*High Performance Mapping Equipment and Materials**

L. W. CROUCH,
Camera Sect., Aerial Reconnaissance Lab.,
Wright Air Development Div., Wright-Patterson AFB, Ohio

ABSTRACT: *Most photogrammetric analyses of mapping photography are based upon mapping photography obtained by means of a qualified T-11 or KC-1 mapping camera. Normally the photography has high-contrast resolution of 15 to 25 lines per millimeter and distortion of approximately 20 microns.*

Errors normally considered second and third order have become first order in present-day, high-acuity equipment. An analysis of errors and materials indicates that, in the near future, resolutions of 50 lines per millimeter and up to 80 lines per millimeter with distortions of 5 to 10 microns, or less, will be realistic. This order of performance requires a careful look at data reduction practices and techniques in order to fully exploit such a capability.

THIS paper presents a résumé of higher performance lenses and sensitized materials, along with parameters and techniques for controlling resolution and distortion. Very briefly the "state-of-the-art" today will be reviewed and then will be outlined what it is believed the future holds for improved mapping photography, for use by the photogrammetric industry. Also, it is believed the higher performance will be of primary concern at altitudes above 35,000 feet.

At present, the term good quality mapping photography for military purposes is generally accepted as 6-inch focal-length, 9×9 inch format negatives, properly exposed by means of a qualified T-11 or KC-1 mapping camera along with Class L or Super XX film. The camera may or may not be used with a stabilized mount. These cameras have been in use for approximately 8 to 10 years and it is believed that most agree that both cameras have done a fairly good job. During this time period numerous improvements have been made in the cameras to keep pace with photogrammetric needs. The most recent improvement was reworking of the Planigon lens to reduce the distortion values to below 10 microns, where previously the distortion ranged up to 25 microns.

In Table 1 are listed the improved lenses and their distortion characteristics. These lenses have been installed in a group of KC-1B Cameras. This improvement was the result of the ability of the photogrammetric compilation equipment to sense distortions of 10 microns or greater. This in essence brings up to the present the "state of the art" for resolution and geometric fidelity in standard production equipment.

During the past two years, the 10 micron planigon lens became a reality and many new problem areas are apparent. Fortunately, from these problem areas there resulted a number of solutions to the various problems. When one puts all of these together, it is apparent that a bright new era may be unfolding in the photogrammetric field.

Resulting from programs within the Aerial Reconnaissance Laboratory of WADD, it is believed possible, in the immediate future, to make a large advance in the "state of the art" in mapping and supplemental photography. From the present-date high-acuity programs at WADD, many things have become apparent which indicate that errors normally considered to be second and third order, must be treated as first-order errors. Figure 1 shows the results of a study and test program of a 24″ focal-length system to determine internal effects of a camera and mount system on photographic resolution. This illustration has been extracted from an Air Force Technical Note No. WADC TR-58-208 entitled "Internal Vibrations and their Effect on the Performance of Aerial Photographic Reconnaissance Subsystems."

Figure 1 illustrates the degrading effects of motors, solenoids, etc., on system resolution. From this illustration, one concludes that either everything is standing still in the cam-

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TABLE 1

KC-1B CAMERAS

Camera No.	*Lens No.*	*Make*	*CFL*	*Radial Distortion*	*Tangential Distortion*	*AWAR*
59-001	410	Goerz	151.318	.009	.003	26.8
59-002	187	Goerz	150.827	.007	.009	26.7
59-003	611	Goerz	151.920	.009	.004	28.8
59-004	122	Goerz	151.683	.009	.007	25.6
59-005	484	Goerz	152.566	.008	.014	22.9
59-006	XF6718	Goerz	153.035	.006	.009	25.7
59-007	XF6743	Goerz	152.100	.009	.003	24.8
59-008	402	Goerz	152.511	.007	.009	23.2
59-009	279	Goerz	151.167	.002	.007	26.9
59-010	102	Goerz	151.294	.005	.009	26.9
59-011	476	Goerz	152.137	.004	.005	25.8
59-012	141	Goerz	152.353	.003	.005	25.0
59-013	129	Goerz	151.717	.007	.009	28.7
59-014	111	Goerz	151.926	.007	.007	25.7
59-015	498	Goerz	151.830	.006	.006	26.1
59-016	266	Goerz	151.311	.006	.006	22.7
59-017	475	Goerz	151.311	.005	.008	26.4
59-018	202	Goerz	151.425	.007	.005	26.3
59-019	614	Goerz	151.260	.009	.003	26.4
59-021	325	Goerz	151.455	.010	.005	28.9
59-022	543	Goerz	151.941	.009	.006	26.7

