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A REVIEW OF AIRCRAFT PHOTOGRAPHIC SYSTEMS

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FOREWORD

This progress report covers that period of Contract AF 33(616)-2268 devoted to the literature survey and study. The material contained in Part One represents the present state of the art of fog and frost prevention as determined during the study period. The material contained in Part Two describes the nature of the work being done by this laboratory with respect to the optic and thermodynamic problems associated with photographic windows.

TABLE OF CONTENTS

A REVIEW OF AIRCRAFT PHOTOGRAPHIC SYSTEMS

PART ONE

I. INTRODUCTION

Reconnaissance may be defined as the act of surveying a region to gain useful information. Modern aerial photographic reconnaissance is, then, reconnaisance conducted from an airplane by means of photography.

Aerial photography, as conducted by the Air Force today, has as its main objectives (1) the collection and documentation of large quantities of detailed information, and (2) the interpretation, summarization, and distribution of the final results as rapidly as possible. These objectives are accomplished in three types of missions: photographic reconnaissance, photographic mapping, and instrumentation photography (photography of meters, radar scopes, etc.).

During wartime, the aerial-photographic effort of the Air Force is used to secure information concerning the intent and potential of the enemy and to assess the damage inflicted upon him. The import of aerial photography is clear when it is realized that up to eighty percent of all information gained concerning our enemies during World War II was obtained by aerial photographic reconnaissance. In peacetime the photographic effort is directed toward photographing and mapping the world. Considerable nongovernment aerial photography is carried out also in forest surveys and city-planning mapping.

The information obtained from any photographic effort results after a train of events has taken place. One may define this train of events as the photographic system. By photographic system, then, is meant the sum of those components which act upon and contribute to the final information.

The rapid advancement of aircraft performance characteristics is continually imposing new problems upon the photographic system. A few years ago, a camera was merely held by hand over the side of the cockpit or over an open hole in the floor of the airplane fuselage. The low temperatures and

pressures encountered in present-day high-altitude flights have brought about the requirements for photographic windows; camera compartments must be sealed and maintained at relatively constant temperature and humidity in order to preserve the film and to avoid temperature gradients in the camera lenses. (It has been reported that temperature gradients in the camera lens reduce the resolution severely (1-7).) The major problems arising from the introduction of windows into the photographic system are fogging, frosting, bending, shattering, and icing. The increasing flight speeds of present-day aircraft have brought about a need for faster camera shutters. Although shutter speeds have advanced considerably, still faster speeds are desirable to eliminate completely the blur caused by the forward motion of the plane. However, this requires a shutter speed so great that the light available for forming the image becomes insufficient. The strip-film, shutterless camera has been designed to eliminate this problem and has experienced considerable success in this respect. In this type of camera, the film moves forward at a speed comparable to that of the aircraft, and thus no shutter is required.

Supersonic flight brings about even more complicated problems, such as further compacting of the system. Supersonic aircraft are of such streamlined and narrow cross sections that available space for camera installations has become limited. Shock waves induced in transonic and supersonic flight create problems in optics; temperature gradients and sharp refractive-index gradients created by the shock waves cause abrupt changes in the path a light ray follows.

The advancement of aerial photography is further reflected in the development of night-photographic techniques. Flash photography is possible up to an altitude of 12,000 feet by means of the Edgerton flash unit; this unit consists of a 7200-microfarad, 4000-volt condensor which allows photography at 1/200 of a second. A newer development which is making the Edgerton flash obsolete is the small flash cartridge which has an output of 110 million candle power. For high-altitude photography (photography from an altitude of 25000 feet and above), the magnesium flash bomb is used. This type of bomb is constructed ballistically to fall just outside the cone of vision of the aerial camera and is set to explode at a considerably lower altitude than that at which the aircraft is flying; thus the illumination may be as great as possible on the ground. The weight of these bombs is of the order of 50 pounds, thus the number of pictures which can be taken on a given flight at high altitudes is limited.

During World War II, German research in infrared techniques proved to be of great value in advancing the development of infrared devices for night vision. Long-range infrared photography was evolved, infrared telescopes were developed, etc. Much of this work has led to the advancement of these techniques in this country. Radar photography is also becoming an important tool for night reconnaissance missions.

