*Photography Remains King in Aerospace Age**

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THE aerial photographic world has recently heard loud rumblings in the Midwest that Aerial Photographs are obsolete and will in the not-too-distant future be replaced by other sensing devices which will revolutionize the art of data acquisition from aircraft and space vehicles. Naturally, when I heard about this latest forecast, I contacted many aerial photographic friends in the Washington area and assembled a few observations which will be covered in my talk. Amongst the prognostications of the wonders of the things to come was one that shook me a little. I believe I am accurate in quoting it as "the know-how now exists by utilization of satellites and other techniques to produce an X-ray mosaic of the entire earth's crust." Now I would not want to doubt that this is true, but since I am now starting to view each glass of milk with skepticism as to its strontium 90 content and its effect on my future virility, I can't say that I am looking forward to this predicted electron bombardment with any degree of enthusiasm.

It is my observation that aerial photography is not *only* very much alive but is spawning at a very rapid rate. This applies in the military government mapping agencies and the world-wide commercial industry.

As a build-up to the main points I wish to stress in my talk, I think it would be a good idea to give you a brief outline of the difficult days we experienced at Wright Field after years of financial starvation prior to the Second World War. Also, the miracle we were expected to perform in providing our rapidly expanded field forces with the necessary aerial photographic equipment.

In 1937 our total budget for Air Corps Research and Development was less than $100,000. This was supposed to cover the development of cameras of all descriptions, portable laboratories, night photo illuminants, photographic processing equipment, mapping equipment and so forth. Up to 1940 we were developing equipment for National Guard Observation Squadrons and our total appropriation never exceeded $200,000. Suddenly the country was at war; money or the lack of it was no longer a problem. My mission was simple—get the material, get it quickly and be sure that it works. For one so long accustomed to starvation funds, this would seem like a bonanza—but, with almost the pick of the vast United States industrial complex available to me, I found my biggest problem was in finding the industry, that company, that corporation with the right combination of men, machinery, know-how and an appreciation of the tolerances associated with aerial photographic equipment to be of any immediate value. Luckily, this did not apply to the film, paper and chemical industry which did an outstanding job of expanding facilities and channeling civilian products to the military.

The American optical industry at that time could meet only a small fraction of the requirements for research and development and procurement. We needed to develop new mapping and long focal-length lenses. We were in such desperate need for a certain type of lens for strike-recording aerial cameras that I had a California company hurriedly manufacture hundreds of lenses made with lucite lens elements.

Because of changes in aircraft which would fly photo missions at greater heights, we needed to develop exceptionally long focal-length lenses. I went to Kodak and to Bausch & Lomb, our main sources for the development of such lenses. Also, to line up the facilities to make thousands of lenses of every description. At each plant I found that I was standing in the rear of a long line of high-ranking officers, each one with a list of requirements a mile long.

At that time I was a Lt. Colonel and ahead of me in that line were two-, three- and four-star Generals, arranging to book almost all of the facilities for the R & D and the production of range finders of every description for

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EDITOR'S NOTE. The reader of this paper will be interested in comparing Gen. Goddard's opinion with that of Dr. Talbert Abrams as expressed in his paper published in the December 1961 issue.

artillery, aircraft and tanks. Also in the line-up were Admirals putting in their orders for submarine periscopes and for the vast amount of optical goods used by the Marines and the Navy.

Two days later when I reached the head of the line I was given a terribly discouraging set of answers. If they could get to it, it would take one or two years to design, construct and test my requirements for telephoto optics, night photo, instrumentation and mapping lenses. Furthermore, it would take months to get a sufficient supply of raw optical glass. It was certain that the Germans would not give us any. Germany was the source of considerable first-class optical glass prior to the War.

Realizing that I had to DO something about the matter, I went to call on Dr. Vannevar Bush, Director of the Inventor Council, and submitted a plan to him. This plan was to immediately expand our glass-making facilities and, in addition, to establish an optical research and development facility at Harvard where we would have the services of Dr. James Baker, who had shown outstanding talent in the design of advanced aerial camera lenses, particularly of long focal-length for high-altitude photo reconnaissance missions. Drs. Bush, Compton, Millikin, Johnson and others accompanied me to Harvard to see Dr. Shapely. Before the day was over, we had an agreement to move all the books out of one of the large Harvard libraries and make this an Army Air Corps Optical Research Center.

