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E. LESTER JONES, Director

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AERIAL SURVEY OF THE MISSISSIPPI RIVER DELTA

BY

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AERIAL SURVEY OF THE MISSISSIPPI RIVER DELTA

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INTRODUCTORY

Surveying a battle field in time of war has always been a task that required the utmost ingenuity on the part of the surveyor in order that satisfactory results might be obtained. The war just passed into history was the first one in which "no man's land" was adequately mapped, and the credit for this was due to the aerial camera, largely a product of the war. This instrument, along with other areial equipment, developed rapidly under stress of war-time conditions, and it would have required many years of peace-time development before an equal stage of perfection could have been attained. Advantage has been taken of this product of the war in many mapping projects. The aerial camera has been satisfactorily used in the survey of the Mississippi River Delta, an area that, owing to its marshy character, has always been almost as inaccessible to the surveyor as a battle field. The results obtained in this survey, as well as in other projects where aerial photographs have been used, demonstrate that the value of the airplane camera as an aid to the map maker in time of peace should rank with its value as an instrument of war.

Every survey in which aerial photographs are used will have its own problems for solution. The engineer and the aviator should cooperate and should make their plans, adapting them to suit the conditions encountered. The survey of the Delta was governed largely by local conditions, aerial equipment available, and the results desired. While the methods used were those best suited to the particular project, it is believed that a description of them will be of assistance in future projects, especially in localities where there is very little difference in elevation between topographic features.

While aerial photography owes its present stage of development to the World War, it had received some attention previous to that time. About 1845, Colonel Laussedat, a French Army officer, suggested the possibilities of aerial mapping from balloons. Since that time much has been written on the subject, and some few experiments made, but it was not until 1911, that the first satisfactory aerial camera put in an appearance. Captain Scheimpflug, an Austrian, brought out his eight-chambered camera, designed for mapping work from balloons or dirigibles. He also designed a transformer for the laboratory work of correcting inclined pictures. His apparatus, and the principles involved, were the signal achievements in aerial mapping previous to the war, but since that time his camera has been relegated to the background, due to the rapid development in the heavier-than-air machines and the design of cameras specially suited for that type of craft. The airplane is far superior to the dirigible or balloon in maneuvering qualities, and therefore is better suited for mapping from the air.

It was natural that map makers should have their attention drawn to the possibilities of aerial photography by the results obtained in the war. Governmental surveying bureaus in particular were interested, as well as the air services, as it appeared that there were great possibilities for peace-time use of equipment, and also training of personnel. Plans were early made for making use of this promising development in aeronautics. The ink was barely dry on the armistice documents before definite plans were agreed upon.

EARLY EXPERIMENTS IN THE USE OF AERIAL PHOTOGRAPHS BY THE COAST AND GEODETIC SURVEY

The Coast and Geodetic Survey is charged with the task of charting the coastal waters of the United States and possessions as well as the land adjacent to the coast. Almost the whole coast line of the United States has been mapped at some time or other, but resurveys are necessary due to the fact that in some localities changes are constantly and rapidly taking place.

It appeared that the best use of aerial photographs would be as an aid in revision surveys, as there would probably be little trouble in tying the photographs to the unchanged features. It was also believed that aerial photographs might be used as an aid in charting underwater features as well as the details that appeared above the ground.

Experiments at Atlantic City.—To test the possibilities in revision work, an experimental survey was made in June, 1919, of Atlantic City, N. J., and vicinity, including the marshland between Atlantic City and the mainland. This area included a built-up city, sand beaches, and the marsh that is so characteristic of the South Atlantic and Gulf coasts. The experiment was very thorough, as photographs were made by both the Army and the Navy Air Services, using various types of aircraft and of cameras. The best results were obtained by an Army plane using a K-1 camera and flying at an altitude of 7,000 feet. Incidentally, this was the greatest altitude at which photographs were made. While the personnel engaged in the photography were more or less inexperienced in this class of work, results obtained indicated that there were great possibilities in the use of mapping cameras for revision work, and there were also indications that aerial photographs would be very valuable in original surveys. Although the project was experimental in character, the data obtained from the photographs were used in the revision of the chart of Atlantic City, so that the chart as issued to-day shows the results of this first aerial photographic experiment along our coasts made for the Coast and Geodetic Survey.

Photographing underwater features.—To test the possibility of aerial photography as an aid in charting underwater features, experiments were made along the Florida coast at the same time that the Atlantic City project was under way. It was believed possible that aerial photographs would show the coral heads and shoals that are prevalent along the Florida Keys, inasmuch as successful photographs of submerged objects had been made by naval aviators during the war. The waters in the vicinity of Key West were chosen for the experiments, as there was a naval air station there, as well as a survey vessel engaged in hydrographic work in the vicinity. The numerous coral heads near Key West promised good photographic material.

Charting coral heads has always been an expensive problem. Many coral heads are in the form of pinnacles, almost impossible to locate with the lead line. The wire drag is necessary in this type of bottom. The wire drag is expensive but all dangers are located when it is used. The photographic experiments were made with the idea in mind of eliminating some of the wire-drag work, and possibly all, especially in clear waters. It was also hoped that a correct picture of the bottom would be obtained, as that would be an aid to the hydrographer and the cartographer.

The experiments near Key West were as exhaustive as conditions permitted. Photographs were made at various altitudes and under various light conditions. The camera was held pointing directly down for some pictures, or inclined at various angles for others. It was used without filters and with them. Different plate emulsions were tried. It was hoped that some combination of circumstances would produce satisfactory results.

After a study of the results of the experiments, the conclusion was reached that aerial photography had very little practical value as an aid to the hydrographer. Development in the art may change this view, but it will probably be some time before extensive use can be made of photographs of underwater features for charting purposes. The photographs were too uncertain as to their indication of varying depths. Some photographs showed varicolored bottom clearly, while others, under exactly the same conditions, would show no shoals where they were already known to exist. Level bottom, covered with patches of sand, coral, or grass, would appear in the photographs as bottom of irregular depths. This would be very confusing, and, unless the photographs could be examined stereoscopically or otherwise, would entail unnecessary field work to verify conditions. The uncertainty of the photographic method, and its apparent inability to eliminate field work to any extent, resulted in its rejection for the time being, at least until that future date when methods and equipment will be advanced enough to obtain satisfactory results.

Photographs of shallow bays or tidal flats may be of some value to the cartographer, especially to indicate possible channels, but it is questionable if much expense should be entailed in order to obtain the photographs.

Topographic revision of the coast of New Jersey.—A very striking demonstration of the value of aerial photographs for revision work was made in 1920. In March of that year an Army airplane photographed the outer shore line of the coast of New Jersey from its southern limits, Cape May, to within a few miles of Sandy Hook. The project proved a very economical one from start to finish. The photographs were made while the plane was on a coast-patrol flight between Norfolk and New York. The only expense chargeable to photography was the cost of the two rolls of film, as no special field preparation was necessary. It required a little over two hours to take the single strip of photographs that covered 120 miles of coast. Very little groundwork was necessary on the part of the engineer, as control points were still available from previous surveys. The only field work needed was the verification of the photographs on the ground and the identification of old control points on the photographs. This only required a few days in the field by an officer of the Coast and Geodetic Survey.