era during exposure, or it is made as near vibration and dynamic free as possible. Actually, both solutions have been achieved on our high acuity systems. A solution means that it is now possible, with the camera system airborne, to achieve near-laboratory optical bench resolution. This proves that resolution considerably greater than 20 to 25 lines per millimeter is possible in the air. This is a major milestone in aerial photography and opens the door for other major advancements.

At this point examination will be made of those portions of the airborne systems, basic to the photogrammetrist, which will yield the improved performance. First consideration will be given to the films. Table 2 outlines various film types and some of their characteristics as presented in a paper in the December 1959 issue of PHOTOGRAMMETRIC ENGINEERING that is entitled "Kodak Panchromatic Negative Films for Aerial Photography." Examining Table 2, the improvement in low-contrast resolution and grain size with the Plus X, SO-213 and SO-243 films, presents some stimulating thoughts relative

TABLE 2

MAXIMUM RESOLVING POWER

Kodak Material	*Maximum Resolving Power (lines 1 millimeter)*		*ASA Rating*
	1,000:1	1.26:1	
Super XX Aerographic	80	15	100
Plus X Aerecon	94	27	80
Plus X Aerecon (thin base)	115	35	64
SO-213	180	55	6
SO-243	225	95	1.6

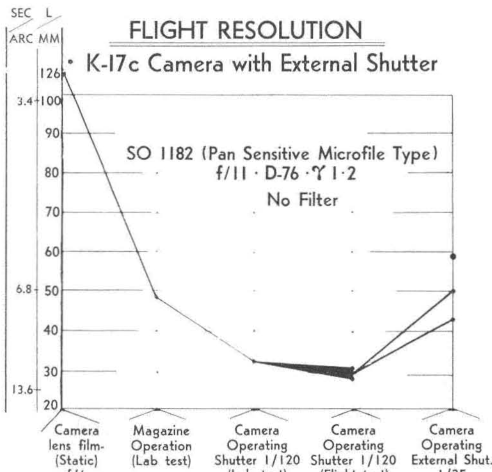

FIG. 1.

to photographic performance in the future. If the lens performance can progress to a point near the diffraction limit, then system performance can approach the limiting capability of the film.

The above fine-grain films have been responsible for the development work at WADD to provide the technology for diffraction-limited-optics. One formula for diffraction-limited-optics is 1,490 per *f* number of the lens equals resolution limit in lines per millimeter. This is for an average or mean wave-length of light. From this, one concludes that larger aperture lenses will be playing an ever increasing role in aerial photography.

In the high-acuity programs of WADD, lens technology has progressed to the point where lenses are approaching their diffraction limit. In layman terms, this means that the basic image is well corrected and there is less scatter of light. The result is more distinct edge images and an over-all increase in photographic detail information, even if the lines-per-millimeter resolution is numerically the same. Figure 2 illustrates this and is a photographic comparison of the 6″ T/11 Geocon lens and the present day 6″ *f*/6.3 Planigon lens which is used in the KC-1 camera. The targets are high contrast. To achieve performance near the diffraction limit for a lens is ex-

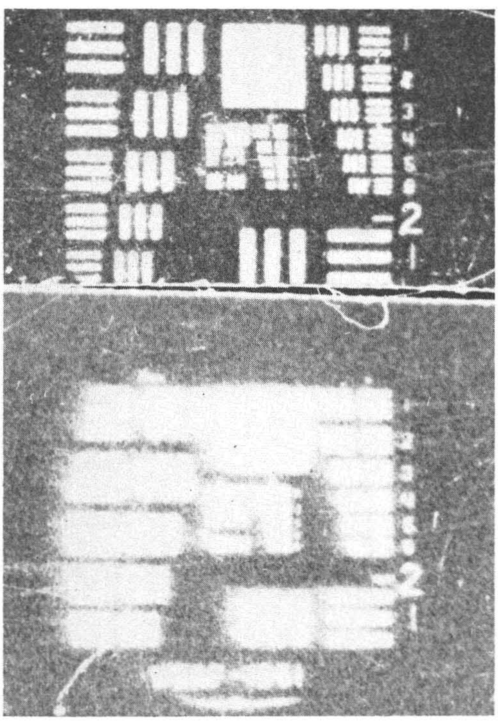

FIG. 2.

