A Preliminary Evaluation of Narrow-Gauge Runway Lighting and Runway Surface Illumination

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A PRELIMINARY EVALUATION OF NARROW-GAUGE RUNWAY LIGHTING AND RUNWAY SURFACE ILLUMINATION*

SUMMARY

A preliminary flight evaluation of the narrow-gauge lighting concept was accomplished through use of mock-up lighting units set in various patterns on a concrete runway 150 feet wide, which was served by conventional radio and visual aids. Runway identification and directional and roll guidance were improved by the narrow-gauge lights, providing the aircraft was on the runway centerline, but height guidance for flare and touchdown was inadequate. Runway floodlighting, using a continuous strip of fluorescent units mounted close to the surface along each edge of the runway, was installed to provide low-level pavement illumination in the touchdown area This was effective in providing height sensitivity, and in supplying additional runway identification and directional and roll guidance The optimum system for operation under the lowest visibility nighttime conditions may combine runway illumination for touchdown with a simplified narrow-gauge or centerline pattern for supplementary guidance during takeoff and landing roll-out

INTRODUCTION

Increasing use of high-intensity, centerline approach-light systems for low-visibility landing operations, with the pilot descending directly over and increasingly close to a pattern of high-intensity light sources as he approaches the runway threshold, has improved his guidance up to the threshold point, but has only accentuated the need for comparable improvements in the runway lighting system which lies ahead The effect has been described as that of descending into a black hole, with inadequate directional guidance, very little roll guidance, and inadequate height sensitivity for controlling flare and touchdown The situation is not so critical during daylight operations when the runway texture and markings normally are visible in the last stages of the landing operation, even during heavy fog In clear or moderate visibility conditions, the pilot can get some indication of runway texture during night landings by using his landing lights to illuminate the runway surface and markings. In heavy ground fog, however, the landing lights illuminate the fog particles rather than the pavement, and guidance is lost

The general problem has been discussed by Jenks,[1] Cutrell,[2] and others, and a system of narrow-gauge lighting, supplementary to the usual lights along the runway edges, has been proposed as a solution to the problem The proposed narrow-gauge system consists essentially of two rows of light bars composed of three light units each. The two rows would be centered about the runway centerline and extend for a distance of 3,000 feet from the approach threshold. Similar bars would be placed on the runway centerline at 500-foot spacing A longitudinal spacing of 100 feet for narrow-gauge bars has been generally recommended, and the gauge width most frequently suggested is 60 feet between the innermost lights or 75 feet between the centers of 15-foot bars This is independent of runway width. Figure 1 shows a partial layout of the proposed system. It has been assumed that the pairs of horizontal bars will provide roll guidance, the narrowed gauge between rows will sharpen directional guidance, and the pattern of lights within the runway surface will enable the pilot to determine the elevation of the "landing mat" for sensitive height guidance at touchdown

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*Manuscript submitted for publication January 1958.

[1] Arthur E. Jenks, "The Black Hole," The Air Line Pilot, April 1956

[2] E A Cuttrell, "Runway Lighting for Low Visibility," The Air Line Pilot, January 1957.

