DEVELOPMENT OF A PHOTOGRAPHIC INSTRUMENT RECORDER

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SUMMARY

A satisfactory method of recording data from the instruments in the cockpit of an airplane has long been needed. The Technical Development and Evaluation Center has developed a photographic instrument recorder for this purpose. The recorder employs infrared illumination in order not to disturb the pilot's vision and consists of a camera illuminator unit and a power supply unit. These units weigh 5.6 and 12.2 pounds respectively and can be installed quickly in any airplane. Approximately 75 watts of power are required for operating this equipment, using either the airplane electrical system or a separate battery.

Flight tests have been made under various conditions, and all tests indicated that the recorder is satisfactory and should be useful in the field for which it was designed.

INTRODUCTION

Prior to the development of the photographic instrument recorder, a separate "photo panel" with an auxiliary set of instruments was generally used to record flight test data. This required the laborious installation and servicing of the auxiliary instruments, and such panels were often placed in inaccessible parts of the fuselage. Furthermore, it was difficult to determine whether these instruments were in agreement with those being used by the pilot. The development of an easy-to-install photographic recorder which would take pictures of the cockpit instruments was considered desirable.

Developments in this field were initiated by the Civil Aeronautics Administration in 1936, at which time continuous logging was the objective. Photography by incandescent continuous lighting and by condenser-discharge type of flash illumination was used in the early recorder models. Very dark red filters and infrared sensitive film were tried in order to permit the use of the equipment at night without disturbing the pilot's vision. Incandescent illumination was abandoned because its limited intensity required longer exposure times that resulted in blurred images of the vibrating instruments. In 1943, the need for a more convenient type of photographic instrument recorder for flight test purposes resulted in shifting the original objective from continuous logging to intermittent logging. The photographic instrument recorder covered by this report was developed by TDEC through contract with Edgerton, Germeshausen & Grier, Inc., of Boston, Mass.

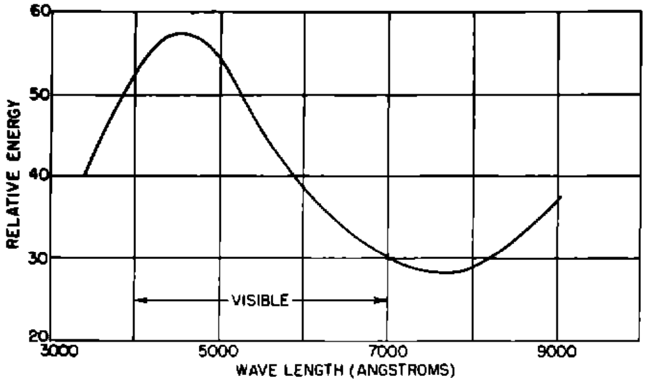
REQUIREMENTS

The original basic requirements for the camera were that it should be convenient to install, should not distract the pilot during operation, and should require no auxiliary set of instruments.

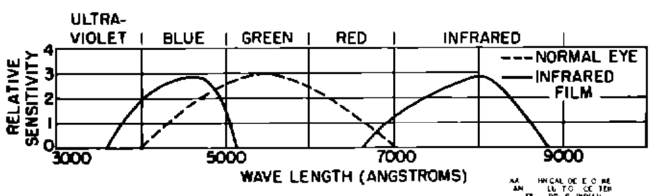
Both incandescent and electric-flash lighting are visible to the human eye. Hence, to avoid distracting the pilot, some method had to be used to render the illumination essentially invisible and, at the same time, to permit the exposure of a photographic film. The spectral distribution of the light from a standard flash tube shows that the maximum output is in the blue-violet, although a rise again occurs in the infrared region. See Fig. 1A.

Infrared film is sensitive to both the blue-violet and the infrared radiation. See Fig. 1B. Thus, the visible light could be filtered out and either the infrared or the blue-violet ends of the spectrum might be used for photographic purposes.

Let us consider first the method employing the blue-violet region. A filter having high transmission below approximately 4,000 angstroms and zero transmission above would be quite efficient due to the large amount of blue-violet energy available from the flash tube and the high sensitivity of photographic films in this portion of the spectrum. Practically, however, filters having a sharp cutoff at approximately 4,000 angstroms and good transmission below this wavelength are not available. Available filters that will not transmit above approximately 4,000 angstroms have poor transmission in the shorter wavelengths, or usable part of the blue-violet. Therefore, filters were chosen that had a high transmission in the blue-violet, but which cut off wavelengths below 4,700 to 5,000 angstroms. Filters, such as Wratten Nos. 34 and 39 in combination, provide high efficiency. However, since the flash is still visible, this method requires the pilot to wear special glasses which contain a yellow filter, such as Wratten No. 8, which does not transmit wavelengths below 4,700 to 5,000 angstroms.



(A) Spectral Distribution



(B) Color Sensitivity of Normal Eye and Infrared Film

Fig 1 Radiation From Standard Flash Tube

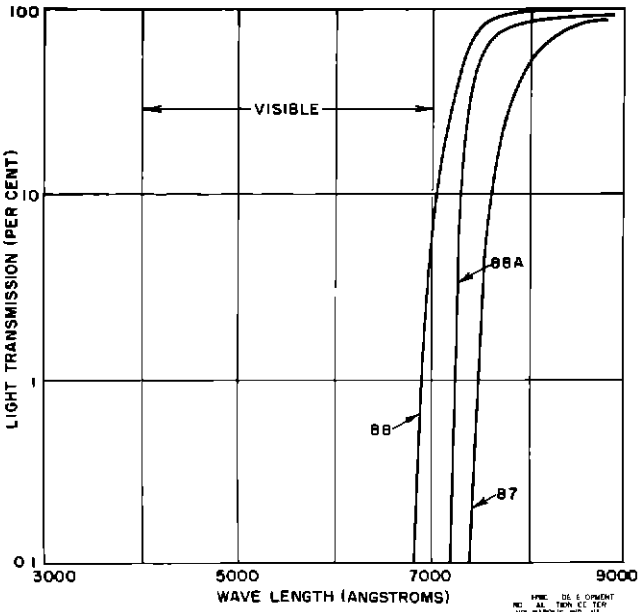


Fig 2 Efficiency of Wratten Filters Used With Infrared Radiation

The second method employs the infrared portion of the spectrum Sharp cutoff filters, Wratten Nos 87, 88, and 88A with near zero transmission of visible light, are available See Fig 2 Because of the smaller amount of infrared energy in the flash source and the lower sensitivity of infrared film, the system has considerably lower efficiency, but the pilot need not wear special glasses

