*Metrical Photography**

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ABSTRACT: *Metrical photography is defined as the art and science of obtaining reliable measurements by means of photography. The accepted scientific word, having the same meaning as metrical photography, is photogrammetry.*

A summary of the highlight material presented is: brief history of the heritage of the perspective from the primitive age to the advent of the camera, the perspective from the viewpoint of the artist and the engineer, the father of photogrammetry, the camera as an angle recording instrument, integrating the knowledge, practical experience, and instrumentation of the technical photographer and the photogrammetrist for the purpose of serving science, engineering, and industry by means of photographic measurements.

INTRODUCTION

WHAT is metrical photography? The word "metrical" is an adjective meaning "measured." The word "photography" is derived from the Greek, meaning "to draw with light." It may be concluded from the word derivations that metrical photography has something to do with *measuring a drawing that was produced by the action of light.*

The accepted scientific word, having the same meaning as metrical photography, is *photogrammetry.* "Photogram" meaning "photograph" and "metry" meaning "measurement." Therefore, photogrammetry is the *science of photographic measurement.*

The artist or engineer may think of the photograph as a perspective projection or drawing that illustrates the basic facts of shadow and perspective. The artist and engineer have more points in common than is normally realized, but if we must distinguish between them perhaps the simplest terms of distinction are that the artist deals with the intangibles of beauty while the engineer deals with the measurable.

In an integrated system of balanced precision, one major component cannot be considered more important than another if one honors the adage that the chain is no stronger than its weakest link. Nevertheless, the theoretical heart of the photogrammetric system is the photograph or perspective drawing. Data recording and data reduction instrumentation perform their primary function of reconstructing object space in accordance with the theory of perspective.

PERSPECTIVE DRAWING

If the perspective drawing is, figuratively, the center of the photogrammetric universe, a brief review of its heritage may prove beneficial in that current or future solutions to problems can be more fully appreciated, conceived, and exploited.

The word "perspective" is also derived from the Greek, meaning "to see across." Realism is given to a painting by aerial and linear perspective. Aerial perspective is the haze effect given to distant objects, and linear perspective is the geometric configuration resulting from projecting object space through a perspective center onto an image surface.

* From a paper presented before the Fifth National Industrial Photographic Conference and reprinted with permission from *The National Photographer*, the official publication of the Photographers' Association of America, Inc.

EDITOR'S NOTE: The author presented this paper at two meetings during March 1957. The first was at a regular meeting of the Engineering Society of Cincinnati and the other at the Fifth Annual Industrial Photographic Conference. These and the published paper constitute one more outstanding demonstration of the efforts made by Society Members to "sell photogrammetry" to non-users who would benefit through use and to others who now know little or nothing about this relatively new science.

Primitive art lacks perspective, but sometimes there is an apparent awareness.[2] Ancient Chinese art portrays aerial perspective but not linear perspective. Foreshortening is evident on painted Grecian vases dating back to 530 B. C. The perspective, however, did not rigorously conform to geometric projection. The Romans inherited perspective from the Greeks. Since the Romans were interested in realistic paintings and statues, they sought to display perspective accurately. As Roman power increased and the Christian era took hold, realism in art declined in favor of art expressing spiritual values and symbols of faith. Realism in art was so infrequent in the centuries to follow that by the time of the Renaissance, perspective was re-established as though it were a new discovery.

The Renaissance—Rediscovery

The Renaissance has been defined as the rediscovery of man, nature, and classical antiquity. I prefer to call it the rediscovery of perspective. Artists turned again to realism and by the sixteenth century the principles of scientific perspective were accepted as a part of the revival of realism. Artists and geometricians examined the principles of scientific perspective to clarify and discover geometric and mathematical relationships. Art and science came upon the law of inverse squares: If an object is moved to twice its distance, the image is reduced to one-fourth of the original area. Artists of the Renaissance enthusiastically experimented with the new science of perspective. Leonardo da Vinci was closely allied with the development of *scientific perspective.* His world famous painting, "The Last Supper", (Figure 1) is an excellent example of parallel or one-point perspective (Figure 2). The lines formed by the panels on the ceiling, the window frames, the edge of the table, and the decorations on the side walls, all represent a system of parallel lines in object space. These construction lines on the painting converge and intersect within the image of the head of Jesus. Artists of the Renaissance occasionally presented angular or two-point perspective (Figure 3) and oblique or three-point perspective (Figure 4).

