DEVELOPMENT OF HELICOPTER BLADE TIP LIGHTING

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SUMMARY

This report describes the further development of blade-tip lighting for helicopters. The program was conducted through the co-operation of the Department of the Air Force, the Department of the Navy, General Electric Company, Westinghouse Electric Corporation, and the Technical Development and Evaluation Center of the Civil Aeronautics Administration.

Special high-intensity lighting units were developed to be housed in the blade tips, which were modified to accomodate the units and to include clear plastic windows. The mass dynamics and the aerodynamic contours of the tips were unchanged.

Special lamps having high-strength filaments and having intensities of 32, 35, and 50 cp were developed. Flight observations were conducted with the 50-cp lamps installed in the tips. This arrangement was visible from a distance of 6 1/2 miles on a relatively clear night and with a background of city lights, and the aircraft could immediately be distinguished as a helicopter. This lighting system required less than 300 watts of electrical power and it showed promise from the standpoint of both commercial and military usage.

INTRODUCTION

The requirements for external aircraft lighting are that they

1. Attract the attention of the pilot of other aircraft.
2. Identify the aircraft as an aircraft and broadly identify the type.
3. Indicate what maneuvers the aircraft is making.

Helicopters and fixed-wing aircraft have very different flying characteristics. Therefore, they require distinct types of lighting.

The Naval Air Test Center, Patuxent River, Maryland, undertook the development of a distinct type of lighting for helicopters and prepared development specifications for helicopter blade-tip lighting.[1] This development was continued by the Naval Air Test Center through a contract with Sikorsky Aircraft Division of United Aircraft Corporation, Bridgeport, Connecticut. Two sets of metal blades and one set of fabric blades were equipped with tip lighting and were delivered to the Naval Air Test Center in May 1950. The two sets of metal blades were damaged in flight before sufficient data concerning this installation could be obtained.[2]

In the early part of 1950, the Civil Aeronautics Administration called a meeting to discuss the near crashes involving helicopters and other aircraft. Helicopters were equipped with conventional red and green position lights on either side of the fuselage. Thus equipped and viewed from a distance of 50 feet, a helicopter appeared as a fixed-wing aircraft flying at a much greater distance. It was decided that pending the development and testing of satisfactory blade-tip lighting an interim means should be taken to reduce this hazard.

A Sikorsky H5H helicopter was supplied by the Department of the Air Force and was equipped with a dome-type rotating light by the Naval Air Test Center This lighting unit is a standard item manufactured by The Federal Sign and Signal Corporation, formerly known as Federal Enterprises, Incorporated, of Chicago, Illinois, and is used on fire trucks and police cars The unit consisted of two 75-watt sealed-beam lamps located back to back, rotated at 50 rpm in a horizontal plane inside a red glass dome, and giving 100 flashes per minute This unit was mounted on top of the cabin just ahead of the pylon This type of lighting was shown

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*Manuscript submitted for publication March 1954.

[1] "Experimental and Development Specification Exterior Lighting for Helicopters Rotor Blade," TED No. PTR EL 650, U. S. Naval Air Test Center, Patuxent River, Maryland, December 12, 1949.

[2] "Final Report on Installation and Test of Helicopter Rotor Blade Lighting," TED No. PTR EL 658 ET 311-120, U. S Naval Air Test Center, Patuxent River, Maryland, May 22, 1952.

at a meeting of representatives of aircraft and air-transport industries held at the Technical Development and Evaluation Center in August 1950.[3] It was the general opinion of those attending the meeting that the light was effective as a warning light, was attention-getting, but lacked distinctiveness. However, it was considered satisfactory as an interim measure.

A demonstration of blade-tip lighting was conducted at TDEC in October 1950.[4] A Sikorsky H5H helicopter was again supplied by the Department of the Air Force. A set of wood-and-fabric blades designed for the helicopter and equipped with 3-cp lamps in each of the three tips was supplied by the Naval Air Test Center. The lamps could be operated steadily or could be flashed 68 or 80 times per minute.

It was the consensus of those attending the demonstration that blade-tip lighting is very distinctive and that it does not disturb the pilot. In fact, the pilot stated that it was an aid to making night landings.

It was also the consensus that further development of blade-tip lighting should be undertaken and that the following requirements should be met

1. Clear (white) lighting should be used.
2. The lights should not flash.
3. The lights should be visible for a distance of 5 miles.
4. The lighting system should not require more than 300 watts of electrical power for its operation.
5. The lighting system should add as little as possible to the weight of the helicopter.

It was recommended that additional flight tests be conducted with specially constructed lamps of greater intensity in the blade tips. The program was to be conducted through the co-operation of the Department of the Air Force, the Department of the Navy, the lamp divisions of both General Electric Company and Westinghouse Electric Corporation, and the Technical Development and Evaluation Center.

