LIGHTING PATTERN DISTORTION CAUSED BY RAIN ON AN AIRPLANE WINDSHIELD

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SUMMARY

This report describes a limited series of observations to study the effectiveness of airport lights and light patterns when viewed through an airplane windshield during rainfall It was found that the rain between the windshield and the lights being viewed caused some obscuration but little distortion The visual distortion caused by the uneven surface of the water film on the glass was determined to be a function of the rate of water interception per unit area of the windshield The water on the windshield tends to broaden the image of the lights, thus reducing the effectiveness of geometric patterns of lights and obscuring their positional relationship with respect to other elements on the airport

It was found that the maximum rainfall rate that can be tolerated without the use of windshield wipers is approximately one-half inch per hour, assuming an airplane speed of 120 miles per hour (mph) The use of an anti-wetting agent on the windshield greatly reduces the distortion and results in effectiveness of the lights at rainfall rates of two to three inches per hour

INTRODUCTION

It is a common experience to anyone who has looked through a rain-streaked window or has driven a car in the rain to see everything blurred and distorted This effect is even more marked in the case of the pilot of an aircraft The most difficult viewing tasks for the airplane pilot occur during approach and landing operations, particularly at night The pilot is then dependent on a pattern of white and colored lights which he must be able to see and interpret correctly These lights are signal lights rather than lights to illuminate the surrounding area It is of the utmost importance, therefore, that they can be seen in their true relationship to each other and that the pattern with respect to the runway can be determined Any distortion of the lighting pattern will hinder the pilot's effort and may delay or even prevent the landing of the airplane

The visual difficulties arising under conditions of rainfall can be assumed as resulting from the following factors

1 The rain between the airplane and the lights
2 The layer of water on the windshield
3 The effect of the air stream on the water on the windshield

Rain in the atmosphere between the airplane and the lights will reduce the visibility of the lights In addition to this reduction in visual range, the individual drops will cause scattering of the light and will tend to produce a halo around each light source This condition is particularly evident when the droplets become small enough to result in fog instead of precipitation

The distortion resulting from the water flow over the windshield is caused by the varying thickness and nonuniform surface of the water The curvature of the water surfaces causes the light incident on these surfaces to be refracted to varying degrees, and the image formed by this light is consequently distorted and partially obscured In effect, the raindrops and water streaks form random lens surfaces over the wet area of the glass This condition is magnified in a moving aircraft because its windshield intercepts a quantity of water that is nearly proportional to its forward velocity

The air stream blowing across the windshield during flight can have two counteracting effects The motion of the air serves to blow the water off the windshield, thus tending to prevent the formation of a thick layer of water With suitable flow lines, the air stream can even prevent some of the water from striking the windshield by deflecting the raindrops upward and sideways before they are intercepted by the glass However, the effect of the air stream on water which does reach the windshield is to produce streaks, thus resulting in less uniformity of the water surface on the glass

This report covers a limited study of the importance of rainfall as a limiting factor in the effectiveness of signal lighting systems, such as approach lights or runway lights

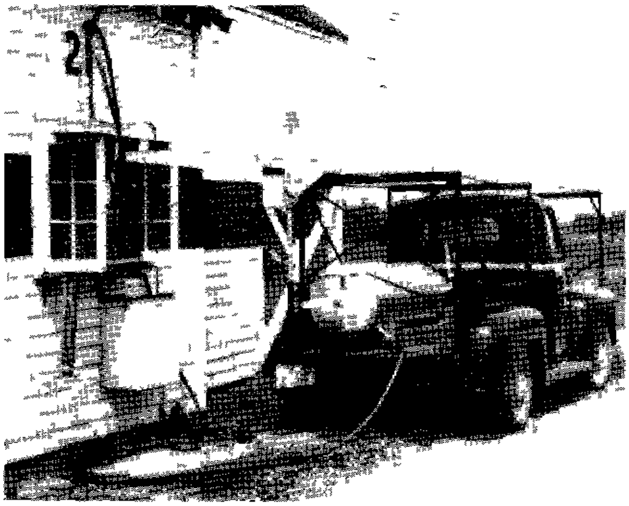

Fig 1 Test Equipment Setup

PROCEDURE

Visual effects were determined by direct observation, and photography was selected as the best means of recording the observed effects The most direct way to investigate the visual distortion under actual operating conditions would have been to make observations and take motion pictures through the windshield of an airplane engaged in landing operations during rainfall Consequently, a mount for a motion-picture camera was installed on the back of the pilot's seat of a C-47 airplane in such a position that the camera could be aimed through a portion of the windshield not covered by the windshield wipers It proved impractical to accumulate sufficient data by this means because of the inability to obtain an airplane on short notice when there was sufficient rainfall to perform the experiments and because the air traffic problem is more acute during rainfall than in clear weather Because of these difficulties the study was broken down into three parts, one for each of the possible factors affecting distortion, as listed previously

