CLARICE L. NORTON, CHAIRMAN
ISP, Com. I, WG-3
Hill Air Force Base, UT 84056

Image Properties with Environmental Factors

Interim Report of Working Group 3, Commission I, International Society for Photogrammetry.

ABSTRACT: *Cartographic cameras are calibrated under rigidly controlled laboratory environments, but acquire imagery under a wide range of vastly different conditions. The environments of the aerial survey and the affects they have on the image properties of geometry and resolution are discussed. A few "rule of thumb" suggestions for improving the image properties are offered and plans for empirical studies are considered.*

INTRODUCTION

THE FRUITS of an aerial survey are the exposed rolls of film awaiting the professional processing of the photographic laboratory. Processing must optimize the imagery and maintain dimensional control. All subsequent stages of accuracy and quality are based on the accuracy of calibration, the survey conditions, and film handling. The environments under which cameras are calibrated in the laboratory are rigidly controlled and the pressure changes negligibly from that of the ambient area. Temperature is usually held at 20 ± 0.5°C with a smooth flow of air. The camera and the test equipment are mounted on a structure having very low frequency characteristics such that the recorded photographic images are neither degraded nor displaced when exposures of several seconds duration are made. Measurements are made with precision comparators under temperatures controlled conditions. The results supply numerical values, which test after test, year after year, prove the reliability of the camera system. This aristocrat of cameras emerges from the Calibration Laboratory with usually impeccable credentials. From that day forward this electrical-optical-mechanical system is expected to deliver the same superior performance with every survey, where performance is evaluated in terms of image quality on a piece of film—resolution, modulation transfer function, acutance, and, essentially, geometry.

The working world of the cartographic cameras, however, is the aerial survey. No longer is the temperature constant, the pressure controlled, the vibration negligible. The environments that now affect image properties are not only these existant at the time of film exposure, they are also those which contribute to environmental preconditioning of the camera. Within a half hour it is possible to go from a hot air field with closed camera compartment to a survey run 5,000 metres high in a frozen sky, with the bay doors open. The low grade pressure-temperature shock which could result when the doors open might be significant. It might affect the sharpness of an edge, or its position within a few micrometres. Even slow changes to the camera might be significant and, since differences in calibration techniques are now known to produce different camera constants, it seems advisable to investigate the environments to which survey cameras are subjected to determine if some of these differences can be explained, and corrected. The idea is not new in itself since engineers and scientists, including certain members of our present working group, have already published significant findings. The attempt to determine image variables due to environmental factors is a Commission I study being conducted by Working Group 3.

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The Environments which Affect Camera Image Characteristics

The environments which vary the basic quality of aerial cameras, as treated in this study, are vibration, temperature, and pressure. Vibration may be treated as a periodic sine wave, having a frequency range with resonance points which are a function of the mass and center of gravity, and an amplitude that varies with the frequency. Depending on whether the camera is mounted solidly with the aircraft or to an intermediate mount which is designed to suppress the aircraft vibrations, the camera itself vibrates. Carman (1973) has shown how the actual wave form of the vibration may be recorded, and he uses exposure time to segment the wave and evaluate resolution loss.

One can expect the wave form (frequency and amplitude) to vary with the combination of camera, mount, and aircraft. Superimposed will be the random wave effects of turbulance, pitch, roll, and yaw. Image degradation, i.e., a blurring of the image, is the result of an angular change which occurs during the exposure time.

This may be compared to the resolution loss due to image motion, computed as the ratio of ground speed times the focal length and divided by altitude. In both cases, vibration and image motion, the best control may be the shortest exposure time.

Vibration affects all aerial cameras, reconnaissance and mapping, and its affect is greater as the focal length of the lens increases.

Temperature changes the size of objects, or the distance between two parts of the same object, each material having its individual coefficient of expansion. The affect on a camera is to change focus and the distance between fiducials. Changes in temperature and pressure result in different indices of the atmosphere. These act to change focal distances and the position of images, in effect, a variance of principal distance and distortion in mapping cameras. (See Meier (1975, 1978) for detailed discussion.)

Mathematical corrections are possible provided the true conditions are known. Unfortunately, the conditions are complex and difficult to monitor and each camera type will respond differently. A list of precautions may be the best guide.

WG-3 Questionnaire

Working Group 3 of Commission I is concerned with the variables of image properties due to environments which differ from controlled laboratory conditions under which cameras are calibrated. A questionnaire was developed to determine the actual environments of temperature and pressure which existed when photography was acquired. The questionnaire heading also requested information on preflight environments. The paragraphs which follow quote the question, summarize the answers, and make limited analyses.

An analysis of the 73 respondees to the questionnaire by application and by nation was made to determine interest in the working group study. Results are as shown:

By Application of Photography or Work Project

Civilian Survey Companies	40
Civilian Gov't Agencies (except Highway)	12
Highway Dept	8
Military Agencies	9
Unidentified	4
Total	73

Respondees by Nation

Australia	1
Cypress	1
England	7
Finland	1
German Fed Rep	5
Israel	1
Japan	2
Jordon	1
Pakistan	1
Sri Lanka	1
South Africa	7
Sweden	2
Switzerland	3
Syria	1
Thailand	1
Turkey	1
USA	37
Total	73

QUESTION 1: What cameras do you use?

Wild RC-5	5
Wild RC-8	32
Wild RC-8 (18 × 8 format)	1
Wild RC-9	7
Wild RC-10	25
Williamson F49	1
Vinten F95-1	1
70 mm Recon Type	1
Aeroview 8¼	1
Hazzelblad E170	1
Zeiss RMK A 8.5/23	6
Zeiss RMK 11.5/18	1
Zeiss RMK 15/23	36
Zeiss RMKA 15/23	1
Zeiss RMKAR 15/23	1
Zeiss RMK 21/23	6

Zeiss RMK 30/23	6
Zeiss RMK 60/23	1
Fairchild KC-1	2
Fairchild CA-14	2
Fairchild KC-3	1
Fairchild T-12	2
Fairchild Modified K-17	2
Fairchild Modified 12″	1
Manufacturers—7	
Models—24	
Units—143	

QUESTION 2: What aircraft do you use?

