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Report No. RD-64-107

INTERIM REPORT

Project No. 430-201-01E

FOG CHAMBER TESTS OF CATEGORY II APPROACH, TOUCHDOWN AND RUNWAY CENTERLINE LIGHTING SYSTEMS



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INTERIM REPORT

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TOUCHDOWN AND RUNWAY CENTERLINE LIGHTING SYSTEMS

PROJECT NO. 430-201-01E
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Prepared From Data Obtained Under Contract No. ARDS-434 by
the University of California

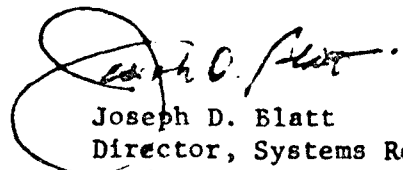
REVIEWED BY:

Walter N. Pike, P.E.
Chief, Environmental
Development Division

L. C. Vipond
Project Manager

NOVEMBER 1964

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Joseph D. Blatt
Director, Systems Research
and Development Service
Federal Aviation Agency

Environmental Development Division
Washington, D.C.

Federal Aviation Agency, Systems Research and Development Service,
Environmental Development Division, Washington, D. C.
FOG CHAMBER TESTS OF CATEGORY II APPROACH, TOUCHDOWN AND RUNWAY CENTERLINE
LIGHTING SYSTEMS

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ABSTRACT

Aircraft will soon be operating routinely in restricted visibility conditions where the visual range is as low as 1200 feet., which is otherwise defined as Category II weather conditions. To determine candlepower, light distribution, beam orientations and other characteristics required of visual aids (approach lighting, touchdown zone lighting, etc.) for safe landings in such low visibilities, a real fog environment is needed. This report describes a novel and economical method of fog testing of airport lighting fixtures and systems. A very large chamber was constructed and in it real fog was generated, controlled, and measured. Various patterns of lights were installed on the floor of the chamber, and simulated approaches and landings were made through the fog using live observers in an airplane cockpit riding on overhead rails.

A total of 36 experienced pilots participated in the tests. Only candlepower values and photometric distributions were varied during the test runs, except for a modification of the pattern of the inner 1000 ft. of approach lighting nearest threshold.

The tests showed that - at night - the present visual aids could be considered adequate, although marginal, for Category II operations. However, a need for better threshold lighting and more candlepower in the runway centerline lighting was indicated. During the daytime tests, where the higher background brightness was found to have a profound influence on required intensities, it was concluded that: (1) the modified approach pattern was more effective, (2) "bolder" threshold lighting was a necessity, (3) light output of touchdown zone lights should be improved, (4) runway centerline lights needed a minimum of 2000 peak cp, with 7500 cp preferred, to make them effective in bright daylight fog and (5) a definite need for well maintained painted runway markings to supplement the lighting in bright daylight fog.

It should be borne in mind that the test results in this report are subjective. There was no way to measure the pilots' abilities to use the information received from the visual aids to make corrections. Full scale operational tests - based on these fog chamber "screening" results - will be conducted at the Federal Aviation Agency's National Aviation Facilities Experimental Center (NAFEC), Atlantic City, New Jersey.

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INTRODUCTION

Historical Information. In past years the testing of airport lighting systems to see how effective they are in actual low visibility conditions has presented a tremendous problem to research and development engineers. The big trouble is that the weather is never cooperative in these endeavors. Quite often an ideal low visibility fog will settle on an experimental installation of airport lighting, but it always seems to dissipate by the time the engineers and test pilots can get their aircraft in the air to evaluate the lighting. In other words, when the experimenters are ready, the fog isn't.

Finding but scant cooperation from Mother Nature, a number of experimenters tried the technique of generating fog with air and water nozzles in a chamber in which were placed various types of miniature lights. Generally, the lights were viewed and studied through a window. These early experimental fog chambers were usually quite small, and the studies centered around automotive and marine lights. The University of California, on the other hand, had made some preliminary studies of airport lighting in fog chambers of fairly substantial size. It was decided to take advantage of their experience in this area, and the present Contract ARDS-434 was the result. Using a rather bold approach, the present FAA fog chamber was made large enough to place the experimenters and observers inside with the lights and the fog. No looking through windows. The results have been gratifyingly realistic.

Importance Of This Report. Already much useful data have been obtained from the FAA fog chamber to verify patterns and spacings of lights and to graphically demonstrate the efficacy of runway markings used in combination with lighting in daylight fog. This particular report contains the results of a concentrated series of tests made in the fog chamber to determine the desirable intensities and characteristics of approach, threshold, touchdown zone and runway centerline lights for safe landing operations in 1,200 feet of visual range. In addition, the tests sought to determine whether a minor modification of the inner 1,000 feet of the standard U. S. approach lighting pattern would be desirable for Category II operations.

In these tests the standard 3:3:3 pattern for the touchdown zone lights was used, and the runway centerline lights were spaced at 25 feet intervals. No pattern variations were introduced to confuse the issue, except for the minor modification of the inner 1000 feet of approach lighting. All test runs, of course, utilized approach lights to make up the integrated Category II lighting system. Highly qualified pilots were used as observers. Most were senior air line captains with years of experience. The test results are useful guides in the design of lighting systems for Category II operations.



Fig.1 Exterior view of fog chamber. The building is 820 ft. long by 30 feet wide. The height varies from 30 ft. high in the foreground to 10 ft. at the midpoint.

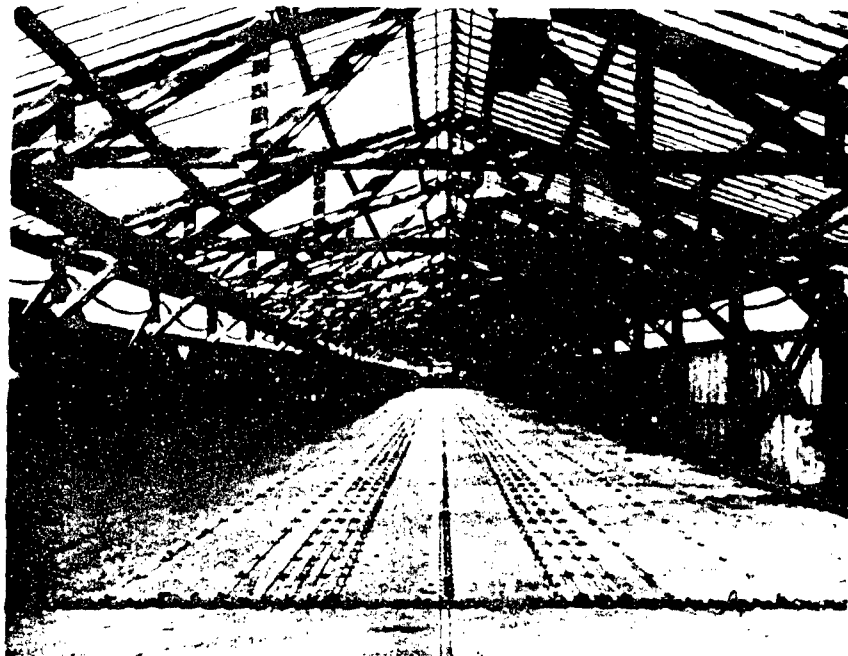


Fig.2 Interior view of fog chamber from threshold showing tramway rails and lighting fixtures. The overhead plastic panels allow low visibility tests to be conducted under day and night conditions.

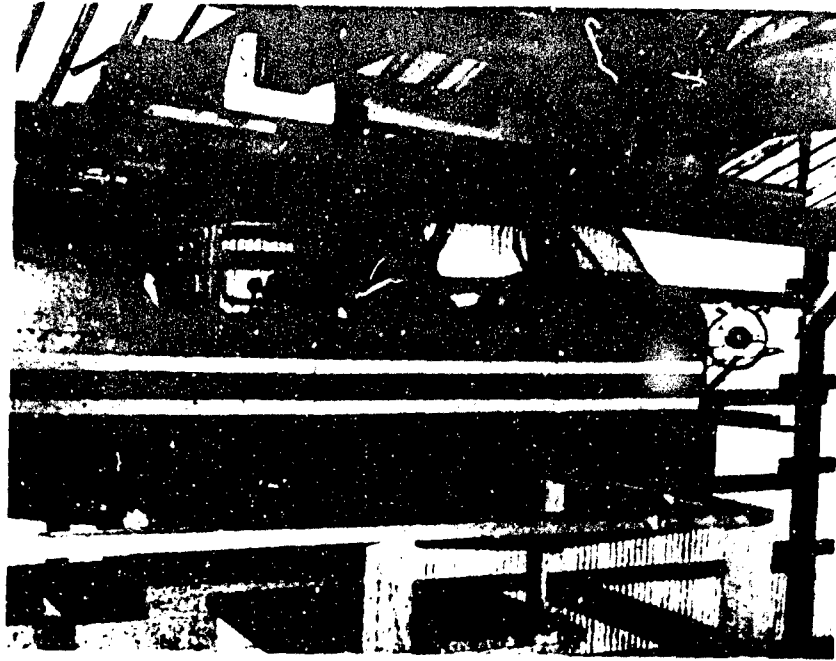


Fig.3 Observers' cockpit at "launch" platform at high end of chamber, poised for a test run.

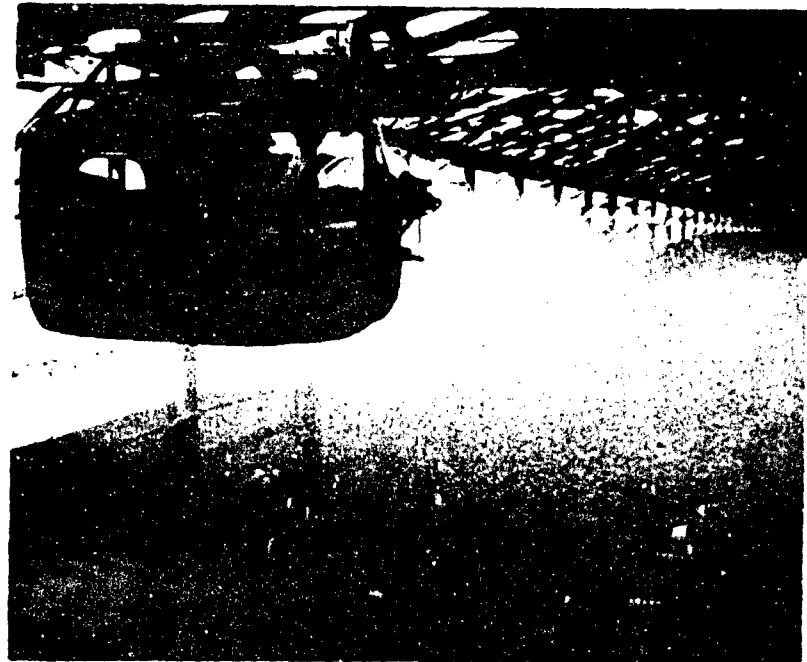


Fig.4 Observers' cockpit on trial run as fog builds up rapidly in the chamber.

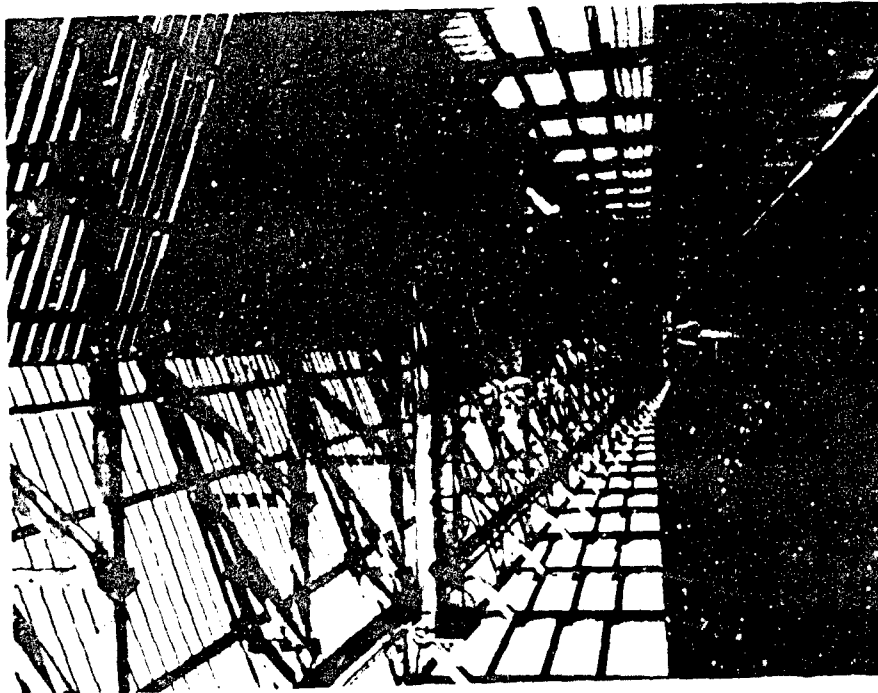


Fig. 5 Daylight view of full length interior of fog chamber showing the tramway carriage and observers cockpit, as well as lighting system.