1 The Rain Between the Airplane and the Lights

The effect of rain in the atmosphere between an observer and a pattern of signal lights was determined by viewing and photographing the slope line approach lights through natural rain without use of a windshield and without relative motion between the lights and the observer The observers and camera were sheltered by a small building which was available in the southwest approach area of Weir Cook Municipal Airport, Indianapolis

2 The Layer of Water on the Windshield

A windshield was mounted in a window opening of the same building in order to determine the effect of various rates of water flow across it Water for the study was supplied from a tank mounted on a truck A small air compressor was provided to maintain pressure in the tank, and a variable-stream nozzle was used to spray the desired amount of water on the windshield One half of the glass was treated with an anti-wetting agent [1] The run-off water was collected in a trough and the rate of flow was measured with a water meter The test setup is illustrated in Fig 1

A grid consisting of white lines against a black background was arranged so that it could be mounted immediately in front of the windshield when desired The visual angle subtended by the individual lines of the grid at the distance from which it was photographed was approximately the same as that angle subtended by the individual linear light sources of the approach system from a distance of one-half mile

With these setups, photographs were made of the approach light units and of the grid, with varying rates of water flow over the windshield Windshield wipers were not used, because simulation of the worst possible condition was desired The method of calculating the rate of flow of water corresponding to a given operating condition is outlined in the Appendix

3 The Effect of the Air Stream on the Water on the Windshield

The same water tank and truck shown in Fig 1 were used to determine the effect of the air stream blowing across the windshield The hose and nozzle were attached to the truck so that the water flowed over the truck windshield, part of which was treated with the anti-wetting agent Motion pictures of high intensity runway lights were made through the windshield when the truck was standing still and when the truck was traveling along a runway at about 60 mph The quantity of water striking the windshield per unit time was the same in both cases Windshield wipers were not used

DISCUSSION OF RESULTS

More than 200 still photographic records and 150 feet of motion-picture film

[1] The anti-wetting agent used for these tests was a wax known commercially as "FC-10" It was originally developed by the National Research Council of Canada, Ottawa, Canada

Fig 2 Slope Line Approach Lights Photographed During Heavy Rainfall

were taken during this study It should be recognized that a photograph can show the condition existing at only one particular instant and may fail to present the integrated visual effect noted by observers As a result, the pictures used in this report are those selected by the observers as the best records of their visual impressions

Fig 2 is a night photograph of the slope line approach lights taken from the building in the approach area during very heavy rain Unfortunately, the rainfall was highly variable, and it was impossible to obtain an accurate measurement of the rate at the time the picture was taken It was estimated at one inch per hour The photograph shows some halation around the individual light sources, but it is not sufficient to destroy the effectiveness of the pattern, and the visibility is adequate for beyond 1300 feet Because of the minor distortion caused by the rain in the atmosphere, it was determined that the greater part of the distortion of light patterns usually seen by pilots at night was caused by the rain actually hitting the windshield It was therefore possible to continue by concentrating on a study of the effect of water on the windshield by use of artificial rain

Figs 3 through 6 are reproductions of a few of the photographs taken to study the effect of varying the rate of water flow over the windshield The calculations to determine the rainfall rate that is being simulated are based on an airplane speed of 120 mph At approximately this speed the quantity of water intercepted by the windshield per unit time is very nearly in direct proportion to the speed, as can be determined from the relationships shown in the Appendix

Fig 3 shows slope line approach lights in three photographs obtained through an untreated windshield at varying simulated rainfall rates The lowest rainfall rate of 0 6 inch per hour shown in this figure appears to be the upper limit of tolerance from a consideration both of distortion and of obscuration The views of the co-ordinate grid, Fig 5, confirm the same results, Figs 5B and 5C show distortion and obscuration above the limit of effectiveness In Fig 5A, where the rainfall rate is 0 4 inch per hour, the distortion and obscuration are not sufficient to destroy the effectiveness of the pattern