The advantage of the blue-violet light method is that it requires only one sixth to one third the energy of the infrared system Using the same energy, the lens can be stopped down 1 1/2 to 2 1/2 stops smaller than with infrared This results in better definition and depth of focus

The disadvantage of the blue-violet light method is that it requires the pilot to use yellow goggles to render the light invisible These yellow goggles are not too objectionable in color, but they must cover the eyes very completely to prevent light from entering around the edges of the frames

Advantages of the infrared method are that such radiation is essentially invisible without the aid of supplementary glasses, the contrast between white figures of the instruments being photographed and the surrounding black or dark objects is greater than can be produced by the blue-violet method, and daylight illumination will have less effect on the exposure through an infrared filter than through a blue-violet filter

Disadvantages are that the infrared film packaged in 16 mm size is not so readily obtainable as a normal panchromatic or blue-violet sensitive film, this film is more difficult to store until ready for exposure, and this system does not utilize the energy of the light source or the sensitivity of the film to any large degree of efficiency

Review of these two methods resulted in the choice of the infrared system It appeared that the advantages outweighed the main disadvantage, that of less efficiency

A relatively long exposure time was required by the limited light intensity of incandescent lamps using an infrared filter This had the result of producing images blurred by the vibration of the aircraft Levels of illumination higher than 100 candlepower filtered for infrared were needed, and shorter exposures were necessary to eliminate aircraft vibration effects An electric flash as the source of infrared illumination offered the possibility of decreasing the exposure time because of its high intensity and because it would eliminate the blur due to vibration

Tests revealed that the maximum usable camera distance was less than four feet, and that the camera and illuminator should be separable for proper lighting in some installations

Fig 3 Components of Photographic Instrument Recorder

In view of the findings in the investigations, the following specifications were decided upon

A Camera

The camera shall operate at one picture per second With a 25 mm lens, the picture shall cover an area of 11 by 14 inches at a working distance of 36 inches At the 36-inch distance, with the camera 30° off axis from the instrument panel, the depth of field shall be plus or minus three inches (From Eastman data, a 25 mm lens at f/1.9 has a plus or minus three-inch depth of field at 36 inches This should permit lens apertures up to f/1 9) The camera shall be supplied with an infrared filter to exclude daylight exposure effects

B Lamp

The lamp shall be as small as practicable and designed so that it may be attached to the camera or detached and mounted separately The lighting shall cover an area of 11 by 14 inches, and the lamp shall be supplied with an infrared filter

C Power Supply

The power supply shall be capable of operating the lamp at one flash per second and shall not exceed 25 pounds in weight The recorder shall be operated by remote push-button control

D Power Input

The complete system shall operate from 12 volts dc

E General

Each camera shall be operated separately with one lamp and power supply Where two cameras are to operate together, operation in exact synchronization is not necessary Power requirements per unit shall not exceed 100 watts

DESIGN AND CONSTRUCTION

The complete equipment shown in Fig 3, including power supply, camera, lamp-house assembly, and cables, weighs 18 pounds A specially-fitted case, Fig 4, is provided for carrying the complete unit and extra film magazine Its dimensions are 16 3/4 by 13 1/4 by 8 1/4 inches

Flash Tube

The choice, as previously discussed in this report, was made to use only the infrared output of the flash tube Using infrared filters, infrared film, special cameras, and the correct distances and angles, tests were made to determine the energy input to a standard FT-220 flash

Fig 4 Components of Photographic Instrument Recorder in Carrying Case

tube to give a somewhat better exposed negative at f/1 9 than the acceptable minimum The incident light on the instrument panel was then measured with an integrating-type light meter Later when it was discovered that the infrared efficiencies were often improved by operation at low voltage, a more sensitive meter with a red sensitive photocell and an infrared filter was used to re-establish the proper infrared light level required

The FT-220 flash tube was not considered as the source of energy because of its size, weight, and relatively low efficiency at the required energy loading A much smaller source was desirable It appeared necessary to design a special flash tube for the recorder

Two seemingly incompatible factors enter into the design of a flash tube that is to operate at high repetitive rates If the

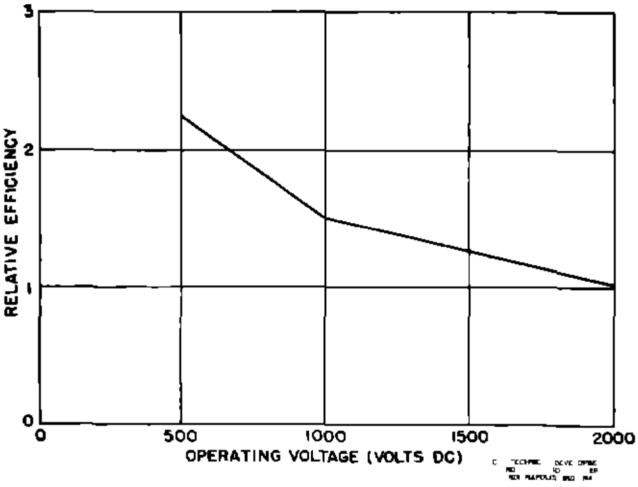


Fig 5 Relative Efficiency of Infrared Radiation for CAA Quartz Flash Tube

tube is small it will overheat due to the average power input, but at the same time it will have high efficiency If the size of the tube is increased to handle the average power, the lamp efficiency will decrease and the tube will thus require a higher average power input When these conditions apply, it is advantageous to construct the tube of quartz, in which case it can be operated at a much higher temperature level than if made of glass The small U-shaped tube was designed as a compromise between reasonable efficiency and ability to handle the necessary power without overheating The energy per flash required to give the previously established illumination level is 12 to 14 watt-seconds, or a power input of 12 to 14 watts

