A LIGHTING PATTERN FOR RUNWAY ZONE IDENTIFICATION

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TABLE OF CONTENTS

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FOREWORD

The work described in this report was accomplished by the Technical Development and Evaluation Center of the Civil Aeronautics Administration under U. S Air Force Project No. R656-2115-10 The necessary funds and equipment were supplied by the U. S. Air Force under Purchase Order No. (33-600)-52-4354-E.

All of the experimental systems tested were assembled from components of the standard U S. Air Force portable high-intensity runway lighting system. This served a threefold purpose, viz.,

1. It provided maximum flexibility of experimental systems with a minimum of manhours.
2. It insured that any system recommended would be practicable and capable of immediate production and installation.
3. It provided valuable operating experience with the standard components of the U. S. Air Force system under controlled conditions not available elsewhere.

All installations, tests, and analyses of data were closely supervised by Wright Air Development Center engineers, and all conclusions and recommendations were reached by mutual agreement. The report has been reviewed and is approved for publication.

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SUMMARY

This report describes an investigation of various methods of providing a pilot with visual information for determining his longitudinal position along the runway

The runway zone-marking system which is recommended utilizes additional colored lights located in the section at each end of the runway to define a safe touchdown area on the approach end and a caution area on the far end

INTRODUCTION

When a pilot landing an airplane has passed a certain point in his approach, he must decide whether he will be able to land with sufficient runway length available on which to finish his landing roll safely If this is not possible, he will normally pull up and try another approach In many types of aircraft, a pilot is committed to land very early in his approach If this is the case, he must land and, if necessary, take emergency measures to stop the airplane before it reaches the end of the landable area The pilot of an airplane on take-off is confronted with a similar problem, that is, at some time during his take-off run he must decide whether he will be able to become airborne or whether he must attempt to stop the airplane before it gets to the end of the runway

In order to make sound decisions both on take-off and landing, the pilot must know his longitudinal position along the runway With runways as long as 10,000 feet in use today, it is often impossible for him to see the full length of the runway because of terrain or because of atmospheric conditions Even if conditions are such that the whole runway is visible, the lack of reference scale makes it difficult for him to determine his location with respect to the ends of the runway This is especially true because of the variation in widths of runways

On runways equipped for all-weather instrument operation, markings are sometimes painted on the runway surface to indicate 500-foot intervals along the first and last 2,000-foot lengths These markings serve to indicate to the pilot his position while near the ends of the runway, and they are very effective in daylight even under relatively poor visibility conditions They become obscured by rain, snow, or dirt, however, and often become obliterated by tire scuff marks

There is definite need for a visual aid that will serve at night and under the poorest visibility conditions to supplement the information given by the painted runway markings A runway lighting system, together with the threshold lights at each end of the runway, should tell the pilot quickly and positively whether he is able to land within an area where there is available sufficient runway for landing roll It should also warn him when he is approaching the end of the runway where he must either become airborne or stop quickly In effect a good runway lighting system, in addition to indicating the location and direction of the runway, should define a safe touchdown zone on the approach end of the runway and a warning or caution zone on the far end of the runway

Efforts have been made to provide some of this information by means of quarter- or half-way markers and by yellow warning lights For the latter, it has been standard procedure to use 180° yellow filters in the lights along the last 1500 feet of a runway These are potentially useful in indicating to the pilot that he is approaching the end of the runway They do not mark the section on the approach end of the runway on which it is safe to land This system is also relatively ineffective because of the lack of contrast between the clear runway lights and those with yellow filters This inadequacy of contrast is so great that many pilots have been unaware that such a marking system existed

Recognizing the need for more adequate zone-marking, the Department of the Air Force requested the CAA Technical Development and Evaluation Center to study this problem In addition to the zone-marking investigation, this project also included a study of the desirability of reducing the spacing of runway lights to less than the existing 200-foot standard The experimental system was installed on a comparatively narrow (150-foot) runway, and ground