Aero Commander	8 models	27 planes
Piper Cubs	3 models	12 planes
Beech	4 models	14 planes
Beechraft	3 models	4 planes
de Havilland	3 models	3 planes
Douglass	1 model	5 planes
BM Islander	1 model	3 planes
Dornier	3 models	5 planes
Lear Jet	1 model	2 planes
Convair 5807		1 plane
Martin		1 plane
Riley Rocket		1 plane
Rigby Rocket		1 plane
Iljuskin 28		1 plane
Partenavia Victor		1 plane
Lockheed Lodester		1 plane
Money		1 plane
Saberliner		1 plane
Lockheed Air Macci		1 plane
Wasp Helicopter		1 plane
20 Different Aircraft	38 Models	86 Units

QUESTION 3: Do you have good control of temperature and pressure and can you give range?

Note: While many aircraft are not pressurized, some cameras are sealed with rubber gaskets, subjecting the lens and filter to external temperatures and pressures. A temperature gradient is thereby created.

Temperature Control (Windows)	17
No Temperature Control	26
Camera Heaters	19
Pressure Control (Windows)	17
No Pressure Control	53
Reduced Pressure	8
Pressure to 30,000 feet, −42°C	

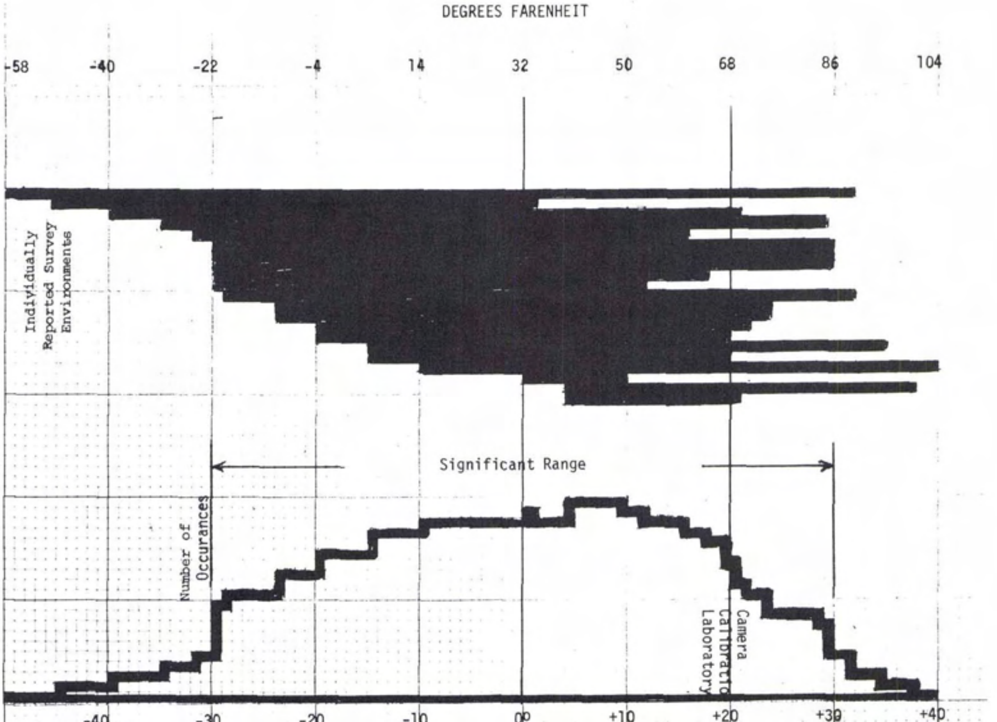

FIG. 1. Temperature experienced by survey cameras. Each horizontal line of the upper diagram shows the range of temperature reported in an individual answer (for those who answered). The lower diagram sums the temperatures for the same data, giving a distribution of values.

QUESTION 4: Do you have a window? Is it heated?

No Window	55	
With Window	17	
Window Not Heated		7
Window Heated		10

QUESTION 5:

a. What are the coldest temperatures at which you do aerial surveying?
b. How do you protect the camera prior to flight?
c. What would be the maximum cold temperature during flight?

a. and c. are essentially the same question and where there were differences, the coldest value was used. Figure 2 shows the distribution of the 67 values plotted which extend from −60°C to +20°C and peak at −30°C. 86 percent lie between −50°C and −5°C and 60 percent were 30°C or lower.

The answers to preflight protection of the cameras are most interesting. They show that many photographers are knowledgeable of temperature problems.

21 store camera in aircraft
7 store in air conditioned area
9 store in carrying case
17 have no particular protection
2 gradually bring to outside temperature

QUESTION 6:

a. What is hottest temperature at which you do aerial surveying?
b. How do you protect camera prior to flight?
c. What is the maximum highest temperature during flight?

Again a. and b. were evaluated together and are shown in the same Figure 2. This curve is narrower than the extreme cold curve defined. Note that at its lower edge it includes the controlled temperature at which most laboratories operate. Note also that the peak of the extreme cold temperature curve is 50°C lower than the laboratory temperature.