A description of the methods and equipment used is not necessary, as practically the same program was followed on the Mississippi River Delta, the details of which will be described later.

FIELD WORK OF THE DELTA SURVEY

The Mississippi River Delta is an area where aerial photography will show at its best. The character of its soil and vegetation is such that the cost of surveying it properly by any other method is almost prohibitive. For this reason it has long been neglected. Surveys of the Delta were needed by the Coast and Geodetic Survey for the purpose of bringing the charts up to date, and by the Corps of Engineers of the Army for the purpose of recording and studying the changes in shore line that bear such an important relation to the engineering problem on the Delta. Early in 1921 these services asked the Naval Air Service to photograph the Delta for mapping purposes. Cooperation on the part of these three branches of the Government was necessary for the successful completion of the project.

The photographic work was started in the spring of 1921, at which time the lower end of the Delta was photographed. Additional photographs were to be made in the fall of that year, but a mishap to the plane delayed the work until December, when unfavorable weather conditions caused the recall of the plane to wait for spring weather. In the spring of 1922 the work was again taken up with the result that the whole Delta was completed below Doullut Canal. The photographic party remained on the Delta for a period of three months at this time in order to complete the work.

Ground control for the photographs was in the form of triangulation. This was completed over the lower end of the Delta in the spring of 1921 and over the northern section of the work in the fall of 1922, when an examination of the photographs in the field was also made. The office work on the reduction of the photographs was begun in January of 1923 and completed in November of that year.

The methods employed on the Delta were those best suited to conditions. Plans were made so that the photographic program, ground control, and the office reduction methods all interlocked so as to produce the best results. These factors were all governed by local conditions, equipment available, and the results desired. Some of these will be enumerated here in order to give an idea of their importance.

Local conditions.—The marshy character of the Delta prohibited the use of landplanes and limited the choice of type to seaplanes.

Transportation is practically limited to the water, so that signals could be built only at places easily approached by launch or small boat. This influenced the method of control, and also had its effect on the direction of the photographic lines of flight, inasmuch as they were made to coordinate with the ground control.

Equipment available.—The seaplane used could only maintain an altitude of 8,000 feet for practical mapping purposes. A greater altitude was desired, in the interests of economy, accuracy, and speed.

Results desired.—The data obtained were to be plotted on regulation plane-table sheets, for a comparison with Coast and Geodetic Survey methods. This influenced the type of control, direction of flights, and office reduction methods.

CONTROL

The use of the aerial photographs in the Delta survey was in part experimental. It was the first large project to engage the attention of the Coast and Geodetic Survey. Previous experiments indicated that the photographs could be used for the correction of the chart, but it was felt that here would be an excellent chance to compare the use of aerial photographs with plane-table surveys in every way possible, especially as to cost, time, accuracy, etc. For the purpose of making a comparison, the results were to appear in the same form and if possible with the same degree of accuracy as required for ordinary topographic surveys made for the Coast and Geodetic Survey. This necessitated control by secondary triangulation. In fact, if this survey had been made without any specifications as to the form of control, it is doubted if any other method than triangulation would have been used.

The construction of triangulation signals and scaffolds was limited to the shore line of the river and the passes accessible by boat, as it is a difficult problem to travel on the Delta in any other way. The firmest ground for signal building is that adjacent to the banks of the passes.

Establishing control points on the lower end of the Delta was very easy. There were numerous camps scattered about, as well as occasional survey signals erected by State and other surveyors. It was only necessary to erect a few pole signals to supplement these and completely cover the lower end. The geographic positions of the principal lighthouses and towers had been determined in previous years, so that very little instrumental work was needed to locate all the signals. Lighthouses, towers, and houses all appeared very prominently in the photographs, and it was an easy matter to identify them. Pole signals did not show in the photographs, but when they were erected, a sketch would be made showing the relative position of the pole and prominent objects nearby that would appear in the photographs. The exact position of the station on the photograph could be plotted at any future date.

Established control points were not so numerous over the northern section of the work as over the lower end. It was necessary to carry a scheme of triangulation across the Delta from a base on the east side to the southwest shore. Ten observing tripods and scaffolds, each about 16 feet high, were constructed. There were numerous camps in the vicinity and they were used as supplemental control points. Only five pole signals were needed in areas where there were no camps. The numerous camps and the signals erected proved to be ample control for this section.

The only area where points were scattered was that southwest of the river, where the tall trees and the lack of navigable streams would have made the construction of signals an expensive project. This is a relatively unimportant area with practically no detail that is of value to the navigator, and would not warrant the expense of constructing the signals. Three signals were erected on the navigable streams in this section.

There was no attempt to maintain a regular distance between signals, nor to construct a definite network. If camps were numerous, geographic position of those at intervals of 1 to 2 miles were determined. If no camps were available pole signals were erected at intervals of from 3 to 5 miles. In all important areas the distance between signals seldom exceeded 3 miles, and usually the signals were much closer. Control was ample on all the principal passes.

An examination of the results of the Delta project indicate that if the plane and the camera are operated by capable personnel, Coast and Geodetic Survey standards of accuracy can be maintained if the signals are placed at intervals of 3 miles. At intervals of 2 miles, good results will be obtained even with indifferent work on the part of the flying personnel, but it would be advisable to specify signals at intervals of 1 mile to maintain standard accuracy, if there is doubt as to the capabilities of the personnel.

The total cost of the triangulation was $3,759.44, or at the rate of $7.32 per square mile. Over the northwest area, where it was necessary to build observing scaffolds, the cost amounted to $19 per square mile.

PHOTOGRAPHY

Local conditions necessitated the use of a seaplane as explained before. A landplane would have been preferred, as it could probably have operated at a greater altitude than the limit of the seaplane used, 8,000 feet.

Plane.—The type of seaplane used was that equipped with twin floats or pontoons, and used by the Navy Department as a torpedo plane. It was a two-seater, the forward cockpit being used by the photographer and the rear cockpit being used by the pilot. It carried fuel sufficient for a two-hour flight at 8,000 feet. A two-hour flight is probably as long as the average aviator wishes to fly at a time, especially when flying for exacting mapping work and when engaged on a large project.

Camera.—The camera used was the K–1 mapping camera. At the time, this type was the one most commonly used for mapping purposes. The K–1 is a film camera taking pictures 18 by 24 centimeters (about 7⅛ by 9½ inches) in size. A roll film is used, 75 feet in length and averaging 90 photographs to the roll. The camera was operated by a wind motor and was almost automatic in operation, it being only necessary for the operator to start or stop the camera by throwing a switch and connecting or disconnecting the wind motor. He changed rolls and governed the intervals between exposures as well as the time of exposures.

Camera mount.—The camera was mounted in the observer's cockpit, and rested in a cradle that could be tilted or rotated in any direction necessary to compensate for the tilting or crabbing of the plane. Cushioned supports eliminated the vibration of the plane. The camera was placed over an opening in the bottom of the fuselage, just large enough for the field of view of the lens. The opening was provided with a shutter that could be closed and afford protection to the lens when the camera was not being used. A level bubble on the camera indicated to the observer the verticality of the camera axis.