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and flight observations were made of the various systems Further work was then done to investigate the additional problems arising with wide (300-foot) runways While the studies were conducted with primary emphasis on the problems of military airfields, the results are applicable to civil installations also

THE PROBLEM

The optimum runway and threshold lighting system should

1 Provide positive identification of the runway
2 Outline the runway
3 Distinguish between the touchdown zone, the center or intermediate zone, and the caution or warning zone
4 Provide zone identification information from one line only
5 Define the entrance threshold
6 Define the exit threshold
7 Require a minimum of power
8 Be susceptible to brightness control
9 Be physically compatible with present runway lighting systems

The primary purpose of a runway lighting system is to define the limits of the area on which an airplane can safely operate The system must be such that it is easily identifiable from the air as a runway, and it must also indicate to the pilot the location, direction, and extent of the runway In order to achieve these ends, the lights of a runway lighting system must be of such intensity and spacing that the pilot can see sufficient pairs of lights to identify positively the lines of light outlining the landing area, even in restricted visibility conditions

For reasons already set forth, an effective runway lighting system should provide means for differentiating the touchdown zone, the warning zone, and the intermediate zone Identification should be continuous as the pilot approaches and passes through each zone The lights used to identify the various zones should be as conspicuous as economically possible but should not detract from the effective functioning of the standard lighting system in outlining the runway area

The system used to identify the zones should be applied to both sides of the runway so that information is available from either line of lights It should be bidirectional also so that the runway can be used for operations in either direction

The entrance and exit threshold patterns should be such that a unique indication is provided to mark the beginning and the end of the landable area Since the threshold lights will be viewed from many different angles, the pattern must be kept simple so that erroneous or misleading information is not given The entrance threshold lights should give an easily identifiable demarcation between the approach lights and the runway lights The exit threshold lights, in conjunction with the caution zone-marking lights, should give an emphatic final warning at the end of the runway They should be of a distinctive color and configuration in order to be sufficiently conspicuous among any miscellaneous lights that may be located beyond the end of the runway

Both the basic runway lighting system and the threshold and zone-marking lights should provide the best possible guidance to the pilot at the least operating cost In order to compensate for variations in atmospheric visibility, the system should be controllable as to intensity so that a light sufficiently bright to be seen at an adequate distance during low-visibility conditions will not be extremely glaring during clear weather The use of colored lights introduces special problems when the brightness is controlled by variation of lamp current Not only are the colored lights inherently less bright because of the absorption of the color filters, but the reduction in lamp current reduces the color temperature of the light emitted This produces a variation in the transmissivity of the colored glass at various brightness settings A reduction in light color temperature increases the transmissivity of filters in the red-yellow end of the spectrum and decreases that of filters in the blue-green end of the spectrum

The requirement that a modified runway lighting system should be compatible with present systems includes the use of the same circuits, controls, and equipment This is especially important from a military standpoint for procurement and supply reasons, but it is also advantageous in the case of civil systems

TABLE I

EXPERIMENTAL RUNWAY ZONE-MARKING PATTERNS

Pattern	IN-LINE PATTERNS	Added Lights
1	Current standard system, clear lights uniformly spaced 200 feet	--
2	Clear lights, 200-foot spacing in intermediate zone, 100-foot spacing in end zones	40
3	Clear lights, 200-foot spacing in intermediate zone, alternate clear and colored lights, 100-foot spacing in end zones	40
4	Clear lights, 200-foot spacing in intermediate zone, alternate clear and colored lights, 200-foot spacing in end zones	--
5	Clear lights, 200-foot spacing in intermediate zone, clear lights, grouped spacing in end zones	108**

SATELLITE PATTERNS
(See Fig 1)