Preflight protection is as follows:

No Protection	29
Air Condition	6
Store in Aircraft	9
Store in Hanger	5
Canvas Covers or Case	5
Gradually Condition	1

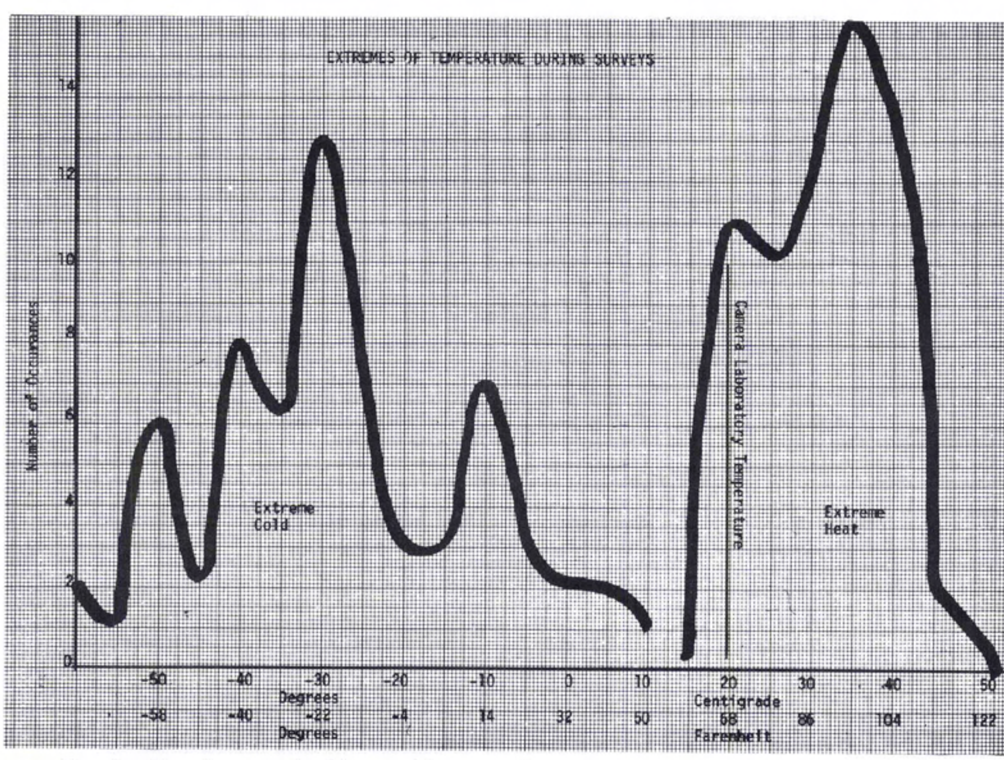

FIG. 2. Distribution of coldest and hottest values experienced during aerial surveying.

QUESTION 7: To what pressure changes is the camera subjected during the survey? If you have a window what is the pressure within the cabin? If no window, what is maximum altitude?

Figure 3 is a graph showing maximum altitudes of surveys without windows reaching altitudes as high as 32,000 feet. Approximately 86 percent use no window. The curve shows that 70 percent fly above 20,000 feet. Of those who use windows, 14 percent maintain cabin pressures equivalent to 10,000 and 14,000 feet. One quotes a differential of 9 psi at 50,000 feet altitude.

QUESTION 8: Are there other environmental conditions which you think are significant, causing loss of image quality and/or affecting geometry? If vibration, please supply amplitudes and frequency if possible.

The answers fell (mostly) into the following categories:

No known problems/no answer	22
Vibration negligible	14
Vibration affects imagery	6
Extreme temperature changes cause condensation	4
Temperature change along camera (30-40°C)	1
Propellor/Air Turbulance	3
Smoke/Haze/Dust Storms	12
Hot spots	2
Window quality inferior	1

In addition a few answers are quoted directly:

"The normal exercise of TLC (tender loving care) is all that is required to keep camera equipment operating at maximum efficiency without going to climatically controlled aircraft" (it is hoped that this respondee will read this report).

"Warm air from engine, hence our interest in suitable modifications. A record of air temperature and camera port temperature is kept. Preliminary calculations indicate this has little effect on geometry but serious affect on quality (of imagery). We undertake lens calibration with a goniometer under laboratory conditions and have been interested in laboratory and test area conditions for some time."

"Although a certain amount of vibration must be present, we find that mounted in the Wild PAVZ Universal mount, vibration of the

