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WORKING GROUP 3

REPORT OF WORKING GROUP I/3

IMAGE PROPERTIES WITH ENVIRONMENTAL FACTORS

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ABSTRACT

The environments under which aerial survey cameras are used often differ drastically from the controlled environment under which they are calibrated. As a result, the image quality and the geometry may differ from the values reported in the calibration certificate.

The environmental conditions of the aerial surveys have been investigated by means of an international questionnaire. The answers provided the range of temperature and atmospheric pressure to which the cameras are exposed. Certain conditions of pressure and temperature have been simulated in the laboratory to determine geometric changes in one American mapping camera. These are reported. Suggestions for better control are advanced. A review of the literature is made and summary results from Working Group member studies are reported.

REPORT OF WORKING GROUP 3, COMMISSION I, ISP

IMAGE PROPERTIES WITH ENVIRONMENTAL FACTORS

SUMMARY

The purpose of Working Group 3 of Commission I was to study the change in image properties of cartographic aerial survey cameras as affected by the environment to which they were subjected during the aerial survey. Studies on vibration (Carman, 1970, 1973) showed the vibration which existed in certain aircraft and the loss in resolution which resulted for specified exposures. He noted that the decrease in exposure time (i.e., higher shutter speeds) will reduce the image blur due to vibration, but causes an indirect loss of system resolution due to the larger lens aperatures and faster film which must be used to obtain adequate film density. Carman suggests that improved camera mounts offer the best solution to reducing resolution loss due to angular motions. His studies are continuing with laboratory investigations of the center of gravity of cameras with respect to that of the camera mount, and the vibration resonance characteristics of cameras.

Change of distortion and focal length due to survey environments of temperature and pressure was reported for Zeiss mapping lenses (Meier, 1975). This was a theoretical study which showed different values of distortion for different environments, the values being significant enough to warrant correction when conditions were adequately known. His study (1972) of glass cover plates (windows) adds to the knowledge of environmental effects.

Worton's study (1977) of temperature and gradients in a Wild RC5 camera, with and without a window, raises questions of loss in image quality and change in distortion that need answering.

The investigation of an American KC-1B camera made by Norton and Peck (this report) shows different temperatures and gradients than that used by Worton although environmental conditions were closely similar to the measured conditions of Worton's study. The difference is considered to be due to the use of aluminum in the American camera rather than steel. The distortion values obtained in the Norton study, due to temperature and pressure changes from that in the laboratories, should be considered as a trend and values should be verified with further tests.

All studies indicate that the camera should be given maximum protection from the extreme environments which affect the image quality and geometry. It is obvious that cameras and mounts will respond in accordance with (1) design, (2) the environmental atmosphere, and (3) the presurvey conditioning of the camera.

It would be advisable for aerial surveyors to investigate, in some detail, the environments of vibration, pressure and temperature to which their own cameras are usually subjected, instrumenting their cameras to determine the temperature and temperature gradients which exist during the time the film is being exposed. With experimental knowledge, it should then be possible to obtain information from the camera manufacturer on the

changes in distortion and focal length that, theoretically, can occur.

The placement of internal and external heaters is critical. Some gradient, small or large, will exist along the physical axis (usually vertical). It is important that the temperature differences in planes perpendicular to this axis be small enough so that warping of the camera or lens, does not occur.

The study of the effects of the environment is difficult to pursue because of the many physical variables, the problems in simulating environmental survey conditions, the cost of providing a stable array of geometric targets, the cost of survey data and measurement and analyzing of tests.

The investigation needs to be continued, determining the image quality and geometric response of cartographic cameras to the aerial survey environments. Complete theoretical analyses of operating cameras should be verified empirically. The data should be used to develop methods of control of the camera.

QUESTIONNAIRE ON THE ENVIRONMENTS OF THE AERIAL SURVEY

A questionnaire was circulated to member nations requesting information regarding temperature and pressure conditions of surveys. The much condensed questions and answers follow:

Question 1: Which cameras do you use?

Answers: 87 used 5 models of the Wild Camera.
61 used 8 models of the Zeiss Cameras.
14 used 11 other cameras, some modified reconnaissance.
It was evident that the military mapping cameras were not reported.

Question 2: What aircraft do you use?

Answers:

TYPE	MODELS	UNITS
Cessna	8	43
Aero Commander	6	32
Piper Cubs	5	18
Beechurst	7	20
DC-3		7
DeHaviland		4
Dornier		4
Lear Jet		3
18 Other Makes		1 to 3
Wasp Helicopter		1

The large number of manufacturers and models predicts the possibility of a large range of vibrations. Each type may present different problems for the aerial photographer.