Operating base.—The base of operations for the photographic party was the Army Engineer station at Burrwood, near the lower end of Southwest Pass. This base was not centrally located for the project, but this proved a disadvantage in only one particular, and that was in the observation of weather conditions, especially during partly cloudy weather. Quite often the position of clouds that appeared to be over the main body of the Delta could only be guessed at from Burrwood whereas if the base had been centrally located, the observing of weather conditions would have been easy. A central location was not necessary in order to save travel by the plane, as the plane could take off from Burrwood and while climbing to 8,000 feet could so maneuver that it would be in any position, even the most distant, in the area to be photographed.

Burrwood had accommodations for the photographic party and also was equipped with a floating derrick that could be used in docking the plane. This proved to be almost a necessity. An occasional dry-docking was of great benefit, as the fresh water of the river had a deteriorating effect on the pontoons. Repairs were more easily made while the plane was on dock. The dock also proved to be a safer resting place in stormy weather than the anchorage, which was exposed.

An Engineer's launch was available for handling the plane between the mooring and the middle of the pass where the plane would take off or land. Ordinarily a seaplane is able to go up to its mooring under its own power, but the anchorage in Southwest Pass was so cramped and the current too strong to allow safe maneuvering of the plane.

Personnel.—The personnel of the aviation party consisted of the aviator in charge, the photographer, and two mechanics. This party proved to be none too large as they all were needed in order that the best advantage could be taken of favorable weather conditions when they occurred. A launch crew was also necessary when towing the plane.

Photographic flights.—The first factor considered in planning the flights, their direction and length, was the efficient covering of the area by the aviator. Landmarks to serve as guides were few and far between. The only features on the surface of the Delta that could be of any use as a guide to the aviator were the river and the principal passes. None of these were absolutely straight so that they could only be used as approximate guides.

The Delta was divided into sections, with natural features as boundaries, and each area was photographed in turn. This proved to be the most efficient way for several reasons. The aviator could better remember the territory covered in each flight, and this would serve as an aid in each succeeding flight. Each area would be completed under as nearly uniform conditions as possible. The handling of the individual photographs proved to be easier, as they would be grouped in one vicinity. The completion of each section in turn also served the purpose of keeping the survey completed up to date, so that any unforseen circumstances which might terminate the work at any time would leave the project in such shape that it could be considered as finished, at least for the area photographed. With this in mind the work was carried from the lower end of the Delta.

The first area completed was that south of Pass a Loutre and east of South Pass. The flights here were approximately in a northwest and southeast direction. The first flight was made adjacent to the northern half of South Pass and all the flights made in turn, each one overlapping the preceding one as well as the aviator could determine. Compass courses were flown. The interval between flights was determined by time. A negative lens in the floor of the cockpit was also used, as this showed the area covered by the photographic strips. Eighteen flights were needed to cover this area. There were four narrow gaps left in the photographs between adjoining flights, each about 3 miles long. These were covered later on.

The next area taken up was the Cubit Gap area. Thirteen flights were made approximately parallel to the river, each about 10 miles long and covering the territory northeast of the main river, between Pass a Loutre and the Jump. The flights were approximately northwest and southeast in direction. There were no gaps in this area.

Southwest Pass was then completed. This area proved to be a comparatively simple task as only a few flights were needed parallel to the pass.

The most difficult section was next taken up, the area southwest of the river and northwest of Southwest Pass. There were very few well-defined features in this section, and the aviator showed exceptional ability in that only 5 gaps were left between flights in the 40 flights required to cover this area. The flights were, in general, made normal to the river, each about 10 miles long, and extending from the river to the southwest coast. The general direction was northeast and southwest. The compass was used entirely for guide in these flights, the aviator noting his position over the ground at the beginning and end of each flight.

The northeast portion of the Delta was then taken up and 30 flights were made, averaging about 5 miles in length and, in general, normal to the river. There were three gaps left on this side of the river in this section.

Flights were also made following along the river and all the principal passes. These were for the purpose of providing adequate control and also to obtain a check on the location of the shore line of the passes, as this was considered of the utmost importance. Two of these control or check flights were made on the southwest side of the river in a general northwest and southeast direction and crossing the flights made over the area where little control was available. These control or check flights proved of great value in checking the accuracy of the results.

It may not appear economical to divide an area into sections and cover these sections with short flights, but there is no doubt that it will prove economical in the long run, especially in terrain where it is difficult to pick up landmarks as guides. Long lines are not needed in the office reduction, as it was found that mosaics covering an area 10 miles long on a scale of 1:8,000 were too cumbersome to handle conveniently.

Unfavorable weather conditions proved to be the greatest handicap on the Delta project. Haze or low clouds delayed the work considerably. Good photographic days would average about one in three. Weather conditions were often deceptive, especially as regards clouds. On some days it was very difficult to determine whether or not the clouds hung over the Delta. Some days when no clouds could be seen from Burrwood, the aviator would report solid banks of cloud over the Delta, about 20 miles away. Again, clouds would be visible apparently over the Delta, and the aviator would report that they were many miles beyond. A central location would have proved a benefit for observing cloud conditions.

Only two flights could be made each day, each flight using a full tank of gasoline. Two flights of over two hours each proved to be about the maximum time that the aviator could handle his plane efficiently, as the exacting flying required for mapping is a great physical strain upon the pilot. Two hundred and fifty photographs was the maximum number made in any single flight.

Owing to lack of equipment in the field the films were developed at Washington in a special tank, forwarded to Pensacola, where the prints were made, and the prints were then mailed to Burrwood for inspection. The prints were studied and rough mosaics constructed in order to see if all had been covered, and also for the purpose of noting if any gaps had been left. The small number of gaps speaks very well for the abilities of the pilots, who had had very little previous experience in this class of work. The gaps were plotted on a chart and covered in subsequent flights made especially for that purpose.

OFFICE REDUCTION

In order to compare the results with the topographic results obtained by the Coast and Geodetic Survey, the data were plotted on standard plane-table sheets. One of these sheets was on a scale of 1:40,000 and covered the northern section of the work. Five other sheets were on a scale of 1:20,000 and covered the southern section, showing all the principal passes on this larger scale. Polyconic projections were made and triangulation stations plotted in their geographic position.

The work was divided into three distinct operations: First, the construction of strip mosaics; second, the pantographic reduction from the same; and third, the transfer of the reduced data to the topographic sheets and the inking of these sheets.

As to the advantages of these methods in comparison with other methods of reducing data from aërial photographs, the construction of strip mosaic and the reduction of each in turn is far more accurate than the construction of solid mosaics consisting of several strips of flights. It was found that no two adjacent flights had the same scale, owing to slight difference in altitude, and to attempt to juggle these photographs is a very uncertain process and decidedly inaccurate. It is doubted if any time can be saved by constructing a solid mosaic, especially if any care is exercised.

The pantographic reduction has an advantage over the photographic method in that the selection of data and the reduction to scale is all done in one process. Whatever method is used, it is necessary for the draftsman to go over either the original mosaic or the reduction and outline the data to be transferred to the map. The photographic method of reduction means that the photographic step is an additional one.