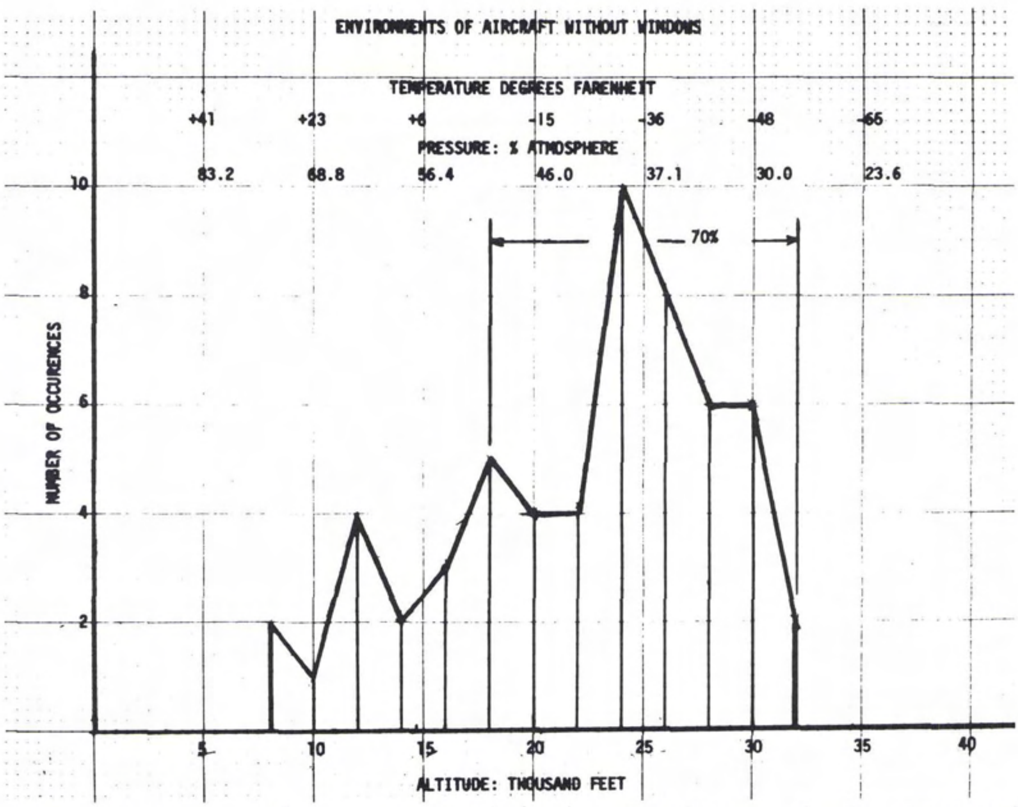

FIG. 3. Aerial surveys without windows. This figure shows the distribution of surveys experienced without windows. The temperatures and pressures at those altitudes are noted.

camera body at time of photography is virtually nil. We have also tested for temperature gradients in the air just below the camera lens but find that, due to the flow of air, the air beneath the lens is free of any hot air from the exhaust, emissions, etc., although, some distance away, on either side, there is a significant temperature gradient."

"Yes, the humidity differences between central Anatolia and other air fields located seaside. Generally, missions are far from our center and quite large, so we are located for a few weeks at this humid airfield. Then geometric accuracy is affected."

Analysis of Answers to Questionnaire

There were 73 respondees to the questionnaire coming from 15 different nations. Forty answers come from survey companies, eight from highway agencies, nine from military agencies, twelve from civilian government agencies other than highways, and four were not identified in these categories. As shown above, the sampling and distribution are such as to provide a satisfactory level of confidence in the answers provided.

Cameras (Question 1). There are old and modern mapping cameras in the 143 units reported. There are also a few modified aerial reconnaissance cameras. The majority of cameras employ the 23 by 23 cm format. Ninety percent of the quantity reported are manufactured by Wild and Zeiss. It is obvious that a large number of military cameras are not reported. There are modern Fairchild and Itek mapping cameras which are not included. The sampling and distribution is nevertheless good.

Aircraft (Question 2). The 20 manufacturers and 38 models show the possibility of a large range of vibration spectrums. This ties in with the facts that 14 respondees reported vibration as negligible while six considered that it affects image quality. Carman's study (1973) will show the vibration characteristics of certain aircraft, but combinations of vibration spectrums with the range of camera mounts and cameras is too extensive to be covered completely at this time.

Temperature/Pressure (Questions 3-7). The function of mapping cameras is to acquire quality imagery on film of a geometric accuracy capable of producing all types of maps. This implies that the calibration data of the camera can be applied and that the imagery quality tests, resolution, acutance, or modulation transfer function are the measure of quality of the operating camera. Since any type of measurement varies with the condition of measurement, the equipment and procedures of camera calibration are carefully controlled. The elements of interior orientation as reported in the Camera Calibration Certificate are precisely applicable only under those controls. This does not mean that there is a wide range of environments where the certified values do *not* apply. It is obvious from present map accuracies that good work has been done. Nevertheless, better image quality, which means cleaner edges and more accurate reproduction of the target, is obtainable if the effects of the environment could be known in measurable quantities so that individual surveys could be planned to avoid the problems. There is obviously no simple solution in the real world of surveying where the present trend is toward accuracy of micrometres, but an understanding of the degrading effects of particular flight conditions will provide the surveying photographer with knowledge to make significant modifications to his flight procedure. It is easy to see that a camera exposed abruptly to the cold of 30,000 feet will suffer a temperature shock. The ARDC Model Atmosphere shows the change from 20°C to −44°C, a 65°C difference. For this change a six inch piece of steel will shrink by 0.0043 in. (0.109 mm) and a six inch piece of glass by 0.0031 in. (0.080 mm). Simultaneously, the distortion characteristics of the lens will change due to temperature and pressure, and as shown by Meier (1975, 1978), this is the function of lens design.

Temperature changes that affect metal will, of course, also change distances between fiducials and probably their orthogonality. The abrupt change of temperature that occurs makes it impossible to attain equilibrium throughout the camera and could result in temporary distortions of the lens cone.

Glass has a lower coefficient of expansion than steel, but a change of 30°C will expand or contract the distance between two reseau marks, which were 100 mm apart at the laboratory temperature, by 24 micrometres. Further, when the temperature change is rapid, the scale change over the reseau pattern is not likely to be uniform.

Recommendations

WG-3 expects to compile a list of guidelines for controlling or adjusting cameras to known environments. It will be directed toward aerial surveyors and those concerned with obtaining high quality imagery and known geometry. It is obvious that there is no single nor simple solution and there may be no complete correction for to-day's extreme survey environments. For the present, however, it is suggested that these photogrammetrists become familiar with the environments that affect imagery, determining what conditions of vibration, temperature, and pressure will apply to their individual surveys. By using Carman's and Meier's analyses, they should be able to estimate the magnitude of possible changes and their importance to their own projects. With such knowledge and evaluations it should be possible to take steps which will reduce the variables. The question of "what to do" is probably best answered by those in position to make improvements, the pilots, the photographers, the flight managers. WG-3 would welcome suggestions and would like to receive particulars from those who are able to effect improvement of flight environments of mapping camera.

Working Group 3 Organization and Individual Studies of Workers

The group is composed of scientists and engineers who have recognized and investigated imagery and the effects of the environment on photographic sensor systems. Their individual studies, referenced to Working Group 3, are briefly discussed.