From Figs. 3 and 5, it is seen that rainfall rates of 0 6 inch per hour or more cause too great a water flow over the windshield of the airplane and result in excessive distortion and obscuration of the view Rainfall rates of 0 4 inch per hour do not seriously affect the usefulness of the lights and light patterns From this evidence, an upper limit of 0 5 inch per hour was selected as a maximum tolerance value

A study of hourly rainfall observations made at Indianapolis shows that during the year 1951 a rainfall of 0 5 inch was exceeded during only 0 1 per cent of the time It must be emphasized that rainfall rates are highly variable and that rates greater than 0 5 inch per hour often occur for short periods, even though sustained periods of heavy rain are rare Information obtained from a report published by the U S Corps of Engineers on rainfall and runoff data at an airfield in the

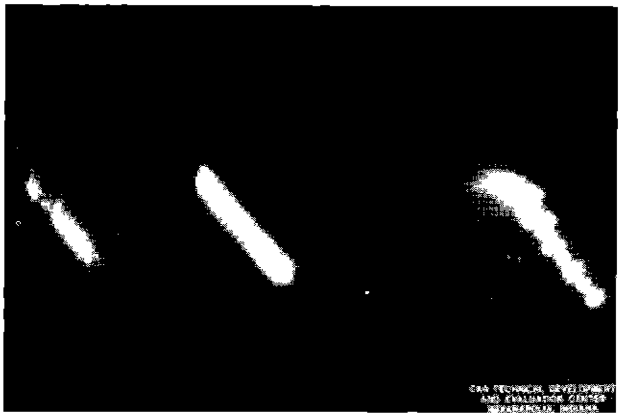

Fig 3A Slope Line Approach Lights Photographed Through Untreated Windshield Rainfall 0 6 Inch Per Hour

Fig 3B Slope Line Approach Lights Photographed Through Untreated Windshield Rainfall 0 9 Inch Per Hour

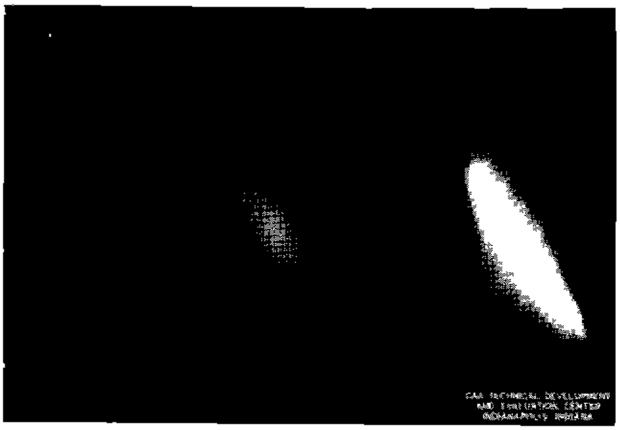

Fig 3C Slope Line Approach Lights Photographed Through Untreated Windshield Rainfall 1 2 Inches Per Hour

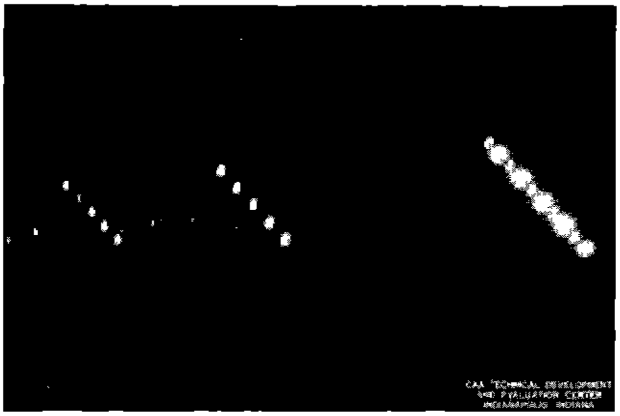

Fig 4A Slope Line Approach Lights Photographed Through Windshield Treated with Anti-Wetting Agent Rainfall 0 9 Inch Per Hour

