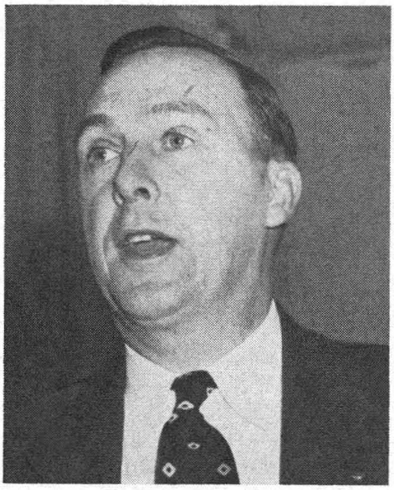
QUALITY CONTROL IN PRECISION CAMERA MANUFACTURING*

Robert Nelson, Chief Inspector, Fairchild Camera and Instrument Corporation

IN THE interest of making more precise aerial mapping cameras, we at the Fairchild Camera and Instrument Corporation have made plans in our new one-story modern camera production plant, now being completed at Syosset, Long Island, to extend the production research and measuring tools necessary for improving our camera production techniques.

With our trained personnel of many year's experience in the field of optics, mechanics and electronics, combined with our well-equipped precision measuring laboratories, we not only carry on our precision calibration of cameras and lenses, but we are also correlating our lens testing with the lens manufacturers to produce a more satisfactory aerial camera. In this way, a great deal of precise data are being compiled on a large number of production cameras. This has already furnished us with a good cross-section of resolution and distortion figures for our guidance in improving camera performance.


ROBERT NELSON

All of this realistic production fact-finding leads us to constant improvements and higher accuracy in our mapping and reconnaissance cameras. In the reconnaissance camera field, high values of resolutions are as important as low values of distortion required in mapping cameras.

Aerial cameras undoubtedly play an important part in modern warfare. When a plane is sent out over enemy territory the lives of the pilot and crew are risked to bring back detailed information that may save more lives. To avoid anti-aircraft fire we know that pilots must fly at higher altitudes, and the final photograph must show the minutest details sharply. Here then the small micro differences in resolution might easily mean, for example, the ability to discern a tank from a stone in the final photograph.

Keenly aware of this problem while building our new plant we installed a specially designed On-Axis Parabolic Multi-collimator system mounted vertically on a spring isolated base weighing approximately 50 tons.

This mounting precaution is being taken to eliminate any possibility of vibration to the optics which might affect resolution, particularly in the long focal-length camera lens. We are also mounting this unit vertically to more nearly duplicate the picture-taking attitudes encountered in actual use.

Nine separate collimators are being assembled in a single bank to include all necessary angles of the lens field. The reduction of thermal gradients has also been considered in this design and less effect is expected from this cause than we have had from former collimator designs.

Lens and lens combinations in the past have generally been mounted in a

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horizontal plane. But with the lens elements and mountings becoming increasingly larger, with a consequently corresponding increase in weight, it is felt that when these units are supported horizontally, it may be possible that mechanical deflections of a small order can contribute to the error in evaluation.

We at Fairchild feel that the problem of Photogrammetry, with all its variables yet to be resolved, is an important problem that we share with all who have an interest or an active part in the important field of photogrammetry. There is no doubt that by pooling our efforts and knowledge, as we have in the past, much mutual benefit will result. We have many good friends in the field of Photogrammetry, in this country and abroad. Photogrammetrists from both private business and Government service have been of great assistance to us through conferences in working out the details in planning and designing the specialized collimator and measuring equipment used to control the quality of our products.

We are faced in our company with not only building a single precision camera, but building quantities of high precision instruments while maintaining complete interchangeability and ease of service and maintenance.

At Fairchild, everybody's business is the business of Quality Control and, conversely, everyone makes quality his business. In the time allotted to me, it is impossible to describe all of the interesting processes and procedures that go into the production of our aerial mapping cameras. However, some photos will cover a few of the high-lights of production manufacturing and Quality Control that makes us all very proud of the Fairchild Aerial Cameras.