	Fig No	Dimensions (Feet) A	B	C	D	
6	1A	10	-	200	200	40
7	1A	5	-	200	200	40
8	1B	5	5	200	200	80
9	1B	5	2	200	200	80
10	1C	10	-	200	200	40
11	1C	5	-	200	200	40
12	1C	5	-	200	400	20
13	1D	5	5	200	200	80
14	1D	5	2	200	200	80
15	1D	5	3	200	200	80
16	1D	5	3	200	400	40
17	1D	5	3	200	500	32
18	1D	5	3	200	600	24**
19	1D	5	3	100*	400	80
20	1D	5	3	100*	500	72
21	1E	5	3	200	400	60
22	1E	5	3	200	600	36**

*100-foot spacing of clear runway lights applies to end zones only
**These figures are based on the use of 1800-foot end zones

PROCEDURE

Two general systems of zone-marking were considered The first system utilized extra lights in line with the regular runway lights This system employs a single line of lights on each side of the runway One pattern of this general type utilized groups of clear lights at varied spacings, this gave a possible advantage of increased guidance resulting from closer spacing of lights and did not have the disadvantage of depending on colored lights In another pattern of this general type, colored lights were alternated with the clear runway lights

In the second general system of zone-marking, additional colored lights called satellites were located adjacent to the regular runway lights on a line perpendicular to the runway centerline Variations in number, location, and spacing of the satellites were tested for effectiveness by groups of observers Some preliminary observations on a pattern of this type had been made at the Landing Aids Experiment Station, Arcata, California, in 1949

As a preliminary investigation of the effectiveness of various zone-marking systems, perspective studies of the patterns were made These were drawn to show what the pilot's view of the runway would be from several different lateral and longitudinal positions at various altitudes

With equipment furnished by the Department of the Air Force, an electrical substation was constructed and a runway lighting system was installed on the North-South runway at Weir Cook Municipal Airport at Indianapolis The lights used in the installation were U S Air Force Type C-1 high-intensity runway lights with 200-watt, 6 6-ampere lamps The cable and the rubber-covered isolating transformers had molded-rubber connectors for easy connection and disconnection of the circuits The cable and the isolating transformers were laid on top of the ground, and the lights were mounted on cone bases so that they could be relocated without difficulty Clear lights were located at 100-foot spacing with a double circuiting arrangement, so that either 100- or 200-foot spacing could be used A third circuit consisted of bicolored lights These lights were Type C-1 runway lights with 180° color filters so arranged that the colored lights in the touchdown zone appeared green and those in the caution zone appeared red

Table I lists the 22 patterns studied in this evaluation The current Air Force standard configuration, which was used for comparison, is included as pattern No 1, this pattern provides no zone identification Four of the patterns used extra lights in line with the rows of runway lights One of these patterns, No 2 consisted merely of 100-foot spacing of clear lights in the end zones and the normal 200-foot spacing in the intermediate zone In pattern No 3, the alternate 100-foot spaced lights in the end zones were colored Pattern No 4 was similar to No 3 except that 200-foot spacing was maintained for the entire length of the runway Grouped lights were used in pattern No 5, these were located and shielded so that lights in groups of threes were located in the touchdown zone and in groups of twos in the warning zone

Colored satellites were used in the other 17 patterns Figure 1 shows the relative location of these satellites with respect to the clear runway lights Table I lists the patterns observed and the dimensions applying to Fig 1 This table also lists the extra lights needed for the installation of each pattern in 2000-foot zones on the ends of the runway If a 10,000-foot runway is being considered, these figures also give the approximate percentage of extra lights needed

Extensive ground and flight observations of all patterns were made Many of the later patterns resulted from suggestions made by observers after viewing the earlier patterns The principal criteria used by observers to judge the value of the various systems were, the ability of the patterns to indicate the zones, the lack of misleading guidance at various angles of view, and the procurement and operating economics of the systems

Successive observations were made to compare the various patterns Some of these were eliminated after ground observations indicated that they gave misleading or inadequate information After preliminary observations were made, the remaining patterns were further evaluated by flight observations When the most satisfactory pattern was determined, an information sheet describing the pattern and its purpose was distributed to interested agencies Visiting U S Air Force and U S Navy pilots and TDEC pilots who observed the system were requested to fill out a carefully prepared questionnaire and to comment on the system in an effort to gather a cross-section of opinion The information sheet and the questionnaire are shown in the Appendix