Clarice L. Norton is chairman of the W.G. 3. For the last three decades she has been concerned with the capabilities and qualities of aerial reconnaissance and mapping cameras, serving as the Director of the Fairchild Camera Calibration Laboratory and Chief of the Optical and Photographic Quality Section until 1968. Since 1970 she has directed the technical activities of the Camera Calibration Facility at Hill Air Force Base, Utah, and provided technical consultation on photographic sensors. She has been involved with image quality and geometry investigating their properties under laboratory, flight, and simulated environments, writing papers and serving as chairman on image quality panels of professional societies.

Mrs. Norton was Secretary of Commission I from 1968 to 1972 and chairman of the OTF/MTF working group from 1972 to 1976. She has been Director of the Photography Division, Chairman of the Color Committee, and Chairman of the Image Quality Committee in the American Society of Photogrammetry. She is presently Chairman of the Sentinel Sigma Image Quality Committee, which is investigating and rewriting U.S. Air Force standards on photographic systems. She has contributed to the Third Edition of the American Society of Photogrammetry's *Manual of Photogrammetry* and to the *Aerial Color Manual.* Norton has a BA from New York University and has pursued advanced courses in photogrammetry. She is a member of ASP, OSA, and SPIE. She is listed in *Who's Who of American Women,* the *World's Who's Who of Women, Who's Who in Engineering,* and others. She received the ASP Photogrammetric Award in 1964. In her WG-3 study Mrs. Norton has drafted a questionnaire on the conditions of pressure and temperature to which cameras are subjected during surveys. The answers, received from 17 countries, are analyzed in a previous section. Plans are made for a simulated laboratory study.

Philip Douglas Carman is conducting the vibration studies reported by this working group. His studies on vibration started during the Second World War and about five years ago renewed interest was generated. Important results of flight and laboratory tests were subsequently published.

Carman earned his BA at the University of Toronto and his MSc at the University of Rochester. He is presently Senior Research Officer at the Canadian National Research Council (NRC), directing the activities of the Camera Calibration Operation. Associated with NRC since 1941, he has been involved with testing, design of photographic equipment, photogrammetry, and research on optical and photographic instruments. Optical and photographic image quality has been a primary concern, as attested by his various papers and membership on national and international standards committees. He has served Commission I in many capacities: as Secretary, as correspondent for several quadrenniums, and in many committees. He was largely responsible for collating the Commission I standard, "Procedures for Calibrating Photogrammetric Cameras and Related Optical Tests."

Carman is a fellow of the Optical Society of America, a member of the Canadian Institute of Surveys, and a member of the Canadian Associate of Physicists.

Carman summarizes his present study as follows:

Angular vibration of aerial survey cameras is a major factor limiting image sharpness, either directly or indirectly. The effect is direct if a shutter speed is chosen at which image motion due to vibration significantly reduces sharpness. It is indirect if, to avoid blurring due to image motion, a high shutter speed is chosen and this high shutter speed necessitates the use of a large lens aperture and/or a high speed film, either or both of which reduce system resolution.

Measurements of vibration of modern air survey cameras in a variety of aircraft over the last few years have shown maximum angular velocities in the range 20 to 50 mr/s (4 to 10 mm/s image velocity at the film). To limit image motion due to vibration to 15 μm requires shutter speeds not slower than 1/270 to 1/660 s. Two comparisons are informative: (1) Image velocity due to forward motion in high altitude photography is typically 1.2 to 2.2 mm/s; and (2) measurements made 30 years ago on reconnaissance camera mounts showed 20 mr/s maximum for a standard mount and 2.5 mr/s for an experimental mount.

According to Carman, if survey mounts could be developed to reduce maximum angular vibration velocities consistently to 5 mr/s or less, vibration would cease to be a practical limitation in present conditions and system resolutions could improve by as much as 40 percent.

Juhani Hakkarainen received his PhD from the Helsinki University of Technology, Finland, his dissertation covering laboratory and correlated flight tests of photographic image quality and camera calibration. Dr. Hakkarainen has conducted research on photogrammetric sensors, testing and calibration procedures, and has taught photogrammetry at the Helsinki University of Technology. He is now professor of photogrammetry at the Finnish Geodetic Institute where he will continue his research.

Dr. Hakkarainen's plans, in assisting WG-3, will extend his image quality studies so that the environmental effects on image properties can be determined. In order to accomplish this investigation, it is planned that the Malmi test field in Finland will be enlarged to accommodate higher flight altitudes. Additional targets of different sizes and types, as used in analytic photogrammetry, will also be employed. Lower contrast targets will be added to the higher contrast ones of the 1973 tests, contrasts of 1:3 and 1:10-15 being considered because of their "natural" values.

Five or more transducers will be installed at different parts of the camera, and as the external and ambient environments are monitored, the temperature and pressure of the camera will be recorded.

The Rockwell Turbo Commander 690A will be used, with and without a window, and flight altitudes will be maximized in accordance with the target control area.

Hans-Karsten Meier is scientific director of the Carl Zeiss Survey Department. He studied geodesy at Hannover Technical University and joined Carl Zeiss in 1955. In the same year he obtained a doctor degree (Dr.-Ing.) at Munich University with a thesis on plumb-line-deflections. Since then he has published about 75 papers dealing with geodetic and photogrammetric problems. Together with Professor Ackermann he is organizer of the Photogrammetric Week.

Dr. Meier's WG-3 study is concerned with the environments of pressure and temperature. He has initiated many technical studies on photogrammetric sensors, calibration equipment, and techniques, being concerned with image quality and geometry both in the laboratory and under conditions of use. This later lead to his investigation of the effects of aerial survey environments on the geometry of Zeiss cartographic lenses.