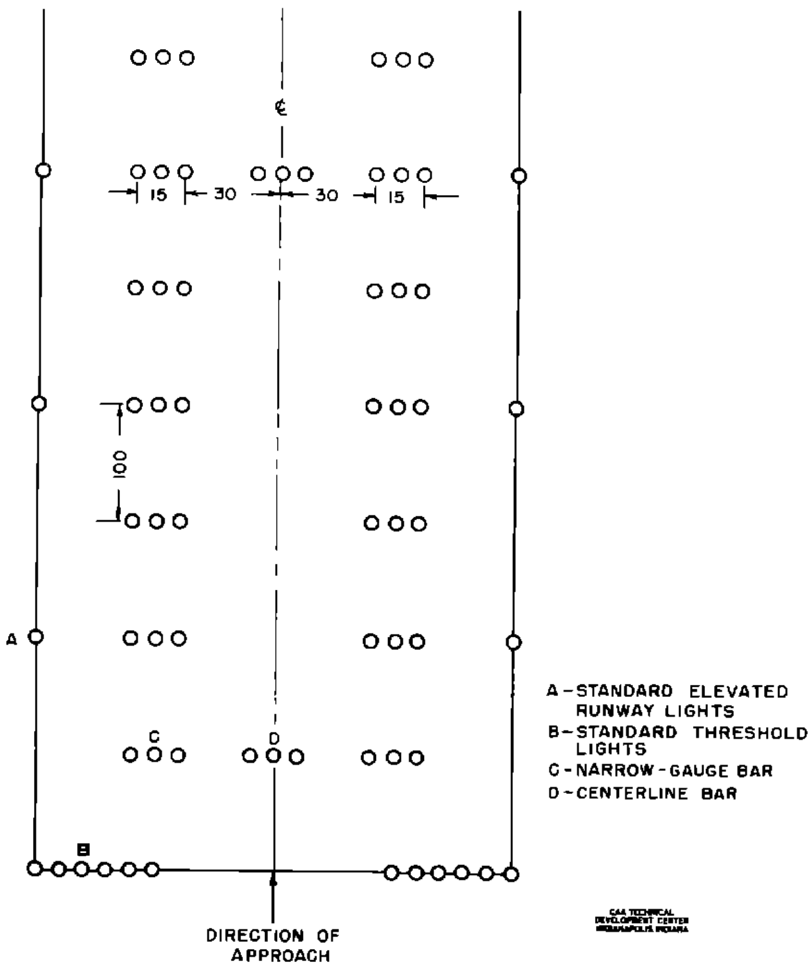

Fig 1 Proposed Narrow-Gauge Runway Lighting

A proposal of this kind, which involves the installation and maintenance of hundreds of high-intensity lighting units within the runway surface itself, immediately raises serious engineering and economic problems With the increasing emphasis on pavement smoothness in the operation of large high-speed aircraft, there also may be a pertinent safety factor involved as there is not available at this time any truly flush lighting unit. Theoretical studies indicated that the sharp lateral cutoff and low-angle cutoff of available semiflush lights might be an important limitation also, even if the narrow-gauge configuration itself was found to be effective

In view of the above considerations, a project for flight evaluation of the narrow-gauge runway lighting configuration was undertaken by the Technical Development Center (TDC) The primary objectives of the project were (1) to provide information on the usefulness of the narrow-gauge system in supplying the missing elements of pilot guidance for low-visibility landings, (2) to determine values of gauge width, longitudinal spacing, bar length, beam spread, and toe-in of the lights for optimum efficiency and economy, and (3) to provide a demonstration facility for flight observation After initiation of the project, its scope was broadened to include some preliminary study of other runway lighting aids, with particular emphasis on developing surface texture by low-level illumination of the runway surface

In an investigation of this kind, in which a major variable is the psychological reaction of the pilot to certain visual stimuli, it is impossible to obtain enough mass data in an abbreviated project for analysis by statistical methods. This report, therefore, simply outlines the nature and extent of the individual investigations and presents the conclusions and recommendations of the group of Civil Aeronautics Administration (CAA) pilots and observers who were most active in the flight program

