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PROJECT AMPIRT

ARPA MULTIBAND PHOTOGRAPHIC AND INFRARED RECONNAISSANCE TEST

CAL No. VE-1931-D-4

Prepared For:
UNITED STATES AIR FORCE
AFSC AERONAUTICAL SYSTEMS DIVISION
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Sponsored By:
ADVANCED RESEARCH PROJECTS AGENCY
OFFICE OF THE SECRETARY OF DEFENSE
WASHINGTON, D.C.
Order No. 377, Amend. 3

PHASE I FINAL TECHNICAL REPORT
Contract No. AF 33(657)-13172
15 October 1965

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CORNELL AERONAUTICAL LABORATORY, INC.
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ARPA MULTIBAND PHOTOGRAPHIC AND INFRARED RECONNAISSANCE TEST.

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FOREWORD

This report was prepared as the final report of Phase I under Item II of Contract AF 33(657)-13172. This is an ARPA project initiated under ARPA Order No. 377, Amend 3.

The technical direction and cooperation provided by the sponsoring agency is gratefully acknowledged. Acknowledgment is also made of the cooperation given by the Co-contractor, the University of Michigan. The authors further acknowledge the technical contributions of many personnel at the Cornell Aeronautical Laboratory, Inc. (CAL), especially the following: W. Close, J. Gallatin, E.H. Gerber, R. Haas, H. Hammill, H. Kleinfelder, E. Lindberg, G. Neumaier, P.G. Roetling, F. Silvestro, H. Thung, G. Snider, F. Wehran, Jr. and R. C. Ziegler.

SYNOPSIS

This final report describes the technical accomplishments achieved on Phase I of Project AMPIRT (AF 33(657)-13172) during the period 30 March 1964 to 1 January 1965. The objective of Project AMPIRT (ARPA Multiband Photographic and Infrared Reconnaissance Test) is to accomplish a cooperative ARPA/Air Force/Co-contractor program to study the use of multiband aerial photographic and full spectrum infrared sensors in detecting target clues in a counter insurgency (COIN) environment. The report contains a summary of test plans, a description of the synthesis of the photographic system, the results of camera and photometric equipment calibrations, and a report on Zone of the Interior (ZI) test results which demonstrated acceptable performance of the system.

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I. INTRODUCTION

Aerial photoreconnaissance has proved to be an effective intelligence collection tool in conventional warfare, but has been of only limited value in guerrilla or counterinsurgency (COIN) operations. This is especially true when such activities occur in a tropical, jungle environment such as the one which is prevalent in Southeast Asia.

The objective of the present program is to study the use of multiband aerial photographic and full spectrum infrared sensors in detecting target clues in a COIN environment. The Cornell Aeronautical Laboratory, Inc. (CAL) is cooperating in a joint program with ARPA-Air Force and a co-contractor. CAL has responsibility for the complete multiband aerial photographic system; its acquisition, operation and maintenance. The co-contractor, the University of Michigan, has responsibility for the HC-47 aircraft modification, and acquisition, operation and maintenance of the infrared sensor system.

A series of flight tests in Thailand is planned as a realistic approach to a study of the problem. These tests will be supported by the military forces from that country who will simulate targets of interest for counter-insurgency intelligence. Examples of such targets include guerrilla insurgents as well as their activities such as training and moving in jungles, caves, tunnels, camps, huts, trails, sampans, and the preparation for ambush, camp sites, and defensive positions. The terrain, vegetation and general environment of Thailand offer ideal test conditions for simulating the type of COIN targets being encountered in Southeast Asia.

The present program is divided into three phases. The objective of Phase I is to acquire the photographic sensors, the HC-47 test bed, ground support equipment and related material for maintenance of the photographic system equipments, and supplies for Phase II of the program. Phase II provides for operation and maintenance of the photographic system for a test program in Thailand. Phase III covers the data analysis, collection of ground control data, and interpretation of the photographs. Phases I and II are included under contract AF 33(657)-13172; Phase III is under a separate contract with the Rome Air Development Center (AF 30(602)-3541).

This report is a final report on Phase I covering the first nine months of the contract from 30 March 1964 to 1 January 1965. It reviews the program's technical objectives for use of the multiband photographic system and describes the following tasks: (1) the design and synthesis of the photographic system, (2) photometric calibrations of the cameras and supporting equipment, (3) evaluation of processing and film handling procedures, (4) installations of equipment in the aircraft, and (5) demonstration of acceptable performance of the photographic system during a series of Zone of the Interior (ZI) tests.

Program Schedule

The schedule of the major program tasks for Phase I is shown in Figure 1.

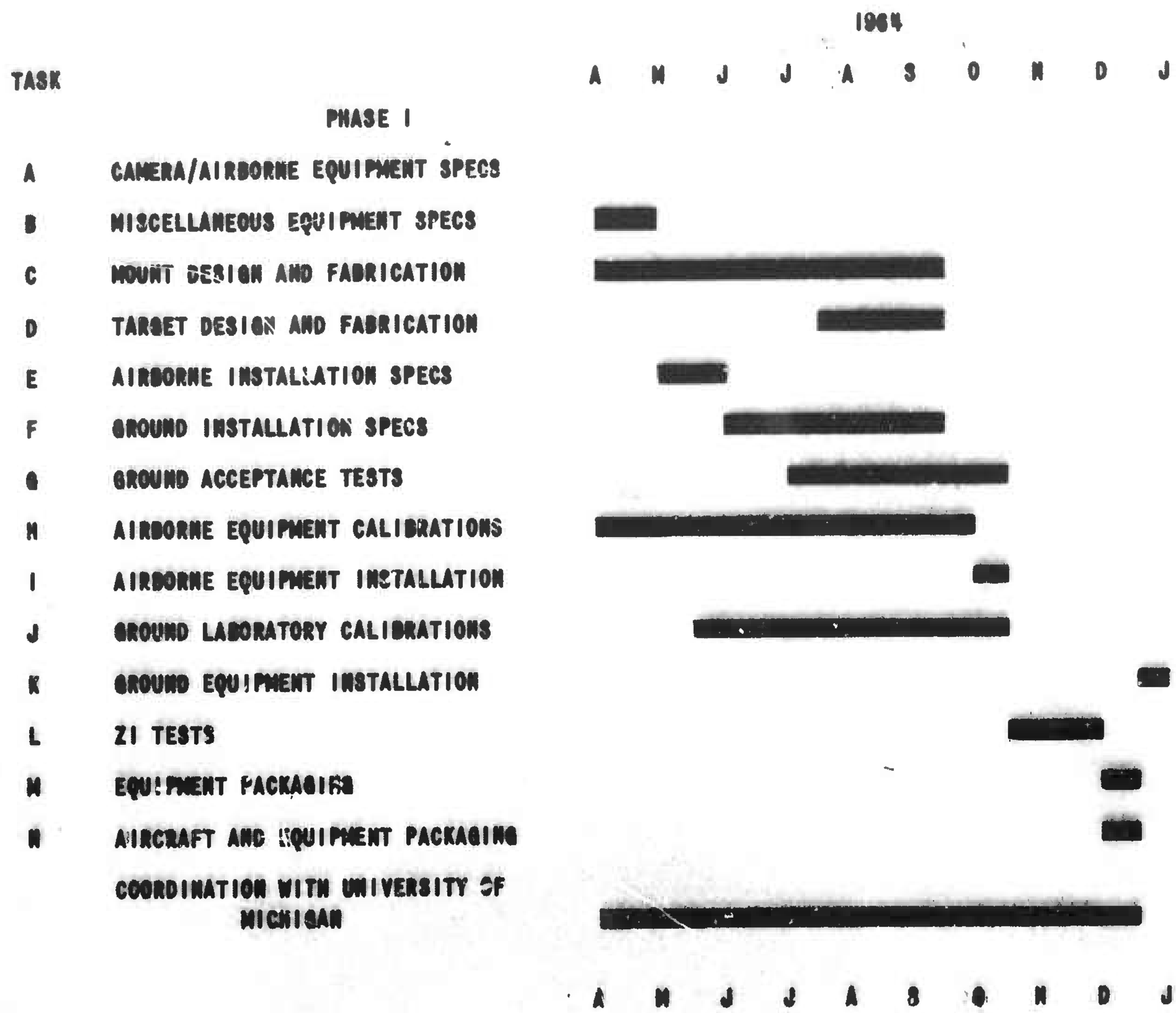


Figure 1 AMPIRT PROGRAM SCHEDULE PHASE I

II. TEST PLAN

A. BASIC PHILOSOPHY

A multiband photographic system may be defined, in its broadest sense, as any system in which two or more cameras are used simultaneously to photograph the same scene or portion of a scene, in which some basic parameter is varied in a controlled manner. For example, various cameras can be used with narrow band spectral filters so that images are formed using light from selected portions of the photographic spectrum and, thereby, permit the detection of variations in the spectral reflectance of targets of interest; cameras with different lenses may be used to obtain multi-scale photographs to determine if different magnifications enhance the ability to detect targets; variations in camera exposure can be used in an attempt to obtain detailed information in shadow regions of the scene.

The basic philosophy which underlies the technical approach to the design of the test program begins with an analysis of the specialized techniques used by the photointerpreter to aid in the detection of targets in photographs. From this point one proceeds to the design of experiments which best capitalize on these specialized interpretation techniques, and then establishes the requirements for the photographic sensors (cameras) and test procedures for obtaining the desired imagery. In addition, the test program includes experiments from which data will be obtained which can be used to test photointerpretation techniques which have not previously been attempted.

In order to conduct the necessary experiments and gather the photographic data needed to assess the merits of the above photointerpretation techniques, it was necessary to synthesize a system of cameras and photometric instrumentation. The airborne system consists of 17 cameras and six photometers installed in a government furnished HC-47 aircraft.

A series of tests will be flown with this equipment in Thailand. Concurrent with the flights, a field crew will set up and maintain a set of special ground targets. They will make photometric and meteorological measurements on the ground to provide control data required for analysis of the imagery obtained from the aerial cameras. A ground laboratory at the airport in Bangkok is equipped to support the operations and includes a photographic dark room, calibration and maintenance equipment and tools, and instruments needed for an on-the-spot interpretation of the photographs. The complete system is further described in Section III.

A test plan for the HC-47 ARPA test program in Thailand (Ref. 1) was issued early in the program and is summarized below. In addition, a test plan for the Zone of the Interior (ZI) tests and a procedure for systems checkout of the equipment to assure proper operation of all the equipment installed in the aircraft was prepared.

B. SUMMARY OF THE PHASE II TEST PLAN

The Phase II test plan was given considerable attention early in this program because the mission objectives and experimental approaches to the tests had to be defined before all of the equipment requirements could be established. Thus, these test plans constitute the basis of selection for the various cameras and photometric instrumentation which were obtained.

The Phase II test plan embodies a series of experiments designed to test various photographic data collection techniques and photointerpretation techniques which may improve the detection of COIN targets in a jungle environment. The selection of these techniques was based upon the experience gained during previous experiments in multiband camera applications to COIN target detection. The techniques include:

1. The use of oblique and panoramic photography for penetrating the vegetation canopy.
2. Measurement of the spectral reflectance of targets using a set of cameras operating in different narrow wavelength bands.
3. The use of blue spectral filters and the use of different exposure settings for improving the detection of targets in shadow areas.

[1] Phase II Test Plan for Project AMPIRT, CAL Report No. VE-1931-D-1, dated 29 January 1965.

4. Stereo interpretation from alternate frames of multi-cameras

5. Interpretation of simultaneous, multi-scale photographs

6. Interpretation of photographs in different broad spectral bands

7. Interpretation of combinations of oblique and vertical photographs

Because many variables will affect the photographic results, the experiments are designed to control or monitor variables in an attempt to assess their significance. Variables which can be controlled include those in the photographic system itself; such as exposure level, film sensitivity, ground resolution, focal length, and angle of view. Operational variables such as flight altitude, offset from the ground track of the target, line of sight, and time of day when flights are conducted can also be controlled. Other operational variables cannot be controlled or are subject to limited control; these include meteorological, diurnal and seasonal changes, potential target areas, terrain, vegetation, and numbers and activities of people.

In order to obtain sufficient data to determine the repeatability of results, and assess the significance of the above-mentioned variables, the test design specifies a series of flights to be conducted during three field experiments, each approximately six weeks in duration during January-February, June-July, and September-October of 1965. These periods were selected to determine the variations due to the dry season, the dry to rainy transition period, and the rainy to dry transition period, respectively. In addition, three different types of target areas in Thailand have been selected; namely, a region of dense forest, a rubber plantation, and a partially cultivated region interspersed with canals. Simulated targets at each of these sites will be supported by the military forces of Thailand in a cooperative effort. In addition, during the flights a technical field crew will monitor certain meteorological factors and obtain control data including ground irradiance measurements and spectral reflectance measurements for both control and natural targets.

In order to conduct the experiments required to evaluate the various techniques outlined above, it was determined that seventeen cameras consisting of three basic types are required for this program. Thus, the photographic system consists of a set of twelve ITEK 70 mm cameras (Type KA-61) which will be equipped with narrow band spectral filters intended primarily to determine the spectral reflectance of targets and contrast changes with wavelength; a set of four 70 mm Maurer KB-8A cameras modified for use on this program which have different focal length lenses and which are mounted in a frame which allows variations in line of sight; and a Fairchild KA-52 panoramic camera which will be used to provide a wide range of "look" angles for a single pass over the targets.

The details of the test program including a further discussion of the technical objectives are included in the AMPIRT Phase II Test Plan (Reference 1). A brief discussion of each technique follows.

The problem of penetrating the forest vegetation canopy is basically one of obtaining a clear line of sight between target and camera, and achieving sufficient exposure. The optimum angle for such penetration depends upon several factors such as the solar angle and the type of vegetation. In a primary rain forest where little undergrowth exists and insurgents can move about freely on the ground, the optimum angle of view may differ from the case of a secondary rain forest where undergrowth is dense and travel is restricted to trails. Furthermore, in a monsoon forest where there is a definite dry season, the vegetation may lose some of its leaves and thus the optimum penetration angle may vary as a function of season as well as solar angle.

In order to determine the optimum penetration angle, two basic experiments are planned. For both, a panoramic camera is required. The mode of operation requires scanning in a fore-aft direction rather than perpendicular to the direction of flight, which is the more common mode of operation for panoramic cameras. The IMC capability in the KA-52 panoramic camera was designed for the side-to-side scanning mode. When the camera is oriented to scan fore and aft there is no image motion perpendicular to the scan direction. Therefore, the IMC mechanism of this camera was disconnected. Over the range of exposure times and aircraft altitudes and speeds to be covered in this program, image motions along the scan direction will be negligible. This is especially true because the effects of image motion will be greatest for near vertical look angles which are of least interest for this application of the camera.

The first experiment will be conducted in the daytime using, if necessary, high visibility targets on the ground. Thus, for example, ground troops would remain in concealed positions for one camera run over the target area; for a second run, they would open white parasols having high visibility. Both films will be scrutinized in an attempt to detect the ground target positions. The second experiment is an alternate approach and will utilize the KA-52 camera during a nighttime flight. In this case a string of electric lights will be laid out on the ground to provide a series of point sources whose exact spacing is known. These nighttime targets should have higher visibility than the daytime targets whose visibility depends on the amount of solar radiation that penetrates the vegetation canopy.

Thus, the KA-52 panoramic camera was selected primarily for the purpose of determining an optimum angle for the line of sight, if such an angle exists. In addition, certain of the other techniques such as use of special film/filter combinations for detection of targets in shadow areas may be useful in helping to solve the problem of canopy penetration.

The spectral reflectance characteristics of targets and their backgrounds are of interest because observations in selected wavelength regions may improve the contrast of images on aerial photographs and thus aid in the identification of those images. The spectral reflectance can be determined in two ways. The first method involves measurements of the target radiance and irradiance from which the reflectance can be computed. The second method involves the use of ground control targets of known spectral reflectances which are used as a basis for comparison. Both methods utilize the set of KA-61 aerial cameras, each having a different narrow bandpass filter. The cameras are aligned with their axes parallel and the shutters are synchronized so that the same general area is recorded by all of the cameras.

The cameras are calibrated against a source of known spectral radiance and sensitometric step wedges are exposed on the films using the filters having the same spectral characteristics as those used on the cameras. The density of the target image is measured for each of the spectral bandpasses as determined by the spectral transmittances of the filters and the spectral responses of the films.

In the first method, the radiance of the targets in each spectral band can be computed from the camera calibration data and the sensitometric data (D vs log E curves). The upward looking airborne photometers and the ground photometers provide irradiance data. The average reflectance in each spectral band is equal to π times the ratio of the radiance to the irradiance. In the second method, a set of ground control targets of known spectral reflectances are used for obtaining the spectral measurements. The densities of the images of the control targets and other ground targets are measured in each spectral band. Using the sensitometric data, the spectral reflectances of the other targets of interest can be determined. Through the use of the control targets, atmospheric scattering of light can be eliminated from the reflectance measurements.

The aerial cameras required for the spectral measurements must be precise instruments with accurate and consistent shutter action. Between-the-lens shutters are preferred over focal plane shutters since they provide a uniform exposure interval over the film format. Furthermore, since the several cameras must simultaneously photograph the same ground scene, each in a different spectral region, they must be sufficiently small so that a set of them can be conveniently mounted in an aircraft.

A survey of 70 mm cameras was made and the KA-61 appeared to be the best compromise for the present program. This camera has a between-the-lens shutter. Furthermore, this camera has image motion compensation (IMC) which permits longer exposure times with a minimum loss of ground resolution. A set of 12 of these cameras was selected, along with a series of 500 Angstrom bandpass dielectric filters. Ten of the cameras will be used to sample the photographic spectrum from 3600 Å to 9000 Å. One of the remaining two cameras will use color film or camouflage detection film; the other will not be filtered and will be used as a "control" camera to assure that proper exposures are being obtained.

The detection of detail in shadow areas requires a special photographic technique. Shadow regions are illuminated by skylight and/or light reflected from surrounding objects and, thus, when the camera exposure is set correctly for the shadow areas, the sunlit areas will be highly overexposed. The spectral character of the skylight scattered into shadow regions is predominantly blue and the ratio of the irradiance due to direct sunlight plus skylight (highlight areas) to the irradiance due to skylight alone (shadow areas) is less in the blue region than in other regions of the spectrum. The test program includes the use of cameras with blue filters and a special blue sensitive film with exposures set for the shadow areas. It is anticipated that an improvement in the detection of shadow detail will result with less loss of highlight detail occurring due to overexposure in the sunlit regions. A second approach utilizes two cameras, with one exposure set for shadow regions, the other for direct sunlight. The resultant photographs will be analyzed by a photointerpreter using a stereoscope and alternate frames from the two cameras. Because obtaining the data necessary to study the detection of targets in shadow regions requires camera techniques which do not impose any camera requirements in addition to those already mentioned, the KA-61 cameras can be used for this experiment. In addition, the modified KB-8A cameras, although primarily selected for other reasons, can also be used for the shadow detail experiment and have an advantage in that they can be oriented at various oblique angles. Thus, the necessary blue filters were obtained for use on both the KA-61 and KB-8A cameras.

The experiment to evaluate stereoscopic photointerpretation from alternate frames of multi-cameras requires the use of two or more cameras operating simultaneously. By using a format length to focal length ratio of 1.5 for each of the cameras and 60 per cent overlap, the normal stereoscopic exaggeration is achieved. The objective of the experiment is to determine if a significant increase in information extraction can be achieved by the photointerpreter. This technique will be tried on the shadow detail photographs mentioned earlier; for two color channels, one overexposed and one properly exposed; and for the case of one color channel and one high definition panchromatic channel.

Another photointerpretation technique of interest requires simultaneous, multi-scale photographs. Often the photointerpreter may locate a target such as a trail in a heavily forested area by finding two sections of trail surface on two photographs separated by several frames on the roll. By analyzing the terrain features and tree cover in stereo, between the two known trail images, he can often locate the trail without actually seeing any additional trail surface. This technique can be evaluated further by using simultaneously-exposed photographs of different scales (area coverage and ground resolution). The only camera requirement which differs from those mentioned previously is that different focal length lenses be used in two cameras. The modified 70 mm KB-8A cameras which have three interchangeable lenses satisfy all of the desired requirements.

Significant target clues may evolve from the scrutiny of several photographs taken simultaneously in different broad spectral bands. For example, scrutiny of simultaneously-exposed frames taken with color, camouflage detection, blue sensitive, and infrared films might reveal the following combination of factors:

a. The color film clearly distinguishes the surface of a foot path from the surrounding vegetation.

b. The camouflage detection film distinguishes emplacements camouflaged with dead vegetation from the surrounding areas having healthy vegetation.

c. Blue sensitive film distinguishes details in shadow areas.

d. Infrared film distinguishes spoils from the dug-in emplacements.

A method to detect the evasive actions used by insurgents to avoid detection by observation or reconnaissance aircraft involves the interpretation of oblique and vertical photographs of the same ground area. The applicable photographic technique would require taking forward oblique photographs with a long focal length camera and taking vertical photographs with a wide angle camera to locate the positions successfully detected on the oblique photographs. This will be achieved by a combination of the KB-8A cameras (for the oblique photos) and the KA-61 cameras (for the vertical photos).

A summary of the camera requirements needed to achieve the various technical objectives of the Phase II test program and which constitutes the basis for the selection of the cameras to be used is presented in the following table.

	Experimental Objective	Camera Capability Required: Panoramic	Oblique	Vertical	Different Focal Lengths
a.	Vegetation Penetration	x	x	x	+
b.	Spectral Measurement	-	-	x	-
c.	Improvement of Shadow Detail	-	+	x	+
d.	Dual Stereo Interpretation	-	+	x	-
e.	Multi-Scale Interpretation	-	+	x	x
f.	Broadband Spectral Interpretation	-	+	x	-
g.	Vertical and Oblique Interpretation	-	x	x	+

Definite Requirement - x

Desirable Requirement - +

III. SYNTHESIS OF THE PHOTOGRAPHIC SYSTEM

A. SYSTEMS ENGINEERING AND DESIGN

The photographic system consists of various basic components. The basis of selection for the 17 cameras intended to achieve the technical objectives of the program has already been discussed in Section II. A special camera mount to hold the cameras in the aircraft and to allow for the operational capabilities demanded by the test plans was designed and fabricated at CAL.

Because photometric control data are required to allow a quantitative analysis of results of the experiments and because suitable photometers are not commercially available, it was necessary to design and fabricate a set of airborne photometers. The set of five upward-looking photometers, mounted in the roof of the aircraft, are intended to obtain measurements of the solar irradiance (due to direct sunlight and skylight) in various narrow spectral bands, as well as the total solar irradiance. An exposure meter was also designed having three channels in broadband red (using a Wratten type No. 29 filter), green (Wratten No. 61), and blue (Wratten No. 47B) regions of the spectrum. This unit is mounted in a downward-looking position, and is intended primarily to provide exposure data for the interpretation cameras.

Because one objective of the test plan requires use of cameras for photometric measurements of ground targets, it was also necessary to develop ground calibration targets and the photometric instrumentation required to ascertain the values of their spectral reflectance. Additional field instrumentation to determine meteorological conditions and certain terrain features, such as soil moisture content, were procured to complete the ground control measurements.

B. AIRCRAFT CONFIGURATION

The basic aircraft configuration showing layouts of all the cameras and airborne support equipment was established during a preconfiguration meeting held at the University of Michigan on 15 April 1964 and has remained essentially unchanged during the program. The final version of the aircraft configuration is shown in Figure 2, which is a simplified sketch to indicate the relative locations of various components of the photographic subsystem.

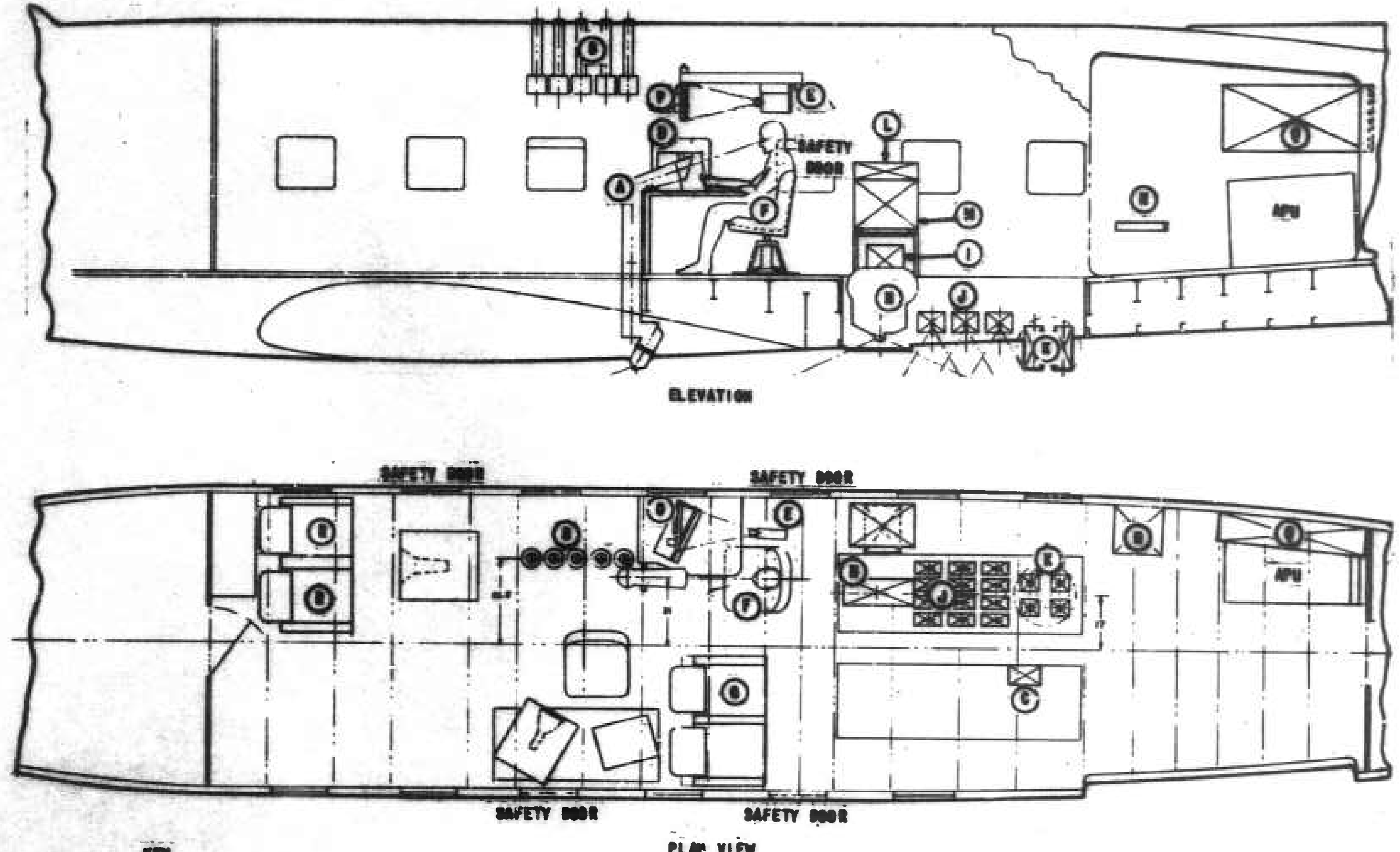
In addition to the photometer mount in the roof of the aircraft, the camera mount, and the downward-looking exposure meter mentioned above, the airborne equipment includes: a multi-channel recorder used with the photometers, a viewfinder which is used by the camera operator for alignment over the target area, a master control console for firing the cameras, which allows remote selection and operation of the cameras as well as other equipment, and a photo data panel. This photo data panel has in it certain aircraft instruments, the camera frame counters and a remote total irradiance indicator which are photographed during aerial camera operation by means of a 35 mm data-recording camera.

C. EQUIPMENT PROCUREMENT OR FABRICATION

1. Cameras

The KA-52 panoramic camera was supplied to CAL as government-furnished property (GFP) at the beginning of the program. This camera could not be operated immediately, however, because a control box was not supplied. After the manufacturer (Fairchild Camera and Instrument Corp.) was contacted to obtain the necessary circuit information, a control box for the KA-52 was fabricated at CAL.

Because this camera had been used extensively prior to receipt for use on the present program, and because special fixtures and equipment would be necessary for a complete test, it was decided that this unit would be returned to Fairchild to be refurbished and have its IMC capability disabled prior to installation in the aircraft. This was accomplished at Fairchild, the



KEY

- (A) VIEW FINDER
- (B) FIVE UPWARD LOOKING PHOTOMETERS
- (C) ONE DOWNWARD LOOKING EXPOSURE METER
- (D) CONTROL PANEL
- (E) DATA RECORDING CAMERA
- (F) NO. 1 CAMERA-OPERATORS POSITION
- (G) NO. 2 CAMERA-OPERATORS POSITION
- (H) PANORAMIC CAMERA (KA-52)
- (I) POWER SUPPLY FOR PANORAMIC CAMERA
- (J) GROUP OF TWELVE KA-61 CAMERAS
- (K) GROUP OF FOUR KB-8A CAMERAS
- (L) RANGE SELECTION PANEL FOR PHOTOMETERS
- (M) RECORDER
- (N) FOLDING SEAT FOR NO. 2 CAMERA-OPERATOR
- (O) TABLE TOP
- (P) PHOTO DATA PANEL
- (Q) STORAGE RACKS FOR FILM MAGAZINES
- (R) OBSERVERS SEATS

Figure 2 GENERAL ARRANGEMENT OF CAMERAS AND EQUIPMENT IN HC-47 AIRCRAFT procedures being witnessed by a CAL representative. After return of the camera to CAL, operational bench tests were made. An illuminated sight was adapted for attachment to the camera mount to project a reference mark onto each frame of the film to facilitate angle of view measurements.

A set of five (one spare unit) KB-8A 70 mm ruggedized cameras was received early in the program as GFP. These cameras were inspected and refurbished by CAL personnel working together with a technician from WPAFB. The original cameras were equipped with a 100-foot wrap-around film magazine. Because of the operational requirement to use these cameras at various look angles, which imposes limits on the size of the mounting frame, and because it is necessary to change film during flight, it was decided to modify the KB-8A cameras. To achieve this, the 50-foot magazine from a model P-2 aerial reconnaissance camera was selected for adaptation to the KB-8A ruggedized camera. This magazine is smaller than the KB-8A magazine and uses spool-wound rather than core-wound film. Both type cameras are made by J. A. Maurer, Inc. Figure 3 shows the KB-8A ruggedized camera, both before and after the magazine modification.

Because the original P-2 magazine was not exactly compatible with the KB-8A camera body, it was necessary to perform certain internal modifications to the film platen plate and to allow for suitable mounting. A photograph showing the original P-2 magazine and the modified P-2 magazine is given in Figure 4. A blow-up photograph of the modification components is shown in Figure 5.

After initial shutter speed, focal length, and AWAR measurements of the modified KB-8A cameras had been completed, a failure occurred which was traced to excessive spacing between the film drive gear in the magazine and the idler gear in the camera which caused excessive wear. To alleviate this problem, an additional modification had to be made to obtain a better mesh between the two gears. The initial tests were then repeated.

