AERIAL SURVEYS FOR HIGHWAYS IN NORTH AMERICA

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The brief history of aerial surveys contained here is an effort to recount as accurately as possible the adoption and use of aerial photography methods throughout North America. Specifically, the uses referred to are those especially applicable to highway engineering. Considerable development and progressive work were accomplished in the field of photogrammetry and stereophotogrammetry many years before their adoption and use by the highway engineering profession. Consequently, identification of several first uses do not pertain to uses in the highway engineering field but are early developments or uses in other fields of endeavor that preceded adaptations and developments for highway engineering purposes.

PHOTOGRAMMETRY is the art and science of making measurements by use of photography. Added thereto in recent years is interpretation for obtaining qualitative information from aerial photography and other types of imagery. Accordingly, aerial surveys are the taking and use of aerial photography and other imagery to accomplish whatever is required, and aerial surveying includes photogrammetry and interpretation and any other aspect of use of aerial photography and other imagery.

A completed and functional highway is a complex amalgamation of a diversity of ingredients blended into one composite form. A highway is created, from beginning to end, by combining the talents and services of a wide variety of specialists who are skilled in many disciplines such as planning, location, design, photography, aircraft use, ground surveying, photogrammetry, cartography, drafting, landscaping, ecology, conservation, history, archeology, materials engineering, and construction equipment operation and use. Mention, therefore, is made of some of the more significant and early thoughts and findings relevant to many professional activities that together constitute highway engineering. Then, the chronological beginnings are given for some, not all, developments leading to progressive changes in and eventual use of aerial surveys by the highway engineering profession.

HISTORICAL CHRONOLOGY OF AERIAL SURVEYS

The first state road building policy in the United States was inaugurated by Kentucky in 1821 when Abraham Lincoln was a boy of 12. Forecast was made in 1839 that aerial photography could be used as an aid in the preparation of maps. This forecast came as a consequence of photography discoveries in France by Niepce and Daguerre. A stereoscope was developed and demonstrated by Wheatstone during his investigations on binocular vision between 1832 and 1838. His work was followed in 1844 by a refracting type of stereoscope developed by Brewster.

The first practical adaptation of a camera to take photographs for surveying was accomplished by Laussedat, who began his work in 1849. His work lead to terrestrial photogrammetry and was the forerunner of the photoalidade.

In 1856 Nadar took the first aerial photograph from a free-flight balloon over Paris, France. The first aerial photograph in the United States was taken by Black and King on October 13, 1860, from a captive balloon at a height of 1,200 ft over Boston, Massachusetts. Several other photographs were taken the same day from a free-flight balloon. In May 1862 Lowe took the first aerial reconnaissance photograph from a captive balloon over Richmond, Virginia. This photograph was obtained for use by the Union Army for observing troop movements of the Confederate Army defending Richmond.

The first photograph taken from an airplane was by Maurisse in 1909 from flight heights of 100 and 200 ft. The first known taking of motion pictures from an airplane was by an unknown cameraman riding with Orville Wright over Centocelli, Italy, on April 24, 1909. The first specific use of aerial photographs as maps was reported by Tardivo on September 25, 1913, at a meeting of the International Society for Photogrammetry in Vienna, Austria. The photographed area was Bengasi, Italy. The first aerial photograph used for illustrative purposes by a newspaper had been taken of a fire at Salem, Massachusetts, on June 26, 1914.

The first major American development in photogrammetric instrumentation is known as the Brock process. Development of the instruments used in this process began during World War I by the Arthur Brock Tool and Manufacturing Works of Philadelphia, which later became the Precision Engineering Co. Developmental work continued into the early 1920s. In 1938 all assets of the Brock and Weymouth Co. were acquired by the Aero Service Corp., which still owns all rights to the process.

In addition to the Brock process of mapping, the earliest aerial cameras used in the United States were built by the Brock Co. One of its earliest models, using tin types, was tested at Fort Sill, Oklahoma, in 1915. Later, during World War I in Europe, nearly all aerial cameras were made by the Brock Co.