The infrared efficiency of this lamp is about 50 per cent higher at 500 volts than at 1,000 volts, and therefore a voltage operating level of 475 to 500 volts was chosen See Fig 5 This lower voltage level has the advantage of simplifying the power supply design for an air-borne application The dimensions of the tube and the pressure of the gas are such as to give reliable starting at this voltage A special mounting base, which protects the fragile graded quartz-to-tungsten seals, fits into a standard fluorescent starter socket which locks the flash tube in place and also makes it easily removable Adequate spacing for the spark lead is obtained by placing its termination well up on the side of the base Sintered electrodes give the tube satisfactory life for this application The small size of the flash tube permits good light control with a small reflector four inches in

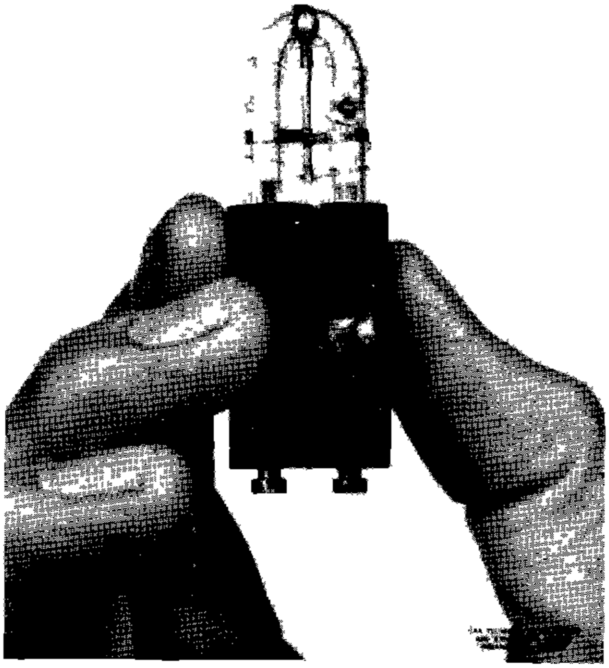


Fig 6 Condenser-Discharge Flash Tube Used in Illuminator

diameter The flash tube is illustrated in Fig 6

Camera and Illuminator

The camera is an adaptation of the Eastman 16 mm magazine Ciné-Kodak The spring motor drive was replaced by electric motor drive, a fast-acting over-riding shutter was installed, and a shutter operated synchronizer switch was added to trigger the flash tube A cover encloses the components on the camera drive plate The lamp house is attached to this camera unit by small snap fasteners and may be easily removed Slack cable coiled in a small compartment permits the lamp house to be operated at a distance of 30 inches from the camera for side lighting

A grooved rubber ring holds over the reflector a Wratten 88A filter, mounted between discs of glass, and prevents any unfiltered light from leaking around the edges of the filter See Fig 7 The rubber ring also serves to hold the reflector in the lamp house The camera lens also has a