DESIGN AND INSTALLATION

A special set of Sikorsky H5H metal blades were supplied by the Naval Air Test Center for the blade-tip high-intensity-lighting program. The factory had installed No. 20 stranded copper wire inside the blades and a single-contact bayonet-base lamp socket at the blade tip. The blade tips were modified at TDEC to provide higher intensity of light outboard in the horizontal plane and lower intensity in the direction of the helicopter cockpit. This was accomplished by mounting special reflectors and lamps inside the blade tips.

The blade tips and the original lamp sockets were removed, and a rectangular section was cut from each blade tip. Transparent colorless plastic was formed to the contour of the cutaway section and was secured inside of the blade tip to produce a window. This modification retained the original contour of the tip and, therefore, did not interfere with the aerodynamics of the rotor blade.

The space available inside the blade tips places definite limits on the types and sizes of reflectors and lamps that may be used. Within those limits, it was found that a circular parabolic type of reflector would provide what was considered to be a desirable distribution. A circular reflector 3/4 inch in radius and parabolic in elevation was so designed that the focal point of the parabola was concentric with the curvature of the circle. These reflectors were equipped with lamp sockets and were cut to fit within the plastic window of the blade tip. Screws were used for securing the blade tip to the blade in order to reduce the amount of time and the number of tools required to replace the lamps. Figure 1 shows the modified blade-tip and lamp assembly.

Experimental lamps were supplied by the lamp divisions of Westinghouse Electric Corporation of Bloomfield, New Jersey, and of General Electric Company of Nela Park, Cleveland, Ohio. The lamps were designed for 12 to 16 volts with additional filament supports to withstand the accelerations that exist at the blade tips. The design characteristics of the lamps are listed in Table I.

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[3] Cecil B Phillips and Alan L Morse, "A Review of Aircraft External Lighting Activities," CAA Technical Development Report No. 215, September 1953

[4] Ibid

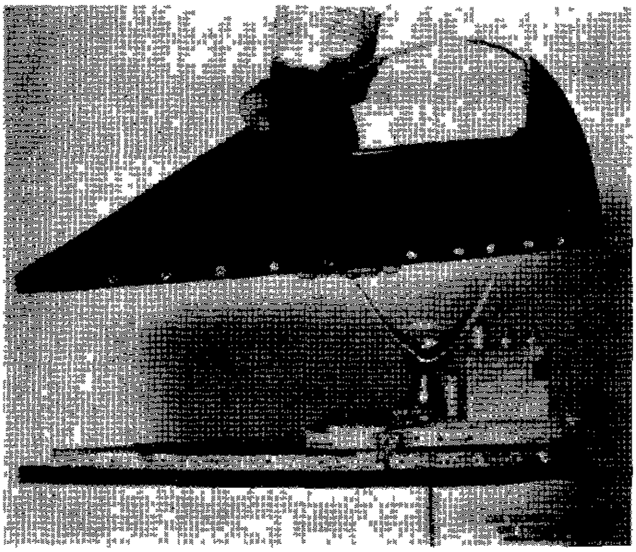

Fig. 1 Modified Blade-Tip and Lamp Assembly

The addition of items of weight in the modification of the blade tips was offset by removing counterweights so that the mass dynamics of the blades remained unchanged.

CENTRIFUGAL TESTS

The blade-tip assemblies and three types of lamps were subjected to centrifugal tests to determine their ability to withstand the rigors of flight. These tests were conducted on a horizontal centrifuge. Each blade tip was mounted on the centrifuge, as shown in Fig. 2, and the table was balanced. One of the 50-cp, 12- to 16-volt lamps representing the most powerful of the lamps then available for helicopter blade-tip lighting was used for the tests. This lamp produced temperatures inside the blade tips as high as the maximum expected during flight.

TABLE I

CHARACTERISTICS OF THE EXPERIMENTAL LAMPS

Lamp No.	Intensity (Spherical cp)	Bulb	Rated Voltage	Base	Filament Supports	Manufacturer
1	32	S-8	12-16	*	4	Westinghouse Electric Corporation
2	35	S-11	14	*	3	General Electric Company
3	50	S-11	12-16	*	4	Westinghouse Electric Corporation

