HISTORY OF PHOTOGRAMMETRIC MAPPING IN C&GS

By G. Carper Tewinkel*

Introduction

The International Society for photogrammetry held its first Congress in 1910 in Vienna, Austria. I mention this fact because one of the delegates was Mr. John A. Flemer of the U.S. Coast & Geodetic Survey in Washington, D. C. Early in the 1890s Flemer, a native of Austria, had been hired by C&GS and assigned the task of determining the boundary between Alaska and Canada using photographic methods. Flemer's Canadian counterpart was Eduarde Deville who was a world-famous professional in this kind of work. They used phototheodolites to take horizontal photographs on glass plates from peaks of that region and compiled positions and elevations by means of a graphic procedure called "iconometry". This includes the application of the principals of perspective geometry using horizon lines, vanishing points, resection, intersection, etc. Flemer lived in Washington until his death about 1950.

As many of you know, photogrammetric mapping was applied vigorously in Europe a decade or two before it was used very much in the United States. Not until World War I, however, did airplanes and aerial cameras become available for aerial

*After using aerial photographs six years in the Cartographic Division of the Soil Conservation Service in Spokane, Mr. Tewinkel was employed from 1941 to 1972 in photogrammetric research and development at the C&GS in the Washington, DC area.

photogrammetry. C&GS became earnestly interested about 1919. Aerocartographs were being used in the 1930s by Denmark for mapping in Greenland. In 1940 Bausch and Lomb began to manufacture in Rochester multiplex projector stereoplotting systems for mapping by the U. S. Army, the U. S. Geological Survey and Tennessee Valley Authority. And not until World War II did photogrammetry begin to flourish in this country. Since the War, the United States has become the leader in photogrammetric development and applications world wide.

An early interest in photogrammetry was expressed by C&GS in 1919 when Lt. C. G. Quillian was assigned to investigate the feasibility of using aerial photographs for compiling coastal topography. Through a cooperative venture with the Air Service of the U. S. Army (which furnished the airplane, camera, film and pilot), a test project was conducted near Atlantic City, NJ.

Quillian was succeeded in 1920 by Lt. George C. Mattison who arranged cooperative projects with the Navy as well as the Army. One test was located in the Mississippi Delta. Mattison and the pilot processed the film and began compiling a map in the field. Mattison worked alone there the balance of the season, and continued the work for two more years. He wrote that this was, "the first aerial mapping project in the United States." He noted, however, that the field of view of the photographs was so small, and so many photographs were needed to cover the area and so much control was required, that some better way was needed to overcome the difficulties. The answer was to use multi-lens cameras. Soon thereafter 3-,4-, 5-lens and tandem 5-lens cameras became available.

Mattison was joined in 1928 by Lt. O. S. Reading whose efforts flourished until his retirement in 1954.

The Era of the Nine-Lens Camera

The Director's annual report for 1928 included the statement, "C&GS has been charged with producing maps for the guidance of aviators flying over the airways of the nation". Working with the Army Air Corps, Reading photographed the Ten Thousand Islands and Canaveral in Florida using a Fairchild 4-lens camera. He was cited as one of the two aerial photographers. The next year he recommended that C&GS purchase, or preferrably construct, "a multiple-lens camera of high precision".

In cooperation with the Arky Air corps, in 1930 Reading contued photographing the east coast of Florida and also on the Hudson River in New York. The next year C&GS obtained 5-lens photographs in the San Juaquin area in California. In 1933 Reading planned and supervised photographic projects throughout the year. Airphoto compilation offices were opened in Savannah, Charleston and New Orleans where Reading of officer-in-charge of aerial photographic mapping.

In 1934 Reading prepared designs for a 9-lens camera and a transforming printer. (He was also directed to design and have manufactured a precision wet-plate copy camera for chart reproduction). C&GS hired about 100 men for the compilation of planimetric maps, mostly from 5-lens photographs.