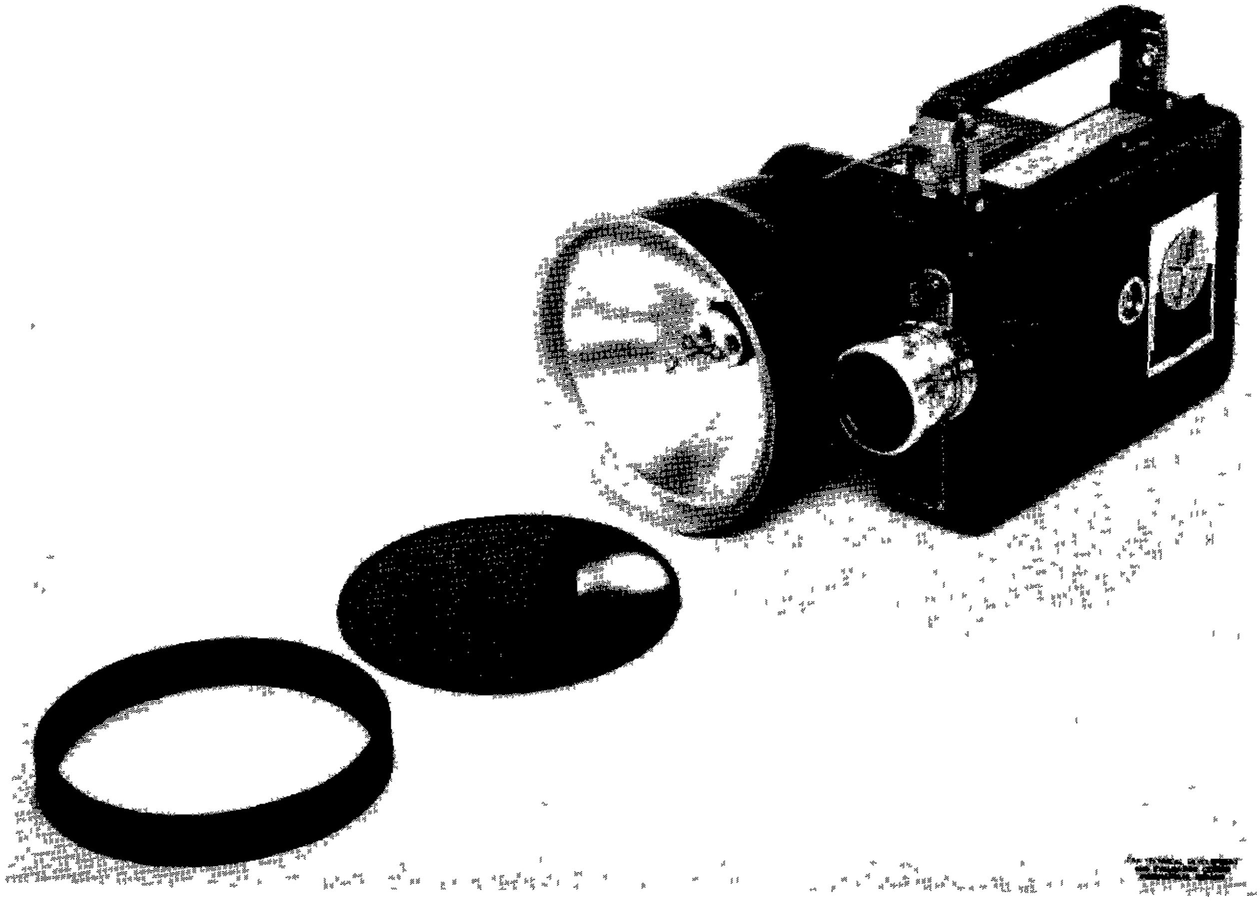


Fig 7 Camera and Lamp House Showing Flash Tube, Filter, and Rubber Retaining Ring

Wratten 88 infrared filter. The flash tube is held so that the legs of the U are in a horizontal plane, thus tending to spread the light across the longer axis of the 16 mm frame The spark connection between the lamp and spark coil is made by a small helical spring The reflector is made of Alzacked aluminum The over-all size of the motor-drive unit and lamp house is easily judged by comparison with the camera to which it is mounted The camera illuminator unit weighs 5 6 pounds

Power Supply and Circuit

The primary power source is the aircraft 12-volt battery system (This equipment can be supplied for 24-volt operation also) Dynamotors were selected as the means of voltage conversion in preference to vibrators in order to obviate the need for transformers and rectifiers. This would not have been practicable if the voltage requirement had been much above 500 volts

The power supply is housed in an aluminum box 9 1/2 by 6 1/2 by 2 3/4 inches The dynamotor is mounted on top of the box for maximum cooling. Fuses, switch, pilot light, and connectors are arranged in a line on the top edge The pilot light serves to insure proper operation of the strobotron, which might fail to fire without the operator's knowledge The power supply unit weighs 12.2 pounds

The cable connecting the power supply to the camera is 8 1/2 feet long A longer cable is not advisable because the increased resistance in the cable tends to cause "hold over," a continuous glow in the tube

The schematic diagram of the electrical circuit is shown in Fig 8 The two 220-microfarad 475-volt electrolytic capacitors C-1 and C-2 are conservatively operated in series to give an energy storage of about 12 watt-seconds Chokes CH-1 and CH-2 both serve to prevent "hold over" in the flash tube FL-1

The tube is in a highly-ionized state after being flashed, and if sufficient current is supplied, the tube will not deionize but will continue to conduct and act as a short circuit across the power supply In order to limit the current and thus prevent "hold over," the choke CH-1 acts as a high impedance immediately after flashing Over a period of one second, it acts as a relatively low impedance and therefore allows capacitors C-1 and C-2 to charge fully before the next flash In addition, choke CH-2 which is in series with the flash tube also tends to prevent "hold over" by causing a slight reversal of voltage, thereby allowing the tube to deionize The amount of reversal is limited to a small value in order to prevent damage to the electrolytic discharge capacitors

To prevent inverse output voltage from the dynamotor, which in turn would cause failure of the electrolytic capacitors, it is necessary to prevent operation of the dynamotor in the event that the polarity of the battery voltage is inadvertently reversed This is accomplished by placing a selenium rectifier RECT-1 in series with the coil of the main control relay RY-1 This prevents the relay from closing if the polarity of the voltage is incorrect

A 12-volt dc governor-controlled drive M-1 is installed to operate the camera at one frame per second to within an accuracy of about one per cent The non-reversal protection described above also prevents the camera motor from driving the film in the wrong direction

The 12-volt battery circuit is fused by F-1 and F-2 When either SW-1 or SW-2 is closed, the pilot light V-1 glows, and the relay RY-1 closes to put voltage on the dynamotor DYN-1. The dynamotor output charges series capacitors C-1 and C-2 to about 450 volts in one second R-1 and R-2 are bleeder resistors The flash tube FL-1 is connected across C-1 and C-2 The resistor combination of R-3, R-4, and R-5 drops the voltage on the strobotron V-2 to about 300 volts and biases the outer grid to approximately plus 50 volts A negative pulse of 300 volts is impressed on the inner grid of V-2 and causes the strobotron to break down or "fire" when the synchronizer contacts SW-3 close in the camera Condenser C-3 then discharges through the primary of the spark coil T-1, and the high voltage pulse from the secondary is applied to the external trigger wire on the flash tube FL-1, causing the enclosed gas to ionize The discharge of C-1 and C-2 through the lamp FL-1 causes a short flash of light

When relay RY-1 closes, power is fed to the camera motor M-1 Whenever the speed is below normal, the centrifugal make-break governor on the motor shaft shorts out the series resistor R-8, and when the speed is above normal, the governor contacts open, placing R-8 in the circuit The filter FIL-1 is used for noise suppression