*Single-contact bayonet

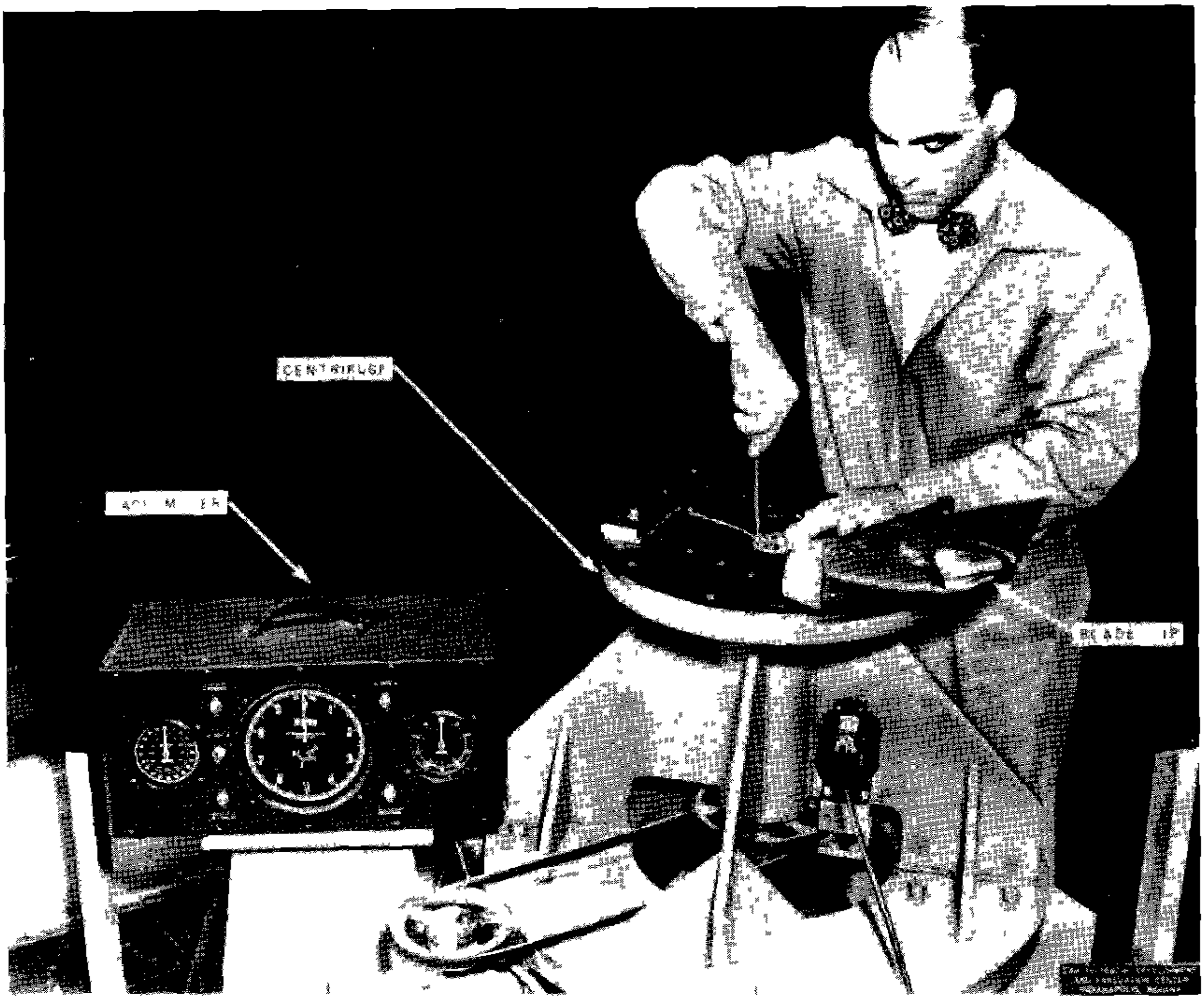

Fig. 2 Centrifuge With Mounted Blade Tip and Tachometer

The lamp was supplied with 14.8 volts by means of slip rings. The acceleration at the lamp filament was computed from the relation

$$a = \frac{4\pi^2 f^2 R}{g} \qquad (1)$$

where

a = acceleration in gravitational units,

g = gravitational units (32.2 feet per second^2),

$f = \frac{rpm}{60}$,

R = distance of the filament from the axis of rotation, in feet.

Each test unit was accelerated at 510 g for 30 minutes at a linear speed of 120 feet per second. Vibration of the centrifuge and of the test unit was not appreciable during the test. At the end of the 30-minute test period, the unit was removed and inspected. No damage to any of the components was evident.