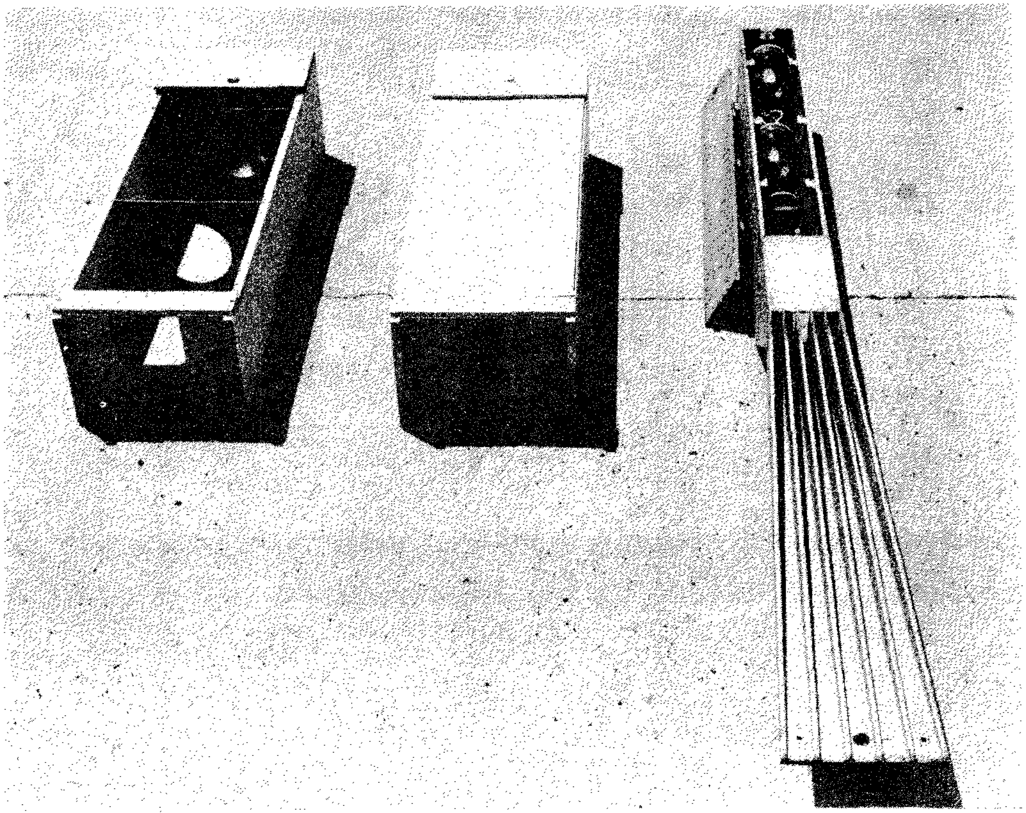

Fig. 2 Mock-Up Lighting Units and an Elfaka Fixture

TEST FACILITIES AND PROCEDURES

Through cooperation of the U. S. Air Force, Runway 10-28 at Andrews Air Force Base (AFB), Maryland, was made available for these tests. The Air Force also furnished electric power, cable, and some of the major items of electrical and lighting equipment. In addition to the experimental narrow-gauge lights and floodlights in the test installation, the runway was served by an instrument landing system (ILS), a standard configuration-A approach-light system with sequenced flashers, and a standard pattern of military Type C-1 runway edge lights. Five intensity control steps were provided.

Equipment was installed for instrument approach from the east. Aircraft on test flights were in radio communication with the Andrews tower, the Andrews RAPCON, and the CAA technician who monitored and controlled the test equipment.

It was a major problem to provide all of the desired lighting patterns on the runway surface and still maintain a reasonable degree of safety during low approaches and actual touchdowns under low-visibility conditions. The installation of flush or semiflush lighting units in the runway pavement was considered out of the question because of cost, inflexibility, time limitations, and structural damage to the runway pavement. It was decided, therefore, to utilize comparatively lightweight, cheap, frangible mock-up units which could be arranged on the runway surface in any desired pattern and which would offer a minimum resistance if struck by an airplane. Sample units are shown in Fig. 2, together with an Elfaka fixture of the general type proposed for narrow-gauge use and used in a portion of the test program. Sufficient units were built and power circuits provided for concurrent installation and operation of two narrow-gauge configurations. Cutouts were installed to permit quick changes in longitudinal spacing in any desired multiple of 100 feet.

The proposed centerline bars at 500-feet intervals (D, Fig. 1) were left out, thus providing a minimum clear space of 60 feet for all operations. This was done for safety reasons inasmuch as the centerline units were not considered vital to evaluation of the narrow-gauge concept itself.

The lamp used in the mock-up units was designed originally for approach lighting. It has a vertical beam spread of 7.5° (to 10 per cent of maximum), a horizontal beam spread of 36.5°, and a peak intensity of about 45,000 candles. By using two different lamp positions and three different baffle combinations, it was possible to obtain light distributions as shown in Table I.

TABLE I

LIGHT DISTRIBUTION OF MOCK-UP UNITS

Description	Beam Width (deg.)	Vertical Spread (deg.)	Maximum Intensity (candles)
Narrow-Beam	8.2	0.2 to 11.4	38,000
Medium-Beam	13.8	2.5 to 9.4	36,800
Wide-Beam	25.2	2.5 to 9.4	36,800

The narrow-beam distribution was intended to approximate that of an Elfaka Type B light manufactured by Structural Concrete Products Corp. The medium-beam horizontal distribution represented the minimum required for continuous visibility during a well-centered approach, as determined by theoretical computation. Assumed conditions were that the lights should be visible during a correctional maneuver from a lateral displacement of 100 feet at the middle marker to 15 feet at touchdown. The wide-beam horizontal distribution was computed as the maximum required for a 250-foot displacement at the middle marker. The vertical distribution of the medium- and wide-beam units was not equal to that of the narrow-beam unit and was not considered theoretically adequate for all airplanes or for all maneuvering conditions, but was the best that could be obtained readily with the equipment available.