"The Effects of Environmental Conditions on Distortion, Calibrated Focal Length and Focus of Aerial Survey Cameras" is the title of Dr. Meier's invited paper to the Working Group-3 Panel (Meier, 1978). The theoretical study examines the changes in four Zeiss mapping lenses for the above characteristics, under three environmental conditions for cameras at altitudes of 6 to 14 kilometres. In the first "protected" case the camera is assumed to be installed in a pressurized cabin viewing the terrain through a window or cover glass of specified thickness. In the second and third cases the camera is exposed to the atmosphere (no window); but in one case the camera is at atmospheric temperature and pressure while in the other case it is subjected to cabin heating, the opening around the camera being sealed. Measurements have shown this temperature to average out at +7°C, under which conditions lens computations show changes in distortion.

The S-Pleogon A 4/85 shows a maximum positive change of 7 micrometres at a radial distance of 75 mm (as estimated from the distortion curve) when installed in a pressurized cabin with a window 45 mm thick, at an altitude of 14 km. The same camera, exposed to the atmosphere at 14 km where the lens and external temperatures are the same, shows a negative change of 6 micrometres at 100 mm radius. With no window but with internal heating adequate to maintain the lens at 7°C, the pressure and temperature effects cancel, with residuals of less than 1 micrometre. While this is obviously the most extreme of the four lenses investigated, it emphasizes the need for knowledge of the flight environments which affect the camera.

The calibrated focal length investigation shows changes that vary with the three environments investigated, and which may exceed the quoted calibration values of accuracy. Dr. Meier calls attention also to the fact that the "alternations are by no means proportional to the focal length."

The changes in focus result mainly from reduction in air pressure as flying height increases. Where the cabin is pressurized the change is least. Largest change occurs when the lens is exposed to the atmosphere but heated to maintain a constant temperature of 7°C.

The data reported in Dr. Meier's invited paper emphasizes the changes that can occur in flight calibration of cameras due to different camera environments. It points up the need for monitoring all flight conditions so that errors can be corrected. It also suggests that we treat our laboratory values as basic controlled data with the camera geometry and image quality varying as a function of known, preferably measured, environmental conditions (author's analysis).

William P. Tayman is presently directing the activities of the U.S. Geological Survey Camera Calibration and Optical Testing Facility. He has been engaged in the calibration of aerial cameras for over 25 years, formerly at the National Bureau of Standards. He has evaluated new aerial lenses, prepared specifications and technical data, written a number of papers on photogrammetric lenses, and contributed to the Third Edition of the *Manual of Photogrammetry.* He received his formal education at George Washington University, and the Department of Commerce, N.B.S. Graduate School. He has served as American Society of Photogrammetry liaison to the American National Standards Institute, Committee PH1, since 1960 and is now serving as the U.S. Correspondent for Commission, I, ISP. He has been active on ASP Image Quality Committees.

Mr. Tayman is now involved in a project to measure the resolution of aerial negatives, undertaken jointly by the National Ocean Survey and the U.S. Geological Survey. The primary objective is to determine whether aerial resolution can be improved by exposing slow-speed, fine-grain film in a camera equipped with image motion compensation. A secondary objective is to test the alternative approach of exposing normal-speed film at maximum aperture, with a shorter exposure time minimizing the effect of image motion.

During the past year an investigation has been underway to determine whether new methods of camera calibration will provide the desired degree of accuracy for analytical projects. One example is the accuracy of film dispositive distortion; when dispositives are made with new vacuum stable platens, distortion is in the order of +2 micrometres. In earlier work dealing with diapositive radial distortion, appreciable differences in measured values were obtained due to vacuum induced warpage of the film platen. Measurements made on new platens indicate a much higher degree of flatness, both with and without vacuum applied. It is accordingly certain that asymmetries arising from this condition have been very materially reduced.

Lorin C. Peck is a member of WG-3, supervising some of the simulated environmental tests which are planned to be conducted at Hill Air Force Base, Utah. Mr. Peck is working in the Production Engineering Branch of Maintenance. His work brings him in close contact with production problems of the aerial photography and photogrammetry sensor systems which support Air Force reconnaissance and mapping. Methods of analysis of image properties, design of image tests as quality and reliability criteria, and writing specification and technical orders for photographic systems are his present responsibilities. With a BS in electronics, he is now completing his MS, emphasizing the modern optics applicable to image quality analyses.

He is a member of the Optical Society of America, Society of Photographic Scientist and Engineers, the American Society of Photogrammetry, and the Society of Photographic Instrumentation Engineers.

Status of Environmental Studies

Itek Study. There are few papers on environmental effects which are published in the literature. Perhaps this is due to the design engineer's belief that environment is only one of many problems and not worthy of separate consideration. Be that as it may, a short paper by Wood (1976) cites a number of significant facts which he presents as nomographs. Half of these are concerned with environments which affect photographic sensors. There are nomographs used to evaluate "tradoffs" in the consequences of operational conditions relative to resolution and also to show how camera modifications and environmental control can be used to increase effective resolution.

Wood treats the effects of temperature change (from controlled laboratory temperature) showing changes of focus and resolution for four focal lengths and four apertures.

To show the refractive properties of air, which vary with density of air which in turn is dependent on temperature and pressure, he uses the same four focal lengths and apertures to again show focal changes and resolution degradation. He does not treat vibration as such but the angular motions of pitch, roll, and yaw are evaluated in terms of resolution loss per millisecond duration. He selects two similar 152 mm f/6 lenses and subjects them to different conditions of flight; different temperatures, pressures, altitudes, ground speed, and angular motions. In analyzing the results, Wood notes that the "index of refraction change, temperature change, and forward motion smear contribute markedly to resolution loss."