Figure #1

This shows our completely enclosed temperature and humidity controlled precision tool and gage inspection laboratory. Here all measurement standards are set and maintained for the shop. Our primary standard of measurement is the Master set of Johanson blocks with an accuracy of .000004 (4 millionths) or 0.1 of a micron.

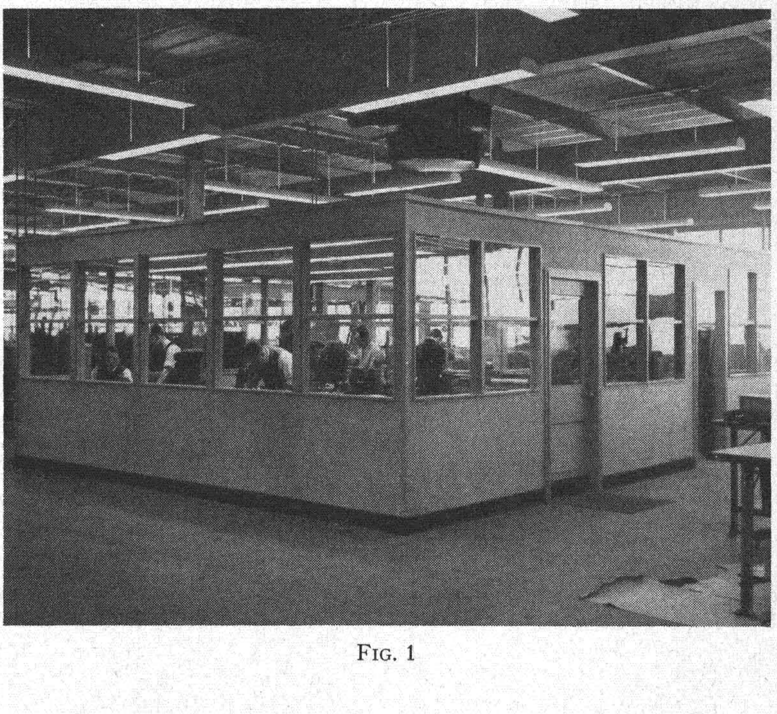

FIG. 1

In our criteria of measurement we endeavor to use tools that are accurate to one-tenth the tolerance to which we are working. For instance, a working tolerance on a machine part of .0005″ would call for a gage accuracy of 50 millionths.

Skilled inspection personnel maintain mechanical measurement standards by periodically checking gages and precision measuring tools to be sure they have not become worn or out of tolerance. Parts or products are only as good as the ability to measure. At Fairchild we recognize and stress this point.

Several pictures will show the various control functions carried out in this laboratory.

Figure #2

The inspector is checking plug gages on the Super micrometer. A new master set of Johanson blocks just received from Sweden is shown at the right.

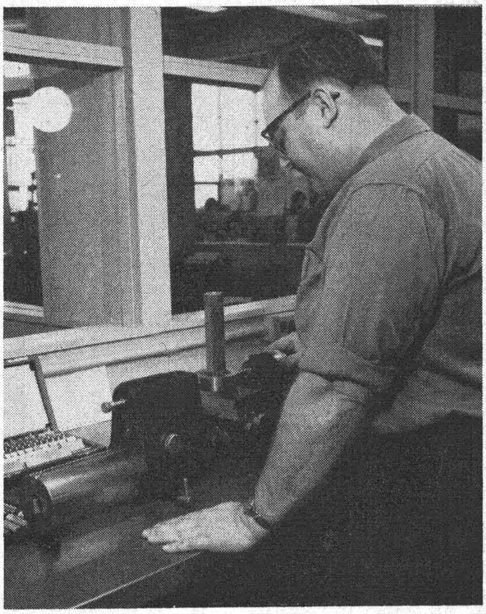

FIG. 2

FIG. 3

Figure #3

This shows the checking of ring gages on the Internal measuring machine. The calibration of this unit is in 25 millionths of an inch steps and can be read to ¼ of that amount.