A small group of photogrammetrists from the general Washington area one evening in Reading's home to discuss the possibilities of creating a national photogrammetric society. Thus the American Society of Photogrammetry was formed. Reading attended the Congress of the International Society for Photogrammetry in Berlin. (He also would attend the next congress four years later in Rome).

The 9-lens camera was being constructed in 1935 by the Fairchild Camera and Instrument Corp. of Yew York. The wet-plate camere was received and installed, and Reading was instructed to have manufactured a reling machine for drawing map projections. The 9-lens camera was delivered and calibra- and testing were begun immediately; its first photogrammetric project was accomplished in 1937.

A rectifying camera (distinct from the transforming printer) was nearing completion in 1941 for processing the 34 by 34-inch composite 9-lens photographs. Also two stereoscopic plotting instruments for drawing contour lines as well as planimetric detail from the 9-lens photographs were in the process of construction; one was completed in 1943 and the other a year later.

In 1943 the aircraft carrying the 9-lens camera crashed on takeoff from Adak, Alaska, killing the two C&GS personnel, all the plane crew and several army passengers. The aircraft was a U. S. Coast Guard PBY-5 flying boat. The 9-lens camera was thrown away from the wreckage, badly damaged and charred. The camera was sent back to C&GS and returned to the Fairchild company for reconstruction with several minor improvements. Photography with the 9-lens camera was resumed in 1946, carried by a Coast Guard PBY-5A Catalina.

The Division of Photogrammetry was formed in 1945 with Comdr. K. T. Adams as its chief. The names of a few of the personnel come to mind: Bennett Jones, Les Lande, Reynold Ask, Ralph Berry, Shirley Griffith, William Harris, Charles Wittman, Byron Hale , Harlan Cravat.

In 1946 the aerial photographic laboratory was operating on two shifts printing 9-lens photographs. Arrangements were made with the Coast Guard to furnish a PB1G B-17 to carry the 9-lens camera. The Division received a long-term loan of a captured German Zeiss Stereoplanigraph plotting instrument for single-lens photographs. A multiplex projector system was purchased (also a stereo plotter for single-lens photographs), and two men were being trained by the U. S. Geological Survey.

Comdr. L. W. Swanson established in 1947 a camera calibration test area near McClure, Ohio. It was 5 miles square, almost in a common plane (not quite horizontal), and was permanently pre-marked. A 9-lens photograph would be taken of the area at the beginning and end of each photographic season. The next year the 9-lens camera calibration laboratory was moved from the Department of Commerce Building to a small building on the astronomy grounds in Gaithersburg, MD. Reading attended the Congress of the International Society for Photogrammetry at the Hague, Netherlands, and was elected president of that organization, which meant that the next Congress would be held under Reading's direction in Washington in 1952. (This is an appropriate place to comment that Reading took a great interest in the congresses, and that he continued to attend after retirement as long as his health permitted including Helsinki in 1976.) Reading was promoted in 1949 to the rank of captain and he became the chief of the division. He retired in 1954.

C&GS began in 1952 to assist actively the country of Liberia to create a photogrammetric unit and map their country. Aero Service Corp. provided photographic coverage. C&GS supplied a plane, cameras, and three men in 1954. Two Liberian nationals spent one year in the Division of Photogrammetry. The project was completed in 1955.

Special Applications

Capt. L. W. Swanson succeeded Reading as the chief of the Division of Photogrammetry. One of Swanson's first activities was to purchase in 1956 the first-made Wild RC-8 aerial camera that could take color photographs as well as black-and-white. In 1957 a compatible Wild A-8 stereoplotter was added to the Division's group of instruments.

An important contribution inaugurated by Swanson was to coordinate the operation of the airplane with operations on the ground via two-way radion communication between the pilot and a field chief, such as for tidal current studies and tide-controlled shoreline mapping. This required a careful organization in advance, and an authoritative and knowledgeable coordinator on the ground in the area who could weigh the reports of ground observers and transmit practical instructions to the pilot. He was usually assisted by field helpers and also by a specialist in tidal movements. The idea was to begin taking photographs at a point on the high-water line within one minute of a prescribed time, to cease photography at another time, and then get ready to photograph someplace else nearby when notified.