The KA-61, 70 mm cameras intended primarily for investigating spectral effects were also supplied as GFP. Because these cameras had not yet been manufactured at the start of the program, it was not possible to meet the original CAL program schedule outlined in the proposal. The program

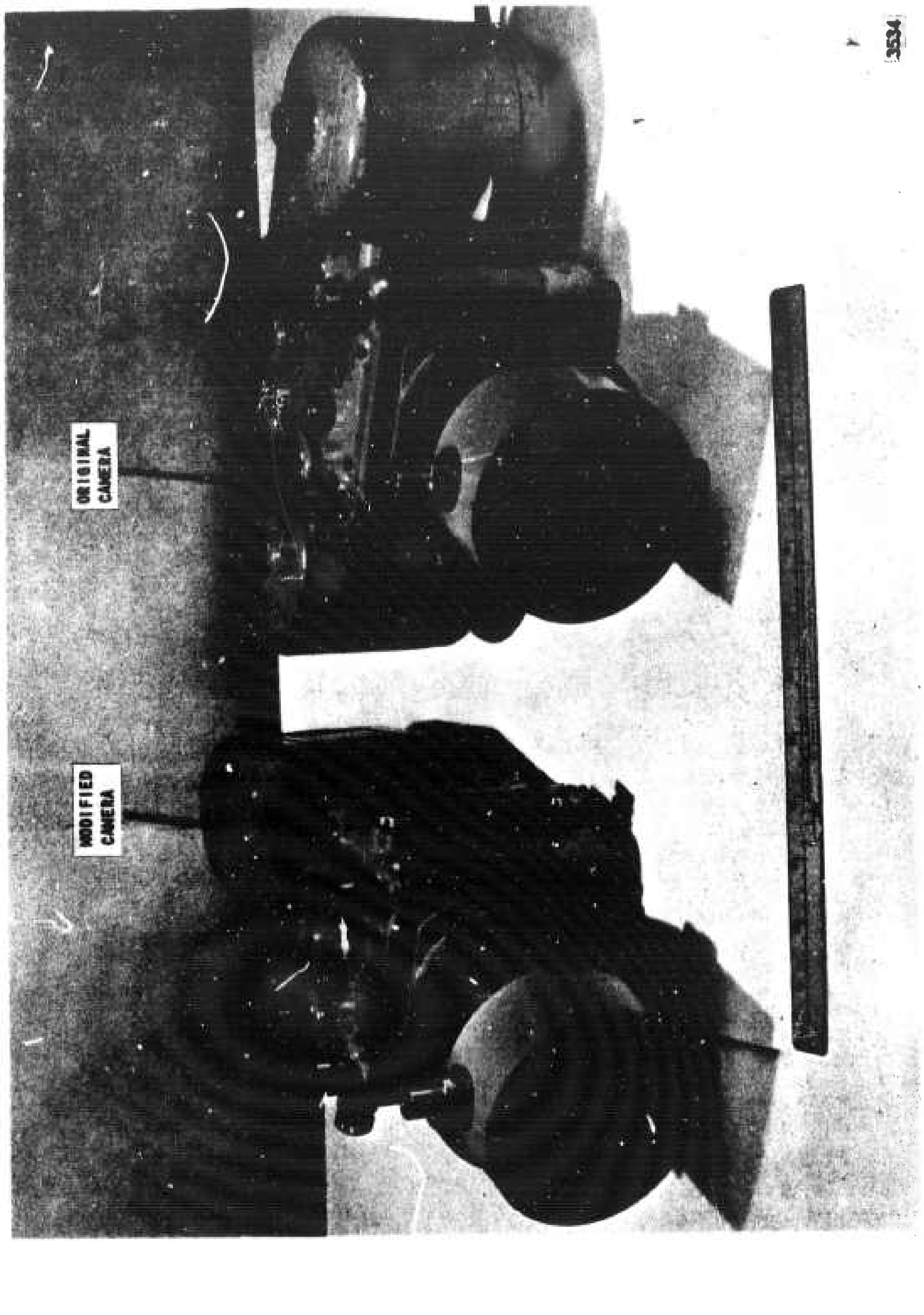


Figure 3 KB-8A RUGGEDIZED CAMERA, BEFORE AND AFTER MODIFICATION

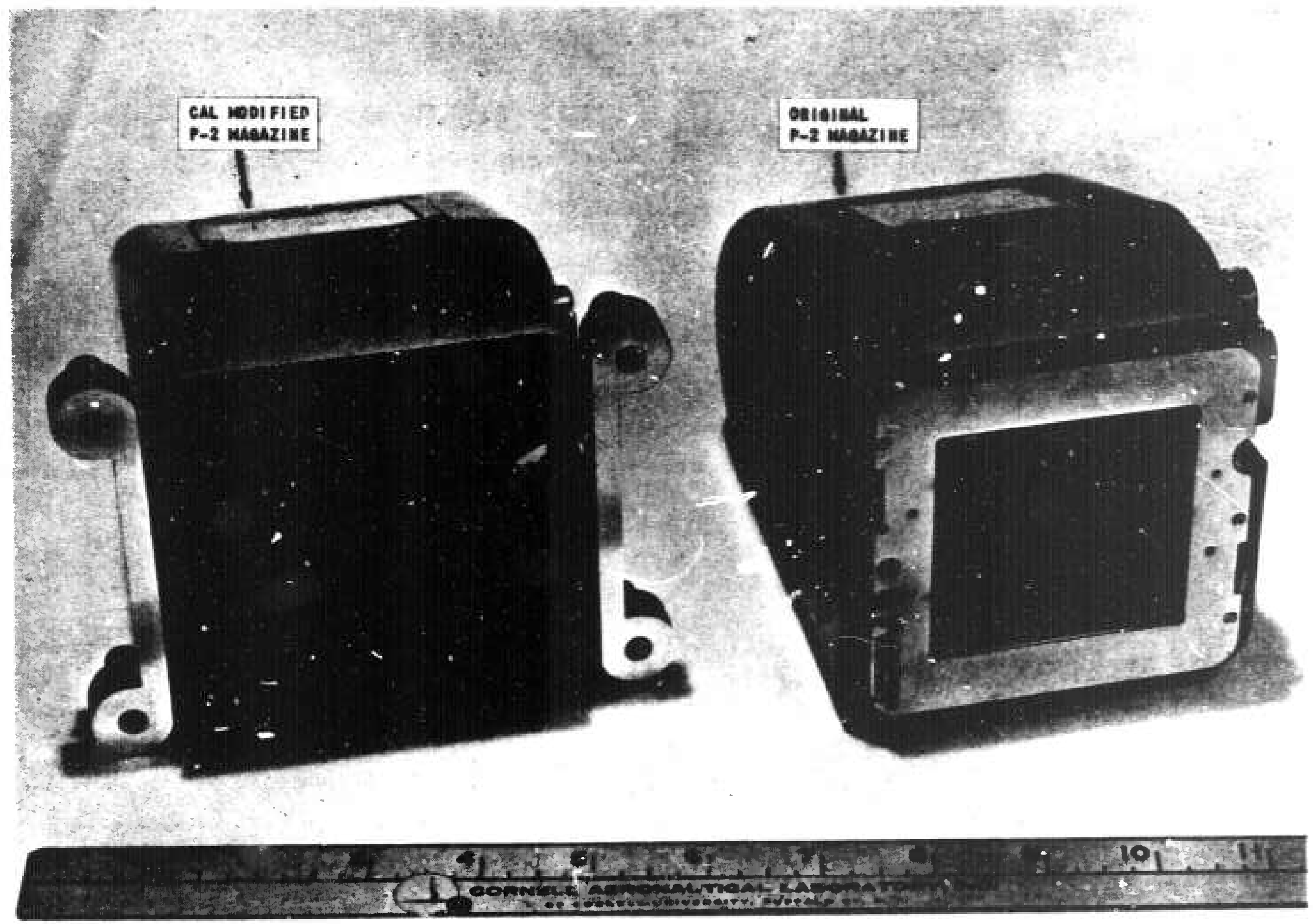


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Figure 4 50' FILM MAGAZINE FOR P-2 CAMERA SHOWING CAL MODIFICATIONS

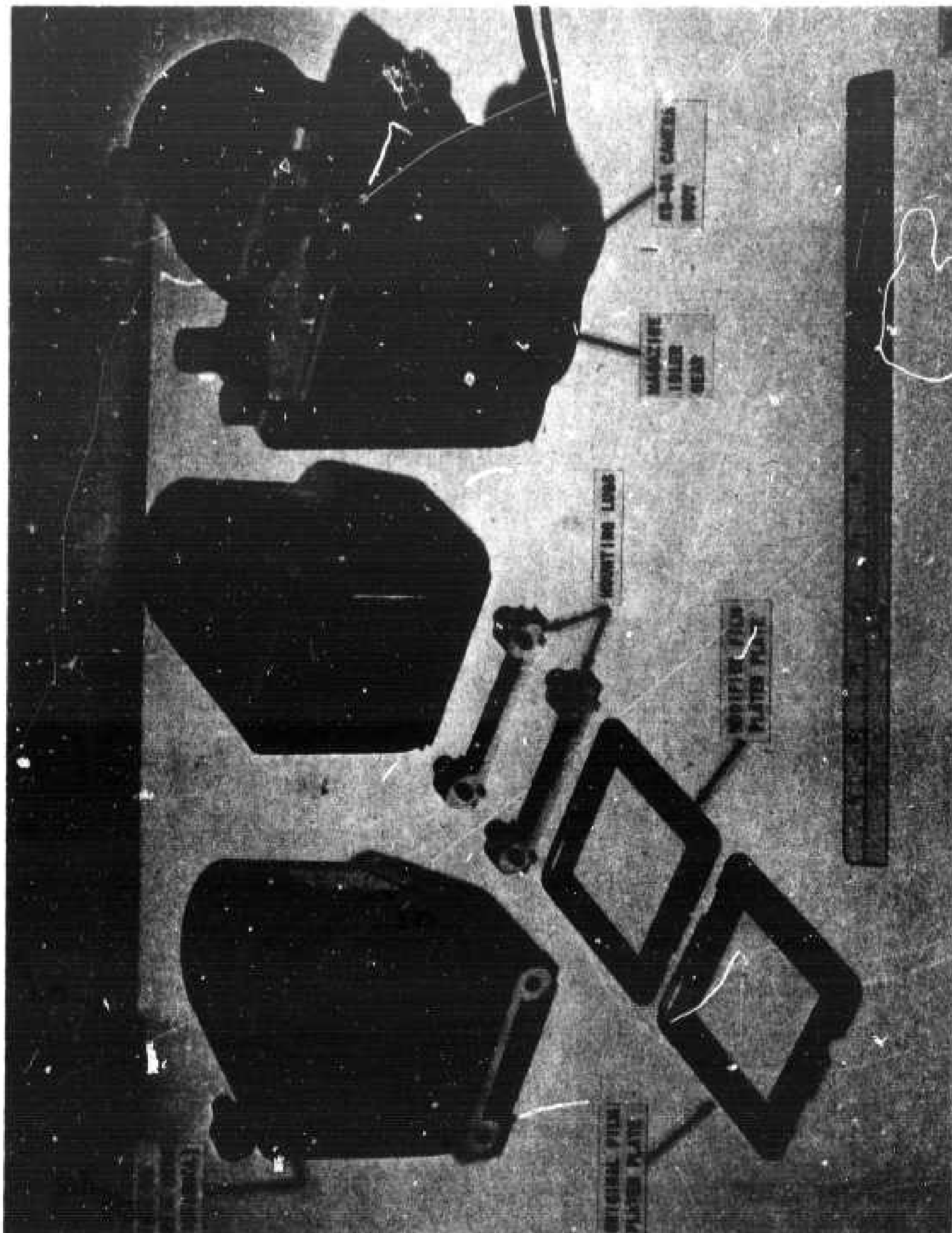

Figure 5 DETAILS OF P-2 CAMERA MAGAZINE MODIFICATION

schedule was revised because of delays in the delivery of the KA-61 cameras, and because of a number of failures and mechanical operating difficulties which occurred. These operating difficulties have been corrected and the cameras have performed well during the flight tests conducted to date. A photograph of the KA-61 camera in Figure 6, shows interior details of this camera.

2. Camera Mounts

After consideration of several different individual and combined camera-mount configurations, it was decided to mount all 17 cameras in a large framework, which is shock mounted and incorporated as an integral unit into the airframe of the HC-47 airplane. Figure 7 is a photograph of this basic camera mounting frame. Figure 8 shows a top view of the camera frame. The KA-61 cameras are mounted in the center section of the frame. The opening on the left side is for the panoramic camera and the large circular opening on the right supports the fixture which holds the four KB-8A modified cameras. Figure 8 also shows two of the special camera brackets which were designed and fabricated at CAL to provide the required support for the KA-61 cameras. These camera brackets for the KA-61 cameras were necessary to permit aperture and shutter speed settings on these cameras to be changed during flight operations without removal of the cameras from the camera mount. The brackets also provide for the filter holders which could not be attached directly to the KA-61 cameras. The details of the camera brackets are shown in the photograph, Figure 9. Figure 10 shows the special filter holder in the bottom of the camera bracket, which has one of the KA-61 cameras mounted in it.

A special mounting fixture for the KB-8A cameras was fabricated for use on the camera frame. Figure 11 shows the fixture with one of the KB-8A cameras mounted in it. It also shows the mechanism which allows the camera axis to be varied from 0° to 60° from the vertical. Figure 12 shows the same fixture with all four KB-8A modified cameras mounted in it and assembled in the camera mounting frame. The cameras are shown in a raised position, which is the one used for changing film magazines, and

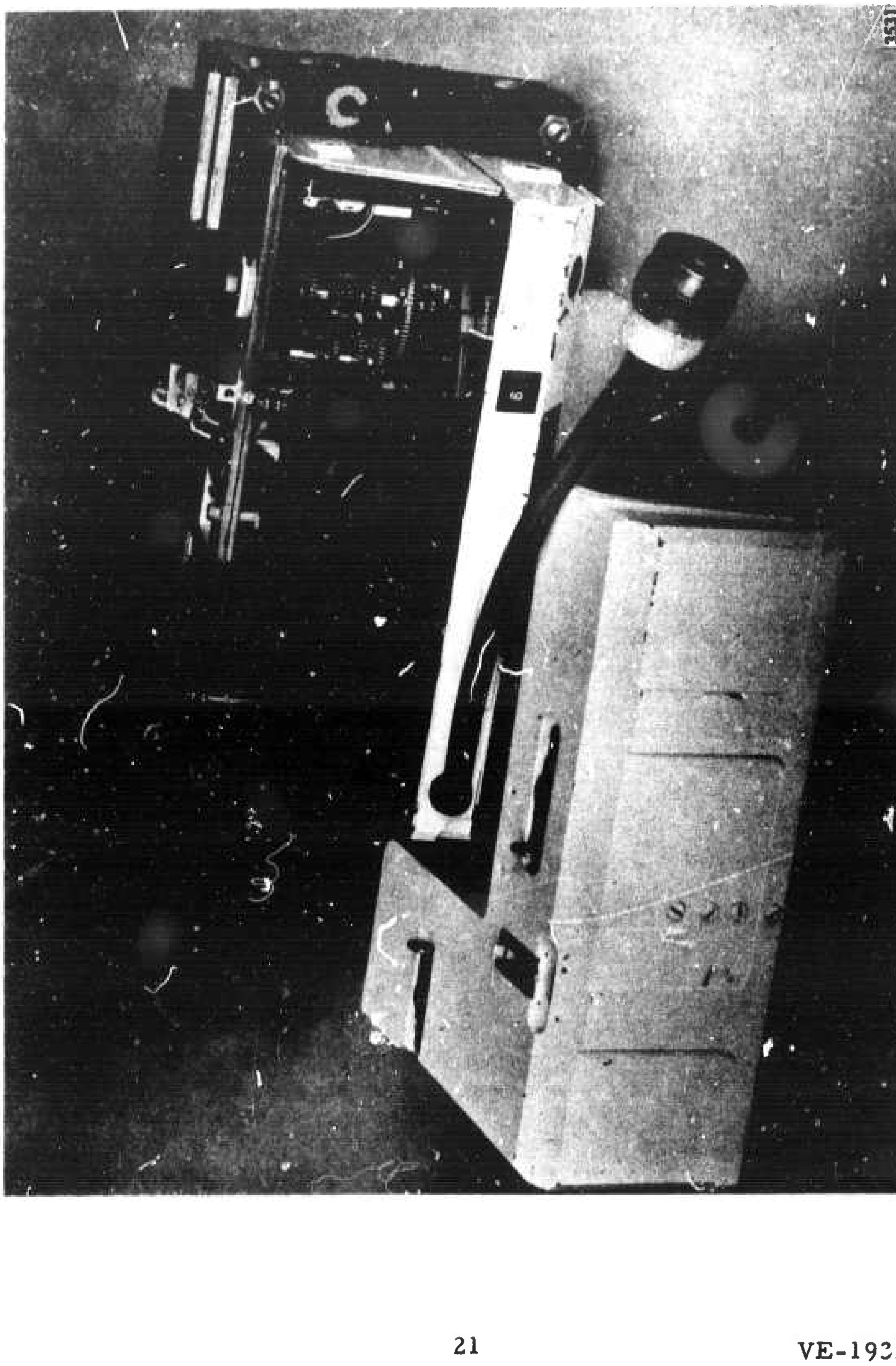

Figure 6 KA-61 CAMERA SHOWING INTERIOR DETAIL

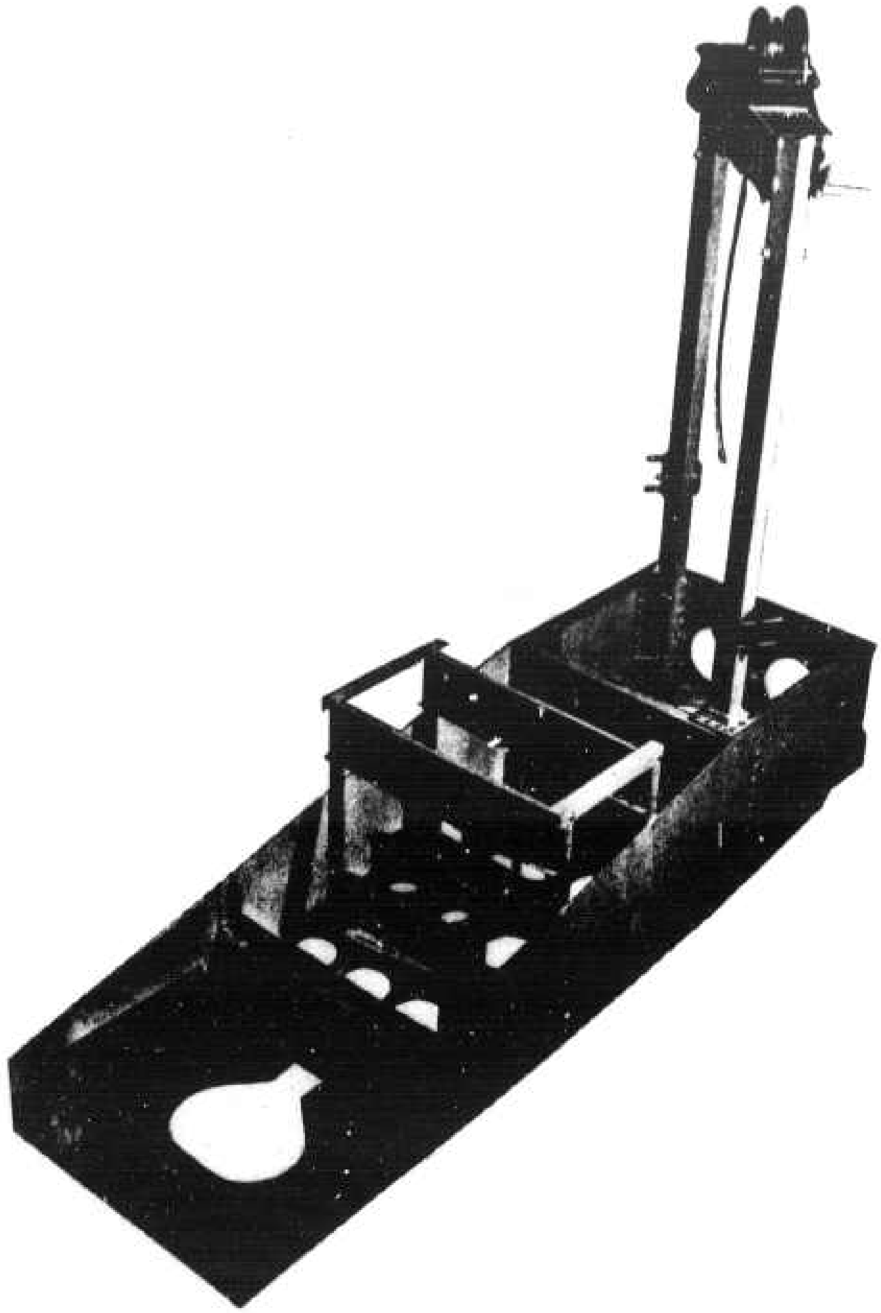

Figure 7   CAMERA MOUNT FOR HC-47 AIRCRAFT

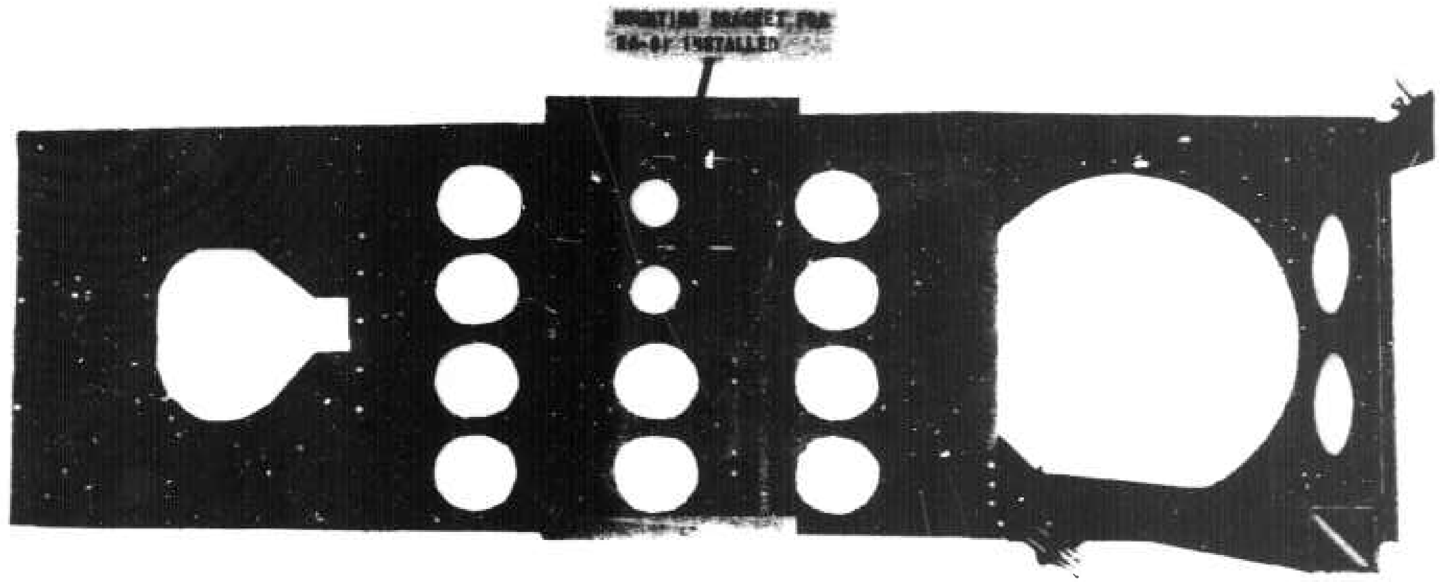

Figure 8 CAMERA MOUNT, TOP VIEW

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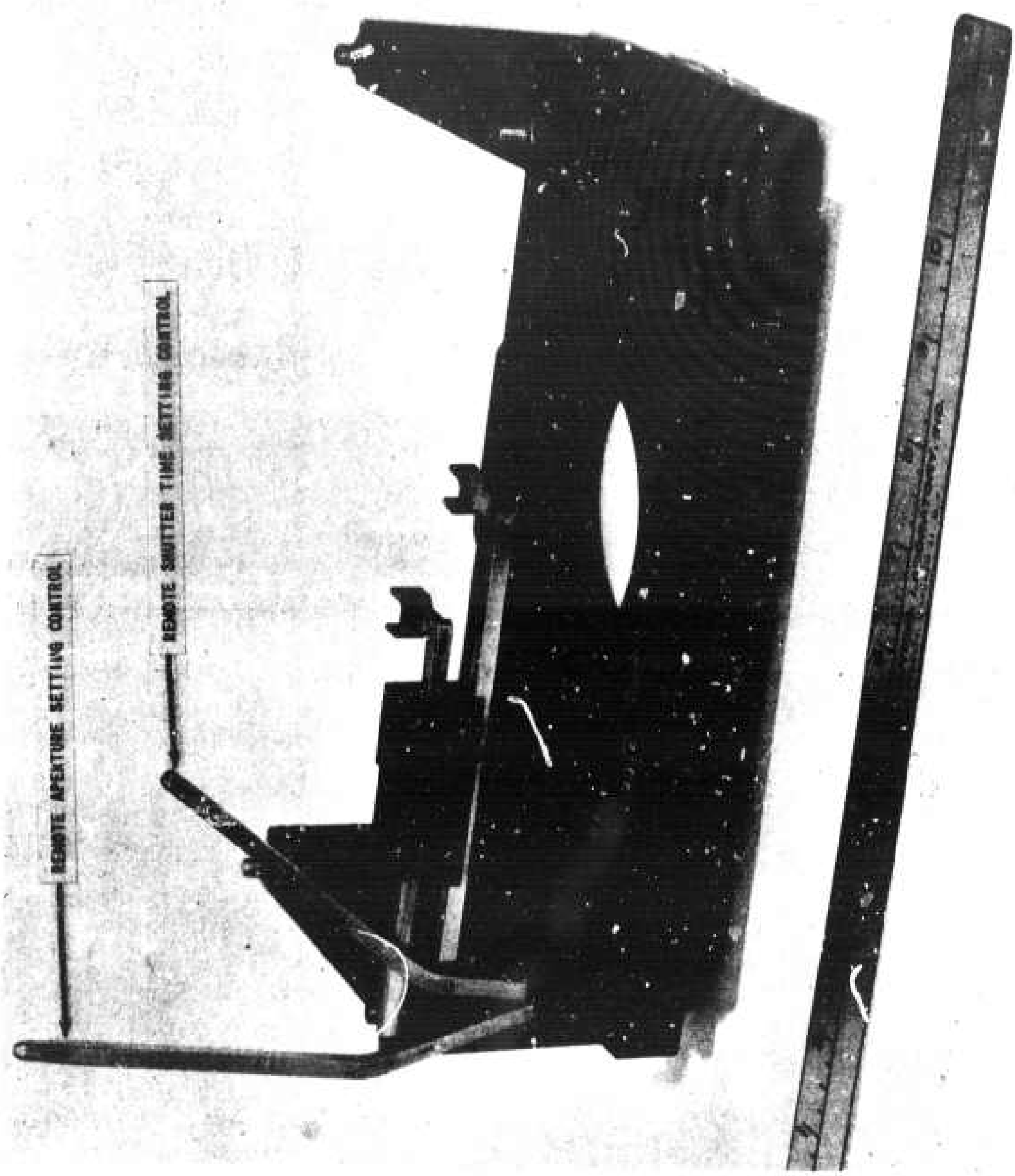

