Requirements of Threshold Lights

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TABLE OF CONTENTS

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SUMMARY

This report analyzes the functions and conditions of service of threshold lights and considers patterns and characteristics of equipment best adapted to meet the needs of this service A study of the requirements for visibility and conspicuity from the outer segments of the areas to be covered indicates that this part of the function can be performed most practically by assigning it to a special lighting fixture The basic pattern developed during this study consists of closely spaced units forming bars, supplemented by legs extending in along the runway edges

INTRODUCTION

While threshold lighting in aviation performs a vital function in the landing of aircraft, little attention has been paid to the requirements for development of these lights This theoretical study was made as part of a project conducted at the CAA Technical Development Center (TDC) for Wright Air Development Center (WADC) with funds provided by the Department of the Air Force It was designed to analyze the functions of threshold lights and to establish the basic requirements for an effective threshold lighting pattern and design

BASIC REQUIREMENTS

The pattern of threshold lights is required to mark the beginning or end of the landing area. As this essentially is a horizontal line normal to the runway axis, the threshold light pattern basically is a horizontal line normal to the lines of runway lights

Threshold lights have a double function. They must form a pattern which is visible and recognizable from various zones in the approach and from the runway They also must provide sufficient conspicuity, so that they can be picked up easily and recognized amid the adjacent approach, overrun, and runway lights

A study of threshold lighting must include consideration of the line or other pattern, the colors used, the distribution and intensities of light required to provide visibility from all the pertinent zones, and means for providing the essential conspicuity

Pattern

A line of recognizable lights across the approach end of the runway is the obvious pattern for threshold lights Such a line is normal to the adjacent lines of lights and to the path of the aircraft However, there is a serious limitation to such a line Unless it is visible to a pilot for several seconds before he reaches it, he might miss seeing the line altogether if his attention is diverted momentarily This difficulty can be alleviated by modifying the linear threshold pattern to expand the line into a threshold zone which could merge into a landing zone.

Another problem with the line of threshold lights is to develop its maximum definition as distinct from the runway lights A threshold line which extends out beyond the lines of runway lights, forming a T with each line of runway lights, adds materially to the definition

A threshold line, for optimum effectiveness, should extend completely across the end of the runway This would require lighting units which are flush, or nearly flush, and which can withstand the impact of landing wheels Such lights are not now available, and existing patterns of threshold lights include a wide gap in the middle of the line This produces a pair of lines or bars defining the outer ends of a threshold line As a pilot on final approach sees such transverse lines from a direction essentially normal to them and sees foreshortened

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*Reprinted for general distribution from a limited distribution report dated April 1955 lines of runway lights, it is necessary to reduce the spacing of the units in the threshold lines in order to preserve the appearance of coherent lines

The longitudinal location of the line with respect to the runway end is determined by two considerations Enough space should be left to minimize the likelihood of collision with the wheels of landing aircraft and to reduce as much as possible the effect of jet blast on the lighting units At the same time, the threshold bar must be close enough to the paved landing area to prevent aircraft from touching down short of the paving. Experience based on commercial operations indicates that the gap can be as much as 50 feet, but military experience shows that pilots land much closer to the threshold and the maximum gap should not exceed 20 feet.

Color

Long-established aviation practice has standardized the use of aviation green lights for threshold marking and has developed a pilot response to green as marking a threshold There is every reason for continuing this practice, but this makes it important that green lights be used with extreme caution for other airport purposes and that the use of a line of green lights be restricted to this specific function A similar line of green lights has been used in the United States to mark the exit end of the runway This practice is illogical because it introduces a possible source of misinterpretation and confusion Some experimental work has been done with red lights substituted for green at the exit end. This is recognized practice in several parts of Europe but is not standardized in the United States

A pattern of colored satellites added to clear runway lights was developed[1] to mark three runway zones, using green satellites to mark the length of a touchdown zone and red satellites to mark the length of a final or warning zone The intermediate zone was marked only by the clear runway lights The use of green to continue the "safe landing" indication given by the threshold lights is effective and is consistent with the principle of restricting green to mark landings The use of red satellites was similarly effective in marking the warning zone or final section of the runway The marking of this warning zone, however, tended to reduce the effectiveness of red exit lights as marking the extreme end of the safe runway This red line, under certain conditions, tended to appear as a continuation of the red satellite markers The problem here is to emphasize the cross bars by reducing the spacing, thus increasing the conspicuity