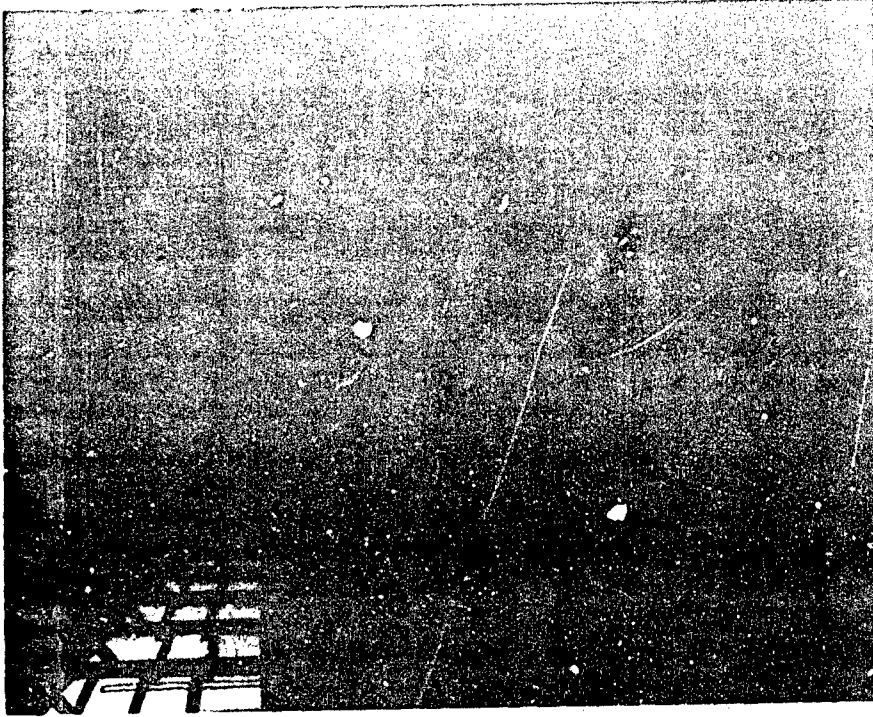


Fig. 6 Full length view of interior of chamber at dusk showing test pattern of lighting prior to filling chamber with fog.

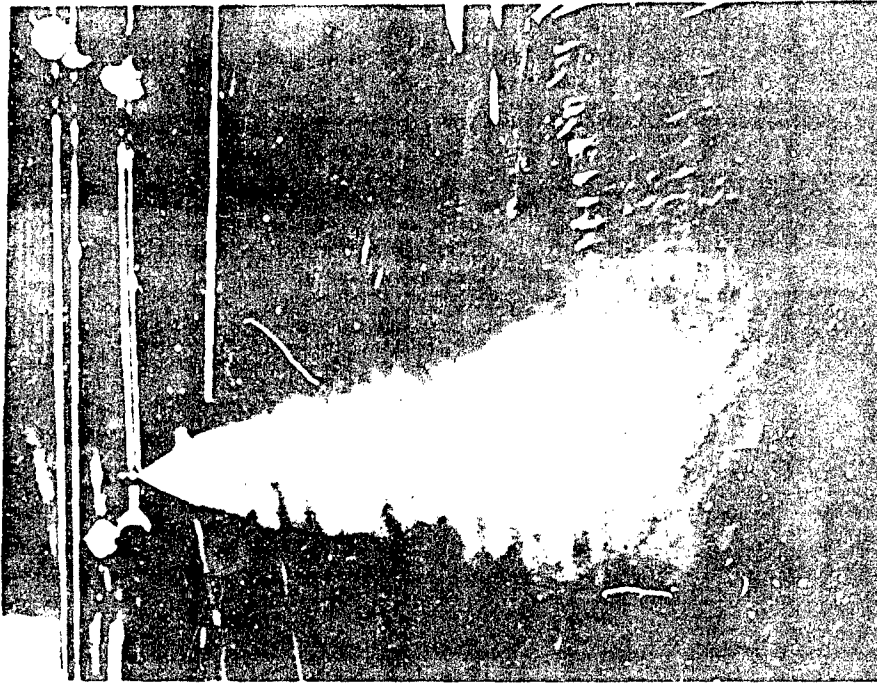


Fig. 7. Fog being generated through one of the 100 or more nozzles. Air and water are fed into the nozzle under pressure.

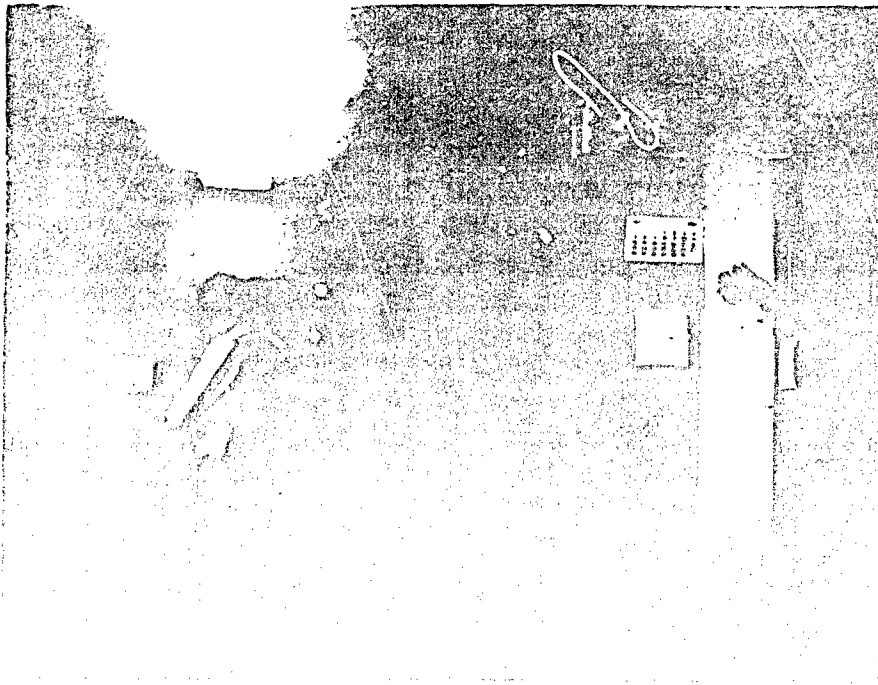


Fig. 8. Interior view of test sled and sled also attached to the fog chamber. The fog is being generated from the nozzle.

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DESCRIPTION OF THE FOG CHAMBER

Under existing Contract ARDS-434, the University of California, constructed for the FAA an outside fog chamber at their Richmond Field Station near Berkeley, California. The test work is performed by the Institute of Transportation and Traffic Engineering of the University of California under the direction of the Project Manager representing the Systems Research and Development Service, Federal Aviation Agency.

The test facility consists of a building 30 feet wide and 820 feet long. The height of the building varies from 30 ft at the high end to 10 ft at a point 400 ft from the high end. The remainder of the building is level at a height of 10 ft. The upper portions of the sides of the building and the roof are covered with translucent corrugated panels. This enables sufficient light to enter the building for daytime fog studies.

Fog is generated in the building by feeding compressed air and water through some 100 nozzles. This fog is in every way comparable to natural fog. The fog particle size can be varied by varying the air to water pressure ratio. The fog generating equipment has the capability of producing fog of any desired density. A semiautomatic control device furnished by the National Bureau of Standards was installed to achieve even greater control over the density and homogeneity of the fog. In the current tests, fog was generated continuously during a test; previously it had been necessary to generate a desired level of fog and then conduct the test as the fog decayed.

The floor of the building is surfaced with asphaltic concrete. On this floor approach lights (U. S. National Standard, but without strobe flashing lights) as well as runway lights have been installed to permit study of the complete approach and runway lighting system. The scale reduction factor for all linear dimensions and approach speed is 1/10.

The length of the building in which fog is generated is 800 ft, that being equivalent to 8000 ft. The approach lights are 80 ft from the high end of the building and extend 300 ft to the runway threshold. In the remaining 420 ft various patterns of runway touchdown zone and runway centerline lights have been installed.

The sloped roof permits an observer to approach the runway on a 2-1/2-deg. glide path (Fig. 5). Steel rails are attached to the roof adjacent to the sides of the building. A tramway carriage supported by steel wheels and operated by an electric motor rolls on the steel rails. Suspended from the tramway carriage is an actual cockpit from a Cessna aircraft. The cockpit can accommodate two observers and an operator. It can be moved laterally (an equivalent distance of 140 ft each side of the centerline) to simulate off-centerline approaches. The tramway carriage can be operated at speeds up to 15 mph, which corresponds to an over-the-threshold speed of approximately 130 knots.

At the high end of the building the eye level in the cockpit is approximately 24 ft above the floor. At the 1000-ft cross bar, the eye level height is 12.6 ft. At the runway threshold, the eye level in the cockpit is at a height of approximately 8.2 ft. From the runway threshold to touchdown, the eye level decreases gradually to 4.4 ft and thereafter remains level over the runway at this height.

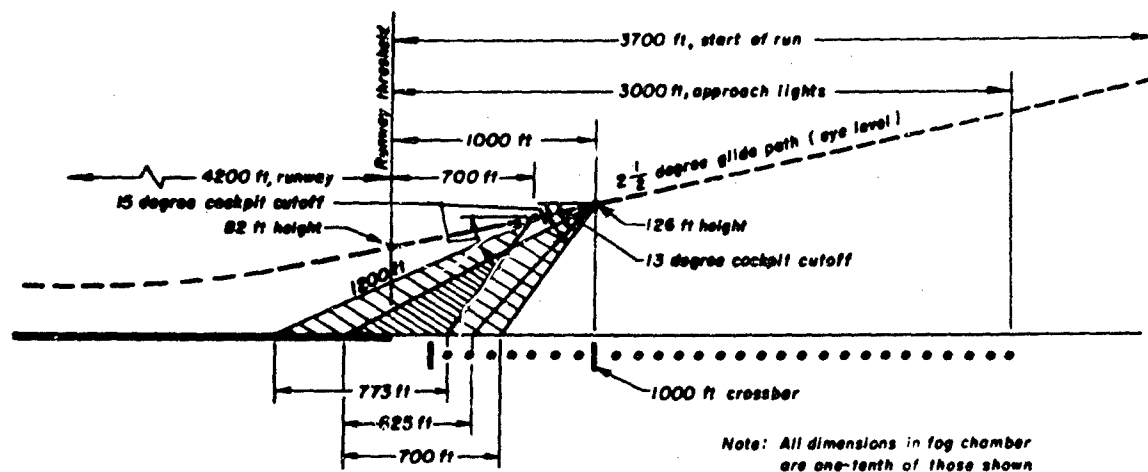


Fig. 9 - Fog chamber glide path and approximate visual cones for 1200 ft visual range

The entire facility has been designed so that the times for perception, adaptation, decision, and the rate of change of the field of view are the same as in an actual landing.

Light-Intensity and Fog-Density Scale Factors

In order to be representative of real-life conditions, the illumination (at the eye) and the average brightness in the fog chamber should be nearly the same as in the field. Illumination varies as the square of the distance from point sources. Since the linear scale factor is 1/10, the illumination must be reduced by $(1/10)^2$ or 1/100. Brightness is defined as the intensity divided by the projected area of the light source. The linear dimensions of the optical parts of the light sources were reduced by approximately 1/10, therefore the reduction in areas is 1/100. If a constant brightness is to be maintained, the intensity of the light source must also be reduced by a factor of 1/100. Thus all of the intensities of the approach and runway lights in the fog chamber are 1/100 of real-life conditions.

To maintain the same light-scattering effect in the fog chamber as in the field, the size of the fog particles and the distribution of their size must be the same. To maintain the same attenuation, however, the concentration of fog particles per volume has to be increased.

The increase in fog particles per unit volume is such that a light will attenuate to the same degree at 50 feet in the fog chamber as it would at 500 feet in real life. While it was easy to generate fogs of almost any desired density in the fog chamber, there were a number of problems encountered in the measuring and recording of desired visibilities, and relating such visibilities to real life conditions. These problems of measuring light transmission through fog are dealt with later in this report.

