After reduction and modification and the assumption that $\alpha=0$ we obtain the general law of error propagation in the x and y directions (4) (5).

$$md\Delta x^2 = \mu^2[(\Delta x^1)^2 QdV_A dV_A + (-\Delta y)^2 Qd\alpha d\alpha + 2[(\Delta x^1)(-\Delta y)(QdV_A d\alpha)]] \quad (15)$$

$$md\Delta y^2 = \mu^2[(\Delta y^1)^2 QdV_B dV_B + \Delta x^2 \cdot Qd\alpha d\alpha + 2[(\Delta y^1)(\Delta x)(QdV_B d\alpha)]] \quad (16)$$

In the above equations $QdV_A dV_A$, $QdV_B dV_B$, and $Qd\alpha d\alpha$ are weight numbers and $QdV_A dV_B$, $QdV_A d\alpha$, and $QdV_B d\alpha$ are correlation numbers.

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*A New Approach to Aerial Map Data Acquisition and a Global Operational Concept**

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A New Technique for Aerial Mapping

A new mapping system is presently under development in the USAF. The Boeing RC-135 which is very similar to the commercial airline Jet 707 will soon be delivered as the USAF's new aerial mapping and surveying vehicle.

This high-speed jet aircraft will provide an extremely stable platform for the most intricate and sophisticated system ever developed for aerial surveying and cartographic mapping.

This new aircraft will reach an altitude greater than 50,000 feet. At a true air speed of about 600 miles-per-hour plus its long endurance will result in exceptionally high mission accomplishments.

The mapping and surveying system being developed will consist of a new 6″ focal-length mapping camera with a resolution of better than 40 lines-per-mm; an inertial platform so precise that it will record the true vertical of each exposure to less than 30″ of arc; and a new electronic surveying system that will give instantaneous ranging of distance from the aircraft to as many as 4 widely separated ground stations. These plus many other innovations will be incorporated in this new system. The result expected from the new system is to secure in addition to the mapping photography, most of the control data required for large-scale maps (1/50,000).

The article attempts to explain some of the intricacies of this sophisticated system, and then gives the views of the author on a global operational concept to rapidly acquire the map deficiencies that face the world today.

A New Concept for Aerial Mapping

Map making is big business. The combined efforts of the Army, Air Force, Navy, U. S. Geological Survey, USC&GS, Department of Agriculture, plus civilian contractors coordinate their talents in the massive efforts of accurately portraying the minute details of the earth's surface.

Map detail is derived from data collected

* Presented at the 1962 ACSM-ASP Meeting in St. Louis, Missouri.

by the ground surveyors, who obtain horizontal and vertical control, and the aerial photographers who obtain the precise mapping photography. National map accuracy standards prescribe the details that appear on the maps published by qualified cartographic agencies.

There have been some advanced developments in the ground surveyor's tools. The Tellurometer and Geodimeter for horizontal measurements have to a large extent replaced the steel tape and chain. The Ground Elevation Meter is being used in some areas to acquire low-order leveling.

The aerial photographer, too, has been developing a highly sophisticated airborne system which is the purpose of this paper.

To start with let us briefly review our present system. Aerial electronic surveying (known by its coined name of Hiran) was developed as a first-order surveying tool after World War II. The Hiran System can precisely measure great distances using a high-altitude aircraft between two ground stations. Measurements accurate to ±12 feet can be made from short distances to distances greater than 550 miles. Hiran has accurately surveyed the Atlantic and Pacific missile ranges and has made the historic and first precise geodetic connection between North America and Europe. This survey, over 2,000 miles long, between the North American continent and Europe achieved an accuracy of 1/314,000 or ±34 feet.

Mapping of an area by a combination of aerial photography and the aerial electronic survey technique would permit adjustment of photos (provided complete area coverage is obtained) to within 25 to 30 meters for horizontal control. This is called Hiran Controlled Photography. A terrain profile is charted by a narrow beam (1°) radar signal sent vertically from the aircraft which is modified with hypsometer corrections. This device is called an Airborne Profile Recorder (APR). Aerial profile readings have been obtained and interpolated to six (6) feet in moderate terrain anomalies.