As a supplementary study to the runway zone-marking problem, observations were made to determine the increased guidance afforded by shorter spacing of runway lights under low-visibility conditions To simulate these conditions, the threshold lights on one end of the runway

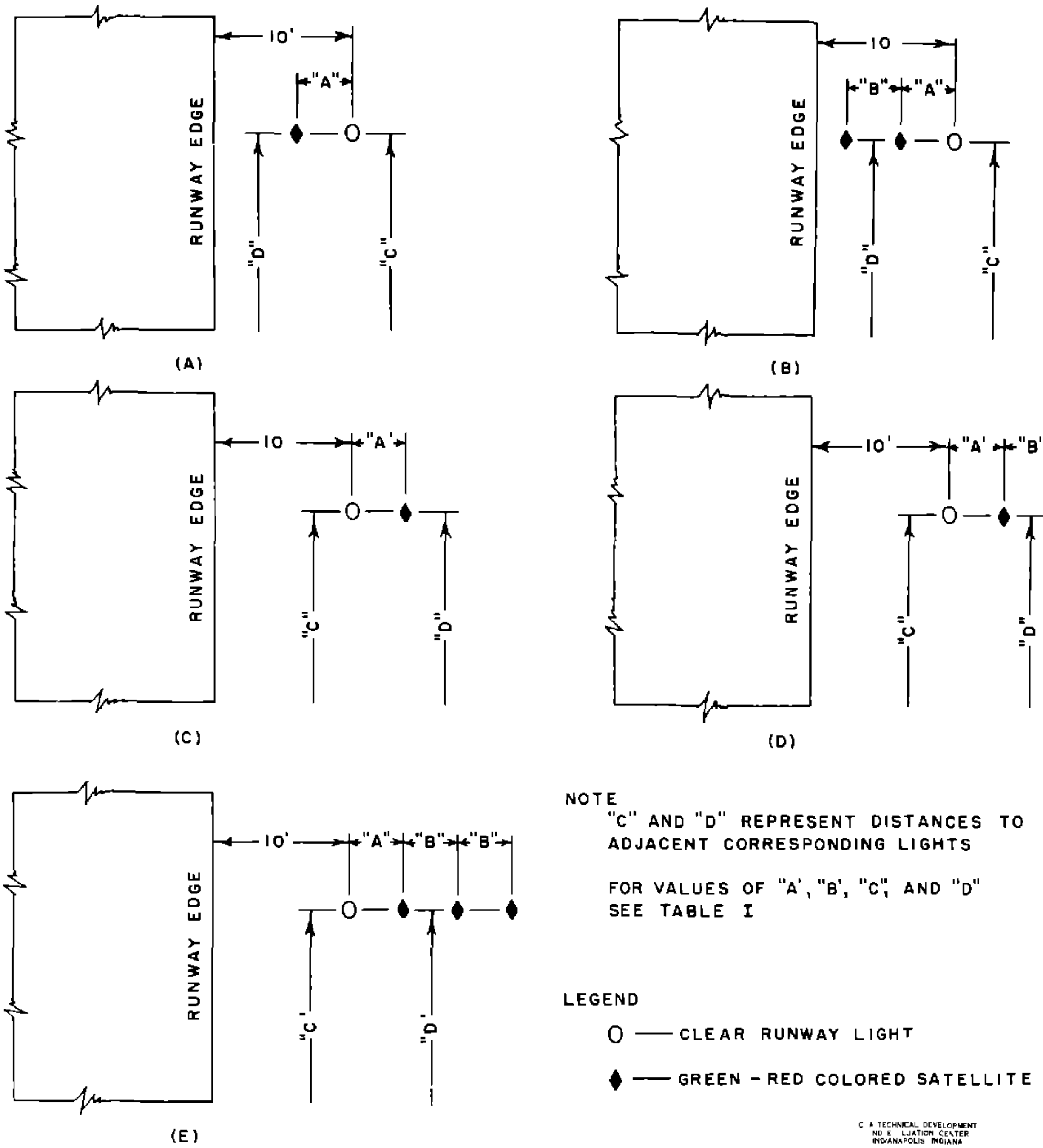

Fig 1 Satellite Zone-Marking Patterns

were disconnected Observers were stationed on the runway a few hundred feet from, and facing, the threshold This simulated the visual limits imposed by very poor visibility conditions, that is, with only two or three pairs of runway lights visible The extra lights necessary to decrease the runway-light spacing to 100 feet were then turned on, and the observers judged whether the increased number of lights in the same distance more accurately indicated the position and direction of the runway

DISCUSSION OF RESULTS

With the exception of one in-line system, all the patterns were simple additions to the present standard runway-lighting system Therefore, they satisfied the requirements of providing positive identification of the runway and of outlining the runway Since all the patterns were applied to both sides of a runway, they all provided the necessary information from one line only All patterns used standard U S Air Force equipment and thus were completely compatible with present systems The major criteria, therefore, on which the patterns were judged were (1) the adequacy of zone-marking guidance and (2) economic considerations

About 200 ground observations and 500 flight observations were made on the various patterns From these observations, it was found that the in-line patterns, Nos 2, 3, 4, and 5, did not provide as good an indication of the limits of the zones as did the satellite patterns The pattern, No 2, with clear lights at 100-foot spacing in the end zones and 200-foot spacing in the intermediate zone did not provide a satisfactory line of demarcation between the zones Therefore, this pattern was not considered usable, although it was somewhat more susceptible to brightness control because it used no colored lights The two in-line patterns, Nos 3 and 4, using alternate clear and colored lights in the end zones were superior to the similar pattern with no colored lights, but they did not provide as good a signal as the satellite patterns Pattern No 4 with alternate clear and colored lights at 200-foot spacing was also somewhat inferior under the runway identification and outline criteria, since the clear lights were located 400 feet apart