Construction of mosaics.—In constructing the mosaics, a standard procedure was usually followed, and it was only necessary to depart from this method in a few cases where there was insufficient overlap or too much water area in the photographs.

The construction of mosaics was based on the assumption that all distortion of the photographs due to inaccuracies in the lens, or shrinkage of film or paper, and all displacements of points due to tilt, difference of elevation and scale, were on lines radiating from the center of the photographs. For all practical purposes this assumption is correct if the center of the photograph approximates closely the optical center of the camera, and also the point on the ground directly below the camera at the instant the photograph was made, otherwise known as the plumb point.

The approximate center of each photograph was determined by the intersection of diagonal lines joining opposite corners.

The mosaics were mounted on compoboards of convenient size for handling. The photographs comprising a mosaic would first be placed in approximate position on the board for the purpose of determining the correct location of the first photograph. The first photograph would then be fastened in place by thumb tacks. The second photograph would then be compared with the first, and two points would be selected, common to the two photographs and as widely spaced as possible, either close to or exactly on the line joining the centers of the photographs. Fine pencil lines would then be drawn through the points on each photograph long enough so that when the second photograph is placed in position on the first, the two lines merge into one continuous line. The two photographs are now correctly oriented with relation to each other so far as azimuth between the centers is concerned. This method of carrying azimuth gave excellent results, especially where the overlap was 50 per cent or more. (See fig. 10.)

The method of carrying distance between photographs was not as accurate theoretically as that employed for carrying azimuth, but actually the results obtained were almost as good. Any errors that might occur in the photographs were distributed. A point would be selected on the line of azimuth about halfway between the centers of the two photographs. The photographs would then be oriented for distance by moving the upper photograph along the line of azimuth until the point would coincide in both photographs. This was accurately done by drawing lines through the point at right angles to the azimuth line, and cutting a small opening in the upper photograph on this line just large enough so that the line on the lower photograph could be seen.

Azimuth and distance would be carried through the mossaic by orienting each photograph in turn. This method is the simplest one and also the quickest whereby mosaics may be constructed with any degree of accuracy.

Control points would then be identified on the photographs and marked in some way. The scale of the mosaic would be determined by measuring the distance between these points and comparing it with the actual distance on the ground.

The method described above would be used wherever possible, but if the overlap was insufficient, or if well-defined points for orientation were difficult to obtain, it was necessary to modify the procedure. A study would be made of the two photographs and two points would be selected for the line of orientation. These might be on a line at right angles to the line between centers. If no tilt was present in either photograph, this was a fairly accurate method.

Pantographic reduction.—The pantograph used for the reduction was similar to the ones used for cartographic work, and of sufficient accuracy for this project. The reductions were made from the mosaics directly to the scale of 1: 40,000 or 1: 20,000 as needed. These reductions were made on the under side of tracing paper by means of carbon paper placed face up under the tracing paper as the medium for tracing the path of the reproducing point. This left a carbon impression of the desired data on the under surface of the tracing paper. The paper would then be placed in position on the topographic sheet, and the data transferred to the sheet by rubbing the tracing paper with a buffer.

Great care was exercised in order that the reductions would be accurate. The pantograph setting would be checked for each mosaic. The table and instrument were kept level. The pantograph, mosaic, and reduction paper were all secured in place to prevent any shifting during the operation. The tracing paper would be examined for evidence of distortion. On rainy days, the tracing paper would undergo changes in dimension.

The draftsman would first transfer all control points, marking them legibly on the tracing paper. He would then outline the data to be transferred, taking great care that nothing important was omitted. In some cases, it was necessary to study the photographs minutely in order to interpret them correctly. Some of the photographic detail was so obscure that it was necessary to examine each section with a great deal of care, studying all adjoining and overlapping photographs, and also any available obliques. The data reduced was only that which was to appear on the topographic sheet, and that which did not appear on adjoining mosaics.

Plotting topographic sheets.—Before plotting on the sheets, it was usual to examine all the reductions of the mosaics adjoining the area to be plotted. These would be compared one with the other, and would also be compared with the sheet for the purpose of checking the accuracy of the reduction with relation to the control points. If the reduction checked in all respects, the data would be transferred to the sheet by placing the tracing paper in its correct location with respect to control points, and rubbing it with a buffer, leaving an outline of the reduced data.

Usually mosaics would be constructed, reduced, and transferred in groups covering a definite area, bounded by control points. Supplemental control would be carried from one mosaic to the next by means of common points in the overlapping area. These groups of mosaics would usually have the two end mosaics of the group controlled by triangulation stations. The group of mosaics would be constructed, and supplemental control points selected and marked. One of the end mosaics would then be reduced, using the scale as obtained from the triangulation control. This reduction would be fitted in place on the sheet, and the supplemental control for the adjoining mosaic transferred to the sheet. This control would then be used for the reduction of the second mosaic, and the transfer of supplemental control for the third mosaic. The supplemental control would be carried from one mosaic to the next until a mosaic with triangulation control would be reached, when a check would be obtained.

The method of carrying supplemental control from one mosaic to the next by common points in the overlapping section proved to be a very good one if the serial work had been carefully done. The biggest percentage of error by this method was found to be 1 in 36, but this was in an area where the photographs were tilted, and the lines of flight were much broken up. An error of 1 in 60 was found in one of the groups, and this is probably the maximum percentage of error that can be expected in average flying. In every case the supplemental control fell short, indicating that the probable source of error was tilt.

Control by means of control flights was used in the same way as if the flights were a traverse. The control flight would be reduced and plotted on the sheet, all supplemental points on overlapping flights having previously been selected and marked. The accuracy of this control flight was usually checked by plotting supplemental control on the other mosaics, as if the control flights had not been made. Comparing the control by the two methods would serve as a check on the accuracy of the control flight.

Supplemental control points were usually chosen with care, especially as regards position, so that any possible errors would be as small as possible.

In the areas that were first photographed, special methods were employed in transferring the data to the sheets. Errors occurred in the early photographs that were almost eliminated in the later, and it was necessary to use different control methods to suit the change in conditions.

In the vicinity of the "Crevasse," just northeast of South Pass, several strips showed evidence of motion during the exposure, and others indicated the presence of tilt. These were among the very first pictures made and showed the greatest percentage of error. Control points were scattered over this section at intervals of about 2 miles. The method used with these strips was to consider the center line of each mosaic as being correct reductions. These center lines were then plotted on the sheet between control points, and the remainder of the detail adjusted to fit these strips of topography.

In the Cubit Gap area, just north of the area mentioned, discrepancies were found that seemed to differ in character from those found in the earlier mosaics. In this area some of the mosaics were apparently in error even along the center line, and these could not be considered for control purposes. It was necessary to study the mosaics closely and select those best suited for control. The data from the selected ones were then transferred to the sheet and the intervening mosaics adjusted to fit. In this area, control points were spaced at intervals of from 3 to 4 miles, but the character of the photography required closer spacing in order to maintain Coast and Geodetic Survey standards.