When it is desired to run two recorders simultaneously, the split control cable can be inserted between P-2 and J-2 When SW-2 is closed both recorders will be turned on, but they will not be synchronized

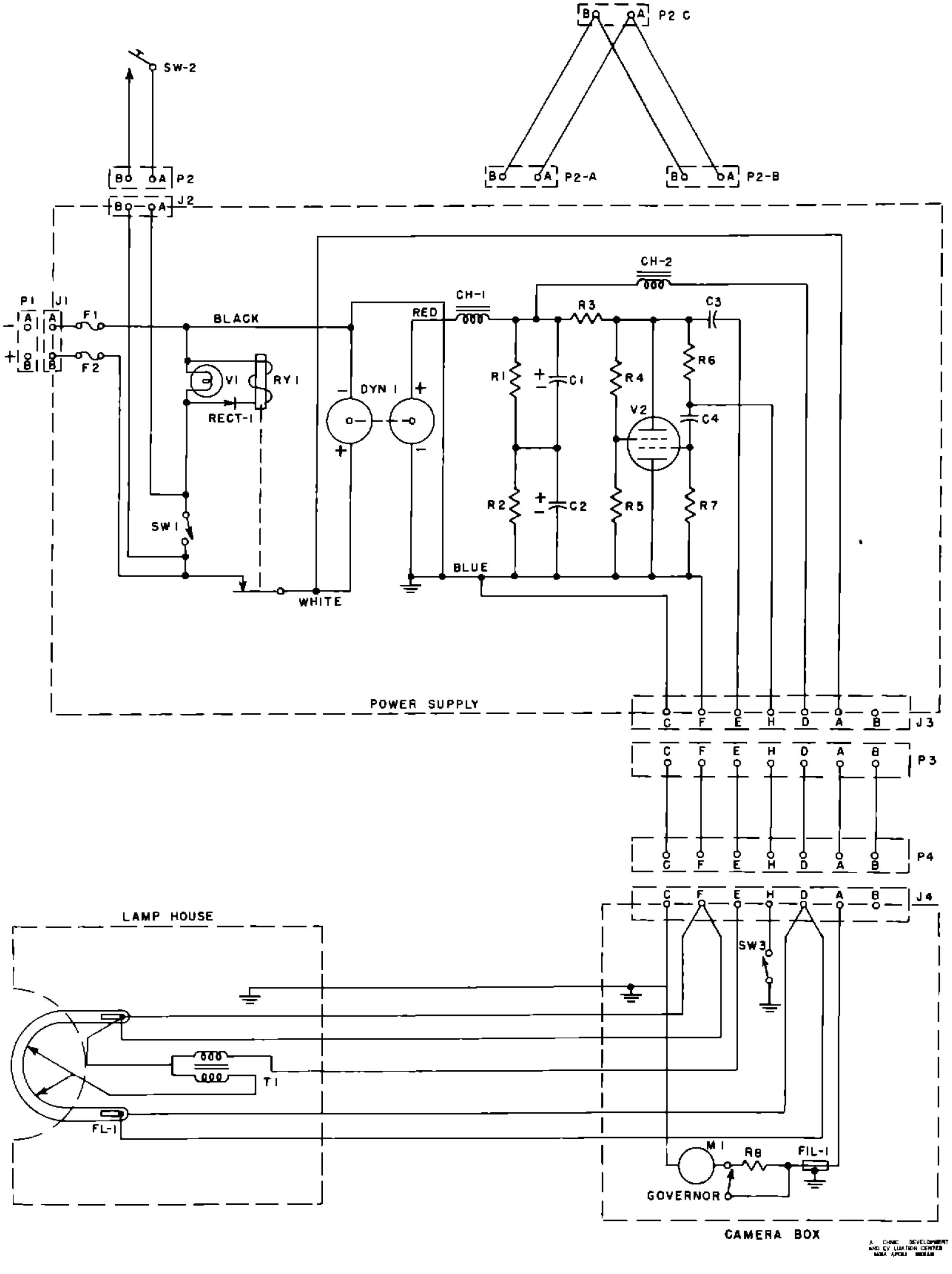


Fig 8 Schematic Diagram of Photographic Instrument Recorder

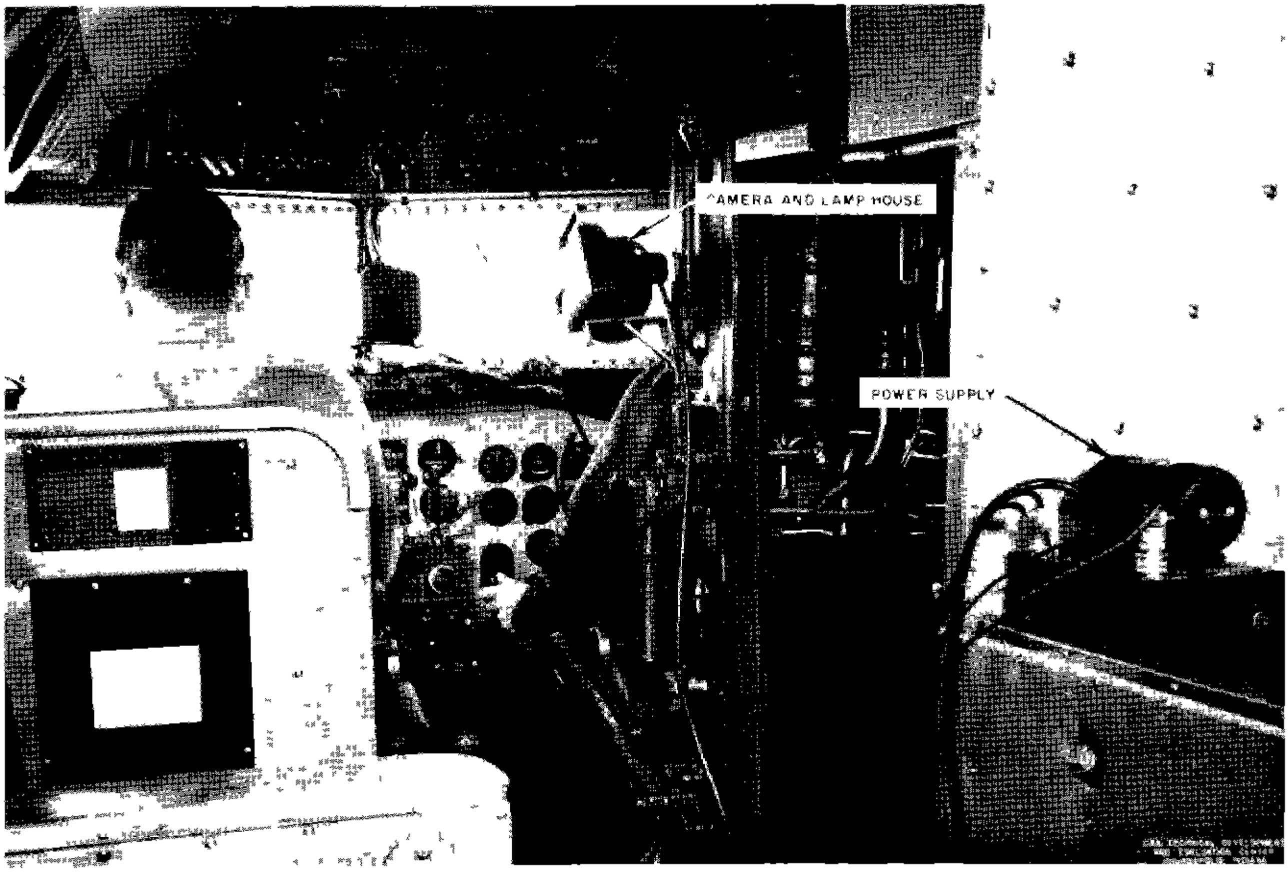


Fig 9 Installation of Photographic Instrument Recorder in DC-3 Airplane

TESTS

The illumination furnished by the flash tube is sufficient to photograph a panel 11 by 14 inches, the approximate area covered by the standard 25 mm f/1 9 lens at a distance of 36 inches Instruments can be read on the photograph when an aperture of f/2 8 or less is used, if the films are properly developed When the camera distance becomes greater than 36 inches, there is a falling off in the exposure although it is still possible to obtain satisfactory photographs

The infrared rays come to a focus farther from the lens than visible rays of light Therefore, a revised focusing index must be used Sharp focusing of the infrared is extremely important if small figures and lines are to be read It is also important because of the shallow depth of field and depth of focus when large apertures are used The 25 mm lens set at f/1.9 and at a distance of 36 inches from the instrument panel, has a depth of field of only plus or minus three inches

Fresh infrared film should be used for optimum results A total of 2, 000 photographs can be taken with a single magazine for a total running time of 33 minutes Tests indicate that DK-50 developer at a temperature of 68° F and a developing time of ten minutes will give the best results in processing the film

A Wratten 88A filter has been used over the illuminator, and under normal conditions no reflected light will be visible unless a direct reflection is seen in one of the instrument cover glasses, the windshield, or some highly-polished surface It is possible that in some installations it will be necessary to replace the 88A filter with the