Although Hiran Controlled Photography seems to be a logical answer to the acquisition of aerial mapping photography with horizontal control data, it is in many areas operationally uneconomical. The necessity for clear weather in the limited area sustained by the ground stations ties the hands of the operating units until suitable photo weather occurs. Months of waiting can make this procedure exceedingly costly.

In this paper will be explained a new approach which has been developed into a new streamlined operational concept and by which horizontal control data can be obtained by the aircraft rapidly and efficiently. This concept was first envisioned using a highly stable aerial platform which is worthy of explanation.

An Air Force policy statement in 1945 directed that reconnaissance and mapping aircraft of the future would be modified from current aircraft production. In consonance with this policy, the USAF has programmed RC-135 aircraft for aerial mapping and electronic surveying. This aircraft was selected because its design features were so compatible with the requirements for a surveying and mapping vehicle.

The Boeing KC-135 aircraft was conceived and designed as a high-speed, high-altitude stable platform for air refueling missions. To maintain its high-altitude, high-speed stability while rapidly discharging its many tons of fuel was solved by retaining its center of gravity throughout the refueling operation. The aircraft was also designed to consume its internal fuel (including tanker fuel), for maximum range or ferry operations. All of its tanker fuel is *below* the cargo floor. Above this floor an area the size of a bowling alley will accommodate multiple cameras electronic survey equipment.

The skilled engineering of the auto pilot complements the stability characteristics of the aircraft and maintains it rigidly in space as a firm stable platform ideal for the aerial mapping mission.

Before proceeding with our discussion on the aircraft development, the author would like to relate his views of the task of the photogrammetrist. This skilled technician receives the geometrically perfect (less than 10 micron distortion) aerial photographs which were taken by the mapping aircraft. The camera, if cradled in our present stabilized mount, is pointing almost vertical when the aerial photographs are taken. But which way that first photo was tilted and how much cannot be determined without the aid of ground control. Accurately surveyed ground positions which can be identified or plotted on the mapping photograph must be correlated with the aerial exposure to correct it to its true vertical. When one photograph has been properly oriented to the ground survey control data, then overlapping stereo photographs can be leveled and the control extended by this procedure; this is called aero triangulation. Aero triangulation works well over a short distance, but accuracy gradually deteriorates as it is cantilevered from the first model or bridged between two separate models. Approximately seven successive stereo photographs are generally considered to be the maximum extension possible for 1st order aero triangulation.

In summary, it would seem reasonable to conclude that one of the major goals of the photogrammetrist is to find the true vertical axis of each and every one of his aerial photographs.

If true vertical photography could be obtained by the mapping aircraft, it would contribute immeasurably to the science of map data acquisition and compilation.

There are two possible ways in which the aircraft may obtain this vertical accuracy. One would be a stabilized mount with an accuracy of 30 arc seconds or less. This would be the preferred solution; however, such precise stability may not be technically feasible at this time.

A second possibility would be to rigidly mount the aerial cameras in boresight alignment with a precision inertial platform and to record the vertical deflection instantaneously with the camera exposure. Engineering studies have concluded that this solution is possible. The author will continue his discussion on this basis of rigid camera mounts with a syncronized vertical readout. However, either system of stabilized or rigidly mounted cameras that could meet the precision standards of 30 seconds verticality would provide the same rapid data collection system and end product.

High-precision inertial platforms which have been perfected for missile guidance systems have achieved vertical accuracies of several seconds. Such a platform can be aligned with the vertical axis of the rigidly mounted mapping cameras. The vertical readout of the inertial platform, recorded and syncronized with the aerial exposure to 30 arc seconds or less would solve one of the principal problems of the photogrammetrist.