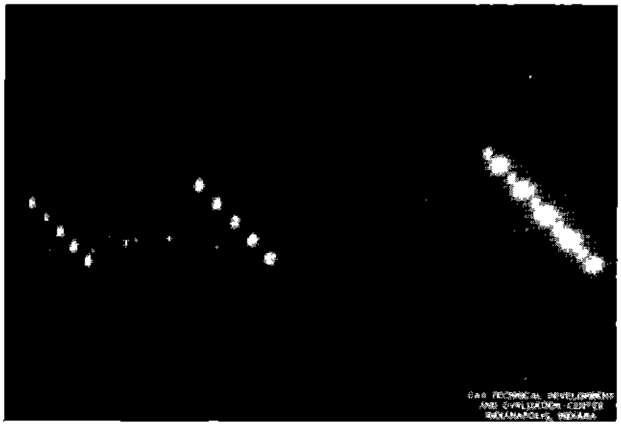

Fig 4B Slope Line Approach Lights Photographed Through Windshield Treated with Anti-Wetting Agent Rainfall 1 5 Inches Per Hour

Fig 4C Slope Line Approach Lights Photographed Through Windshield Treated with Anti-Wetting Agent Rainfall 2 4 Inches Per Hour

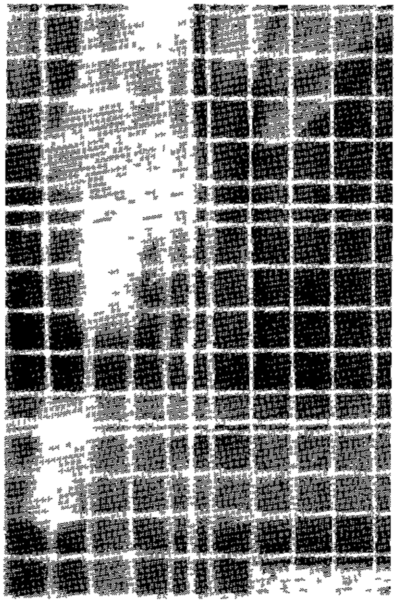

Fig 5A Co-ordinate Grid Photographed Through Untreated Windshield Rainfall 0 4 Inch Per Hour

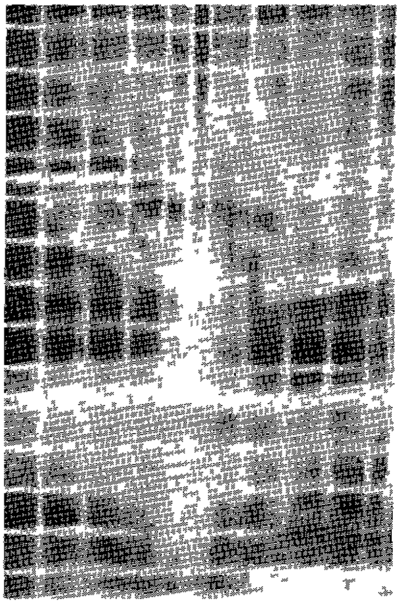

Fig 5B Co-ordinate Grid Photographed Through Untreated Windshield Rainfall 0 8 Inch Per Hour

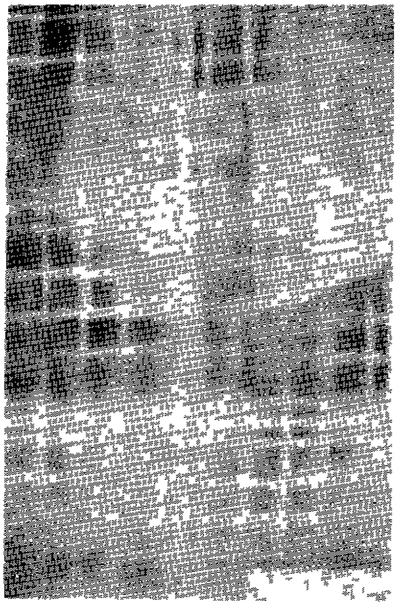

Fig 5C Co-ordinate Grid Photographed Through Untreated Windshield Rainfall 1 1 Inches Per Hour