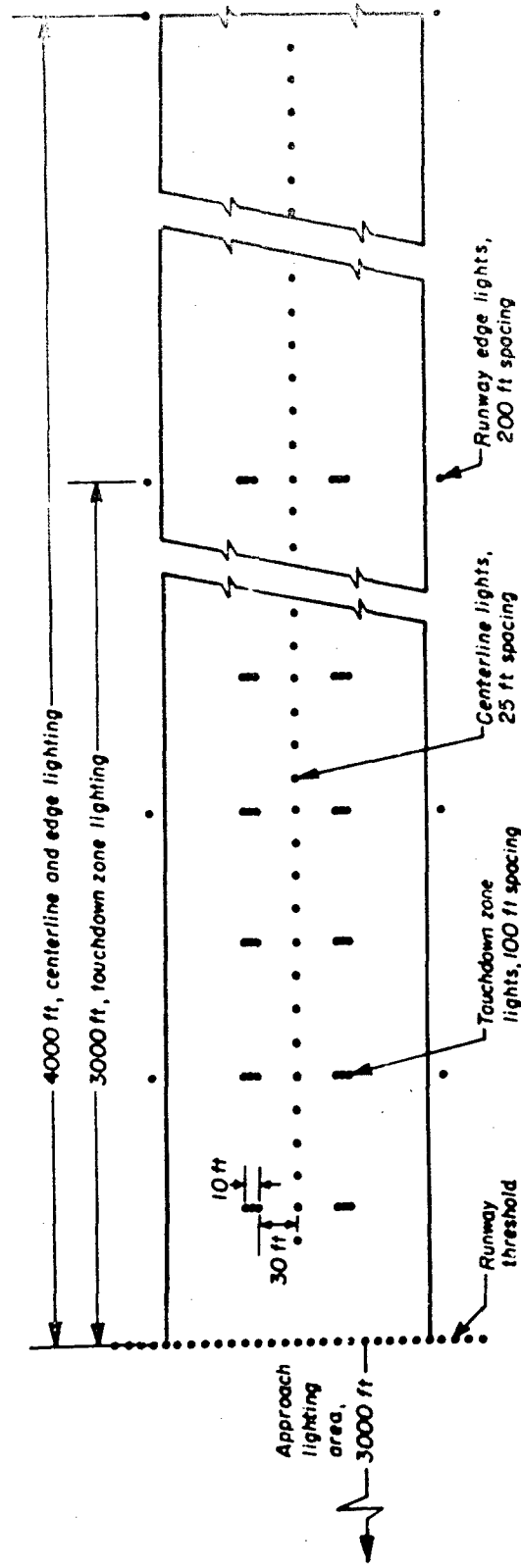
Effect of Reduction in Scale on the Observer

Everything has been reduced in scale in the fog chamber except the observer. He cannot be scaled down in the same sense as the dimensions and the light intensities. But the environments can seem real to him, nevertheless. By scaling all linear dimensions in the external field by 1/10, the visual angles (and therefore the visual size) of all objects remain the same as in the "real" world. The perspective of the central field of view is exactly the same as in a real landing or take-off. However, because of the limited width of the fog chamber, the peripheral field is not a true representation in those tests in which the observer can see the sides and the roof trusses. Only in visual ranges of 2600 ft or lighter fog, in daytime, are the sides and roof trusses very noticeable. In denser fogs, neither the sides nor the roof are seen to any appreciable extent.

The other aspect that has not been reduced to scale is the binocular view of the observer (effect of two eyes, each seeing a slightly different scene). For relatively long distances (100 ft or more) the change in viewing angles from one eye to another is relatively unimportant. One can make almost as good distance judgments with one eye as with two. The binocular clues are more important at close range. But even at distances of 10 ft or more the illusion created in the fog chamber is remarkably good, even with a non-scaled binocular vision.

Attempts to Use Transmissometer

Prior to this test program attempts were made to measure the density of the fog by the same type of transmissometer that is now installed at many airports in the United States. The initial installation of the transmissometer in the fog chamber has not been satisfactory. Correlation of measured values of transmission with observed visual ranges was not accomplished; however, efforts are continuing to establish such a correlation. The transmissometer measures the transmittance of the fog along a fixed base line and this is used to specify Runway Visual Range (RVR). Due to reasons cited later in this report, human observers were used in lieu of the transmissometer to determine fog density for the test program described in this report.



Note: All dimensions in fog chamber are one-tenth of those shown

Fig. 10 - Plan view of runway lighting pattern.

LIGHTING USED IN TESTS

In setting the stage for lighting tests for Category II landing operations it was necessary to hold the variations to a reasonable minimum - a minimum that was consistent with providing useful, realistic data. To do otherwise would mean embarking on a long series of testing that would probably miss the boat. The need for data on Category II lighting operations was urgent and could not long be delayed.

Lighting Variations Used In the Tests. The following combinations of intensities of touchdown zone lights and runway centerline lights were selected for the tests:

<u>Intensity of Touchdown Zone Lights, 100-ft centers, cp</u>	<u>Intensity of Centerline Lights 25-ft centers, cp</u>
Daytime Tests	
7500	500
7500	1000
7500	2000
Nighttime Tests	
7500	500
7500	1000
4000	500
4000	1000

Fixture Intensities. In the preceding tables, the light intensities shown represent peak intensities. A more complete picture of the photometric distribution of the touchdown zone and runway centerline lights as installed in the fog chamber is given below.

The touchdown zone lights used in all tests have the following photometric characteristics when operated to give 7500 or 4000 peak intensity:

1. At least 80% of the peak cp within 0 to 6 deg vertical and 13 deg (total) horizontal.
2. At least 50% of the peak cp within 0 to 7 deg vertical and 23 deg (total) horizontal.
3. At least 10% of the peak cp within 0 to 12 deg vertical and 28 deg (total) horizontal.

The centerline lights used in all tests have the following photometric characteristics when operated to give 2000, 1000 or 500 cp peak intensity:

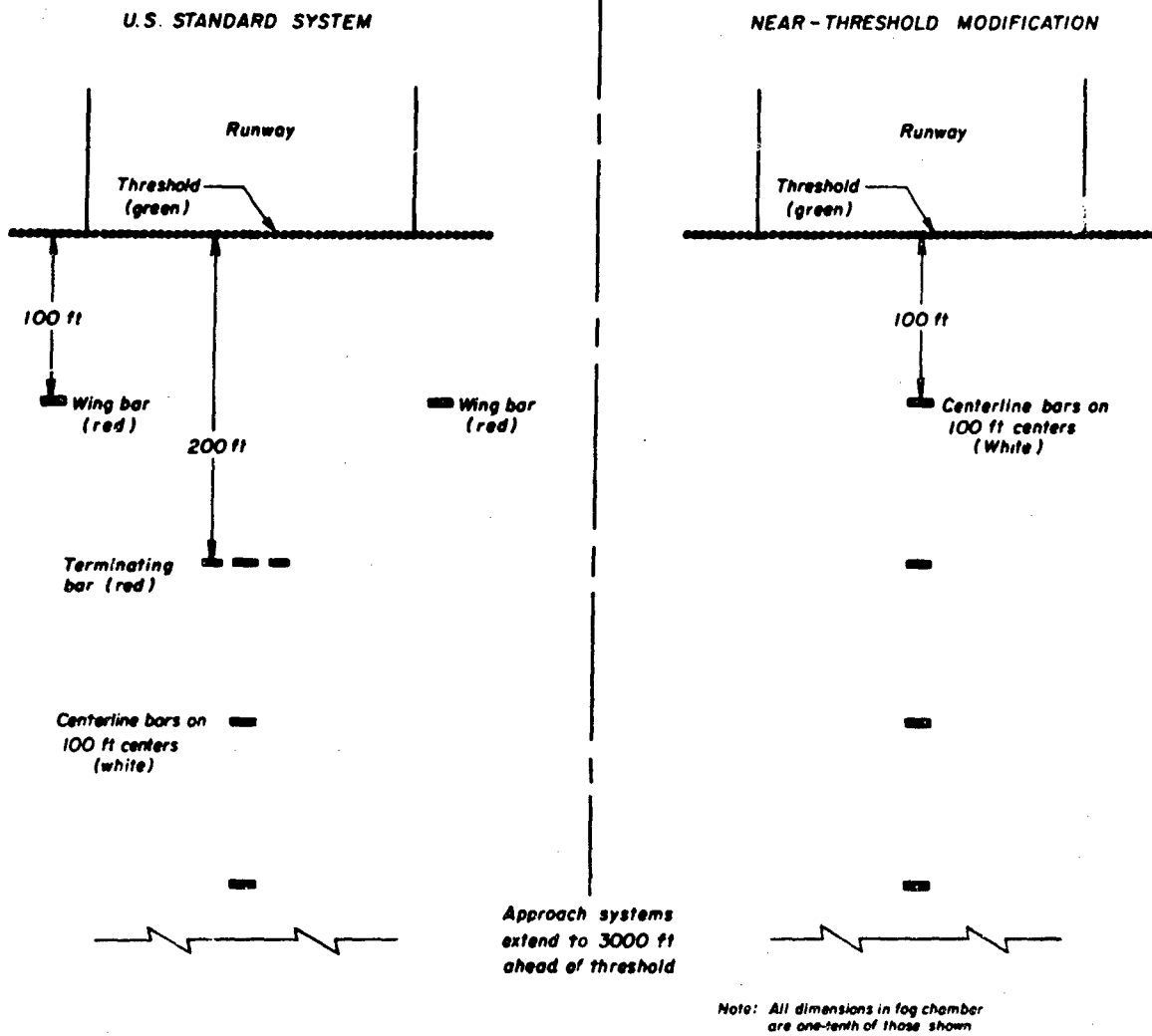


Fig. 11 - Plan view of standard and modified approach lighting systems.

1. At least 80% of the peak cp within 0 to 10 deg vertical and 30 deg (total) horizontal.
2. At least 50% of the peak cp within 0 to 14 deg vertical and 30 deg (total) horizontal.
3. At least 10% of the peak cp within 0 to 16 deg vertical and 30 deg (total) horizontal.

Choosing the 7500 and 4000 cp peak intensities for the touchdown zone lights was dictated by the fact that they correspond closely with the photometric performance of fixtures now being installed under the Federal Aid to Airports Program. It is sufficiently close to the output from fixtures made in accordance with existing FAA specifications L-838, L-843 and L-845.

For the runway centerline lights, the 500 cp peak intensity corresponds roughly to the output of the FAA L-842 "pancake" light with a 45-watt quartz lamp, which is the fixture now being utilized for runway centerline installations under the FAAP. The 1000 and 2000 cp peak intensities were chosen for a prominent part in the testing because preliminary investigation had given an indication 500 cp. was not enough for all conditions down to 1200 ft Category II. In this connection, it is known that 1000, 2000 and up to 7500 cp peak intensities can be obtained from a modified version of fixtures made in accordance with FAA specification L-845. A test installation using the modified L-845 fixtures on new standard FAA base receptacles has recently been made on the centerline of Runway 13-31 at NAFEC.

Approach Lighting. Approach lighting was used for all test runs. During the latter part of each test series a minor modification was made to the standard U. S. system in the inner 1000 ft to find out if it could be made more effective in Category II weather. This will be referred to throughout the report as the "modified approach system."

The modified approach system differs from the standard system in that the red terminating bar 200 ft from the threshold and the red wing bars 100 ft from the threshold are removed; the red terminating bar is replaced with a white light barrette and an additional white barrette is placed 100 ft from the threshold in line with the existing barrettes. Strobe lights had not been installed at the time this test program was under way. The two systems are shown in Fig. 11. It was agreed that for tests during the day the intensity of the approach lights, runway edge lights, and threshold lights would remain the same at step 5 (20,000 cp), and for tests at night the intensity would be reduced to step 4 (4000 cp).

Threshold Lighting. Considerable thought was given to the choice of threshold lights for the tests. Preliminary investigation and previous test experience indicated that the original test threshold lights were not adequate and should not be used. The original threshold lights

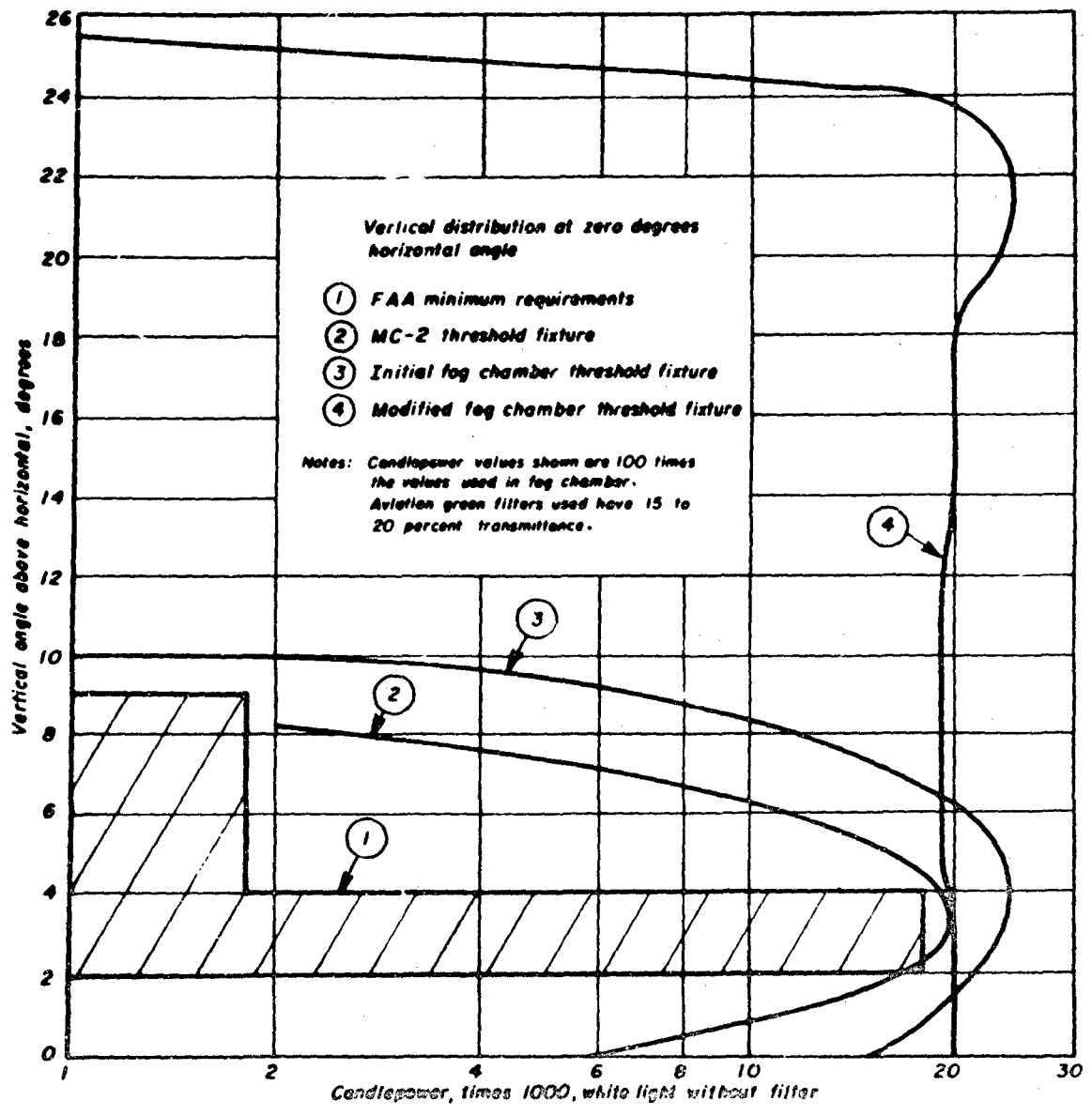


Fig. 12 - Vertical photometric distributions of threshold lights.