This group, headed by Dr. Baker, who soon brought in Dr. Macdonald, now chief of R & D at the Itek Laboratories, designed and tested new advance lenses in a few months—heretofore years had been required. With their help we expanded our optical glass production and met the requirements for the thousands of aerial cameras supplied to our Army and Navy and our Allies. The Russians received thousands of these cameras.

After the War when I returned from the European theater and was assigned to my old job as Director of the Aerial Reconnaissance Laboratory at Wright Field, I saw Dr. Shapely at Harvard and tried to get him to continue the optical R & D program. I promised to put up a new laboratory if he would continue. He refused to consider this, principally because he wanted to get Dr. Baker back into the Observatory to start teaching again.

I then approached Dr. Marsh, President of Boston University. He gladly accepted the offer and promised to put Dr. Duncan Macdonald in as Director to head the technical group which was moved practically intact from Harvard.

The Air Force hurriedly erected three Butler buildings on the Boston University campus, and in a short time, they started to work on a number of important optical and photographic research programs which in later years were extremely valuable to the United States.

Boston University became so interested in the work of this group that they established a university course in aerial photography which was attended by R & D qualified Air Force officers who wound up with Master's degrees after graduation. Many of these officers were later assigned to manage very important aerial photographic projects.

In 1958, long after I had retired from the service, the Air Force had been listening to many advocates of radar and infrared as the modern means of accomplishing reconnaissance missions. This seemed to have been oversold and many top Air Force officers actually began to lose interest in supporting research and development of optics and aerial photography in general.

The funds to support the valuable work at Boston University were cut drastically to a point where the University informed the Air Force that it would have to terminate its contract.

Recognizing the tremendous National asset which this laboratory represented, and the discontent being generated by the temporary lack of support afforded aerial and space photography, a group of visionary scientists under the leadership of Col. Dick Leghorn and Dr. Duncan Macdonald, projected this potential correctly and rounded up sufficient financial backing to insure continuity of the laboratory team and its efforts under the newly formed Itek Corporation. They were able, through the medium of Itek, to assure continuity to important Air Force Research and Development work in this area and to make giant steps forward in the state of the art. This was a fortunate move for the Defense Department, N.A.S.A., and the entire world, for within a year the pendulum had swung in the opposite direction, and the Department of Defense began to realize the tremendous importance of research and development of optics and photography for the space age.

Today, the old Harvard-Boston University group with Dr. Duncan Macdonald in charge of research has expanded three-fold, and now is housed in a new three-million-dollar laboratory at Lexington, Massachusetts. They are supported by a West Coast laboratory at

Palo Alto, California, and further by several subsidiaries. They are equipped with the most modern scientific test facilities conceivable. I always feel proud that I played a part in the early days of the growth of this fine organization.

Aside from the tremendous requirements for photography in space, there is much to be done to meet the ever-increasing photographic requirements of the military services.

For limited or guerilla warfare, I am firmly convinced that night photography will play a big part in obtaining desired information as to the whereabouts of the opposing forces. This was true in the Korean war when the Chinese reversed the habits of military operations by sleeping under clever camouflage in the daytime and not only fighting at night, but performing their entire logistics operations. This was one of the reasons they did so well. In future wars, armies will not move divisions or supplies over roads and open fields in the daytime, especially with the opposing forces using atomic missiles, bombs and artillery.

I am firmly convinced that the Air Force should greatly expand its research and development of equipment and methods of carrying out night aerial reconnaissance. I am certain anyone who has known me cannot accuse me of coming up with this thought for the occasion of this paper. Research work in moonlight photography has been fairly successful to date, but this program should be greatly expanded, particularly in the field of image amplification, higher speed films, improved optics and laboratory processes.

Another area which needs much attention is the improvement of aerial cameras. We are still using the same basic camera designs which were used in the First and Second World Wars. Because of high reconnaissance aircraft and drone speeds, we have speeded up the shutters and film recycling mechanisms to a point where the camera has become a vibrating machine. Panoramic scanning cameras are definitely a good solution to this problem, and such cameras are out of the experimental stage and ready for use. There is need, however, for considerably more development of cameras along the lines of the panoramic type employing the strip principle.

We are now entering an era when the general public, industrial leaders, military leaders, the Congress and Administration all recognize the vital necessity of broad and specific research and development programs. Not too many years ago this recognition was largely lip service. Military research and development leaders, fortunately, were blessed with vision and foresight. They fought with determination to secure adequate funds and resources with which to equip this nation with the most modern weapons systems conceivable.