The significant difference between the practical utilization of the perspective by the artist and the engineer is the degree of geometric fidelity. If the accuracy of the

FIG. 1

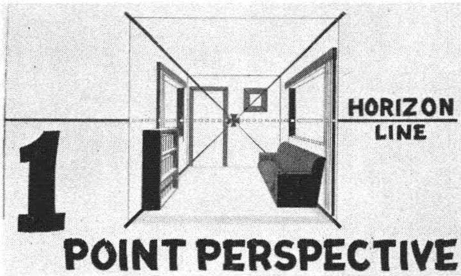

FIG. 2

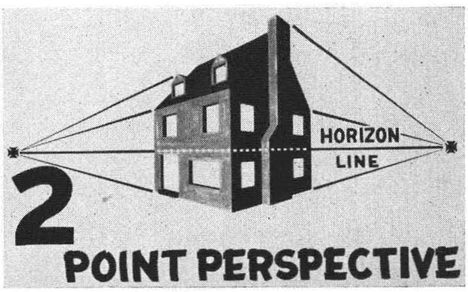

FIG. 3

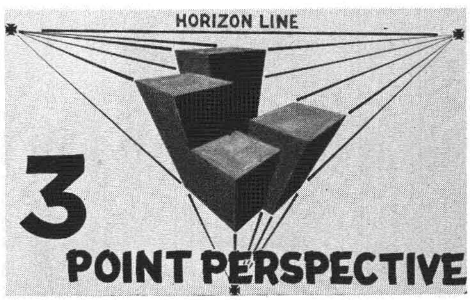

FIG. 4

linear perspective is not faithfully reproduced, the intangibles of beauty in the mind of the artist or observer may not be compromised in the slightest, but even augmented. However, if the engineer's task is to reproduce the scene, the error in the linear perspective may result in measurement data that are unreliable for the successful execution of the project. The artist can legitimately throw linear perspective to the winds under the law of artistic license while the engineer must determine if the residual errors of the perspective are compatible with the accuracy specifications of the project.

The contribution of Brook Taylor to the field of mathematics is well known by mathematicians throughout the world but his contribution to the mathematics of the perspective is little known. In 1920, J. W Gordon noticed an announcement that a portrait of Brook Taylor had been added to the National Portrait Gallery in Trafalgar Square. To pay his reverence to this great English mathematician, Gordon made a pilgrimage to the Gallery. Much to Gordon's surprise he did not find a portrait of Brook Taylor but a miniature study in perspective. The fact that Taylor was represented by a study in perspective intrigued Gordon inasmuch as he was currently in the process of preparing a manuscript entitled "Generalised Linear Perspective."[3] This resulted in a second pilgrimage, this time to Bloomsbury in quest of Taylor's book. Gordon writes of his experience: "Then came one of the moments for which the student bibliophile lives, when in the neglected page of an old author he discovers unsuspected treasure. Here, in Taylor's twenty-fifth proposition, almost at the end of a slender volume, was the rule for finding the horizon in a perspective field, whether erect or oblique, which bridges the gap between a photograph and a plan of the photographed country. In 1715, when that page was printed, no photograph had ever been taken, no practical application of the rule could be foreseen. It was pure unapplied science, wrought, as the devotees of knowledge work their material, to the roundness of a systematic whole."

Until the middle of the nineteenth century, artists were concerned with representing the natural or supernatural in terms of the natural. The painting served to instruct as well as to please the observer. However, with the advent of the camera, realistic presentation as a means to instruct was no longer regarded as a primary function of art. Abstraction and surrealism evolved as two new forms of art to counteract the competition of the camera that served so effectively in presenting realism for instructional purposes.

Metrical Photography History

It is not uncommon to hear metrical photography referred to as a budding new science without realization that the science of photogrammetry is over 100 years old.

The principle that a photograph is a perspective projection of mathematical accuracy was recognized by Arago and Guy Lussac[4] in 1839.

Aime Laussedat, an officer in the French Corps of Engineers, is known as the father of the applied science of photogrammetry. In 1852, the same year as the founding of the American Society of Civil Engineers, Captain Laussedat made a photographic survey of a small village near Paris at the invitation of the French General Staff.[9] Eight collodian wet plates were exposed in three hours. A topographic map at a scale of 1:2,000 covering 500 acres was prepared from the photographs in four days

Laussedat claimed that the success of his method was due to determining the precise focal-length of the camera lens, and recording the principal point and horizon line on each horizontally exposed photograph.