provided a minimum of 18,000 cp (white light) from 1 to 7 degrees above the horizontal, diminishing rapidly to 1800 cp at 10 degrees above horizontal. The threshold lights chosen as best for this test program provided an approximately uniform intensity of 20,000 cp (white light) up to an angle of 25 deg from the plane of the runway. Thus the significant change that was made in these lights was the provision of nearly the same intensity (18,000 to 20,000 cp) but over a much larger vertical angle.

The photometric distributions for both the original threshold lights and the current lights as well as the FAA specifications for threshold lights are shown in Fig. 12. Suffice it to say that the original lights exceeded the FAA specification of 18,000 cp (white light) which required only from 2 to 4 deg above the plane of the runway.

The reason for maintaining a nearly uniform high intensity over a larger vertical angle than before was that the pilot observers felt that in 1200 ft visibility the threshold lights were inadequate regardless of the fact that they exceeded FAA specifications. This inadequacy was in part due to the fact that the vertical distribution of the light beam was too narrow and the aiming was too critical. The pilot was moving out of the peak intensity region into a rapidly decreasing zone of candle power as he approached the threshold. Hence, the observers were not able to see the lights as well as they should at a distance of about 1000 ft ahead of threshold which is approximately the decision point for Category II operations (100 ft altitude).

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THE EVALUATION PROGRAM

The intensities of the runway touchdown zone and centerline lights as well as the modification of the inner 1000 ft of approach lights were evaluated from (1) observations by pilots, (2) brightness measurements, and (3) photographs. For each combination of intensities of runway touchdown zone and centerline lights two approach light systems were used--the standard and modified. The entire evaluation program was conducted in 1200 ft of visual range.

Observations by Pilots

Early in the planning of the project it was recognized that evaluation of the lighting patterns by qualified pilots was essential. Another practical requirement was that the pilots be readily available to participate in the tests. Accordingly, a lighting advisory group was formed with the advice of several major airlines serving the San Francisco Bay Area and the local councils of the Air Line Pilots Association. About half of the group was selected by the airlines and half by the councils of the ALPA.

Members of the All-Weather Landing Committees of the Air Transport Association of America, and the Air Line Pilots Association also participated in the evaluation as well as representatives of the aircraft manufacturers and the Flight Standards Service of the Federal Aviation Agency.

After each approach the observers completed a data sheet. A total of 36 pilot observers participated in the tests. For the purpose of analysis, the questions were grouped into four parts: questions concerning (1) approach lights, (2) runway threshold lights, (3) runway centerline lights, and (4) runway touchdown zone lights.

Each observer was asked to evaluate each part of the system at the following locations: 1000 ft ahead of threshold, at runway threshold, at touchdown, and during roll-out.

Photometric Measurements

A. Brightness of Light Sources and Contrast. Measurements were made at two locations along the glide path: (1) 500 ft ahead of the runway threshold and (2) at the runway threshold, using in both cases a Pritchard Spectra Telephotometer mounted on a turntable in the cockpit. At each location average luminance measurements were made on the runway lights at distances of 600 ft, 900 ft, and 1200 ft ahead of the observer. Measurements were not made at 1000 ft because the visual range of 1200 ft. limited the readings to lights in the approach to the threshold region which were not the primary subject for investigation.

The measurements were made with a 6-minute aperture for 600 ft of viewing distance; a 4-minute aperture for 900 ft of viewing distance, and a 2-minute aperture for 1200 ft of viewing distance.

A telephotometer, rotating on the turntable, scanned across the entire width of the runway at a constant angular velocity. In this manner a continuous distribution of brightness across the entire runway was recorded.

The instrument measures the average light flux at the photocell receiver within the specific acceptance of the aperture. The apertures were varied for the different viewing distances, (e.g., 600 ft, 900 ft, and 1200 ft) in order that the average brightness would be over about the same projected area at the light source regardless of viewing distance. The measurements for all viewing distances yield an average brightness in a circular projected area of about 0.21 ft in diameter at the runway.

B. How "Detection Contrasts" Were Determined. It is important to know the increment in light flux at the pilot's eye due to a light source on the runway. The symbol ΔB was chosen to denote the differences between the average peak brightnesses and the average brightnesses at one aperture diameter away from the peaks. Although this is somewhat arbitrary it appears to be reasonable since the peaks are well defined and the critical differences in brightnesses insofar as the pilot is concerned are determined by the brightnesses immediately adjacent to the peaks.

To show the effect of background brightness it was decided to compare ΔB with the average brightness in the transverse section of the runway. This comparison is in the form of a ratio which is called the detection contrast C_d . The expression for C_d in symbolic form is as follows:

$$C_d = \frac{\Delta B}{B_T} = \frac{B_S - B_O}{B_T}$$

where C_d = detection contrast

B_S = Maximum average brightness of the centerline or touchdown zone lights within the specified aperture (corresponds to "average peak brightnesses" mentioned above),

B_O = Average brightness one aperture diameter away from maximum average brightness within the specified aperture,

B_T = Average brightness over an area extending across the runway excluding the touchdown zone, the centerline lights, and the edge lights within the specified aperture.

C. Using "Detection Contrasts" as a Yardstick. As mentioned above, the determination of detection contrasts may be considered somewhat arbitrary. Nonetheless they provide the experimenters with a useful yardstick in measuring the effectiveness of the lights, quite apart from the subjective reactions of the subject pilots who made the test runs over the lights. It was, of course, necessary to establish what contrast detection values would be considered the "minimum perceptible value" and what would be considered the "practical usable minimum." As a measure of adequacy, conditions were selected which approximate those used by the U. S. Weather Bureau in determining the meteorological visibility as follows:

Daytime: $C_d = 0.05$ minimum perceptible value

$C_d = 0.15$ practical usable minimum

Nighttime: $C_d = 0.10$ minimum perceptible value

$C_d = 0.30$ practical usable minimum

These numbers are only guides. They reflect the generally accepted idea that the required contrast for well-defined objects increases as the background brightness decreases, but on a nonlinear basis. In a fog, the scattering both increases the background brightness and decreases the sharpness of the definition of the object, therefore the brightness increment due to the object is not well defined. The background brightness is not well defined, especially at night, since there are multiple light sources in the field of view with large gradients surrounding each source.

To further complicate the problem, it should be noted that while the contrast required for a given level of certainty of detection at night increases, the threshold for detection decreases. This can be interpreted as meaning that, although the required ratio of the incremental brightness to the background increases at night, the necessary increment in brightness decreases. Thus one might have a ΔB of 14 footlamberts for a touchdown zone light in the daytime and have the contrast at or near the minimum perceptible value, whereas at night the same measurements might yield a ΔB of 4 footlamberts with a contrast that is well above the practical useable minimum. The results of tests to determine detection contrasts of the lights for different test conditions are discussed later in the report. They are also summarized in TABLE 3 - SUMMARY OF DETECTION CONTRASTS.

D. Relation of Contrast to Visual Range. While on the subject of detection contrasts it is worthwhile to point out how the values can be affected by distance. This has a further bearing on the taking of photographs as explained below in the paragraph labeled "Photographs."

For a uniform daytime fog that has a visual range of 1200 feet defined as the distance that a 10,000-cp light can be seen, the following detection contrasts would be developed at different distances (based upon exponential attenuation):

Distance	Available Contrast	
1500 ft	0.024	
1400	0.030	below visual
1300	0.039	threshold
1200	0.050	barely visible
1100	0.064	
1000	0.083	more visible
900	0.105	
800	0.135	Practical usable minimum
700	0.174	
600	0.223	
500	0.287	readily visible

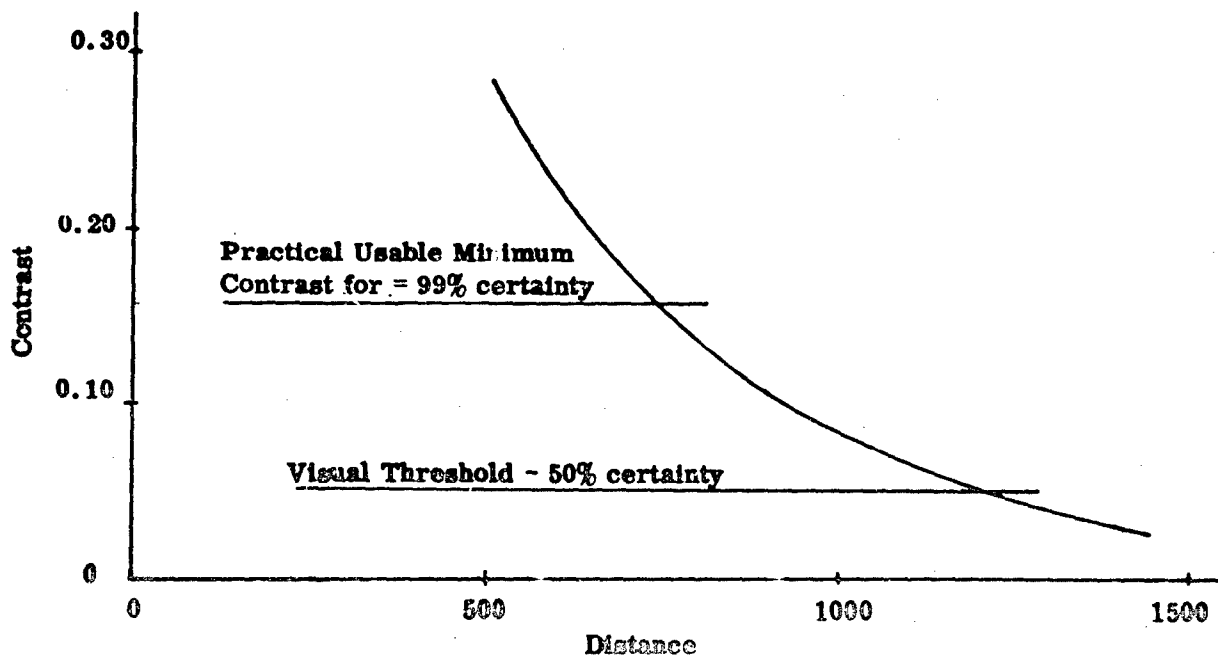


Fig. 13 - Contrast vs Distance in a Uniform Fog of 1200 ft Visual Range.

E. Background Brightness. The background brightness was determined by a photometer located at the far end of the fog chamber approximately 10 ft above the level of the floor. The instrument was pointed toward the threshold and measured the brightness within a 6-degree cone.

Photographs

Still (black and white) photographs were taken at threshold, and 700 ft. ahead of threshold using a cockpit cutoff angle of 15 deg. The 700 ft. distance was used instead of 1000 feet in order to show the lights beyond the threshold in 1200 ft. visual range. At 1000 ft. the limitations of photography will not permit the lights beyond the threshold to show without excessive flaring of the approach and threshold lights. The effect of distance on contrast in 1200 ft. visual range fog is shown on the preceding curve.