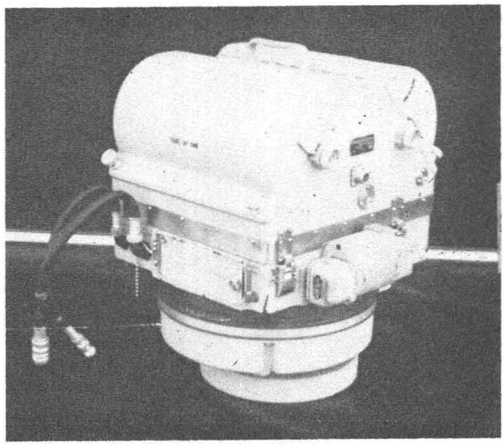

FIG. 3.

tremely difficult and expensive. In designing the lens, the designer must be given almost complete freedom to utilize any type of glass he needs. This is necessary because in reducing second-order color aberrations, one must rely at the present date upon foreign glass for material having the required characteristics. After one designs this near-perfect lens, the next problem is to control the index of the glass. Present glass manufacturing tolerances on the index of refraction are too large, and each lens must be recomputed to take in to account variations in index of the glass blanks. This establishes the final polishing tolerances for the lens elements. The hard facts are that all manufacturing tolerances must be reduced to as near zero as is possible and that each lens becomes an extremely precise item.

The Air Force has designs of a 6″ T/11 and a 3″ *f*/2.5 lens, which are highly corrected. These were designed by Dr. Baker on a WADD development contract. In papers presented previously, these lenses have been described. One 6″ lens has been produced and installed in a KC-1 camera body. Figures, 3 and 4 show the modified KC-1 camera. Figure 5 shows the lens schematic along with the Pleogon and Aviogon lenses. The 6″ T/11 lens distortion is below 10 microns; it is believed that ultimately the resolution should approach 45 lines/mm. AWAR, on Plus X type film.

Table 3 presents test data obtained in the laboratory with the modified camera. The most important yield from the resolution test data is to point out the growth potential of the photographic system when SO-213 type film is utilized. Figure 6 is an enlarged print from an SO-213 negative exposed with the

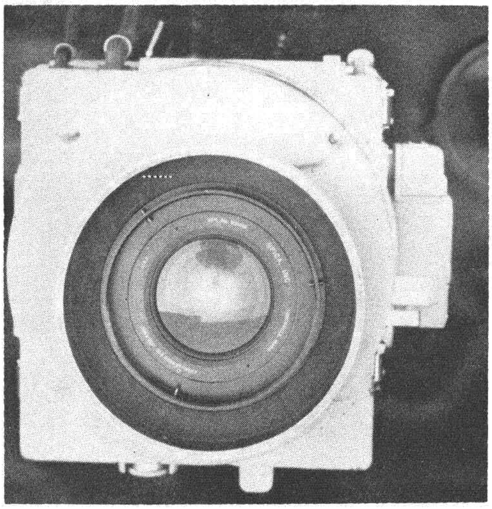

FIG. 4.

T/11 lens at *f*/8 and 1/100 second shutter. The film was given normal development. Even with the Plus X Aerecon film, the information content in the aerial negative is more than twice that of present Planigon lens photography. This is even more evident in the low-contrast resolution area which, with ever increasing altitudes, becomes a domineering factor in system requirements.

From these data it becomes evident that when a camera equipped with a 6″ T/11 lens and Plus X film is utilized with the present-day supplemental coverage camera, in all probability the mapping camera will have better ground resolution than the supplemental camera.