Figure 9 CAMERA BRACKET FOR KA-61 CAMERA

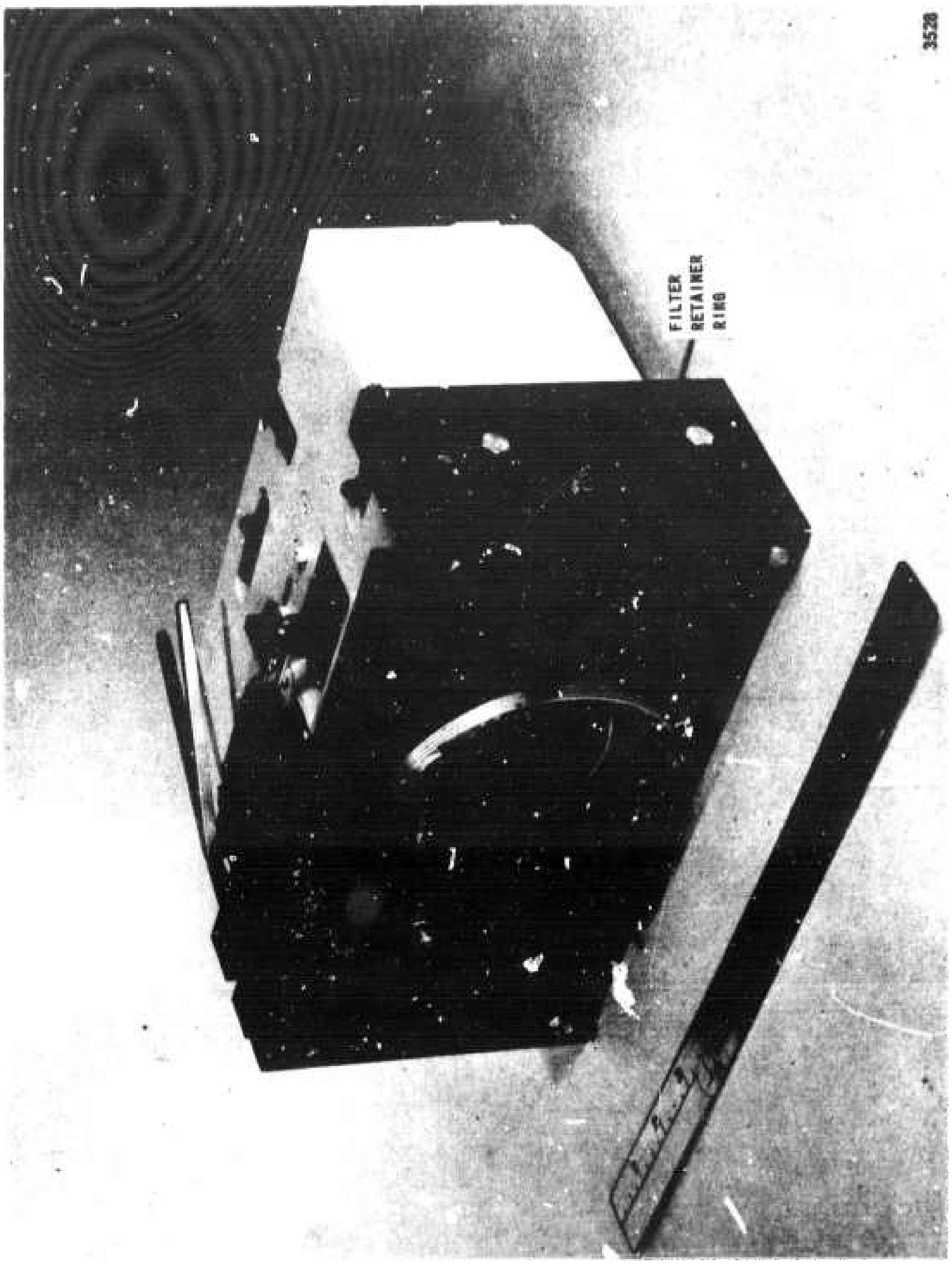

Figure 10 KA-61 CAMERA MOUNTING BRACKET, BOTTOM VIEW

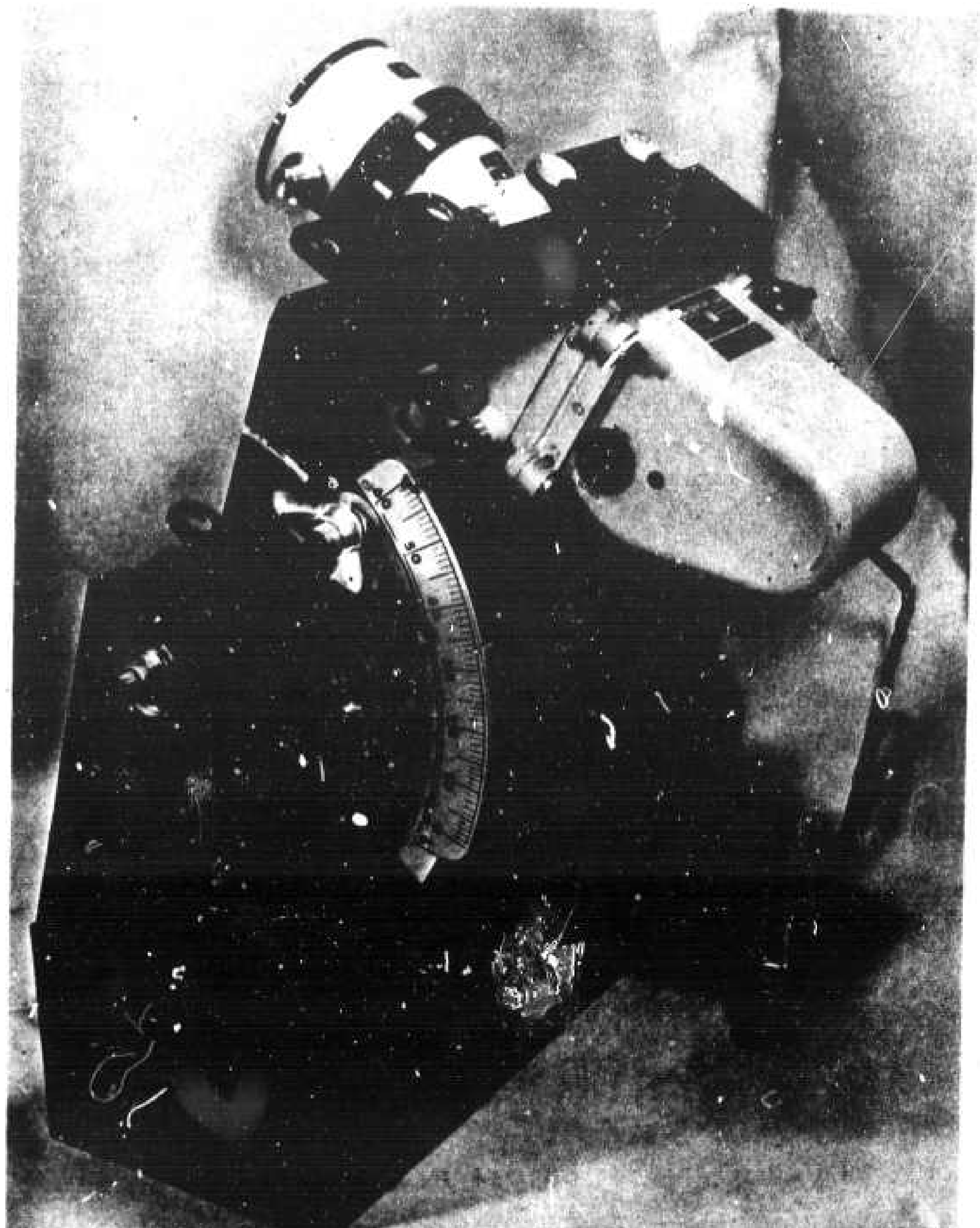

Figure 11 MOUNTING FIXTURE FOR KB-8A CAMERAS

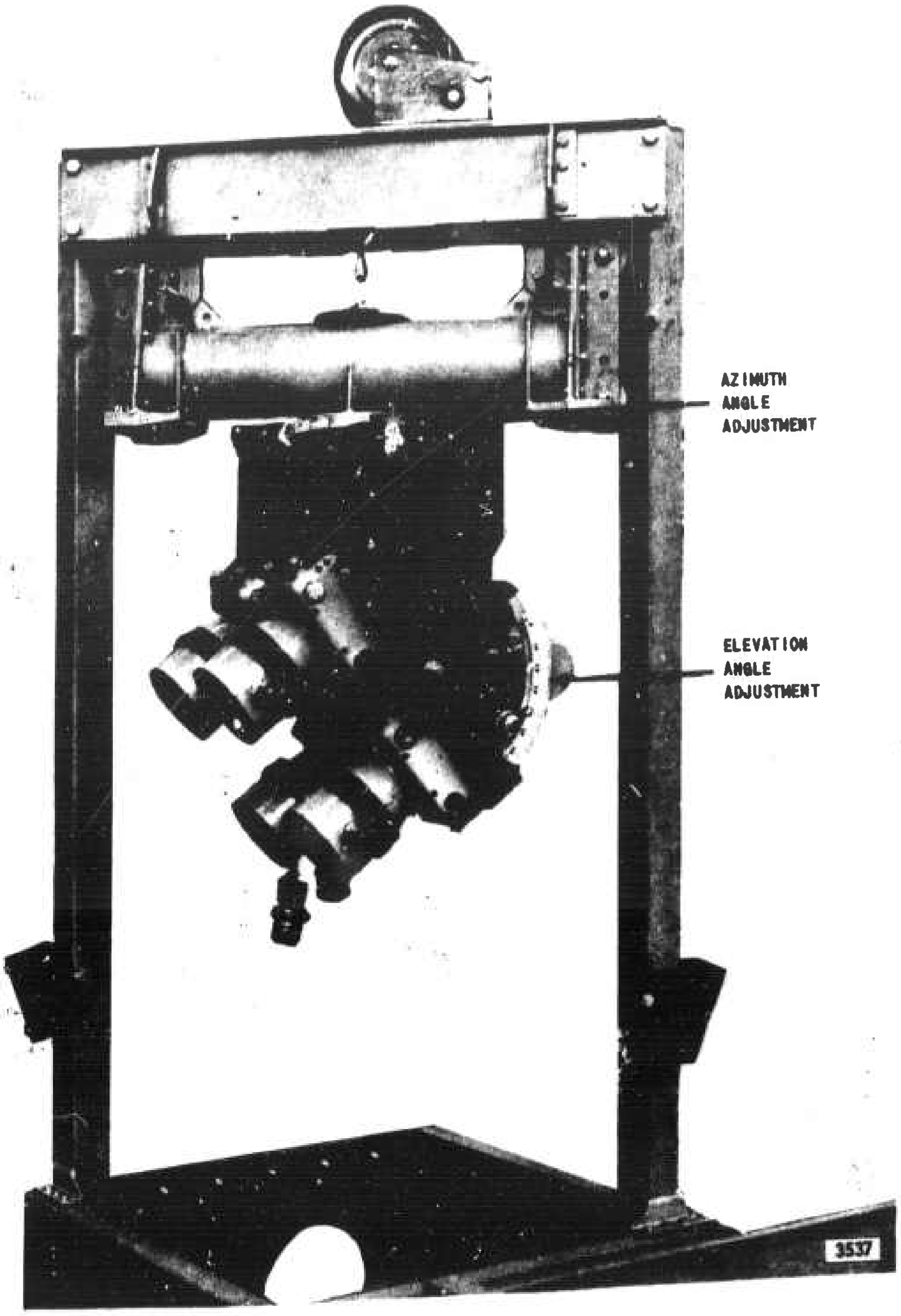

Figure 12 KB-8A CAMERAS IN MOUNTING FIXTURE INSTALLED IN CAMERA FRAME

during takeoff and landing. Note that the entire fixture can be rotated to any azimuth angle before it is lowered to the operating position through the bottom of the camera mount.

3. Narrow Bandpass Dielectric Filters

In order to acquire the spectral data with the KA-61 cameras, ten narrow bandpass filters covering the spectral range from 3600 Å to 9000 Å are used. A review of available filters was made prior to and during early stages of the program. However, no available filters were found having suitable bandpass, transmittance tolerances, and stability characteristics necessary for use in a tropical environment. Because of these problems, it was necessary to prepare a specification for narrow bandpass dielectric filters which had to be made to order.

The spectral transmittance curves for four sets of the dielectric filters are shown on a composite plot given in Figure 13. The curves show both the peak transmittance and the bandpass for each filter. Four of each of the filters were procured because they are also required for use in the airborne photometers and in the sensitometer on the ground.

4. Photometric Equipment

Because it was not possible to find commercially available photometers with suitable sensitivity and performance specifications, it was necessary to design and fabricate a set of airborne photometers for use in obtaining irradiance data. Figure 14 is a photograph showing an assembled and a disassembled airborne photometer. The components are appropriately labeled. A set of five of these airborne photometers is used in the aircraft during all camera operations. Four of these photometers use dielectric bandpass filters similar to those being used in four of the KA-61 cameras. Data from these photometers will be used to check variations in the solar spectral irradiance curve which can vary from flight to flight. The fifth photometer is unfiltered to give total irradiance information. The output from each of the photometers goes to the multi-point recorder via a range selector panel to allow recording of the readings during flight testing. In

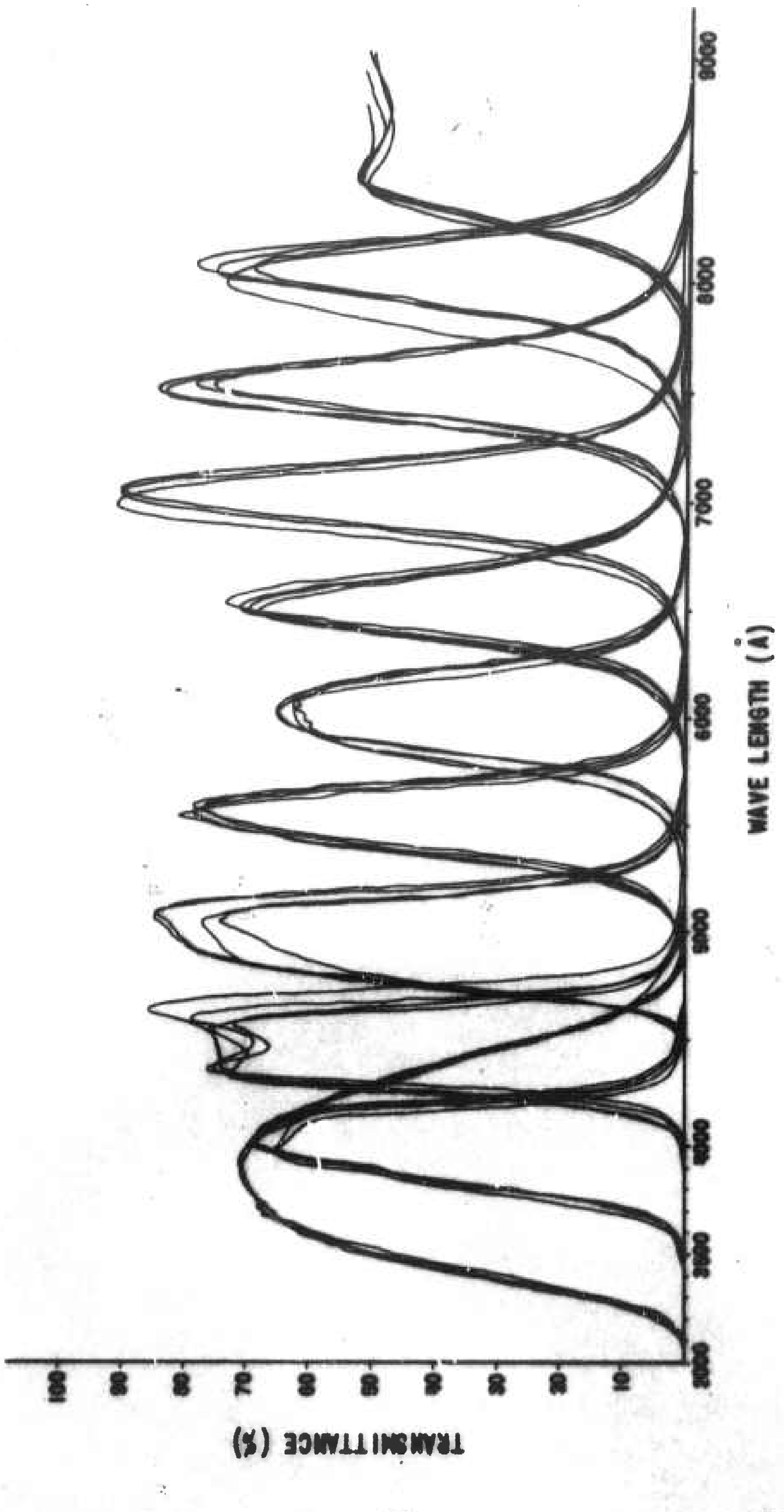

Figure 13 SPECTRAL CURVES FOR NARROW BANDPASS DIELECTRIC FILTERS

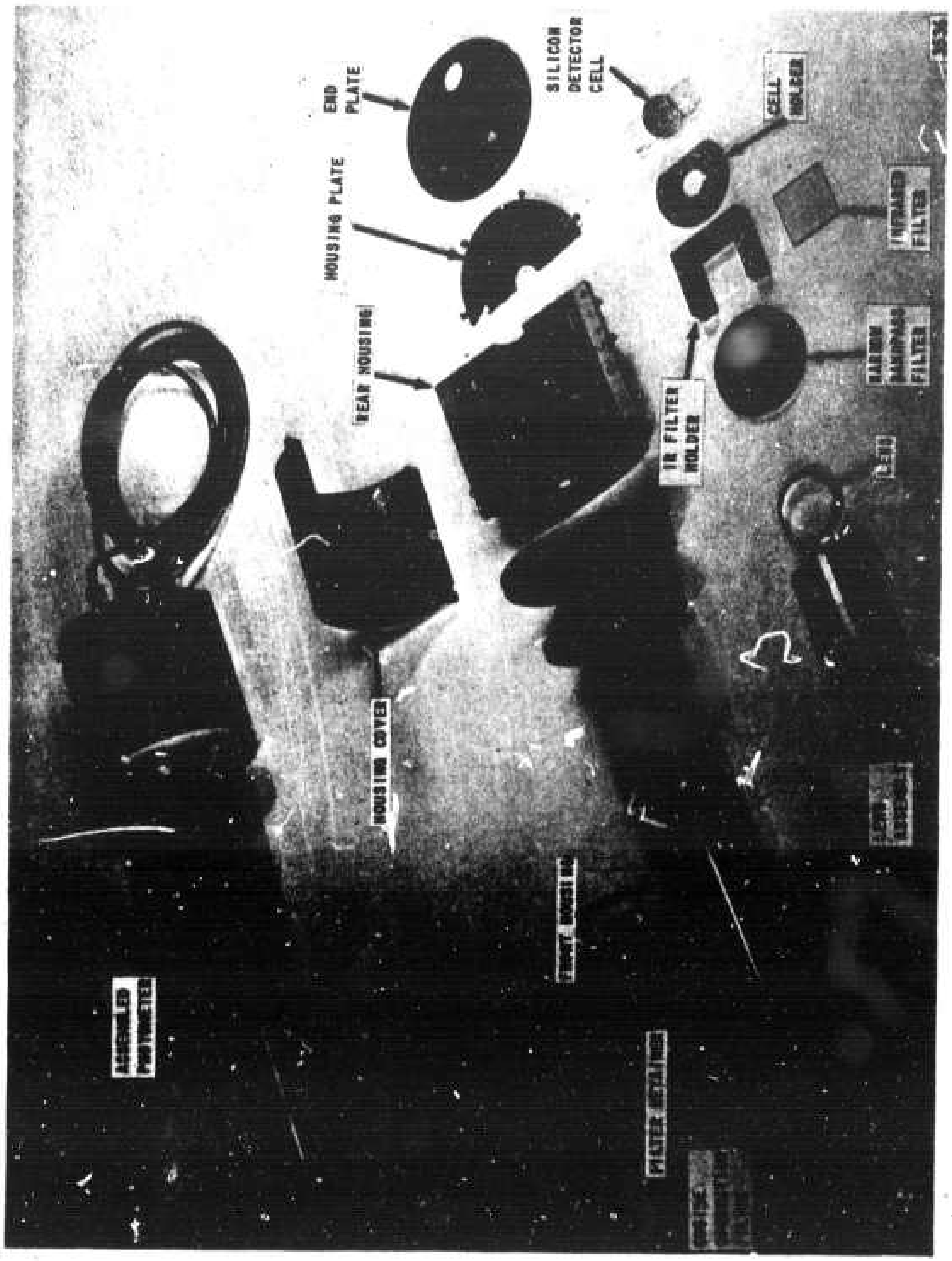

Figure 14 AIRBORNE PHOTOMETER, ASSEMBLED; DISASSEMBLED

addition, the reading from the total irradiance photometer goes to a panel meter on the photo data panel so that it can be conveniently monitored by the camera operator during each run. The photograph shown in Figure 15 shows all five airborne photometers in the photometer mount connected to the multipoint recorder prior to installation in the aircraft.

A three-channel photometer was also designed and fabricated at CAL to be used as a downward-looking exposure meter to provide data necessary for interpretation camera exposure settings. The exposure meter consists of three detector cells, each having a broadband filter selecting the red, green, and blue regions of the spectrum. The internal construction of this exposure meter is shown in Figure 16.

In order to perform a quantitative analysis from the photographs, it is desirable to have on each roll of the film images of some object whose reflectance is known. To facilitate such measurements, as well as to test various capabilities of the cameras, several targets were designed and constructed for use on the ground to provide control data during the ZI tests. Two "spectral" control targets are 8' x 8' panels, each painted a different shade of gray, whose spectral reflectances were determined in the laboratory using a spectrophotometer. Three other spectral targets, 4' x 4', 2' x 2', and 1' x 1', are painted yellow and were used to test the ability of the cameras to measure the spectral reflectance of "unknown" targets. High contrast and low contrast resolution charts were used to test resolution capabilities of the cameras. A point source was used to check for image motion control and vibration. A string of light bulbs was used to test the ability to make accurate angle measurements with the panoramic camera.

To provide necessary control and photometric calibration data for the spectral targets placed on the ground in the target flight area, and to obtain ground truth on the spectral characteristics of targets of interest, it was necessary to procure photometric instrumentation for measurements on the ground. The total irradiance ground photometer shown mounted on a tripod can be seen in Figure 17. This photometer measures the direct solar plus skylight irradiance over the spectral range from 3500 Å to 10,000 Å in the vicinity of the control target panels.

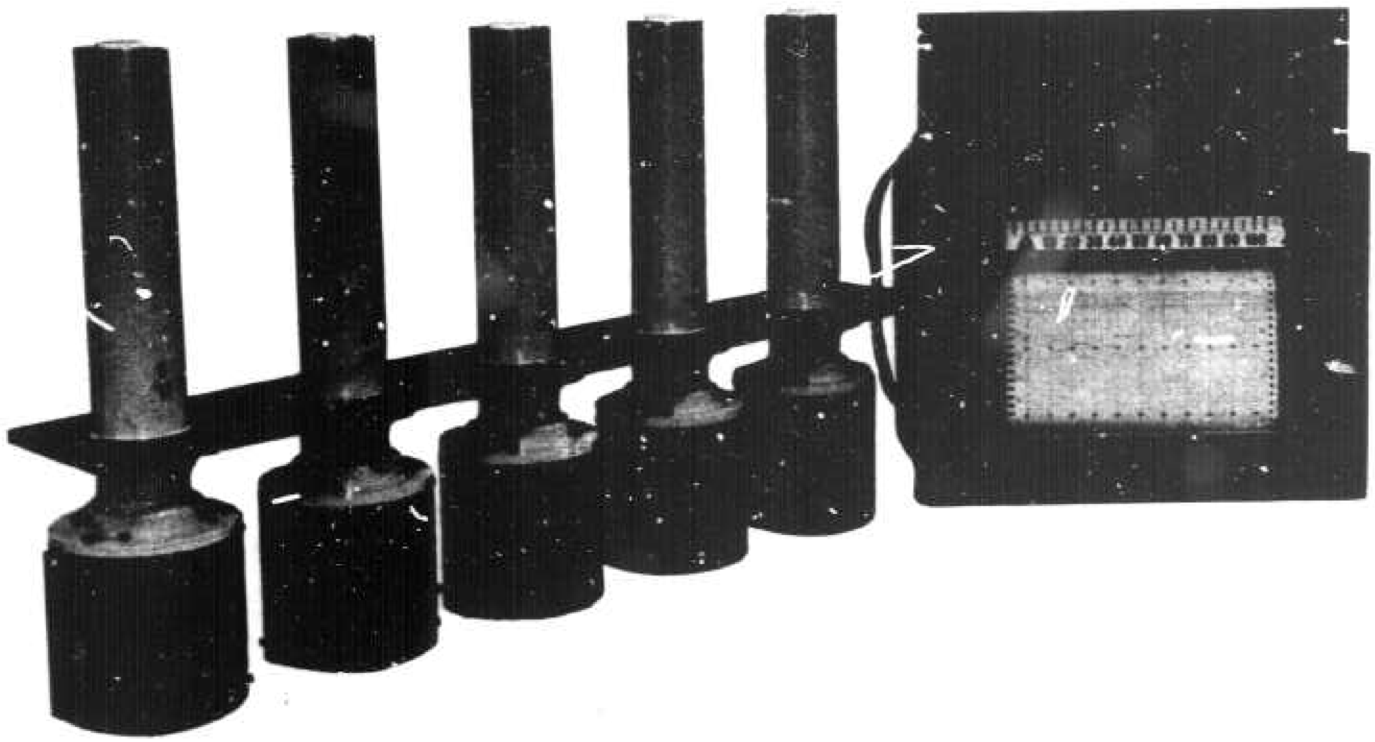

Figure 15 AIRBORNE PHOTOMETERS IN AIRCRAFT MOUNTING PLATE

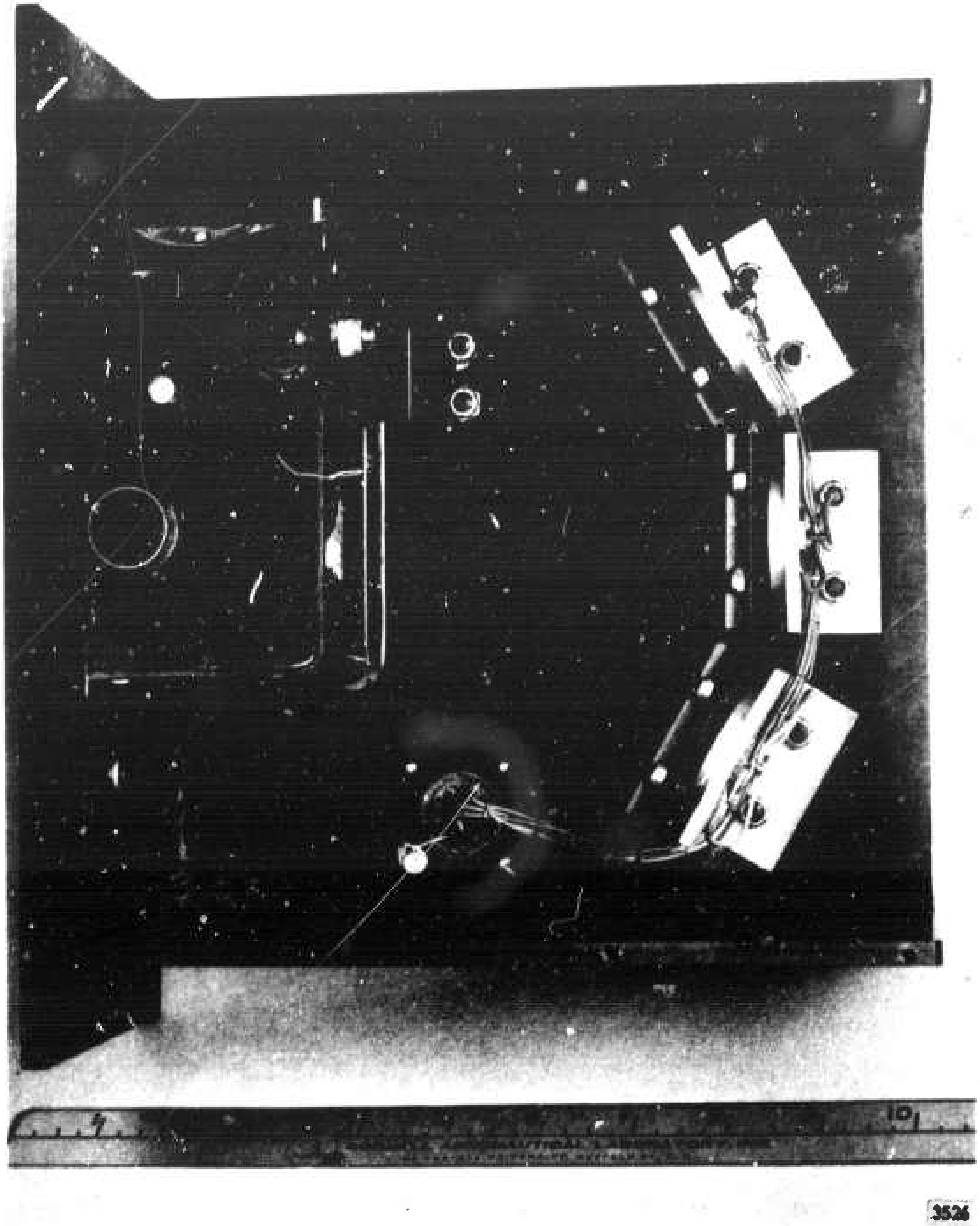

Figure 16 AIRBORNE EXPOSURE METER

Figure 17 TOTAL IRRADIANCE GROUND PHOTOMETER

Additional portable photometers were purchased, along with a set of dielectric filters which, when matched to the detector cells in these photometers, yield a relatively flat spectral response. These portable photometers are used to measure target reflectance data in the same narrow spectral bands as used in the KA-61 cameras in the aircraft.

5. Ground Support Equipment

a. Darkroom Equipment

It was planned that most of the film used for the Thailand tests would be returned for processing to RADC, but that film from the control camera and the ground data cameras would be developed in the field to assure that proper exposures are achieved and to permit on-the-spot photo interpretation. Thus, equipment was procured for equipping a complete darkroom for field processing of photographic film. The photograph, Figure 18, shows the major components of equipment. The roll film processor can handle 70 mm film. The enlarger is used for magnifying particular frames of the 70 mm film for use in field photointerpretation. The rapid print processor allows prints to be made quickly to allow further data analysis in the field. Additional darkroom supplies and equipment (not shown) were also procured, such as chemical storage tanks with mixing motor, thermometers, safe lights, and timers.

In order to place sensitometric control data on each roll of film exposed in the aerial cameras, a sensitometer was obtained. Because none of the existing sensitometers were completely adequate for the present application, it was necessary to modify a standard Air Force sensitometer (FSN 6740-559-9735) so that the narrow band spectral filters used in the KA-61 cameras could be inserted into the light beam to obtain sensitometric step wedges on the film with the desired spectrally filtered light. The modified sensitometer is shown in Figure 19 with the CAL fabricated filter holder removed from the instrument.

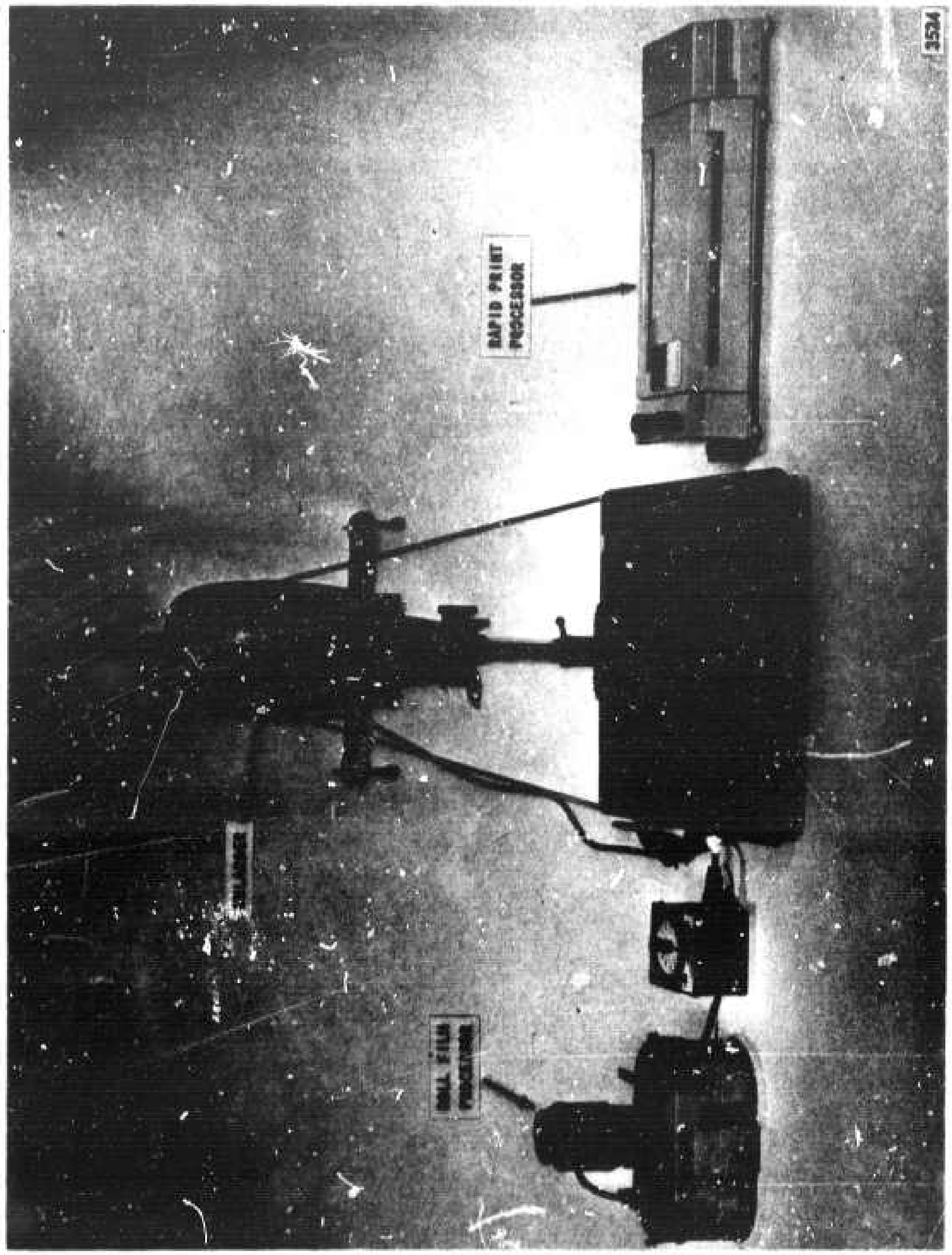

Figure 18 FIELD DARKROOM EQUIPMENT

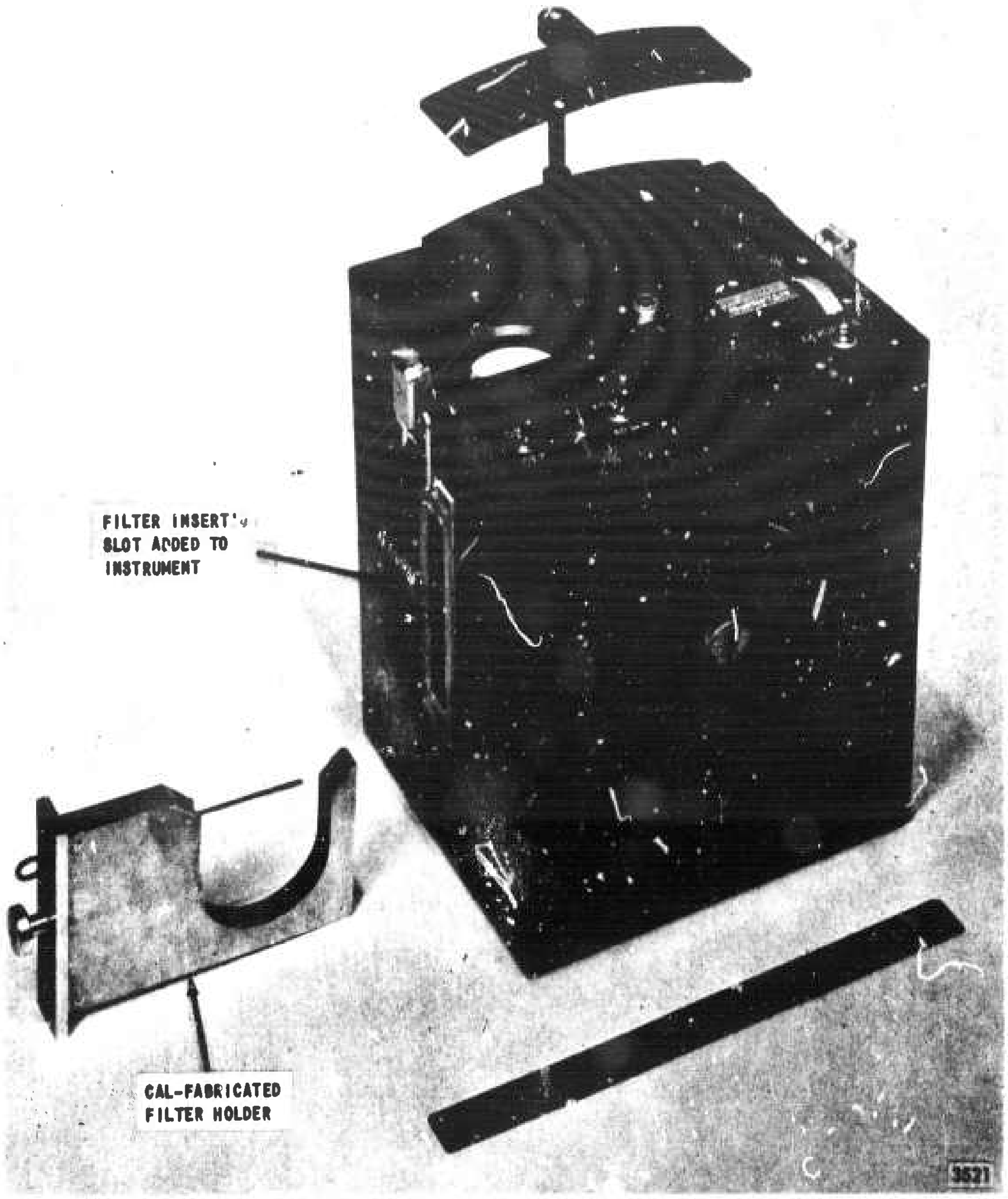

Figure 19 MODIFIED SENSITOMETER

b. Field Photointerpretation Equipment

For analysis of the photographic film developed in Thailand, light tables and a zoom stereo microscope were procured. In addition, a densitometer was obtained to permit density versus log exposure (D log E) curves to be plotted and the exposure range to be determined.

c. Maintenance and Calibration Equipment

The following equipment was obtained for calibration checks of the cameras, filters and photometric equipment: an oscilloscope with camera, a stroboscope, a double rod optical bench, a collimator, an electronic counter, and a spectrophotometer with spectral recording attachment. In addition, two calibration light sources were fabricated at CAL and their spectral radiance curves were determined for three different power inputs. Details of the light sources are shown in Figures 20 and 21. A test device was also designed and fabricated at CAL for use in camera IMC and synchronization tests (see Figure 22). This device has two discs driven at different speeds by two synchronous motors.