Questions 3 to 7: Requested information on the temperature and pressure conditions to which the camera was subjected prior to and during the flight. The answers provided the following summarized data:

26 respondees used windows in some of their aircraft maintaining pressure within the aircraft adequate for personnel and temperature (generally above 10^{o}C).

18 of the 26 had heat blown across the window to keep it free of frost.

53 respondees reported aircraft not equipped with windows. Many cameras were sealed to the mount or aircraft in various ways which partially protected the upper part of the camera from outside cold. Pressure in this case was that of the altitude of the aircraft.

With the lens subjected to the outer atmosphere and the camera warmed by internal heaters, a temperature gradient would exist from the outer lens to the focal plane. This gradient was obvious from the conditions reported, but, no measurement on the camera except Worton's, were available. Various methods were used to protect the camera from heat and cold prior to flight. These included:

a. 33% by storage in aircraft, with aircraft in heated/unheated hangars in winter.
b. 8% in temperature controlled areas in summer.
c. 11% stored cameras in carrying cases prior to flight.
d. 26% reported no particular protection.
e. 5% gradually conditioned cameras to change in temperature.

Cameras were subjected to a large range of temperatures during flight, a significant number covering the range from minus 30^{o}C to plus 30^{o}C.

Question 8: Requested information on "other environmental conditions" which affect image quality. Answers were as follows:

No known problem	28
Vibration negligible	14
Vibration affects image	7
Extreme temperature change causes condensation	4
Change in color IR due to low humidity at high altitude	1
Distortion of window at high altitude	1
Propellor/Air Turbulence	4
Haze/smoke/dust storms	15
Inferior window quality	1

Based on these answers, it was decided that an altitude of 25,000 feet with temperatures of approximately -30^{o}C was not an unusual environment for aerial survey using aircraft without windows. It was this condition that was simulated for the Hill Air Force Base test.

HILL AIR FORCE BASE STUDY - WG-3

PURPOSE

The purpose of the test was to determine what changes in geometry occurred when the camera was operated in an environment simulating the extreme conditions of an aerial survey. The conditions, simulated by means of a vacuum chamber, cooled with liquid nitrogen, were as follows:

a. Control tests were made (1) exposing an array of eleven collimators on spectroscopic plates using only the camera body, and (2) with the operating camera coupled with the magazine recording on 2402 film.

(1) Prior to testing: 5,000 feet altitude and 20°C recording on plates and film; 30,000 feet altitude and 20°C recording on spectroscopic plates.

(2) Following testing: 5,000 feet altitude and 20°C, recording on plates and film; 30,000 feet altitude and 20°C recording on spectroscopic plates.

b. Simulated survey tests were made with the operating camera only. Test conditions were as follows, recording on 2402 film:

(1) 5,000 feet altitude 20°C, (prior to testing)

(2) 15,000 feet altitude, -27°C

(3) 20,000 feet altitude, -26.5°C

(4) 25,000 feet altitude, -24°C

(5) 4,300 feet altitude, -22.7°C

(6) 5,000 feet altitude, 20°C, (following testing)

Between (1) and (2) the camera was cooled, reducing the temperature 47°C over a four hour period. Two frames were measured from each set. The fiducial distances of the film, A_x, B_x, C_y and D_y were compared with those on spectroscopic plates and shrinkages/expansions factors obtained. These factors were used to correct the measured distances between the images of the collimator targets. The distance to each image was then corrected by the radial distortion for that point, obtained from tests on the camera calibrator, and further corrected by the angular change due to the change in the index of refraction inside the vacuum chamber which varied with pressure and temperature. The selected criteria of change in geometry was the accuracy with which the angles of the collimators could be reclaimed.

CONSIDERATION OF KC-1B CAMERA GEOMETERIC VARIABLES

The Lens: The KC-1B camera is equipped with the 153mm Planigon lens. The last element of this lens is a glass plate, approximately 41mm thick, whose specific thickness is used to correct the distortion of the preceeding lens elements, each being individually processed for that purpose. When the camera is subjected to extreme cold the thickness of the plate will decrease changing the position of oblique rays. The position of the image at the 30^{o} angle will change by 4.2 microns and the 42.5^{o} ray by 6 microns when the temperature decreases by $37^{o}C$. The thickness of the other elements will also change, but, their effect on geometry has not been computed at this time. It is possible that most of the total increase in distortion and change in focal length is due to the effect of temperature but a complete ray tracing should be made to verify the empirical data.