Within the United States, the early 1920s mark the beginning of photogrammetric compilation of topographic maps using aerial photographs. An early report of such use of aerial photography pertains to topographic map compilation completed in 1922 by Brock and Weymouth for reservoir and hydroelectric purposes. Another early compilation of topographic maps using aerial photographs was in 1924 by the Pioneer Aerial Engineering Co. and the Photomap Co. These jointly operating firms used a "paralaxer," similar in principle to the stereocomparagraph.

One of the earliest strips of aerial vertical photography specifically designed for stereoscopic examination and interpretation to make route investigations was taken in 1927 and 1928 for the Mt. Vernon Memorial Highway. There were 262 photographs of 7- by 9-in. format exposed at a scale of 1:6,000.

A large plan for development was prepared by use of this aerial vertical photography. This earliest plan for development has significant historic interest because it was prepared from enlarged photographs and mosaics fitted to the ground survey controls established by the Bureau of Public Roads for the 15-mile length of the memorial project. This is the first known example of preparation and publication of a complete plan for construction of a highway on a route location determined using aerial photography specifically taken for stereoscopic examination and interpretation.

The first mapping projects in the United States were controlled originally by the use of radial templates. This is a graphic method of extending supplemental control to all the points required to orient each stereoscopic model. A U.S. patent was issued to Adams in 1893 for the use of radial templates in connection with photographs taken from balloons. Added attention was focused on the radial template method developed by Schiempflug in 1906 and Finsterwalder in 1921. The real impetus to the use of radial templates was provided by Bagley in 1923.

Radial line templates continued in use throughout the 1920s and into the 1930s. In 1935, while watching personnel struggle with the hand templates, Collier of Fairchild Aerial Surveys developed the idea for the slotted template method.

In 1933, Fairchild Aerial Surveys introduced into the United States two German developed instruments, the stereoplanigraph and the multiplex. These instruments began to replace the radial template method for extension of horizontal control. The stereoplanigraph performed analog extension of control, and the multiplex performed an analog aerial triangulation by so-called bridging techniques. These procedures continued to be used until the implementation of analytical aerial triangulation for effective and economical use in about 1964.

Aerial analytical triangulation had its beginning at the College of Applied Science of Syracuse University during a 4-year period starting in 1929. This work was accomplished using Guggenheim funding. The photographic measurements were made with monocomparators, stereocomparators, and photogoniometers. The method did not gain general use until the early 1960s when agencies became equipped with the necessary electronic computers to facilitate the lengthy computations.

The second significant photogrammetric instrument development in the United States is credited to Kelsh. He developed the Kelsh double-projection stereoscopic plotter in 1948.

Aerial surveying in highway engineering made another giant step in 1956. That year the Ohio Department of Highways initiated and completed development of the first analog to a digital recording instrument to record automatically the measured dimensions of profiles and cross sections as well as cadastral data.

During October 1959, development was started in Region 9 of the U.S. Bureau of Public Roads, and completed in March 1960, of an instrument that became known as the Auto-trol Scaler. This instrument was also an analog convertor to digital data of stereoscopic model measurements made using a double-projection instrument.

These instrumental developments were the forerunners of electronic recording of photogrammetric measurements made by optical train instruments, monocomparators, stereocomparators, and double-projection instruments.

One of the first reported tabulations to compare earthwork quantities determined by photogrammetric methods and ground surveys was released in November 1944. The report indicated a difference of only about 4 percent, even in those early days of predominantly manual methods of performing the work.

The year 1956 was notably significant for other reasons. The Federal-Aid Highway Act of 1956 initiated the Highway Trust Fund and financing for the Interstate Highway System on a 90 percent federal and 10 percent state sharing basis. Also, the Act authorized federal-aid funds for employing photogrammetry on a professionally negotiated basis to make highway surveys. In addition, the Act revised the definition of construction and authorized use of federal-aid funds appropriated for highway construction for financing the making of basic control surveys along highway routes to specifications of the U.S. Coast and Geodetic Survey (now the National Ocean Survey). That same year, use of electronic computers was started for computing highway alignment, for volumes of excavation and embankment using photogrammetrically made measurements, and for numerous other engineering purposes.