It was found from the perspective studies that a pattern, No 5, utilizing longitudinally grouped lights would not be very effective unless the spacing between the lights in a group was very small compared to the spacing between groups

In all the patterns using colored lights, the clear lights were somewhat more conspicuous than the colored lights when all circuit controls were adjusted to the same brightness setting

In general, satellites located outside the line of runway lights were much more effective than those located between the runway edge and the clear lights, because those inside the row of runway lights tended to merge into and become lost in the line of clear lights This eliminated further work on configurations of the type shown in Figs 1A and 1B, patterns Nos 6, 7, 8, and 9

The use of satellites in pairs instead of singly greatly increased their effectiveness, but three satellites in a group were not materially superior to two Therefore, single and triple satellite patterns, Nos 10, 11, 12, 21, and 22,outside the row of runway lights were eliminated, and the work was concentrated on the double satellite pattern located outside the row of runway lights, as shown in Fig 1D

It was necessary to keep the nearer satellite not more than five feet from the adjacent clear light in order to form a recognizable pattern If this spacing was less than five feet, the satellite tended to become obscured by the higher brightness of the clear light Where multiple satellites were used, a spacing of three feet between them appeared to be optimum At this spacing, the multiple units tended to give the satellites configuration as well as a color distinctiveness Patterns Nos 15 through 20 are examples of this type

It was found unnecessary to space the satellites less than 400 feet along the runway in order to provide continuous information to the pilot One pattern was observed during a thick daylight fog when the object visibility distance was only 600 feet With the lights operating at the highest brightness, both the clear lights and red satellites were visible for about 900 feet Thus, even in the worst weather conditions, at least two pairs of satellites spaced 400 feet apart along the runway should be visible from within the end zones Patterns with satellites spaced less than 400 feet (No 15) were thus somewhat superior but were considered uneconomical Patterns with satellite spacing as much as 600 feet (No 18) did not provide adequate guidance