In 1864, while an instructor at the School of Arts and Crafts in Paris, Laussedat announced a course in photographic surveying for rapid reconnaissance and for extension of the photographic method to the surveys of buildings and machinery.

Laussedat corresponded with scientists throughout the world, promulgating the new science internationally. His work was not lost, then, when a stubborn resistance to photogrammetry developed in the French Army.

Although Laussedat is universally recognized as the father of photogrammetry, others were independently working with the problems of photographic surveying, for example, Porro in 1853 and Meydenbauer in 1858. Bertaud in 1858 produced a lens with a 30 degree field and Brunner in 1859 utilized Bertaud's lens in the first serviceable camera for photographic surveying.

Inasmuch as photographic surveying was recognized internationally by military authorities as a means of preparing maps for defense, the promotion of photogrammetry began in many lands.

Beauty or Geometry

The development of photogrammetry for the past 100 years would, indeed, make an interesting technical saga of the integration of men, optics, mechanics, engineering, economics, and specialty salesmanship. Such a history would require more time that is allocated to me here. The purpose of presenting the short history of the perspective from the primitive age to the time of Laussedat is to emphasize and give meaning to the difference between a photograph as a picture of beauty and the photograph as a drawing conforming to geometric and mathematical relationships. The significant point is to know the difference and plan the photography accordingly.

We are basically interested in the utilitarian role of physics, chemistry, and mathematics as they team up with engineering to solve practical problems. Almost everyone is elated at the sound of the word "practical." Even in those rare moments when man is struck with a bolt of true humility, he seldom confides that he is not practical. We must not discount the fact that the abstract theories and the so-called long-haired mathematical equations of today are potentially the framework for the solution of the practical problems of tomorrow.

Observation and Mathematics

As we all are very much aware, knowledge in all physical sciences is based on observation.[11] Observation, however, can determine only what is. When observation is combined with mathematics it is possible to predict what can be.

Once a workable theory is established in metrical photography, instrumentation is required to record and to reduce the data. The continuing requirement for increased accuracy of data recording and speed of data reduction poses development considerations of time and finances. However, man, time, and finances do eventually simplify instrumentation. For the past 50 years photogrammetry, like many other sciences, has been dominated by machines. A stimulating thought about machines appears in Antoine de Saint-Exupery's book[10] "Wind, Sand and Stars." "The machine itself retreats behind its functions as it becomes more perfect. It seems that every technical attack of the human being, all computations, all night vigils over plans and drawings, ever and again produce, as final visible result, the greatest simplicity. Obviously perfection does not arise when there is nothing further to be added, but rather when nothing further can be taken away. In its highest perfection the machine becomes inconspicuous. Perfection of an invention borders closely on absence of invention. Only when every visible trace of technical elaboration has disappeared from our instruments and we see them as self-evidently and naturally as gravel rounded by the sea, will one gradually forget that it at all is a matter of a machine."

Photogrammetry, or metrical photography, has many uses. The popular conception of photogrammetry is confined to mapping, and with good reason. For both economic and military reasons, the mapping of the face of mother earth has been the most significant single application of photogrammetry since its founding by Laussedat. Photogrammetry is, and has been, primarily preoccupied with theory and instrumentation for the specialized application of mapping the irregular surface of the earth to fulfill an ever-increasing need for maps. The photogrammetrist has specialized and has become expert, in the past 100 years, in the determination of space positions.

Photogrammetry Covers Broad Field

There is more to photogrammetry than mapping, however. Photogrammetry is officially defined by the American Society of Photogrammetry as "The art or science of obtaining reliable measurements by means of photography." It should be particularly noted that the photography is not confined to an aerial exposure station for the purpose of topographic mapping.[5] The metrical photography may be exposed from the air, ground, underground, water, underwater, or within the confines of a building for the purposes of topographic mapping, astronomy, ballistics, architecture, medicine, anthropology, zoology, physics, biology, geology, meterology, hydrography, deformations, criminalistics, industrial measurements, physical education, aviation, military intelligence, or determining the dimensions of an individual for a tailor-made suit. Metrical photography is capable of determining the position of points, the orientation and length of lines, the area of surfaces, and the volume of solids.

Metrical photography can also be used to determine time, and quantities integrated with time, such as velocity and acceleration. Time may be recorded on the exposure, or the exposure sequence may be time-controlled by electromechanical components. When the space positions of two points are known, the distance between the points can be determined. Distance relative to time is velocity. The time rate of change of velocity is acceleration. Time can be solved for by the photogrammetrist because the solution is dependent on a direct measurement in image space.