The 3″ *f*/2.5, 4.5×4.5 inch format lens, exists as a paper design. Figure 7 is a schematic of the lens. It is for all practical purposes of the same size and weight as the 6″ T/11

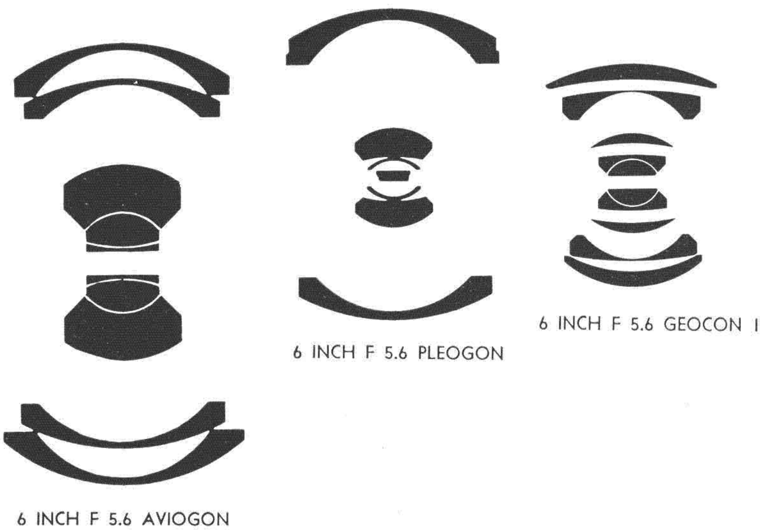

FIG. 5.

TABLE 3
BAKER T/11 LENS RESOLUTION DATA
(Lines/MM)

Film	*0*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*AWAR*
Plus X Aerecon											
f/8 Hi Contrast	48/43	54/45	51/48	54/51	57/51	51/45	38/38	28/43	27/51	30/49	36
f/5.6 Lo Contrast (3:1)	31/31	31/31	33/34	32/30	33/27	28/23	27/23	23/20	20/16	18/13	25
SO-213											
f/8 Hi Contrast	100/112	100/79	104/92	97/79	105/65	86/41	66/35	43/40	34/36	35/35	59
f/8 Lo Contrast (3:1)	56/56	56/56	62/52	64/44	62/44	59/34	48/36	38/36	28/31	33/26	43
f/5.6 Hi Contrast	70/100	74/80	74/64	71/74	94/63	71/44	61/42	51/35	40/23	37/35	54
f/5.6 Lo Contrast (3:1)	56/40	47/47	53/46	51/49	53/40	53/33	46/35	41/23	32/22	33/24	38

FIG. 6.

lens. It is believed capable of resolution of approximately 80 lines/mm. AWAR high contrast when used with SO-213 film, and should have distortion of approximately 5 microns, maximum. The intended use of the 3 inch lens would be in a volume and weight limited vehicle where a savings in film weight and volume can be realized.

Having achieved mapping camera lens-film resolution of approximately 80 lines/mm. under laboratory conditions, the next problem is extending and retaining these values during operating conditions and environments. The flight effects of pitch, roll, and yaw have satisfactory solutions for this level of resolution in mapping photographs, by means of the torquer stabilized mounts. As numerous papers have been presented on this

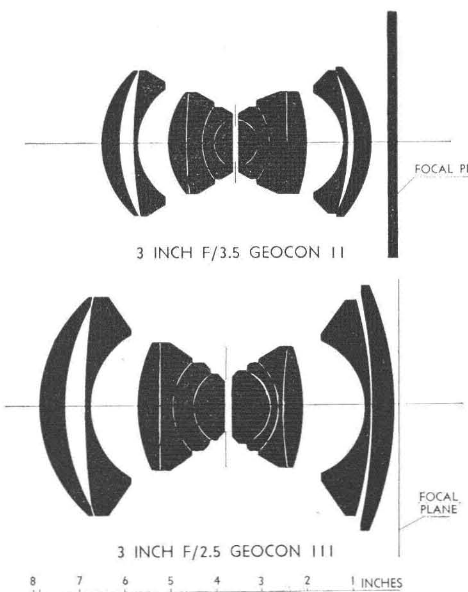

FIG. 7.