FIG. 4

Figure #4

This inspector is measuring the flatness of $\frac{3}{4}$ inch thick glass plates that when selected will then be coated with photographic emulsion on the flat side. These plates are used for critical distortion measurements on our mapping cameras. The technique here used is unique and was developed at Fairchild as one step in a controlled process for insuring very accurate results. The glass is mounted on Johanson blocks, and a specially designed block with an air orifice, pointed at the glass, is slid along on the block granite surface plate. The single column air gage then indicates in .0001 inch (large graduations) and can be read to a $\frac{1}{4}$ or .0001 or $\frac{1}{2}$ micron.

The same technique is used to check the film platen or surface plate of our precision mapping cameras, the readings of flatness are plotted on a form showing the exact areas measured, and this information becomes a matter of record.

Figure #5

The Optical Comparator, with its lens turret giving magnifications of 10–20–50 and 100 times undistorted image projection, permits accurate and quick checking of odd shaped objects, such as cams and small shutter parts, against layout templates.

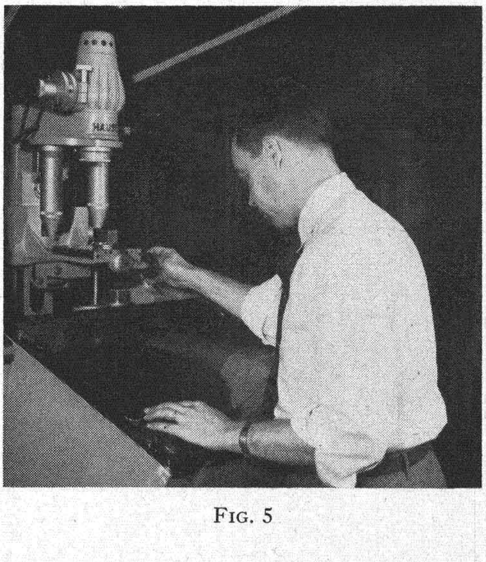

FIG. 5

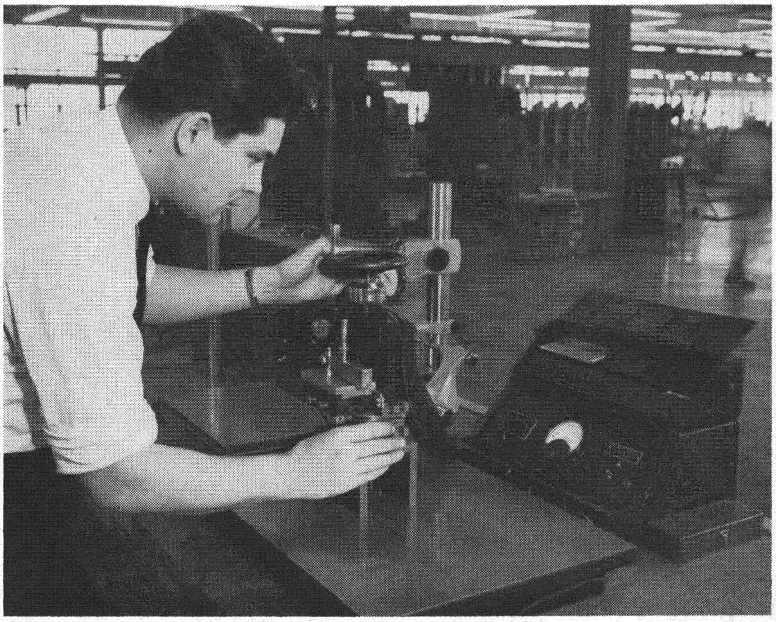

FIG. 6

Figure #6

The fine finishes required on shutter parts and other working parts in the cameras are specified and carefully measured by the profilometer method of measuring the RMS value.

Figure #7

A camera lens purchased by us and made to rigid specifications starts a long series of inspections in this laboratory. A metrogon lens is mounted in this English optical dividing head accurate to ±3 seconds. We check the mounting hold locations and obtain the positioning of the lens in our camera relative to the direction of least tangential distortion. This information gives us the figures for locating our mounting holes in the inner lens cone. This lens then goes to the camera calibration laboratory and the Flange focal-length is determined. From this information the lens seat can then be accurately machined from the focal plane position.