The Aluminum Cone: The $37^{o}C$ decrease in temperature will change metal dimensions, aluminum more than steel. The length of the aluminum cone will shorten by 126 microns (0.005"). A softer image and some reductions in resolution will result. The change in image quality is not extreme because the maximum aperture is an f/6.3 which generally allows about $\pm$ 75 microns depth of focus. The decrease in temperature also changes the distance between fiducials and a temperature gradient across the cone may change the angle between opposite fiducials. The temperature of the cone also effects the temperature of the air within the cone thus changing its index of refraction. The index of refraction of the air inside the camera, within the light beams, therefore, differs from the index of refraction outside of the camera within the light beams. The latter which changes the incident rays entering the vacuum chamber were corrected mathematically. The former are considered natural to the environmental condition of survey and no corrections were made. (A full ray tracing would help to substantiate the empirical data).

Film Handling, Processing and Measuring: Kodak 2402 film was used from one roll and processed at one time in a Versamat. Processing liquids were $85^{o}F$ and drying was $120^{o}F$. Every frame can be considered to have received identical processing. Film handling may have differed, however, since the film was on the supply roll during temperature decrease. This might effect differences in roller tension, platen flatness, vacuum uniformity, film adhesion to the platen surface, or film drive. Table I shows that the camera "soaked" at the extreme ambient cold, with camera heaters working, for four hours before exposures were made. A series of exposures were then made at $-30^{o}C$ and ambient pressure before going to altitude. The first few of these were out of focus, but, the last ten frames showed acceptable focus. It appeared that the unrolled film had been affected by the cold and did not handle normally until film further into the roll was exposed.

Measurements were made directly on film, after 24 hours had elapsed after film processing. The film was sandwiched between two clear plates and loosely clamped to the comparator stage, all mearsurements being made at one time and referenced to the imaginary line drawn between A and B fiducials (as the X-axis) and the Indicated Principal Point (where the C-D line crosses the A-B line) as the origin. The distance on each leg A_x, B_x, C_y, and D_y, was compared to the same distance on spectroscopic plate exposures and a factor obtained. Since the images were positioned along the AD to BC diagonal, the A_x and D_y, factors were averaged and applied to correct the image positions in the AD quadrant, and the B_x and the C_y factors were averaged and applied to the images in the BC quadrant. Instead of a smooth change in factors, as would occur in the physical condition, a change occurred at the center point. (The addition of corner fiducials would have improved the control). This may have allowed a small geometric error which a smoothing technique would have helped to correct. (This was not done).

RESULTS

Before discussing the numerical results, it would be appropriate to dwell rather briefly on the differences in mapping camera designs. The theoretical change is distortion and focal length due to environment of pressure and temperature extremes has been reported by Meier (1975) for certain Ziess mapping lenses. There is now a report of environmental tests on Wild Heerbrugg lenses by Bormann which will be delivered at the Hamburg Congress (1980). Lens studies are basic, but a camera is not just a rigid system with all designs similar. Where geometry is important the use of iron (or steel), or aluminum for reduced weight, can affect results. Magazines have different types of platens and platen actions and film is handled variously. The internal heaters are placed in different parts of the cameras with selected controls. Thus, subject to similar environments, cameras of different design respond differently, both with respect to temperature at various parts of the camera, and geometry as obtained from the recorded image. The results of the study at Hill Air Force Base must, therefore, be considered as an individual case until further data can be obtained on other cameras of the KC-1B design to substantiate the characteristics. The study does, however, point out the fact that changes in pressures and temperature extremes affect the geometry and the study should be extended to cover all modern mapping cameras.

ANALYSIS OF TESTS

Table I, Summary of Film Tests, contains the relevant data. Columns A, B, B' and C show the angles of the collimators of the special calibrator (which was positioned under the optical window of the vacuum chamber) as the angles were reclaimed, for an average of two exposures. Column A data was obtained from exposures with the camera body only recording images of the calibrator and fiducials on spectroscopic plates before and after the tests. These closely agreed. The environment was ambient, i.e., 5,000 feet altitude and 20^{o}C. Column B contains the exposure data measured on film for the operating camera system prior to the test and B' following the test, both at environments similar to those of Column A. C is the average of the B and B' data against which comparisons are made with data from tests at four different altitudes at very low temperatures, and one high altitude with normal temperature. These comparisons are shown in Columns D, E, F, G and H. The comparison between averages of spectroscopic plate data and operating camera film data is shown in Column C'. The maximum difference of +6 micrometers and the ± 3 micrometers at the center images does not seem to be justified since the platen is plane within 2 micrometers and the vacuum was observed to be holding the film in good contact with the platen under normal