Relatively few daylight flights were scheduled as the basic problem is primarily one of better guidance under nighttime low-visibility conditions. Traffic coordination of the test flights with normal operations at Washington National Airport (WNA) and Andrews AFB was a major problem except under the lowest visibility conditions when regular operations were cancelled. Most flights were scheduled in the late nighttime periods when other traffic was at a minimum. Low-visibility weather conditions were utilized to the fullest possible extent, but it also was possible to utilize fair-weather flights in obtaining comparative observations of certain test variables. Even in good weather the problem of height guidance could be simulated to some extent by keeping the light intensities low and by not using the aircraft landing lights.

A motion-picture camera mounted adjacent to the head of the copilot provided a permanent record of the appearance of the lighting system on most approaches. While the camera could not cover as great a field nor keep the lighting configuration as well centered as the pilots could do by moving their heads, it did provide a reasonably realistic view except in extreme correctional maneuvers. Motion pictures also were taken from the top of a crash truck driven slowly along the runway centerline, thus providing a more leisurely view of the configurations from a viewing height of about 17 feet. Still photographs were taken from the same vantage point with the camera at various lateral positions across the runway.

In addition to the CAA testing program described above, the military establishments, the airlines, and other industry representatives were invited to participate in the flight program and evaluation to the fullest possible extent. Participating pilots and observers were briefed prior to flight as to the facilities available for guidance, and were encouraged to file written reports and comments on their observations.

DISCUSSION OF FLIGHT TEST RESULTS

At the start of the test program, two narrow-gauge configurations were placed in service. One had an inner gauge width of 60 feet, representing the minimum width proposed, the other was 90 feet wide, intended as a maximum. Figure 3 is a photographic view of the mock-up lights in place on the runway. The two patterns were test flown alternately, using longitudinal bar spacings of both 100 and 200 feet.

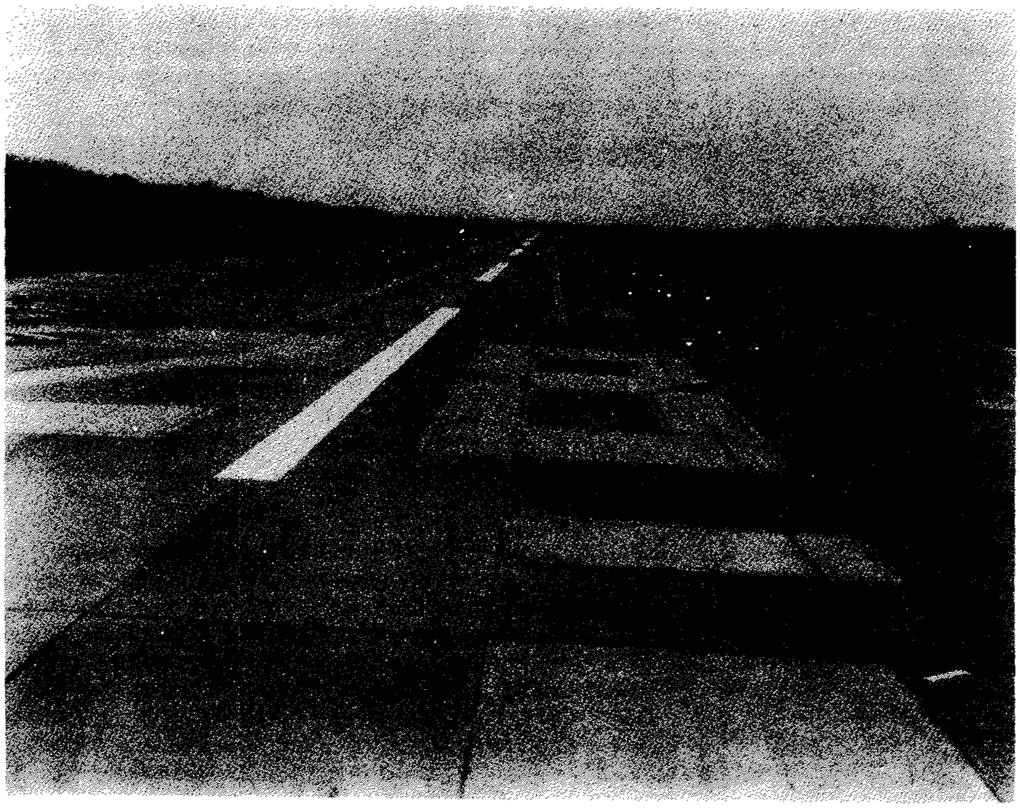

Fig. 3 General View of Mock-Up Units in Place on Test Runway

The narrow-beam mock-up lighting units were used in both configurations. All units were aligned so that the center of each light beam intersected the centerline of the runway about 430 feet ahead of the light position. The resulting toe-in varied from 4° for the innermost lights of the 60-foot gauge to 8° for the outermost lights of the 90-foot gauge.