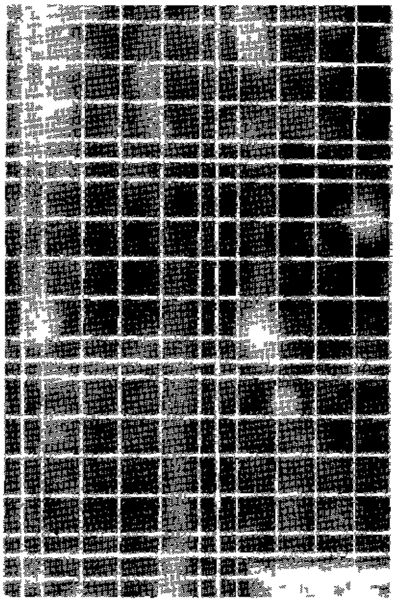

Fig 6A Co-ordinate Grid Photographed Through Windshield Treated with Anti-Wetting Agent Rainfall 1 3 Inches Per Hour

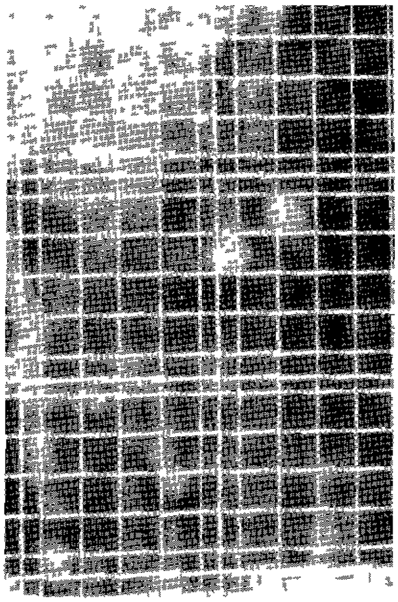

Fig 6B Co-ordinate Grid Photographed Through Windshield Treated with Anti-Wetting Agent Rainfall 2 0 Inches Per Hour

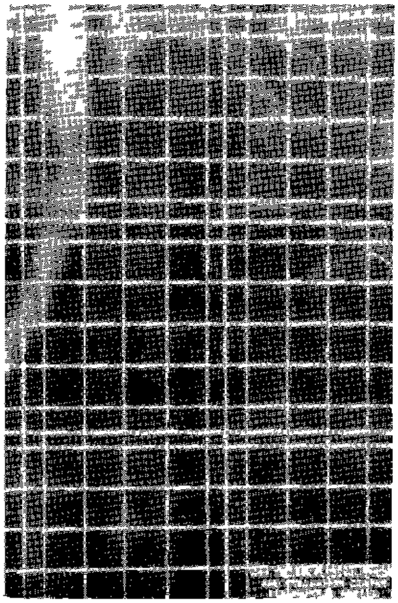

Fig 6C Co-ordinate Grid Photographed Through Windshield Treated with Anti-Wetting Agent Rainfall 3 3 Inches Per Hour

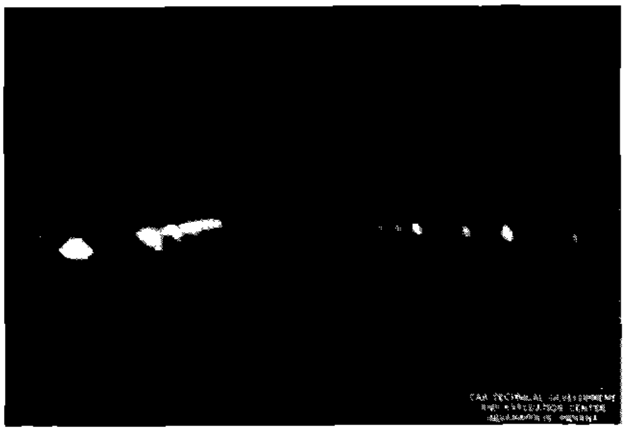

Fig 7 Photograph of High Intensity Runway Lights Through Water-Covered Truck Windshield (Right Half Treated with Anti-Wetting Agent) Truck Standing Still on Runway