FIG. 7

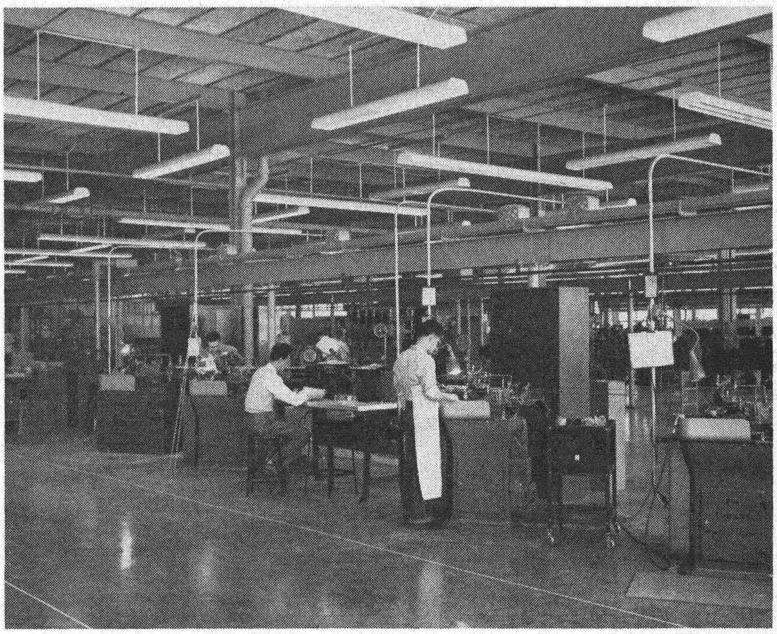

FIG. 8

Figure #8

Here is a portion of our clean, well lighted and efficient Machine Shop. This is a group of Swiss Tornos automatic machines that were selected for special operations planned to produce many of the intricate close-tolerance parts of the Fairchild Rapidyne Shutter. We found that it was impossible to purchase shafts, pivots, etc. to the close tolerances required in our Rapidyne Shutter. These parts with 4 and 5 characteristics when inspected would disclose 2 or 3 dimensions within tolerance, but the 4th or 5th were invariably out of tolerance. Therefore, our management selected the correct type of production machine, and planned the critical operations for our own production of these parts in quantity and completely within the tolerances required. This is the pattern that we have followed with a great degree of success in making our cameras, from a quantity and quality viewpoint.

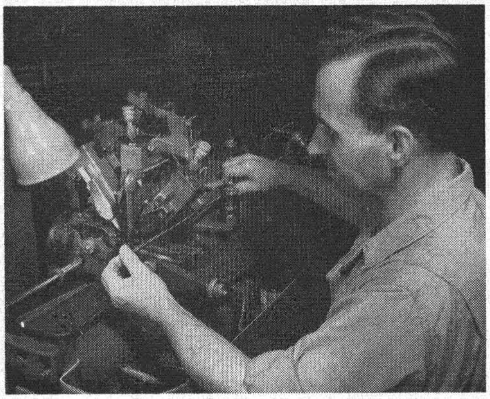

FIG. 9

Figure #9

Statistical Quality Control charting at the machine guides the operator in keeping his close settings, and this quality control tool is used wherever practical for "in process" control only.

This is a close up of one of these machines.

Figure #10

This new high speed shutter, called the Rapidyne, is a truly remarkable piece of engineering that combines watch makers' accuracies with the ruggedness of an aircraft instrument. This design eliminates the vibrations present in most shutters due to the shock of mechanism operation and the resultant distortion in the final photograph. To produce such a unit calls for special methods and special production and inspection equipment to control these small parts to the tolerances required. We found it was impossible to purchase parts to these tolerances from outside sources; therefore we set up to do this job.

This is the 1st base plate assembly of this shutter. When you realize that you can hold this entire mechanism in the palm of your hand you have some idea of its size.