At the lower end of Pass a Lutre where the character of the topography would not allow the construction of continuous mosaics, it was necessary to plot the short mosaics that could be constructed, and the control strips, and fit the remaining mosaics to these. There was no way of checking this reduction, but the experience gained in the other reductions indicated that good results could be expected, especially with the short mosaics.

Interpretation of aerial photographs of the Delta could only be done by one familiar with the locality. The various kinds of vegetation, usually growing in large patches, caused confusion, especially in the photographs with poor detail. Many of the bayous and lakes were covered with water lilies that obscured the surface completely. In some cases wooded areas had the same appearance as patches of cane, and in other localities they could not be distinguished from water-lily patches. A knowledge of the localities where willows grew helped considerably, and a study under the stereoscope usually furnished the desired information.

A field inspection of the photographs proved of great value in the interpretation. A few key photographs studied on the ground solved almost the whole problem of the office examination.

A few oblique photographs were made by the aviators in the spring of 1922, and these proved of great value as a check on the correct interpretation of the sections that were obscure on the photographs.

COST

The tabulation of the costs of the Delta project does not include overhead, but an attempt is made to include all costs that may be properly charged to the project. Accounts were kept by each of the bureaus interested, and the cost data are as a whole very accurately arrived at, only a few approximations being necessary where exact data were not available.

EXPENDITURES ON SURVEY OF DELTA

Triangulation

Field work, spring of 1921	$1,451.00
Office computations in 1921	302.50
Field work, October and November, 1922	1,666.94
Office computations, 1922	339.00
Total	3,759.44

Photographic field work

Expenditures by Navy Department:	
Transportation to field from Pensacola, including cost of escort planes	$527.20
Pay of Navy personnel	1,726.00
Repairs to plane	275.35
Depreciation of plane	663.38
Total	3,191.93
Expenditures of Coast and Geodetic Survey:	
Gasoline and lubricating oil for planes	426.47
Salary and expenses of engineer in field	1,196.28
Total	1,622.75
Expenditures by United States Engineers:	
Subsistence of Navy personnel	114.25
Transportation of personnel	15.00
Gasoline and oil for plane	99.20
Care and handling of plane	393.61
Total	622.06
Total cost of photographic field work	5,436.74

Photographic supplies and laboratory costs

Expenditures by Navy Department:	
Films	744.00
Chemicals (approx.)	236.00
Labor (approx.)	100.00
Total	1,080.00
Expenditures by Coast and Geodetic Survey:	
Paper	73.48
Chemicals	25.00
Labor	40.00
Total	138.48
Grand total	1,218.48

Office work of reduction

Salary of officer in charge (time spent in drafting, etc.)	$1,544.80	
Draftsman up to Nov. 30, 1923	1,360.00	
Total	2,904.80	
Total cost of survey		$13,319.46
Total area sq. stat. mi.		513.6
Cost per square mile		$25.93

CONCLUSION

Examination of the results of the Delta survey indicates that there is room for improvement, probably not as markedly in this particular object, as it would be in future projects where the character of the terrain allows greater freedom for control. Owing to conditions encountered, the Delta survey could probably have been improved in only one respect, and that was in the flying and photography. The ratio of closing error of 1 in 36, as attained in one section where supplemental control was used, could have been bettered to 1 in 100 if the flying had been all of the same quality as that attained in the last stages of the work. Additional ground control was almost an impossibility in the particular area mentioned, so that improvement had to be made in some other way.

In future projects some changes should be made in the methods described above, if conditions permit. Each project will have its own problems and methods will vary. It would be difficult to prepare exact specifications for general use, but the following recommendation will contain the improvements suggested by the results of the Delta survey.

Specifying improved flying takes into account the personal equation. It would be preferable to improve the equipment as far as possible, allowing greater latitude to the aviators in their operation of the plane and camera. Even with improved cameras, equipped with tilt indicators, errors may be expected under unfavorable conditions, and it would be wise to have some method of checking the accuracy of the photographs either by adding to the control or by developing office methods that will rectify the photographic detail.

Ground control should be well distributed. In order to maintain Coast and Geodetic Survey standards of accuracy, control points should be spaced at intervals of 1 mile. These need not necessarily be triangulation stations but could be located by other methods at the time the field inspection of the photographs is made. Accurate results will be obtained with stations 1 mile apart, as this will allow of rectification of individual photographs if necessary. Office work would be considerably simplified by the additional control points.

The office work is the least expensive of the steps necessary to complete an aerial project, and it would seem to be the logical thing to develop the office methods even at increased cost, as it would increase the total cost but a small per cent. One objection to increasing the office work is that it would delay the final results, unless additional draftsmen could be obtained. The simple methods used on the Delta project required the entire time of one draftsman almost a year, and the part time of an engineer and other draftsmen, bringing the total time for one man up to 15 months. It would be preferable to shorten the office work, and if additional draftsmen are available, let them combine to produce the final results in as short a time as possible.

Specifications for future aerial surveys for the Coast and Geodetic Survey may be summarized into briefer form. The work for the near future should be limited to the flat coastal plain.

Photographic work to be done with a mapping camera of proven merit, from an altitude as high as possible, maximum allowable scale of the photographs 1:20,000. Photographs to overlap 50 per cent. Control points to be spaced at intervals of 1 mile. Office reduction to follow methods used in Delta survey, except where tilt is present.