Measurement of Fog Density

Due to the uncertainty in transmissometer readings that is known to exist in visibilities of 1200 ft. and lower and also due to problems arising from trying to locate a transmissometer in the fog chamber, it was decided to use a more meaningful procedure for determining visibility in lieu of a transmissometer. The runway edge lights at an average intensity of 10,000 cp are now used as a basis for correlating transmissometer readings and Runway Visual Range. On this basis, it was arranged that human observers should be used and that the visibility should be determined on the basis of the number of 10,000-cp sources that the observers could see both in day and night conditions. Accordingly a row of 10,000 cp light sources was placed along one edge of the runway on 200-ft. centers. The observers were stationed on the opposite edge of the runway, one at threshold and the other approximately 1000 ft. past the threshold. When both observers saw the same number of lights, the visibility was considered at proper test conditions (e.g., for 1200-ft. visibility, 6 lights had to be seen by both observers). It should be noted that in the daytime the background brightness seen by the visual range observers can be different than seen by a pilot observer. The magnitude of the difference is not known, but it may have resulted in a somewhat different visual range along the glide slope than was reported for the run. The visibility measured in this manner has been defined in this report as Visual Range rather than Runway Visual Range since the latter term is associated with transmissometer measurements in the United States. Accordingly, all visibility measurements in this report are given in terms of Visual Range as described above.

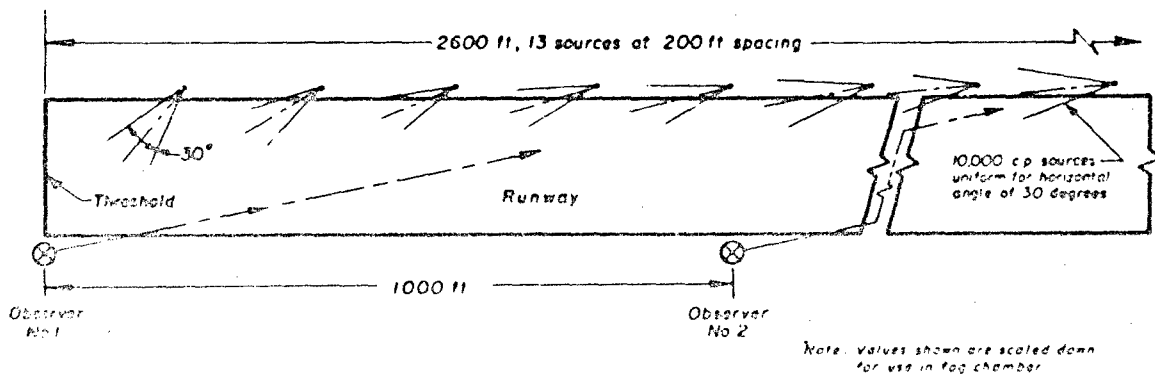


Fig. 10 - Plan view of lights used for determining visual range.

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RESULTS OF THE EVALUATION PROGRAM

The results of the evaluation program are divided into three categories: (1) observation by pilots, (2) brightness measurements, and (3) photographs.

1. Observation by Pilots

A. Ground Rules and Terminology. As stated previously, specific questions were asked of each pilot observer concerning the approach lights, the threshold lights and the runway touchdown zone and runway centerline lights. The lighting was evaluated for one visibility condition, 1200 ft visual range over a wide range of daylight conditions and at night.

In Tables 1 and 2, the responses to the questions asked of each pilot observer are summarized. Several of the observers requested the opportunity to view intensities other than those specified in the test program.*

The numbers in Tables 1 and 2 indicate the number of observations, not the number of observers. During the daylight the results have been grouped in two categories of background brightness; (1) in excess of 300 foot-lamberts and (2) 300 footlamberts or less.

The observers were given the opportunity to view each combination of intensity of runway touchdown zone and centerline lights (e.g., 7500 cp and 500 cp, 7500 cp and 1000 cp, etc.) with both the standard and modified approach light systems. A detailed examination of the answers to the questions indicated that the type of approach light system had very little influence on the evaluation of the runway section of the lighting system. For this reason the answers pertaining to runway lighting have been combined for both approach light systems.

In all discussion of pilot observations, the following terminology is used:

about half - about one-half the observers gave the same answer

majority - about two-thirds gave the same answer

nearly all - about 90% gave the same answer

As mentioned previously during the daytime the background brightness was measured during each observation. Fig.15 shows the number of observations in each 100-footlambert increment of background brightness. The

* (1) At night 2000 cp in lieu of 1000 cp for the runway centerline.

(2) At night step 5 for the approach lights (20,000 cp) in lieu of step 4 (4000 cp).

range of background brightness was from 8 footlamberts to 1700 footlamberts, but the majority of the observations were conducted when the background brightness varied from 400 to 8 footlamberts. The highest background brightness as recorded in the fog chamber can be exceeded in field operating conditions. For example with a relatively shallow fog with bright sunshine overhead the background brightness may be on the order of 3000 footlamberts.

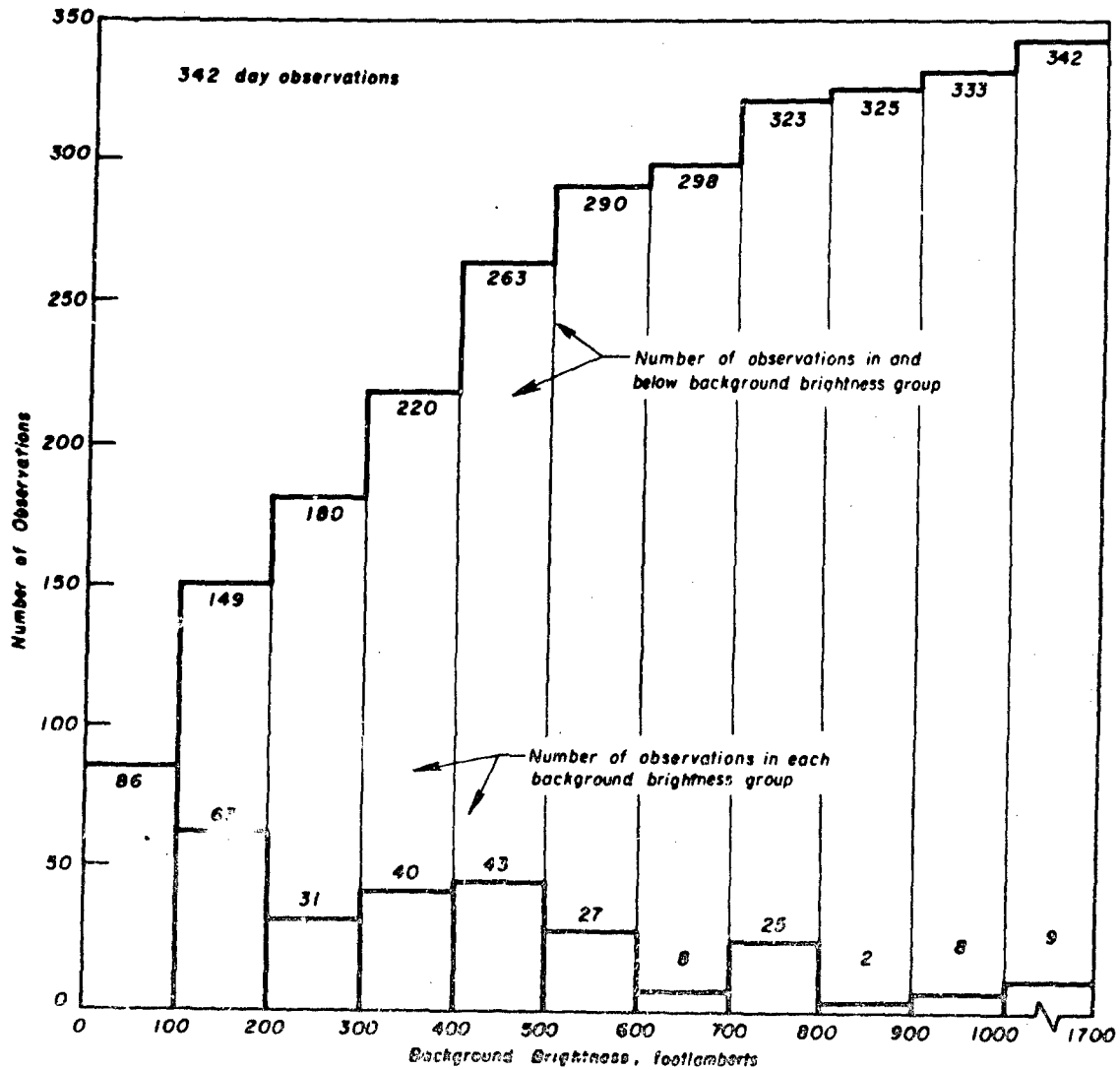


Fig.15 - Distribution of day observations by background brightness.

TABLE 1 - PILOT OBSERVATIONS OF APPROACH AND THRESHOLD LIGHTS

Question	Number and Percent of Observations						
	Day ¹		Day ²		Flight		
	No.	%	No.	%	No.	%	
<u>Approach Lights</u>							
1. Are the approach lights satisfactory from the start of the run to the 1000 ft bar?	Yes	74	51	96	64	170	71
	No	51	48	53	35	68	28
	No response	1	1	1	1	2	1
2. Did you clearly identify the 1000 ft bar?	Yes	108	74	143	95	229	95
	No	37	26	7	5	11	5
	No response	-	-	-	-	-	-
3. From the 1000 ft bar to runway threshold, was the intensity of the approach lights:	Too high	-	-	1	1	6	2
	Acceptable	128	88	116	77	215	90
	Too low	17	12	33	22	19	8
No response	-	-	-	-	-	-	-
You have completed two series of runs, one with the <u>Standard Approach Light configuration</u> , one with a <u>near-threshold modification</u> .							
9. With green threshold lights, which system do you feel provided better guidance information?	Modified Standard	15	94	23	77	23	89
	No response	1	6	7	23	3	12
	No response	-	-	-	-	-	-
<u>Runway Threshold Lights</u>							
4. At approximately the 1000 ft bar (about 100 ft altitude) did you clearly identify the green threshold lights?	Yes	93	64	89	59	171	71
	No	50	35	61	41	67	29
	No response	2	1	-	-	2	1
You have just made a run with the <u>green filters removed from the runway threshold lights</u> .							
10. At approximately the 1000 ft bar (about 100 ft altitude) did you clearly identify the white threshold lights?	Yes	13	81	27	90	21	81
	No	3	19	3	10	5	19
	No response	-	-	-	-	-	-
11. Do you feel that it is desirable to have a specific color identify the threshold?	Yes	11	69	24	80	24	92
	No	4	25	5	17	2	8
	No response	1	6	1	3	-	-
1. Background brightness greater than 300 footlamberts							
2. Background brightness equal to or less than 300 footlamberts							

TABLE 2 - PILOT OBSERVATIONS OF RUNWAY LIGHTS

Question	Number and Percent of Observations																	
	Day ¹						Day ²						Night					
	TDZ 7500 cp			TDZ 7500 cp			TDZ 7500 cp			TDZ 7500 cp			TDZ 7500 cp			TDZ 7500 cp		
	CL 500 cp	CL 1000 cp	CL 2000 cp	CL 500 cp	CL 1000 cp	CL 2000 cp	CL 500 cp	CL 1000 cp	CL 2000 cp	CL 500 cp	CL 1000 cp	CL 2000 cp	CL 500 cp	CL 1000 cp	CL 2000 cp	CL 500 cp	CL 1000 cp	CL 2000 cp
No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	
5. For continuing and landing, was the intensity of Runway Centerline Lights:																		
Runway Centerline Lights																		
A. At 1000 ft bar	20	37	22	46	28	65	17	33	12	32	34	55	1	2	27	42	19	30
Too high																		
Acceptable																		
Too low	15	28	13	27	1	2	10	20	6	16	5	8	17	26	11	20	18	28
Not seen	19	35	13	27	14	33	24	47	19	52	23	37	19	30	15	27	27	42
No response																		
B. At runway threshold	39	72	43	90	39	91	35	69	34	92	57	92	54	84	54	96	50	78
Acceptable																		
Not acceptable	15	28	5	10	4	9	16	31	3	8	5	8	10	16	2	4	14	22
No response																		
C. At touchdown	41	76	44	92	42	98	38	75	35	95	59	95	54	84	54	96	56	88
Acceptable																		
Not acceptable	12	22	4	8	1	2	12	24	2	5	3	5	10	16	2	4	8	12
No response	1	2					1	1										
Runway Touchdown Zone Lights																		
6. For continuing and landing, was the intensity of Runway Touchdown Zone Lights:																		
A. At 1000 ft bar	32	59	32	66	28	65	27	53	15	41	32	51	1	2	46	72	4	6
Too high																		
Acceptable																		
Too low	8	15	6	13			6	12	5	14	3	5	2	3	4	7	20	17
Not seen	13	24	10	21	15	35	17	33	17	45	26	42	12	19	12	22	21	33
No response	1	2					1	2										
B. At runway threshold	50	92	47	98	43	100	45	88	34	92	56	90	53	83	47	84	52	81
Acceptable																		
Not acceptable	3	6	1	2			6	12	2	5	6	10	11	17	9	16	12	19
No response	1	2																
C. At touchdown	53	98	46	96	41	96	45	88	36	97	57	92	52	81	44	79	58	91
Acceptable																		
Not acceptable							5	10	1	3	5	8	12	19	12	21	6	9
No response	1	2	2	4	1	2	1	2										
7. Do you feel that you could complete a landing with the visual guidance provided, from about the 1000 ft bar (assuming that you have proper alignment and altitude at the 1000 ft bar)?																		
Yes	37	68	37	77	35	81	45	88	29	78	51	82	59	92	55	98	54	84
No	10	19	6	13	5	12	4	8	6	16	9	15	5	8	1	2	9	14
No response	7	13	5	10	3	7	2	4	2	5	2	3					1	2
8. For guidance during rollout, was the intensity of the centerline lights acceptable?																		
Yes	32	59	39	81	39	91	39	76	34	92	58	94	52	81	52	93	56	88
No	21	39	8	17	4	9	13	24	3	8	4	6	12	19	4	7	8	12
No response	1	2	1	2														

1. Background brightness greater than 300 footlamberts
 2. Background brightness equal to or less than 300 footlamberts

B. Approach Lights. During the day in the early afternoon when the background brightness was greater than 300 footlamberts, about half of the responses indicated that the approach lights were satisfactory from the start of the approach (3,700 ft from threshold) to the 1,000-ft bar. During the latter part of the day (background brightness 300 footlamberts or less) the majority of the responses indicated that the approach lights were satisfactory in this portion of the approach. There are many comments by the pilot observers concerning the need for including the sequenced flashing lights in the approach light system. These lights were not available for the tests due to lack of time to design, procure, and install suitable units.