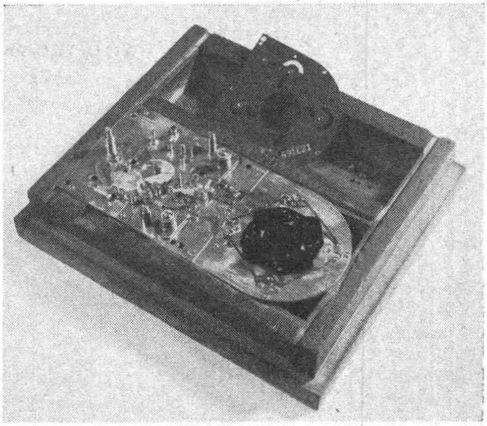

FIG. 10

Figure #11

The shutter consists of a series of mechanisms and two sets of leaves. The parts of this unit are extremely precise. The tolerances on hole sizes, spacing of holes, and thickness are extremely close.

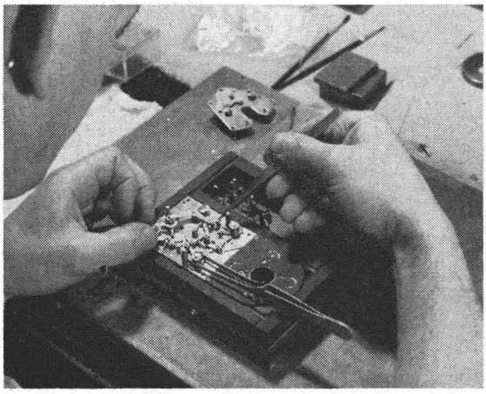

FIG. 11

To obtain this precision on stamped parts, shaving dies are used which allow a slight amount of material for polishing. It is not possible to obtain the surface finish required—by shaving dies. Therefore, hand polishing must be resorted to in order that finishes of 4 micro inches or better be realized.

The location of hole centers in these plates are accurate to tenths of thousandths.

Boring holes on most of the shutter parts are rough machined to .0005″ or better. Burnishing and polishing of these bearing hole surfaces is done by hand in the shutter assembly department.

All pivots and shafts for the shutter are rough machined on Swiss Automatics to close tolerances. Final sizing is done on precision grinders. This is followed by burnishing operations to obtain final accuracy and surface finishes. Surface finishes on these small parts are checked under a microscope by comparison with standard finishes on larger pieces, as they are too small to be checked on the Profilometer, which is our standard surface measuring instrument and reads the Root Means Square Value of the hills and valleys in the piece.

It is important that these surface finishes be extremely low in order to maintain high speed, low inertia qualities of this shutter. This is also important for another reason. Inasmuch as this is an adjustable speed device, there is a retard mechanism built into the shutter. This retard mechanism is of the energy-absorbing type. Therefore, for purpose of final adjustment of speeds, it is important that parts be uniform. Crush grinding of the retard pallets enables us to manufacture completely identical parts.

The shutter is assembled under close control with intermediate inspection steps that are planned ahead and spelled out on our methods or operation sheet which accompanies each job with the blueprint and the specifications. The assembly of this unit is done by a select group of men that are trained particularly for this type of fine assembly work. Each part is polished and examined carefully under magnification for scratches and material defects before assembly. Our instrument makers are all men of long experience in the aerial camera field. Many of these men have been with Fairchild fifteen years or more. Most of our supervisors have been with us from fifteen to twenty-five years. Precision is not a word to these men, but a matter of habit.

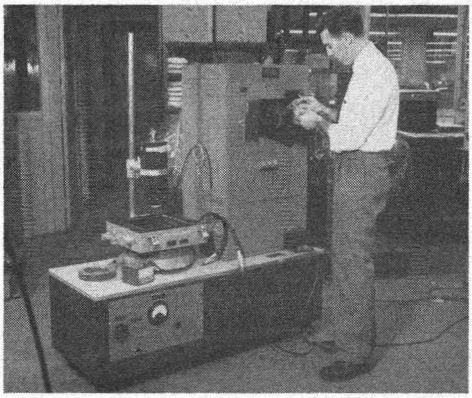

FIG. 12

Figure #12

Having completed our shutter we now test all settings for speed and efficiency. This electronic shutter tester draws a permanent graph of the results which controls production setting and also furnishes a record for file. This production test unit was developed at Fairchild and is adaptable to all our cameras and shutters.