The use of 500-foot spacing of satellites (patterns Nos 17 and 20) was investigated because the painted runway markings are spaced 500 feet apart in the end zones However, with the runway lights on 200-foot spacing, some of the satellites were adjacent to clear lights and some were not This presented a confusing pattern When the runway-light spacing was decreased to 100 feet, the 500-foot spacing of satellites was nearly as effective as 400-foot spacing

Table I lists the extra lights necessary for installation of the various patterns None of the patterns that used less than 40 additional lights to mark the zones were considered adequate Although some of the patterns that used as many as 80 extra lights were slightly superior, the advantages gained by the use of more than two satellites in a group or by locating the satellites at less than 400-foot spacing were not considered sufficient to justify the additional cost of these patterns

Of the patterns using 40 extra lights, the one shown in Fig 2, pattern No 16 in Table I, was considered optimum This pattern was kept in operation for three months, and visiting pilots were invited to observe and comment on the system

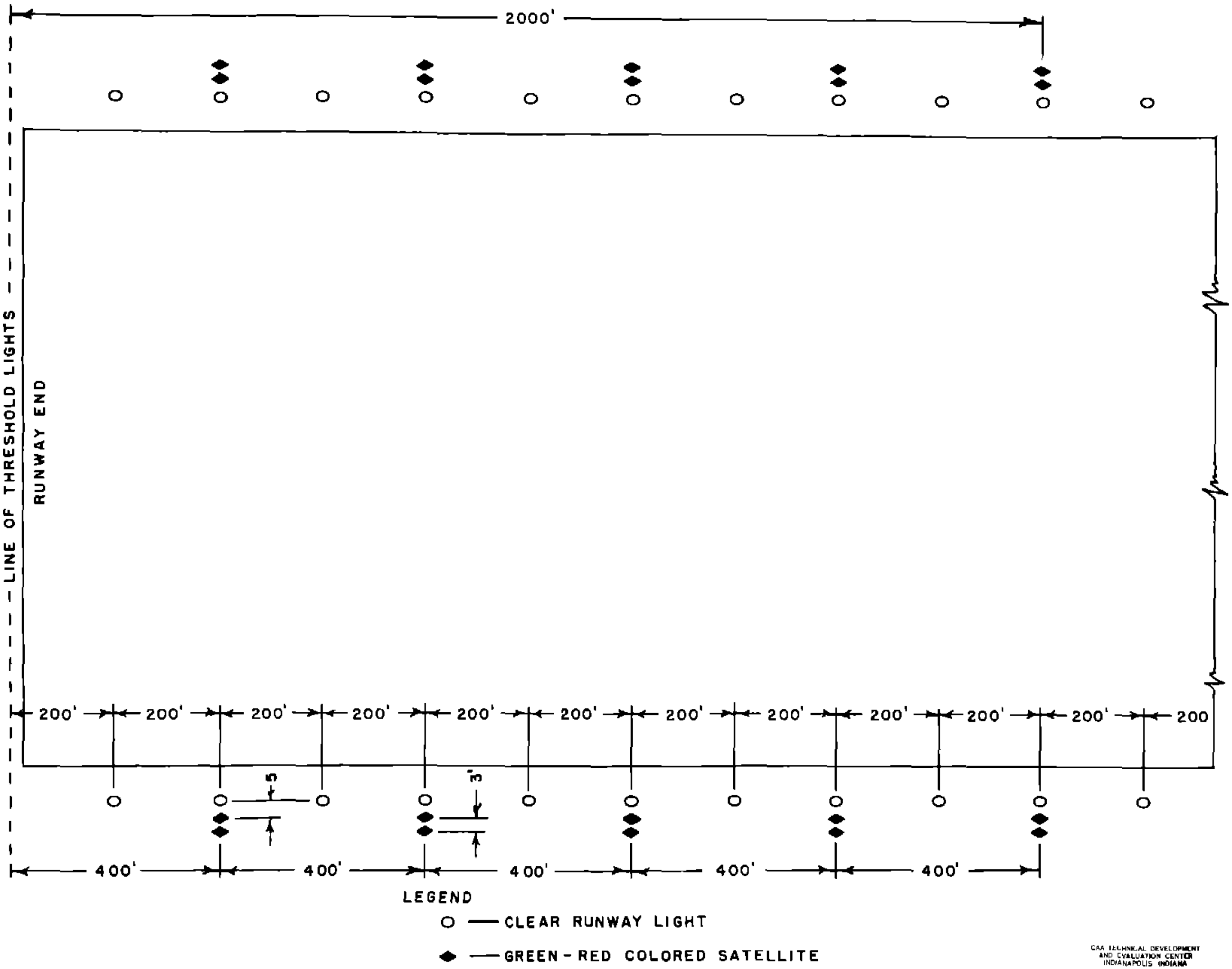

Fig 2 Recommended Zone-Marking Pattern Applied to Standard Runway Lighting System

Twenty-nine completed questionnaires were returned by the U S Air Force, U S Navy, and TDEC pilots who had observed the zone-marking installation A summary of these answers follows

Question 1 "Did you see the green satellites?"

Yes 28 No 0 No Answer 1

Question 2 "Did you see the red satellites?"

Yes 27 No 1 No Answer 1

Question 3 "If landing, in which zone did you touch down?"

Question 4 "If taking off, in which zone did you become airborne?"

Questions 3 and 4 were designed to determine whether the pilots understood the purpose of the system and whether they could use the system to determine their position along the runway Eight pilots answered that they only made low passes and had neither landed nor taken off Two pilots did not answer these questions, and one pilot said that he did not know his position Incidentally, this pilot was the same one who did not see the red satellites, his comments indicate that he did not know the purpose of the system at the time of observation Also, he did not answer question No 8 The other observing pilots who gave answers to questions 3 and 4 indicated that they knew their position at the time of touchdown or take-off

Question 5 "Do you object to colored lights along the runway?"

Yes 0 No 28 No Answer 1

Question 6 "Would you prefer red exit threshold lights?"

Yes 8 No 16 No Answer 5