Another development introduced by Swanson included a series of innovative applications of aerial photogrammetry to a variety of projects completed in addition to the dominant responsibilities of coastal and airport mapping. Several of these Special Applications are now cited.

Dulles Airport

In the late 1940s the Federal Aviation Administration (FAA) asked C&GS to help them with the preliminary surveys of Dulles Airport. Photographs were taken on February 1 with a single-lens camera from the B-17 airplane at 3000 feet. It had snowed about six inches the previous night and a bright clear sky was beneficial. The ground in wooded areas was white with the shadows of the naked tree trunks making it easy for a photogrammetrist to "set the floating dot on the ground" in the Kelsh stereoplotters.

Five plotters had been calibrated by measuring a test plot of one stereoscopic model of the area that had been contoured by field methods. A correction graph was prepared for each plotter showing how much it was necessary to change the elevation of the floating dot. Correction graphs were drawn in heavy lines on a large blank sheet of heavy paper. Contours were drawn on a transparent manuscript sheet through which the operator could see the correction graphs. The scheme thus accounted for errors introduced by unknown lens distortions of the aerial camera and the projector lenses, the error of the ball-cam correctors of the plotters, and the unflatness of the slate table tops. The operators were cautioned against interchanging either the projectors or the filters, and to operate insofar as possible from the same side of the table.

Five-foot contours were drawn and the maximum expected 90 percent error was expected to be about 2.5 feet in conventional practice. But accuracy tests after the fact indicated an error of only 1 foot. The FFA interpolated 2-foot contours and all the major earth movement was accomplished with no difficulty.

Passamaquaddy Bay

During the 1950s the Department of Commerce requested aerial photographs of Passamaquaddy Bay in northeast Maine to study the feasability of developing a hydroelectric project based on the extremely high tides and rocky headlands in that part of the Bay of Fundy. C&GS obliged, but I never heard what the results were.

Washington Beltway

In 1956 photographs were desperately needed for a project of the Bureau of Public Roads to develop the beltway around Washington, DC. Early in the year C&GS rented a Piper Tri-Pacer civilian aircraft inasmuch as C&GS photographic airplane was not available. The photographs were obtained as desired.

Tidal Current Surveys

Several tidal current surveys were conducted photogrammetrically since 1958 in marine estuaries, river mouths and coastal circulations. The scheme was to repeat aerial photographic coverage (perhaps once per hour) during at least one complete tidal cycle. A second small plane is used to drop from a very low altitude small paper bags of aluminum powder (at first other materials were used, such as sheets of plywood) at designated sites at regular time intervals. The paper bag would break open on impact and the powder would spread out into a huge blob (30 feet in diameter) floating on the surface of the water. The spots can be identified on the separate photographs for a few hours after being dropped. The progress of the spots can be measured with a plotting instrument and, as each photograph shows the face of a clock in the camera, the velocity of the spot can be determined. Not only does the system work well in practice, but also a great deal of added information is recorded, such as different velocities in different parts of an estuary and the number of spots is virtually unlimited.

Omni Range Program

The FAA began in 1957 to improve their airport mapping procedure, called the Omni Range Program, and asked C&GS to help implement it. An Omni Range Station was built a few miles beyond the end of the primary landing runway. The new program included additional photographs extending to the station. Not only did the new program include all the information of the current approach and landing charts, but also glide paths were indicated on the charts. These paths needed to be designed, drafted and printed. C&GS already had a half-dozen or so mobile parties of three or four men who spent several days at designated airports establishing photo-control points, identifying and delineating important features, measuring the heights of obstructions, checking the lengths of runways, referring an airport bench mark to the nearest C&GS network, and fixing the azimuth of at least one runway by means of a polaris or solar observation.