Conspicuity

Conspicuity in a light or in a line of lights can be produced by several means One is to make the intensity higher than that of adjacent lights Another means is to give the light a distinguishing color A third is to give the light a periodic change in position or intensity or to cause it to flash on and off

The selection of intensity of a signal light is affected not only by its use but also by weather and visibility conditions Runway lights, threshold lights, and lead-in lighting normally are controllable in intensity to compensate for different degrees of visibility In general, the intensity of a signal light is adjusted to the minimum required for a given visual range under existing weather conditions, but it frequently is set at the maximum which will be tolerated by pilots without complaint If the threshold lights are set at a perceptibly higher intensity than runway and lead-in lights and operated on the same control, there is a serious danger of producing glare when lights are operated at the higher intensity steps

The effect of intensity in producing glare varies markedly with the angle between the line of sight and the direction of the light The smaller this angle and the closer to the fovea that the light appears, the greater the dazzle Runway lights normally are viewed by peripheral vision as the pilot fixes his eyes between the lines As threshold lights extend inward from the lines of runway lights, they appear closer to the line of sight and the dazzle effect is enhanced

Although the intensity distribution of these lights must be adjusted to yield the visual ranges required in each direction, the brightness of adjacent lights sets a level which establishes minimum intensity values for threshold lights For this reason, the intensity of threshold lights, in every direction from which they are required to be visible, must be at least of the same order of intensity as the adjacent lights This will result in an intensity level of not less than one-tenth of the intensity of the runway lights

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[1] Arthur T Tiedemann, "A Lighting Pattern for Runway Zone Identification," CAA Technical Development Report No 208, December 1954

Although conspicuity can be produced by providing sufficient intensity, there are certain limits to practical intensity levels Among these are source limitations, filter limitations, and the necessity of avoiding glare or dazzle An alternate means of securing conspicuity is by means of periodic variations in the appearance of the light such as undulating it or flashing it The periodic change of appearance of the light has the effect of attracting attention and, hence, of increasing conspicuity

It is possible to flash an entire line of threshold lights but this, while increasing conspicuity, makes it more difficult to establish the location of the line, as the observer's eye has nothing on which to fix during the period of eclipse Such a focus of fixation can be provided by undulating the intensity so that the lights never become invisible A simpler and equally effective means has been found in applying the flash to only one or two lights in the pattern and making the others steady-burning This achieves several desirable features It provides steady-burning lights for fixing location, and it simplifies the controls and equipment It also makes it possible to locate the flashing light at the outboard end of the threshold line where high intensity will affect the pilot's vision least when he is close to the threshold

Flashing or undulating signal lights for aviation service must be designed with the conditions of this service in mind The pilot, in making a landing, is moving at about 200 to 300 feet per second The rate of operation of the light must be sufficiently rapid that the pilot can observe several complete cycles during the most critical part of his operation Flashers which operate by turning a lamp on and off must allow sufficient time for the filament to heat up and cool This requires a slow flashing cycle, on the order of 1 to 3 seconds, for the size of lamps employed in threshold work Flashers which operate by shutters or moving optical elements are not subject to this slow rate of flash and have proved more effective

Where more than one flashing unit is included in the threshold pattern, it is important that the flashes be synchronized If the flashes are not synchronized, the lights appear to the observer to be moving from point to point This effect can be very disturbing For this reason, a single flashing light at one end of the line appears more practical than one at each end of the line

Visibility

The zones within which pilots are concerned with the location of threshold lights and from which threshold lights should be made visible include the pathways followed during the downwind leg of the approach and during the final approach after the turn into the wind has been completed The downwind leg zone should include all normal pathways of the various types of aircraft operating on that airport The normal pathway consists of a course parallel to the runway and displaced from it by the diameter of the aircraft's 180° turning operation This displacement distance seldom exceeds 10,000 feet with an altitude of 1,000 to 1,500 feet A zone extending out to 15,000 feet and to an altitude of 2,000 feet above the runway should cover all normal downwind approach patterns