This question was designed to determine whether the red satellites in the caution zone and the green exit-threshold lights at the end of this zone would give a confusing signal However, most of the pilots seemed to prefer the green lights for exit as well as for entrance thresholds

Question 8 "Is the advantage gained by this pattern sufficient to justify a recommendation for its adoption as a standard?"

Yes 15 No 5 No Answer 9

Most of the replies to these questions indicated that the observers favored the adoption of the system Also, four of the five who answered question 8 in the negative indicated that they felt that the system would be of more value if present weather-minimum restrictions were lower

The observations described were all conducted on a comparatively short (4,600-foot) and narrow (150-foot) runway Under these conditions the Type C-1 runway light with colored filters served adequately as the satellite Further observations on a 300-foot runway showed that the selected zone-marking pattern was entirely satisfactory The beam width of the Type C-1 light was not as great as desired but was usable For civil systems where the procurement and supply problems are not as acute, satellite units could be designed that would be somewhat more effective and efficient than the Type C-1 light

It was determined from limited ground observations that the location of lights at 100-foot spacing instead of the normal 200-foot spacing on the approach end of a runway should materially increase the guidance given to the approaching pilot during limited-visibility conditions If a pilot were able to see six pairs of lights instead of only three, even though the distance to the last visible light were the same, he would be better able to determine the position and direction of his airplane with respect to the runway Under visual-flight-rule (VFR) conditons, however, the closer spacing is not necessary, and a few of the pilots who observed this system under these conditions expressed a preference for the normal spacing The recommended zone-marking pattern can be applied to either normal or short-spaced runway-light systems with no variation If the reduced spacing is applied to the approach end of a runway, the point where the spacing changes is not readily apparent to an incoming pilot

CONCLUSIONS

The results of the study of runway zone-marking systems show that the desired indications can be obtained from a simple addition to the present standard runway lighting system The pattern recommended, No 16 in Table I and shown in Fig 2, fulfills the necessary requirements adequately and can be used on both narrow and wide runways A large majority of the pilots who observed the system gave favorable comments on the guidance afforded by the recommended pattern