It was mentioned earlier that Hiran Controlled Photography was not operationally feasible but there is another technique used with the present Hiran system that has been successful; this is called Secondary Control Photography (SCP). It is used to locate a pinpoint target such as an off-shore island or an inaccessible point, when first order accuracy is not required. The SCP technique does not require a large clear weather area; only the pinpoint target need be unobstructed by clouds.

Secondary Control Photography is obtained in the following manner. While the aircraft is accurately and continuously positioned in space in relation to two ground stations, a series of photographs is taken on each of four flight paths. The operational flight pattern is designed to cross the target (SCP) in an *X* pattern on each of the four cardinal compass headings. A minimum of 13 aerial mapping photographs are taken on each flight path. The combined total of 52 exposures is centered on the (SCP) target. This large number of photographs will then be analyzed in attempting to "average out" the tip and tilt. Or if expressed in another way, the 52 photographs are analyzed to determine, as nearly as possible, the relationship of the true vertical to the aerial photographs. The averaging of the 52 photographs will normally permit a vertical determination to within four minutes of arc. The recorded Hiran distance measurements must also be analyzed for the most probable position by relating the distances measured on each of the four flight paths. The final computed position of the secondary control point (SCP) will be accurate to something less than 50 feet.

This current SCP technique can be radically upgraded in accuracy with the new mapping aircraft and survey systems under development, and will be called *Control Point Photography* rather than Secondary Control Point Photography.

The technique of acquiring Control Point Photography will be fully explained later in this paper. Before proceeding any further on this thesis the author would like to direct the consideration of the readers to the task that faces the world's mappers.

Take a look at the major areas of the world. (Figure 1—World Triangulation Chart). The countries that have achieved growth and development are synonomous with the surveyed sections shown on this chart of the world's triangulation. The world's total land area contains some 54,000,000 square miles. A few years ago, world map deficiencies were estimated as over 23,000,000 square miles. Almost half of the world was still unsurveyed and as can be seen, by Figure 1, most of these uncharted areas are in the more primitive and inaccessible areas of the world.

The past and present method of map compilation from aerial photographs has depended upon the ground surveyor's accomplishments. The ground surveyor's task is slow and laborious, and in addition, he is unable to traverse much of the world's primitive and impenetrable areas. A system that relies solely on the ground surveyor's accomplishments to complement aerial photography will not satisfy the urgent needs of our mapping requirements.

Prototypes of a new electronic surveying system for the Air Force are under development at the Cubic Corporation, San Diego, California. Performance specifications required a precision measuring capability of 6′ accuracy for measurements up to 450 miles line of sight distance from each ground station. Development specifications dictate that a high order of reliability be built into this system. The results will be recorded on digitized tape and compatible with our electronic computors. The new system will also permit the aircraft to record four channel measurements simultaneously from widely separated ground stations; this will greatly strengthen its potential as an airborne surveying tool.

When this system becomes operational, a trilateration network of aerial electronic measurements, with ground stations separated 100 to 300 miles, will provide a basic geodetic framework of 1st-order horizontal control. This geodetic framework is of course inadequate for large-scale (1/50,000) map compilation. However, the new surveying system will have the ability for instantaneous distance recording from any or all of the four ground stations. This feature is a key element of the new concept which makes possible the accomplishment of what the author termed "Control Point Photography." Control Point Photography can be obtained by recording the simultaneous airborne distance measurements from three or four ground stations encircling the aircraft which will pinpoint it for a strong geometric fix. This geometric fix synchronized with the mapping camera exposure along with its vertical deflection of less than 30″ arc sec. 3 sigma will permit the photo nadir to be plotted to an accuracy of ±15′ within the trilateration net.

From an operational standpoint this (SCP) is a very desirable technique since scattered to broken cloud conditions would be no hindrance to securing Control Point Photography in the project area. Since 3/10 to 5/10 cloud cover is the *normal* weather condition that can be expected 90% of the time in the majority of areas of the world, a dense network of stereo, control point photos could be easily obtained where the ground is not obstructed by scattered or broken clouds.