As the photographic system becomes more complicated, greater attention must be given to systems analysis in order to determine the weak link, if any. Each component in the photographic system must be examined to determine whether it is the limiting factor upon the final resolution obtained; the optimum performance with respect to the overall system must be obtained if the final resolution is to be increased. Further improvement in lens design or film characteristics may be useless if the photographic windows are of poor optical quality, if severe mechanical vibrations are present in the camera mounts, or if some other component contributes to the gross loss of resolution in the system.

II. AERIAL-PHOTOGRAPHIC WINDOWS

As mentioned previously, higher altitudes and increased flight speeds have brought about the requirement for photographic windows. Many factors must be considered to determine the effect of the introduction of the window on the performance of the photographic system. Obviously, the optical quality of the window glass must be high. Ideally, it should be of the same quality as that of the camera lens in order to produce results comparable to those which could be obtained in the laboratory with the same camera, all other factors being neglected. Due to the high cost of production of optical quality glass, a compromise has been made wherein under present practice, selected plate glass is used. A tolerance system has been established by the Air Force such that the optical quality of the window conforms to the type of camera installation used. The two main defects to be looked for in plate glass are wedge angle and surface flatness. Other more obvious defects are striae, bubbles, and foreign matter.

During flight at high altitudes, pressurized compartments may be subjected to pressure differentials as high as ten pounds per square inch; thus, bending of the windows must be prevented by proper choice of window thickness. If the windows bulge, a simple lens is formed and a shift in camera focus is experienced; aberrations may also be introduced by nonuniform bending. Thermal bending and possible shattering must also be considered since fairly large lateral and transverse temperature gradients will exist in the glass, depending upon the method of window defrosting utilized.

Other minor problems exist in connection with the windows, especially during flight operation, such as maintenance of clean and scratch-free windows.

Maintenance of Fog- and Frost-Free Windows

One of the major problems associated with the use of photographic windows is the maintenance of the window fog- and frost-free during flight. Extremely low temperatures are encountered at the high altitudes of present-day flights; thus, in order to prevent fog formation on the window, the inner surface of the window must be maintained above the dew point of the cabin air. Many methods have been proposed for prevention and/or removal of fog and frost formation. Systems currently in operation utilize hot-air blasts across the interior surface of the windows. These systems are usually rather bulky and cumbersome and severe limitations are placed on them to prevent image deterioration by the hot-air blast. Laminar-flow nozzles exhausting cabin-temperature air are recommended for long-focal-length cameras, while air 50°F hotter than the ambient air may be used for smaller-focal-length lenses, i.e., 24 inches or less. Care must be taken in either case that the blast does not directly impinge on the camera lens. In spite of these restrictions, this system is reported to operate quite well.

Conductive coatings are beginning to receive some attention and thus far they show considerable promise. Conductive coatings have been produced for a number of years and have been applied to air-exhaust tanks, wall heaters, fuel-line heaters, etc. It has only been recently, however, that coatings have been produced which are semi-transparent. In the transition zone of 5-40 microns thickness, the requirements of conductivity and light permeability can be met. A number of metals, gold, silver, copper, platinum, cadmium, tin, aluminum, and chromium, have been investigated as possible coating materials. Copper, silver, and gold were found to be the most suitable from a resistance-versus-permeability standpoint. Present trends seem to be toward the use of gold and tin oxides as the coatings.

At least two techniques are used for applying the conductive film to the glass-window surface: (1) spraying of a liquid solution of the metal ion on the red-hot sheet of glass, and (2) evaporation of the metal and condensation on the glass under vacuum. Of these two techniques, the latter is preferred since the optical quality of the glass is impaired by the heat required in the former method. The oxide coating obtained is protected by a boro- or florosilicate film which is reported to be nearly as abrasion-resistant as the glass itself. Light transmission is reduced about 25 percent by the dual coating, but this reduction is not considered serious. Although this method of heating has not been adequately tested to date, it appears that it will solve many problems in window defogging. Power-dissipation rates up to 2000 watts/sq ft are reported possible. This is even considered sufficient for deicing in many cases.

Other Proposed Methods. The more important methods which have been proposed, but which have received very little operational tests will be mentioned here.

Infrared Heating: This method of heating utilizes radiant energy as the source of heat. The incident radiation causes molecular excitation in the irradiated body and thus the temperature of the body rises. The system has the advantage that it is relatively simple and compact. However, absorption of the incident radiation by the windows is very low -- of the order of 10 to 20 percent in the region where the maximum radiation is produced by presently available sources. Reflection of energy incident upon the metallic frames supporting the window appears to be a problem which may cause fogging of the photographic film during exposure. It is possible that reflections may be reduced to a minimum by proper selection of materials of construction, however. Finally, one other difficulty appears to be the realization of a uniform distribution of energy incident upon the window.