Color Aerial Photographic Laboratory

C&GS created in 1961 a color aerial photographic laboratory, the first one in the world to my knowledge. The equipment included stainless steel tanks and trays, automatic processors for paper prints, a LogEtronic contact printer for color, a special densitometer and other tools. The operation was renamed later to Imagery Processing Laboratory. (At this writing the Photogrammetry Division no longer has an aerial photographic laboratory; the function is now performed by a private firm on contract.)

Photobathymetry

Aerial photogrammetry through water in shallow ocean areas was attempted several times through the years without success. (An important reason for failure was that most aerial cameras had a red filter to overcome lens aberrations to improve image sharpness. This was corrected in the Wild RC-8 camera). In 1958 an experimental project was conducted in Florida and Puerto Rico. The test was successful although several innovative techniques were applied. Thereafter the system was applied wherever needed.

Counting Pleasure Boats

In a cooperative arrangement with the U. S. Coast Guard, C&GS photographed congested boating areas along the Atlantic Coast over the July 4, 1963, holiday. The Coast Guard was able to count the pleasure boats in operation.

Earth Crustal Movement

At the request of Salt Lake City, Utah, C&GS cooperated in 1963 by photographing a portion of the city in a research project to measure earth crustal movement.

Earthquake Damage

On Good Friday in 1964 a disastrous earthquake struck Anchorage, Alaska, and other locations in the area. As quickly as practical, C&GS dispatched its large Coast Guard plane to the scene with men, aerial cameras and film. Plans were formulated on the areas to be photographed, including all affected areas such as towns, harbors, coastlines, glaciers, ice fields as well as the epicenter. More than 2500 miles of photography was taken. A well illustrated report was published in book form.

Tide Controlled Shoreline Surveys

In 1966, the Photogrammetry Division conducted a tide-controlled shoreline survey on the Louisiana gulf coast to establish a sea-level line for the determination of whether offshore oil wells were subject to taxation by the state or by the federal government.

Tide gages were placed in the area and the water level monitored for a prescribed length of time to include the periodicity of the tidal cycle. Observers with portable radios were stationed at tide staffs. When the water was at mean tide level, a field crew was notified and the aerial photographic mission overhead was instructed to proceed to take photographs with two cameras, one with panchromatic film and one with infrared film. The high-resolution panchromatic film served to map the general area while the infrared photographs showed a distinct line at the edge of the water.

The system worked well. The location of the shoreline on the new photogrammetric maps permitted one to apply the definition of the 3-mile and 12-mile limits along a sinuous shore which is subject to considerable change with time.

Oil Spills

Because of C&GS's capability to obtain panchromatic, color and infrared photographs simultaneously, occasional requests were received to photograph oil spills. This happened on at least two occasions. In 1979 in the Gulf of Mexico, oil was escaping from an oil rig and was drifting toward shore.

Persian Gulf Project

In cooperation with the State Department and the Army Map Service, C&GS photographed in 1966 for Saudi Arabia a portion of the Persian Gulf for shoreline mapping. A pilot/navigator and an aerial photographer travelled by commercial airline to Dhahran where they met a U. S. Air Force C-130 carrying photographic gear. They photographed a large portion of the coast between Kuwait and Katar with panchromatic and infrared films to record the mean low-water line. The film was developed there and returned to the United States by the Army Map Service crew.

That completes my discussion of Special Applications although Analytical Aerotriangulation and Satellite Triangulation are treated in the next sections.

The name Photogrammetry Division was restored in 1979 after having been a part of the Coastal Mapping Division since 1972.

The stellar calibration of aerial cameras was conducted after the introduction of the method as a part of the Satellite Triangulation project. Heretofore aerial camera lenses had been routinely calibrated by the National Bureau of Standards.

The 9-lens camera was used for the last time in 1961. It had been in service 38 years and had taken 141,000 photographs. It was said that the saving in the cost of field control work on its first mission in Florida was more than the cost of manufacture.

The 9-lens camera was replaced with a Wild RC-9 superwide-angle camera and a compatible B-9 stereoplotter. Needless to say, the lesser camera bulk and weight would reduce the necessity for such a large aircraft and/or allow a moderately large platform to operate three single-lens cameras simultaneously with different films: panchromatic, color and infrared.