For the maintenance and troubleshooting of equipment, a volt-ohm-milliameter was procured as well as the oscilloscope and electronic counter previously mentioned. A complete set of hand tools, including special tools for the cameras, was procured for the repair and maintenance of cameras and other instrumentation.

d. Equipment for the Field Crew

The field crew operates in the target area during the flights in order to obtain ground control information. For this purpose, meteorological instruments, including an anemometer, soil moisture meters, a dew duration meter, and an evaporimeter were obtained. The field crew also requires photometric equipment including the total irradiance ground photometer and the target radiance photometers which were mentioned earlier. Miscellaneous items such as hand transits, binoculars, and cameras were also obtained for use by the field crew.

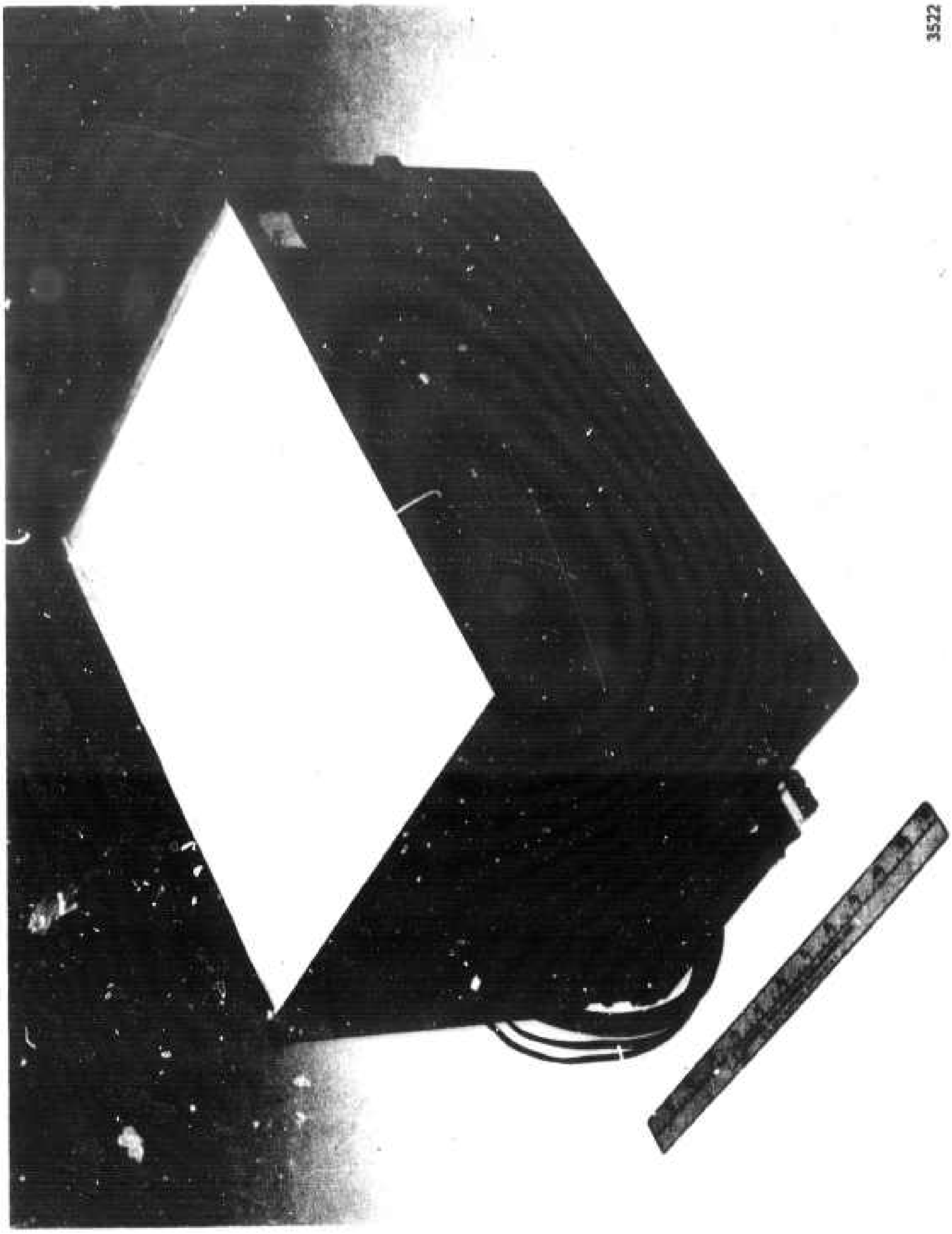

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Figure 20 CALIBRATION LIGHT SOURCE

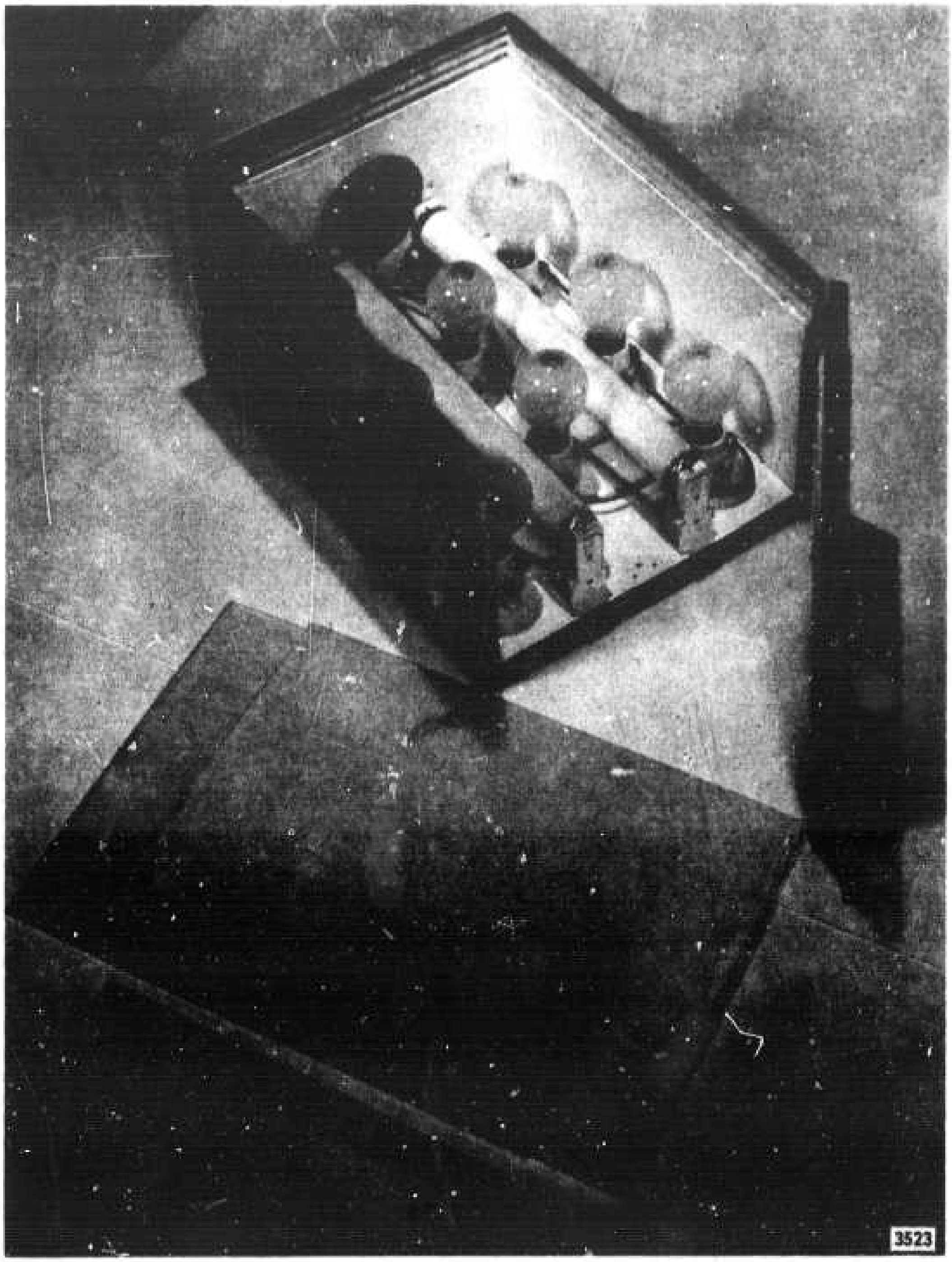

Figure 21 CALIBRATION LIGHT SOURCE, INTERIOR DETAILS

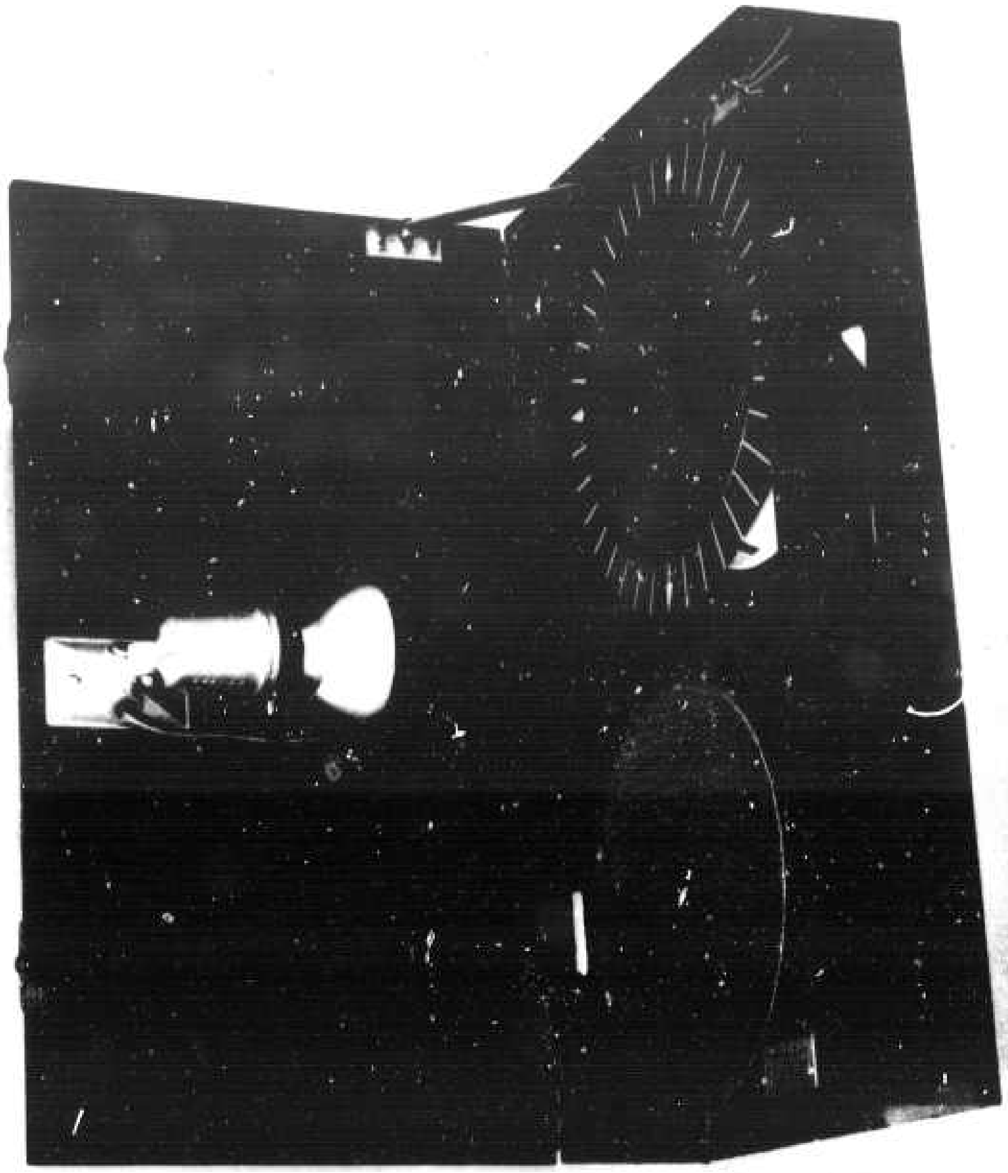

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Figure 22 IMC AND SYNCHRONIZATION TEST DEVICE

6. **Supplies and Spare Parts**

Film for the cameras was the major item of supply which had to be obtained for the program. In addition, developing materials for operation of the darkroom as well as general laboratory supplies for maintenance of equipment were obtained. Spare parts for KA-61 cameras were supplied as GFP, but spare parts for the other cameras and all remaining equipment were purchased. The spare part requirements were established on the basis of recommendations from the manufacturers of various items of test equipment.

IV. CALIBRATIONS

A. CAMERAS

Calibrations and functional tests were performed on all of the aerial cameras, as well as the photometric equipment, required for the collection of data in Thailand. The tests were intended to assess the capabilities of each camera in performing its assigned function and to measure the physical parameters required to compute the desired quantitative data. A discussion of the tests performed and the results obtained during Phase I of the AMPIRT Program is given in the ensuing paragraphs.

1. KA-61 Cameras

The tests and calibration for the KA-61 cameras included: the measurement of the area weighted average resolution (AWAR) as a function of wavelength, the measurement of the relative exposure at the film plane as a function of position in the format, the determination of the relative exposures achieved for given combinations of shutter speeds and aperture settings, a check and calibration of the image motion compensation (IMC) capability, and a test of the ability of all twelve cameras to operate synchronously.

The purpose of performing the resolution tests as a part of the calibration of each of the KA-61 cameras was twofold: to select the optimum combination of camera lens and narrow bandpass filter, and to assure that an adequate ground resolution could be obtained with each camera/filter/film combination to meet the resolution requirements of the program.

The KA-61 camera resolution tests were performed using the equipment setup schematically shown in Figure 23.

The collimator was first focused with the narrow bandpass filter over the light source. A standard bar resolution chart was used as the test object. The camera was aligned so as to be coaxial with the collimator. The test chart image was then in the center of the format at the film plane of the camera. The camera was next loaded with a roll of the same type of

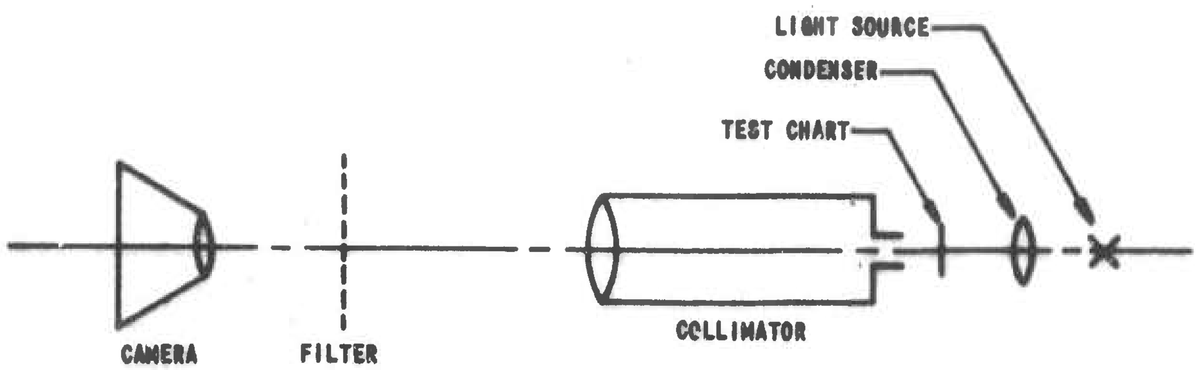

Figure 23 EQUIPMENT SET-UP FOR RESOLUTION TESTS

film to be used during the spectral reflectance experiments. The roll of film used had control step wedges (using the same narrow bandpass filter) placed on each end of the roll of film for appropriate sensitometric control. The maximum relative aperture (f/3.5) was used for these tests. A shutter time was selected which would yield a good exposure for the light source used. After taking a test photograph of the resolution chart image on axis, the camera was rotated in steps of 5 degrees about each diagonal axis (on the format) to an angle of 35 degrees off the boresight axis, and additional test photographs were exposed.

After the test roll of film was processed each frame was scrutinized to determine the number of lines per millimeter represented by the smallest resolution pattern which could just be resolved. From these measurements it was possible to determine the AWAR for each camera/filter/film selection. The resolution test was repeated for each camera using several of the narrow bandpass filters. In general, it was not necessary to test each camera with the complete set of spectral filters since the manufacturer (Itek Corporation) had set the camera focal lengths for a nominal "red," "green," or "blue" wavelength band during preliminary adjustments at the factory. From the measurements made in these resolution tests, it was then possible to plot AWAR versus wavelength for each camera and select the camera/filter combination which gave the best resolution. In a few cases it was necessary to adjust the location of the focal plane by the use of lens shims in order to improve the AWAR capability of the camera/filter combination.

After the completion of the ZI Flight Tests (see Section VI), it was found that the resolution for cameras No. 11 and No. 12 as determined from actual aerial photographs was inadequate. For these two cameras additional laboratory tests were performed and adjustments were made in an attempt to improve the resolution capabilities. The adjustments were successful in improving resolution for both cameras.

A summary of the AWAR measurements obtained during the laboratory calibrations for the KA-61 cameras is presented in Table 1. The table also shows the film and filter which will normally be used with each of these spectral cameras for the spectral reflectance experiments.

TABLE I

SUMMARY OF AWAR MEASUREMENTS FOR KA-61 CAMERAS (LABORATORY CALIBRATION)

CAMERA NO.	SERIAL NO. (ITEK)	FILM USED	FILTER	AWAR
1	14	PLUS-X	MINUS BLUE (= WRATTEN 15)	24
2	15	EKTACHROME	COLOR BALANCE	23
3	22	IR	3800Å	33
4	13	PLUS-X	4500Å	34
5	12	"	5000Å	27
6	21	"	5500Å	20
7	17	"	6000Å	37
8	19	"	6500Å	32
9	16	IR	7000Å	20
10	18	"	7500Å	24
11	23	"	8000Å	18
12	20	"	8825Å	22

a. Relative Photometric Calibration and Off-Axis Exposure Measurement

In order to use the KA-61 cameras for photometric measurements a relative photometric calibration was performed for each camera/filter combination to be used during the operational field program. The purpose of this test was to determine the relative exposure obtained for each combination of shutter speed and aperture setting. The change in exposure at the film plane as a function of angle off the boresight axis is also of importance and could be determined from the same experiment.

The procedure followed was simply to take photographs of the calibration light source (an extended diffuse source) for each shutter speed and aperture setting combination for each camera/filter combination. Sensitometric step wedges, using the same filter, were placed on each roll of film to establish the density versus log exposure curve in each case. Using this curve and a densitometer measurement of the center portion (boresight axis) from each frame of the light source photographs, the relative exposure calibration was established. From a densitometer trace across the entire format of this imagery it was also possible to determine the exposure falloff as a function of off-axis angle. The curve shown in Figure 24 is typical of the exposure falloff for the KA-61 cameras. The data are in good agreement with the expected cosine to the fourth power variation.

Although not performed in the present program, the data obtained in this test, along with the knowledge of the absolute spectral radiance of the calibration light source, can be used to perform an absolute photometric calibration for the cameras.

b. Shutter Time Measurements

A check of the shutter times on the KA-61 cameras is required to insure that the shutter times repeat accurately for successive exposures. Also, the shutter time is an important parameter for use as a cross check along with the aperture setting for the exposure measurements described in the preceding section. The equipment setup required for the shutter time measurements is shown in Figure 25 and requires the use of an

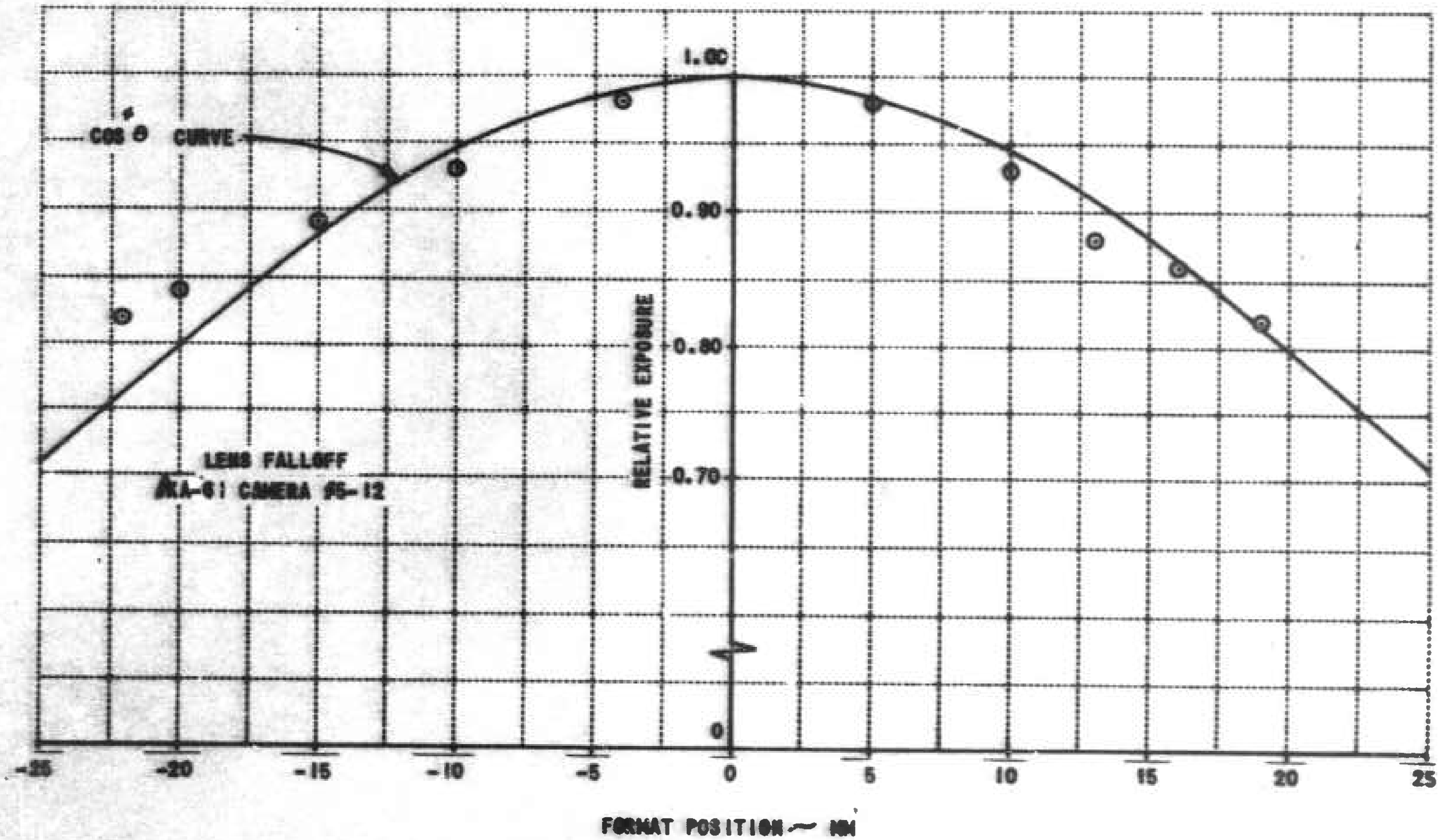

Figure 24 RELATIVE EXPOSURE AS A FUNCTION OF POSITION IN FILM PLANE

oscilloscope, a time interval meter, a photocell detector and a variable intensity light source. The photocell output was checked for linearity using the oscilloscope and a series of neutral density filters to vary the light intensity. After insuring that the photocell was linear within the range of source intensities to be used, the oscilloscope amplitude controls and light source intensity were adjusted to give a full scale signal on the oscilloscope cathode ray tube when the shutter was held open. The light intensity was then reduced until the photocell output was 50 percent of the previous reading. At this point the sensitivity control which triggers the counting gate on the time interval meter was adjusted to just start (and stop) counting. The light source intensity was readjusted for a full-scale reading on the oscilloscope. At each shutter speed setting, the shutter was operated and the shutter time was read directly from the time interval meter. In addition, oscilloscope traces were recorded with the oscilloscope camera.

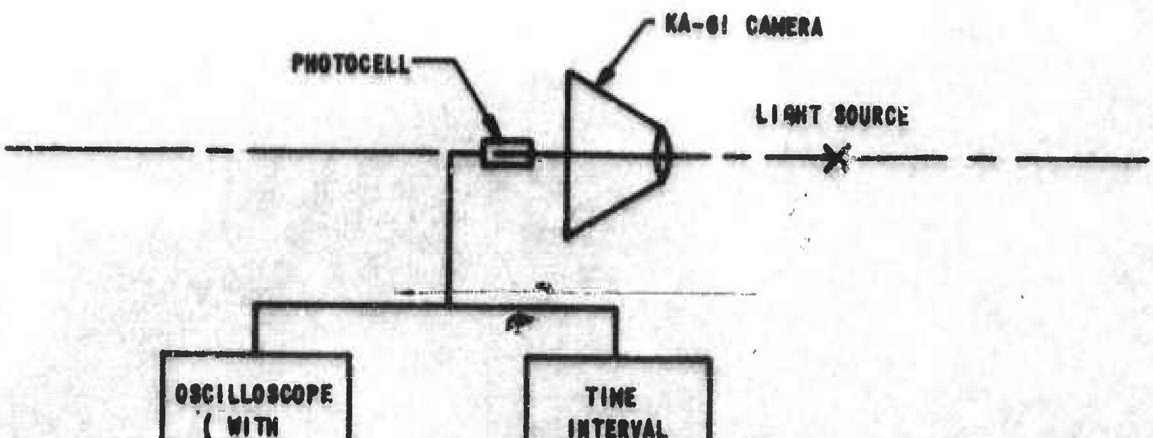

Figure 25 EQUIPMENT SETUP FOR KA-61 SHUTTER TESTS

The shutter times were tested for all twelve of the KA-61 cameras. In addition, the shutter time test was repeated for each of the cameras at each of its aperture settings. The variation in shutter time with aperture setting is essentially nil except for the slowest speed (1/60 second). Figure 26 shows a plot of the shutter time setting compared to the actual shutter time as measured in the above procedure. A number of replications (at least ten) was made for each of the shutter time measurements. The spread in readings is indicated by the vertical lines associated with each point. The graph shows the results for three cameras: the one having worst agreement with its calibrated settings on the fast side; the one showing worst agreement with its settings on the slow side; the other showing maximum deviations at the 1/60 setting. In general, the agreement was sufficiently good that no correction factors need be applied for any of the KA-61 cameras.

c. Image Motion Compensation Calibration

The KA-61 camera has image motion compensation available with a range of film velocities between 0.0 and 3.0 inches per second. It is important to measure the actual film velocities to compare the calibrated dial settings on each camera. This information must be known for the cameras to be properly set for a given aircraft velocity and altitude in order to obtain proper image motion compensation.

The procedure for performing the image motion compensation calibration requires the use of the IMC and Synchronization Test Device fabricated at CAL and described in Section III of this report. The procedure is simply one of photographing a disc rotating at a known speed and then determining the location of the sharpest image. A closeup "portrait" lens was placed over each camera lens to enable the cameras to be focused on a close object. A schematic diagram of the equipment setup is shown in Figure 27. The disc having a dot pattern was used for the IMC test and placed a distance of 2 meters from the closeup lens.

Simple analysis shows that there will be a point on the image of the rotating disc where there will be no relative motion with respect to the moving film. There will be no image blurring of this point

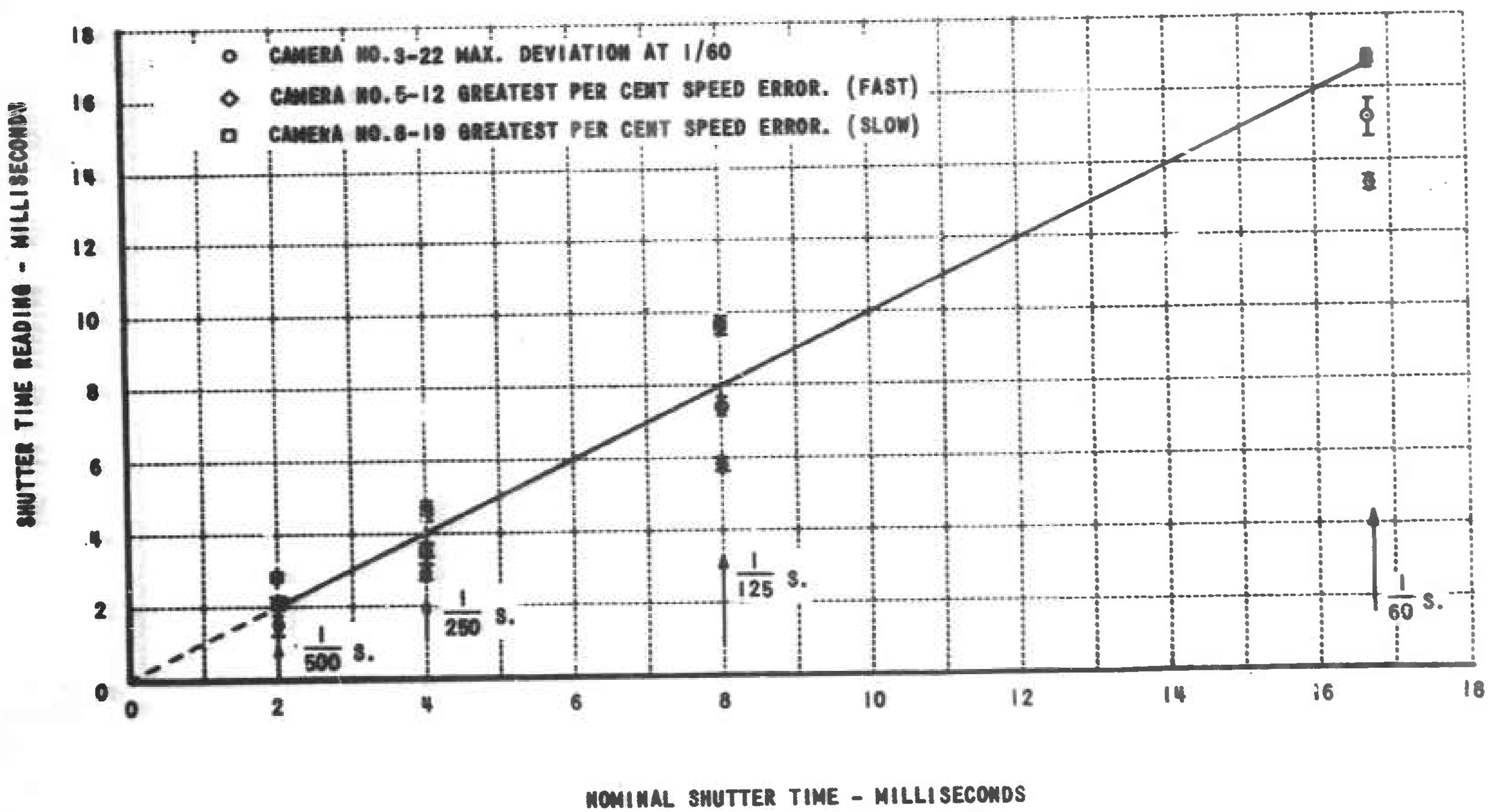

Figure 26 SHUTTER CONSISTENCY - KA-61 CAMERAS

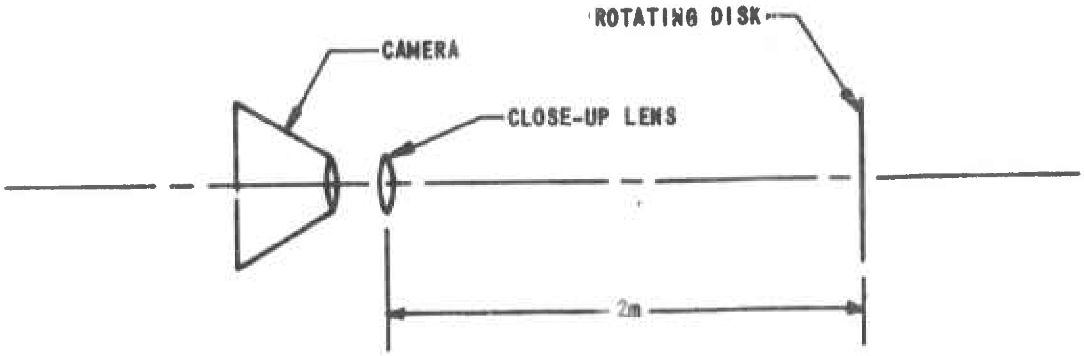

Figure 27 IMC TEST SET-UP

on the film. Figure 28 is a photograph of the rotating disc taken during the IMC tests. From a knowledge of the location of this point, the known rotational speed of the rotating disc and the scale of the image, it is possible to determine the IMC film velocity.