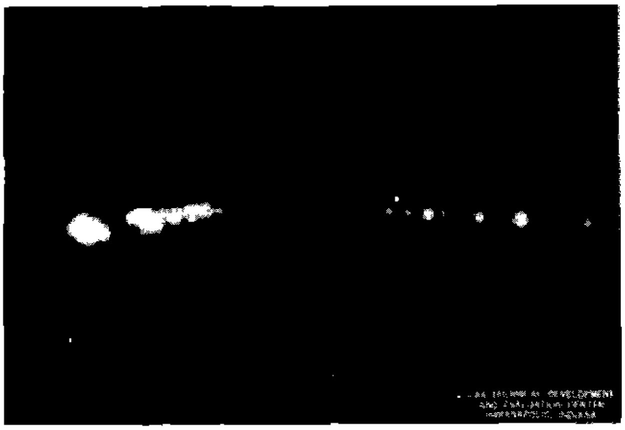

Fig 8 Photograph of High Intensity Runway Lights Through Water-Covered Truck Windshield (Right Half Treated with Anti-Wetting Agent) Truck Moving Along Runway at Sixty Miles Per Hour

Indianapolis area illustrates this point well[2] This report tabulates rainfall rate data covering the two years from August 1944 to August 1946 These rates were determined for periods as short as one minute During these two years, there were only about nine hours total time during which the rainfall rate exceeded 0 5 inch per hour, and the longest continuous rainfall exceeding this rate was 37 minutes long For periods of five minutes or less, however, rates of four to six inches per hour were not uncommon

Fig 4 shows views similar to those of Fig 3, but these were taken through a windshield treated with the anti-wetting agent There was no distortion or obscuration even at the high rainfall rates simulated Similar results were obtained from the views of the co-ordinate grid shown in Fig 6

Figs 7 and 8 are enlargements of motion-picture frames taken to determine the effect of the air stream on the water flow over the windshield The right half of the photographs were made through treated glass and the left half through untreated glass Fig 7 is a view looking down the runway from the truck standing still, Fig 8 shows a view from the truck which was traveling along the runway at 60 mph The rate of water flow was set with the truck standing still so that the lights as viewed through the untreated part of the windshield were at the limit of their effectiveness Since the rate of water flow was not changed at any time, the only difference observed with the truck in motion would be due to the air flow Although there is a slight increase in the halation at each light with the truck in motion, the effect is small compared to the increased distortion resulting from increasing the rainfall rate on the windshield as illustrated in Fig 3

Fig 9 is an enlargement of a motion-picture frame taken from an airplane during a comparatively light rainfall There is some reduction in visibility but practically no distortion Note the streaks of water flowing upward and to the left Fig 10 shows a similar photograph taken in 1949 during experimental landing operations at the Landing Aids Experiment Station, Arcata, California The distortion of the left row of lights shown in this figure is excessive since it was caused by water from the wash of the windshield wiper However, it does illustrate the possible effect that can result from extremely heavy water flow on the windshield

CONCLUSIONS

From the data presented, it can be concluded that the distortion resulting from rain during flight is almost wholly a result of the quantity of water intercepted by a unit area of windshield per unit time The correlation between greater distortion of light patterns and increased quantities of water presumably results from the greater possibility of less

[2] War Department, Corps of Engineers, Ohio River Division, "Report on Drainage Verification at Military Establishments, Appendix II, Rainfall and Runoff Data," Louisville Engineer District, Louisville, Ky , June 1947, pp 21-41