HIGHWAY ENGINEERING USES

It is difficult to determine the earliest writings that pertain especially to photogrammetric use of aerial photographs for highway engineering purposes. Scattered and casual comments in papers and reports were usually written with other emphasis, but some of them indicate utilization of aerial surveys in an elementary way for highway engineering purposes beginning early in the 1920s. Nearly all first uses were photographic, interpretive, and illustrative. In most cases, the photographs were assembled and used as photographic mosaics, generally referred to as maps.

Among the early works containing information on aerial surveys for highways is a paper by Sarason (1). In his paper, Sarason noted that George Washington, early in his life, had training as a surveyor. He continued by saying,

> It is therefore not surprising to find that as early as May 7, 1784, a committee of the Continental Congress, headed by no less than Thomas Jefferson, reported 'An ordinance for ascertaining the mode of locating and disposing of lands in the western territory.' This ordinance provided for 'townships 6 miles square containing 36 sections of one mile square by lines running North and South and others crossing these at right angles.' These were the first specifications for land surveys....

Most surveys for highways, before the acceptance and use of aerial surveys, were made by staking and measuring on the ground angle line traverses along each selected route, measuring its profile and cross sections, and making ties from the traverse, known as the P-Line for preliminary survey, to all topographic, cadastral, and land use details of concern. Nevertheless, planimetric maps were usually compiled, and occasionally topographic maps were made based on the preliminary survey measurements.

Significantly, Sarason mentioned mapping for highway location purposes. Seemingly, however, some of his thoughts were not widely accepted and applied until the advent of

the use of aerial surveys, for he wrote:

> The State of Illinois was one of the first to recognize the value of maps for highway location. No new location is authorized without a strip topographic map about 3 or 4 miles in width on a scale not less than 2,000 feet per inch with 5-foot contours. An agreement has been made with the U.S. Geological Survey to furnish these maps, the State paying the additional cost above the usual Geological maps of (a scale of) an inch to a mile. It has been suggested to the Federal Bureau of Public Roads that it require a proper map before approving a highway location where Federal aid is given. This Bureau has the power to fix the grade and curvature and an economic location involves these and other factors.

Although Sarason indicated that Illinois was the first state to pay the extra cost of producing large-scale maps for highway engineering needs, Missouri actually used topographic maps published on a quadrangle basis at a scale of 1 in. = 1 mile as early as 1921.

Only within the past two decades have some highway departments cooperatively financed topographic mapping on a quadrangle basis by the U.S. Geological Survey at a scale of 1 in. = 2,000 ft. Wherever these maps are available, they are invaluable for use in conjunction with recently taken aerial photographs of the areas of concern for accomplishing area analysis, determining feasible highway route alternatives, selecting a route by comparing the alternatives, and making a preliminary survey at adequately large scale of the selected route for accomplishing highway design and preparing detailed construction plans.

Before World War II, only one significantly large route topographic mapping project was undertaken using aerial surveys. This project comprised the mapping of a route selected by stereoscopic examination of photographic coverage through the Lochsa River region of Idaho, now known as the Lolo Pass Highway, extending between Lowell, Idaho, and Missoula, Montana. Approximately 600 miles of route alternatives were compared to select the more than 50-mile segment of highway route that was mapped at a scale of 1 in. = 500 ft with a contour interval of 10 ft for a width of 1,000 to 2,500 ft. This work was completed by the state of Idaho in 1930 by the Aerotopography Corp. of America.

Three projects of major significance on which aerial photography served as a primary source of information and topography dimensions for feasible route determination, comparison, and selection were the Inter-American Highway, the Alaska Highway, the Pan American Highway, and the Mississippi River Parkway.