Dessicant Hood: A camera hood with a dessicant has been mentioned and an improvement using a dry-air source with a valving system to correct for pressure variation due to altitude changes has been suggested by this laboratory. This system would provide a low-dew-point zone around the camera and provide for pressure fluctuations due to rise and descent of the aircraft. The fogging problem would be eliminated by this system; however, no protection is offered for deicing or for fog or frost prevention on the outer surface during rapid descent.

External Hot-Air Discharge: An external hot-air discharge has been suggested and given limited tests. In this method, hot air is bled into the boundary layer to maintain the outer surface of the window at a temperature essentially that of the cabin temperature. This method appears promising despite NACA tests which indicated that more heat is required than for an inner hot-air blast.

III. EVALUATION OF THE PHOTOGRAPHIC SYSTEM

A. Photographic Resolution

The main objective in the design of any photographic system is to obtain as high a resolution as possible. The better the resolution, the more information that can be extracted from a given photograph by the photo-interpreter, provided the proper contrast is present. In order to determine the relative influence upon the overall resolution by any one of the component parts, it becomes necessary to examine each component individually. Maximum resolution will be obtained by proper adjustment of those components which contribute most to the loss of resolution.

The Film. Photographic films and plates being manufactured today are capable of yielding resolution of the order of 50 lines per millimeter for fast films. Slow-speed films such as positive emulsions may resolve as

high as 100 lines/mm, while special emulsions have been made which resolve 1000 lines/mm. Kodak Aerographic Super XX film is used in this country for aerial photography in the visible region while Kodak Aerographic Infrared film, which is about as fast as Super XX, is used in the infrared region. Either film strips or plates may be used; the former type is preferred, however, because it is less bulky and lends itself to automatic operation more readily. Shrinkage of the film is one defect which must be guarded against when using strip film. Film shrinkage leads to distorted results and serious error in estimated distances and heights. Special films which have a shrinkage coefficient due to processing of the order of 0.6 percent are employed for topographic or mapping photography. The difference between lateral and transverse shrinkage of these films amounts to about 1/10 of 0.6 percent. Proper precautions must also be taken to prevent expansion of the film due to humid conditions. That is, proper humidity control as well as temperature control must be maintained if the film is to retain desirable characteristics.

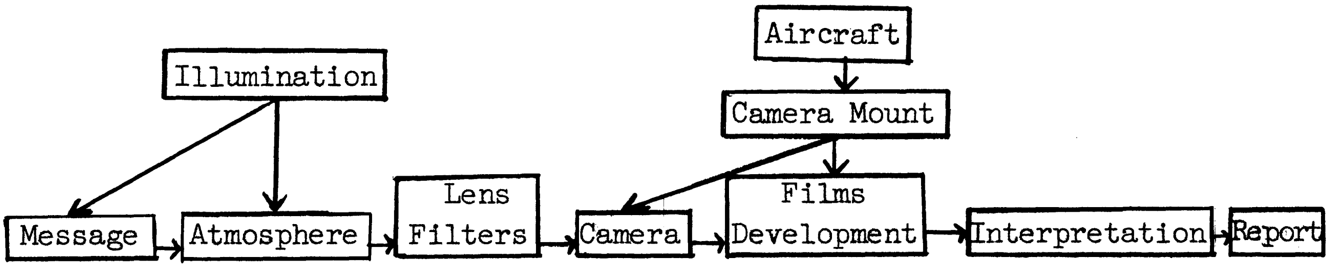
Lenses. Since the beginning of World War II, noticeable advances have been made in the design of photographic lenses. The focal length and aperature of the lenses have steadily increased; lenses with up to 100-inch focal length are common today and special lenses for infrared and wide-angle photography have been designed. Kingslake (J-7) gives an extensive listing of cameras and lenses used during World War II; the many fine lenses in use today are too numerous to mention here. Proper precautions to maintain the lenses at a uniform temperature during operational use appears to be the only improvement required with respect to the lens at this time.