more dense Wratten 87 filter The greater probability is that more visible light can be tolerated, so that a Wratten 88 filter could be substituted for the 88A This would result in increased exposure of the film and would be advisable when the recorder is installed farther than 36 inches from the instrument panel. The Wratten 88 filter over the camera lens allows only a minor exposure due to daylight

The photographic instrument recorder was installed in a TDEC DC-3 airplane, and day and night flight tests were made with satisfactory results Fig. 9 shows a typical installation

Figs 10A and 10B are enlargements from 16 mm films exposed in airplane installations Data for the figures is as follows

1 Distance from panel to camera — 36 inches

2 Camera setting — three-foot mark opposite dot on infrared focusing scale.

3. Camera depressed below horizontal — 20°

4 Lens setting — f/1 9

5 Filter, camera — Wratten 88

6 Filter, illuminator — Wratten 88A

7 Illuminator location — attached to camera

8 Developer DK-50 — full strength

9 Developer temperature — 68° F

10 Developing time — ten minutes

The previous data also applies to Figs 11A and 11B, except that the camera distance was 46 inches, and in Fig 11A, the airplane was parked on a runway with sunlight shining through the windshield but not directly on the instrument panel

It should be noted that in the installation shown in Fig 9 the camera is located 46 inches from the instrument panel This is 30 per cent farther than the distance set up in the specifications At a distance of 46 inches, the illumination on the instruments is approximately 60 per cent of that which would be present if the camera were placed at the specified 36 inches The enlargement from the 16 mm frames is satisfactory It should also be noted that in practice the data is analyzed by projecting the film and not by making enlargements of the individual frames

CONCLUSIONS

A photographic instrument recorder that satisfied the original basic requirements was developed in which