On the Inter-American Highway, aerial photography was taken as early as 1932. It was not used to any great extent until 1948 when the areas were rephotographed. During 1948 photography was used to make an area reconnaissance survey, locate route alternatives, and select the route for the closing 120-mile link in Costa Rica and Panama. Again during 1964 and 1965, use of aerial photography enabled engineers of the Bureau of Public Roads, now Federal Highway Administration, to close the gap in the Pan American Highway of North and South America through southeastern Panama and northern Colombia by locating a route to and across the large Rio Atrato Swamp in Colombia, which had previously been considered uncrossable.

Early in 1942, long segments of the Alaska Highway through Canada were located with the aid of aerial photography, augmented by intensive reconnaissance surveying on the ground.

Probably the most extensive use of photography on one project during the period of 1950 to 1952 occurred when a reconnaissance survey was made to determine the feasibility and probable cost of the proposed Mississippi River Parkway (the Great River Road). This particular project involved the purchase of nearly 40,000 aerial vertical photographs covering an area of approximately 100,000 square miles throughout the 10 states bordering the Mississippi River. The river has a winding length of 2,552 miles between Lake Itasca in Minnesota and the Gulf of Mexico.

By stereoscopic examination and interpretation of the photographs, plus use of parallax measurements, more than 10,000 miles of feasible route alternatives were located and compared at a total cost of $140,000 for all salaries, travel, equipment, training,

aerial photographs, and preparation of a report to the Congress of the United States. This low cost represents only $14 per route-mile located and only $70 per route-mile for one 2,000-mile route extending the full length of the project.

Following World War II, topographic mapping, using aerial surveys for engineering purposes, gradually began to be accepted and used. Impetus for this had its beginnings during the war in a few eastern states—Connecticut, New York, Massachusetts, and Rhode Island—and in California.

Some early papers (2-8) that influenced the acceptance and use of aerial surveys by highway engineers focused on the following areas: photographic mosaics, stereoscopic pairs, photogrammetric compilation of topographic maps, and aerial survey procedures.

Contemporaneous with and subsequent to these early publications, numerous other articles pertaining to principles and practices in the use of aerial surveys in the highway engineering field were published. These papers mention procedures and accomplishments and, in some instances, indicate first use. Some of the earliest and most significant applications are given in Table 1. It is not intended to imply that the applications given in Table 1 were actually the earliest, as compared to uses in the manifold fields of endeavor. Moreover, no attempt has been made to consider all procedures and techniques of employing aerial surveys.

Early uses were essentially pictorial and qualitative. Gradually, the dimensional aspects were applied in the photogrammetric use of aerial photographs on an analog basis.

Graphical determination of horizontal position of pass points for supplemental control was begun in the mid-1950s at scales as large as 1 in. = 100 ft, using stereotemplates. Concurrently, where available, optical train instruments were used to determine supplemental control by analog methods. It was not until 1964 that analytical techniques began to be used effectively for determining supplemental control. The principles, of course, of aerial analytical triangulation had been known for many years. Despite frustrations and seeming setbacks, steady progress has been made in the improvement of techniques and procedures.

Of the 50 state highway departments reporting, Massachusetts indicated the earliest date (1941) for sending highway engineers to attend a school in aerial photography. Michigan followed in 1946, Mississippi in 1947, and Louisiana and Texas in 1948. These four schools were conducted by Abrams Aerial Survey Corp.

Michigan was also one of the first states to establish a position of photogrammetric engineer in its highway department. This was done in 1949 through their Civil Service Commission, and the classification required professional registration.

Aerial surveying schools have been conducted on a request basis since 1950 for state highway departments and field officers of the Bureau of Public Roads and the Federal Highway Administration. These schools were conducted by qualified engineers of the Federal Highway Administration primarily for giving the highway engineer an insight into the basic principles, techniques, procedures, and stages of use of aerial surveys for engineering and associated purposes. Accordingly, engineers who are concerned with traffic, location, design, soils, construction materials, drainage, rights-of-way, maintenance, conservation, aesthetics, and so forth attended these schools, which served as a bridge between the taking of aerial photographs and their interpretation and photogrammetric use for accomplishing essential engineering and related work.