With regard to the question of identifying the 1000-ft bar, nearly all of the responses indicated that the 1000-ft bar was clearly identified during the night and during the day when the background brightness was 300-footlamberts or less. When the background brightness was greater than 300-footlamberts the majority of the responses indicated that the 1000-ft bar was clearly identified. Very few responses were obtained at very high background brightness so this condition could not be extensively evaluated.

The majority of the responses indicated that the intensity of the approach lights from the 1000-ft bar to threshold (Step 5, 20,000 cp without sequence flashers) was acceptable during the day. At night, nearly all of the responses indicated that intensity of the approach lights (Step 4, 4000 cp) was acceptable.

The pilot observers were asked to indicate a preference for the two approach light systems. During the day nearly all of the responses indicated a preference for the modified system. At night a majority of the responses indicated a preference for the modified system. The pilots comments indicated that there were mixed feelings concerning the need and usefulness of the red wing bars and red terminating bar in the present approach light system.

C. Threshold Lights. At the 1000-ft bar the pilots were asked if they could clearly identify the runway threshold lights. Most of the evaluation was conducted using green filters furnished by the National Bureau of Standards (15% to 20% transmittance). A limited number of evaluations were conducted with a white threshold, which was obtained simply by removing the green filters, resulting in approximately a five-fold increase in intensity. Only about half of the responses indicated that the green threshold could be clearly identified during the daytime when the background brightness was greater than 300 footlamberts. A majority of the responses indicated that the green threshold could be clearly identified during the day, when background brightness is 300 footlamberts or less and at night.

When the white threshold was used, the ability to clearly identify the threshold was slightly better than when the green was used. Although this was the case there were some very strong reservations expressed by the pilots concerning the use of white light for marking the runway threshold. A majority to nearly all of the responses indicated a preference for the use of a colored threshold in all test conditions.

D. Runway Centerline Lights. The observers were asked to evaluate several intensities of the runway centerline lights at three locations along the approach and landing as follows: at the 1000-ft bar, at runway threshold and at touchdown. In addition they were asked if the centerline lights provided sufficient guidance during roll-out after touchdown.

At the 1000-ft bar during the day between about half and a majority of the responses indicate that 2000 cp was acceptable. At night about half of the responses indicated that 1000 cp lights were acceptable.

At the runway threshold, nearly all of the responses indicated that 1000 cp was acceptable during all test conditions in the day and at night.

At touchdown, nearly all of the responses indicated that 1000 cp was acceptable during all test conditions in the day and at night.

During roll-out, nearly all of the responses indicated that 1000 cp was acceptable during all test conditions in the day and at night.

In general, for any particular intensity of the centerline lights, the intensity became more acceptable as the approach and landing progressed toward touchdown and roll-out. From the 1000 ft bar, the higher intensity of the centerline lights resulted in a greater acceptability. However closer to the threshold there is less difference in the acceptability between the various intensity settings.

E. Runway Touchdown Zone Lighting. The pilot observers were asked to evaluate the intensity setting of the runway touchdown zone lighting at three locations along the approach and landing as follows: the 1000 ft bar, the runway threshold, and at touchdown.

At the 1000-ft bar, during the day about half of the responses indicated that 7500 cp was acceptable. During the day about half of the responses indicated that the intensity of the touchdown zone lights was "too low" or not even seen. At night about half of the responses indicated that the 4000 cp was acceptable while a majority indicated that 7500 cp was acceptable.

At the runway threshold, during the day nearly all responses indicated that 7500 cp touchdown zone lights were acceptable, while at night both 4000 cp and 7500 cp were considered as acceptable.

TABLE 3 - SUMMARY OF DETECTION CONTRASTS

Test Conditions		Detection Contrasts									
Observer Position	Observed Distance	TZ	TZ	CL	CL	CL	CL	CL	CL	CL	CL
		7500 cp	4000 cp	7500 cp	2000 cp	1000 cp	500 cp	200 cp	100 cp	50 cp	20 cp
<u>Observer 500 ft from Threshold</u>											
<u>Daytime</u>											
	600	4.6	--	5.1	1.4	0.87	0.21	0.098			
	900	0.75	--	0.61	0.20	0.19	0.041	0.017			
	1200	0.042	--	0.14	0.062	0.025	0.0	0.0			
<u>Nighttime</u>											
	600	67(49)*	34	--	21(18)*	8.8(7.4)*	2.9	0.30			
	900	18	8.6	--	9.6	4.0	1.3	0.23			
	1200	0.96	0.31	--	0.36	0.098	0.11	0.05			
<u>Observer at Threshold</u>											
<u>Daytime</u>											
	600	5.8	--	4.3	1.9	1.0	0.50	0.93			
	900	0.78	--	0.77	0.49	0.37	0.11	0.045			
	1200	0.10	--	0.082	0.0067	0.0	0.0	0.0			
<u>Nighttime</u>											
	600	56	44	--	26	18	5.6	3.3			
	900	14	6.7	--	8.4	3.7	0.9	0.41			
	1200	1.1	0.16	--	0.18	0.022	0.0	0.0			

*White Threshold.

At touchdown during the day nearly all responses indicated that 7500 cp touchdown zone lights were acceptable. During the night nearly all responses indicated that 4000 cp touchdown zone lights were acceptable. Also between a majority and nearly all responses at night indicated that 7500 cp was acceptable (not glaring).

2. Brightness Measurements

The results of measurements of detection contrasts are summarized in Table 3. These data include four additional intensities that were not a part of the pilot evaluation test program, i.e., 200-cp and 7500-cp centerline lights in the daytime and 200-cp and 2000 cp centerline lights at night.

A. Runway Centerline Lights. Considering the daytime conditions first, the detection contrasts for 500-cp intensity runway centerline lights are below the practical usable minimum value of 0.15, except for distances of 600 ft or less ahead of threshold. Increasing the intensity to 2000 cp provided much greater detection contrasts (from four to six times). Increasing the intensity to 7500 cp shows further improvement but not in direct proportion. With 2000 cp the detection contrasts are in excess of the practical usable minimum value except at distances of 1200 ft ahead of the observer. It is to be expected that the detection contrast would be near the minimum usable value at 1200 ft since this is the distance used to establish the visual range. The contrast measurements during the day confirm the results of the pilot observations.

At night nearly all of the detection contrasts for 600-ft and 900-ft distances ahead of the observer for the centerline lights were in excess of the practical usable minimum of 0.30. The measurements taken at 1200-ft distance show that all of the intensities are reduced to values at or below the practical usable minimum values. However, because the contrasts for the 1000 cp intensity were so much greater than for the 500-cp intensity it is easy to see why the pilot preference was for the higher intensity.

B. Touchdown Zone Lights. The detection contrasts for the touchdown zone lights during the day and night were always larger than or near the practical usable minimum to a distance of 1200 ft ahead of the observation point when the intensity was 7500 cp. The detection contrasts for the 4000-cp intensity were not measured in the daytime but were at or above the practical usable minimum at night up to 1200 ft ahead of the observation point. These measurements also confirm the results of pilot observations.

3. Photographs

A. General Notes on Photographs. As mentioned previously, black and white photographs were taken along the glide path at the runway threshold

and 700 ft ahead of threshold with a cockpit cutoff angle of 15 deg. The photographs are shown in Figs. 16 to 25. During the day the photographs were taken when the background brightness averaged about 600 footlamberts and the variation from the average was small. However, during the summer when there is bright sunshine over a relatively thin layer of fog the background brightness can be considerably larger.

The photographs include three additional intensities of centerline lights which were not a part of the pilot evaluation test program. These are 200 cp and 7500 cp on 25-ft centers during the day and 2000 cp on 25-ft centers during the night.

In the printing and reproduction of photographs, attention has been given to portraying conditions as they appear when actually observed. It should be noted, however, that this objective is not entirely attainable, and conclusions should not be reached by examination of photographs alone. The contrasts in a photograph are normally far less than can be observed in real life. Nevertheless the following comments may be pertinent.

B. Approach Lights. As previously explained, the photographs were taken 700 ft ahead of threshold and therefore cover only the last few barrettes of the approach-light system. It is clear from the photographs why there was a greater preference by the observers for the modified system during the day than at night. During the day the touchdown zone and centerline lights were not clearly identified at 1000 ft ahead of threshold nor are they clearly identified in the photographs at 700 ft. The continuation of the white barrettes in the modified system provides the pilot with additional guidance information to the threshold. At night one sees the runway centerline and touchdown zone lights more clearly and hence the need for additional guidance information in the approach is not as great.

C. Runway Threshold Lighting. During the day the photographs indicate that the green threshold lights are clearly identifiable from 700 ft ahead of threshold and the majority of the pilot observers indicated that the lights were also clearly identified from 1000 ft when the background brightness was in excess of 300 footlamberts.

During the night the photographs indicate that the green threshold lights are clearly identifiable 700 ft from threshold. This tends to confirm the pilot observations wherein the majority of the responses indicated that the green threshold lights were adequate 1000 ft. from threshold. The photographs also show that when the green filters are removed the increase in scattered light enlarges the halo effect and therefore reduces the clarity of the runway touchdown zone and centerline lights beyond the threshold.

D. Runway Centerline Lights. An examination of the photographs during the day tend to confirm the results of the pilot observations. It should be remembered that the photographs were taken at 700 ft ahead of the threshold in order to get some of the runway lights to show on the prints without excessively flaring the approach lights. At the 1000 ft bar less than a majority of the pilot responses indicated that 2000 cp for the centerline was acceptable. No pilot responses were obtained for the 7500-cp lights. It should be noted that increasing the intensity of the centerline lights from 500 cp to 2000 cp (four times) does not appear to appreciably improve the length of the guidance segment. A photograph (Fig. 16) taken from 700 ft ahead of threshold is shown with 7500-cp centerline lights which clearly indicates that very high intensities are required to provide a clearly identifiable centerline during the day.

At the runway threshold the daytime photographs confirm the results of pilot observations and photometric measurements that 1000 cp provides a clearly identifiable centerline and that there appears to be very little gain in visual range when the intensity is increased from 1000 cp to 2000 cp.

The photographs also clearly indicate that runway marking becomes more identifiable at this location on the glide path than at 700 ft ahead of threshold.

At night the photographs appear to indicate that the 1000-cp centerline lights are clearly identifiable from 700 ft ahead of threshold. But less than a majority of the pilot responses indicated that 1000 cp was satisfactory 1000 ft from threshold. The observers judged the adequacy of the lights 1000 ft from threshold while the photographs were taken 700 ft from threshold. At the runway threshold the photographs confirm the pilot observation and photometric measurements that 1000 cp is adequate for guidance.

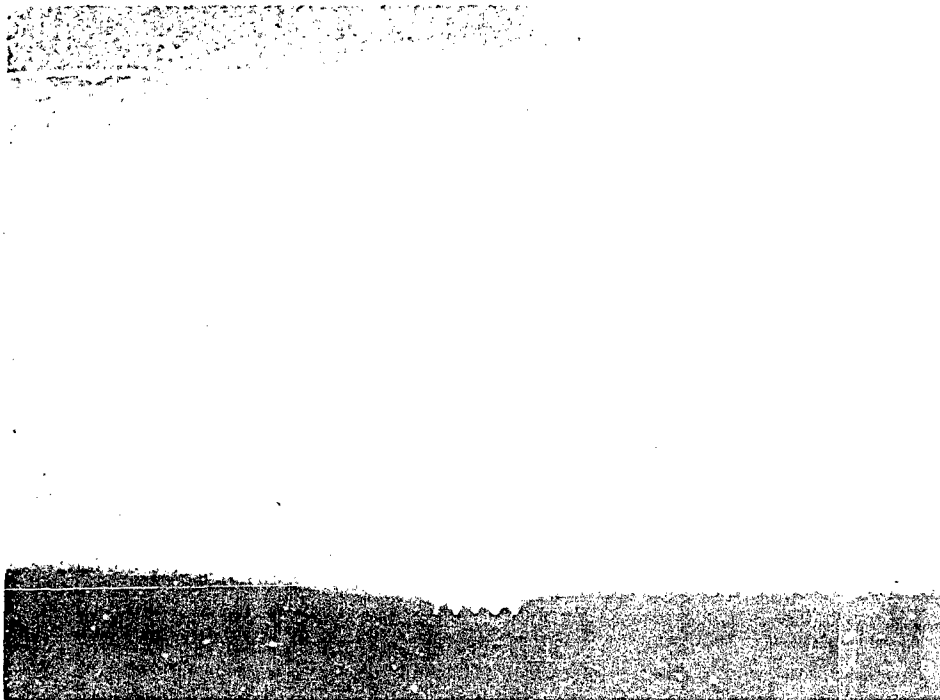
E. Runway Touchdown Zone Lighting. The photographs from 700 ft ahead of threshold would tend to confirm the consensus of the observer responses that during the day 7500 cp was marginal at 1000 ft from threshold. The photographs, photometric measurements and observer responses show that the touchdown zone lights are more acceptable at runway threshold. During the night it is evident from the photographs at 700 ft why nearly all of the responses indicated that 7500 cp was adequate. At the runway threshold the photographs verify the pilot observers comments that either 4000 cp or 7500 was acceptable.