His conclusion is succinct and applicable to all aerial and space cameras. Wood says "It becomes clear then that systemmatizing can pay benefits relative to the maintenance of resolution and, thus, should be taken seriously. What hasn't been discussed here is the similar penalties that are paid in terms of geometrical changes when cameras and aircraft are employed as general purpose tools. All factors that induce focal shifts also upset one's knowledge of geometry and, thus, degrade the photogrammetric quality of derivative products." The Itek engineer suggests focusing cameras to operate under a limited range of conditions which includes environments.

Testing and Environmental Simulation—an Air Force Policy. Technical Report AFAL-TR-74-204, consisting of eight papers authored by Air Force personnel from Wright Patterson Air Force Base, was presented at the National Aerospace and Electronics Conference (Mower, 1974). The eight papers are involved with dynamic and environmental test evaluations and analyses of reconnaissance systems. This review is such as to briefly show the importance of environmental testing in the U.S. Air Force and the status of simulated environmental analysis at this research facility. It has been proved economical in time and money to simulate the flight environment under controlled laboratory conditions as the most direct method of improving camera performance or working out certain types of operational problems.

F. J. Worton, Fairey Air Surveys Limited, England, in a company technical report, reports his findings on "The Vibrational Characteristics of the Wild RC 5a and the Eagle IX Camera Mounting when used in a Piston Engined Aircraft" (Worton, 1959). The practical flight test was made to measure the vibration of a Dakota aircraft camera support structure and to determine the degree of isolation afforded by the camera mounting.

The aircraft was flown at night at right angles to a line of fixed lights and a 100-cycle-per-second flashing light. Runs were made over a range of engine revolution and boost settings that might be used during survey photography. The 100 cps flashing light provided the frequency time base and amplitude was determined by precise measurement of image displacement.

Worton concludes that (19 years ago) the (then) existing camera mountings were "just coping" with the vibrations of the Dakota aircraft, which was fairly representative of the aircraft then in use for survey work.

The "Airborne Camera Environment" is on reported by Worton (1977) as being entirely different from that of the Camera Calibration Laboratory where the elements of interior orientation are obtained. His data were obtained from two flights at 7000 metres altitude by instrumentation of 14 areas. These areas were as follows:

Temperatures at:

1. Outside of filter
2. Inside of filter
3. Lower lens flange
4. Central lens casting
5. Upper lens flange
6. Focal plane pressure plate
7. Magazine contained air
8. Outside camera window
9. Inside camera window
10. Camera bay ambient air
11. Aircraft outside air

Relative Humidity at:

1. Magazine contained air
2. Camera bay ambient air
3. Aircraft altitude

The RC5a camera used in the tests was fitted with two heating rings, one each around the front and back lens flanges, which cut in when the temperature falls below 8°C. The first flight was made with a window and the second without a window. Each test covered six photographic runs made in two hours time. With the window installed, the outside air was between −24°C and −32°C, the outer side of the window registering 2° higher and the inner sides 3° higher. The camera bay air showed a constant decrease in temperature with time from 10°C to −9°C at the end of the 4th run, approximately 1 hour 20 minutes after camera standby, leveling off at −9°C to the end of the photographic run. Simultaneously, the outside of the filter dropped to −2°C while the focal plane rose to +16°C and dropped to 12°C, maintaining a difference between 14 and 15°C. The total temperature difference of the imaging forming system from outside of the window to the focal plane was 42°C.

In the second flight, there was no window but the camera was sealed with a rubberized fabric membrane to prevent the penetration of outside air to the camera bay. At the first run the outside of the filter reached −17°C, which was 18° higher than the outside air. It remained within 2° (to −19°C) for the remainder of the photographic runs. Simultaneously, the focal plane temperatures dropped from +15°C to +11°C. Differences across the camera image volume were, therefore, 32°C to 29°C, with no condition of equilibrium.

Worten's test and his general discussion leads to the question as to how accuracy of geometry under such varying conditions can really be known. Unfortunately, it is not possible to calibrate under conditions of the environment of each survey, to obtain this data. The first task, therefore, is to determine the geometric and image quality variables for certain known survey environments. Then, by instrumenting cameras so that temperatures and pressures can be known, a measure of correction can be applied. The use of control targets would also increase the accuracy.

Ziemann, of Canada's National Research Council, discusses changes in image geometry attributable to changes in temperature which in turn change camera dimensions (Ziemann, 1972). Four particular situations, which can occur at any state of the imaging process, are changes in the camera body, during the film flattening in the aerial camera, due to aging, and during measurement.

His point, that the fiducial marks needed to reconstruct the image (position) at the instant of exposure requires that the marks maintain their position at any temperature to which the camera is likely to be subjected, emphasizes the concern of WG-3. Ziemann goes into well needed detail in describing handling of film in the camera and through the processing and drying stages, all of which can introduce distortions which are not in the optics or due to lack of platen flatness.

Humidity, of course, changes the film dimensions; and changes due to film handling (mishandling) can be significant, giving appreciable errors. Surveyors and film processors not conversant with these errors might develop individual methods of control by reviewing and gaining an understanding of the problem from Ziemann's paper.

NASA Cameras. The National Aeronautical and Space Administration has used many cameras in the exploration of space. Both film and non-film cameras are affected by their environment and NASA has, therefore, preadjusted them for the environmental conditions which they will experience on the actual mission. Tests under simulated environments to prove the correctness of the adjustments have then followed. The long focal length reconnaissance cameras, for instance, are very sensitive to temperature changes, degrading the image quality as the focus shifts. The most stable conditions of the environment of the photographic compartment of space craft have to be furnished in order that optimum image quality may be assured.

Following centuries of telescopic observation from Earth's platform, vidicon cameras were able to utilize satellite platforms for a closer look at the moon and, subsequently, other planets. As experience assured the return of satellites, men and cameras with film became satellite tenants and as a result a high quality of information and more accurate geometric positions for targets was obtained.