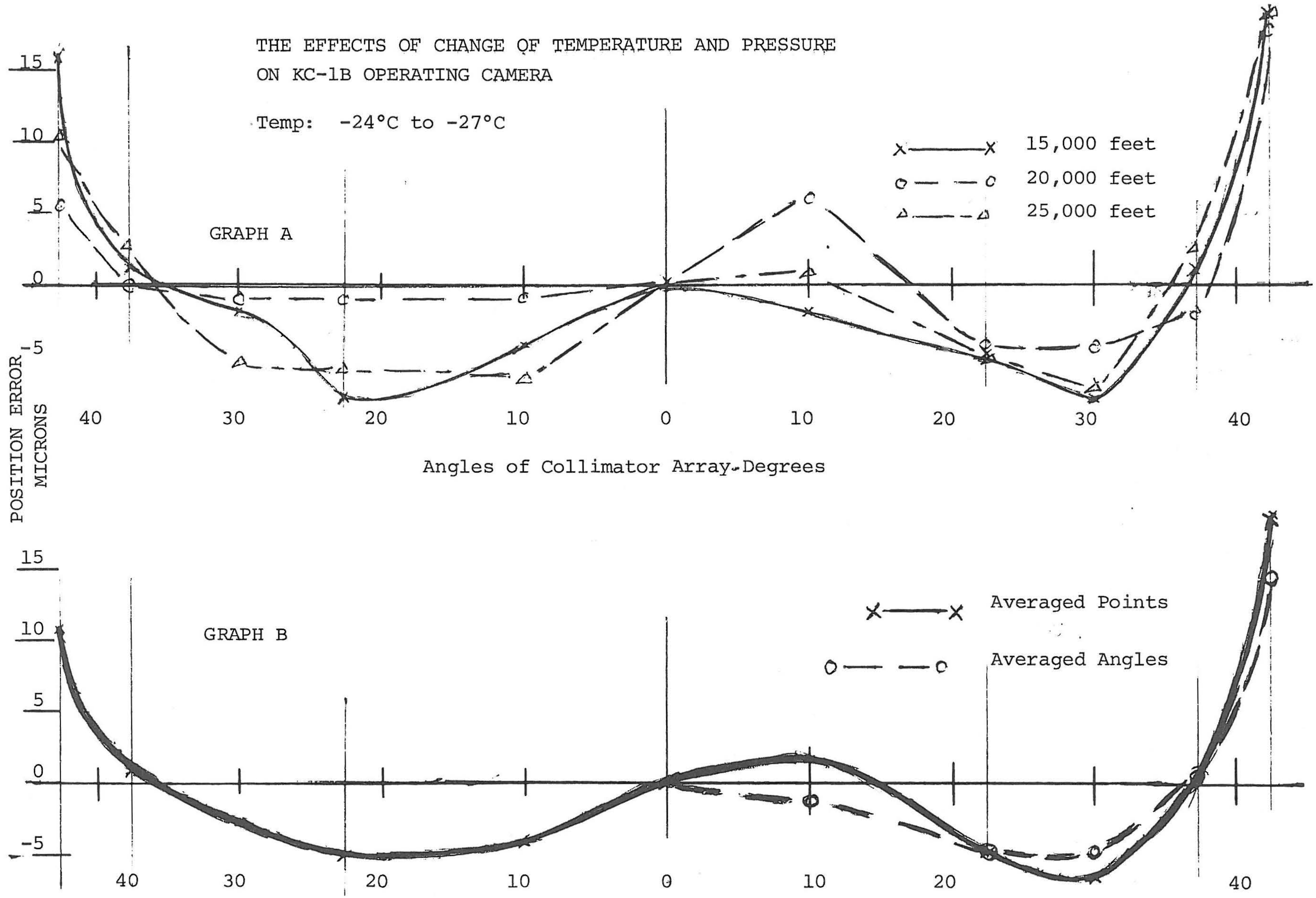
TABLE I - SUMMARY OF ENVIRONMENTAL TESTS