The key to the capabilities of metrical photography is that a direct measurement in image space can be used to determine an indirect measurement in object space.

In the field of science, whenever indirect measurements are determined from direct measurements, one must traverse the interconnecting link of theory. The interconnecting link in the science of metrical photography is the theory of perspective. The theory is proven when all indirect measurements based on it are verified.

While the photogrammetrist has been primarily absorbed with the problems of interior orientation, exterior orientation, and the calibration of the opticomechanical instrumentation, scientists, engineers, chemists, and technicians have been busy in other photographic societies with the problems of film, filters, optics, processes, lighting, cycling rates, and instruments and apparatus of many functions.

It is apparent that the future growth of metrical photography into the many branches of science, engineering, and industry is as optimistic as a seed catalog. The photographer and photogrammetrist have already established the necessary ground work. First, science, engineering, and industry must be informed that metrical photography is a proven scientific method of measurement, and what metrical photography can and cannot measure with sufficient accuracy and economy. Second, the photogrammetrist and the scientist, engineer, or industrialist must determine what the requirement really is and mutually state the problem. Third, the photogrammetrist must make available the methods, techniques, and instrumentation that are compatible with accuracy, cost, and operational requirements.

The significant advantages of metrical photography are:

1. REMOTE CAMERA STATION (FIGURE 5)
   Measurements can be made without touching the object or occupying the immediate vicinity of the object, for example, in radioactive, explosive, gaseous, hostile, inaccessible, and security areas. Minimum mental and physical demands are important to the operator working under adverse weather conditions or in dangerous areas. Data can be reduced under favorable office conditions and at a convenient time. The remote camera station is of obvious advantage to the military, but it has now been extended to business in those cases when management does not wish to display overtly their initial interest or plans of a proposed development to the public or competitors.
2. FREEZE PHENOMENA IN MOTION (FIGURE 6)
   A point object in motion can be stopped and measurement data obtained. In deformation problems where many points may move at varying rates, the action of the many points can be frozen simultaneously and the deformation relative to time determined without the influence of friction or inertia, since the point objects have no mass but position only.
3. PHOTOGRAPH SERVES AS AN ELABORATE SURVEYOR'S NOTEBOOK (FIGURE 7)
   Photographs can be stored as a permanent record and made available for checking, and if required, additional data reduced at a later date owing to the wealth of detailed points.
4. ECONOMICAL (FIGURE 8)
   Metrical photography is basically economical through the saving of time and therefore money. However, in certain instances time may be considered more important than economy.
5. RELIABILITY (FIGURE 9)
   This is one of the basic reasons for photography's high regard in military circles. Ground intelligence reports may indicate, for example, a possible oil storage capacity of 1,000,000 barrels. A high degree of reliability is established when the data can be measured from photographs instead of relayed in words that cannot be verified.