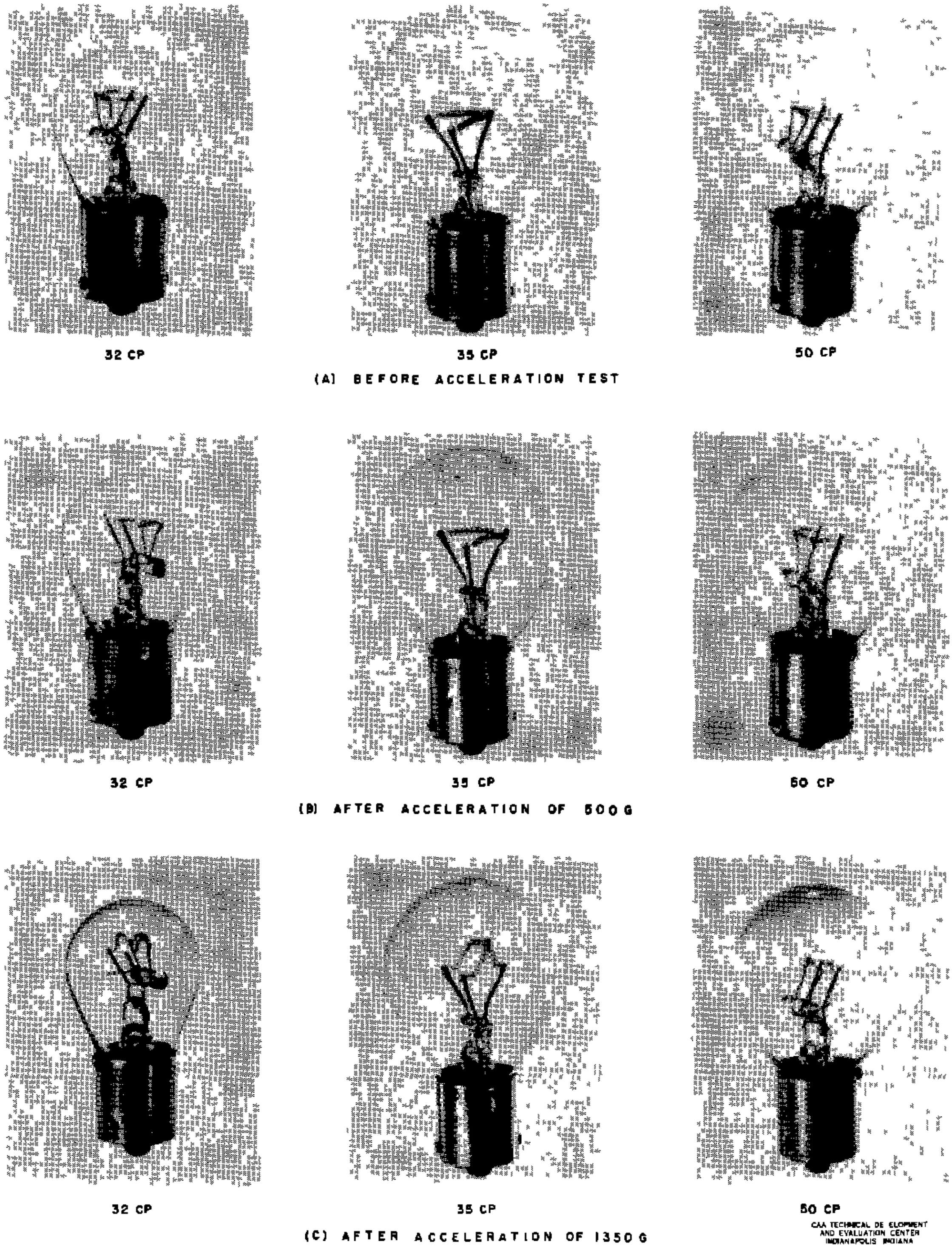

Fig. 3 Three Experimental Lamps for Helicopter Blade-Tip Lighting

These test conditions imposed higher centrifugal forces than those forces encountered at the blade tips of the helicopter on which the blades were to be used. The danger zone of the H5H helicopter is established at 240 rpm (maximum allowable blade rotation) The radius of

TABLE II

TESTS OF EXPERIMENTAL LAMPS

Lamp No.	Rating (volts)	Rating (amperes)	Acceleration (g)	Remarks
			850	Filament slightly distorted between filament supports
1	14.0	3.3	1,200	Filament shows more distortion
			1,350	Filament and supports distorted
			400	Filament slightly distorted between supports
2	14.0	3.8	1,000	Filament distortion more exaggerated
			1,350	Filament elongated and distorted
			950	Filament slightly distorted
3	14.0	4.1	1,280	Filament shows more distortion
			1,350	Filament and supports distorted

Note Acceleration time for each test was one minute.

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the rotors is 25.5 feet. Under these conditions, the blade tip has an acceleration of 490 g and a linear speed of 630 feet per second. The linear speed of the blade tips during the test was less than would be reached in flight, however, the effects of this higher linear speed in flight were considered negligible since the aerodynamics of the blade tips were not changed. The results of these tests provided a reasonable indication that the blade-tip assemblies were capable of withstanding the rigors of flight.