It soon became apparent that the narrow-beam light was inadequate in lateral coverage. Even on well-centered approaches there was a disconcerting change in brightness and apparent size of the light source as the observer's eye passed through the light beam. Comparatively small lateral deviations in airplane position during approach and touchdown caused the pilot to view an uneven pattern. Larger deviations obliterated the lights entirely on the near side of the runway except for a dim glow visible only in clear weather. Some of the lights on the far side of the runway still were visible but did not present a recognizable pattern for corrective guidance. This effect is shown in Fig. 4. The vertical range of the light beam was adequate for all maneuvers.

If the airplane was well centered, a sufficient number of lights were visible to form a recognizable pattern. This pattern was effective in sharpening directional guidance and also was helpful in maintaining airplane attitude during the flare and touchdown. The 60-foot gauge was the more effective of the two gauges studied, particularly for directional guidance.

The bar effect of the triple narrow-gauge units was effective in providing roll guidance as long as the airplane was well centered. When displaced laterally, the bar effect from lights on the opposite side of the runway was lost and view of lights on the near side was obliterated entirely, as previously noted. The undesirable "orchard effect" which appeared when the light patterns were viewed obliquely was lessened somewhat by use of 200-foot longitudinal spacing. No attempt was made to go beyond this spacing as this would not permit viewing a sufficient number of bars for guidance during the lower visibilities.

Moisture on the windshield, either from fog or from precipitation, created special problems. In some instances the distortion was sufficient to destroy the bar effect of the closely spaced lights.

Height guidance from the narrow-gauge pattern was disappointing. Although the "black hole" between the light rows was reduced in width, it still existed and even was

NIGHT VIEW

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DAY VIEW

Fig. 4 Effect of Narrow-Beam Cutoff. Sixty-Foot Gauge Viewed from 60 Feet to Right of Runway Centerline.

accentuated by the contrast to the comparatively bright narrow-gauge light sources immediately adjacent to it. Many approaches were carried to actual touchdown, but the pilots still were "feeling" for the runway surface and had no definite indication of height above the runway. It should be emphasized, perhaps, that this situation existed only when ground fog or other atmospheric conditions prevented effective use of landing lights, or when such

Fig. 5 Reflected Light from Elfaka Fixtures. Standard Model in Center; Other Two Units Coated with Aluminum Paint.

conditions were simulated by not using the landing lights under better visibility conditions. Height guidance was no particular problem as long as runway texture was visible. This was demonstrated by test flights in daytime fog.

The next phase of the evaluation program was to determine whether or not the narrow-beam mock-up units were at least as effective as the Elfaka production units which they were intended to simulate. The first 30 mock-up units (500 feet of runway length) in the 60-foot configuration were removed and replaced with Type B Elfaka units, and the next 30 units were replaced by Type A Elfaka units. These units were placed on the runway surface and were leveled and aligned to correspond to the mock-up units which they replaced. Alignment and vertical setting of the lamps in the fixtures were checked by a representative of the manufacturer.