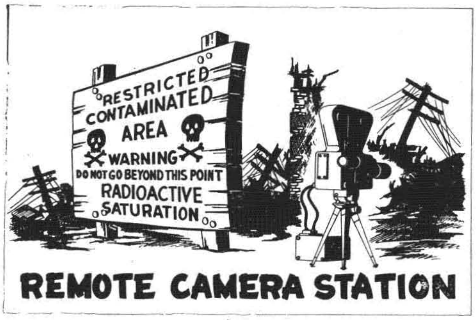

FIG. 5

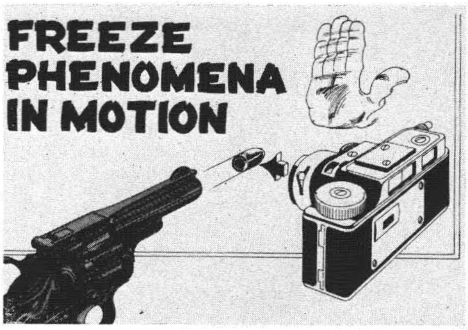

FIG. 6

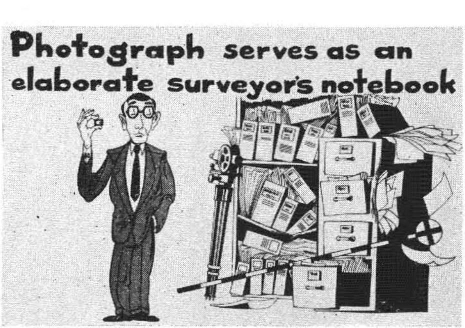

FIG. 7

FIG. 8

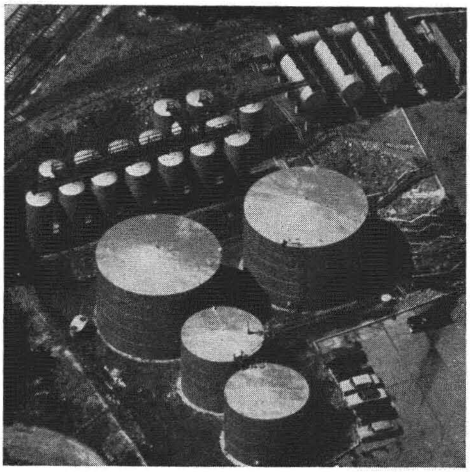

FIG. 9

Basically, a metrical camera is an angle-recording instrument similar in function to a transit. The metrical camera, however, simultaneously records many pointings to objects while the transit is confined to one pointing at a time which is represented by the intersection of the cross-hairs.

Let us review a very simplified case of transit surveying[6] (Figure 10):

a. The base line AB is measured. Assume AB is horizontal.
b. A transit is positioned at A and the angle a is recorded.
c. The transit is moved to B and the angle b is recorded.
d. The angle θ is equal to $180° - (a+b)$.
e. From the law of sines the distance from each of the base terminals to the object point P can be determined:

$$AP = \frac{AB}{\sin\theta}(\sin b)$$

$$BP = \frac{AB}{\sin\theta}(\sin a)$$

It may be summarized then that any point in object space can be positioned horizontally, if a horizontal base length and the included horizontal basal angles to the point are given.

Let us also review a very simplified case of photographic surveying (Figure 11):

a. Two metrical cameras are geometrically arranged so that their optical axes are horizontal, parallel to each other, and perpendicular to the camera base which is also horizontal. This is called the normal case of stereo-

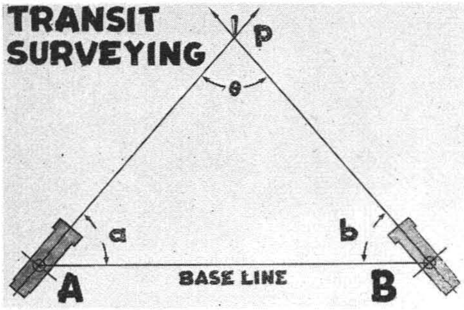

FIG. 10

photogrammetry.

b. The angle subtended at the lens A between the optical axis and the image of P is:

$$\tan c = m/f$$

also at lens B:

$$\tan d = n/f.$$

c. Angle $a = 90° - c$
Angle $b = 90° - d$

d. Angle $\theta = 180° - (90° - c) - (90° - d) = c + d$

e. The base AB, or the distance between the twin lenses, is measured.

f. The base and the two included basal angles are now determined. It is then possible to employ the same procedure to position the point P as was previously outlined for the transit surveying procedure.

The vertical position of the object point is simply determined by multiplying the horizontal distance from the camera station to the object by the tangent of the angle of elevation or depression.

These mathematical relationships demonstrate that the metrical camera is an angle-recording instrument similar to the

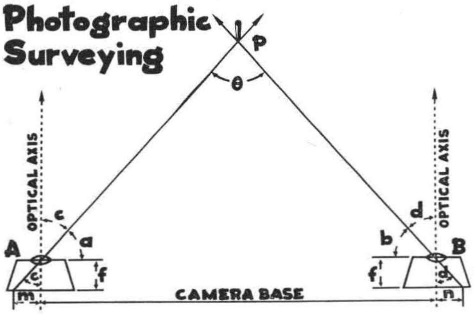

FIG. 11

transit. In practice, however, the mathematical reduction of the three-dimensional position of an object point, under the normal case of stereo-photogrammetry, would be performed as follows (Figure 12):

a. Measure the photographic coordinates x_1 and z_1 on photo 1 and x_2 and z_2 on photo 2.

b. The camera base, B, and the focal length, f, are measured or are known from being previously calibrated.

c. The constant, K, is determined:

$$K = \frac{B}{x_1 - x_2}$$

d. The X, Y, and Z coordinates of the object point are simply determined by multiplying K by x_1, f, and z_1, respectively.