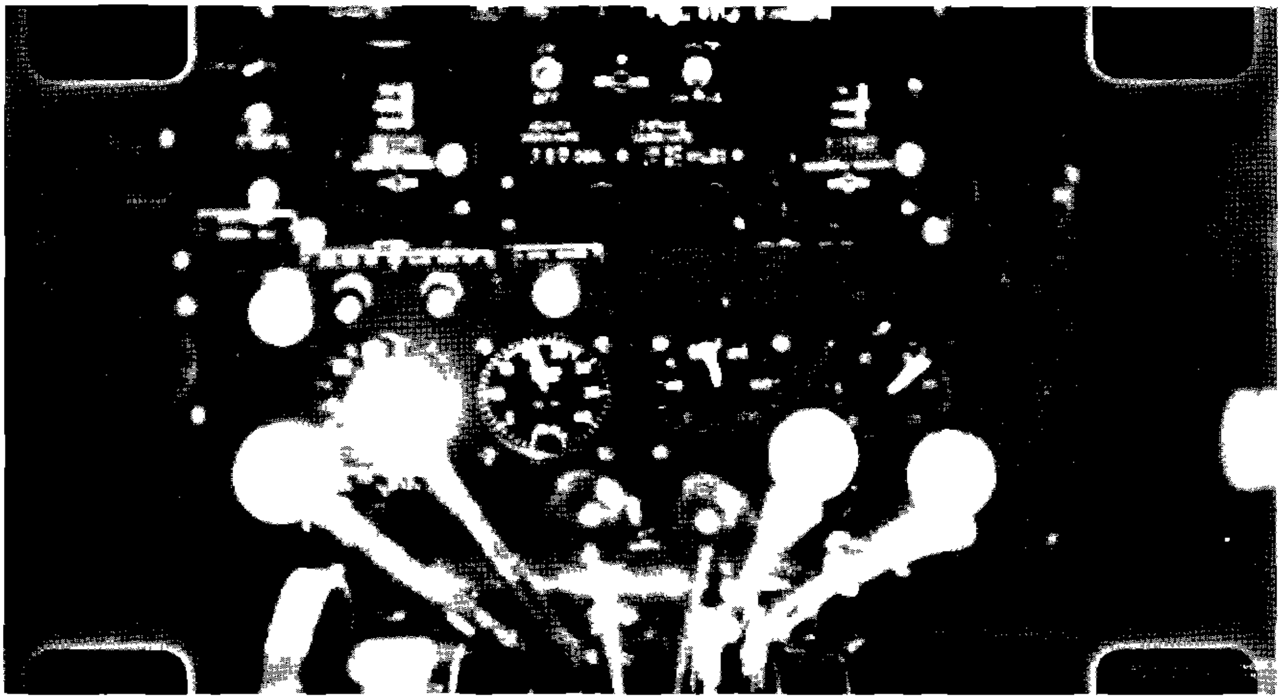
1 The pilot is not distracted by the operation of the photographic instrument recorder in daylight or in darkness

2 The recorder is easy to install in such a position that it obtains clear photographs of the cockpit instruments without interfering with the pilot's operations

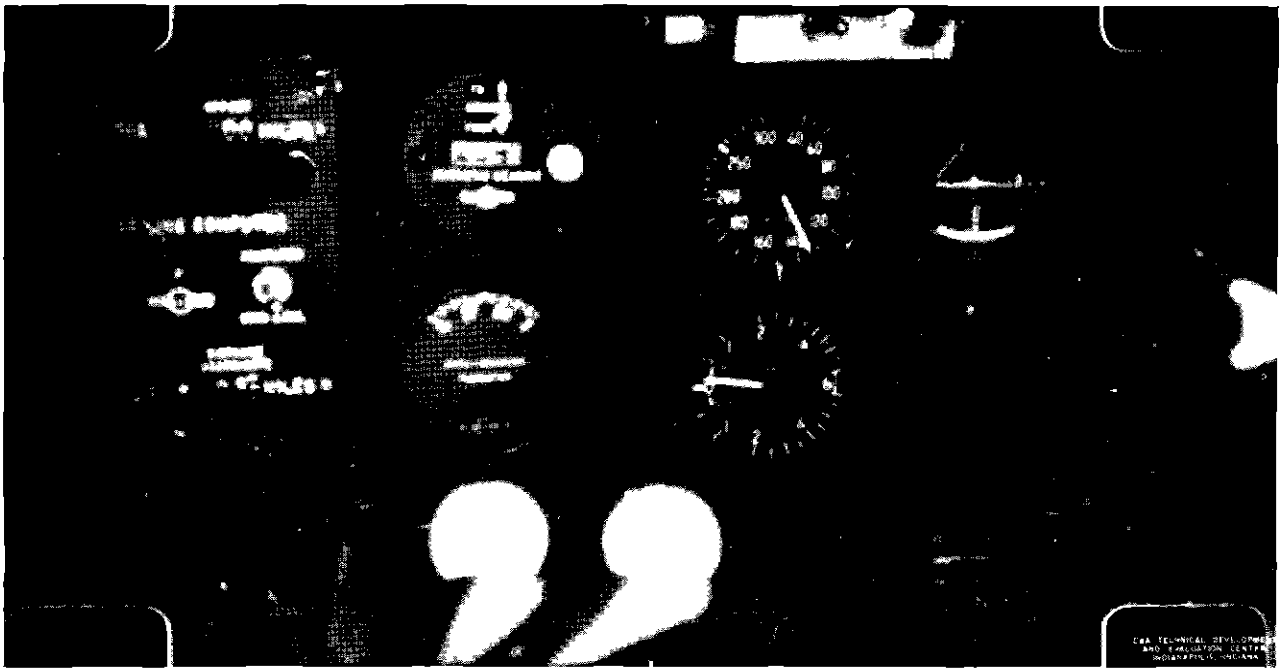
3 The weight, size, and power requirements of the recorder are well within practical limits