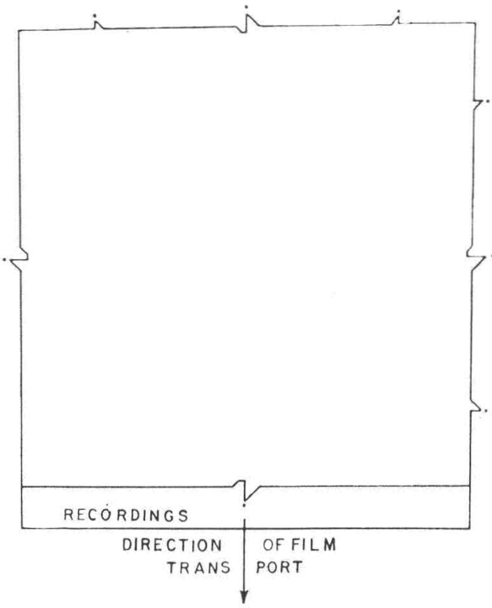

FIG. 8.

subject, it will not be discussed further in this paper.

The remaining vehicle motion is forward-motion. Previously image-motion compensation in a mapping camera has been prohibited because of loss of the position of the nadir point in the photography. This is due to moving of the film during exposure. In a standard KC-1 mapping camera without IMC, when operated at 20,000′ altitudes, 400 MPH and 1/300 second shutter-speed, the image is smeared approximately 12.5 microns during the exposure. This corresponds to 20 lines/mm. resolution and may also be in the "noise level" of film shrinkage and distortion characteristics.

When extending operations to 40,000′ and a velocity of 500 MPH, it becomes desirable to use finer grain film for higher ground-resolution. Under these conditions the image smear for a 6″ lens at 1/100 second shutter-speed is 25 microns and at 1/300 second shutter-speed is 6 microns. Assuming no IMC, the photographic system resolution would be limited to approximately 20 1/mm. for the 1/100 exposure and 60 lines/mm. for the 1/300 exposure. This is high-contrast resolution. With a maximum IMC error of 10 per cent, the system photographic resolution limit could become considerably greater than 150 lines/mm. or within the theoretical lens-film resolution limit.

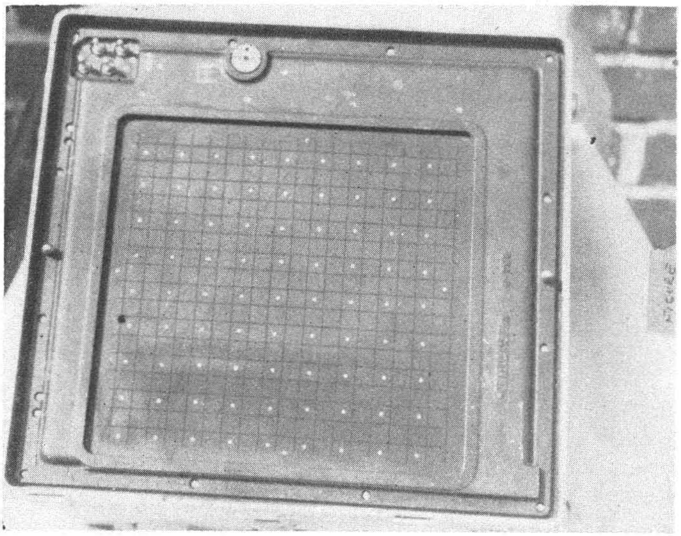

FIG. 9.

The question at this point is, can the nadir point be recovered? The KC-2 mapping camera utilized the Rapidyne shutter equipped with trip magnets for activation of the "*A*" and "*B*" blades from separate trip pulses. These pulses can be utilized to expose the fiducial markers. Figure 8 illustrates the fiducial marker arrangement on the negative format. To recover the nadir, the regular markers can be recorded by means of the "*A*" pulse to indicate the principal-point and nadir-point at start of exposure. The film shrinkage markers along the direction of film transport can be recorded by means of the "*B*" blade shutter-pulse. This provides a reference point for the nadir at the end of exposure which can be related to the primary markers. By means of ground-calibration of the lens cone, the distance between markers can be measured and recorded with the lens-distortion data. These same measurements can be made on the aerial negative at the time of compilation; the differences between the measured sets of data represent the film movement distance during the terrain exposure. The probable accuracy on this is 6 microns.