For military installations, where it is highly desirable to standardize and simplify the equipment for reasons of procurement and supply, the Type C-1 runway light with a red- and green-color filter can be used as the satellite Although the width of the beam of this light is not sufficient to cover the complete width of wide runways under the worst visibility conditions, it will cover enough of the runway so that at least one line of lights is visible from any lateral position

For use at civil installations, equally effective satellite units could be designed that would be cheaper and more efficient than a standard runway lighting unit

Observations of runway lights on 100-foot spacing, as compared to the normal 200-foot spacing, indicated that the shorter spacing would give increased guidance under poor-visibility conditions It is recommended that 100-foot spacing be adopted where there are frequent periods of extremely restricted visibility The recommended zone-marking pattern will serve equally well with either 100- or 200-foot spacing of runway lights

APPENDIX

The following description of the project and of the recommended zone-marking pattern was distributed to interested civil and military agencies Included with this sheet was a sketch, similar to Fig 2 of this report, showing the system as it was installed at Indianapolis Visiting military pilots and pilots attached to the Technical Development and Evaluation Center were requested to fill out the questionnaire after observing the system

EXPERIMENTAL RUNWAY LIGHT PATTERN

"Present standard runway lighting systems make no attempt to indicate to the pilot his longitudinal position along the runway If weather conditions are such that he cannot see the entire length of the runway he has little or no idea whether he has plenty of runway ahead of him or whether he must take drastic measures to stop the plane or get it off the ground The yellow filters which have been used in the past to mark the last section (caution zone) of a runway near the exit threshold were found to be unsatisfactory because they were seldom noticed by the pilots Also no effort was made to mark the first section of a runway (touchdown zone) just inside the threshold lights The lack of touchdown- and caution-zone identification has been a contributing factor to many accidents

"In view of the above, the Lighting Section, Equipment Laboratory, WADC, USAF, has transferred funds and standard portable runway-light equipment to the Technical Development and Evaluation Center, CAA, in order to establish a joint project for the development of a standard lighting system for identifying the zones

"The system must meet the following major requirements

(1) Must provide positive short-range identification of touchdown and caution zones It is considered that long-range identification is not required and that the pattern can be effective in bad weather for as far as the runway lights can be seen

(2) Must not interfere with the performance of, or appreciably alter the appearance of, the standard runway lights

(3) Should be a simple addition to an existing system so that a major change of circuits or equipment would not be required

"Many suggested methods have been investigated during this project Ground and flight observations have shown that the system on the attached sketch will do the job well, this system combines distinctiveness of pattern with color to identify the touchdown and caution zones This pattern employs pairs of colored runway lights, called satellites, on 400-foot centers These satellites are in addition to the standard clear runway lights The satellite colors are green to mark the touchdown zone and red to mark the warning zone The satellites are intended to provide continuous zone identification without interfering with the continuity of the lines of the runway lights The installation is bidirectional with split-color filters being used in the satellites as shown on the accompanying sketch Runway 18-36 of the Weir Cook Airport at Indianapolis has been equipped with this system Because of the limited length of the runway, the touchdown and warning zone lengths are established at 1600 feet, but the pattern is readily applicable to mark 2000-foot zones

"The installation is set up for ready control from the control tower and can be observed by radio request Since the opinions of pilots viewing any new pattern are the ultimate measure of its value, it is hoped that as many pilots as possible will examine this pattern and will leave their comments and suggestions

GENERAL INFORMATION

Date
Time of observation
Type of airplane·

RUNWAY LIGHTS

1 Did you see the green satellites?
2 Did you see the red satellites?
3 If landing, in which zone did you touch down?
4 If taking off, in which zone did you become airborne?
5 Do you object to colored lights along the runway?
6 Would you prefer red exit threshold lights?
7 COMMENTS

8 Is the advantage gained by this pattern sufficient to justify a recommendation for its adoption as a standard?"

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