes based on this system and the system proposed in 1956 revealed no operationally significant differences between the two methods (TV9)

The feasibility of determining visual range along the approach path by use of measurement of light back-scattered by the atmosphere (pulsed-beam transmitted light was used) was investigated theoretically and experimentally by Motorola in 1957 The experimental equipment did produce useful signals in the range of 1000 to 2000 feet. Although this range is not adequate, extrapolation of the data indicate the possibility of assembling a larger system as a means of securing large ranges (TV13)

In England, it was suggested in 1958 that marginal weather conditions be reported according to one of the following categories cloud base condition, uniform haze, fog, or shallow fog (GA8)

The problem in effectively determining what visibility conditions the pilot will encounter lies in the fact that in most cases atmospheric conditions vary markedly according to position and time. These unpredictable variations in the atmospheric transmission and in the position of the aircraft limit the accuracy with which guidance can be predicted For these reasons, it appears that development of equipment which will precisely determine the pilot's slant visual range or height is either impossible or impracticable (TV5)

GPO 897390

Flareout and Landing--- height guidance over the runway to touchdown in night and IFR operations, runway distance remaining information

Turnoff and Taxiing---- anticipatory identification information of high-speed turnoff exits, taxiway route identification for airport ground movement

Takeoff--------------- runway distance remaining information, directional guidance on runway during take-off run in night operations

Total AML System----- a resolution of the apparent conflicts between standardization goals and economic realities and among differing requirements of military, commercial, and civil traffic

Many of the problems identified are the focal points of current research and development For others, analysis has progressed to the point where semi-operational or operational evaluations are in order Still others will require initiation of research and development in order to determine basic facts and data on which solutions can be based An outline identifying the areas in which further work is necessary is presented in the report

Technical discussions and analyses supporting the flight mode functional analysis are attached to the report as Technical Notes A catalogue of marking and lighting literature is presented in a separately bound Appendix In the Appendix, annotations and bibliographies of published materials reviewed during the study are organized in a form easily usable by airport design engineers and research personnel engaged in airport marking and lighting work