Figure 29 shows a plot of the IMC setting on a typical KA-61 camera versus the IMC film velocity obtained during the laboratory calibrations accomplished during Phase I of the AMPIRT Program. The bias error causing a shift in the curve from the design curve appeared to be characteristics of all of the KA-61 cameras. Although the data shown were taken with increasing dial settings only, other tests did not reveal any significant backlash error.

d. Camera Synchronization Test

All twelve of the KA-61 cameras were placed in the camera mount in the laboratory and tested for synchronous operation. It is important that the shutters on all twelve cameras operate synchronously since this will

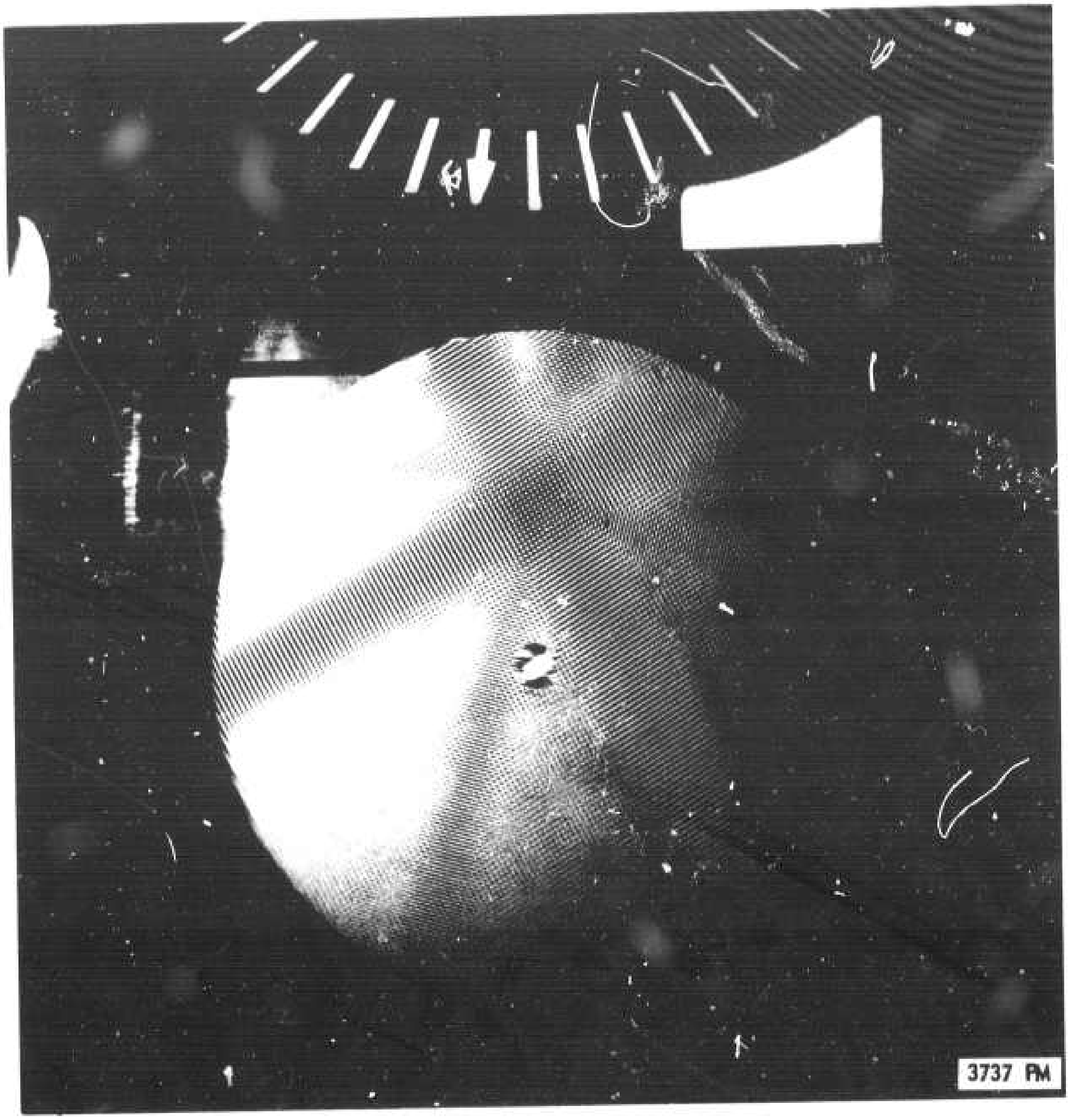

Figure 28 EXAMPLE OF IMC TEST PATTERN

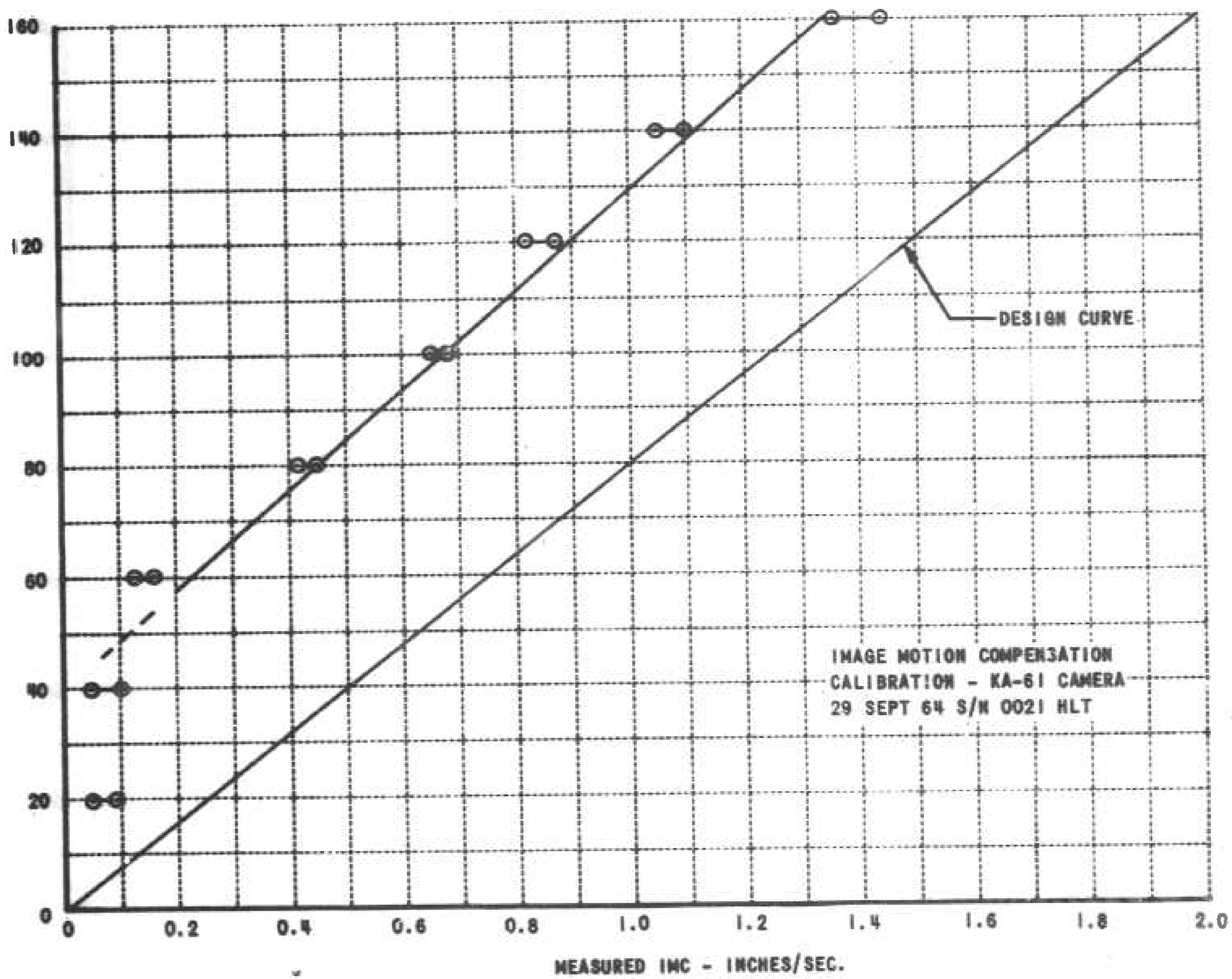

Figure 29 IMAGE MOTION COMPENSATION CALIBRA ION FOR KA-61 CAMERA

assure the same ground coverage on all cameras. The equipment setup used for the synchronization test is essentially the same as that for the IMC test discussed previously except that the synchronization test disc is used on the IMC and Synchronization Test Device. The synchronization disc is basically a rotating point source of light which acts effectively as a clock to measure the relative time during which the shutter is open on each of the KA-61 cameras. Since it was not possible to align all twelve cameras and the Synchronization Test Device conveniently in line, a plate glass mirror was used to project the image of the synchronization disc into the cameras so that its image would be recorded on all twelve cameras simultaneously. The setup is shown in Figure 30. The distance between the synchronization disc and the portrait lenses was 2 meters.

Scrutiny of each of the simultaneously exposed frames obtained during the synchronization test reveals a blurred arc, the angular position and length of which correspond respectively to the starting time and the duration of time during which the shutter is open. Theoretically, the starting time for all twelve cameras should be the same since the triggering pulse is initiated by the intervalometer in the control console for the KA-61 cameras. This means that the arc on each frame should start at the same angular displacement for each of the twelve cameras. The different relative locations of the start of this arc can be converted to time differences knowing the angular speed of the rotating disc.

Results of the synchronization test reveal that eleven of the twelve cameras could be operated synchronously within ±1 millisecond. The remaining camera (Itek Serial No. 14) could not be brought into synchronization with the remainder of the cameras despite several attempts at readjustment. Consequently, this camera was relegated to the role of camera No. 1 in the bank of twelve which is used only for an exposure control camera with a minus blue filter. In this capacity the film is processed in the field and none of the photographic imagery enters into the quantitative analysis performed for imagery from the remainder of the spectral cameras.

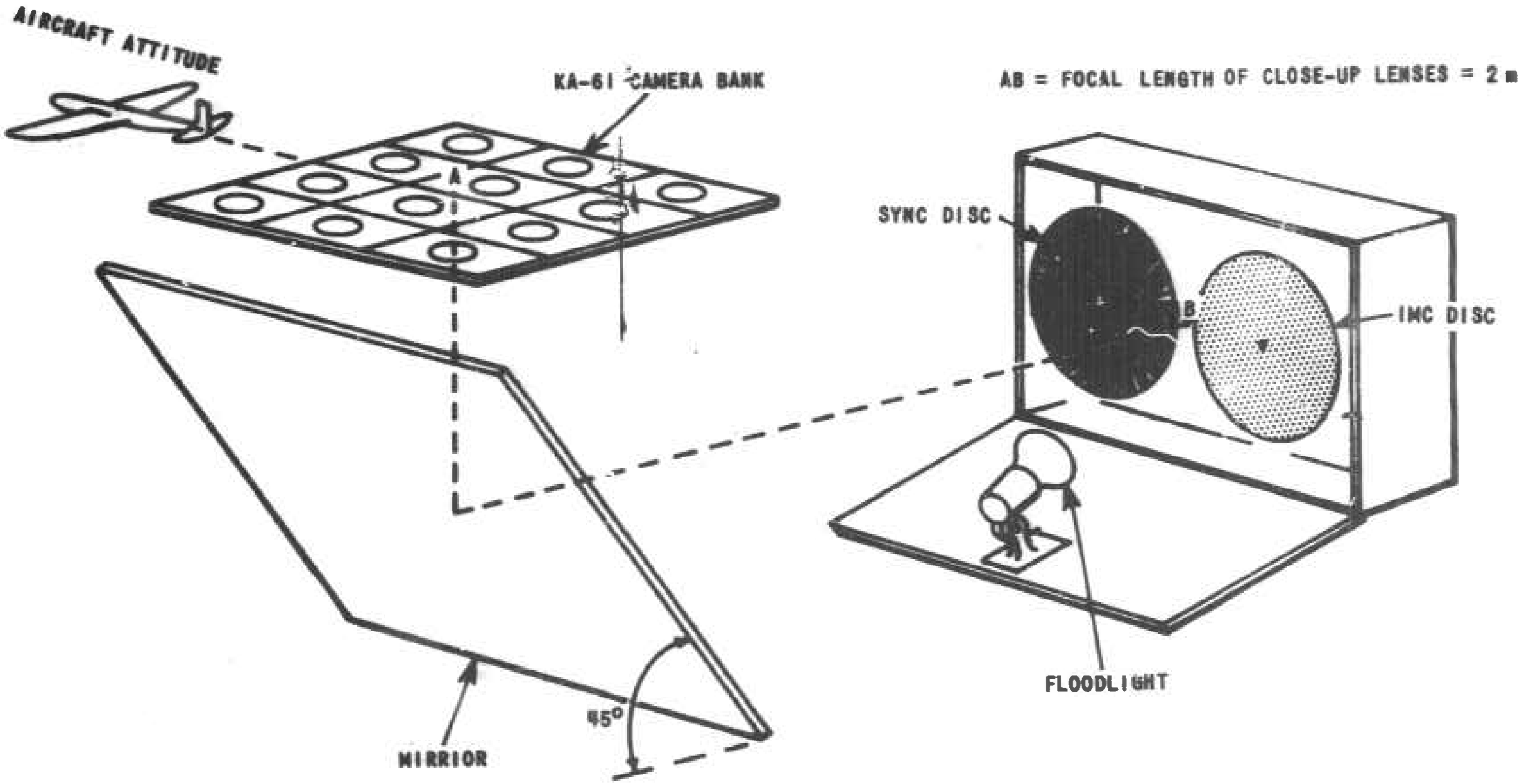

Figure 30 SYNCHRONIZATION TEST EQUIPMENT SET-UP

2. Modified KB-8A Ruggedized Cameras

In general, the calibration checks for the modified KB-8A cameras were somewhat less extensive than for the case of the KA-61 cameras. Special care was exercised in performing the functional tests for these cameras to assure that the modifications made at CAL as discussed in Section III of this report did not have a detrimental effect on the performance of the cameras. In addition to resolution tests made for the cameras, focal length measurements and shutter time measurements were made for each of the cameras and the various lenses with which they will be used during Phase II of the program. These checks are discussed further in the following paragraphs.

a. Resolution Tests

AWAR measurements were made for each of the KB-8A cameras in various combinations with the 1.5 inch, 3 inch and 6 inch lenses supplied with each of the cameras. The measurements were repeated for various f-number settings, for the various types of special films to be used with these cameras, and with the broadband filters procured specifically for these cameras. The same procedure was used for these AWAR measurements as was described earlier for the KA-61 cameras. A standard low-contrast resolution bar chart target was again used.

Results of the laboratory calibrations for AWAR indicated excellent performance for these cameras. For example, after selecting the best combination of cameras and lenses and using Plus-X film, without filter, the worst AWAR measured for the 6 inch lenses was 30 lines per millimeter. This corresponds to a ground resolution of approximately 1.5 inches at an altitude of 500 feet. Similarly for the 1.5 inch lenses the worst AWAR was approximately 20 lines per millimeter (corresponding to approximately 8 inches ground resolution at 500 feet.) When the AWAR tests were repeated using various films and broadband filters which will be used during the operational phase, the resolution was degraded to a certain extent. For example, when one of the 6 inch lenses was used with Plus-X film and without filters, an AWAR of 30 lines per millimeter was achieved. When this same lens was combined with an infrared filter (equivalent to Wratten type 89) and IR film, the AWAR decreased to less than 12 lines per millimeter. A special lens shim was then constructed for use with this lens in this particular combination of filter and film so as to increase the AWAR to 20 lines per millimeter. Similarly, shims were constructed for other lens/filter combinations.

In all cases it was felt that the resolution obtained with the KB-8A cameras was more than adequate for the photo interpretation work for which these cameras were intended. These predictions were confirmed by the results of the ZI Tests.

b. Focal Length Measurements

Focal length measurements were made for the various lens/filter combinations to be used with each KB-8A camera. The apparatus used for the focal length measurement is the same as that used for the resolution tests (Figure 23). The focal length of the collimator was previously determined to be 24.24 inches from a measurement of the positions of the rear nodal point and the focal plane. The camera focal length measurement is made by determining the scale of the image produced on the film by the camera. For this purpose fiducial marks at a known separation were placed on the same test charts as used for the resolution tests. Photographs taken with various filter and lens combinations were analyzed and the ratio of image to object size measured. This gives the ratio of the focal lengths of the camera and the collimator .

c. Shutter Time Tests

The KB-8A camera, unlike the KA-61 camera, has a focal plane shutter wherein a shutter curtain is pulled across the film plane to expose the film. Thus, for these cameras both the actual shutter time as well as the uniformity of motion of the curtain across the format is of importance.

The equipment setup needed for this experiment is shown schematically in Figure 31. In this experiment the camera lens is placed close to a stroboscopic light source and photographs are taken for various shutter time settings. As the shutter curtain travels across the focal plane, the instantaneous position of the curtain opening is recorded on film for each flash of the strobe light. The curtain speed can be determined by the distance traveled between light flashes, and the exposure time by the width of the curtain opening. The frequency for the strobe light should be selected so as to form several images of the curtain opening (See Figure 32).

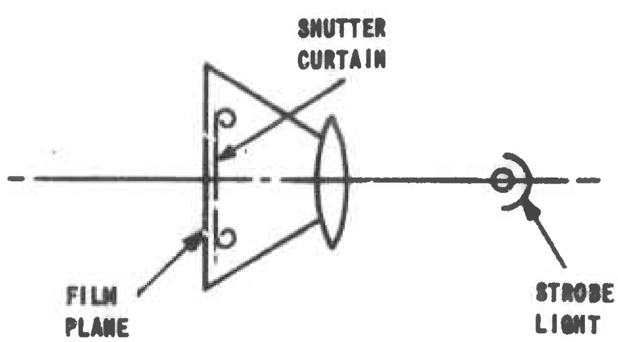

Figure 31 SHUTTER TIME TESTS FOR KB-8A CAMERAS

For a focal plane shutter, the shutter time is equivalent to the exposure time for any point image on the film format. Letting W be the width of the slit in the shutter curtain, L the distance on the film traveled by the image between light flashes, and τ the time between pulses, then the exposure time, T, is given by

$$T = \frac{W}{L} \times \tau.$$

Figure 32 is a photograph of the slit images formed across the film format for a typical test with one of the KB-8A cameras. The overexposed central area of the photograph is a result of direct imaging of the strobe light on the film. This region was avoided when making the exposure time measurements. The graph of exposure time as a function of position on the format is plotted below the photograph.

In general, the shutter time tests were primarily intended as functional tests to ascertain whether or not the shutters were operating smoothly. At the end of the Phase I effort the shutter times as well as the uniformity of shutter motion for all of the KB-8A cameras were adequate for recording the interpretation imagery for which these cameras are intended*.

3. KA-52 Panoramic Camera

As mentioned previously, the KA-52 panoramic camera was returned to the manufacturer (Fairchild Camera and Instrument Corporation) to be refurbished and tested. When the camera was returned to CAL, the laboratory test consisted primarily of a functional test to assure that the equipment operated satisfactorily. In addition, the focal length was determined by measuring the angular positions of a series of known objects and the linear positions of the corresponding image points on the film. After reviewing the imagery obtained with this camera during the ZI systems flight tests, an assessment of the resolution capabilities of the camera within a practical range of angular displacements indicated that the resolution would be adequate for the intended camera application.

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*

On several occasions during the Phase II program the shutters on the KB-8A cameras jammed.

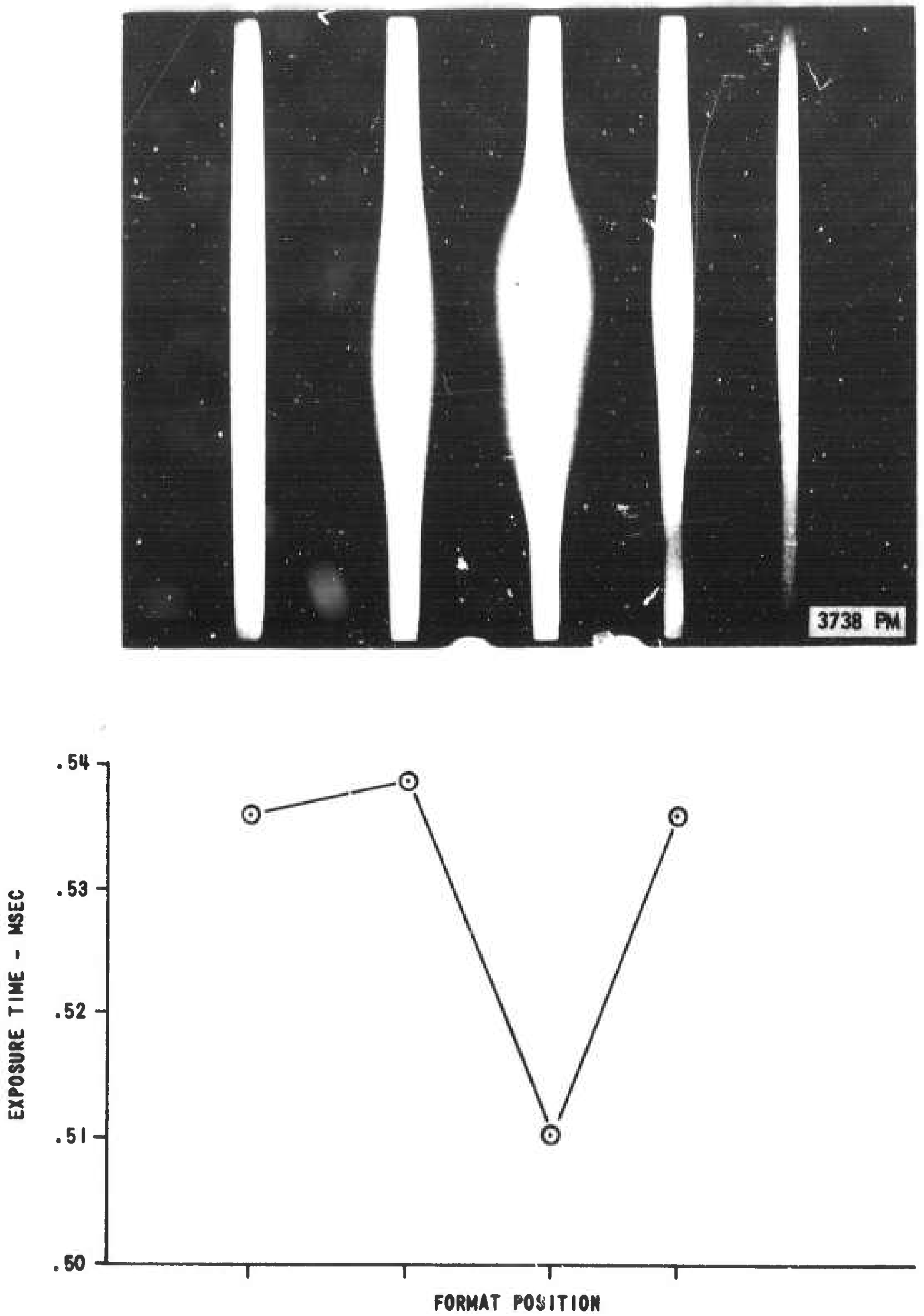


Figure 32 EXPOSURE TIME VARIATIONS OVER FORMAT FOR KB-8A CAMERA

B. PHOTOMETRIC EQUIPMENT

All photometric equipment fabricated at CAL or procured on the program was calibrated. Included are the CAL-fabricated extended light sources, airborne photometers, exposure meters, ground irradiance meters, the purchased target radiance photometers, and the sensitometers obtained as GFE and modified at CAL . The calibration procedures are briefly described below.

1. Calibration Light Sources

The two CAL fabricated calibration light sources (see Figures 20 and 21) which are extended, diffuse light sources, are used as working standards in the field laboratory and were calibrated by measuring their spectral radiance. The absolute spectral radiance of the sources was determined by using a spectrophotometer to compare the sources with an NBS radiance standard. This calibration was repeated for three voltage and current levels supplied to the sources to provide three different radiance levels.

Figures 33 and 34 are the spectral radiance curves for the CAL fabricated diffuse light sources.

2. Photometers

As indicated previously, the upward looking airborne photometers consisted of a total irradiance photometer plus four spectral photometers for use in monitoring both the total solar irradiance as well as the spectral solar irradiance in any four of the same spectral bands as employed by the KA-61 spectral cameras. The downward looking exposure meter basically consists of three photometers having broadband filters in the "red" (Wratten #29), "green" (Wratten #61), and "blue" (Wratten #47B), regions of the spectrum. It is calibrated to read radiance values. The ground irradiance meter, similar to the total irradiance photometer in the aircraft, measures total solar irradiance, but at ground level. The portable target radiance photometers are used in the field with a set of ten spectral filters (whose bandpasses again correspond to those filters used with the

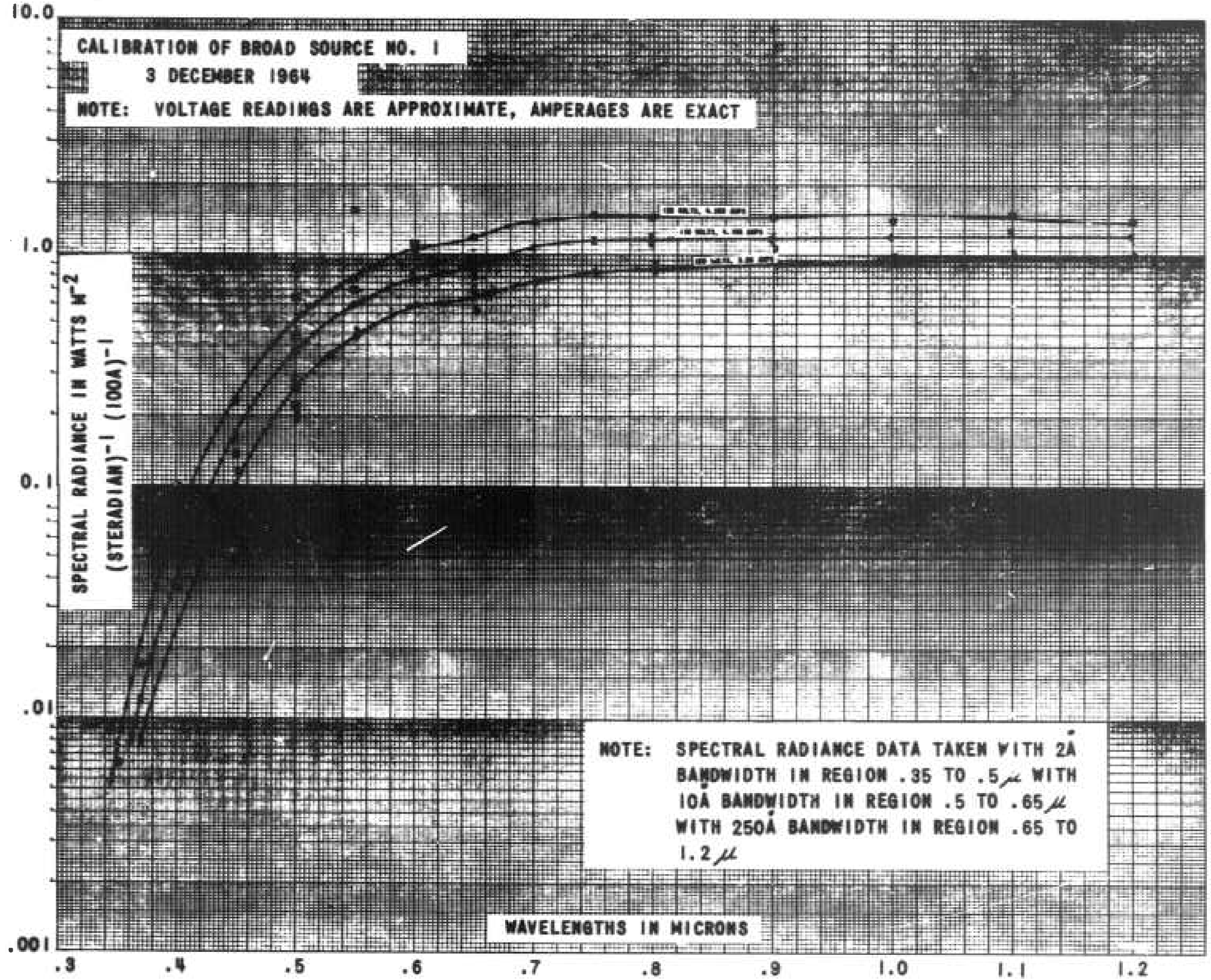


Figure 33 CALIBRATION OF BROAD SOURCE NO. 1

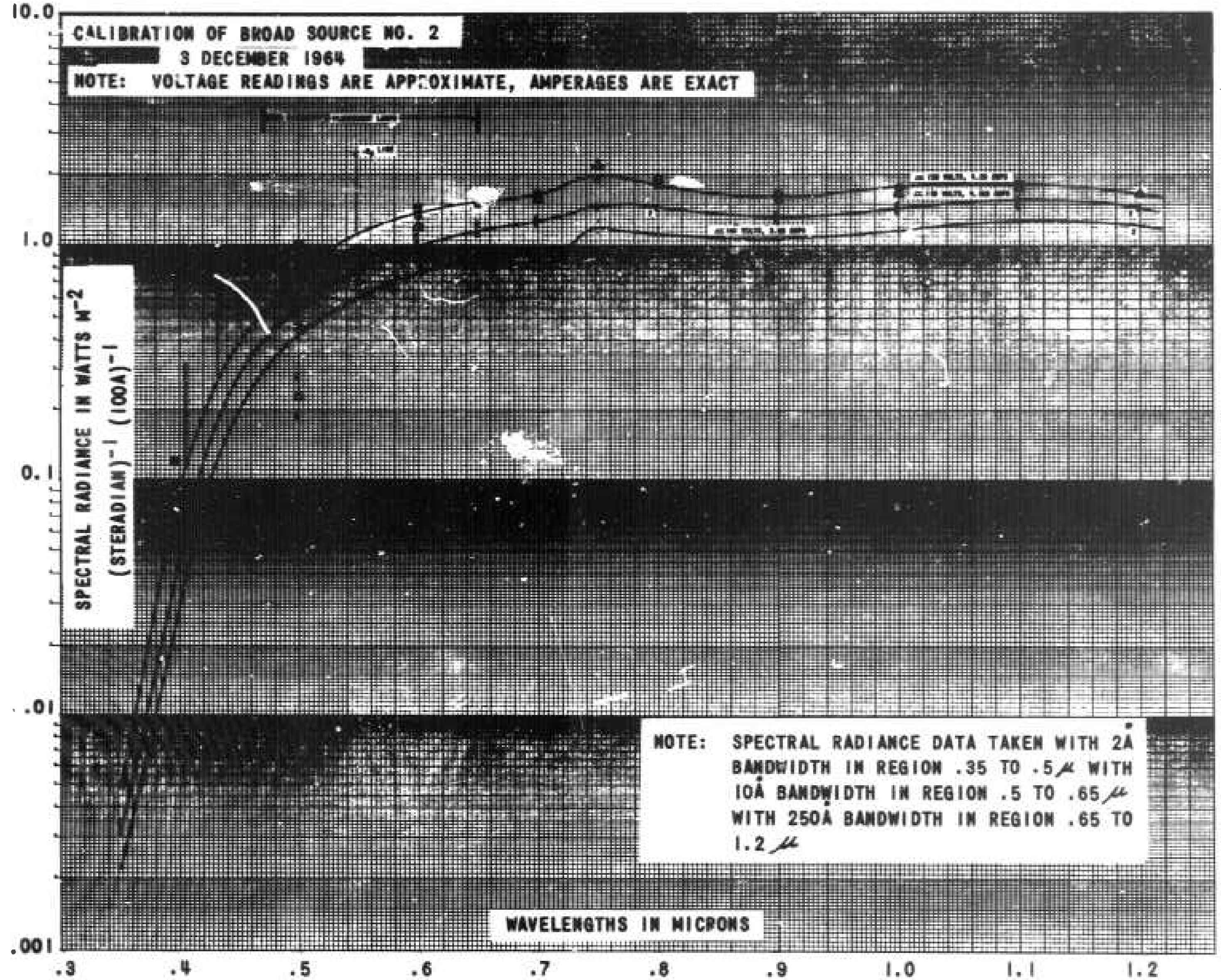


Figure 34 CALIBRATION OF BROAD SOURCE NO. 2

KA-61 cameras) to determine the spectral reflectances of targets in the field relative to the reflectances of control targets. Since these reflectance measurements are relative, an absolute calibration of these target radiance photometers was unnecessary. Since all of these photometers are essentially the same, i.e., a detector cell plus various optical elements, their calibrations were similar.