It is recognized that, during this portion of the approach, a pilot is interested primarily in determining the location of the threshold It is not necessary for him to be able to see the threshold pattern if he can see and identify some marker associated unmistakably with the location of the threshold This can be done by means of the flashing lights considered for conspicuity purposes This downwind location information frequently is derived from the runway lights by noticing where the lines of runway lights end Such indication is inherently unreliable because the lines of runway lights are interrupted by intersections and turnoffs, giving indications which can be misleading Secondly, such an indication is negative, as it depends on the absence of a visual indication A positive indication definitely is preferable and more reliable than a negative indication

The zone occupied by aircraft on the downwind leg lies between the horizontal angles of 10° and 135°, or 225° and 350° for the case shown in Fig 1 The altitude may extend up to 2,000 feet above the runway elevation. The zone occupied by the aircraft during the final approach is covered by a horizontal angle of 20°, symmetrical about the approach axis This zone can be considered as extending out into the approach for 10,000 to 15,000 feet and to an altitude of 800 feet above the threshold elevation

Circling approaches are permitted, in general, when visibilities are 1 mile or more and when ceilings are at least 400 feet When visibility conditions are below these minimums, operations are restricted to straight-in approaches These different techniques have different requirements for visual aids, and the visual ranges and angles of the threshold lights must be considered separately for the two conditions