Inasmuch as the procedure can be utilized to determine the three-dimensional position of more than one point, the absolute distance from one object to the other or

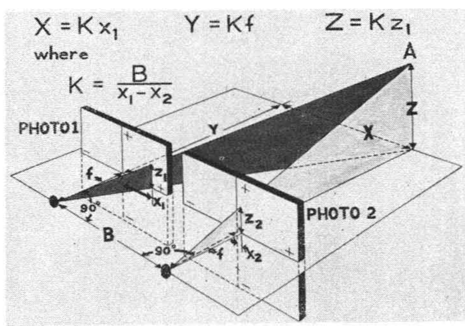

FIG. 12

the size of objects can be determined without knowing or measuring a single dimension in object space. All that one needs to know is the calibration data of the camera. It is believed that this unique condition should be of great interest to the field of science, engineering, and industry. There are no metrical requirements placed on the photographer such as taping distances, or placing the customary pack of cigarettes or ruler in the field of view for the purpose of an approximate scale. If the purpose of the project is to determine the position of objects without reference to a horizontal plane, the camera base and optical axes need not be held horizontal, and the exposures may be made from any angular orientation. The stereo camera is calibrated by the photogrammetrist before it is taken to the field of operation and the film is metrically reduced by the photogrammetrist subsequent to the exposures. The only stipulation placed on the photographer is the most effective technical composition.

Photogrammetric Evaluation at Work

A few applications of metrical photography will now be presented. They are not necessarily the most interesting, important, glamorous, frequently encountered, nor are they necessarily representative of the many thousands of applications that will materialize someday. It is hoped that these run-of-the-mill examples will function as a lever to the imagination.

An excellent demonstration of resourcefulness is illustrated by Charles Burns[1] of the British Iron and Steel Research Association (Figure 13). The association was confronted with the problem of securing information "on the 'combustion zone' of the blast furnace where the pieces of iron ore, coke and limestone, which fill the furnace, are burned together to produce iron under a blast of preheated air." The furnace reaches a temperature of 1,900°C. and is separated from the observer by a wall of refractory brick several feet thick.

The preheated air is forced into the furnace through a tuyere which is approximately 8 feet long and 8 inches in diameter. One end of the tuyere contains a door with a small inspection window through which the violent motion of the particles can be viewed under the influence of the blast of the preheated air.

The potentially significant measurements for design consideration of blast furnaces are the depth of blast penetration and the distance over which the particle motion occurs.

It was found that motion pictures at a rate of 64 frames per second were blurred beyond recognition. However, a rate of 1,000 to 3,000 frames per second resulted in well-defined single frames and a slow-motion picture at normal projection speed. The intense illumination from the furnace permitted the lens to be stopped down to a relatively small aperture.

The tuyere door was modified (Figure 14) to accommodate stereoscopic motion-picture photography by the insertion of two circular windows of fuzed quartz on $4\frac{1}{2}$ inch centers and two valves between the windows and the furnace.

The valves were closed whenever it became necessary to remove the windows for cleaning without cutting off the furnace.

A fully reflecting beam-splitter for the motion-picture camera was constructed and consisted of two outer mirrors with screw adjustments for convergence and two inner mirrors, the latter being formed by aluminizing a right-angle prism.

The beam-splitter is placed about 12 inches from the camera lens. The 16 mm motion-picture frame (Figure 15) is split vertically with images from the left and right mirrors of the beam-splitter.

A single-lens motion-picture camera with a split frame records the left and right images simultaneously and thereby precludes the problems of synchronization and more elaborate instrumentation.

The standard Bolex stereoscopic projection lens with built-in polarizing filters is mounted on a standard projector, and with the aid of polarized glasses the slow-motion pictures or the single still frames are viewed on the screen in 3-D. The still frames are used to determine the measurement data of the particles in motion.

A very simple measuring device, or analyzer (Figure 16), was easily, rapidly, and cheaply constructed from war surplus equipment. Mirrors with the necessary movements were obtained from an aerial sextant and the spotlights from gunsight collimators.