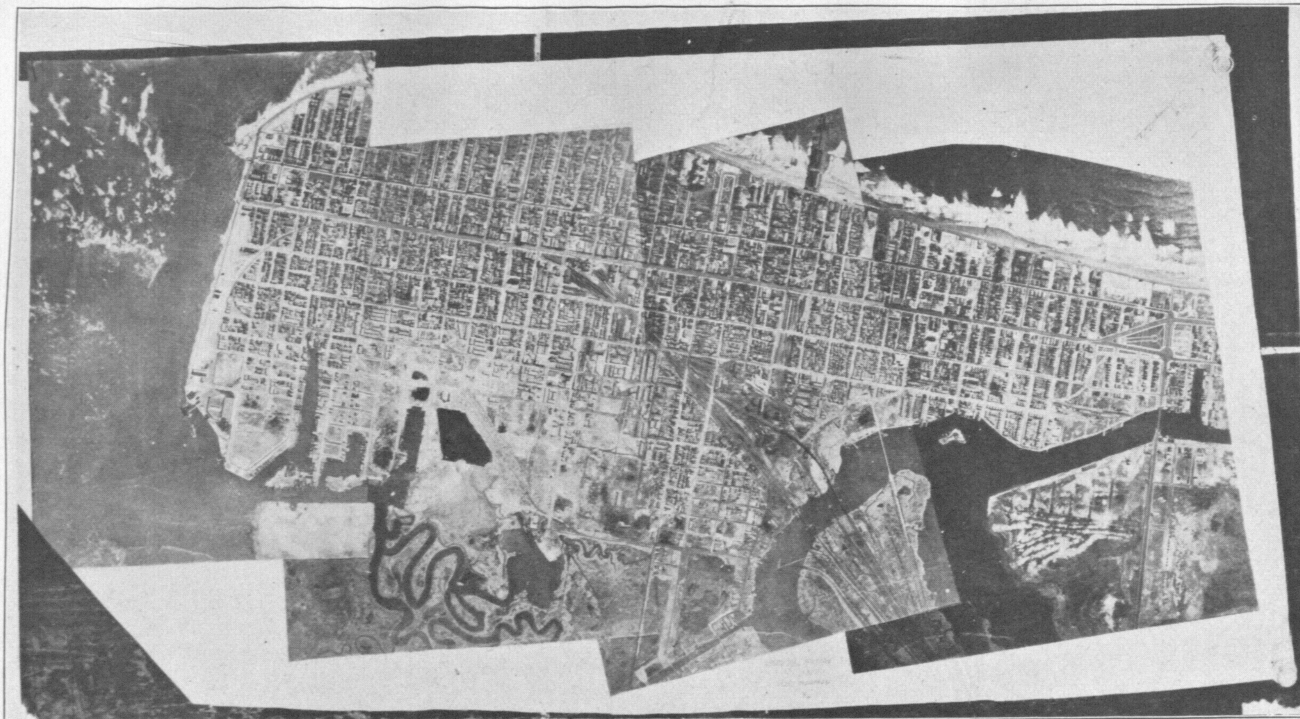

FIG. 1.—ATLANTIC CITY MOSAIC

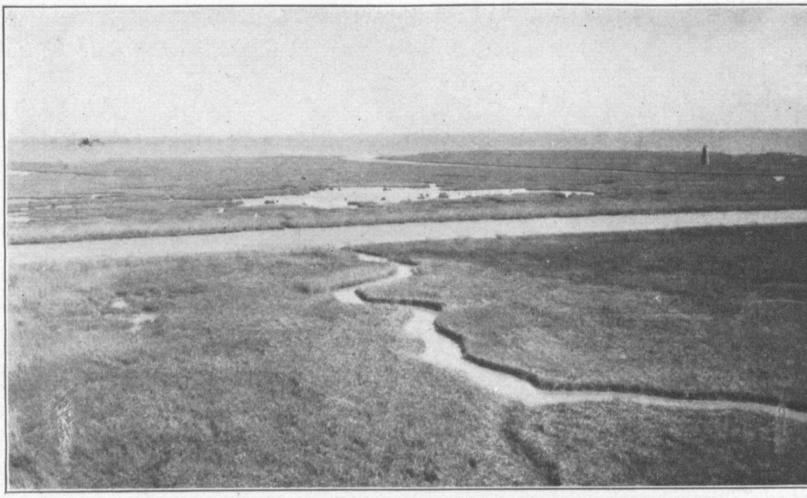

FIG. 2.—TYPICAL TOPOGRAPHY OF THE DELTA

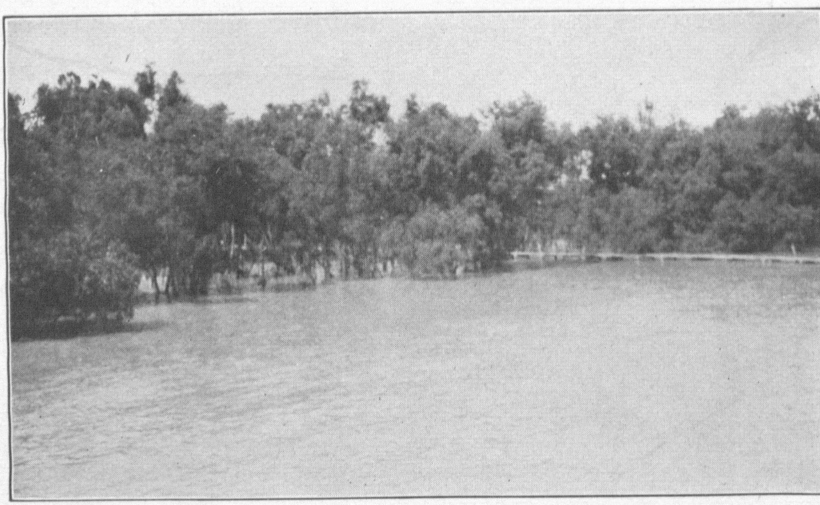

FIG. 3.—WILLOWS ALONG THE BANKS OF THE MISSISSIPPI RIVER

FIG. 4.—WILD CANE WHICH COVERS A GREATER PART OF THE DELTA