The leaders in aerial surveying use are those states from which the engineers attended the schools and thereafter followed through in using aerial surveys. The most extensive and comprehensive uses are within the states that have become equipped and staffed to take aerial photographs and use them photogrammetrically for making essential measurements and compiling maps that are photographic, planimetric, topographic, or all three.

During the past 20 years, a substantial part of the photogrammetric use of aerial photographs has been accomplished through the use of double-projection instruments, mostly the Kelsh stereoscopic plotter.

Optical train instrumentation for engineering had its beginning in the United States when photogrammetric engineering firms first became equipped during the 1950s with stereoplanigraphs, or wild autographs, or the Gallileo-Santoni stereocartograph and

Table 1. Early aerial surveys for highway purposes.

Year	Early Use by State and Organization					
	Photographic Mosaics	Stereoscopic Pairs	Mapping From Photographs[a]	Cadastral Surveying	Supplemental Control[b]	Automatic Recording[c]
1922	California					
	New York					
1923	Illinois					
1924	Connecticut					
	Florida					
1925	Michigan					
1927	Virginia		Indiana[d]			
1928	Alabama	California				
	Maryland					
	Pennsylvania					
1929	Ohio	Colorado				
	Texas	Ohio				
1930	Bureau of Public Roads	Idaho	Connecticut			
	Idaho		Idaho			
	Massachusetts					
	Tennessee					
1931		Michigan				
1932	Mississippi	Texas				
	New Jersey	Washington				
1934	Arizona	Arizona				
	Indiana					
1935		Mississippi				
1936	Colorado	Missouri				
1937	Minnesota	Bureau of Public Roads				
		Delaware				
		Minnesota				
1938		Virginia				
1940	Georgia	Georgia				
		Nebraska				
		New York				
1941			New York			
1942	Alaska	Alaska				
1943			Massachusetts			
1944	Kansas	Kansas	California			
	North Carolina	Utah				
1945		Maryland				
1946	New Hampshire	Florida	Florida			
			Ohio			
			Virginia			
1948				Connecticut	Public Roads Administration	
1949		Kentucky				
1950		New Mexico	Colorado			
		North Carolina	Maryland			
			North Carolina			
			Texas			
1951		Arizona	Washington			
1952			Arizona	Idaho		
			Oregon			
1954	North Dakota		Kentucky			
			North Dakota			
1955			District of Columbia	Bureau of Land Management		
1956			Illinois	Maine		
			Maine	Nebraska		
			Montana			
			Vermont			
			Wyoming			
1957		Hawaii	Hawaii			
1958			Georgia	Illinois	Arizona	
			Texas	Indiana		
			Pennsylvania			
1959				New York		Bureau of Public Roads
1960				North Carolina		
1961						California
1962					California	Virginia
1963						North Carolina
						Texas
						Washington
1964			New Mexico	California	Federal Highway Administration	Georgia
					Georgia	Pennsylvania
					Texas	
					Washington	
1965				Georgia		Wyoming
1966					Virginia	Kentucky
						New Mexico
1967						Idaho
						Illinois
						Vermont
						Wisconsin
1969					Illinois	Kansas
					Pennsylvania	New York
						Oklahoma
1970				Florida	Florida	
				Oregon	Texas	

[a]This tabulation indicates the earliest date for which mapping was done either by consultants or by state staffs using state-owned equipment. The tabulation does not necessarily indicate all states now employing aerial surveys for doing survey mapping.

[b]Photogrammetric determination of supplemental control (radial templates, analog, and analytical).

[c]Automatic recording of measured profile and cross sections.