The three types of experimental lamps were also tested on the centrifuge to determine the maximum acceleration under which operation of each lamp would be practical. Figure 3a is a photograph showing the strengthened filaments of the lamps. Each of the test lamps was mounted on the centrifuge with the base toward and perpendicular to the axis of rotation. The lamps were lighted and were subjected to accelerations of one-minute duration. They were removed and inspected after each acceleration step. No structural failures of the lamps were apparent at accelerations lower than those experienced at the blade tips of the H5H helicopter. Table II shows the voltages and accelerations of the lamps during the test and also the results of the test. Figures 3b and 3c show the distortion of the lamp filaments after being subjected to accelerations as indicated. These data indicate that all the lamps tested should operate successfully at the blade tips of the H5H helicopter.

CANDLEPOWER DISTRIBUTION CHARACTERISTICS

Candlepower distribution characteristics of the blade-tip lighting for the helicopter were determined from the measured candlepower distribution of a lighted blade tip and from an analysis of the effect of blade rotation.

Standard instrumentation consisting of a photocell and a galvanometer to indicate the light intensity and of a goniometer to measure the angle from an arbitrary zero reference line was used to obtain the candlepower-distribution measurements. The instrumentation was

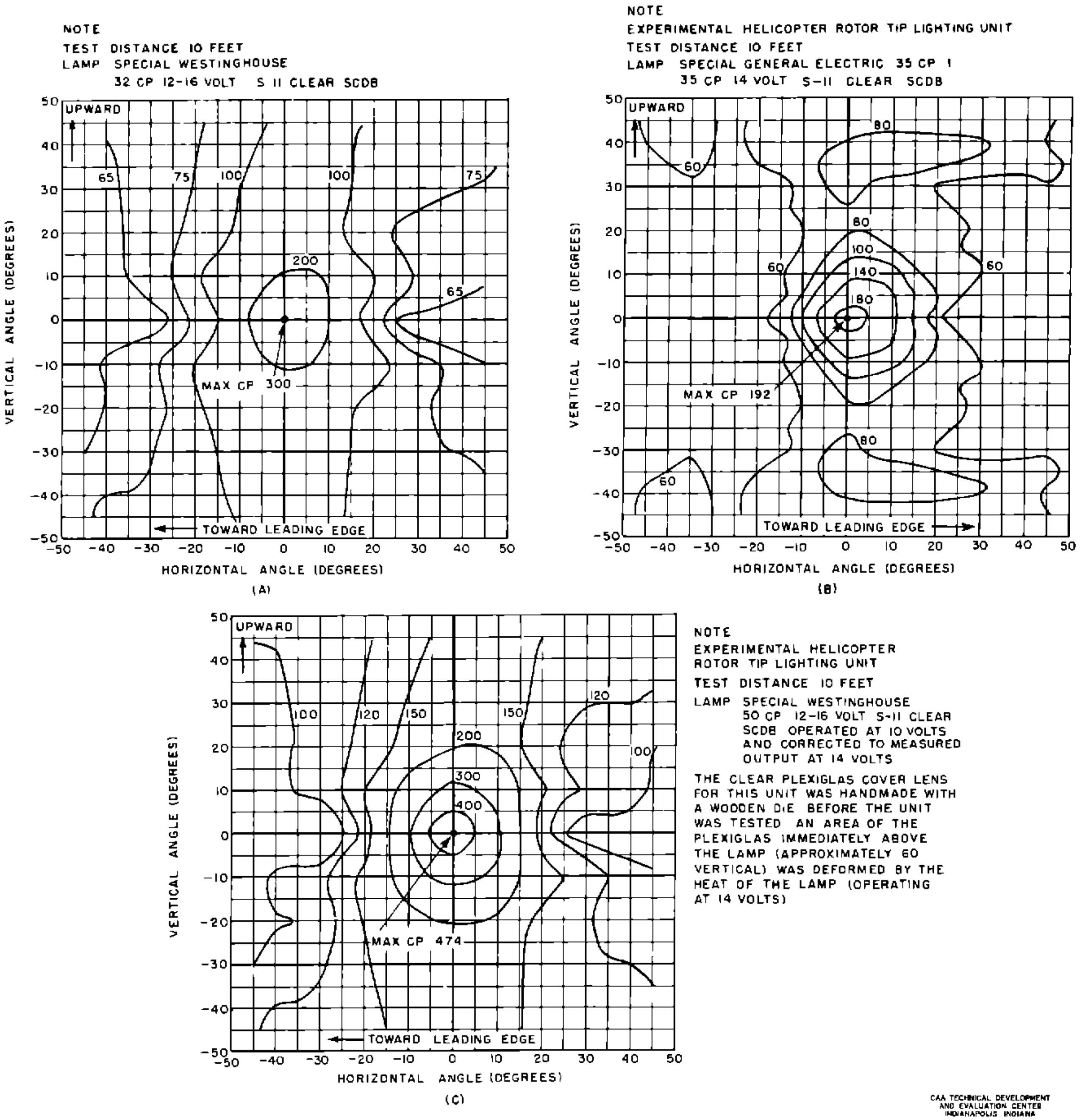

Fig. 4 Isocandle Diagrams for Blade-Tip Lighting

calibrated with a standard lamp. Lamps used for the candlepower-distribution measurements were operated at their rated voltage for approximately 20 hours to season and to stabilize the filaments before any measurements were made.