All of the photometers, both airborne and ground-based, were calibrated by determining the relative transmittance of all optical elements and the relative spectral sensitivity of the selected detector cells. The relative transmittances of all the optical elements were determined by using a recording spectrophotometer. The relative spectral sensitivity of the silicon detector cells was checked by comparing the cells to a calibrated thermopile using the spectrophotometer as a monochromator.

The relative spectral response curve of each of the assembled photometers was calculated using the relative spectral transmittance data for each of the optical elements and the relative spectral sensitivity data for the detector cell. The effective photometer bandwidth (between 5% intensity points) was obtained from the overall spectral response curve. A mean wavelength, λ_m , can be defined for each photometer/filter combination such that the product of the relative spectral response of the combination at the mean wavelength and the effective bandwidth gives the same total energy (area under the curve) as would be obtained from an integration of the actual spectral response curve.

The absolute calibration for each of the narrow-band photometers was established by measuring its output when irradiated by the calibration light source, whose spectral radiance had been established with the NBS standard. The irradiance on the photometer from the calibration light source was calculated knowing the geometry of the equipment setup for this test. Thus, with a knowledge of the irradiance on the photometer over its spectral bandpass, an absolute sensitivity was determined for each of the narrow bandpass photometers. Since the same dielectric filters were used with the photometers as were used with the KA-61 cameras, the effective bandwidths (see Figure 13) are about 500 A. For the wide band or total irradiance (or radiance) photometers, numerical integration of the spectral radiance curve of the calibration light source was necessary to establish the absolute calibration. Both the airborne and ground total irradiance photometers were calibrated in the spectral region from 4150 to 9750 Å.

As noted above, the target radiance photometers are used for relative measurements (reflectance) only and thus, an absolute calibration was not necessary. A linearity check of the indicator was, however, performed by using a series of neutral density filters and a constant light source.

Calibration data for the photometers is summarized in Tables 2, 3, and 4.

3. Sensitometer

The standard Air Force sensitometer (FSN 6740-559-9735), modified at CAL to accommodate the narrow bandpass spectral filters, was used to place sensitometric control step wedges on the film for the spectral experiments. The sensitometer was calibrated by determining the spectral irradiance at the plane of the step wedge in the instrument. These data, along with the transmittances of the step wedge and any filters used, permit the calculation of the irradiance and absolute exposure of the step wedges on test film.

Table 2
CALIBRATION DATA FOR AIRBORNE PHOTOMETERS

PHOTOMETER SERIAL No.	*SPECTRAL FILTER	MEAN WAVELENGTH λ_m	** CALIBRATION CONSTANT	
			X 1 RANGE	X 10 RANGE
1	<4000Å	4100Å	15.6	
1	4500	4530	3.33	35.63
2	5000	5020	18.4	198.7
2	5500	5550	10.1	103.0
3	6000	6050	20.3	
3	6500	6525	25.8	
4	7500	7510	26.7	
4	8000	7950	37.9	
6	7000	7025	18.4	
7	>8500	9150	25.4	

* EACH PHOTOMETER CONTAINS ADDITIONAL FILTERS FOR INFRARED REJECTION AND COSINE CORRECTION.

**THIS FACTOR ($1/S_o$) GIVES THE NUMBER OF WATTS m^{-2} (100 Å)$^{-1}$ FOR FULL SCALE (100 DIVISIONS) RECORDER DEFLECTION.

Table 3

CALIBRATION DATA FOR AIRBORNE EXPOSURE METERS

PHOTOMETER SERIAL NO.	*FILTER (WRATTEN TYPE)	DETECTOR	MEAN WAVELENGTH λ_m	**CALIBRATION CONSTANT
1	47B	CADMIUM SULPHIDE	4450Å	0.51
	61	CADMIUM SULPHIDE	5450	0.16
	29	SILICON	7900	4.5
2	47B	CADMIUM SULPHIDE	4450	0.74
	61	CADMIUM SULPHIDE	5450	0.08
	29	SILICON	7900	7.7

* EACH PHOTOMETER CONTAINS ADDITIONAL FILTERS FOR INFRARED REJECTION AND COSINE CORRECTION.

** THIS FACTOR ($1/S_0$) GIVES THE NUMBER OF WATTS M^{-2} (STERADIAN)$^{-1}$ (100 Å)$^{-1}$ FOR FULL SCALE (100 DIVISIONS) RECORDER DEFLECTION.

Table 4

CALIBRATION DATA FOR TOTAL IRRADIANCE PHOTOMETERS

PHOTOMETER SERIAL NO.	INDICATOR	CALIBRATION CONSTANT ($1/S_0$)	UNITS
5 (AIRBORNE)	RECORDER	1.496 (X 0.1 RANGE)	WATT M^{-2} PER RECORDER DIVISION
		15.71 (X 1 RANGE)	WATT M^{-2} PER RECORDER DIVISION
1 (GROUND)	MICROAMMETER	0.298	WATT M^{-2} PER MICROAMP DEFLECTION
2 (GROUND)	MICROAMMETER	0.284	WATT M^{-2} PER MICROAMP DEFLECTION
3 (GROUND)	MICROAMMETER	0.305	WATT M^{-2} PER MICROAMP DEFLECTION

V. EVALUATION OF FILM PROCESSING PROCEDURES

A. GENERAL APPROACH

Carefully controlled processing of the aerial photographic film is of great importance. Because quantitative data are obtained from the photographic film by the use of the densitometer measurements, any variations in the film density due to variability in the processing procedure result in errors and scatter in the data. In order to minimize this potential problem area, a special study on the film sensitivities and processing control was made during an early phase of the program. The film manufacturer (Eastman Kodak) assured us that film sensitivities as given in their published data are closely maintained as a result of their quality control procedures and that the primary variations that might occur will be due to variations in the film processing.

It was planned that most of the film used on this program would be processed at the Rome Air Development Center (RADC). Therefore, a series of experiments was conducted at RADC to assess the repeatability of the processing procedures. Black and white film is processed in a Versamat processor (manufactured by Eastman Kodak), and color is processed in a Fairchild-Smith roll film processor.

To test the Versamat processor, several rolls of each of the types of the black and white film used in the 70 mm cameras were selected for the experiments. Sensitometric step wedges were placed on each roll of film using unfiltered as well as filtered light in various regions of the spectrum. A series of processing runs was then made using these exposed film strips, carefully recording the various settings and temperatures used in the processor. The developed film was then analyzed by measuring the densities of the step wedges and plotting the corresponding D-log E curves. The results of the tests, which are detailed in the next section, indicate that excellent repeatability and control could be maintained with the Versamat processor. Because no quantitative measurements were planned for the color film, a complete and thorough analysis of the Fairchild-Smith processor was not performed, although the processor settings, developer temperatures, etc. were recorded for future reference.

B. RESULTS OF PROCESSING CONTROL EXPERIMENTS

The photographic processing control experiments were conducted at RADC to provide quantitative data on the following:

1. Time-gamma relationships
2. Gamma as a function of actinic wavelength
3. Inherent film and machine gamma variations

Tests were conducted using the following Eastman Kodak films: Plus-X Aerocon 8401, Tri-X Aerocon 8403, Special Panatomic-X Aerographic SO-136, Infrared Aerographic 5425, Royal-X Pan (Spec. 483) and Photoflure Blue. Qualitative tests were made on the color processing procedures using Eastman Kodak films Aerial Ektachrome 8442 and Ektachrome Infrared Aero (camouflage detection) 8443.

To analyze the results of the processing control experiments, D-log E curves were first plotted for each of the step wedges placed on each roll of film. The series of step wedges placed on each roll of film were made without a filter and with a series of filters so that the wavelength variations in gamma could be ascertained. This series of step wedges was then repeated at intervals of four feet along the entire length of the roll of film. For each of the D-log E curves, the gamma values were measured using a gamma meter designed to compute:

$$\gamma = \frac{\Delta \text{density}}{\Delta \text{Log E}}$$

at the 0.3 maximum gradient point on the D-Log E curve. The quantity E is the exposure and is equal to the product of incident light intensity and exposure time. The experiment was repeated for several rolls of film using different settings on the Versamat corresponding to the processing times recommended by Eastman Kodak.

Two potentially important problems were uncovered during this calibration and assessment of the Versamat processor which should be noted. First, the Versamat processor has an automatic developer replenishment system which will affect the resultant value of gamma, if the replenishment rate changes during the processing. Secondly, the recommended processing cycles for Infrared Aerographic film were found to be incorrect since the emulsion for this film had been changed by Eastman Kodak after the manufacture of this particular machine, and the users had not been notified.

From the results of the processing control experiments, a series of graphs were prepared which showed the machine settings required to obtain the desired gamma values for each of the films as a function of wavelength.*

Additional results from the processing control experiments were obtained from the D-log E curves for the various films used. Those curves showed the useful log E range (dynamic exposure latitude) for each film/filter/processing time combination. This information was then factored into the mission test plans to aid in selecting the camera settings which would be needed to record the anticipated range of radiances for targets on the ground.

C. FIELD OPERATIONAL EFFECTS

For the field operation, standard darkroom development procedures are followed since the film developed in Thailand is used only for qualitative assessments. Thus, no special evaluation of field darkroom operating procedures was made.

Because most of the film exposed in Thailand is shipped to RADC for processing, the film handling and shipping procedures were studied to insure that proper control of imagery can be maintained. A procedure was prepared and an experiment initiated to assess any handling or shipping problems which might occur during the operational phase (Phase II). The experiment utilized IR Aerographic film, which is most sensitive to environmental variations.

*During the Phase II operation, machine setting curves have been continually updated to allow for a closer control in obtaining the desired values of gamma. In addition, procedures have been initiated to compensate for the apparent aging effects on the imagery which yielded a higher value of gamma than desired. This aging effect was noticed on the first batch of film received from Thailand.

Stepwedges were exposed on the first half of each of the 35 mm rolls of film used in the experiment. Control rolls were kept under refrigeration at CAL while the remaining rolls were shipped via Air Mail to Bangkok, Thailand. After various time intervals during a several week period, rolls of film were removed from refrigerated storage in Bangkok, kept at ambient conditions for 72 hours, and returned via Air Mail to CAL where they were processed along with the control rolls after exposing additional stepwedges on the last half of each roll.

Analysis of the results of this experiment indicated that a definite increase (10% to 20%) in gamma occurred for the initial stepwedges over the final stepwedges. These results could not be correlated with environmental factors since the control rolls kept at CAL showed an increase in gamma similar to the rolls shipped to Thailand and back.* The increase appeared to be associated more with the time between exposure and processing than any environmental factor.

*The first shipment of film from the Phase II tests also showed an increased gamma (about 2.2); ensuing shipments of film were processed so as to compensate for this aging effect to obtain a more desirable gamma (~1.8).

VI. ZONE OF THE INTERIOR (ZI) SYSTEMS TEST PROGRAM

A. GENERAL

By the end of September 1964, all of the camera and photometric equipment had been calibrated, airborne equipment was installed in the HC-47 aircraft, and ground support equipment and targets for the field crew were on hand. Darkroom and maintenance equipment to be used later in the field laboratory in Bangkok was set up for operation.

The various airborne equipments had been tested in the laboratory (discussed in preceding section) in preparation for installation in the aircraft. A complete checkout of the photographic system installed in the HC-47 aircraft was made in three phases: systems tests and preliminary flight tests at CAL after equipment installation, flight testing at the University of Michigan and, finally, a composite systems flight test at Wright-Patterson Air Force Base.

The basic objective of the ZI test program was to calibrate and perform operational tests on the complete photographic system and to ascertain the ability of the system to achieve the technical objectives planned for Phase II. The purposes of the CAL tests were to achieve proper operation of all photographic and photometric sensors, and to assure that there were no environmental interference problems. Tests at the University of Michigan were to determine the influence, if any, which the operation of the photographic subsystem might have on the operation of the infrared sensors and vice versa. Finally, the tests at WPAFB were intended to demonstrate acceptable performance of the combined systems to the Air Force.

The operational tests at CAL included the synchronous operation of all cameras, alignment of the cameras' optical axes, calibration checks and a complete preflight check. In addition, environmental factors such as vibration, noise, cross talk, and radio interference with the standard aircraft equipment were ascertained. The ground-support operations were conducted to test operational procedures and to determine proper calibration data through the use of the CAL-fabricated targets and ground photometric measurements as required for data analysis. These tests also afforded an opportunity to check out the equipment and the film processing procedures to be used in the field darkroom, as well as those to be used at RADC. Finally, the photographs were scrutinized by photointerpreters. Microdensitometry and other data reduction was performed as required, and data analysis procedures were tested.

The tests at the University of Michigan and at WPAFB basically duplicated the initial systems tests but were directed toward an evaluation of particular problem areas.

B. SPECIFIC TEST OBJECTIVES

The ZI Test Program was intended to check out the complete system of equipment, to provide an operational systems test and to serve as a training program for personnel for the collection of data in Thailand. A summary of specific objectives of the tests is presented in Table 5. This table also gives the locations where each of the tests was conducted.

Table 5
SUMMARY OF ZI TEST OBJECTIVES

OBJECTIVE	TEST SITE CAL	U. OF M.	WPAFB
EQUIPMENT OPERATION	X	X	X
RESOLUTION	X	X	X
SPECTRAL REFLECTANCE	X	X	X
ANGULAR MEASUREMENT	X	X	
SPECIAL INTERPRETATION		X	X
IMC OPERATION	X	X	X
VIBRATION	X	X	X
RADIO INTERFERENCE		X	
PHOTOGRAPHY OF DETAIL TARGETS	X	X	X

C. DESCRIPTION OF THE GROUND TARGETS

A set of special ground control targets was designed and constructed at the Laboratory for use at the three test sites. Figure 35 is a photograph of the targets set up at the CAL test site in Wilson, N. Y. The point source target, consisting of a 14-inch-diameter, silvered-glass sphere mounted on a low-reflectance, dark gray background, was for use in determining uncompensated image motion or vibration effects from the aerial photographs. The spectral control targets consisted of two 8-foot square plywood panels, one painted a dark diffuse gray, the other, a light diffuse gray. The "unknown" spectral target was a 4 x 8-foot plywood panel upon which a four-foot, a two-foot and a one-foot yellow square were painted on a dark gray background.

The primary resolution targets consisted of a low contrast and a high contrast standard bar chart with bar sizes ranging from 1-1/4 inches to less than 5/16 inches in width. On the panel upon which the low-contrast resolution target was mounted, a one-foot and a two-foot light gray square were painted on a dark gray background to demonstrate that a 1-foot-square target could be resolved by the 52 mm lens in the KA-61 cameras.

For the tests on penetration angle measurements, a 1500-foot string of lamps was used at the CAL and University of Michigan test sites.

Several additional targets were available during the tests at the University of Michigan. These consisted of: red, white and blue canvas panels, a canvas resolution target (bar sizes down to 6 inches in width) and a 20-inch-diameter polished aluminum sphere point source. Several Army vehicles: an M-48 tank, a tracked prime mover, a 3/4-ton truck and a 2-1/2-ton truck were also moved into the target area. The University of Michigan test site is shown in the photograph, Figure 36.

At Wright-Patterson Air Force Base, the test program included flights over the permanent resolution targets consisting of low, medium and high contrast targets with bar sizes as follows:

Medium Contrast	2 ft. 6-1/4 in. to 1-3/16 in.
High Contrast	5 ft. 7-1/8 in. to 1-3/16 in.
Low Contrast	2 ft. 6-1/4 in. to 1-3/16 in.

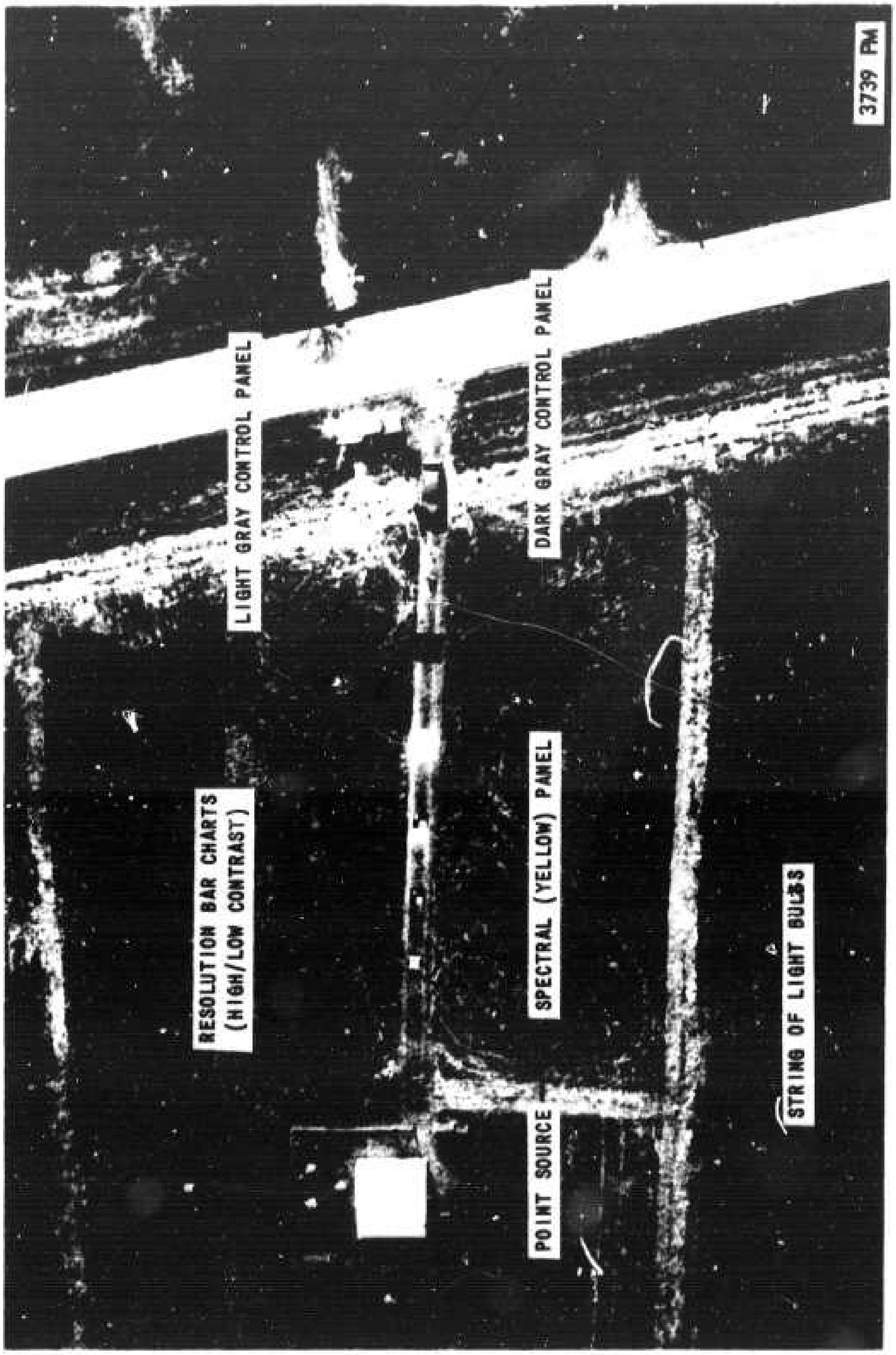


Figure 35 AMPIRT TARGETS AT WILSON TEST SITE

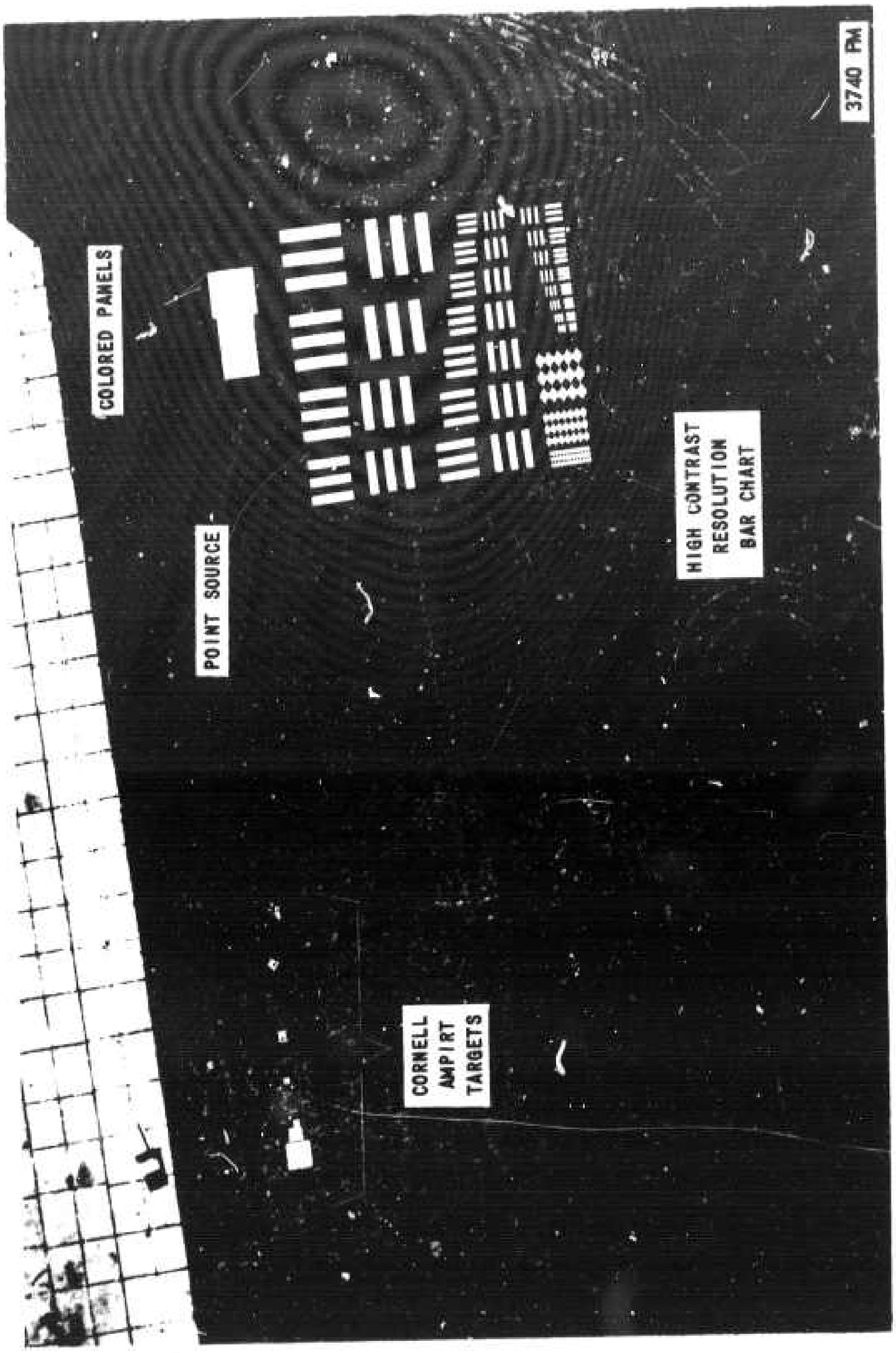


Figure 36 UNIVERSITY OF MICHIGAN TARGET SITE

At the Wright-Patterson Air Force Base Test Site the red, white and blue canvas panels, and a 10 foot by 100 foot ten step gray scale target were also photographed. Figure 37 is a photograph of this test site.

D. DISCUSSION OF ZI EXPERIMENTS AND RESULTS

1. Equipment Operation

Proper operation of the photographic subsystem and compatability of this equipment with other aircraft equipment was a primary objective of the ZI Test Program. The equipment in the system has been described in detail previously in Section III. The airborne system consists of: twelve KA-61 cameras to be used to gather imagery for spectral analysis; four KB-8A cameras to provide high resolution coverage for photointerpretation; the KA-52 panoramic camera for angular coverage of the photographic test area; an upward-looking total irradiance photometer being used as a spectral exposure meter; four spectral photometers to determine spectral variations in solar irradiance; a downward-looking exposure meter for the interpretation cameras; and the control console and appropriate recording equipment. The field crew equipment used to support the flight operations consisted of the ground photometers and various meteorological instruments previously described. The operations were also supported by field laboratory darkroom and maintenance equipment.

Operator tests to improve the operation of the airborne equipment were conducted during the ZI flight tests. Some minor changes were made, such as: replacement of switches in the control console to withstand higher loads, attachment of additional grounding straps in the control console, and addition of a warning light to assure that the camera door was open before camera operation began. In general, the performance of all airborne equipment was good after this initial series of flights and some minor adjustments. Performance of all ground support equipment was satisfactory. Results of some environmental tests and specific camera performance will be discussed in ensuing sections.

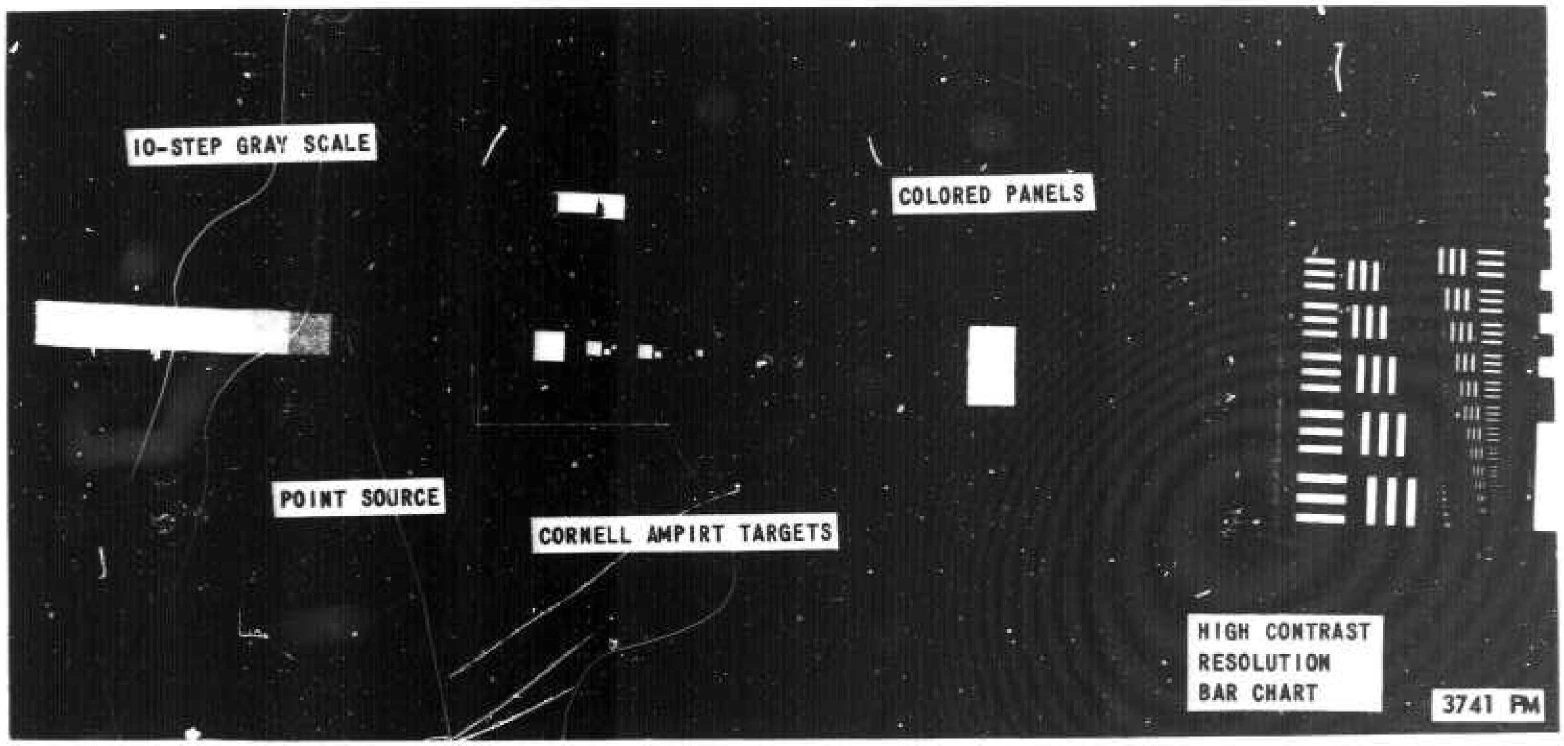


Figure 37 TARGET COMPLEX AT WRIGHT-PATTERSON AIR FORCE BASE

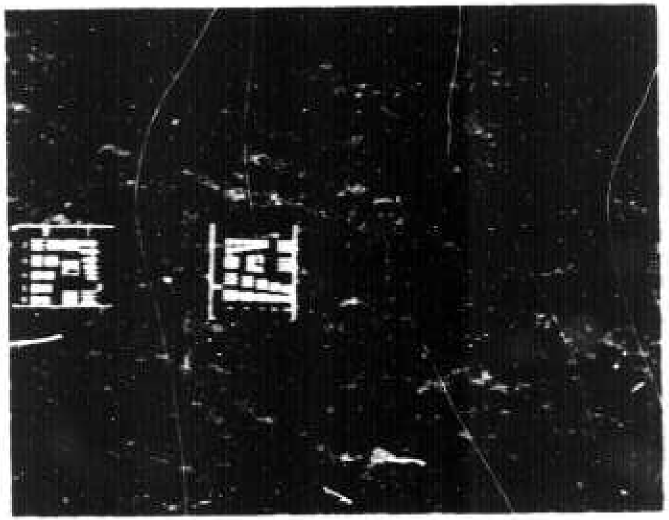
2. Resolution Tests

Camera resolution was initially tested for each camera during the Laboratory calibration tests prior to installation in the airplane. For example, the KA-61 cameras had each been tested with several of the narrow bandpass spectral filters in order to select the best camera/filter combinations to yield highest resolution. Laboratory resolution tests were also performed for the KA-52 and KB-8A cameras. After equipment installation in the HC-47 aircraft, additional resolution tests were performed by taking aerial photographs of standard bar chart resolution targets located on the ground.