The analyzer works like this: Two light beams are adjusted so that one beam falls on the left image and the other beam falls on the right image of the particle on the screen. This condition is accomplished stereoscopically. The stereoscopic probe-beam is adjusted so that it falls on and appears to float at the same depth as the stereoscopic image of the particle. The stereoscopic probe-beam is so coupled to a mirror system that two converging plotting-beams are projected to the side of the instrument at the same scale as object space. The known distance to, and the diameter of, the tuyere nose are used as control data to adjust the analyzer. A full-scale plot is compiled of all the particles in the stereoscopic field of view and velocities computed. A reasonable estimate is also made of the nature of the cavity created

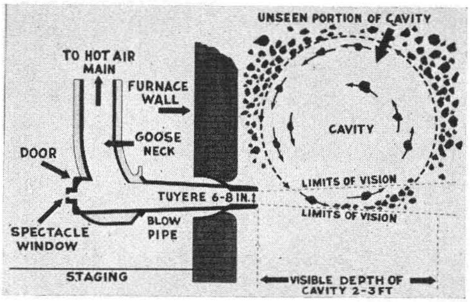

FIG. 13

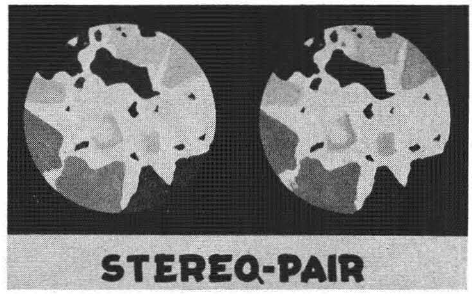

FIG. 15

by the blast in the region not covered stereoscopically.

The solution of this unusual problem in stereoscopic cinephotography is an intriguing demonstration of conforming to the performance specifications and still maintaining simplicity based on ingenuity and resourcefulness.

Metrical photography is not used to any significant degree in the field of medicine. Still, motion picture, and stereoscopic photography are frequently utilized in medicine but basically for qualitative and not quantitative analyses. Dr. E. A. Miskin[8] ventures to state "That little use of measurement of stereoscopic photographs is made is perhaps due to the medical practitioner's usual dislike of anything mathematical: particularly is this the case when errors of precise measurements are concerned. Stereoscopy as a means of illustration is used much more widely and there is no doubt that the technical skill and adaptability of the medical photographer is high, both in the field of black and white, and in colour photography. The ability to produce good stereo-pairs is not lacking, and the possibilities of this type of photography are appreciated."

Brief outlines of some medical problems involving three-dimensional space measurements are:[8]

(a) Deformation and swelling.
(b) Correlation of specific diseases with particular body types, surface area, and volumes. It is of interest to point out that the method to determine the body area is to paste small pieces of paper over the patient and to measure the total area of the paper.
(c) Tumorous growth of the eye. The rate of growth of the tumor is sometimes the deciding factor as to whether the eye should be removed.
(d) Location of opaque objects in the body. Stereo X-ray negatives have been used for many years but little use has been made of measurements.

Another use of metrical photography is better appreciated in Switzerland than the United States. For many years the Swiss Police have been covering accidents with stereometric cameras. The Swiss law enforcement authorities are to be congratulated for their foresightedness and technical approach to accident evaluation. Un-

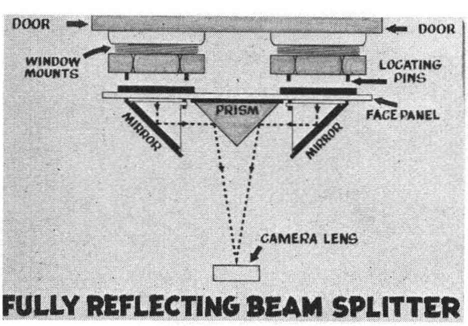

FIG. 14

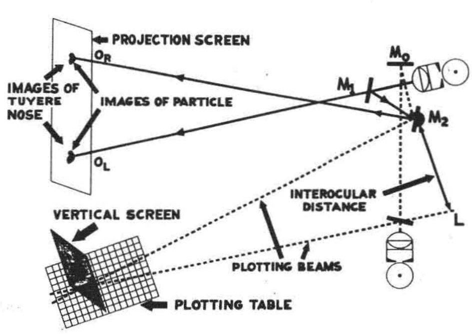

FIG. 16

fortunately, no such comprehensive technical approach to accident evaluation is evident in this country. We have always been under the impression that as soon as an economic need existed for a particular commodity or technique that it would soon be developed and distributed. It certainly appears to us that something equivalent to the Swiss approach to accident evaluation is timely for application in this country. For example, during the past decade the City of New York has had over 1,000,000 automobile accidents resulting in more than 6,000 deaths and 500,000 injuries. During the past years the premiums on automobile insurance have increased appreciably throughout the country, owing to an increase in the number of accidents, much larger judgments awarded by juries in law suits, and substantial increased costs of automobile repairs.