The nature of research, the definition of terms, and the determination of boundaries have been studied and examined many times. Sage men have made an effort to *definitise*, for example, the division between basic and applied research, between research and development, and between development and testing, and again between the various stages of testing. No one has ever come up with a suitable set of terms nor an adequate delineation of boundaries. It is certainly *not* my purpose here to attempt a new set of definitions or the establishment of new boundaries. It *is* my purpose, however, as one who has long been involved in one area of basic research, applied research, development, testing, production, operation and maintenance of the resultant product—one that has traditionally been given lip service during peace time and frantic last-ditch effort in war time—and I refer, of course, to reconnaissance and, more specifically, photographic reconnaissance—*to attempt* in a small way to set the record straight and to pass on a small segment of the results of my experience.

Someone has defined basic research as searching for the unknown. This is about as good as any, but the process is not so poorly defined. Basic research is the result of inquisitive minds who either observe some phenomena and then systematically attempt to find out the reason the phenomena occurred, to come up with an explanation and a set of rules of behavior for these new phenomena. Another method is just plain thinking in a particular area. Reasoning that if this is so, then why shouldn't that happen when something occurs to disturb the status quo, etc. At any rate, the basic researcher is usually satisfied to observe, report, prove his discovered rules of behavior, and to go on searching for new or related phenomena.

The applied researcher, on the other hand, is searching for a specific solution to a specific problem that has hitherto defied solution or where the existing solution was deficient in some way or another. The smart researcher uses the results of basic research liberally in his search for a solution. At some place in that search the development process begins. We have everything from working models, breadboards, schematic models, prototypes, preproduction prototypes, pilot-line models and you-name-it.

It is usually in this last area where previous rules denied solution, or previously accepted limitations lend only partial or unsatisfactory solution, that the greatest satisfaction is gained when a marked improvement has been achieved. Everyone likes to say "I told you so" to some extent. It is in this area that the successful developer or applied researcher usually begins to predict that the previous method or device will soon disappear as the result of his finding or his development. Sometimes this is true, but mostly the new device takes its place in the roster of tools and performs its function as an addition and not a replacement.

In the area of aerial photography, in which I can claim at least longevity, we have been put out of business on almost an annual basis. But aerial photography still has and always will have a most important place in the scheme. At first we had no cameras designed for the job, but every successful picture was the subject of great wonder and awe to the laymen and great disdain to the ground-borne photographer. At that time optics were crude, shutters were crude, the film or plates were crude, and the airplane itself was also crude. The airplanes shook, rattled and vibrated; they were mostly open cockpits. The temperature extremes encountered wrought havoc not only with the shutters and the film, *but* with the poor photographer. We had to take pictures only when the light was right. Even so, reconnaissance photos revealed a wealth of military information—when you could get the combat commander to look at the photo and believe that it was an actual picture.

One by one we have overcome limitations previously imposed by optics, shutters, film, magazines, rapid development and printing, vibration and lack of light. Precision aerial mapping has made the cartographer's problem infinitely simpler and more accurate. Each year the Air Photographic and Charting Service (Mats) flies more than 80,000 linear miles of aerial mapping photography. When processed this photography is turned over to other agencies of the government to become raw material from which new maps and charts are made. Hyran distance measuring equipment and high-resolution photography are highly desirable in this work in order to orient each photograph in its exact position on the earth's surface. Enemy forces have had to rely upon elaborate and eventually fruitless camouflage methods to conceal their intentions; today a combat commander no longer fights in a vacuum—he knows what the opposing commander possesses and its disposition, not only before the battle is joined, but during its course as well.

We have come a long way, but there is still a long way to go.

We now hear that we have been put out of business once again. This time by side-looking radars, infrared, radiation, X-ray, masers and lasers. We who have had considerable experience in this game welcome these new devices into the family. We are eager to use them. Sidelooking radars make impressive photos even through cloud cover; they lack the necessary detail, however, to satisfy the precision requirements of modern military science; they become a very useful adjunct but certainly not a replacement.