The operational procedure would call first on the ground stations to be installed in an appropriate network pattern. As soon as the ground stations are installed a trilateration net can be flown. While these ground stations are in place a dense network of Control Point Photography can be acquired which will precisely locate the nadir of each of the stereophotos throughout the project area.

Compilation to satisfy horizontal control criteria for the required 1/50,000 scale maps should be possible with approximately 50% area coverage by means of Control Point Photography. In addition to the trilateration net and Control Point Photography of the project area, a terrain profile will be obtained by the aircrafts Airborne Profile Recorder (APR). Complete visual aerial mapping of this project area will be obtained when good photo weather prevails. The visual photo operational phase will not normally be accomplished during the same period in which the trilateration net and the control point photography is accomplished. This procedure is more fully explained in the next section entitled A Global Operational Concept.

A Global Operational Concept

World-wide mapping and survey requirements can be pursued more realistically by using three main bases of operations. An operational unit in Europe, one in the Far East, and one at Turner AFB, Georgia, will place all areas of the world just hours away from the mapping and surveying aircraft. An immediate reaction capability to acquire mapping photography in any area of the world (except behind the curtain countries) would thus be possible for the first time.

Normal operation of the three-team global concept would permit visual photo to be accomplished in any clear weather area. The high-speed and long-range of the RC-135 make it possible to reach this good weather area *quickly*, with sufficient endurance for major mapping accomplishments.

A key role in the visual mapping operations will be tied to the future weather satellite vehicles. It is planned to have the national Meteorological Center analyze the satellite reports and to send each key operational location a "best bet" photo area similar to those provided the mapping wing in the United States. To illustrate what can be expected refer to John Glenn's recent orbit