Even though the police authorities may conclude that capitalization of stereometric accident apparatus may not be financially feasible at this time, it may prove economically sound for the various automobile insurance companies to mutually support such a program. Favorable decisions to only a few large litigations would more than cover the initial investment. Our company served as photogrammetric consultants on an accident case that involved suits amounting to more than a quarter of a million dollars. The awards resulting from four such cases would procure a million dollars worth of stereometric equipment. We are of the opinion that the economic need is apparent. Possibly the parties that would have most utilization of the photogrammetric procedure are not cognizant of its presence or availability.

An interesting example of photogrammetric evaluation was experienced a few years ago. A lawyer presented me with an inexpensive 8 mm movie-camera and a roll of colored film poorly exposed on a hazy day. The lawyer requested that I determine the altitude of the aircraft when the last frame was exposed. The plane had been occupied by the pilot and a passenger. The passenger was exposing low-oblique aerial movies of the countryside. The aircraft engine suddenly stalled. The passenger stopped taking movies, the plane crashed, the pilot was killed, and the passenger severely injured. The case had many legal aspects, but one of the most important points to be resolved was the height of the aircraft at the time of engine failure. The flying height would tie in many loose ends of other scientifically prepared data. The testimony of witnesses as to this height varied from 200 feet to 2,000 feet. Very little progress was being made with the case until nearly two years subsequent to the accident when the lawyer learned that movies were being exposed at the time of engine failure. The lawyer was an ex-Marine officer with experience in the Pacific Theater, and was generally familiar with the role aerial photography played in the successful execution of the war. He reasoned that possibly an altitude could be determined from the color transparency by a specie of the human race technically referred to as a photogrammetrist.

The problem was as challenging as it was novel. First, the 8 mm. movie-camera was calibrated for focal-length and plate perpendicular by an application of a technique well-known to surveyors as the three-point problem. Two days were spent over the microscope examining one frame of the color film to identify control points. Six control points were selected for two independent solutions. Distances between the control points averaged approximately one-tenth of an inch. The corresponding ground-control points in the vicinity of the crash were surveyed. The flying height, tilt, and swing were determined by a graphical method.[7] The computed values resulted in an altitude of 700 feet and a tilt of 40 degrees.

Inasmuch as the flying height was greater than 500 feet, thereby conforming with aeronautical regulations for the countryside, it was the first big turning point in the status of the case. The flying height was then integrated with other complicated technical data, and the evidence took firm shape for the first time. The case was soon settled out of court, although it was three years subsequent to the aircraft accident. The lawyer gratefully acknowledged that the successful conclusion of the case was due largely to the metrical data made available through photogrammetry.

After the file covering the accident was stamped "*Closed*" and neatly filed away, I visited the lawyer to learn to what degree the science of photogrammetry had impressed him. The lawyer offered four significant points of impression:

1. The metrical analysis of the photo-

graph gave him rejuvenated confidence in the case.

2. He did not realize the degree of accuracy obtainable by means of photogrammetrical analysis.

3. Without the metrical analysis of the photograph he had no support and therefore no means to refute contributory negligence as to the altitude and attitude of the aircraft.

4. The fact that film can be exposed, developed, stored, and years later removed for a metrical analysis.

Inasmuch as the science of photogrammetry is not well known, budgets to pursue metrical photography projects are usually nonexistent or very meager. Even when metrical photography is recognized as the means of performing the measurement survey, the capitalization of recording and reduction instrumentation may appear to some to be relatively high. A vicious cycle or round-robin appears to exist. Manufacturers cannot anticipate all the special applications of metrical photography and, if they could, the many and varied applications may not be compatible for standardization and production of stock items in the interest of more attractive pricing for the potential user. In the meantime, the potential user must either improvise, modify, utilize existing components, or procure a custom-made system. As we are all aware, custom-made systems can be many times more expensive than an equivalent production item. I would hesitate to venture a guess as to the cost of one of our popular automobiles if it were custom-made. Possibly an initial solution to the capitalization problem for organizations with limited budgets is one that has been utilized before in other fields under similar circumstances, and that is for one organization to capitalize the instrumentation, conduct comprehensive metrical photography research, and offer the service to others.

The establishment of metrical photography as a universally recognized service tool to science, engineering, and industry will be dependent not only upon the status of our technical competence, practical experience, or fineness of instrumentation, but also upon our ability to understand people and their requirements, so that the problem can be clearly stated and the solution satisfactorily performed.

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