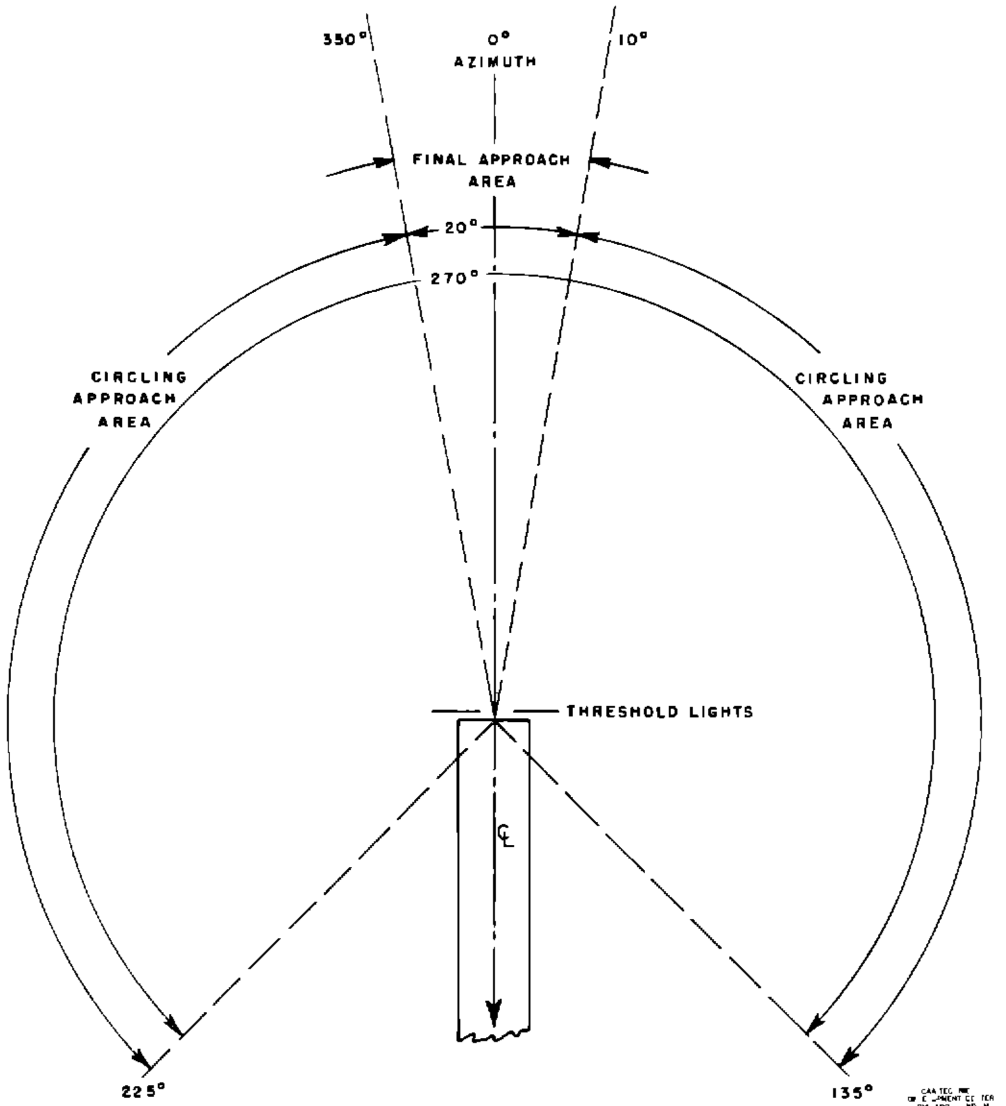

Fig 1 Horizontal Approach Zone Angles

For circling approaches, visibility is required during the downwind leg and from the point where the airplane turns into the final approach leg While the downwind leg normally is flown at altitudes of 1,000 to 2,000 feet, this altitude may be as little as 400 feet when a minimum ceiling exists, and the light distribution must cover this low path The light intensities for the downwind path have to be based on 1-mile meteorological range or better For the final approach, meteorological ranges must be based on the lowest limit for instrument approaches The existing limit is 1/2-mile, and it would be advisable to design for 3/8-mile to allow for a future reduction of this limit The following summary outlines the zones and distances throughout which threshold lights should be visible

Assuming an azimuth of 0° along the runway axis looking outward from the threshold, the lights should be visible throughout these zones

A For circling approaches

1 Lateral coverage, 225° through 0° to 135°
2 Vertical coverage

a On axis, 350° to 10°, up to 800-foot elevation at 10,000-foot distance, or a vertical angle of 4° 34'
b Off axis, 225° to 350° and 10° to 135°, up to 2,000-foot elevation at 15,000-foot distance, or a vertical angle of 7° 35'

3 Visual range of lights, at 1-mile meteorological range

a On axis, 10,000 feet.
b Off axis, 15,000 feet.

B For straight-in approaches

1 Lateral coverage, 350° to 10°
2 Vertical coverage, up to 250-foot elevation at 3,500-foot distance, or 4° 05'
3 Visual range, at 3/8-mile meteorological range, 3,500 feet

The zones set up in the preceding summary are based solely on the desirable coverage, without regard to the practicability of providing the necessary distribution A sampling computation of intensities required in representative directions will indicate the areas where impractical intensities would be required and where modifications must be made

Distribution

The distribution required of the lights to cover the desired zones can be computed from the angular requirements, the visual ranges, and the meteorological ranges listed A sample distribution is given in Table I

TABLE I

INTENSITY REQUIREMENTS

Zone	Distance (feet)	Height (feet)	Vertical Angle (deg -min)	Meteorological Range (miles)	Intensity (candles)
Circling	15,000	2,000	7 - 36	1	4×10^6
Circling	15,000	1,000	3 - 48	1	4×10^6
Final Approach	10,000	800	4 - 34	1	$7\ 8 \times 10^4$
Final Approach	3,500	250	4 - 05	3/8	$4\ 8 \times 10^2$

The intensities required for the 15,000-foot ranges to cover the circling zones, with the wide distribution called for, are beyond the capacity of practical single units Even a reduction in distance to 10,000 feet would require 78,000 candles throughout a solid angle of 270° by 7 1/2° Similarly, the more remote areas of the straight-in zones require distribution not available from existing Air Force Type C-1 units

The rotating light is not subject to the same limitations A beam can be designed to produce high candlepower, and by being rotated about a vertical axis, it can be made to cover any desired horizontal angle If the function of covering the zone occupied by the downwind leg and the more remote portion of the final leg is assigned to a flashing light, the remaining zones which will require fixed light distribution from a threshold unit can be served by a unit with the distribution of the existing Air Force Type C-1 light This is feasible as long as the flashing light is visible and distinctive, as the pilot is relatively unconcerned about the pattern until he approaches the latter part of the final approach A pattern of threshold lights conforming to this requirement is shown in Fig 2 An alternate method would be to use wider angle units for the approach bar and separate units to cover the downwind zone