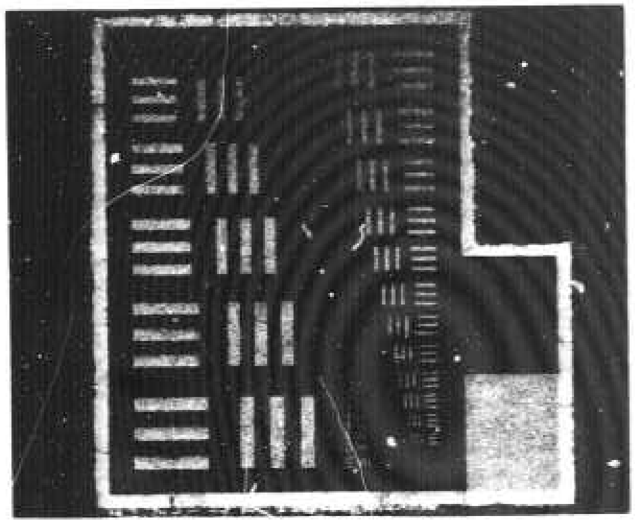
The most critical resolution test for the photographic system was performed during the Wright Field flight tests. Figure 38 shows copies of some of the best negatives from these tests. The first bar (largest) on the low contrast target (upper left-6 inch lens) is only 1-3/8" wide. In the other three frames the bar size for the large low contrast resolution chart varies by a factor of the sixth root of two from a width of 2 ft. 6-1/4 in. down to 1-3/16 inches. The pattern with bar width of 4-1/4 inches (pattern No. 18) could be readily resolved with the lenses used. The actual resolution on the negatives exceeds that shown in the reproductions presented here and was considerably better than the one foot ground resolution established as a design objective.

Figure 39 shows the distribution of resolution values at different off-axis positions achieved with three of the KA-61 cameras in the visible region of the spectrum for the medium contrast targets at Wright Field. Since the distributions were essentially similar for the image positions considered, an average resolution was used for the system. In this case the average photographic ground resolution was 6 inches. This means that for a standard resolution chart, a 3 inch bar can be seen.

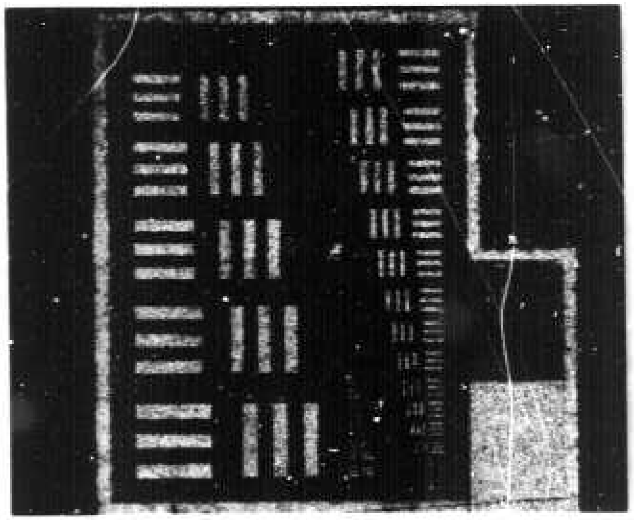
Table 6 shows the average resolution of the KA-61 cameras expressed in lines per millimeter. A resolution value of 19 lines per millimeter is approximately equivalent to resolving a 3 inch bar on the ground targets at an altitude of 500 feet. The results for KA-61 cameras #11 and #12 were below expectations. After completion of the ZI tests, but prior to shipment of the equipment to Thailand, these two cameras



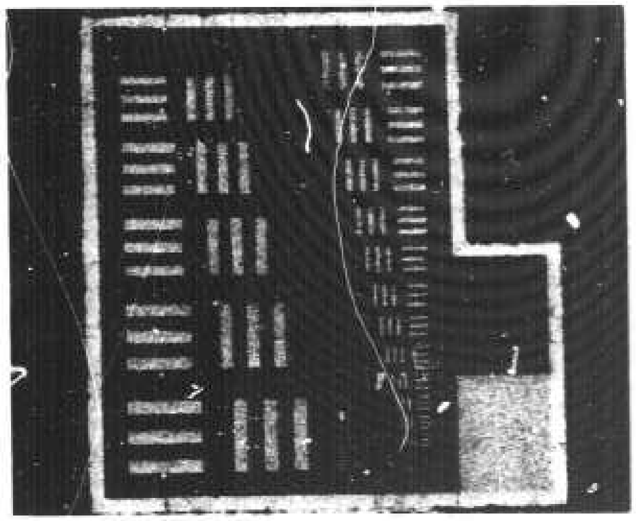
KB8A - 6"



KB8A - 3"



KB8A - 1 1/2"



KA61 - 2"

3731 PM

Figure 38 CAMERA RESOLUTION TESTS AT WPAFB

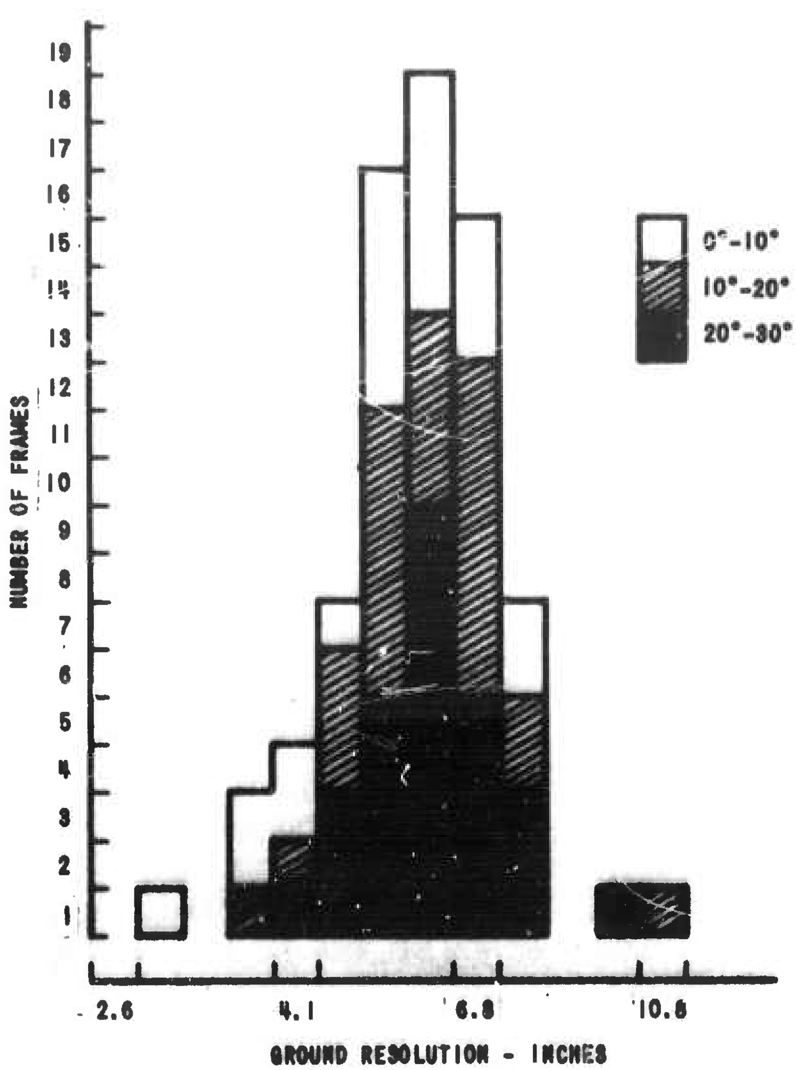


Figure 39 RESOLUTION DISTRIBUTION FOR THREE KA-61 CAMERAS (VISIBLE SPECTRUM)

were refocused and retested in the Laboratory. The focus was readjusted with lens shims for cameras #11 and #12 so as to increase their low contrast resolution to about 16 lines per millimeter and 22 lines per millimeter respectively.

Table 6

ZI RESOLUTION CALCULATIONS: SUMMARY

KA-61 CAMERA NUMBER	FILM	FILTER	RESOLUTION (ℓ/mm) HIGH CONTRAST	MEDIUM CONTRAST	LOW CONTRAST	*RESOLUTION (AWAR) LAB-CALIB.
1	PLUS-X	MINUS BLUE	25	27	18	24
2	EKTACHROME	COLOR BALANCE	22	24	15	28
3	IR	3875 Å	16	17	-	33
4	PLUS-X	4500 Å	23	21	10	34
5	PLUS-X	5000 Å		NO DATA		27
6	PLUS-X	5500 Å	18	20	11	20
7	PLUS-X	6000 Å	22	24	13	37
8	PLUS-X	6500 Å	20	23	14	32
9	IR	7000 Å	22	23	13	29
10	IR	7500 Å	19	18	8	24
11	IR	8000 Å	15	12	4	16**
12	IR	8625 Å	13	12	5	22**

*AWAR USING LOW CONTRAST RESOLUTION TARGET DURING LABORATORY CALIBRATION

**FINAL LAB CALIBRATION AFTER COMPLETION OF ZI TESTS

The resolution results presented in the table were achieved using the film/filter combinations which will normally be used on spectral flights during Phase II of the program. Infrared film was used in the camera filtered for the band in the vicinity of 3800 A because in this spectral region the sensitivity of the IR film is more nearly equivalent to that of the other films used with their respective bandpass filters. Most blue sensitive films which one might normally select for this (blue) region of the spectrum have too high a sensitivity in the 3800 A band, and would require different camera exposures. This would introduce an undesirable difference in ground resolution between this camera and the other eleven.

3. Spectral Reflectance Experiments

Data for the spectral experiments were obtained primarily with the KA-61 cameras. These cameras have an f/3.5 Kalimar lens which has a nominal focal length of 52 millimeters. Shims were used in the laboratory tests to adjust the focus on each camera to obtain the optimum resolution for each lens with the narrow bandpass spectral filter with which it would be used for the spectral experiments. Table 7 presents data showing the film and filter combinations normally used for the spectral experiments. The center wavelengths for the spectral filters are shown, the bandpass being approximately 500 A except for the first (3875 A) and the last (8625 A) filters which are broader band, but are employed as cutoff filters which effectively give a 500 A bandwidth when the spectral characteristics of the film are considered.

The data for trial determinations of the spectral reflectances of "unknown targets" were obtained from microdensitometer scans of film obtained on two ZI test flights. Sensitometric control was obtained by putting step wedges on each end of each roll of film using the modified sensitometer which allows light to be filtered through the same filter type as that used on the camera.

Table 7

FILM/FILTER COMBINATIONS FOR SPECTRAL EXPERIMENTS

KA-61 CAMERA NUMBER	FILM TYPE	FILTER
1	PLUS-X	MINUS BLUE (EQUIVALENT TO WRATTAN #15)
2	EKTACHROME	COLOR BALANCE
3	INFRARED	3875 Å
4	PLUS-X	4500 Å
5	PLUS-X	5000 Å
6	PLUS-X	5500 Å
7	PLUS-X	6000 Å
8	PLUS-X	6500 Å
9	INFRARED	7000 Å
10	INFRARED	7500 Å
11	INFRARED	8000 Å
12	INFRARED	8625 Å

Spectral data were analyzed by scanning the images of the spectral target (i.e., the yellow panel) and the two large spectral control panels (light gray and dark gray) with an Ansco Model 4 Microdensitometer. All scanning (target images and step wedges) was done with a fixed set of optics such that variations in density with numerical aperture of the scanning optics would not be a problem. These data along with D-log E curves obtained from step wedges on the ends of each roll of film can be used to compute the spectral reflectance of any unknown target. A Beckman Model DU Spectrophotometer was used in the laboratory to ascertain directly the spectral reflectances of all three panels by scanning a small sample cut out of each panel. As a test of the system performance, the spectral reflectance for the yellow target, computed from measurements on the filtered images, was compared with the spectral reflectance of the target panel as measured on the spectrophotometer.

The first data were obtained from Flight #4 at CAL's Wilson, N.Y. Test Center. Due to either camera failure or gross exposure error, four of the ten spectral frames could not be used. Figure 40 shows the

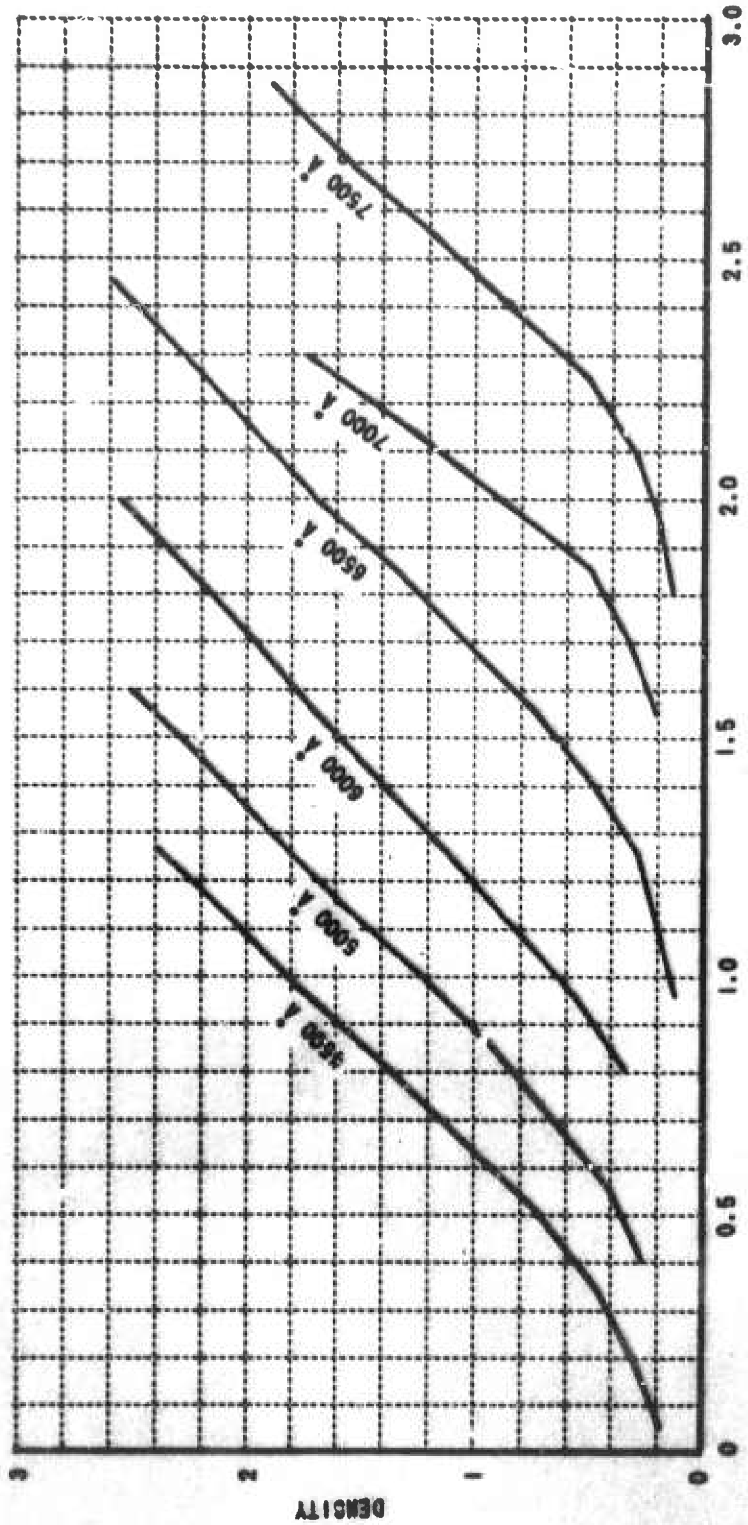


Figure 40 D-LOG E CURVES FOR WILSON FLIGHT

relationship between density and the log of relative exposure for each of the spectral cameras used in the test. Table 8 gives the spectral data from the Wilson flight.

Table 8
SPECTRAL DATA FROM WILSON FLIGHT

FILTER	TARGET DENSITY			SPECTRAL REFLECTANCE		
	DARK GRAY	LIGHT GRAY	YELLOW	DARK GRAY	LIGHT GRAY	YELLOW
4500 A	1.72	3.39	1.15	0.085	0.705	0.04
5000	0.75	2.69	0.91	0.065	0.665	0.09
6000	0.72	2.33	2.38	0.055	0.610	0.66
6500	0.11	1.11	1.27	0.050	0.590	0.70
7000	0.21	1.65	2.01	0.050	0.570	0.66
7500	0.55	2.03	2.16	0.045	0.505	0.64

Reflectance values may be computed using the following relationships:

$$E_{i,n} = \alpha_n \rho_i (\lambda)_n + \beta_n$$

where $E_{i,n}$ is exposure for the ith target for the nth filter,

α_n is a constant independent of the target,
$\rho_i(\lambda)_n$ is a reflectance of the ith target at λ_n,
β_n is a constant representing the flare and scattered light contribution to the exposure.

To compute the reflectance α, β, and E must be known. Using data from two ground targets of known reflectance in the vicinity of the unknown target, one can determine the reflectance from a set of three equations for the three targets:

$$E_{y,n} = \alpha_n \rho_y (\lambda_n) + \beta_n$$

$$E_{w,n} = \alpha_n \rho_w(\lambda_n) + \beta_n$$

$$E_{B,n} = \alpha_n \rho_B(\lambda_n) + \beta_n$$

For the three equations, the three unknowns are α_n, β_n, and the unknown reflectance, designated here by $\rho_y(\lambda_n)$. The other two reflectances, ρ_B and ρ_w, are the reflectances of the two control panels and are known. The exposures (actually, the relative exposures) are determined from the microdensitometer data for the D-log E curves.

It can be seen from the spectral data for the Wilson Flight in Table 8, that the density values sometimes exceed the highest values in the corresponding curves in Figure 40. When this occurred, the D-log E curve was extrapolated upward. The "known" reflectance values of Table 8 (dark and light gray) were taken from the curves of Figure 41 and the unknown reflectance (yellow) was computed from the set of equations above. The resulting values are compared to the spectrophotometer curve for the yellow panel in Figure 42.

It was noticed during the performance of the above tests that while reflections from the dark and light gray panels were diffuse, the reflection from the yellow panel was highly specular in spite of efforts to obtain a diffuse surface. This means that the value of reflectance can be quite sensitive to small differences in the measuring geometry, such as might exist between the illuminating and detection angles of the spectrophotometer and the actual flight geometry. For this reason a new yellow panel was constructed using a different yellow paint. The second set of spectral data was obtained from Flight #6 at Wright-Patterson Air Force Base using the new yellow target along with the two gray targets. As in the Wilson Flight, camera failures and exposure errors occurred and only seven of the ten frames were usable. The relative D-log E curves are shown in Figure 43 and the Wright Field data are given in Table 9. The new computed

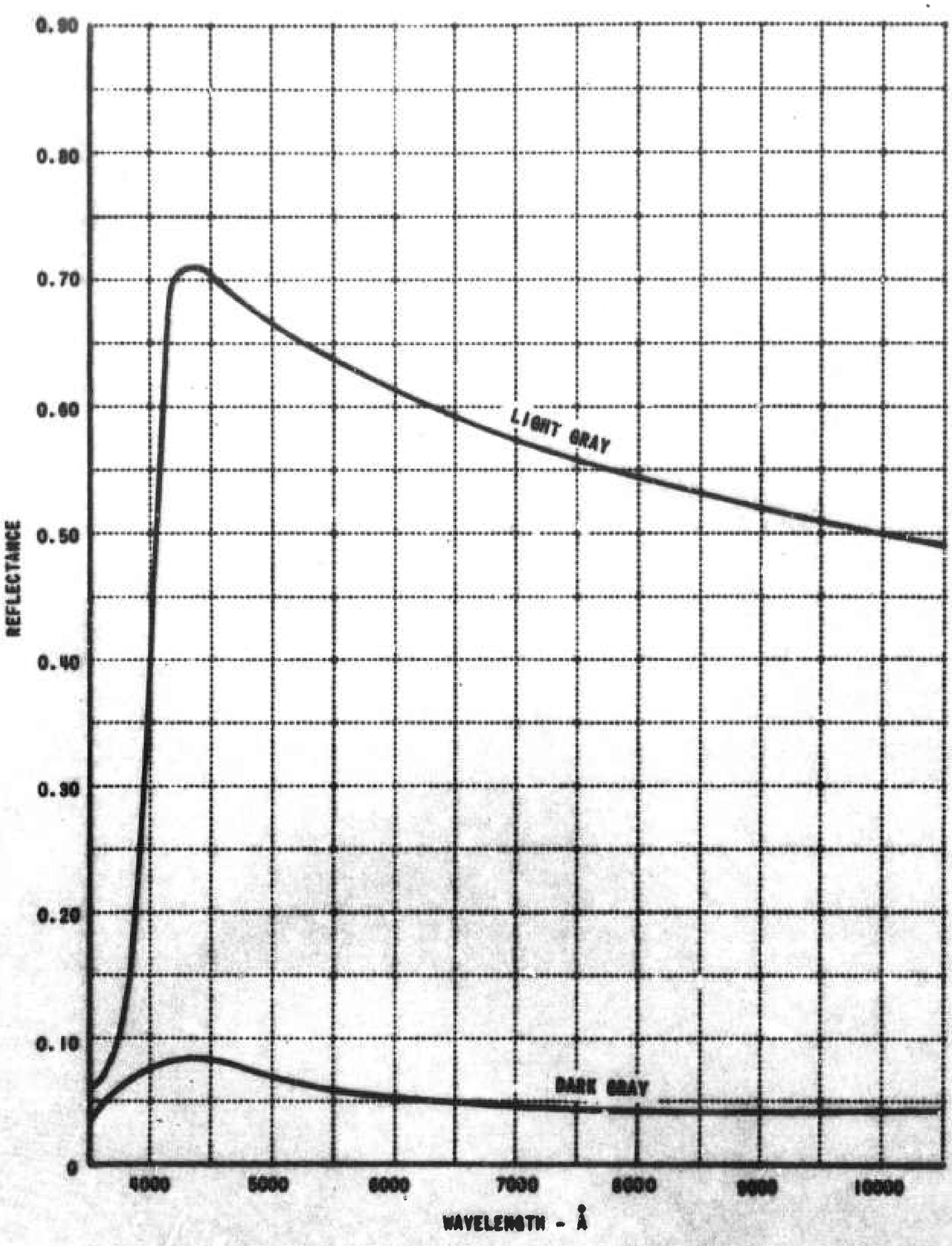


Figure 41 SPECTRAL REFLECTANCE OF CONTROL PANELS

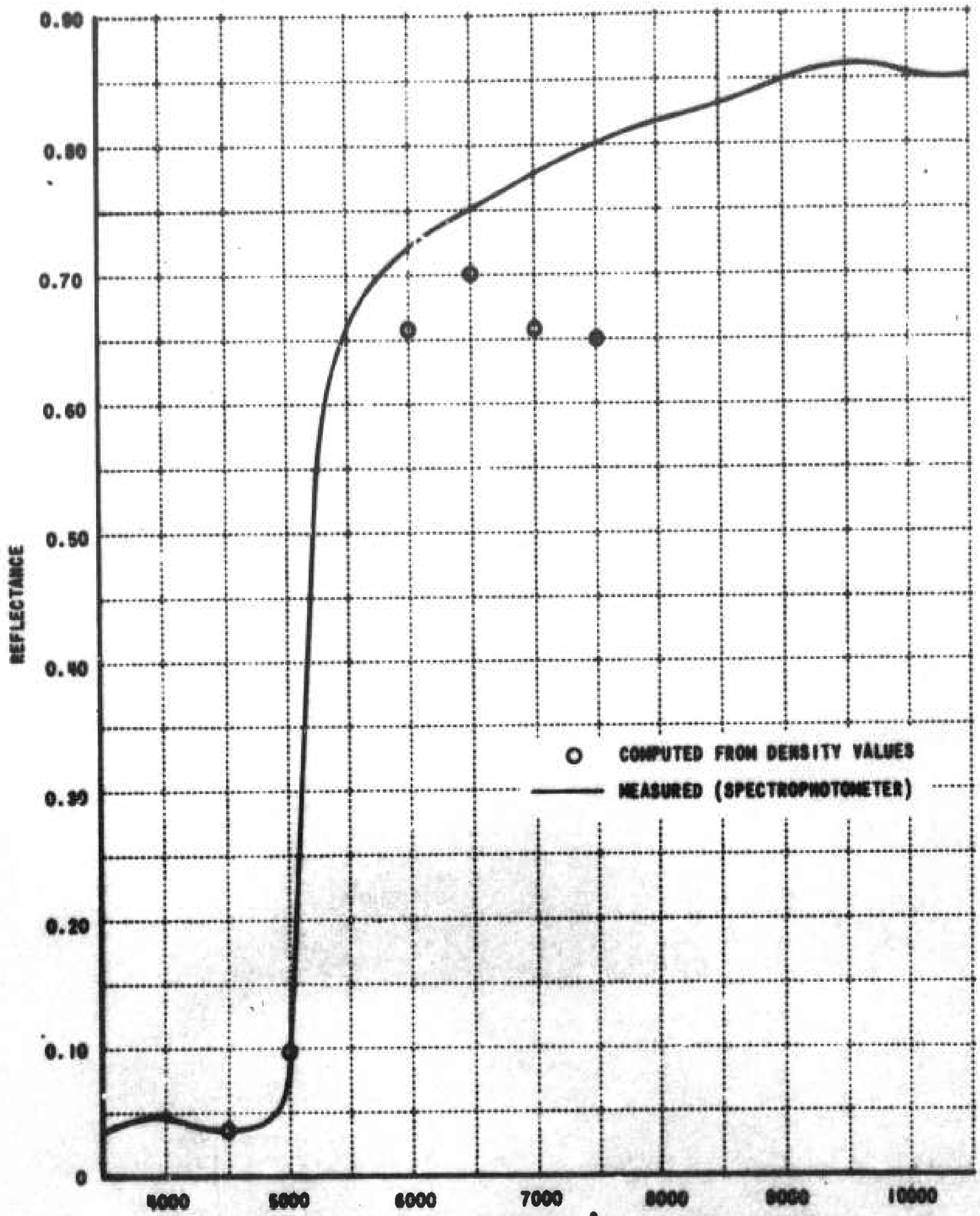


Figure 42 COMPARISON OF MEASURED TO COMPUTED SPECTRAL REFLECTANCES FOR YELLOW PANEL (WILSON FLIGHT)

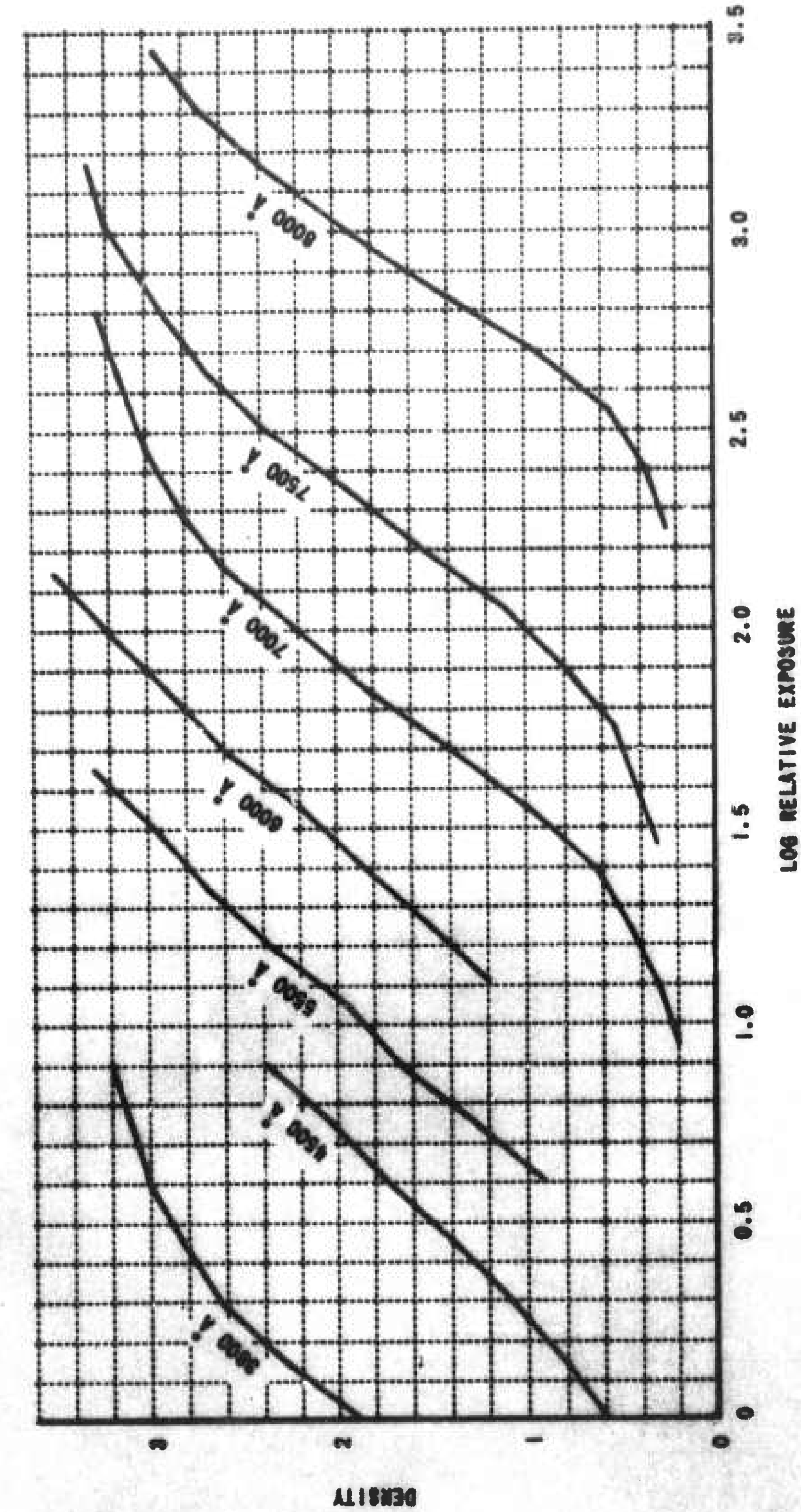


Figure 43 D-LOG E CURVES FOR WRIGHT FIELD FLIGHT

values of reflectance are compared to the spectrophotometer curve for the new yellow panel in Figure 44. The new data points are in better agreement with the expected curve than are those shown in Figure 42.

Table 9

SPECTRAL DATA FROM WRIGHT FIELD FLIGHT

FILTER	TARGET DENSITY			SPECTRAL REFLECTANCE		
	DARK GRAY	LIGHT GRAY	YELLOW	DARK GRAY	LIGHT GRAY	YELLOW
3800 A	2.53	3.34	2.52	0.065	0.105	0.06
4500	0.75	2.64	0.70	0.085	0.705	0.08
5500	1.09	3.39	3.23	0.060	0.640	0.53
6000	1.24	3.57	3.58	0.055	0.610	0.62
7000	0.84	3.08	3.22	0.050	0.570	0.82
7500	1.38	3.05	3.15	0.045	0.505	0.81
8000	0.88	2.98	2.68	0.040	0.540	0.83

Another result demonstrated by analysis of the data from the spectral reflectance experiments was the reversal of contrast as wavelength changes. In Figure 45, the reflectance measurements made with the spectrophotometer in the laboratory for the light gray panel, the dark gray panel, and the yellow panel (from Wilson Site) are plotted. From these curves, one would predict that at, say, 7500 A the contrast of a yellow object against a dark gray background will be positive (light object against dark background). Furthermore, at, say, 4500 A one would predict that a yellow object against a dark gray object should have a negative contrast (dark object against light background). These predictions are verified by comparing in Figure 46 the reflectances evident for the various targets shown in the four simultaneously exposed frames taken from the various spectral bands indicated. The imagery was obtained during the Wilson flight tests.