Shutters. Probably the most obvious deleterious effect upon resolution is the image shift or blur due to the forward motion of the aircraft. In order to stop the motion and eliminate this blur, faster camera shutters are required. Compur shutters have been operated up to 1/500 of a second and focal-plane shutters at considerably higher speeds, but sufficient light is not usually available for the shutter speeds necessary to stop the motion completely. Development of the S-7 strip camera, a shutterless camera, has yielded remarkable results in stopping image motion. A method of image compensation was designed by Kodak during the war; this method imparts an oscillatory motion to the camera at the instant of exposure and is called the "sweep" method.

Mounts. Camera mounts have received some attention but it appears that considerable improvement in their design may be possible. An improvement in design would result in less vibration from the aircraft and camera mechanism and thus improve resolution by reducing image blur.

B. The System

The photographic system as defined previously may be described by a flow sheet as follows (B-7):



The detail or resolution obtained in a photograph is measured in terms of the number of equally spaced black and white lines per millimeter which are just discernable. Under laboratory conditions, the degree of resolution obtainable today is of the order of 35 lines/mm. Under flight conditions however, the errors mentioned previously are introduced. It is reported that the photographic quality before World War II averaged about 8 lines/mm and increased to 12 during the war. At present, the average resolution which can be obtained is of the order of 20 lines/mm; the goal desired is considerably higher than this, i.e., 40-50 lines/mm. Considerable improvement should be possible, then, by proper operation of the system. The loss of resolution due to atmospheric conditions may be impossible to avoid, however.

IV. FUTURE PROBLEMS ASSOCIATED WITH INCREASING AIRCRAFT PERFORMANCE CHARACTERISTICS

The increasing flight speeds of present-day aircraft and missiles require designs which are streamlined as much as possible; thus needle noses, flat airfoil sections, and small tapered fuselages are common. Such design limits the available room for the aerial-camera installation. The increasing focal length of aerial cameras may well reach a limit because of space limitations rather than because of design difficulties in the lens system. Camera installations, then, must be made more compact and in some cases may require mirrors to rotate the image into a different plane from the photographic windows.

The optical picture also changes in high-speed flight. A boundary layer will develop, across which very large temperature and density variations occur; a gradual refraction of the light rays will occur when the light passes through the boundary layer. The magnitude of such effects is as yet not definitely established, especially for the case of the turbulent boundary layer, although some attempts are being made to determine it. Shock waves

create a more abrupt change in the light path due to the change in density across the shock. It is conceivable that the photograph of an area taken during supersonic flight may be totally different from one obtained in subsonic flight.

Fogging and/or frosting of photographic windows probably won't be a problem at the higher flight speeds, due to the effect of aerodynamic heating. It is conceivable that cooling of the windows may be required if aircraft flight speeds of Mach 2 to 3 are realized or if guided missiles are used to carry photographic equipment. It appears then, that aircraft will be flying through a range of speeds in which fogging of vision surfaces may occur at the lower speeds, thus requiring heat addition, while cooling of the window surfaces may be required at the higher speeds.

CONCLUSIONS

From the preceeding discussion, it can be seen that many problems still exist concerning the photographic system and that many more are anticipated as supersonic flight takes place. Research along the lines pointed out should be fruitful indeed.

PART TWO

CURRENT ACTIVITY OF THIS LABORATORY

In conjunction with the literature survey reported upon in Part One of this report, this laboratory has been engaged in the study of problems associated with photographic-window fog prevention and removal. Solution of the defogging problem introduces a problem in optics of one form or another, regardless of the method of defogging. Since most defogging and defrosting systems are of the thermal type, it was felt advisable to investigate the wedge-angle effect produced by the thermal boundary layer. Exploratory calculations showed that the thermal boundary layer actually does act as an optical wedge. The analysis of the wedge angle produced by a plane jet has been begun and some experimental verification is anticipated.

At the request of the Air Reconnaissance Laboratory, the investigation of the heat requirements for maintaining fog- and frost-free windows on the McDonnell RF-101 Aircraft during rapid descent has been undertaken. This

aircraft is the first military aircraft to be fully equipped with photographic windows which are coated with an electrically conductive film produced by the Libby Owens Ford Company. The cases being investigated include steady-state heat requirements and surface temperatures attained at altitude for various Mach-number flights and the transient heat requirements and temperature distributions through the windows during rapid descent from 50,000 feet to sea level. Both analyses are being carried out on the forward oblique and midship windows. The icing problem on the forward oblique window is also being studied. The results of this investigation will be issued in a separate report.

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