A blade-tip unit was secured to the table of the goniometer with the symmetrical axis of the reflector perpendicular to the light-sensitive face of the photocell. The symmetrical is of the reflector was taken as the zero reference line, and the leading edge and the upper surface of the blade tip were taken as the positive direction from the zero reference line. The lamps were operated at 14 volts.

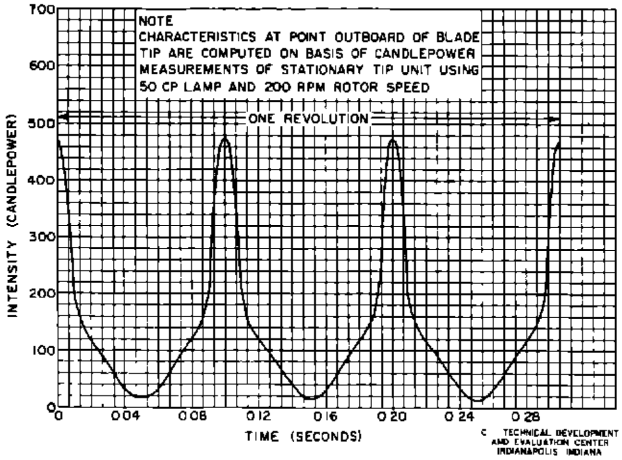

Fig. 5 Intensity Versus Time Characteristics of Rotating Blade Tip

Galvanometer indications were recorded for photocell positions throughout the area illuminated by the blade tip. This procedure was followed with each of the three experimental lamps in the blade tip. After approximately 20 minutes operation with the 50-cp lamp in the blade tip, the plastic immediately above the lamp became distorted from the heat. Further heating of the plastic was prevented by cooling the plastic with an electric fan. Isocandle diagrams for the blade tip lighted with each of the 32-, 35-, and 50-cp lamps are shown in Figures 4a, 4b, and 4c, respectively. From these it will be seen that the candlepower distribution produced by the 32-cp lamp is similar to that produced by the 50-cp lamp but of less intensity. The candlepower distribution produced by the 35-cp lamp, however, does not resemble that of the other two lamps. The candlepower-distribution variations are caused by differences in filament sizes, shapes, and locations since the same blade tip and reflector were used in each case. As indicated in Figure 3a, the 32-cp and 50-cp lamps have filaments of approximately the same size, shape, and location in the lamp. It will be noted that the reflector has effectively increased the candlepower of the helicopter lights by 500 to 900 per cent of the rated candlepower of the lamps.

Figure 5 is a curve of intensity versus time from a point in the plane of rotation of the helicopter blades. This curve was derived from the measured candlepower distribution when the blade tip was lighted with 50-cp lamps and when the blades on the H5H helicopter rotate at approximately 200 rpm, or cruising conditions. A light on each of the three blade tips rotating at that speed gives a flashing frequency of 10 cps. Because of the persistence of vision and the flicker-fusion frequency of the eye, this curve does not indicate how the lighted helicopter appears to the observer. The passing of the lighted blade tips at 10 cps causes them to appear to the observer as a slightly broken line of light. However, this appearance varies greatly with the intensity of the background brightness. As the background-brightness intensity increases, the frequency must increase to make the light appear steady.[5] Under normal operating conditions of the helicopter, the line of light has a decided flicker effect.

The relative intensities at various angles of elevation measured with respect to the blade axis are shown in Fig. 6.

The effects of voltage variation on the total light output and current of the lamps were determined by laboratory measurements. A five-foot integrating sphere was used for these measurements. The test lamp was placed at the center of the integrating sphere, and a calibrated photocell-and-galvanometer system was used to indicate the relative light output. The voltage across the filament of the lamp was increased in steps from 10 to 16 volts. Recordings were made of the light output and the current for each voltage setting. Figures 7a, 7b, and 7c show the percentage of light output versus the voltage and current as plotted from these data. The light output obtained at 14 volts was considered to be 100 per cent.

[5] Donald H. Jacobs, "Fundamentals of Optical Engineering," McGraw-Hill Book Company, Inc., New York, 1943, Chapter V.