A	B	B'	C	C'	D	E	F	G	H(1)
COLLIMATOR ANGLES	CONTROL TESTS OF OPERATIONAL CAMERA		AVERAGE OF B & B'	A-C (SECONDS)	C-FR 109 (SEC)	C-127,8 (SEC)	C-132,3 (SEC)	C-137,8 (SEC)	C-142,3 (SEC)
42°38'16"	42°38'16"	42°38'15"	42°38'15.5"	+0.5	-0.5	+16.5	+5.5	+10.5	+12.5
37°30'28"	37°30'26"	37°30'29"	37°30'27.5"	+0.5	-0.5	+1.0	0.0	+2.5	+1.0
30° 1' 0"	30° 0'57"	30° 1' 3"	30° 1' 3"	0.0	-1.0	-2.0	-1.0	-5.5	-2.5
22°33' 4"	22°32'57"	30°32'59"	52°32'58"	+6.0	-1.0	-8.0	-1.0	-6.0	-9.5
10° 0'37"	10° 0'34"	10° 0'34"	10° 0'34"	+3.0	-1.0	-4.5	-1.0	-7.0	-15.5
9°58' 4"	9°58' 7"	9°58' 7"	9°58' 7"	-3.0	+1.0	-2.0	+6.5	+0.5	+10.0
22°29'26"	22°29'28"	22°29'26"	22°29'27"	-1.0	-2.0	-5.0	-4.5	-5.6	+6.0
30° 1'39"	30° 1'39"	30° 1'38"	30° 1'38.5"	+0.5	-3.5	-8.5	-4.5	-7.5	+3.0
37°30'21"	37°30'20"	37°30'20"	37°30'20"	+1.0	-2.0	+1.0	-2.5	+2.5	+5.0
42°48' 6"	42°48'11"	42°48' 8"	42°48'9.5"	-3.5	-0.5	+19.0	+18.0	+19.0	+16.5
5000 ft alt 20°C	5000ft 20°C	5100 ft 20.6°C			25,000' 20.3°C	15,000 -27.5°C	20,000 -26.5°C	25,000 -24.2°C	5000' -23°C
SPECTROSCOPIC PLATES	FRAME 103 PRIOR TO TESTING	FRAME 148 FOLLOWING TESTING	CONTROL DATA		FRAME 109	FR 127 & 128 AVG	FR 132 & 133 AVG	FR 137 & 138 AVG	FR 142 & 143 AVG
CFL 151.222 PS(mm) 0.080	151.215 0.040	151.220 0.000			151.220 0.025	151.230 0.040	151.230 0.055	151.230 0.040	151.230 0.025
NOTE: TWO EXPOSURES BEFORE & FOLLOWING FILM TESTS	COMPLETE CAMERA OPERATIONAL USING 2402 FILM. TESTS MADE BEFORE & AFTER ENVIRONMENT CHANGES.			DIFFERENCE BETWEEN PLATES & OPERATING CAMERA	DIFFERENCE BETWEEN CONTROL AND ENVIRONMENTAL TESTS USING OPERATING CAMERA EXPOSURE TIME AS FOLLOWS:				

a. SPEC PLATES 08:50 & 09:54 Hrs, 1 FEB 80
09:00 & 09:45 Hrs, 4 FEB 80

b. FR 103 (10:20 HRS), FR 109 (10:40), FR 127 (15:08), FR 133 (15:12), FR 137 (15:17), FR 142 (15.22), FR 148 (08:20, 4 FEB).

(1) A QUICK CHANGE IN PRESSURE IS NOT NORMAL SURVEY CONDITION.


THE EFFECTS OF CHANGE OF TEMPERATURE AND PRESSURE
ON KC-1B OPERATING CAMERA
Temp: -24°C to -27°C
15,000 feet
20,000 feet
25,000 feet
GRAPH A
POSITION ERROR
MICRONS
15
10
5
0
-5
40
30
20
10
0
10
20
30
40
Angles of Collimator Array-Degrees
GRAPH B
Averaged Points
Averaged Angles
15
10
5
0
-5
40
30
20
10
0
10
20
40

environments. (A comparative geometric test, comparing spectroscopic plate data with film data from operating camera system, is strongly recommended for all cartographic cameras as a quality control procedure since such differences are not unusual). The distortion which results from subjecting the camera to the space environments shown has a strong negative trend beyond 37.5^{o}. (The signs must be reversed for distortion). Column D which shows the change for altitude at 25,000 feet with no change in temperature shows a small change in distortion which is almost negligible. Columns E and G show fairly uniform results while F has peculiarities, particularly the +6.5 seconds at the $9^{o}58'7''$ angle. Column H is almost unbelievable, with plus and minus values at opposite angles along the diagonal. In this case, the pressure dropped rapidly while the camera was still very cold, an unrealistic condition for aerial surveying, but not for military reconnaissance. However, the extreme cold is not likely to be experienced in military aircraft which have windows and are generally heated.