Aerotriangulation

Graphical aerotriangulation, using transparent radial templets, was applied by C&GS beginning in the early 1920s in compiling maps from single-lens photographs, and later from multiple-lens photographs. Essentially all the nine-lens photographs were treated in this manner where the templets were 36 inches square and composed of low-shrink plastic. The photographs were mounted on aluminum sheeting before transformation printing. The templets themselves became the bases for rectification inasmuch as the prick-holes represented the correct final image positions after rectification (which was ordinarily applied only if contour lines were to be compiled.

Slotted metal templets were used from 1942 to 1945 for single-lens photographs, mostly for airport surveys.

For a short time after 1950, C&GS applied semi-analytic aerotriangulation techniques where songle-lens strips were formed at double scale with a stereoplanigraph on tracing paper and laid out on long tables (10 to 20 feet) over crossection paper. A scheme developed by the Army Map Service was used with little or no change to correct the positions of points. The principal project was done for the Army Map Service. They had flown the photographs at a scale of about one inch per mile extending from southern Arizona through Montant for small-scale mapping.

The Coast & Geodetic Survey was one of the first (if not the very first) mapping organization to develop and apply classical analytic aerotriangulation in its photogrammetric procedure. I had been very interested in the subject for more than a decade when Dr. Hellmut H. Schmid of the Ballistic Research Lab. in Aberdeen, MD presented a paper in 1954 at the annual meeting of the American Society of Photogrammetry. That was the first scheme that made sense to me with respect to mathematical rigor, the application of least squares, etc., and the computation was straight forward. Schmid's scheme was analagous to that used in C&GS for area geodetic triangulation.

In 1957 Capt. L. W. Swanson agreed that W. D. Harris (of my office) and I accept Schmid's invitation to spend a month in his office to learn as much as we could.

After some reformulation of the scheme, Mr. Morton Keller programed the procedure for computation in 1960. We accomplished our first test in 1959-1960, and it worked very well. We tested a 180-photograph block in Kansas with pleasing results: the standard error was about 2 feet. Another test in 1968 was done here in Rockville involving 25 photographs. There were 4 control stations, all points were premarked, and the error was 6 inches.

Mr. Chester C. Slama developed (1978) a superior arrangement of instrumentation and operation designed to reduce systematic errors in the photogrammetric system.

Mr. James R. Lucas reported (1981) on a test in Ada County (Boise), Idaho. The area was covered with 438 photographs taken from 10,000 feet with a new 6-inch aerial camera. The camera had a reseau plate with a cross every 2 centimeters. The camera was calibrated using the stellar method, and was focused especially for the color of targets being used. Targets were placed at the 17 geodetic control points and at 346 section corners. Photographs were flown in two directions. Lucas reported: "There is no question that the densification of geodetic control can be accomplished more economically by photogrammetry than by conventional ground surveying. This project has shown that a precision of 5 centimeters (2 inches) is attainable, which should satisfy most requirements." Additionally, approximately 84 percent of the points had standard errors less than 5 cm, and only 1.2 percent of the errors exceeded 6 cm.

Satellite Triangulation

In 1957 Capt. Lawrence W. Swanson and others of C&GS visited the office of Dr. Hellmut H. Schmid at the Aberdeen Proving Ground Ballistic Research Laboratories. Schmid had already in operation a stellar camera with which he could determine the latitude, longitude and elevation of the camera from photographs of a satellite traversing the star background. Also Schmid had programmed the necessary calculations on the ENIAC computer.

By that time Sputnik I and II had been launched by the Russians. The C&GS was invited to develop and operate a system to determine geodetic positions world wide which would integrate for the first time all the national geodetic systems. Swanson was named project manager, and Schmid transferred to C&GS. Several difficult logistic tasks were involved and time was of the essemce.

Schmid's camera was modified for rugged operation and 14 units had to be prepared. Chopping shutters were needed to break the star and satellite trails into discrete segments appropriate for easy measurement with comparators. Designs were completed and manufacturing contracts were negotiated for these two items in 1960 and 1961, respectively.