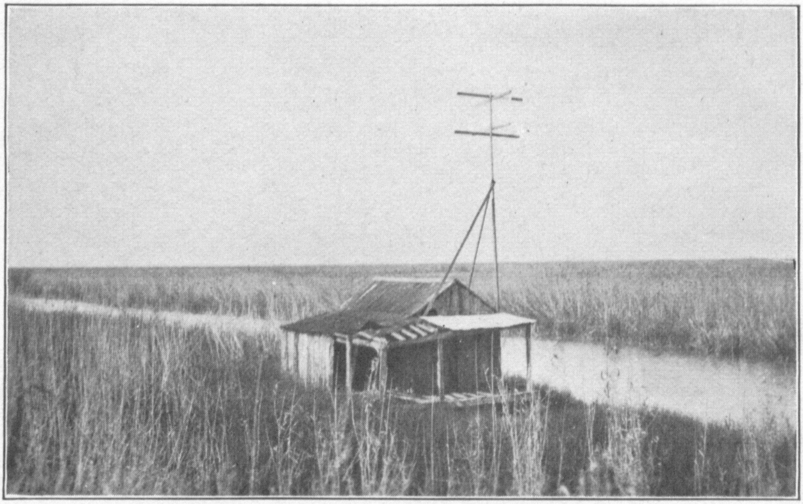

FIG. 5.—ONE OF THE SIGNALS USED FOR CONTROL

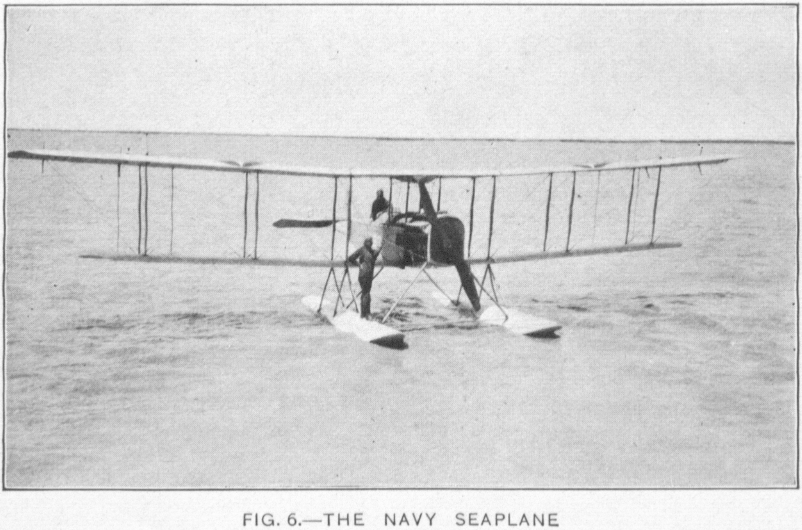

FIG. 6.—THE NAVY SEAPLANE

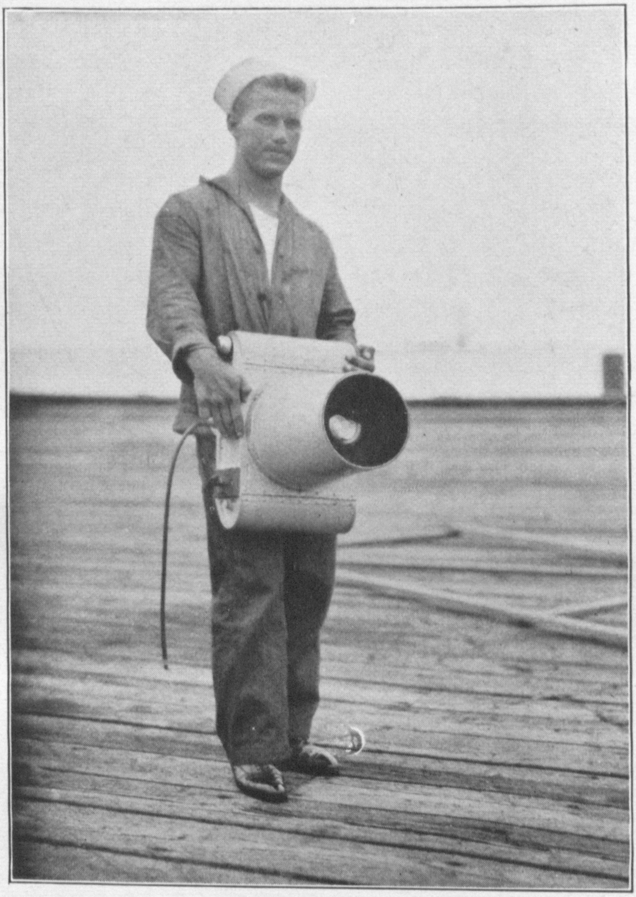

FIG. 7.—THE K-1 MAPPING CAMERA

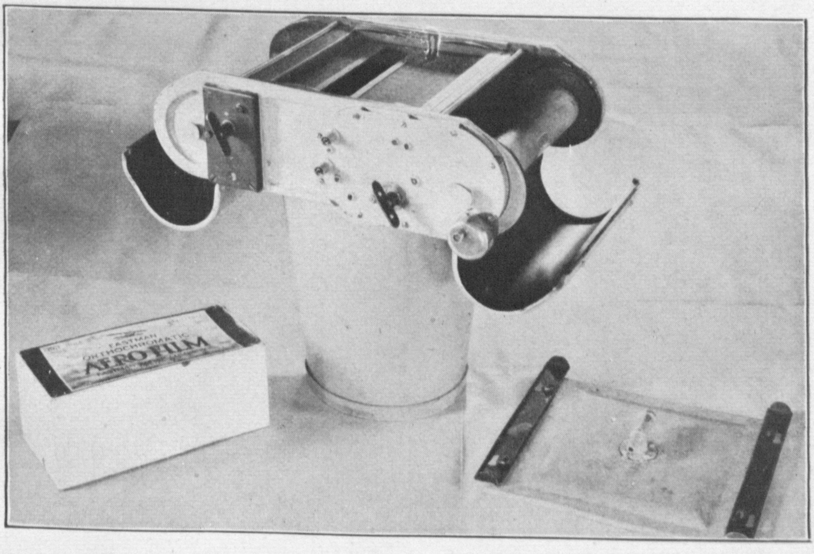

FIG. 8.—ANOTHER VIEW OF THE CAMERA