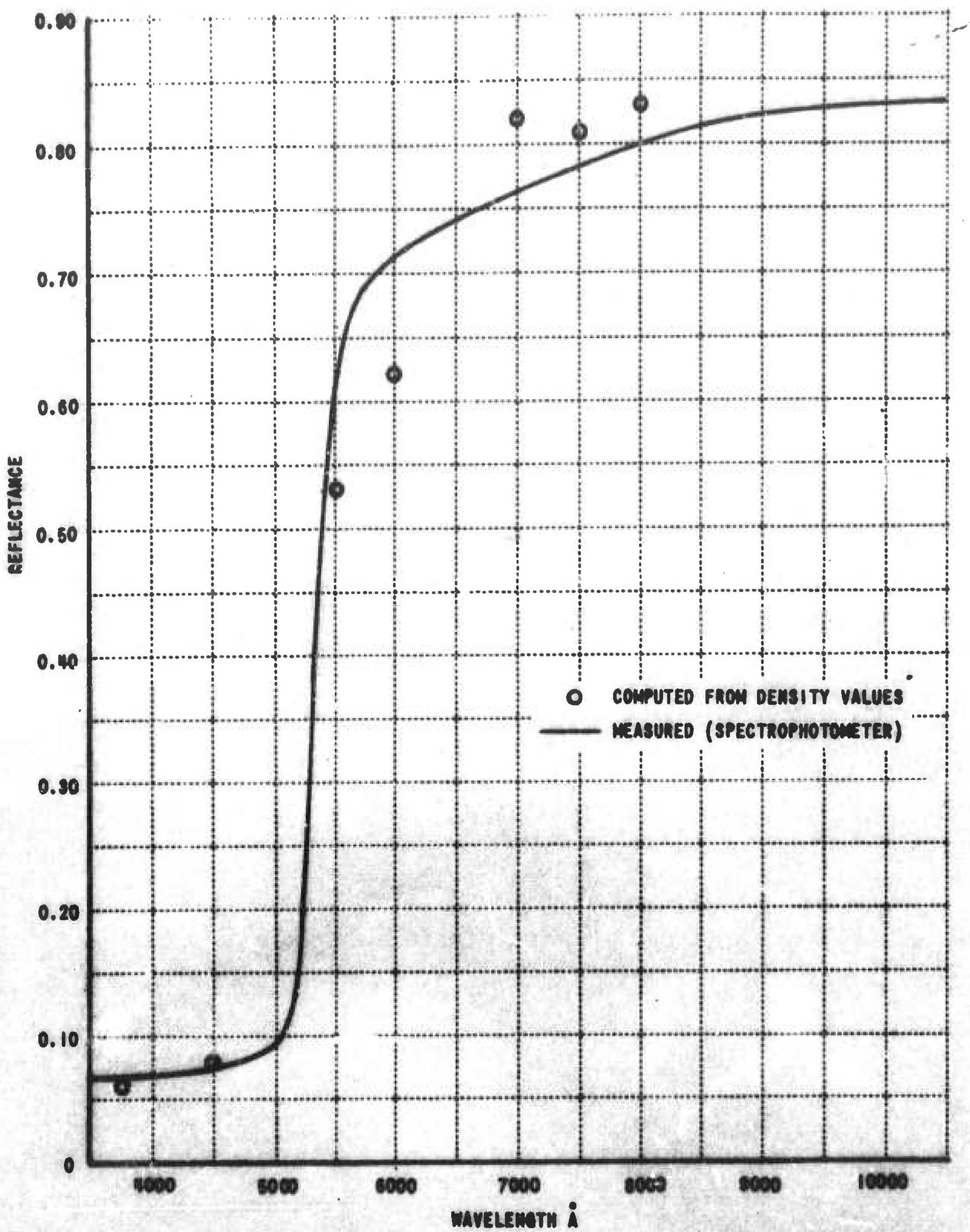


Figure 44 COMPARISON OF MEASURED TO COMPUTED SPECTRAL REFLECTANCES FOR NEW YELLOW PANEL (WRIGHT FIELD FLIGHT)

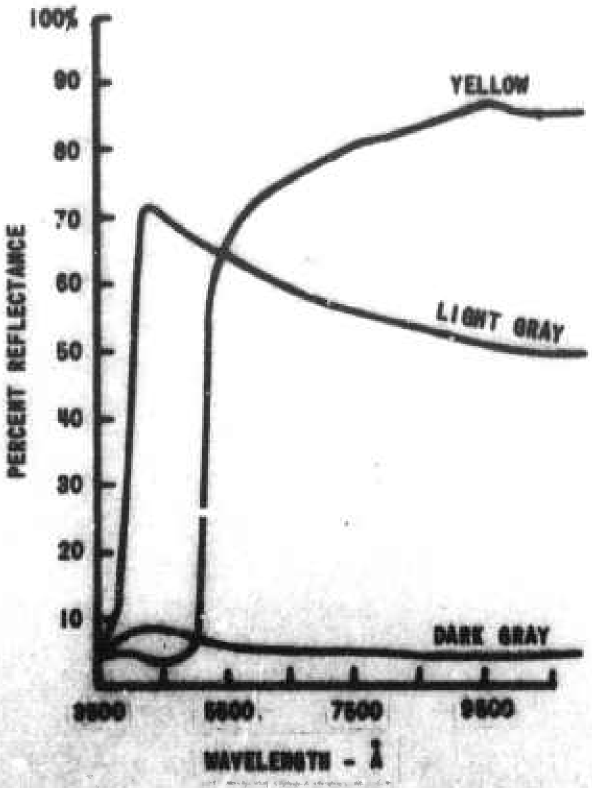


Figure 45 COMPARISON OF REFLECTANCE CURVES FOR TARGET PANELS

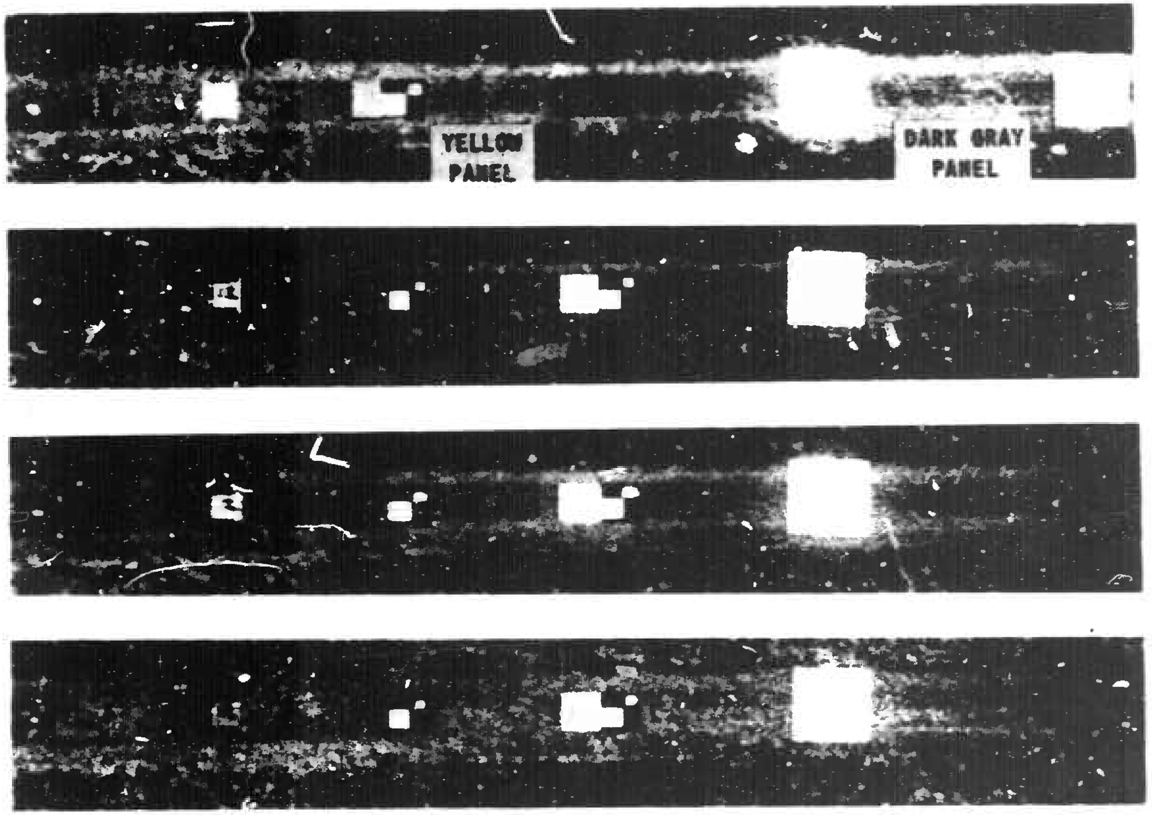


Figure 46 COMPARISON OF SPECTRAL REFLECTANCES TO DEMONSTRATE CONTRAST REVERSAL (WILSON TEST SITE)

4. Angular Measurements

One of the tests to be conducted in Thailand is the determination of whether or not there are preferred angles for photographing targets under a jungle canopy. In several of the ZI tests the objective was to show that angular measurements could be made either by using a grid over the negatives from daylight photographs with the panoramic camera or by taking nighttime photographs of a string of lamps located at predetermined positions. The KA-52 panoramic camera used Plus-X film for the daylight flights and Tri-X film for the night flights. The results of the experiment indicated that angle measurements could indeed be made from either daylight or night flights and a grid was constructed for use with negatives from the panoramic camera. Figure 47 shows one frame from a KA-52 Panoramic camera daylight flight with the angle grid overlay aligned for angle measurements.

5. Special Interpretation Experiments

Experiments were conducted during several of the flights to obtain data upon which some of the special photointerpreter techniques could be tested. Of course, none of the techniques could be satisfactorily tested because of the lack of appropriate tropical environments, a lack of appropriate counterinsurgency targets, and the lack of such special situations of, say, an appropriately simulated ambush situation. Photography was obtained, however, using the various lenses for the KB-8A cameras to obtain multi-scale photographs. Various films and broadband filters were used in the KB-8A and the KA-61 cameras in order to determine that proper exposures and settings could be made so as to effectively perform the broadband and special film tests. The ability of the KB-8A cameras to be adjusted so as to take photographs at different oblique angles was functionally tested to demonstrate that the camera mount for these cameras could be adjusted both in azimuth and elevation over the desired angular ranges.

The use of special techniques for observation of detail in shadow areas was tested by using various combinations of filters, films and exposure settings. Figure 48 illustrates the application of blue light photography to enhance target detection in shadow areas. Enlargements are presented of

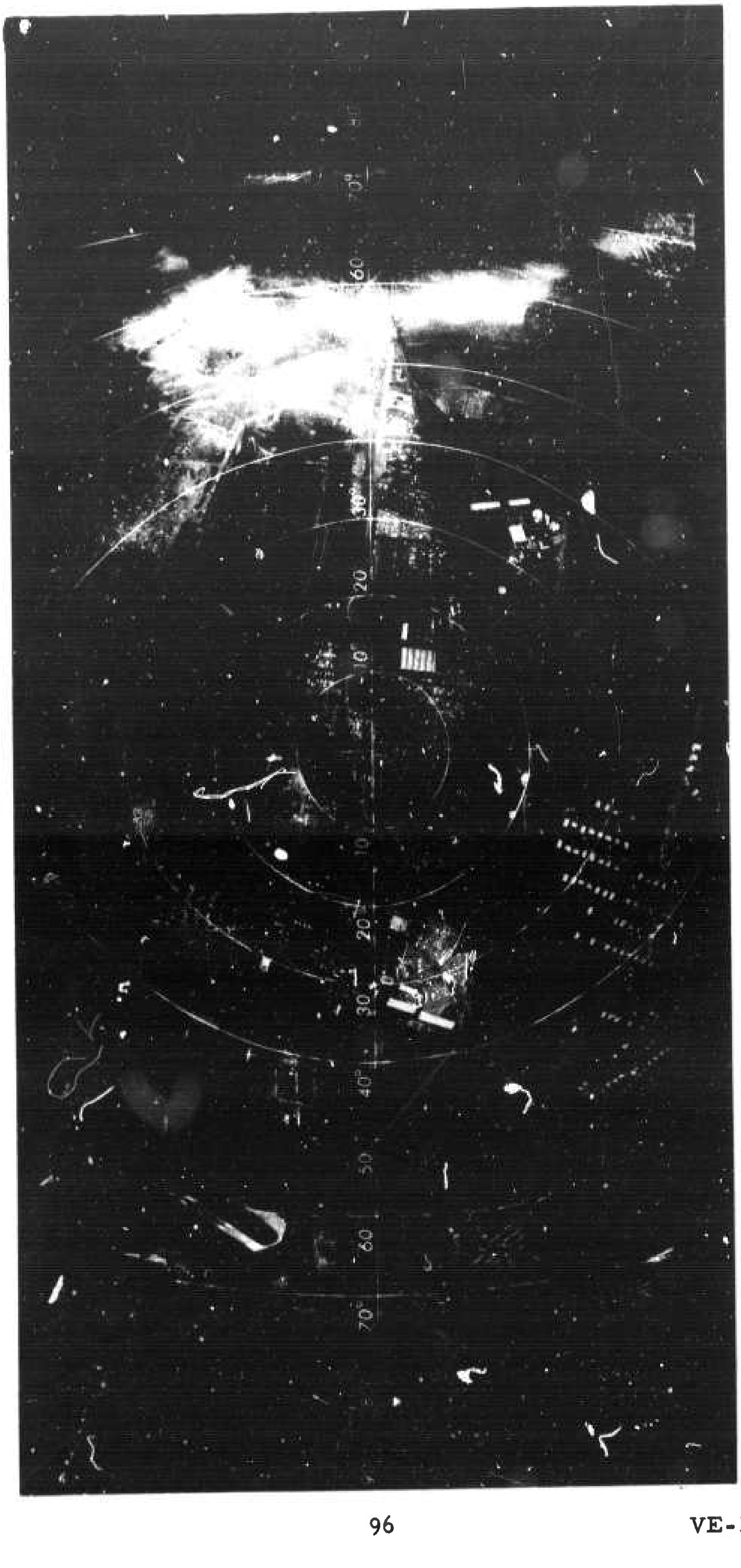
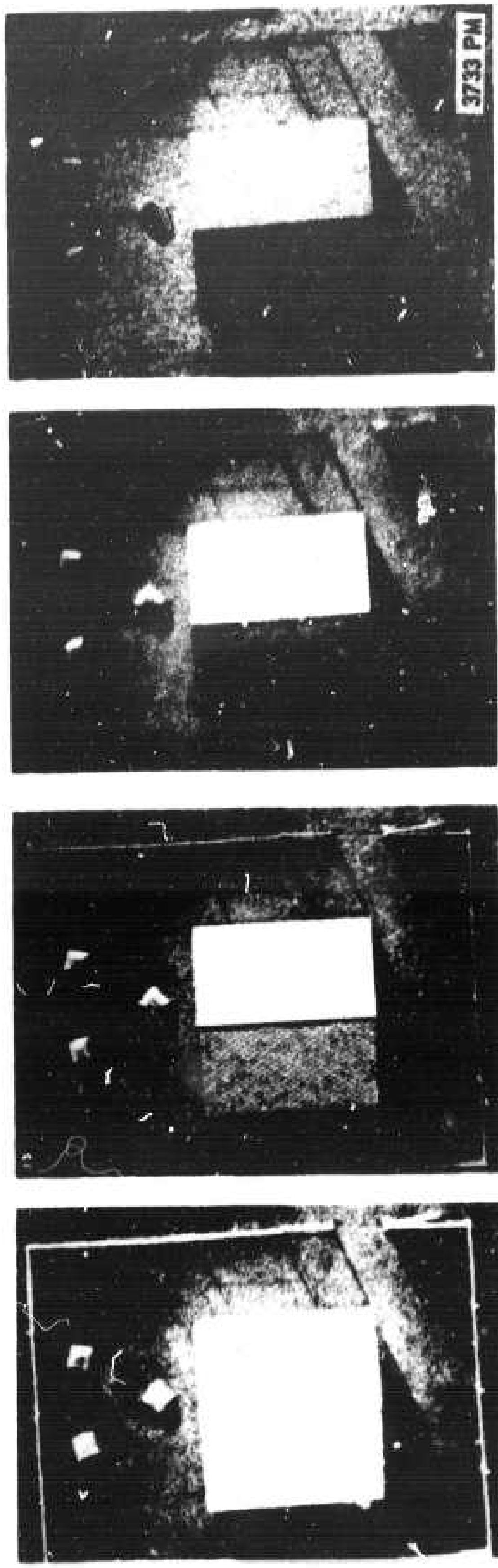


Figure 47 PANORAMIC FRAME WITH ANGLE GRID OVERLAY



4500 Å

6000 Å

7000 Å

7500 Å

Figure 48 APPLICATION OF SPECTRAL REFLECTANCE DIFFERENCES TO REAL TARGETS

the same section of four frames which were simultaneously obtained with the KA-61 cameras in four different spectral bands. Because a better exposure balance between shadow and sunlight areas can be achieved at shorter wavelengths, the images of objects in shadow areas would be expected to have higher contrast in the blue region of the spectrum. Figure 48 shows that objects in the shadow of the garage can be more readily detected in the 4500 A photograph than in the other photographs. This principle is to be used during Phase II of the program to study photographic detail in shadows.

6. IMC Operation

During the preflight systems tests of the KA-61 camera bank of twelve cameras, their capability for image motion compensation (IMC) and their capability for synchronous operation was tested. In addition to these ground tests, however, the operational capability of the bank of cameras to achieve proper IMC and synchronization was again checked during the ZI flight tests. The IMC tests showed that the largest observed errors resulted from gusts and crosswinds which prevented establishing a constant ground speed on the basis of the measured airspeed. Adequate ground resolution was achieved on most of the photographic passes by using the calibrated IMC setting, but some blurring due to uncompensated motion did occur. The need for "repeat" passes under severe wind conditions became evident from the ZI tests.

As noted earlier, the result of the preflight tests indicated that all cameras were within one millisecond of synchronization except for one camera which was later assigned the role of the camera used for field determination of proper exposure settings, where synchronization with the remaining cameras was unimportant. From the flight test data, scrutiny of the simultaneous photographs from all twelve cameras revealed that the combined errors which might be attributed to either lack of synchronization or an error in alignment of the boresight axes of all twelve cameras was hardly measurable.

7. Vibration Environment

Review of the first films obtained in the ZI flight tests indicated some degree of blurring of the point source which could be attributed to vibrational effects. In order to further assess the effects that vibration would have on the photographic imagery, camera vibrations were purposely induced, while exposing film by varying the airspeed and camera cycle rate, by lowering the KB-8A camera group into the airstream to a maximum extent, by loosening camera tie down bolts, or by simultaneously operating all cameras in the aircraft. The series of tests indicated that the vibration detected in the photographs was of a random nature and could not be attributed to any of the specific operating conditions generated. The tests also showed that the magnitude of the vibration blur would not prevent the system from achieving the resolution required for the program.

8. Radio Interference Effects

To determine the effects of radio noise and interference, two operational flights were conducted at the University of Michigan. No mutual interference problems between the CAL photographic subsystem equipment and the University of Michigan infrared equipment were detected, and satisfactory simultaneous operation of the equipment was achieved. The high frequency radio transmitter installed in the aircraft did, however, cause noise to appear on the Michigan equipment and on the recorded photometer data in the photographic subsystem. This interference can be avoided during Phase II by prohibiting the use of the high frequency transmitter during the period when the cameras are operated.

9. Photography of Detailed Targets

Figures 49 through 53 are reproductions of aerial photographs taken at various of the target sites in order to demonstrate that detailed target photography can be achieved with the photographic subsystem developed under this program. Figure 49 shows one member of the field crew seated in the target area. Figures 50 and 51 shows members of the ground crew in the target area looking up at the aircraft. Figure 52 shows three photographs

Figure 49 PERSON RECLINING 6" KB8A

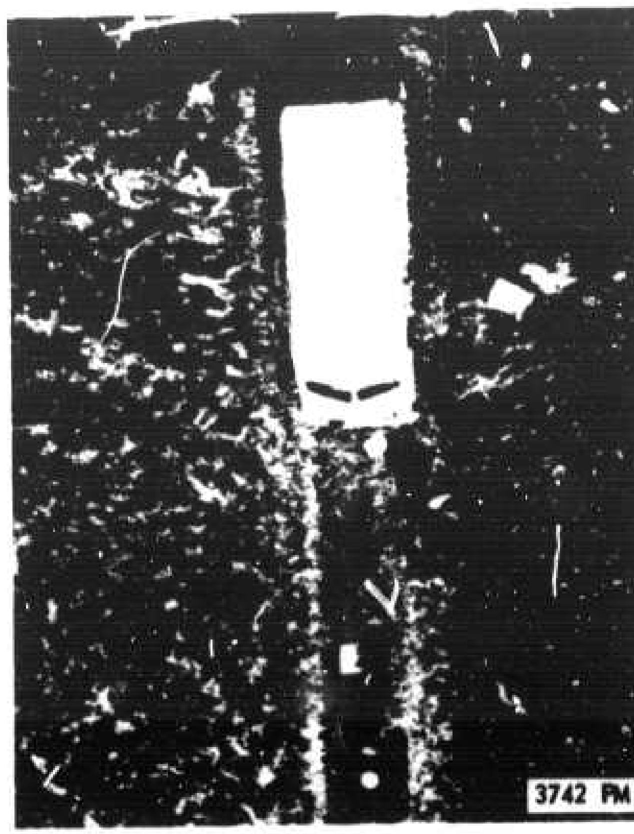


Figure 50 PERSON BENDING BACKWARD AND STANDING

6" K38A

Figure 51 PERSON KNEELING/STANDING

6" KB8A

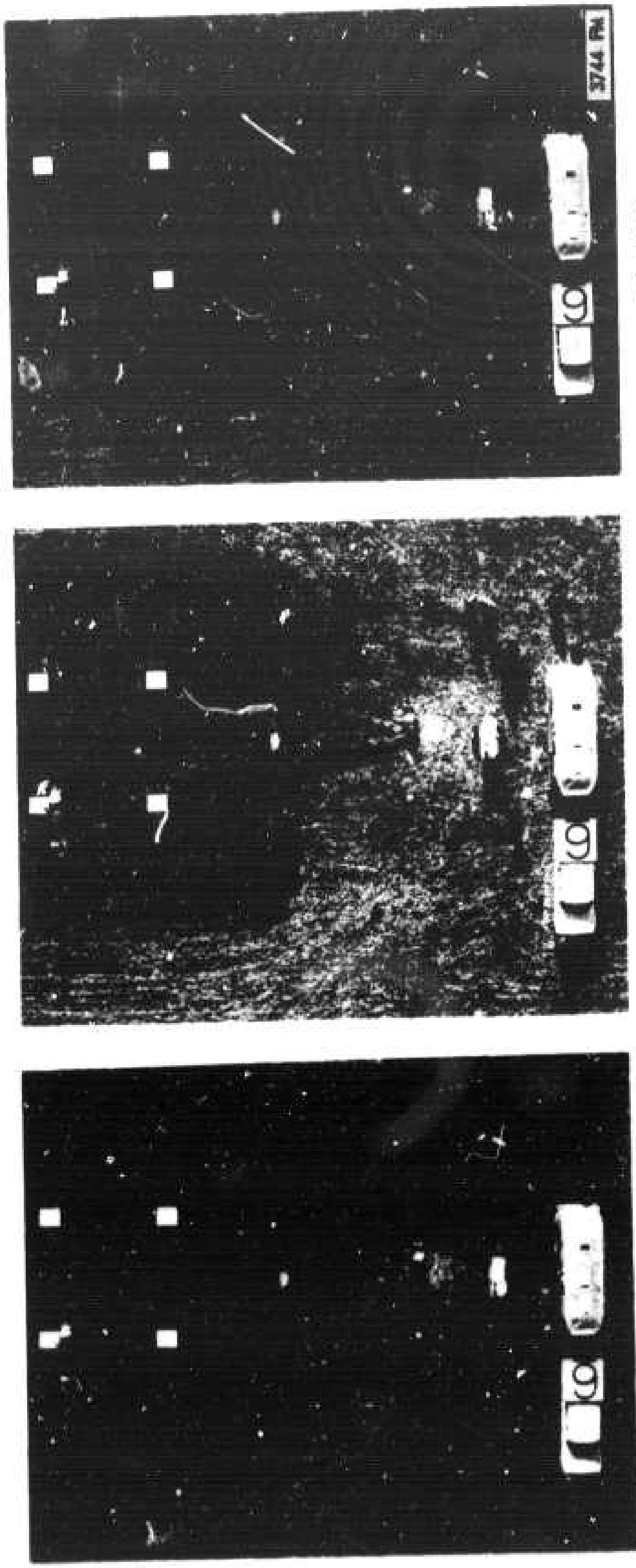
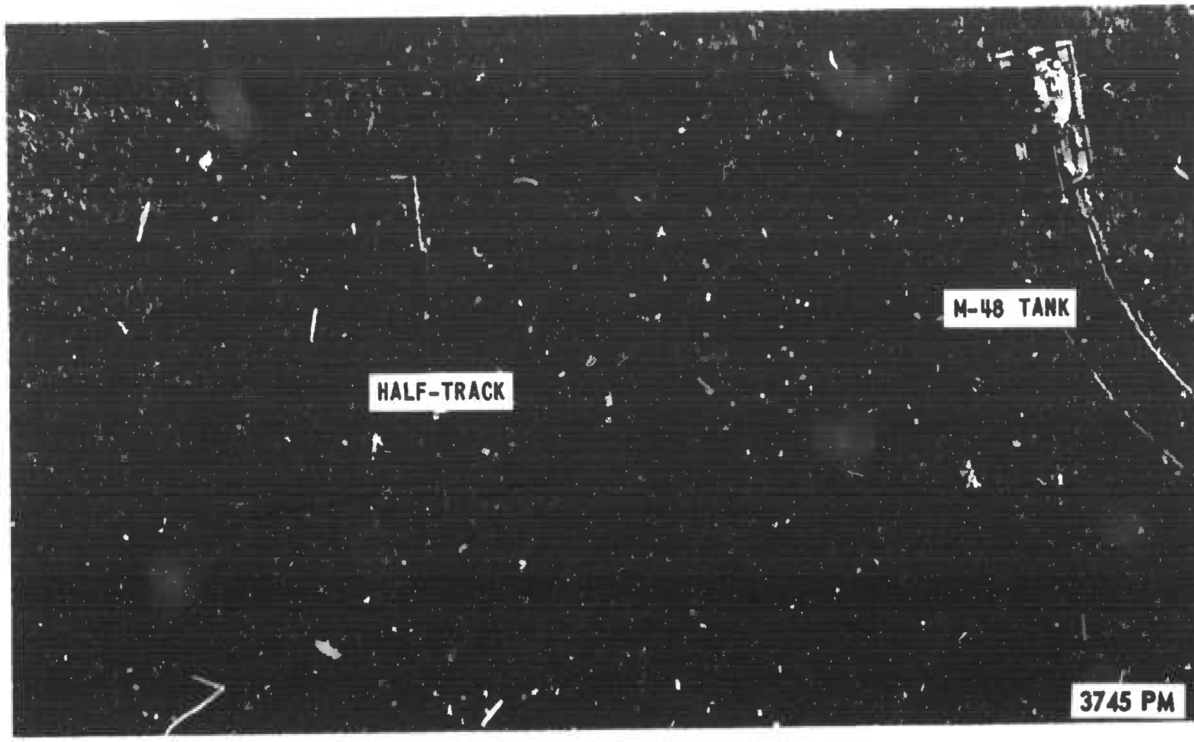


Figure 52 COMPARISON OF KB-8A PHOTOGRAPHS USING DIFFERENT LENSES



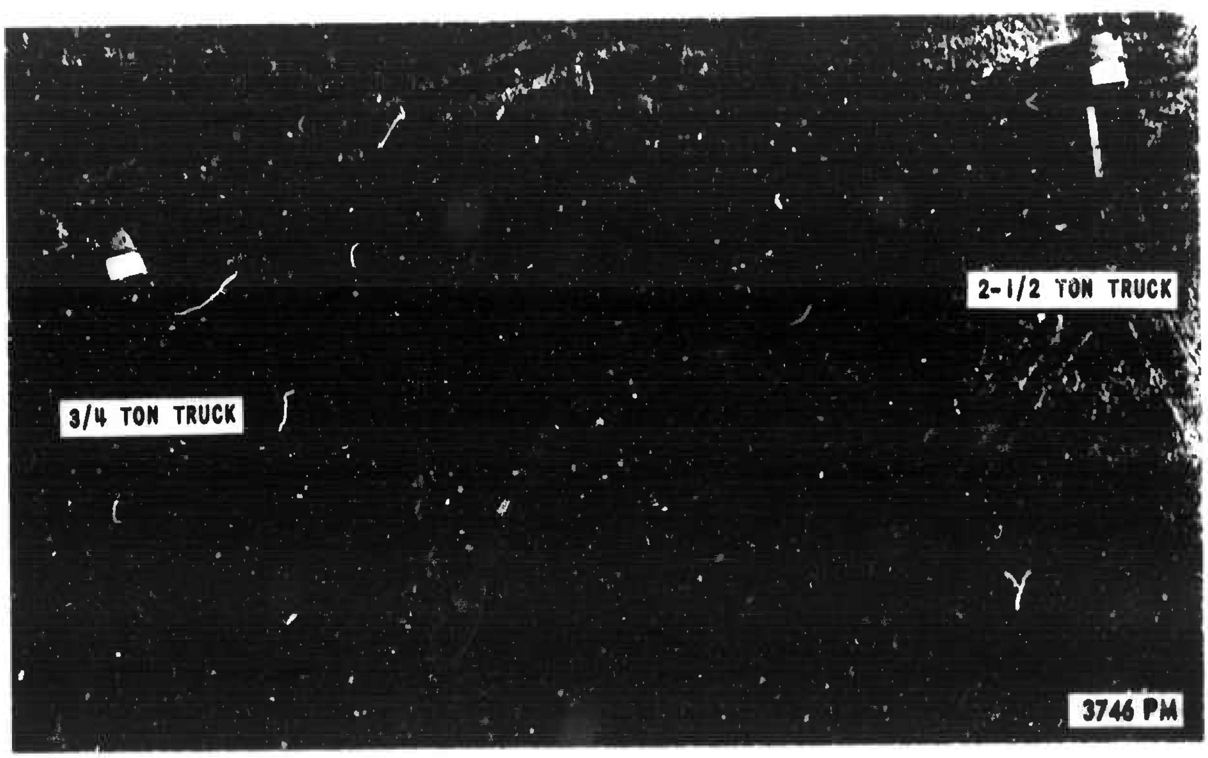


Figure 53 ARMY VEHICLES AT UNIVERSITY OF MICHIGAN

of a group of people in the target area obtained simultaneously with the 1-1/2 inch, 3 inch, and 6 inch lenses on the KB-8A cameras. The remaining figure demonstrates the ability of the system to photograph in detail such targets as the army vehicles shown.

VII. SUMMARY AND CONCLUSIONS

Phase I of Project AMPIRT was essentially concluded at the Cornell Aeronautical Laboratory with acceptance of the photographic subsystem by the sponsoring agencies at a briefing at RADC in mid-December 1964. Subsequently, all equipment was removed from the aircraft, packaged in water-tight reusable shipping containers to meet AF level "A" protection for overseas shipment, and shipped to Thailand for the start of the Phase II field tests. Accomplishments of Phase I have been discussed in this report and may be summarized as follows:

1. Systems engineering for the photographic subsystem was performed to design the system and test program to evaluate various photographic techniques and photointerpreter techniques which have potential promise in enhancing detection of counterinsurgency-type targets in a jungle environment.
2. A Phase II test plan for implementing the program objectives by gathering the required photographic data in Thailand was drafted to define specific mission objectives and establish equipment requirements.
3. Necessary equipment was procured or fabricated to synthesize the photographic subsystem. Included were the aerial cameras and photometers, aircraft mounts for the airborne equipment, control targets and ground support equipment for field crew use at the target sites, and tools, supplies and maintenance equipment for laboratory support in Thailand.
4. All cameras and photometric equipment were calibrated in laboratory tests.
5. An evaluation of necessary film processing procedures was made by a series of controlled experiments.

6. After installation of airborne equipment in the HC-47 aircraft and erection of control targets, ZI flight tests were conducted for systems testing and demonstration of performance.

7. Analysis of results from the ZI tests has shown acceptable performance of the entire photographic subsystem to the extent possible using the simulated targets and ZI environments.

REFERENCE

1. Phase II Test Plan for Project AMPIRT (ARPA Multiband Photographic and Infrared Reconnaissance Test Program), Interim Special Report No. 1, VE-1931-D-1, Cornell Aeronautical Laboratory, Inc., 29 January 1965.