Figure #13

This shows the T-11 Camera inner cone that mounts the lens in its precise position. The inspector is measuring the plane parallelism over the fiducial markers which lie directly in the focal plane. This comes after an extensive hand-lapping assembly job and careful stoning to remove all burrs.

It is important that this final item, the lens cone, and other castings used in our cameras be completely stable products. No dimensional changes, however small, are permitted to occur on castings like this inner cone. Therefore, the castings are normalized and seasoned before any work is done on them. This process is a product of time and temperature. The castings are placed in a large baking oven and raised to a high

FIG. 13

temperature. The heat is removed after a certain period and the entire affair allowed to come back to room temperature slowly. As a result of this process all strains in the castings are removed.

All machining is done by a series of gradually diminishing cuts. The first operation is a roughing operation. The casting is again normalized to remove machining strains induced by the roughing operation. The last cut is a skin cut that removes no more than .005. All our camera castings follow this procedure.

The tooling is quite extensive for this part. To avoid differences of machining due to different set up and differences of opinion on machining, tools are provided for every operation. These tools range from simple holding fixtures to extensive drill jigs. Some 100 odd tools are used to produce this one part. These tools can be used on only this one item and nothing else.

The machining of the cone proceeds along definite precision lines. The cone requires approximately 50 machine operations. There are also approximately 50 inspection points on this cone.

A Metallurgical Laboratory in our plant checks the physical and chemical properties of all raw materials, such as castings and critical heat treated steels, for complete quality control.

Figure #14

This shows a .008 diameter hole being drilled in the fiducial marker that mounts in the focal-plane of the lens cone just discussed. It locates the fiducial center on the focal-plane by means of artificial illumination. To drill this hole accurately is a masterpiece of workmanship; infinitesimal burrs must be burnished off. Again we have a specially designed production fixture and, most important, the skill to use it.

The gears for this unit and other units on the camera are machined on Precision Hobbing Machines and gear shapers. The gears are machined slightly oversize and then brought to size by a precision shaving machine. This machine which removes approximately .0005 to .001 from the tooth surface, produces a gear that is long-wearing and has good involute tooth surface. All gears are then checked for run out, P.D., and composite error on the conjugage, which permits magnifications to .0004 and is a very accurate method of gear checking. It is used right at the machine as a control tool and further charts all of the checked functions.

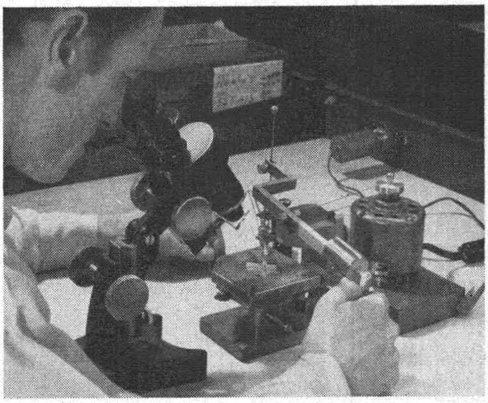

FIG. 14

All of the major units are completely interchangeable. Our production tooling is carefully designed and inspected to assure duplication of tolerances in large quantities.

Interchangeability gages are used on all units in this category, insuring that the parts can be identically reproduced in any quantities, at any time.