4 The recorder obtains adequate photographs either during daylight or darkness

5 Vibration of instruments and/or camera does not seriously affect the clarity of the record

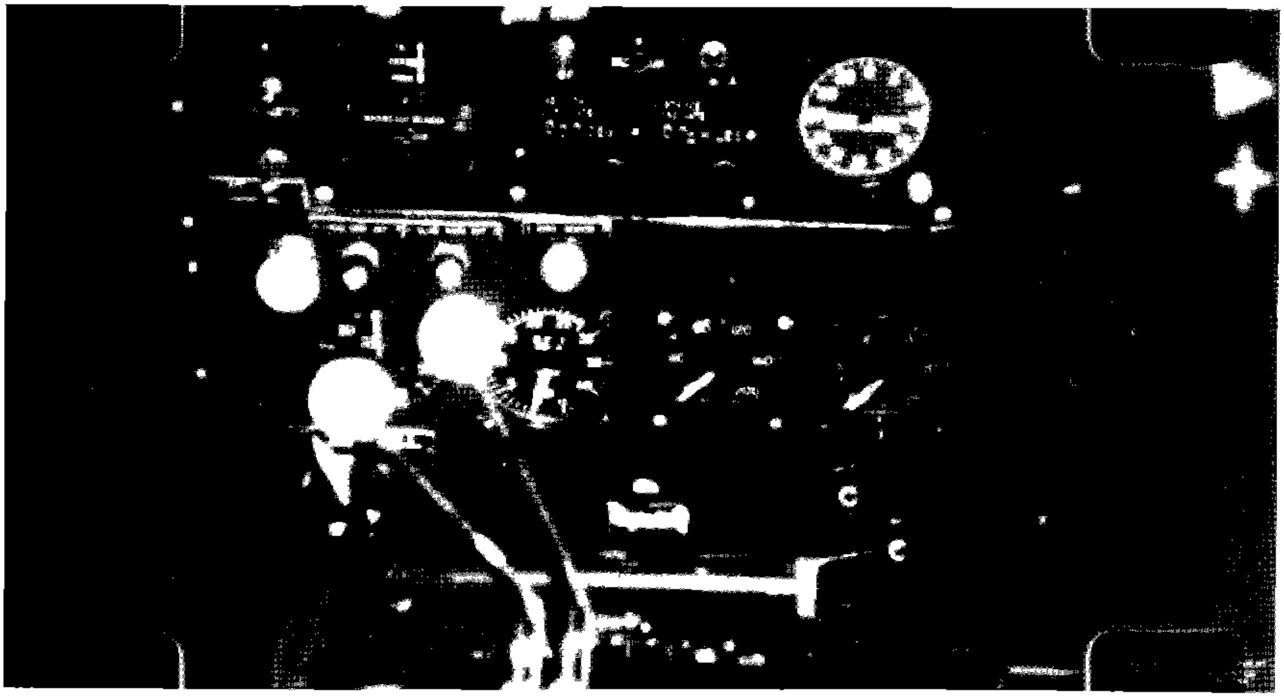


(A) Daylight Exposure

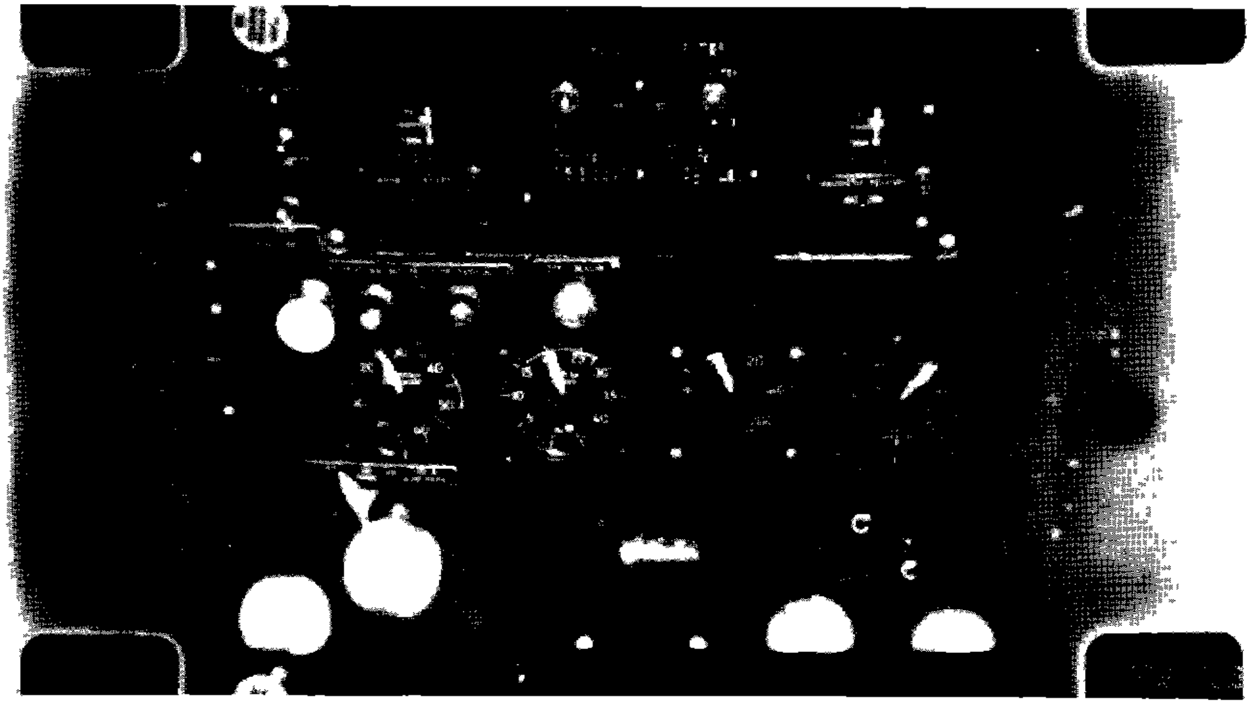


(B) Night Exposure

Fig 10 Enlargement of 16 mm Film Taken in DC-3 (Camera Distance, 36 Inches)



(A) Daylight Exposure



(B) Night Exposure

Fig 11 Enlargement of 16 mm Film Taken in DC-3 (Camera Distance, 46 Inches)

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