Small astrodomes were manufactured, as well as a tending van and trailer which included electric controls so that the entire camera exposure could be accomplished remotely from several feet away from the camera.

Long base-line geodimeter traverses of very high accuracy were needed to give the satellite network a scale element inasmuch as the stellar data yield angles only. Base lines were measured between first-order triangulation stations in North America, Europe, Africa and Australia.

A geodimeter was modified in C&GS shops to incorporate a laser beam, and the manufacturer of the geodimeter agreed to produce the needed number of instruments. Thus the base-line measurements could be accomplished expeditiously during daylight as well as darkness, a factor particularly important in northern Sweden in summertime.

Comparators were modified and calibrated for measuring the image positions on the star plates.

Schmid's computer programs were modified to operate on NOAA computers.

Passports and visas were needed for all field personnel. Permission had to be obtained for field personnel to operate in foreign countries. In one instance difficulty was encountered; it was overcome when the expression "to occupy a station" was changed to less offensive wording.

Some 700 star images and 300 satellite images needed to be measured on each star plate, both direct and reverse, and there was a total of more than 3,000 plates. Plate measurement began to fall behind schedule. To obtain more comparators was not a practical solution, and the operators were already working three shifts plus overtime. It required about four days to measure one plate. The operators agreed to work at their own maximum speed if it would not be necessary to work on a new plate until their four days had expired. More operators were hired and trained and the scheme worked very well--plates were measured in two days or less, and accuracy improved.

A computer program was devised to prepare a transparent plastic overlay for each plate to identify the stars.

Commander Eugene A. Taylor was charged with training field personnel, making equipment operational in any climate or remote location and fully portable for any mode of transportation. He prepared a training manual. One camera unit was set up for training on grounds of Agricultural Research Center in Beltsville, MD. The location also was used for instrument maintenance and repair, supplies and accounting.

Ephemerides were prepared by NASA indicating satellite "look angles" because extended periods occurred when a satellite could not be photographed from a given site.

Preliminary tests were scheduled. The first one included only three stations, another included the locations of Antigua and the Bahamas, and then a 36-station network was completed for North America.

Besides Sputnik, Echo satellite was used, and finally Pageos was launched by NASA especially for this program.

Swanson was successful in obtaining the cooperation of NOAA, the Department of Commerce, the Department of Defense, the Department of State, NASA, The Smithsonian Institution, the Johns Hopkins Applied Physics Laboratory, and the various instrument manufacturers.

Observations began on a 45-station world-wide network in 1966 and were completed in 1971.

Data processing involved 38 people during a 7-year period.

Supplying the field stations with an accurate time standard was accomplished at first by carrying portable crystal clocks, where, on airplanes, it was necessary

a clock
either to hold/in one's lap or on a vacant seat alongside. Sometimes it was necessary to purchase a seat. Later a doppler radio signal was used, eliminating the inconvenience completely.

A total of 266 man-years was consumed in the 45-station network.

The root-mean square error was 5 meters horizontally and 8.5 vertically.

As one can readily understand, this brand new, multi-faceted program required very effective management to be accurate and timely. Swanson ably succeeded in directing the project in a smooth fashion with a final accuracy better than originally thought possible. One of Swanson's techniques consisted of weekly meetings of all the operating section chiefs to identify logistic impasses and removing them on the spot. Swanson was more than an expediter. He was a "block-buster", a nut-cracker (some said sledge hammer). Frequently he interrupted a meeting to go to a phone, and return with a solution.

To accommodate the difference in photographic exposure required for circum-polar and equatorial stars, five groups of five images were obtained for each star, so that one could select the images best suited for comparator measurement. Each image was time-coded with an accuracy of 350 microseconds.

(This system of position determination may never be repeated because in the meantime a superior method has been developed of better accuracy and less difficulty using doppler satellite receivers.)