Graph A is a point by point plot of the affects of cold and pressure changes. Columns E and G show close agreement while F has two points that appear erratic. The possible cause of these erratic values may be indicative of problems that can occur due to sudden changes in environments, and are discussed to some extent in previous paragraphs. As of this writing, they have not been investigated further due to lack of time and the high cost of this type of research.

Graph B shows a smooth curve when the three columns E, F and G are averaged and the curve when the angles are averaged. These latter can be considered the characteristic change obtained when the camera is subjected to the specified flight environments. Note that in terms of distortion, the positive and negative values are reversed. Note, also, that the extreme cold required an increase in focal length to recover the angles of the targets.

SUMMARY: The geometry and image quality of KC-1B aerial cartographic cameras will vary with change in the environment, differing in the optical constants from those reported by the calibration laboratory. Since the environments of the survey may change rapidly, the geometric changes may have both predictable (theoretical) and erratic components, both of which may be a function of lens and camera design.

The final accuracy of a mapping project may depend upon the degree of protection against the environments that the aerial surveyor is able to provide.

STUDIES OF THE EFFECTS OF THE ENVIRONMENTS ON PHOTOGRAPHIC SENSORS

There are few studies of the effects which natural environments may have on the image products of photographic sensors. This is probably due to the difficulty of obtaining controlled test conditions, and particularly for aerial cameras, the high cost of such tests. Information from those tests which have been accomplished is extremely valuable guiding the design of equipment and establishing test techniques which have resulted in improved cameras. Laboratory methods of testing the effects of the environment are less expensive and better controlled than aerial tests and with recognition has come its increased use as an engineering tool for analysis of performance.

Air Force Avionics Laboratory - Dynamic Analyzer (USA). Environmental testing has become an accepted policy of the United States Air Force and a large laboratory complex, called the Dynamic Analyzer has been developed at Wright-Patterson Air Force Base. It is used to analyze system performance when subjected to known, dynamic environments. Studies include those conducted on aerial cameras where degradation of resolution is a measure of the environmental affect. (A paper of WG-3 at the Hamburg Convention will describe the Dynamic Analyzer in some detail giving an example of a test.

Itek Study (USA). A paper presented at the 1976 ASP Convention by George Wood presents nomographs used to evaluate "trade-offs" in the consequences of operational conditions relative to camera resolutions. He shows how camera modifications and environmental control can be used to increase effective resolution. He discusses the changes in focus and resolution due to the effects of temperature on the refractive properties of air. Like Carman, he shows loss of resolution due to angular motion in terms of exposure time. He notes that the factors which degrade focus also cause geometric changes. Itek has applied the "trade-off" to the cameras they have developed for NASA.

Fairey Air Surveys Ltd (England). F. J. Worton reported his findings of "The Vibrational Characteristics of the Wild RC 5a and the Eagle IX Camera Mounting When Used in a Piston Engined Aircraft", in a company technical report in 1959. The test was a practical flight test measuring the vibration of the Dakota aircraft camera support structure and determining the degree of isolation provided by the camera mount. Runs were made at night perpendicular to a line of fixed lights and using a 100 cps flash for the time base. Worton concludes that (21 years ago) the existing camera mounts were "just coping" with the vibration of the aircraft.

The "Airborne Camera Environment" is discussed by Worton in the October 1977 Photogrammetric Record. He notes that the conditions of the aerial survey are entirely different from that of the controlled camera calibration laboratory where tests are conducted to obtain the elements of interior orientation. The temperature environment of the camera was measured by eleven probes during two flight surveys, one with and one without a window. The probes sampled the outside air and the critical points along the optical beam from the window to the magazine. Graphs showed the data for each run and the large temperature gradient through the camera. Humidity was also measured in the camera bay and magazine. Worton questions the geometric accuracy of the survey photography under such extreme changes.

Ziemann (then at Canada's National Research Council) reported in "Image Geometry - Factors Contributing to Its Change" at the XII Congress in Ottawa, 1972, four situations that are critical in the imaging process. These are: changes in the camera body, changes during the film flattening, changes due to aging and changes due to measuring.

Ziemann discusses, in detail, the distortion possibilities due to lack of stability of fiducial marks, film handling in the camera, and processing methods which affect the dimensional changes are also addressed. The report is a good review of the accuracy problems.