When making precise measurements on film, the question of film dimensional stability always enters in. A method exists of recording a reseau through the back of the aerial film at the time of exposure. Tests show this can also be accomplished through peloid backed film. Figure 9 is a photograph of the KC-1 camera platen with a simulated reseau which would be contained within the platen assembly. The dots represent holes through which light would be transmitted by lucite rods. The recording would be accomplished at the time of terrain exposure through the holes in the platen. Figure 10 is an actual negative where the terrain image was recorded in a camera, and the reseau exposed through the back of the film by means of a simple test fixture. The circled dots are the reseau recordings. Crude as the test set-up was, it shows the feasibility of the technique. Tests indicate that if the approximate

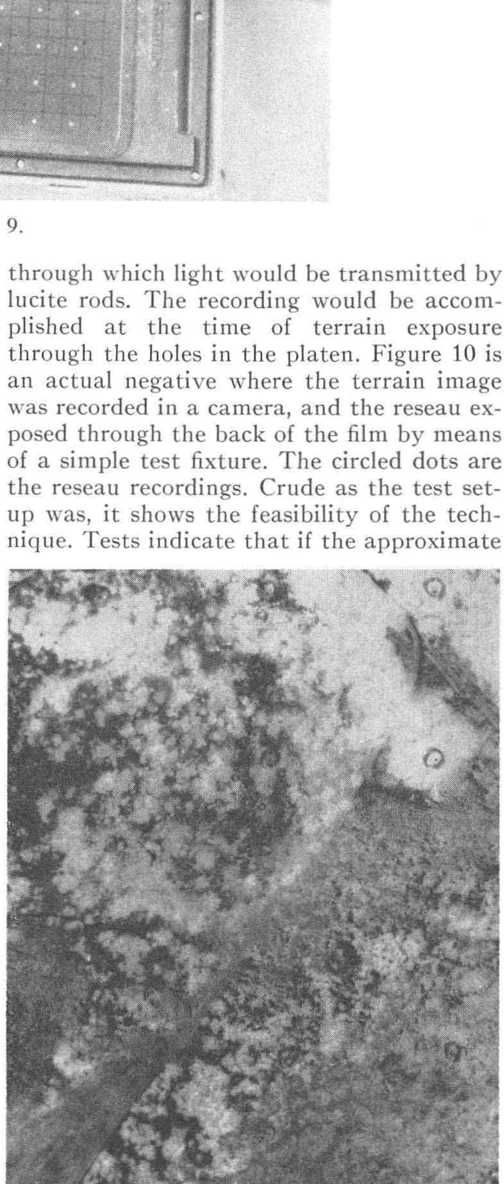

FIG. 10.

position of the reseau dots is known there is little trouble in identifying the dots, even in dense areas of the negative.

The next logical question is—how accurate are they? It is generally concluded that the center of a good dot can be located to about one part in 50. Therefore if the dot is approximately 0.004″ in diameter, or 200 microns, a position reading good to 4 microns would be realistic. By means of ground-calibration of the platen, the reseau can recover differential shrinkage and distortion of the film resulting from processing, drying, ageing, stretching in the camera, etc. In brief, the reseau provides the photogrammetrist with a positive means of quality control and recovery of film dimensional characteristics down to a few microns.

Attendant with higher performance, come other major problems such as thermal gradients and camera windows. Tests to date indicate the high performance optical systems must be temperature stabilized to a tolerance of approximately ±5°F. In addition, the lenses cannot tolerate even the 10°F. as a gradient and maintain the distortion characteristics. Considerable technology was gained during the KC-2 camera development and tests, in the use of blankets and thermal barriers. It is apparent that for low distortion and resolutions of 50 lines-per-millimeter or greater, protective covers must be provided, unless the vehicle compartment has extremely good temperature stabilization. Even with compartment conditioning, the compartment temperatures near the vehicle skin are excessively out or tolerance.

At this date with thermal barriers, the major thermal problem in any system is the entrance pupil area of the lens. This area is subject to radiation from the window, surrounding air, etc. With regards to windows, present practice is to utilize windows of group *M* quality in accordance with Specification MIL-G-1366. The flatness requirement is 1.25 fringes per inch measured over a 2.5 inch area and an over-all wedge of 4 seconds of arc. With resolution values of 80 to 100 lines per millimeter, the above flatness tolerance is excessive and can seriously limit system resolution. It is believed at present the departure from flatness must not exceed 2 wave-lengths or 4 fringes per 12 inch diameter area of suurface. The test fringes should show a smooth curve in one direction only, over the useable surface area. The uniformity of wedge should not depart more than $\frac{1}{4}$ fringe per inch over the usable area and should not exceed 4 seconds of arc. After a window of this quality is manufactured, extreme care must be taken to prevent distorting it by the mounting means or thermal gradients. The permissible thermal gradient is still a controversial question and only through experiments will a conclusive answer result.