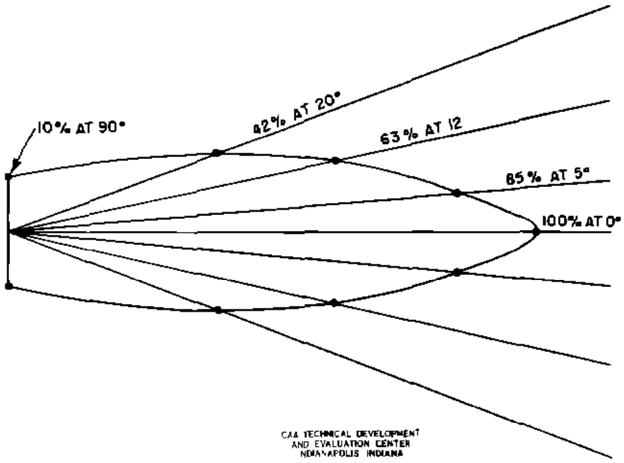

Fig. 6 Relative Intensities at Various Angles of Elevation Measured With Respect to Blade Axis

These curves indicate that a 60 per cent increase of light output may be expected when the lamps are operated at 14 per cent above their rated voltage, however, the normal rated life of the lamps would be reduced.

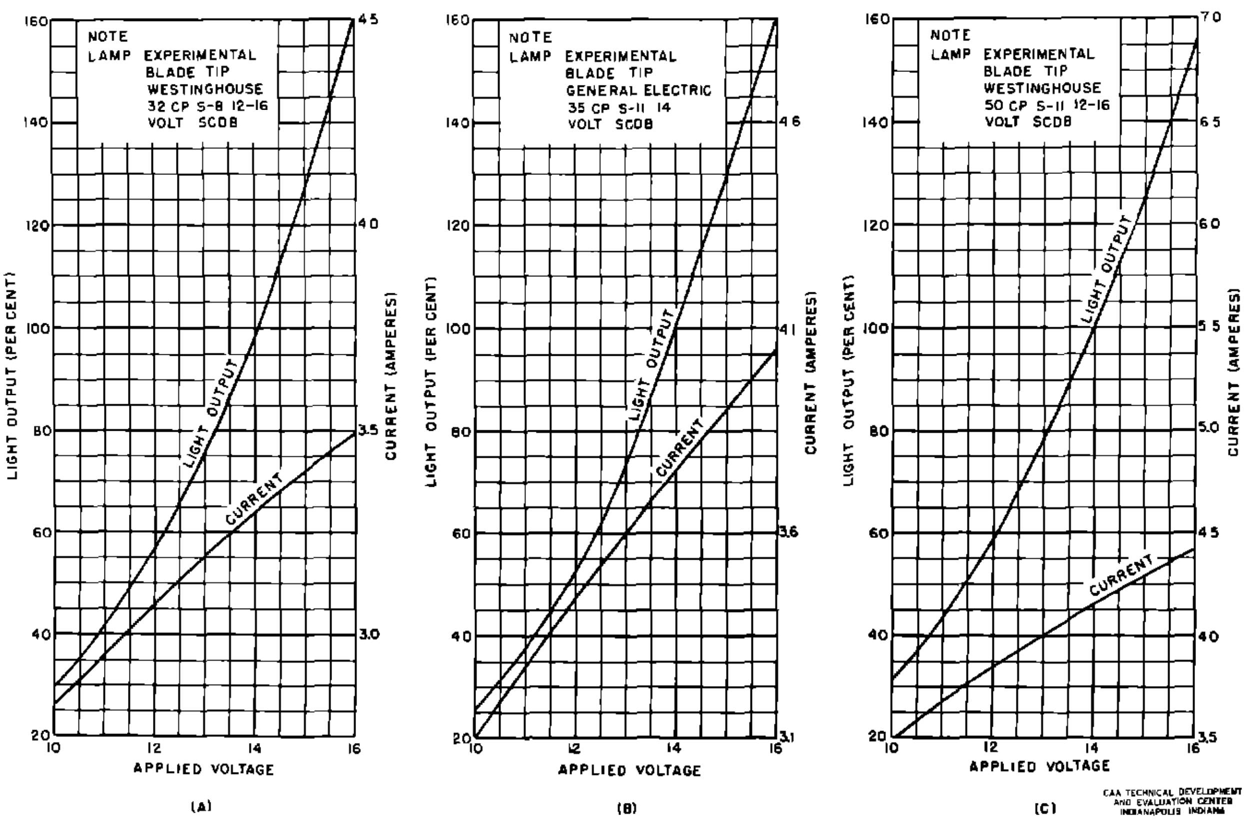

Fig. 7 Percentage of Light Output Versus Applied Voltage and Current for Experimental Lamps