F. General Comments. If the fog is uniform and the visual range is 1200 ft, the distance a pilot can see at 700 ft from threshold on a 2-1/2-deg glide path with a cockpit cutoff angle of 15 deg will be a horizontal

distance of a little less than 800 ft along the ground (see Fig. 9). The photographs show that at night one can see the lights for a distance of 800 ft or more but this is not the case during the day. This is partly due to the limitations of photography and partly due to the definition of visual range. This points up to the desirability of relating the amount of lighting to the visual range which the pilot needs to see to provide him with adequate guidance. In the test program the visual range was measured by observers on the ground counting the number of 10,000-cp sources they could see while the pilot observers were viewing an assortment of intensities along the glide path.



A. Touchdown zone 7500 cp; centerline 500 cp.
Standard approach system



B. Touchdown zone 7500 cp; centerline 1000 cp.
Standard approach system.

Fig. 16 - Daytime tests; observer at 700 feet before threshold
(approach and edge lights at Step 5).



A. Touchdown zone 7500 cp; centerline 2000 cp.
Standard approach system.



B. Touchdown zone 7500 cp; centerline 2000 cp.
Modified approach system.

Fig.17 -- Daytime tests; observer at 700 ft before threshold
(approach and edge lights at Step 5).

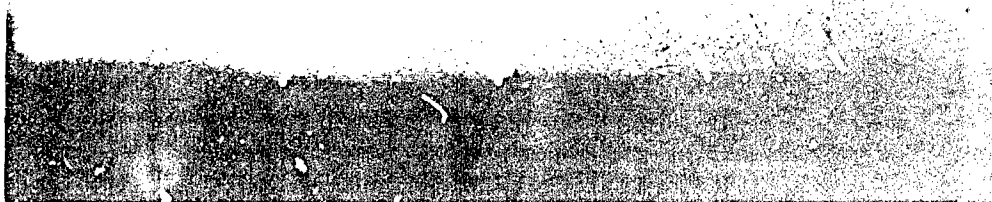


A. Touchdown zone 7500 cp; centerline 200 cp.



B. Touchdown zone 7500 cp; centerline 500 cp.

Fig. 18 - Daytime tests; observer at threshold (approach and edge lights at Step 5).

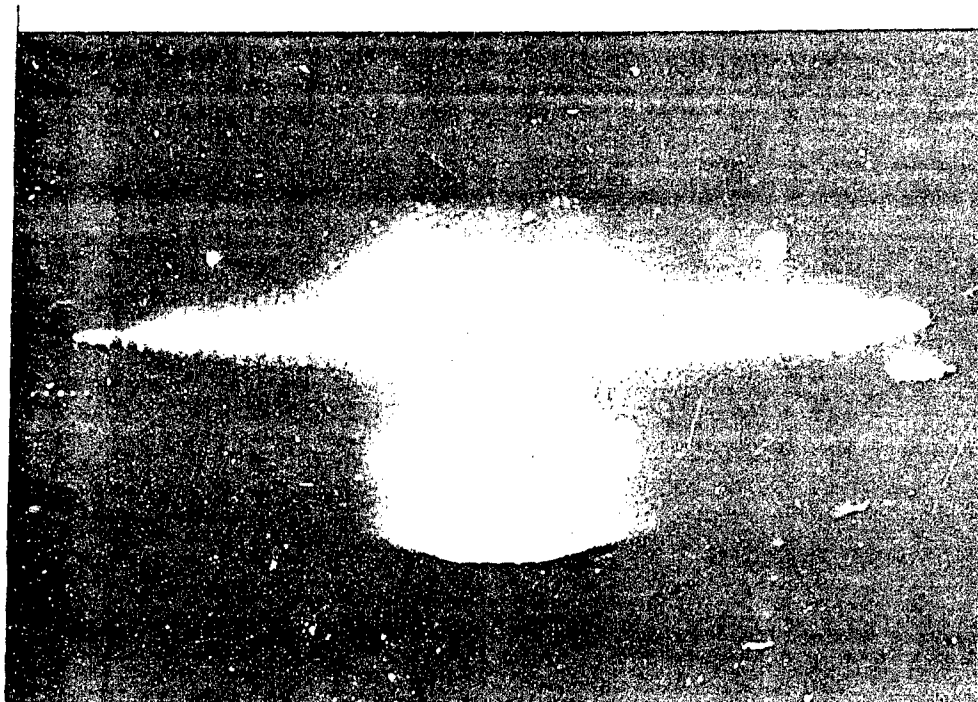


A. Touchdown zone 7500 cp; centerline 1000 cp.



B. Touchdown zone 7500 cp; centerline 2000 cp.

Fig. 19 - Daytime tests; observer at threshold (approach and edge lights at Step 5).

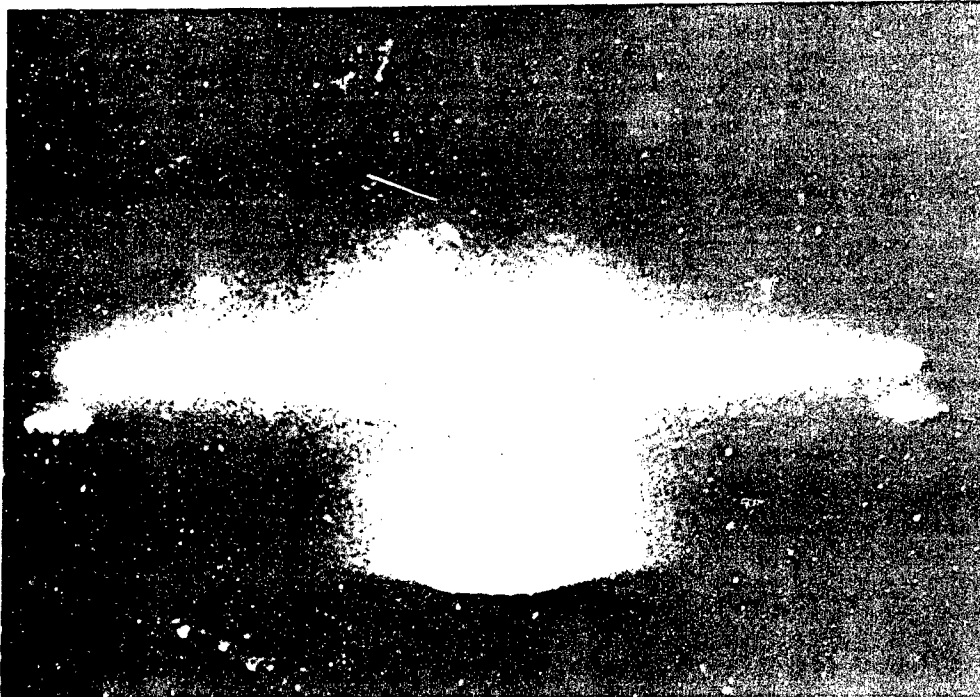


A. Touchdown zone 4000 cp; centerline 500 cp.
Standard approach system.

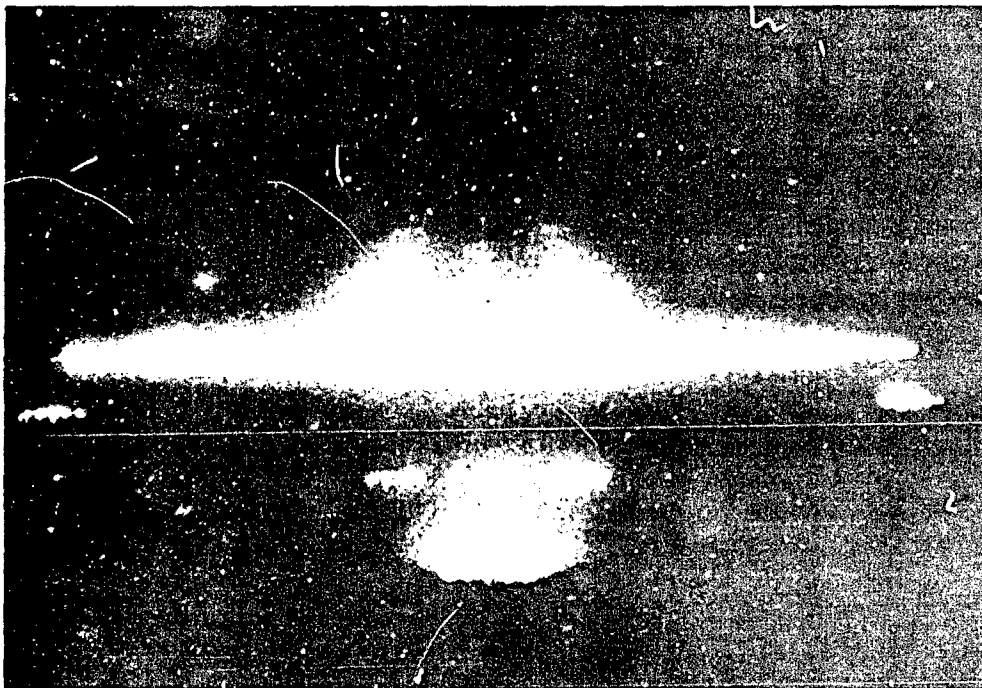


B. Touchdown zone 4000 cp; centerline 500 cp.
Modified approach system.

Fig.20 - Night tests; observer at 700 ft before threshold (approach and edge lights at Step 4).