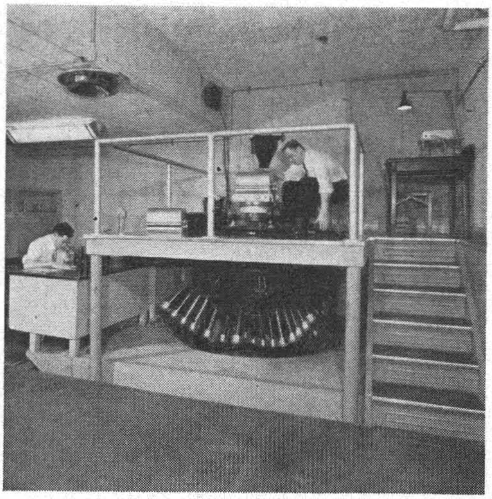

FIG. 15

Figure #15

Our cameras are checked and calibrated in our Calibration Laboratory previously described in PHOTOGRAMMETRIC ENGINEERING. This Laboratory is under temperature control and all measuring equipment is constantly checked for accuracy.

Figure #16

A spectrographic plate is being measured on a measuring machine calibrated in microns. From these measurements distortion is calculated.

FIG. 16

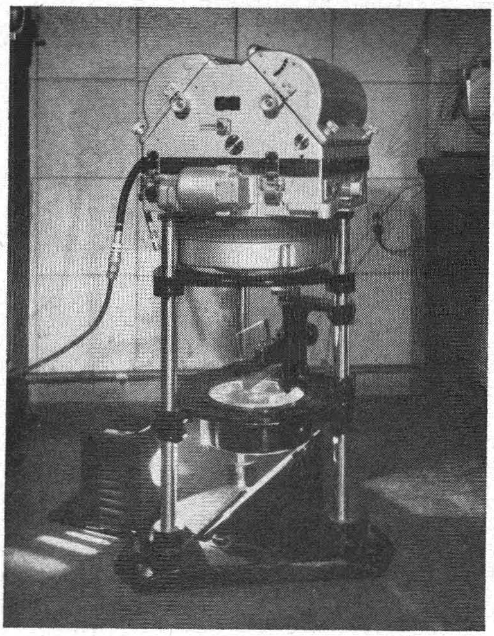

FIG. 17

Figure #17

A completed T-11 Precision Mapping Camera is being tested for film flatness. The unit is focused to the individual camera. A grid of closely spaced parallel lines is projected through the camera lens and extended by means of mirrors to the focal-plane on to film. If the parallel lines are reproduced on the film at the regular film transport rate and timing, then good contact exists between the film and film platen.

This is another Fairchild approach toward obtaining more technical performance data for production of the best in cameras.

Figure #18

This reproduction of a negative from the film flatness tester shows the effect of insufficient vacuum where film was not held flat against the platen in the magazine. It can be easily seen that the curved pattern of these lines indicate an out-of-flatness condition. We can build all sorts of precision into a mapping camera, but if the installation is faulty, or where insufficient vacuum is provided, photographs will not be accurate.

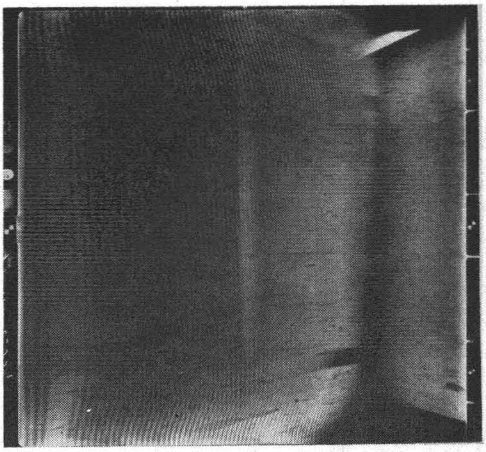

FIG. 18

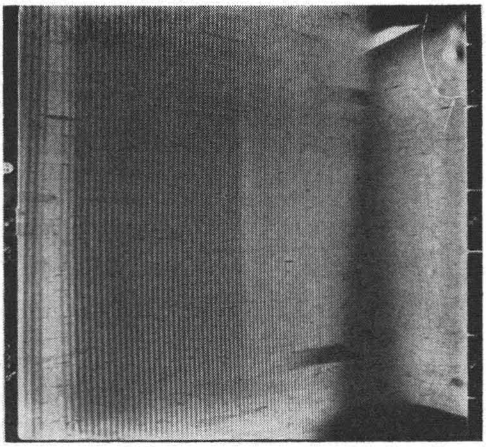

FIG. 19

Figure #19

This slide shows a reproduction of a negative and indicates a faulty camera. The cause was a slight scratch on the film platen. To give some idea of the magnitude of this error, a burr from the scratch was on the order of 10 to 12 microns.