Aircraft: Camera Platforms

Although very important for photogrammetric operations, the subject of aircraft is not fully treated in this brief history. However the subject is well covered by Smith's book noted in the Bibliography.

In the early years, C&GS had neither aerial cameras nor aircraft. They managed to "borrow" the facilities of the U. S. Army, Navy and Coast Guard. The last named furnished a very great portion, including an airplane and operating crew, and C&GS furnished a pilot/navigator, cameras and photographers.

C&GS maintained a regular program of training pilots at the Navy center at Pensacola. The 9-lens camera weighed over 600 pounds, requiring a particularly large airplane. Operating areas included Alaska, Hawaii, American Samoa, Puerto Rico and the Virgin Islands as well as the 48 states. Particular attention was devoted to mapping the ocean shorelines of the nation and some 700 airports throughout the interior.

The usual flying program consisted of one plane being sent to Alaska at the beginning of the season and returning for miscellaneous assignments. A second smaller craft was ordinarily leased for operation by C&GS personnel to photograph airports. A common scheme was to begin photographing airports on the west coast and follow a weather high-pressure area eastward across the nation, venturing to the north and south along the route.

All airphoto crews were instructed to respond without delay to natural disasters such as hurricanes, earthquakes and other great storm areas to delineate the specific affected areas and assess the severity of damage. The planes usually arrived near the scenes before the winds died down.

The cooperative agreement with the U. S. Coast Guard was terminated after 24 years of successful operation, including the use of a B-17 for 13 years (retired in 1957). A grand Commander was leased as a replacement. The first aircraft owned by C&GS was a deHavilland Buffalo in 1969. It had been used as a training plane and was transferred from the U. S. Department of Defense. It remained in service 10 years.

BIBLIOGRAPHY

American Society of Photogrammetry, 1980, Manual of Photogrammetry, Fourth Edition, pages 20 and 477.

Lucas, James R., 1981, "Results of Precise Photogrammetric Densification of Control in Ada County, Idaho." Technical Papers, American Congress on Surveying and Mapping, annual meeting, Washington, DC.

Slama, C. Chester, 1978, "Results of an evaluation of High-Precision Analytical Photogrammetry for Geodetic Control Densification," Proceedings of American Society of Photogrammetry, annual meeting, Washington, D. C.

Smith, John T., Jr., 1983, A History of Flying and Photography in the Photogrammetry Division of the National Ocean Survey, 1949-1979, NOAA National Ocean Survey, Rockville, MD, 486 pages.

Swanson, Lawrence W., 1964, "Aerial Photography and Photogrammetry in the Coast and Geodetic Survey," paper presented at the Congress of the International Society for Photogrammetry, Lisbon, Portugal, 28 pages.

----- 1964, "Logistics and schedules for a World-Wide Satellite Triangulation Program," paper presented at the annual meeting of the American Congress on Surveying and Mapping, Washington, DC, 20 pages.

----- 1970, "Progress Report on the National Geodetic Satellite Program, Sixth U. N. Regional Cartographic Conference for Asia and the Far East, Bankok, 9 pages.

----- 1971, "A progress Report on the World Geometric Satellite Triangulation Network," paper presented at the ASP/ACSM fall convention, San Francisco, CA, 19 pages.

-----1984, "The Development of Geometric Satellite Triangulation and Field Operations," Photogrammetric Engineering & Remote Sensing,(PE&RS) Sept., pp. 1333-1340.

-----, and L. Austin Yeager, 1971, "A New World Geodetic Network, The Polar Record, England, v. 15, n. 99, pages 863-870.

Tewinkel, G. C., 1984, "The Development of Analytic Aerotriangulation," PE&RS, Sept., pp. 1321-1322.

----- 1984, "The Nine-Lens Camera of the Coast & Geodetic Survey,"PE&RS, Sept., 1309-1311.

----- 1984, "In Memoriam, Oliver Scott Reading,"1894-1984, PE&RS, July, pp. 1029-1030.

----- 1985, "Oliver Scott Reading", memorial address, annual meeting of ASP&RS, Washington, DC, July, 969-974.