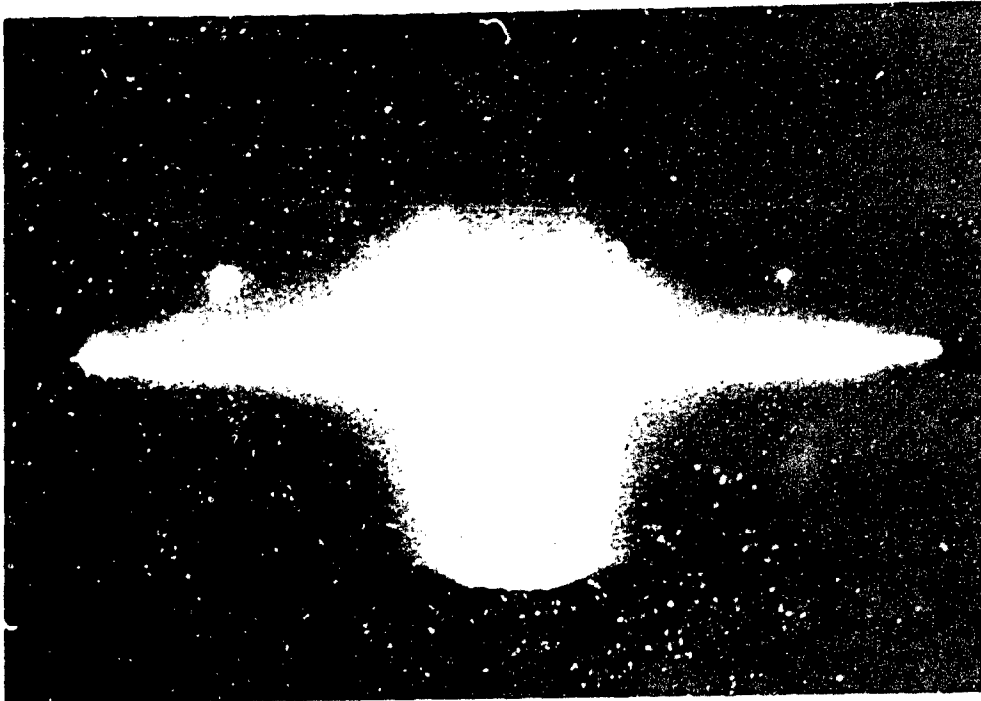


A. Touchdown zone 7500 cp; centerline 500 cp.
Standard approach system.

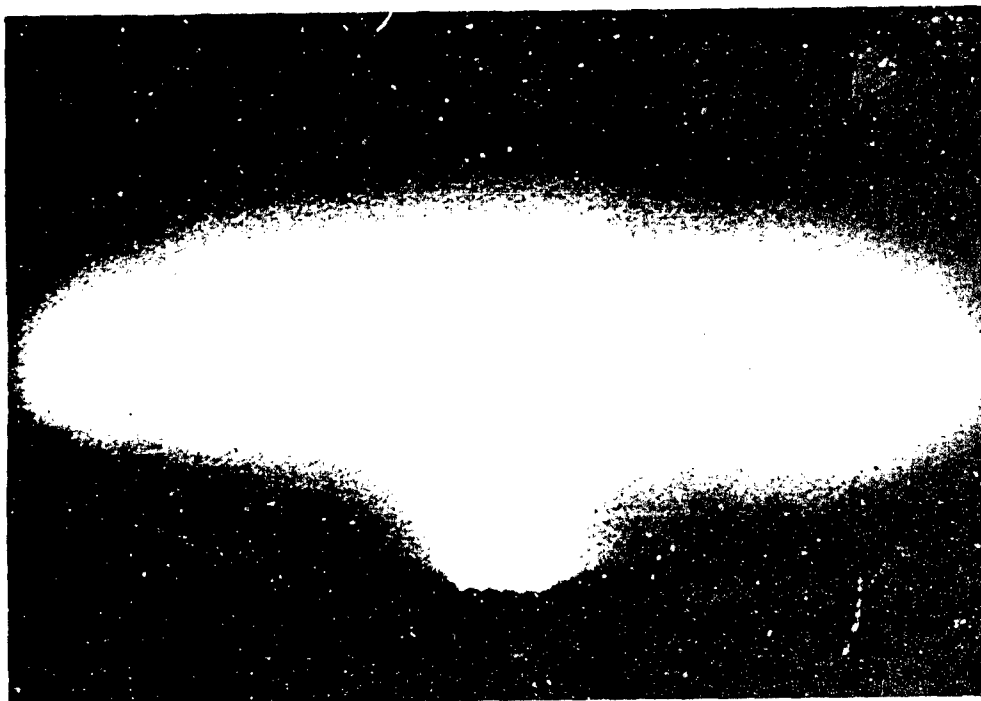


B. Touchdown zone 7500 cp; centerline 1000 cp.
Standard approach system.

Fig. 21 - Night tests; observer at 700 ft before threshold (approach and edge lights at Step 4).

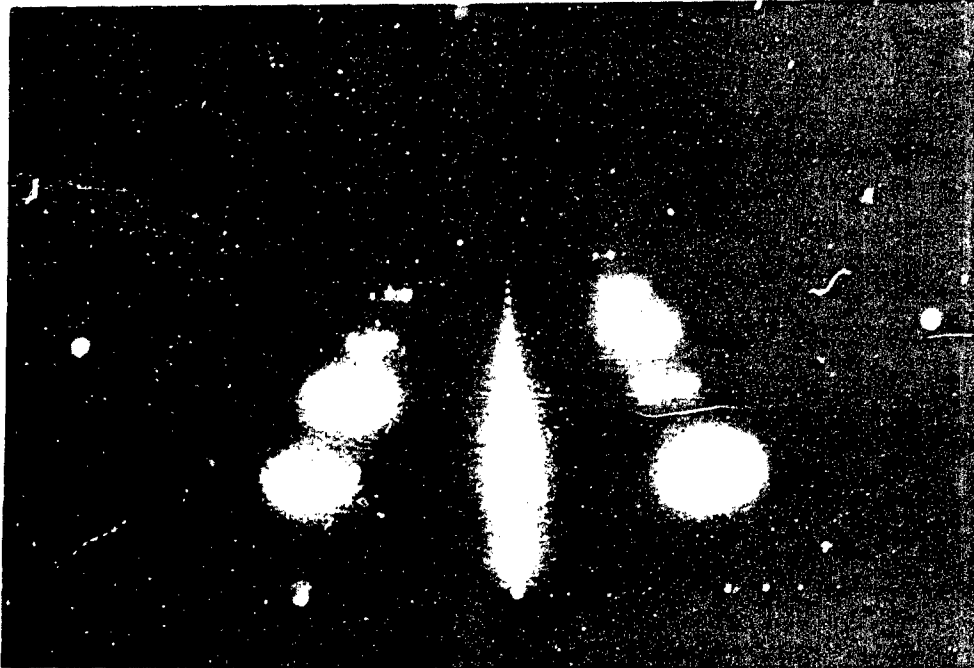


A. Touchdown zone 7500 cp; centerline 1000 cp.
Modified approach system.



B. Touchdown zone 7500 cp; centerline 1000 cp.
Modified approach system with white threshold.

Fig. 22 - Night tests; observer at 700 ft before threshold (approach and edge lights at Step 4).



A. Touchdown zone 4000 cp; centerline 500 cp.



B. Touchdown zone 7500 cp; centerline 1000 cp.

Fig. 23 - Night tests; observer at threshold (approach and edge lights at Step 4).



A. Observer at 700 ft before threshold.
Modified approach system.

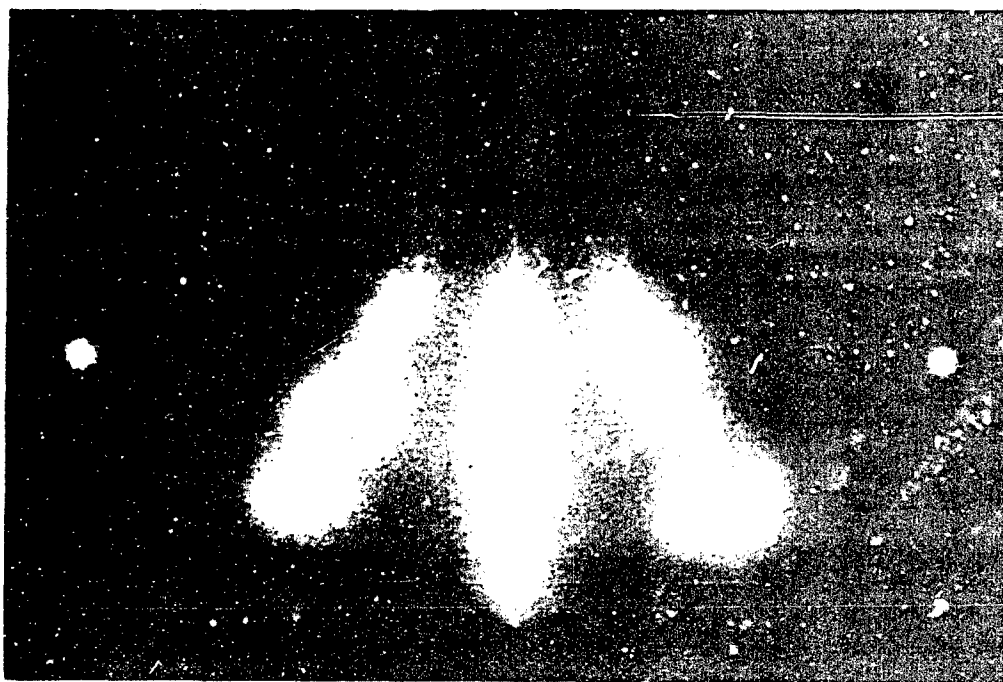


B. Observer at threshold.

Fig. 24 - Daytime tests; touchdown zone 7500 cp; centerline 7500 cp
(approach and edge lights at Step 5).



A. Centerline 500 cp.



B. Centerline 2000 cp.

Fig. 25 - Night tests; observer at threshold; touchdown zone 7500 cp;
(approach and edge lights at Step 4).

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FACTORS AFFECTING THE RESULTS

Some of the factors that affect the results and conclusions of the tests have already been mentioned in the preceding pages of this report. A few of these factors should again be passed in review. They are important to keep in mind when you digest the next two sections on "Conclusions" and "Recommendations".

Pinning Down the Position In Space. During the tests, the observers were asked to evaluate the intensity of the threshold, touchdown zone, and centerline lights from two positions along the glide path: 1000 ft. from threshold and at threshold. Since there was no indicator available in the cockpit to give the pilot accurate information concerning his arrival at these two positions, the best he could do was to judge the situation for himself. This is difficult to do with precision when one is concentrating on the lights. The situation is more critical at the 1000-ft. position than it is at threshold. At the instant the 1000-ft. bar of the approach lights disappears from view due to a 15 deg cockpit cutoff angle, the pilot's eye is about 600 ft. in horizontal distance ahead of this bar and about 1600 ft. ahead of threshold. Near the threshold the horizontal distance is about 400 ft. at the instant the threshold lights disappear from view. While there is no evidence that an accurate indication of position would have materially influenced the results, it would seem to be a point to keep in mind.

The Cockpit Cut-Off Angle. Another factor which is important is the cockpit cut-off angle. While the observers were encouraged to view the lights with a cutoff angle of 15 deg using a reference in the cockpit, each observer adjusted his seat as he saw fit. When the cut-off angle is 15 deg and the pilot's eye height is 126 ft, the horizontal distance seen on the ground is about 700 ft; but if the angle is reduced to 13 deg, the horizontal distance is reduced to about 625 ft. The point is that different seat adjustments by different pilot observers could change the cockpit cut-off angle and possibly affect the results.

Experience Background of Pilot Observers. Generally speaking, most of the pilot observers who participated in the tests were evaluating the lights in a visibility which most of them had not experienced in real life. In any subjective analysis, experience has an influence on the reaction of the observer. In addition, most of the observers had not flown in aircraft with devices for reducing pilot workload now being planned by some airlines. There is an additional item worthy of note in this regard: some of the pilots had not made landings at airports with touchdown and runway centerline lights for the simple reason that very few airports are so equipped at present. The question thus arises as to whether or not appropriate operational experience in 1200 ft. visual range conditions with the full blown system would have changed their answers substantially.

The Problem of Measuring the Fog. It may bear repeating that the visual range for these tests was not measured by a transmissometer but by human observers on the ground counting the number of 10,000 cp light sources they could see. Due to possible background brightness differences for the ground observer and the pilot observer, different detection contrasts could result with the consequence that the visual range viewed by a ground observer may not be the same as the visual range viewed by the pilot observer. Some of the pilot observers tried to equate the 1200 ft. visual range condition in the fog chamber with 1/4 mile visibility conditions in real life. Their general conclusion was that the 1200 ft visual range condition used in the Category II tests in the fog chamber was a denser fog than encountered at an airport reporting 1/4 mile visibility conditions.

Background Brightness Again. The results of this and previous test programs confirm what has been known for a long time, that is, that during a day when the background brightness is high, the intensity required to provide adequate contrast is extremely high. The work in the fog chamber thus far clearly demonstrates that background brightness has a profound effect on the number of lights that a pilot will effectively see. The background brightness is a parameter which must be considered in the design of a lighting system if lighting is to be used as a visual aid during the day. This brings forth the question of "what is the frequency of bright daylight fog at the big jet airports?" Also, where, exactly, is the point of economic no-return in attempting to provide lights of high enough intensities to penetrate bright daylight fogs. The answers to these questions are, of course, beyond the scope of this report.

CONCLUSIONS

Based on the test results recorded in this report for Category II operations it appears that:

1. Approach Lighting: The U. S. standard approach light system does a good job in 1200 ft. visual range conditions, but a slight modification near the threshold will improve it, i.e., continue the white barrettes straight through to 100 ft. from threshold.
2. Threshold Lighting. Presently used threshold lights need to be "beefed up" to make their green light output more nearly comparable in coverage and brightness to the above ground approach lighting fixtures.
3. Runway Centerline Lights. For daylight operations in 1200 ft. visual range the runway centerline should have a capability of 2000 cp, and it should be noted that most of the pilot observers considered these lights to be a primary element of guidance during landings in low visibility.
4. Touchdown Zone Lights. The standard touchdown zone lights of approximately 7500 cp are acceptable, although marginal, for bright day fogs of 1200 ft. visual range.
5. Runway Markings. For daytime operations in Category II weather conditions distinctive runway markings are an important backup for lighting systems. This is particularly true in ground fog with bright sunshine above.

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Federal Aviation Agency, Systems Research and Development Service, Environmental Development Division, Wash., D.C. From data by Univ. of Calif. under FAA Contract A818-134. FOR CHAMBER TESTS OF CATEGORY II APPROACH, TOUCHDOWN AND RUNWAY CENTERLINE LIGHTING SYSTEMS, L. Vipond, Project Mgr. Interim Report, Nov. 1964, 44 pp., incl. 25 illus. (Project No. 430-201-01E, Report No. RD-64-107)

Unclassified Report

Report describes testing of airport lighting systems in day and night fog conditions utilizing a very large chamber and producing fog by compressed air and water through nozzles installed along the side of the chamber. The test results reported are those for restricted visibility conditions defined as Category II, wherein the visual range was 1200 ft. Peak candlepower values and photometric distributions required for Category II operations were determined during the tests covered by this report. Various patterns of lights were installed on the floor of the chamber and simulated approaches and landings were made through the fog using a total of 36 experienced pilot observers. The observers rode in an airplane cockpit suspended from overhead rails. The tests showed that present visual aids could be considered adequate, although marginal, for Category II operations.

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- II. Project No. 430-201-01E
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