Figure #20

In this negative all the lines are parallel and indicates a satisfactory camera. We have found that this is a very effective piece of measuring equipment for evaluating this phase of the final performance of our cameras and we hope to obtain more quantitative data regarding its performance in the future.

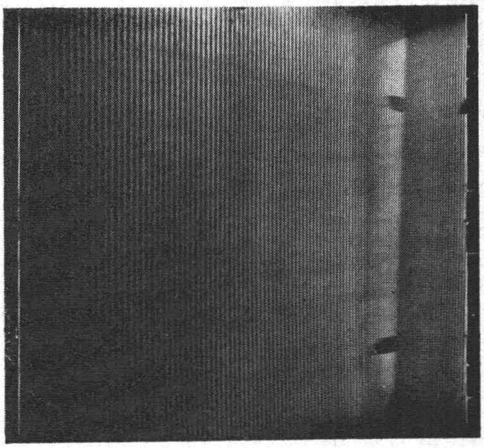

FIG. 20

In conclusion, it is desired to mention a very important function that is carried on as a Quality Control of our manufacture of these cameras. That is environmental and life testing. It is necessary to make all of the environmental type tests on both component parts and final assemblies periodically, based on quantities in production. These are the operational tests designed to simulate the conditions of flight and storage.

Our aerial mapping cameras are built and tested to withstand high and low temperatures, extremely high altitudes, acceleration of aircraft to several g's and vibration of severe amplitudes which are encountered in aircraft.

Salt spray corrosive tests must also be made as an environmental condition encountered on coastal areas and to prove that our finishes are adequate. Prolonged fungus resistant tests must also be made to preclude the possibility of fungus growth in tropical areas and to ascertain that materials used are non-nutrient to fungi or are protected against it.

Sand and dust tests for protection against desert conditions require good sealing. Explosion testing is run to be sure that the electrical wiring and electrical components are designed in such a manner that combustive mixtures present in the aircraft will not be set off by this means. Cameras also have to be checked in a shielded screen for radiation and noise and conducted interference that might cause interference with other radio equipment installed in the aircraft.

Another important phase of the type testing is the durability or life test on the final cameras. This test is run with a fixed torque load in excess of the normal camera load in order to prove the durability which must be built into these cameras to operate for thousandths of cycles without failure. At this point our control of critically stressed machine parts and shafts and cams which have been heat treated is indicated because unless the necessary precautions are taken, long experience has shown us that we would have a group of rejected cameras on our hands with the consequent expensive tear down, rework and delay in shipment.

The Fairchild Camera and Instrument Corporation is made up of people of high skills. Our interest is not restricted to the production of cameras. We are interested in making the best possible cameras for the use intended. We know all about the rigid requirements a precision topographic Mapping Camera must meet. I, my associates, and our skilled mechanics take great pride in the T-11 Camera which not only complies with all photogrammetric requirements but which is sturdy and rugged enough to insure long life and freedom from operating troubles.

NEWS NOTE

A new 12-page booklet published by the Eastman Kodak Company describes advanced methods of optical gaging to cut inspection and tool-room costs. The booklet illustrates the uses of special fixtures and charts to inspect to close tolerances large parts, complex shapes, and blind holes and recesses using contour projection. Profusely illustrated, it shows how optical gaging may be adapted to a wide variety of parts for faster and more economical checking.

Specifications and features of both the Kodak Contour Projector, Model 2A, and the Kodak Contour Projector, Model 3, are described and illustrated. The booklet is obtainable free on request from the Industrial Optical Division, Eastman Kodak Company, 343 State Street, Rochester 4, New York.