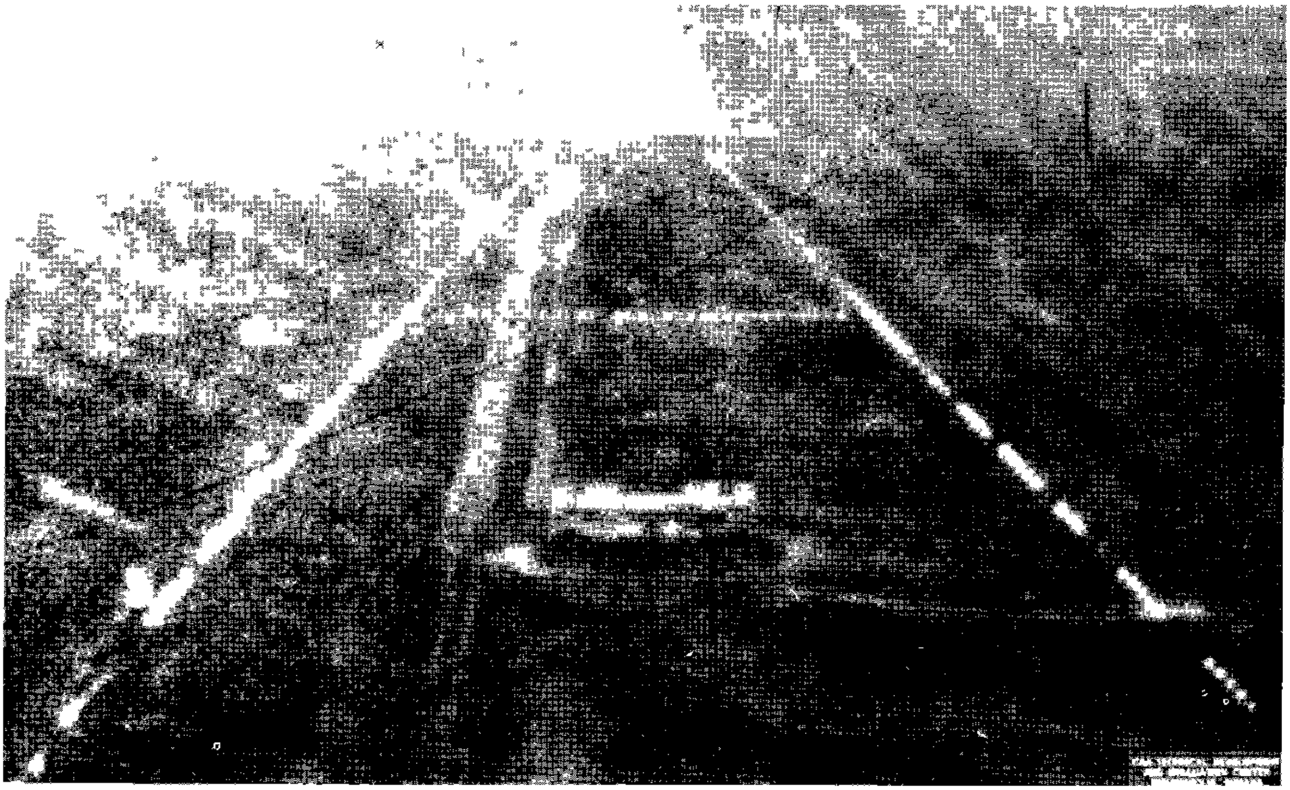

Fig 9 Slope Line Approach Lights at Indianapolis During Light Rainfall (0 02 Inch Per Hour)

Fig 10 Approach and Runway Lights at Landing Aids Experiment Station, Arcata, Calif Showing Distortion Resulting From Water on Windshield

uniformity in the thickness of the layer of the water on the windshield as the thickness increases

At normal approach speeds the light patterns would not be too adversely affected even without windshield wipers if the rainfall were about 0 5 inch per hour or less on untreated windshields When the windshields were treated with an anti-wetting agent, rainfall of four or five times this rate could be tolerated

APPENDIX

In order to simulate the rainfall on the windshield of an airplane traveling through space at a given velocity, it was necessary to know the quantity of water incident on such a surface per unit time For normal airplane maneuvers, the quantity of water striking the windshield per unit time (in cubic inches per second) may be expressed to a close approximation by

$$Q = Vv_h A(\cos \theta) + Vv_v A (\sin \theta)$$

where

A = wet area of the windshield, in square inches

θ = angle of windshield from vertical

v_h = horizontal velocity of windshield with respect to rain, in inches per second

v_v = vertical velocity of rain with respect to ground, in inches per second

V = volume concentration of water in space, in cubic inches per cubic inch

The first term of the equation represents the water collected by the vertical projection of the windshield The second term represents the water collected by the horizontal projection The quantities A, v_h, and θ are either known or can be easily measured It was necessary to determine v_v and V experimentally These unknown factors are not independent, their product is the depth of rainfall collected on the ground per unit time Thus, if either one is known, the other can be determined for any given rainfall

The vertical velocity of rainfall was determined by photographing rain against a co-ordinate grid background with a camera whose shutter speed had been accurately calibrated An average of 50 such determinations gave a vertical velocity of 236 inches per second This value is within the range of raindrop velocities determined theoretically by Green [3] Knowing this value of v_v, V may be calculated for any given rainfall, and these values together with the known values of A, v_h, and θ may be substituted in the equation for Q

[3] Green, Robert L , "Evaluation of Air Resistance to Freely Falling Drops of Water," Agricultural Engineering, Jan 1952, Vol 33, No 1, p 28

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