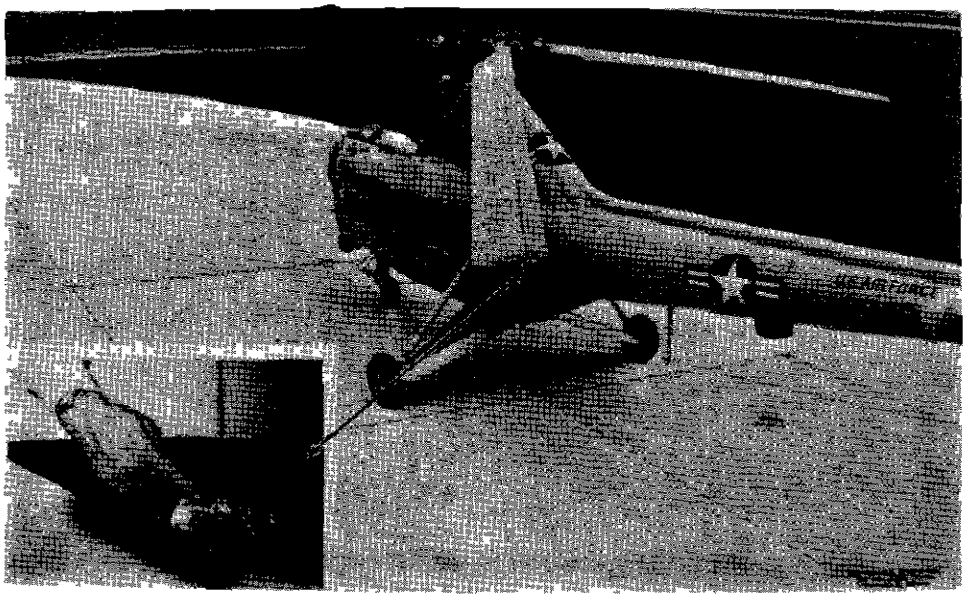

Fig. 8 H5H Helicopter With Experimental Blade-Tip Lighting

FLIGHT TESTS AND RESULTS

Flight tests were conducted to observe and to evaluate the effect of the lighted blades under operating conditions. An H5H helicopter with a pilot and a mechanic were supplied by the U. S. Air Force from Wright-Patterson Air Force Base, Ohio, for installation and demonstration of the lighted blades. Naval Air Test Center and TDEC personnel assisted in installing the blades and electrical wiring.

Electrical power was supplied to the blades through a slip-ring system consisting of a copper ring and a phosphor-bronze brush installed on the rotor hub. Seventy inches of No. 20 asbestos-covered resistance wire was used between the slip ring and the blade to reduce the voltage at the 50-cp experimental lamps in the blade tips from the 28 volts of the electrical system of the helicopter to 14 volts. An ON-OFF toggle switch was located in the cockpit of the helicopter within easy reach of the pilot. Upon completion of the installation, the blades were checked for balance and tracking No adjustments were necessary. Figure 8 is a view of the helicopter with the experimental blade-tip lighting.

Flight observations were conducted at 7 30 and 8 45 pm April 2, 1953. The visibility was 10 miles, the ceiling was 3900 feet overcast, and the wind was 0 mph. The lighted helicopter was flown at an altitude of 1500 feet. It circled about a small designated area at the western city limits of Indianapolis, Indiana, and 6.5 miles east of the Indianapolis VOR (Brownsburg, Indiana). Two DC-3 airplanes carrying the observers approached from the w and circled around the helicopter at 1300 and 2000 feet altitude.

A pictorial computer was available in one of the observer aircraft for determining the distance between the observers and the lighted helicopter. This computer marks the position of the aircraft on a chart of the area around the ground transmitter to which it is tuned and provides position information to an accuracy of ± 1/4 mile.

The helicopter with the lights of Indianapolis as a background was first sighted from a distance of 6.5 miles. It was easily identified from a distance of 5.0 miles. The rotating blades appeared to an observer to be a flickering line of light in the plane of rotation of the blades. Any movement of the controls by the pilot of the helicopter was readily detected by the movement of the line of light. From 1000 feet overhead, the rotating blades appeared as a ring of light. The vertical intensity of the ring was not as high as the horizontal intensity.

It was the consensus of the observers that this type of helicopter lighting distinguished the aircraft as a helicopter and should be helpful to the military in formation flying.

CONCLUSIONS

The requirements originally established for the continued development of helicopter blade-tip lighting were exceeded. The tip-lighting arrangement using the 50-cp lamps operated at 14.8 volts

(a) Was visible against a background of city lights on a relatively clear night from a distance of 6.5 miles.

(b) Required less than 300 watts of electrical power.

(c) Increased the weight of the helicopter by less than one pound.

The tip-lighting installation was structually and aerodynamically satisfactory.

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