NASA Cameras. Molberg of NASA Experimental Systems Division discussed (in private correspondence) the specifications and provisions for testing the complex camera systems carried as payloads in the Orbitar cargo bay. The harsh environments of this bay are divided into 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 space environments pose design problems that must be solved if image quality and geometry are to be valid. Rigid tests under simulated environments are therefore specified and conducted, to be sure that the sensors will acquire good imagery during their residence in the exploring satellites. The qualifications tests include functional tests, temperature control, EMC/EMI, vibration, dynamic resolution, and thermal vacuum whose criteria of acceptable performance is in terms of resolution when image quality is defined. (See Norton, 1980, for more details.)

Radiation is a problem that has to be addressed for space cameras, particulary those which use film; as in Skylab, where special film vaults with solid aluminum wall several inches thick were necessary. Manufacturers who have developed and supplied the satellite cameras and parts for NASA have become quite knowledgeable about the effects of the space environment on their products. Such experience has been helpful in educating scientists, engineers, and technicians on the sensitivity of imagery sensors which experience changes of environments. They have provided many techniques and equipment for protection against the environments.

Weapons Laboratory Study. "Response of Long Focal Length Optical Systems to Thermal Shock" was reported by Joseph M Geary of the Air Force Weapons Laboratory (1980). Five different reconnaissance lenses, 18 to 36 inches, were subjected to thermal shock to determine how long it took after shock to return to a stable state. (Lens was separated from the camera.) Temperatures were raised approximately 70°F and positions of best focus measured as the lens returned to base line temperatures. This period sometime exceeded two hours with two lenses maintaining a fixed difference from the normal conditions. In spite of best refocus, all lenses did not regain optimum image quality since "the image degrades (at best focus) due to altered element spacing, curvatures, and surface asymmetries during transient response...". He concludes that for military cameras "...bays (or pods) must themselves provide a long term stable environment for lens/ mirror objectives regardless of outside ambient temperatures and their rate of change." While these tests were made specifically for reconnaissance lenses the problems of change in focus and image degradation apply also to mapping lenses.

SUGGESTIONS FOR AERIAL SURVEYORS FOR REDUCING THE ENVIRONMENTAL EFFECTS ON MAPPING CAMERAS

The changes in geometry and image quality that may occur in mapping photography are not precisely predictable, because a condition of physical stability rarely exists, and because the environmental conditions are not known with sufficient accuracy to apply mathematical corrections. Never-the-less, it is possible (for the aerial surveyor), by monitoring the environment surrounding and internal to the camera, to determine the magnitude of changes and provide methods of control.

Angular moments (vibration, pitch, roll, and yaw) and changes in pressure, temperature, and humidity act on the camera to reduce resolution and change geometry. The most stable cameras are those which are protected from environmental changes. The following relevant explanations and suggestions for a measure of control are based on the principle of protecting the camera - the use of "tender, loving care" (TLC).

Vibration, (Pitch, Roll, and Yaw), Image Motion: Avoid large or fast angular moments. Use slow, stable ground speeds. Read vibration reports.

a. If possible, learn the vibration characteristics of the aircraft being used and provide isolation against those that degrade the image. (Carman, 1973)

b. Use slow ground speed when possible. Use the shortest exposure time with the largest aperture that gives good definition. (This is not generally the maximum aperture. (Carman, 1978)

Temperature, Pressure, and Humidity: These three factors act to change the index of refraction of the ambient air, and, therefore, the direction of light rays. Under certain conditions the environmental effects may cancel, or partially cancel, leaving small, or negligible, angular changes of the light rays. Read explanatory papers. (Meier, 1975, 1978)

Study the reports issued by lens and camera manufacturers to familiarize yourself with the possible geometric changes of your own camera. (Meier, 1975, 1978; Bormann 1980) (Norton, 1980).

Temperature: Temperature affects the dimensions of materials. It can change lens radii, thickness, and spacing, resulting in image characteristics different from those determined by the environmentally controlled calibration laboratory. Temperature can also change the metal dimensions of camera bodies. Focal distances, fiducial dimensions and angles, reseau distances, and platen surfaces may be effected. It is suggested that:

a. The camera be protected from extreme changes in temperature prior to and during the survey.

b. Temperature probes be employed in different parts of the camera to determine temperatures and gradients for your own surveys. Note that heaters in the camera body and magazine will keep mechanical parts working and are, therefore, essential, but, may set up a temperature gradient along the optical beam leading to differences in the index of refraction of the ambient air. Temperature gradients across the camera may cause small, erratic variations in geometry.