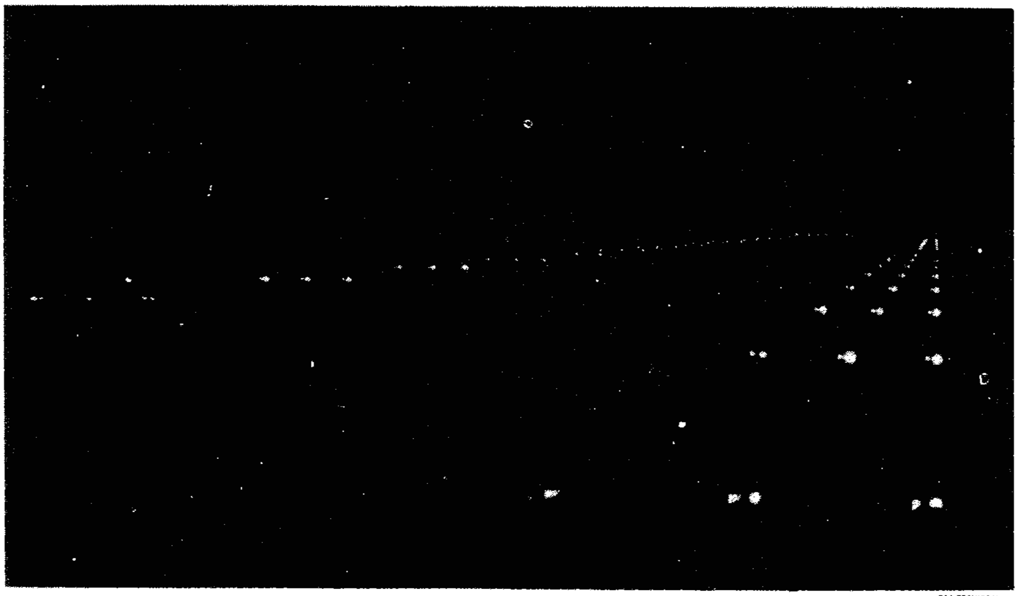
Visual observations and pictures taken both from ground positions and from an airplane during landing maneuvers revealed a very close similarity between the mock-ups and the Elfaka lighting units. Actually, the light distribution of the mock-up units was slightly wider, both laterally and vertically, than that of the Type B (two-lamp) production unit. This fact was shown by the photometric tests conducted at TDC and also is detectable by close examination of some of the field photographs. Practically, the units can be considered equal as signal lights.

There was one point of difference between the mock-ups and the standard Elfaka fixtures which might be considered of possible significance operationally. This was the illumination of the grid opening of the Elfaka unit by the enclosed light source. Figure 5 is a close-up view of this effect on a new standard production unit and on two units which had been coated with aluminum paint by the manufacturer's representative in order to enhance their reflectance. This effect appeared to be lost to the pilots during execution of approaches and landings, even during clear weather. This may be explained by the fact that the attention of the pilots naturally was diverted to the much brighter light sources within their visual fields. This suggests the possibility that effective use of low-level runway illumination as a landing aid, as discussed later in this report, may depend upon the elimination of high-intensity sources from the immediate field of view. This requires further study.

The single-lamp Type A Elfaka units have a vertical beam cutoff of about 4° which proved insufficient for use so near to the approach end of the runway. At a cockpit height of 20 feet, this results in cutting off view of all lights 300 feet or less from the airplane; at a height of 50 feet, the cutoff is 700 feet ahead of the airplane.

During the time that the 60-foot narrow-gauge configuration was being used for comparison of the Elfaka and the narrow-beam mock-up units, the lights in the 90-foot configuration were changed, first to the medium-beam and then to the wide-beam light distribution. The improvement in cutoff was very marked. The medium-beam units were satisfactory for reasonably well-centered approaches and the wide-beam units were adequate for any approach from which a successful landing could be made. Figure 6 illustrates the improved lateral coverage obtainable with the wide-angle lights.

NARROW BEAM



WIDE BEAM

Fig. 6 Comparison of Narrow-Beam and Wide-Beam Lights. Ninety-Foot Gauge Viewed from 60 Feet to Right.

Next, a study was made to determine the proper toe-in angle for the narrow-gauge units. As previously noted, the three units in each bar of the 60-foot gauge were first set at toe-in angles of 4°, 5°, and 6°, causing the centers of the light beams to converge on the runway centerline 430 feet ahead of the units. In the next trial, the inner unit of the bar was set at 3°, the middle unit at 3 1/4°, and the outer unit at 3 1/2°. The corresponding points of intersection with the runway centerline were 570, 660, and 740 feet, respectively, ahead of the bar. These toe-in values were recommended by the manufacturer of the Elfaka lights.