I shall always remember back in England in the winter of 1943 when my *then* boss, Elliot Roosevelt, Chief Aerial Photographer of the 8th Air Force, assigned me to Alconbury, England, to modify a number of K-24 cameras to do special radar-recording missions of German and French cities. We photographed the standard P.P.I. scope. These pictures were badly needed for the bombing objective folders of the 8th Air Force bombing personnel. The cameras were installed in high-flying British Mosquito aircraft. On the first mission it was discovered that radar pictures taken approaching Berlin from the East were quite different from pictures approaching Berlin from the west, north or any other direction. It was then agreed that the special flight of radar recording Mosquitos take four radar pictures of each German city. The bombing crews were then able to select a radar picture to match up with their P.P.I. scope when they made their bombing runs over a city from a certain direction. Since the standard P.P.I. scope is still the principal means of radar presentation and is used in all of the current bombing and navigation radars, very little progress has been made in this area since the war. In oblique aerial photography we can perform restitution in the laboratory, and thus convert unusable photographs to ones useful to mapping. Perhaps here is an area in which the electronic engineers can exercise their ingenuity. I refer, of course to electronic restitution, or the conversion of the present radar oblique presentation to one more closely approximating the resolution and definition of a vertical aerial photograph. And while they are at it, they might just as well change the coordinates from Polar to Cartesian.

When I returned to Wright Field after the War in 1945, I was very enthusiastic about the possibilities of radar-recording for possible use in mapping. A special technical group and large sums of money were readily made available for research and development in this area. Later on the group concentrated on the development of side-looking radar for low-altitude tactical reconnaissance and high-altitude strategic reconnaissance uses.

Considerable progress has been made in side-looking radar over the past fifteen years, but there is still much research and development to be accomplished before it can meet the requirements. If and when it is perfected, it will become a very useful adjunct. I say again that it will certainly not be a replacement for aerial photography with its over 100 lines per millimeter resolution.

Photographic film is a very large band-width medium. A 70 mm. camera (70 mm.×70 mm. picture) cycling at the slow rate of one frame-per-second records at a 50 to 200 megacycle band-width. (Based on 50 lines-per-mm. to 100 lines-per-mm.)

Recent improvement in side-looking radar has made necessary increasing the size of installations and making it much more sophisticated and expensive. This situation presents very serious problems to the weapons systems manufacturers who are developing tactical reconnaissance aircraft and drones for the Air Force, Navy and Army.

In using non-passive radar in military aircraft, we must remember that being a source of active energy they stand out in the dark or in bad weather like a flashlight in a dark stadium. They effectively double the range of the weapons direction-radars which are in place to prevent the successful completion of the reconnaissance mission.

The maser, on the other hand, works on the receiver circuit. Phenomenal gains in signal to noise ratio have been achieved in the laboratory—as high as 39 *dB* gain is theoretically possible and this is truly phenomenal. The only ones in use to date, however, have been in massive radar telescopes. As a passive device, temperature-sensing and recording-systems employing masers are theoretically capable of flying over a hospital, and telling you the temperature of everyone in it. They do have, however, a number of practical limitations. One is, of course, that to achieve these results, the cavity and crystal must operate at the temperature of liquid helium. Helium is a scarce commodity; it is expensive, relatively hard to work with, and once used, it is gone forever. Another limitation is the requirement for very precisely controlled pumping energy systems. They need a very precisely controlled magnetic field which can give trouble to other of the airplane systems.

In most cases they require a relatively large and bulky circulator. They are limited by the noise introduced in the balance of the system, such as the antenna, the wave-guide and other systems components. We welcome the maser and its stepchild, the laser. We eagerly await their entry into the field of practical data acquiring systems, but we do not foresee the time when their entry will place the aerial camera on the shelf of the museum.

The fabulous speeds of compution and the high information-storage capacity of modern high-speed digital computers have been a source of wonderment and awe to the comparative layman. Informed electronic engineers, however, recognize that the current techniques are approaching practical limits in storing information. We now find these computer engineers turning to high-resolution photographic techniques as a source of solution to this problem. It has been recently illustrated that a one-inch-square high-resolution photograph contained enough information to utilize several large rolls of magnetic tape upon which the same data were stored electronically.

It is particularly encouraging for me to see this rapid national reawakening to the mission and power of photo optics. An independent group of scientists has recently petitioned the National Science Foundation, through professional societies, including the Optical Society of America, to react to the national need for a major program in basic optics, suggesting their consideration of a National Optics Program. (A Program, I might insert, to take up in large measure, the gap created by the cancellation of the program at Boston University Optical Research Laboratory in 1957, following a slow-down in that program starting in 1954.) A deficiency recognized by the Range Instrumentation people at Cape Canaveral where a three-time growth in optical instrumentation is now projected over the next five years. This is a value now clearly recognized by the United States Air Force and top Government officials. After years of research and development and operational experience with radar, infrared and television, they now place more dollars into photo-optical reconnaissance than ever before. This can be judged either on an absolute basis or on a relative basis as compared to all other sensors. At last I feel that proper perspective is being achieved.