[d]Source: Photogrammetric Engineering, Vol. 17, No. 5, Dec. 1951, p. 725.

stereosimplex. In the 1960s a few states also acquired optical train instruments, namely, the wild autograph in Georgia and Washington and the stereoplanigraph in Texas and California, and the Zeiss planimat in the Ontario Department of Transportation and Communications. Also, in the 1960s with the advent of aerial analytical triangulation, stereocomparators were obtained by California, Pennsylvania, and Arizona. Monocomparators were obtained by Virginia, Florida, and Illinois in the late 1960s.

Ohio was the first state (in 1946) to become equipped to provide photogrammetric services for its highway department. Engineers in Ohio were also the first (1956) to complete development of an analog to digital recording instrument for use with a double projection instrument to record automatically the measured dimensions of profile and cross sections. Ohio is also the first and only state, thus far, to procure a Nistri analytical stereoscopic plotter, model AP/C. This occurred about 20 years after Ohio's initial start in aerial surveys for accomplishing its highway engineering and associated work.

In 1955, and culminating in 1956, proposals were made for developing an instrument that would, in effect, embody the advantages of double-projection and optical train instruments; be free from the restrictions caused by projection lenses and focal length limitations; use any photographic emulsion; digitize or graphically delineate details as desired; and produce orthophotographs when required. Within the succeeding 4 years, progress was gradually made in the development of a prototype instrument that proved the feasibility of this concept. In the interim, digital scalers and recorders for use with double-projection instruments were developed effectively. Since 1960, budgeting roadblocks have retarded further development of this all-purpose instrument called the omnistereomeasurer.

Other developments involving numerous instrumental approaches have gradually moved in the direction of the initial concept. Among these instruments are the analytical stereoscopic plotter, the stereomat, from which orthophotographs are made automatically, and adaptations of the planimat by which orthophotographs and also automatic digitization and recording of map dimensions are easily done. Also, coordinatographs have been automated that use the coordinate dimensions of photogrammetrically measured details for the automatic plotting of planimetric, topographic, and cadastral maps, and of profile and cross sections as desired.

In the early 1940s most photogrammetrically made map compilations were not based on a plane coordinate system. Instead, no coordinates were used. The maps were purported to be sufficiently accurate for origination of subsequent work, such as rights-of-way and centerline staking on the ground, from features identifiable on the maps that could be found on the ground. By the late 1940s, either a local system or the state plane coordinate system was used. Currently, most maps compiled photogrammetrically for engineering purposes have their basic control surveys originate and close on station markers in the national network of geodetic control, as initially surveyed by the U.S. Coast and Geodetic Survey.

Photographic base plans as a production item were first used in 1950 by the state of Florida. This system allows highway engineers to see all topographic detail, as delineated by contours, as well as all cultural features on the photographs.

The progressive changes from using aerial photographs in assembled form of usually uncontrolled photographic mosaics through stereoscopic examination and interpretation, mapping, photogrammetric determination of supplemental control, and measuring and automatically recording profile and cross sections (also cadastral data in some states such as California, Georgia, Illinois, Ohio, Texas, and Virginia) are easily discerned by study of Table 1. It is not purported to be definitive in every aspect but is the most complete of its kind thus far compiled.

CONCLUSIONS

Progressive use of aerial surveys in the highway engineering field was slow for many years. The literature written regarding uses and successes, the aerial surveying schools conducted during the past 22 years, and the increase in highway engineering and construction, especially since 1956, contributed separately and effectively toward

the progress that has been made. The advances in photogrammetric technology and instrumentation were also significant factors, coupled with the joining together in 1956 of aerial surveys and electronic computers. New and improved techniques of making ground control surveys made important contributions also. The latter include electronic distance measuring instruments and the augmenting use of theodolites.

Although the techniques and procedures of making surveys on the ground are essential and are in continuing use for staking designed centerlines, structures, rights-of-way, slope stakes, and so forth on the ground, aerial surveys have become the foundation on which all engineering and construction are based.

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