Pressure: Pressure, as noted above, affects the index of refraction of air, and, therefore, the direction of light rays. This is well-known, and corrections for refraction are normally made for specific altitudes. Pressure will also affect the lens geometry and image quality, being a function of lens design. There is a need for the camera lens to adjust to pressure changes. It is, therefore, suggested:

a. That photography not be taken during, or immediately after, abrupt changes in pressure.

b. That the aerial surveyor, or photographer, be instructed by the camera manufacturer on the operation characteristic which could be affected by pressure, i.e., image quality characteristics, "breathing holes", vacuum, etc., with details as to the time required for camera adjustment to pressure changes.

Humidity: Humidity as noted above affects the index of refraction of air, and, like temperature and pressure changes the direction of light rays. When in contact with lens elements humidity can also act as a weak-powered lens to change focal length and image quality. No quantitative studies of the effect of humidity on camera performance are known, yet the photographic results of the extreme condition of water condensation in the camera are common knowledge even from the novice. It is suggested that:

a. High humidity is to be avoided. Protect the camera to the extent possible both prior to and during the photographic runs.

b. Abrupt changes in humidity are also to be avoided during the survey. (Condensation of water can also cause damage to operating parts. You have to clean out that "cup of water" as soon as you are on the ground.

The Human Factor: It is obvious from the above discussion and suggestions that there are no positive controls of the three environments, temperature, pressure, and humidity, in aircraft that do not use windows. (Aircraft with windows also have their problems.) Never-the-less, these problems have been dealt with for many years, with some measure of success. As we chase the last few microns, say 3 to 6, the task becomes more demanding. At the present stage of knowledge, it appears that the highest precision and accuracy of cartographic photography depends first on the quality of the equipment, the aircraft, the mount, and the camera; and secondly, on the use of the equipment by knowledgeable men. These knowledgeable men are the photographers who take every precaution to assure good performance of the equipment, meeting the known challenges of the environment with practical and innovative methods of control. In the final analysis, these are the men who are in the critical position to contribute to the final highest accuracy of mapping photography.

WORKING GROUP 3 ORGANIZATION

The Working Group is composed of scientists and engineers who have recognized and investigated imagery and the effects of the environment on photographic sensor systems.

Clarice L. Norton is chairman of WG-3. For the last three decades, she has been concerned with the capabilities of aerial mapping and reconnaissance cameras being involved with test equipment and test techniques. She served as the Director of the Fairchild Camera Calibration Laboratory and Chief of Optical and Photographic Quality Control until 1968. Since 1970, she has directed the technical activities of the camera calibration facility at Hill Air Force Base in Utah, and provided technical consultation on optical and photographic sensors. She has been involved with image quality and geometric studies, investigating camera properties under laboratory, flight, and simulated environments, writing papers, and serving on image quality and environmental panels.

Norton was Secretary of Commission I, International Society of Photogrammetry 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 Committees, the Image Quality Committee, and the Environmental Factors committee of the American Society of Photogrammetry. She has been a national director three times. She is presently chairman of the Air Force Intelligence Sentinal Sigma Image Quality Committee involved in writing standards and testing methods. Norton has a BA from New York University and has pursued advanced studies in photogrammetry. She is listed in Who's Who of American Women, the World's Who's Who of Women and Who's Who in Engineering, and others. She received the ASP Photogrammetric Award in 1964 and is an honorary member of ASP. She is also a member of OSA. She has contributed to the third and fourth Manuals of Photogrammetry and to the manual on Color Photography and has written various papers on Camera Calibration and test equipment.

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 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, 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 Associates of Physicists.

Juhani Hakkarainen received his PHD from the Helsinki University of Technology, Finland, his dissertation on thesis covering laboratory and correlated flight tests of photographic image quality and camera calibration. 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. In assisting WG-3, Hakkarainen will expand his image quality studies to include environmental effects. The results will be reported at the Hamburg Congress.

Hans-Karsten Meier is scientific director of the Carl Zeiss Survey Department. He has studies 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 published about 75 papers dealing with geodetic and photogrammetric problems. Together with Professor Ackermann, he is organizer of the Photogrammetric week.

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. The later lead to his investigation of the effects of aerial survey environments on the geometry of Zeiss cartographic lenses.

William P. Tayman is presently directing the activities of the 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 and Fourth Editions 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 PHI, since 1960 and is now serving as the U.S. Correspondent for Commission I, ISP. He has been active on ASP Image Quality Committees.

Lorin C. Peck is a member of WG-3 supervising the simulated environmental tests which were conducted at Hill Air Force Base, Utah, USA. 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, writing specification and technical orders for photographic systems are his present responsibilities. He has a BS in Electronics and an ME which emphasizes the modern optics applicable to image quality analysis.

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.

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