If a landing airplane is displaced laterally from the runway centerline, the small decrease in toe-in results in better vision of the lights on the near side of the runway but cuts off even more of those on the opposite side. If the airplane is centered, it will be within visual

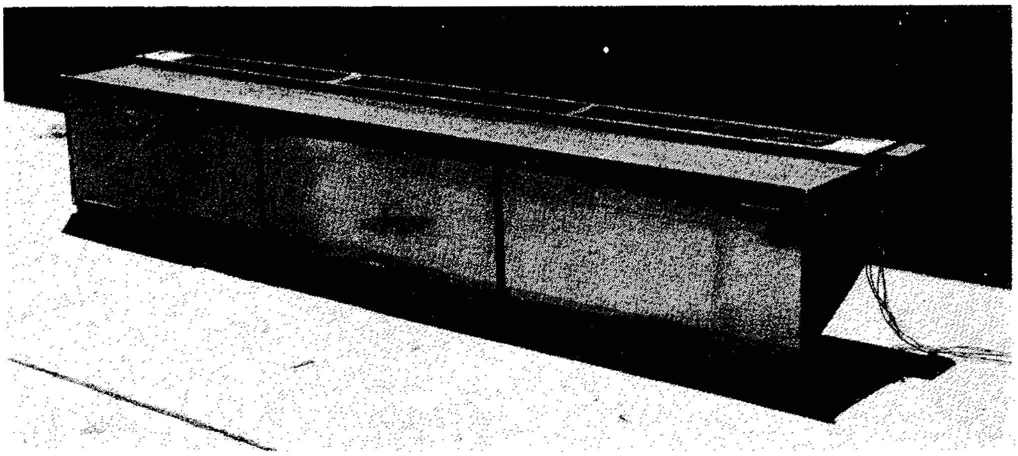


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Fig. 7 Experimental Floodlighting Unit

range of the lights for a somewhat longer distance, but the final cutoff will be somewhat further ahead of the airplane position. These effects are discernible by study of the photographs and were verified by the flight tests.

In further toe-in studies, the inner unit of the bar was set straight ahead, the second unit at 1 1/2° toe-in, and the third unit at 3°. This arrangement was considered unsatisfactory.

Of the three arrangements studied, the one with units set at 3°, 3 1/4°, and 3 1/2° was judged to be the best compromise of conflicting requirements. It should be emphasized, however, that it does not remedy the inherent deficiency of the narrow-beam lighting units in providing lateral coverage.

In a further effort to lessen the "orchard effect" in the narrow-gauge configuration, some tests were made with the 15-foot light bars shortened to 8 feet, still using 3 light units per bar. This was effective for the particular purpose but was not otherwise significant to the investigation as a whole. Other variations in bar length and light spacing were tried also, but did not improve the over-all effect.

Although this project was intended primarily as an evaluation of the narrow-gauge runway lighting configuration, the possibility of obtaining touchdown guidance through a low level of illumination of the runway surface was explored also. Experimental runway floodlighting units developed by Sylvania Electric Products, Inc., were used for this purpose. These units were designed to use 8-foot, very-high-output fluorescent tubes rated at 50 watts per foot. They were mounted about 16 inches above the pavement, and reflectors were provided to direct the light horizontally across the runway. One of the experimental units is shown in Fig. 7.

The lighting units were placed in continuous rows along both edges of the pavement for a distance of 715 feet, starting 500 feet from the approach end of the runway. They were intended to illuminate the runway surface in the touchdown area, thereby providing sufficient indication of surface texture to permit accurate depth perception or height sensitivity. While the light sources themselves were not visible to the pilot during landing, there was enough direct reflection from the fixtures to give the appearance of a continuous high-brightness, broad linear light source along each side of the runway. Figure 8 shows the general effect.

The runway brightness was quite low, being approximately 0.1 foot-lambert at the runway center even under relatively good atmospheric conditions. This was sufficient, however, to provide sensitive height guidance through revelation of surface texture. This proved effective, although to a reduced degree, even under low-visibility conditions and with moisture on the windshield. On one occasion, successful touchdowns were made in a ground fog with the runway visual range as low as 700 feet. The need for artificial illumination vanished with the coming of daybreak, even though the fog was still dense.

Efforts to enhance the effect of illumination by use of painted checkerboard markings and by the addition of light-reflecting crystals of aluminum silicate were of doubtful value. Apparently, the roughness of the pavement itself is the dominating characteristic. This suggests the advisability of further studies on other types of surface. The effect of pavement width is another obvious subject for further tests.

Fig. 8 General Effect of Floodlighting

A very encouraging aspect of the floodlighting technique is the fact that the pilot receives his height guidance through the same visual stimulus and reaction that he uses under normal operating conditions. The necessity for interpreting an artificial pattern of signal lights has been eliminated.