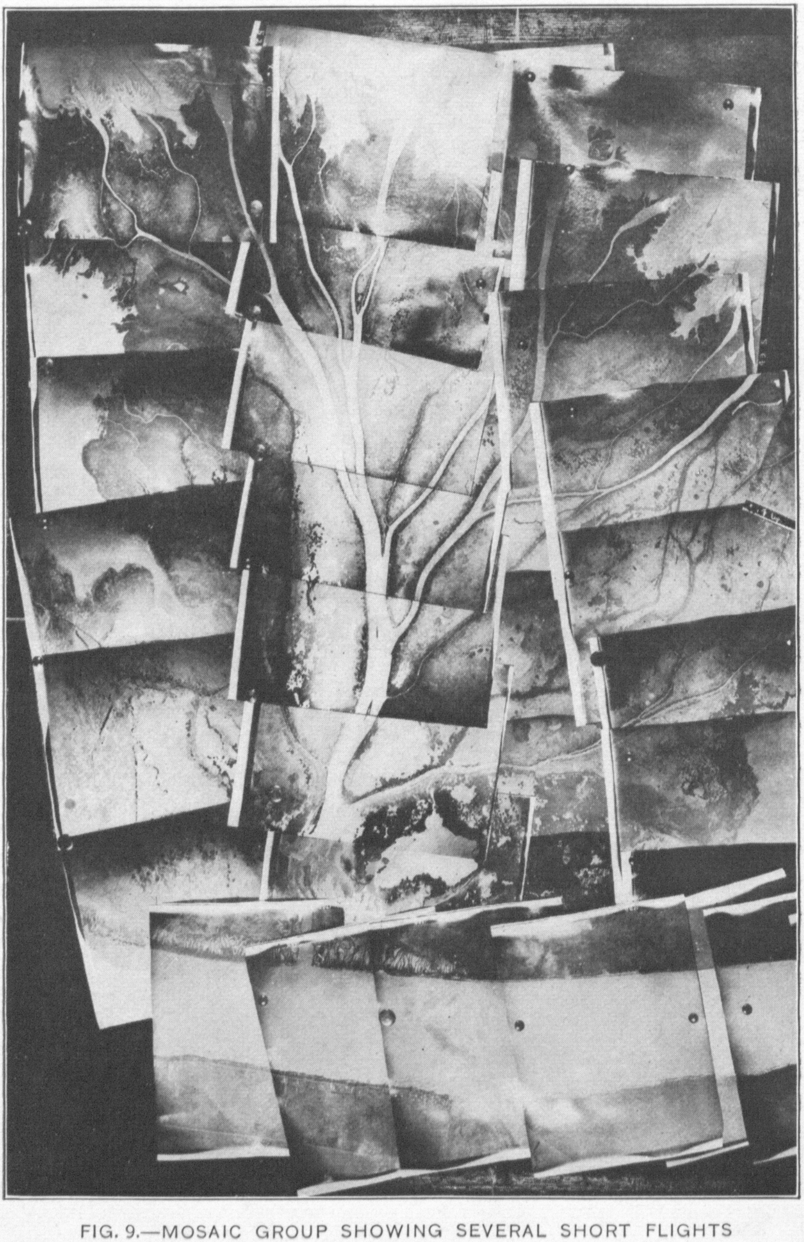

FIG. 9.—MOSAIC GROUP SHOWING SEVERAL SHORT FLIGHTS

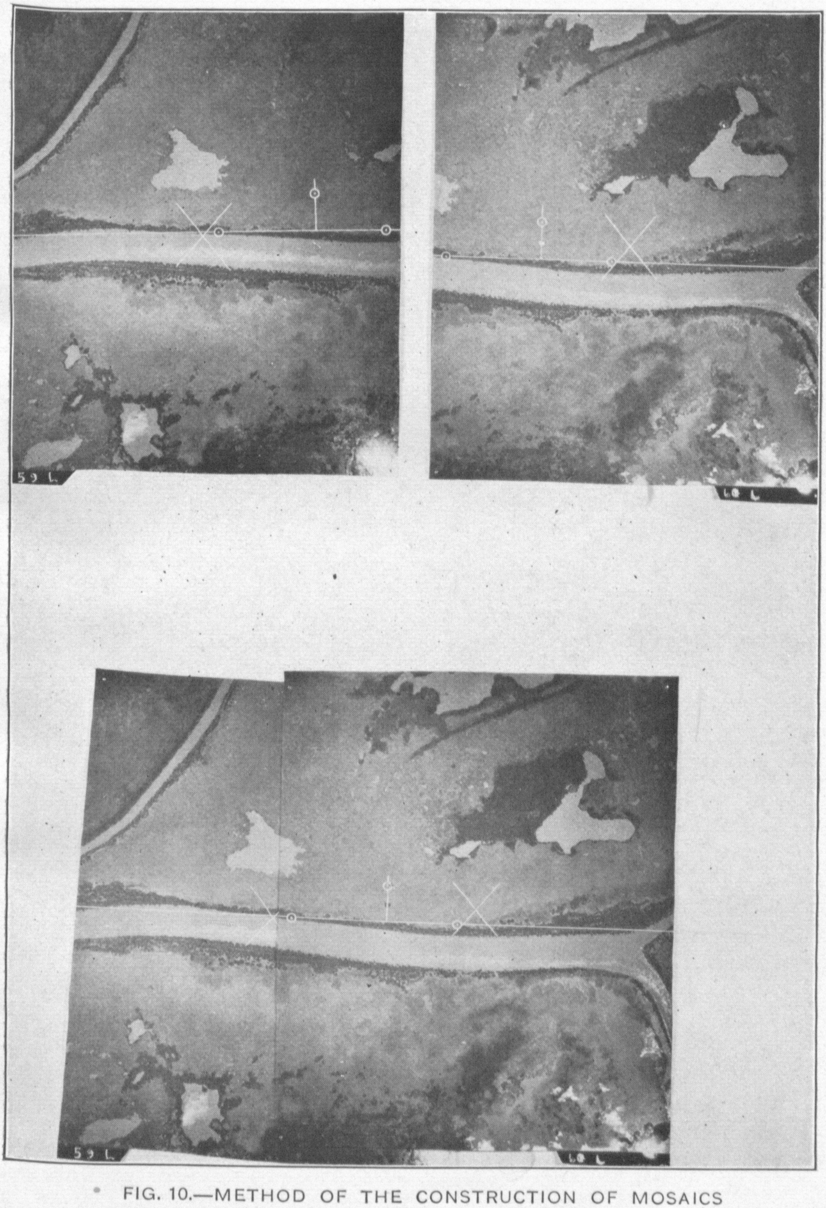

FIG. 10.—METHOD OF THE CONSTRUCTION OF MOSAICS

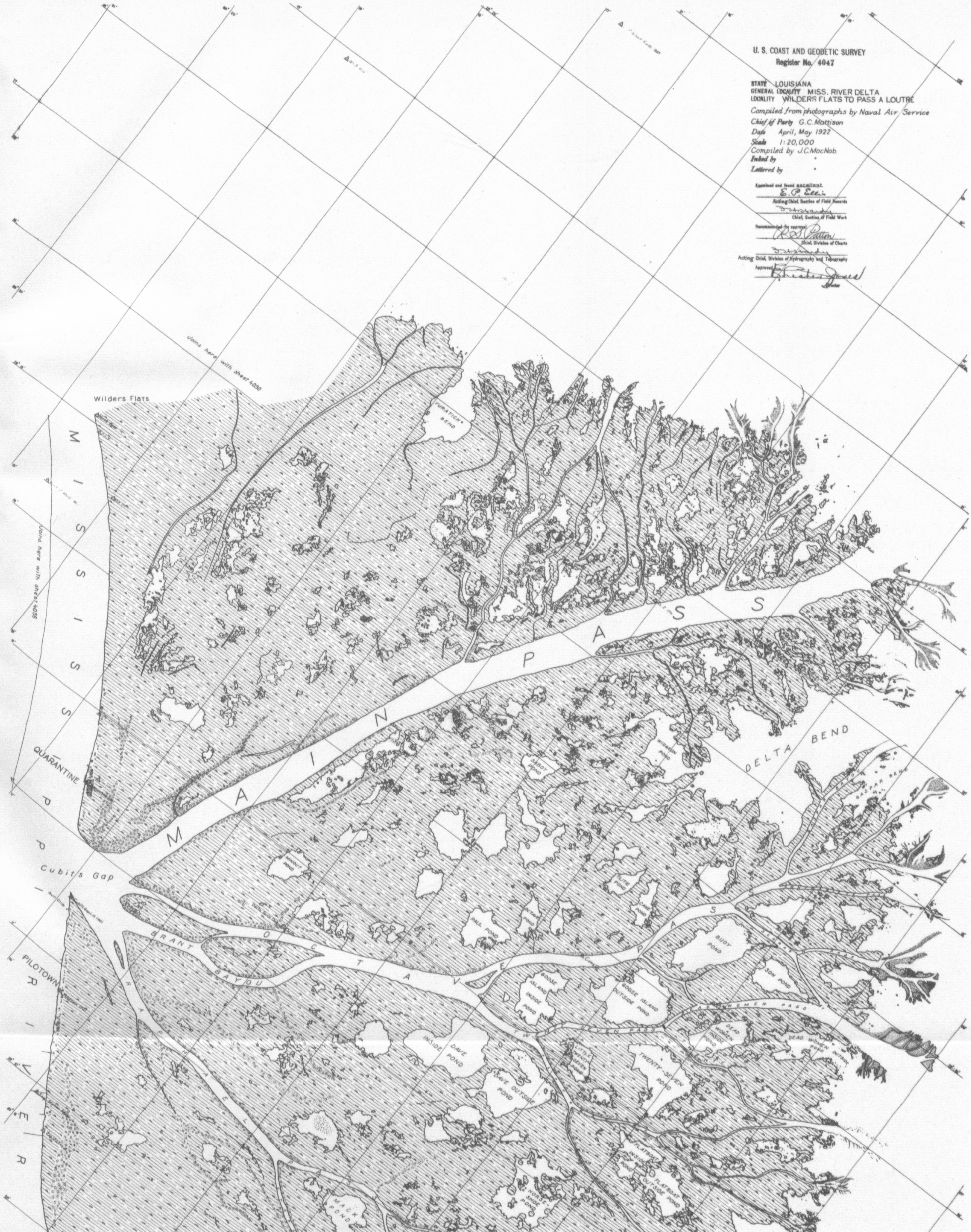

FIG 11.—ONE OF THE TOPOGRAPHIC SHEETS

C.&G.S. Print A-287

C.&G.S. Print A-288

FIG. 12.—THE INDEX CHART