In my career I have been accused of making many provincial remarks. For example, "There is no substitute for focal-length," and "A picture is worth ten thousand words," etc. The funny thing is that while these are all true, it has never been so loudly reported that since World War II I have steadily pushed for the (yet to be invented) integrated receiver which combines radar, infrared and the photo-optical sensors, each in its proper perspective, each supplementary to the other.

I think that the lesson to be gained here is one of profound national significance and one which, based upon my past experience, will not necessarily be heeded. I refer, of course, to the one irrefutable fact that all of the information-gathering techniques have definite limitations governed by their very nature. I believe that the electronic definitions cover this fairly well—the frequency and band-width characteristics of each, based upon physical laws fairly well delineating the limits of each. Success in achieving solution to a difficult problem in any area should not so cloud our judgment with jubilation as to neglect the potential improvements in other areas. Nor should the challenge of solution to a difficult problem in one area consume all of our efforts at the expense of other areas. The necessity of achieving and maintaining balance is one of our Nation's most pressing problems.

If you concede that radar has definite limitations (both practical and theoretical), but that we by no means have yet exploited all of its potential; if you concede that infrared systems have limitations (both practical and theoretical), and that we have only begun to realize its potential—then you must also concede that optical-photography, which also has limitations, has room for growth in its exploitation and in its potential. I will illustrate that we have not yet approached the limit of its potential.

But we must move this entire field of acquisition technology and science ahead on a broad front.

We are absolutely certain of one thing—that operating at the highest-frequency and with the greatest band-width, our rewards are certain to be the highest in the fields of resolution, accuracy and recognition of detail. To get this we must pay the penalty of fair weather operation. Let me briefly outline the untapped resources of aerial photography—

It is perhaps not fully recognized that one of the principal products emanating from the Boston University group was a complete generation-jump in the state of the art of photo-optical techniques. The current lexicon calls this a "Quantum Jump." During World War II and until the early 1950's, we utilized lens systems which I would categorize as being in the f/8 class, super XX emulsion, and we operationally achieved from 10 to 20 lines-per-millimeter. Coming out of this research, markedly aided by advances in film technology at Eastman Kodak, we today find the current state of the art of the f/5 lens types, the broad class of 1188 type emulsions and operational recordings, at 75 to 150 lines-per-millimeter, a remarkable advance in one decade. This means that current camera systems, fully exploiting the current state of the art, become markedly smaller and lighter in order to duplicate the missions of ten years ago and to operate from considerably higher altitudes. Here I observe that the commercial operators have not taken the advantage of this existing state of the art to the degree to which the United States Air Force has taken.

But I do not wish to imply that photo-optics rests on its laurels. Another generation-jump in quality is not only possible, it is imminently probable; and this, coupled with further exploitation of operational techniques, offers tremendous potential advantages. While we must rule out that the short wave-lengths of radiation which photography employs can ever eliminate the weather limitation of cloud or haze, we must accept the fact that ever-higher resolutions are coming; that by properly selecting multiple spectral band photo-recording devices, we can more precisely cover the earth's surface to detect microscopic traces of chemical elements that are due to geologic irregularities of the subsurface. This, I believe, presents to us the most powerful tool for geologic exploration yet conceived.

We must exploit more fully the rapid-processing techniques now available to introduce near-instantaneous viewing.

We must also face the fact that with higher and higher speed materials, improved stabilization and improved aperture lenses, we are on the threshold of winning the battle for a *non*illumination limited photo reconnaissance. I am confident that I shall be here in my current occupation when this goal is achieved.

Finally, we must not forget the role of Mother Nature herself. Mankind receives all his knowledge through his senses—and of these senses—the human eye provides the greatest band-width for receipt of knowledge. Speaking for the analyst—only photo-optics presents information in that form which is familiar to the common experience of the analyst. Therefore, not only in the camera, but also in the analysis cycle, photo reconnaissance will remain both practically and theoretically our best source for quantity collection, quality collection and positional accuracy. For this, we will continue to pay the price of weather limitations.