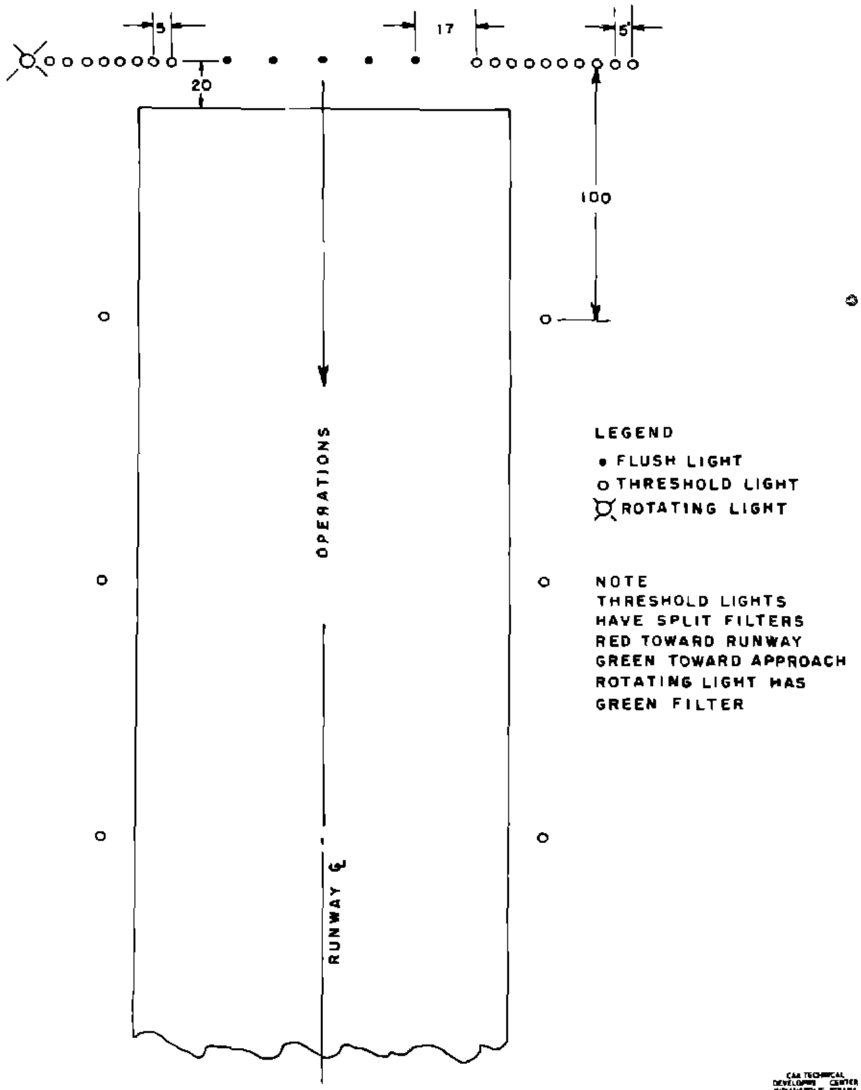

Fig 2 Recommended Pattern for Threshold Lights

CONCLUSIONS

From the study of the basic requirements of a threshold lighting system, it is concluded that the threshold pattern should consist of the following elements

1 Closely spaced green lights forming

a A single continuous crossbar projecting out beyond the runway lights, or
b A pair of lines, leaving a gap on the runway axis and projecting beyond the runway lights

2 Lines of widely spaced green lights set in the lines of runway lights and extending the threshold indication into an area extending well onto the runway

3. A flashing green light or a series of flashing green lights to provide conspicuity and coverage of areas included in the landing operation and not adequately covered by the distribution of the units in the bars

4 Split filters in the bar units and extended legs to present red lights as exit threshold lights.

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