In addition to furnishing height sensitivity through surface illumination, the floodlights provided valuable pitch, roll, and directional guidance in the touchdown area by reference to the continuous bright strip lighting along the pavement edges, as well as the illuminated runway centerline marking. These gave a positive supplementary signal which proved to be very effective.

Although this was primarily an operational evaluation, it may be pertinent to mention briefly some of the obvious shortcomings and deficiencies of the floodlighting equipment and technique. The experimental floodlighting as used is relatively expensive and inefficient, has high power consumption (more than 100 kilowatts per 1,000 feet of runway), interferes with snow removal, is subject to damage by wind, hail, or jet blast, presents a continuous obstruction along the edges of the runway, and cannot be used at intersections. These considerations suggest the need for further development and improvement of the floodlighting fixture. They also suggest the restriction of floodlighting to a touchdown area, possibly 1,500 to 2,000 feet in length, in which height guidance is of primary importance. If use of floodlighting is thus restricted, it may be necessary to consider some supplementary lighting, primarily for directional guidance during roll-out or takeoff operations. Need for the supplemental lighting will depend primarily upon the runway width, as the effectiveness of edge lighting decreases with greater spacing of the light rows. Possible improvement of present edge lighting units or configurations should not, of course, be overlooked.

A simple dual-row configuration, with single lights spaced 68 feet laterally and 200 feet longitudinally, was given a limited test. It was effective in providing directional guidance and some roll guidance but posed the problem of differentiating between the rows of single light units, two in the dual-row configuration, and one at each runway edge. Color coding could be used, but would violate present international standards. It has been suggested that the problem of identification could be solved by using multiple units in the edge lights, which are elevated fixtures and relatively inexpensive. Reduction of the number of units located in the runway surface would reduce construction and maintenance costs, present fewer sources of surface roughness, and still provide the supplementary directional guidance desired for takeoff and roll-out in continuous all-weather operations.

Use of single-point sources of light to delineate the runway centerline was tried also. This is the most simple form of supplementary lighting and has a natural appeal for this reason. It would be relatively cheap. It has the disadvantage of introducing sources of surface roughness in the runway centerline where they would be most likely to be run over by the airplane tires during takeoff or landing operations

A small number of good-weather flights were made on the centerline configuration, with and without floodlighting or other special configurations These approaches could not be carried to the point of actual touchdown because of the obstructions on the runway surface. Most pilots found the centerline lights very helpful for directional guidance but some considered them distracting in the touchdown area. This objection was relieved somewhat by keeping them at low intensity.

The lack of low-visibility weather in the later phases of the flight program made it difficult to arrive at a firm choice between single-row or dual-row supplementary lighting Either could be used, and the obvious advantages and disadvantages of each have been cited above In any event, it appears desirable to provide separate or interlocking controls so that point sources of light in the touchdown area can be turned off when the floodlights are being used

CONCLUSIONS

The following conclusions are based on personal observations and experiences of CAA pilots and observers during the flight tests, on careful study of the motion-picture records, and on thorough discussions with other pilots and observers who participated in the flight program Because of the abbreviated nature of the project and the restrictions on touching down among the obstructions and hazards on the test runway, all of these conclusions may be considered as tentative

1 The narrow-gauge runway lighting, when visible throughout the landing maneuver, was effective in sharpening directional guidance and providing roll guidance during approach, flare, and touchdown. It did not provide adequate height guidance for touchdown

2 The optimum configuration for the narrow-gauge system was composed of 8-foot bars on 200-foot longitudinal spacing with an inner gauge width of 60 feet and with the lights toed in to intersect the runway centerline at a distance of about 700 feet The shorter bar and longer spacing were helpful in avoiding an "orchard effect" when the lights were viewed obliquely.

3 The narrow-beam lights, about 8° between points of 10 per cent maximum intensity, were not satisfactory, as they presented a visible pattern over only about half of the usable runway width. This would be even more critical on wider runways. A beam width of about 14° was adequate for a reasonably well-centered approach A maximum beam intensity of 37,000 candles, with 5-step control from 0.2 to 100 per cent of maximum, was satisfactory

4. Development of runway surface texture by low-level illumination of the surface was very effective in providing sensitive height indication at touchdown. This requirement was most critical in night landings with heavy ground fog The floodlights also provided directional, pitch, and roll guidance in the touchdown area.

5 If floodlighting is restricted to the touchdown area, supplementary signal lighting should be provided for directional guidance on roll-out and takeoff.

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