Regarding the subject of supplemental coverage of the 80 lines per millimeter performance class, Wright Air Development Division has two programs that will provide new equipment and technology for this type of photography. These are the KS-25 High Acuity Camera System, which includes printers, viewers, etc., and the KS-50 Panoramic Camera System. Both require separate papers for proper description. These equipments are scheduled for delivery during 1960 and will start tests at that time. All tests and evaluation of data to date indicate a high degree of probability for achieving the 80 lines per millimeter high-contrast performance. To summarize the various areas, it is believed that the following conclusions can be made:

a. Film resolution performance has progressed to a point where serious consideration can be given for using SO-213 film with the 6″ lens under optimum conditions and Plus X Aerecon film under all conditions.

b. The 3″ *f*/2.5 lens can use the SO-213 film under all conditions and SO-243 film under optimum conditions.

c. When considering system operation above 35,000′ altitude, the 6″ T/11 lens used with Plus X Aerecon film, has equal or better ground resolution than conventional supplementary coverage cameras.

d. Mapping cameras can have IMC and retain the capability to recover the nadir-point, to an accuracy equal or better than the present standard KC-1 cameras.

e. A reseau can be provided in a camera magazine and recorded in the terrain negative through the back of the film, at the instant of terrain exposure. This includes films with peloid backing.

f. The reseau should be required from now on in all new mapping cameras. This will provide the photogrammetrist a positive quality-control tool to detect and recover differential film shrinkage and distortions.

g. Technology and equipment is forthcoming in 1960 for the required high-performance supplemental photographic coverage, from higher altitudes.

h. Care must be taken to preserve the higher photographic performance by suitable thermal protection of the optical systems.

i. For 80 lines/mm. resolution, the camera window quality must be above the Standard Group M quality.

j. In consideration of the above conclusions the time is at hand when a 2 to 4 time improvement in photographic resolution and detail information can be made. With the closer tolerances and control, the mapping lens distortion calibration of below the 10 micron level becomes more meaningful and useful.

In presenting this paper, an attempt has been made to show what is believed to be what the near future holds for increasing performance in mapping and supplemental photography. It is hoped that improvement in the quality and control of the photography may help to solve other problems or, at least to open some doors for future improvements in the many areas of interest.

*The New Zeiss Stereocomparator—An Old and Reliable Principle Applied to Most Modern Techniques**

HERBERT TRAGER,
Zeiss-Aerotopograph, Munich, Germany

ABSTRACT: *The paper discusses and explains the constructional principle of the Zeiss-Aerotopograph precision Stereocomparator, which differs from that of other stereocomparators presently available.*

The extremely high accuracy of this instrument is obtained on account of its far-reaching insensitivity to fluctuations of temperature and the use of extremely short measuring spindles which permit the determination of image coordinates as referred to a very precise measuring grid. The measuring process is facilitated and accelerated by a built-in automatic device, while a built-in optical system of pointers makes it easy to find the points to be measured. The Ecomat Electro-Magnetic Recording Unit which is directly connected to the instrument makes it possible to process the measuring data in any commercial automatic computer.

ON SEPTEMBER 16, 1890, Dr. Ernst Abbe held a lecture in Bremen on measuring equipment for physicists. In this lecture he outlined the principles for comparator measurement and design which up to the present day have conserved their value and importance and which have become known as the Abbe Comparator Principle.

In the aforementioned lecture, Ernst Abbe made about the following outlines:

In the design of comparators, the following two requirements must be fulfilled:

1) The measurement must in any case, both in the contact setting and the visual setting, be based on a graduation with which the distance to be measured is directly compared.
2) The measuring apparatus must by all means be so designed that the distance to be measured is the rectilinear extension of the graduation used for measurement.

It must be taken into account that these requirements apply to comparators for mere distance measurement only and require a certain modification above all in item 2), if they be applied to comparators for image measurement.

The purpose of the first requirement is to eliminate the irregular and partly uncontrollable sources of error originating in the measuring spindles. The aim of the second requirement is to make the measurement largely independent of the mechanical irregularities of the guide elements. Contrary to comparators for distance measurement, the comparator for image measurement must determine two components (x and y), so that the linear

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