Design theory and tests first established the limits of the environment of the photographic compartment of the space craft, pressure and temperature being fundamental. The camera was then developed to work within these environmental confines, or if this was not feasible, a compatible environment was provided. The cameras would then be tested in a simulated environment to determine what degradation (if any) occurred.

The Fairchild mapping and stellar camera, two independent optical systems held in a fixed configuration to each other, were calibrated under fixed pressures and temperatures to determine their interior elements (principal distance, distortion, etc.) and also the fixed angles between the mapping and stellar systems. They were then pre-set for the space confines in which they would acquire photography.

Itek developed several camera systems for NASA from the short focal length multispectral cameras to the long focal length optical bar. Again, careful plans considered the effects of the environment, and designs were modified to assure good image quality.

These cameras performed many remote sensing studies; lunar mapping and geologic studies, Earth Resource, geologic mapping, and Martian geologic surveys. They are being used to determine world agricultural food problems and to provide pollution data to our Environmental Protection Agency. The multispectral cameras have been used extensively to provide new sources of information using both their simple and complex arrangements.

NASA engineers are very conversant with the effects of environments on cameras. Bernard H. Molberg of NASA Experiment Systems Division discussed the specifications and provisions for testing the complex camera systems carried as payloads in the Orbitar cargo bay (Molberg, 1978). The harsh environments of this bay are generally divided into either natural or induced environments. The pre-launch and post landing are considered natural, and the induced environments are those that exist during launch, pre-entry, and landing. On-orbit may be either. The natural ground and induced environments (more or less controlled) are not considered extreme. The natural space environments, much to the contrary, pose problems to design. Pressure is one such problem and at 500 nautical miles (926 km) it is 4.7×10^{-11} torr (9.1×10^{-13} psi). Solar radiation (thermal) is another problem and this orbital altitude is rated at 443.7 Btu/ft^2/hr while the Earth's albedo is 30 percent of the solar radiation. This, of course, occurs at many levels as the satellite orbits the Earth, but only the worst case is tested to assure survival of equipment and integrity of intelligence acquired.

Film is an especially sensitive problem since, under normal conditions for a seven to twenty day mission, environmental enclosures and spacecraft structure give sufficient shielding. On Skylab, for instance, the film vault was the size of a home freezer with solid aluminum walls several inches thick. This was found to be adequately protective against the natural radiation environment of terrestrial space, which consists of (1) galactic cosmic radiation (mainly protons), (2) geomagnetically trapped radiation, and (3) solar flare particle events.

The system qualification test includes the functional tests, temperature control, EMC/EMI, vibration, dynamic resolution, and thermal vacuum which includes static and dynamic resolution. Following these exhaustive tests, there is a high rating of confidence that the space camera will acquire good imagery.

Summary

The studies reviewed by the WG-3 members, their research, and the answers to the questionnaire show that some photogrammetrists are aware that the flight environment can cause degradation of image quality and changes in geometry from that reported in the camera calibration certificate. Because present methods of survey deal with rapidly varying environments, and because responses of camera materials to environments of temperature and pressure are not immediate nor exactly predictable until equilibrium is attained, it is impossible to state the changing values as a function of real time. In other words, since the camera is experiencing gradients during the survey, each exposure may be slightly different in image quality and geometry from adjacent exposures and the first significantly different from the last.

As a result of information available from Meier's studies and knowledge of the flight conditions as established by Worton and the WG-3 questionnaire, a project will be established at Hill Air Force Base to calibrate a camera under simulated flight conditions (other than angular motions) in order to determine geometric changes. Similar tests will be conducted to test resolution response.

The design of the experiment is presently in the discussion stage and details need to be worked out such that the environment simulates the average, extreme survey condition of temperature and pressure. The results of the study will be reported at the ISP Congress in 1980.

A different situation exists for degradation due to angular motions of the camera during exposure—to vibration, pitch, roll, and yaw. Studies presented by Carman and Worton show the magnitude of possible degradation of image quality and point out the gains possible with improved control. Reducing exposure time is one method that lies within the domain of every aerial surveyor/photographer to investigate. The "trade-offs" with exposure time are film speed via film processing, or faster emulsions.

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BOOK REVIEW

Gradient Modeling, Resource and Fire Management, Stephen R. Kessell. Springer-Verlag, New York, 1979, 433 pages, 174 illustrations, hard cover, $39.80.

This book contains very little information directly on topics of photogrammetry and remote sensing. The title suggests that the book deals with vegetation analysis techniques and would catch the attention of ecologists and foresters. However, remote sensing specialists should take notice. Many of the topics covered are of tremendous importance in vegetation mapping and environmental assessment from aerial photography. Furthermore, those individuals involved in the development and design of natural resource information systems will find this book of interest. The following selected chapters and sub-headings from the book should serve as evidence:

- Community stratification and abstraction
- Storage and retrieval of vegetation information
- Sources of vegetation information
- Distribution of tree species
- Management information systems

Many topics covered should be of interest to federal and state agency personnel who are responsible for massive regional resource inventories mandated by recent legislation. Also those land managers responsible for development of zoning regulations and assessing wildlife habitat should note that the following topics are also covered:

- Animal habitat modeling
- Succession modeling
- Gradient analysis
- The diversity mosaic

Perhaps the book's least desirable attribute is the author's heavy emphasis on the results of studies conducted in one geographic area, Glacier National Park. The author uses this test site and his own personal experiences in development of a resource information system as a specific example to illustrate several general concepts. Unfortunately, he does this at the expense of a more thorough presentation of the pertinent literature in general. In fact, over 140 pages of the book are devoted to graphs compiled from data taken in Glacier National Park. However, some readers may find the tremendously detailed documentation valuable.

In summary, despite the heavy emphasis on a single region, the book should be of interest to remote sensing/natural resource specialists.

—Prof. Roy A. Mead
Virginia Polytechnic Institute and State University