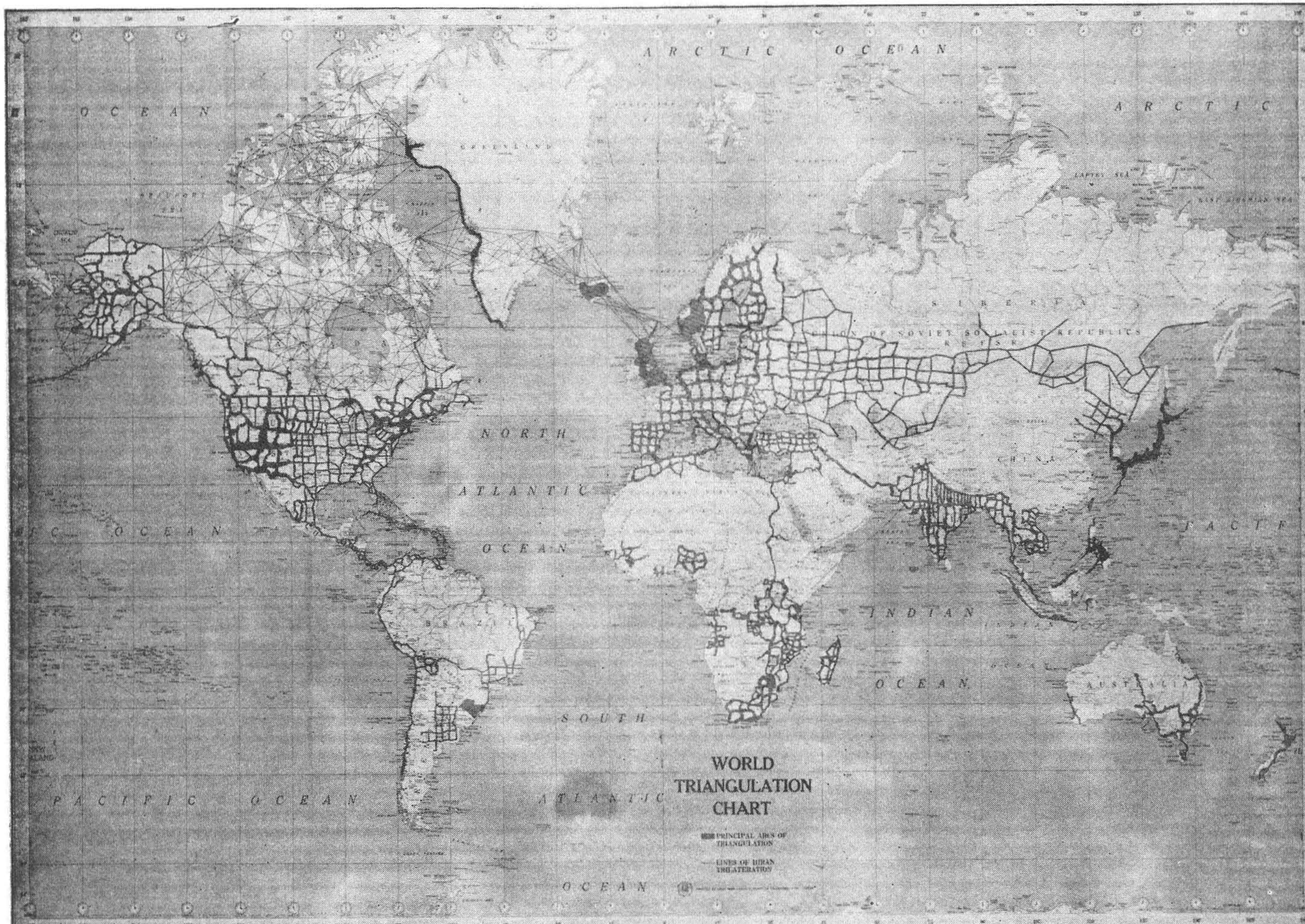

FIG. 1. World Triangulation Chart.

report published in the 9 March 1962 issue of Life's exclusive story; this says: "*One of the things that surprised me most about the flight was the percentage of earth covered by clouds. The clouds were nearly solid over Central Africa and extended over most of the Indian Ocean. Western Australia was clear, but it was cloudy again from Eastern Australia all the way across the Pacific.*" What Glenn saw and reported, future weather satellites will see and transmit regularly, and the high-speed aircraft of the mapping units will be directed to the most probable cloud free areas.

Aerial Electronic Surveying will be independent of visual photo missions. The field support unit, consisting of ten ground stations, will call upon the operational unit only when its ground stations are installed and on the air. Operational mission aircraft will then be sent to the area to accomplish the aerial surveying and control point photography. The long-range RC-135 aircraft will either fly round-robin survey missions from its home base or stage at a suitable airfield. In any event, concentrated flights will rapidly acquire the aerial survey measurements and the control point photography for the 10 operational ground stations in a maximum of a few days. The aircraft will return to its home base where the collected data will be evaluated. The RC-135 aircraft are freed then for other operational missions while evaluation adjustment and ground movements take place.

Each of the three operating locations will have two RC-135 aircraft and four RC-130 aircraft. Two helicopters will support the ground-station movements. The RC-130 aircraft will have a dual role of mission accomplishments and area airlift support. The RC-130 aircraft will accomplish the smaller requirements: individual line measurements, station photo, etc. In effect, the long-range aircraft will be called upon for bulk accomplishments, for which it is best suited, and the RC-130 aircraft will acquire the diversified individual tasks for which it is best suited.

If visualized properly, this operational concept permits a *continuous productive effort.* Visual aerial mapping *pursued daily* in the good weather areas, and the ground stations for aerial surveying, either moving or in place and calling upon the operational unit for a trilateration survey or control-point photography.

Although the operational concept envisions the aircraft capable of obtaining vertical and horizontal control as well as visual photography, there is no intent to conclude or infer that the ground surveyor is obsolete. Instead, the planning of over-all operational accomplishments will *include* project requirements that can be most efficiently obtained by ground survey parties.

It is important to note that the operational area encompassed by the ground stations will not necessarily coincide with the visual photo area. The trilateration net and control-point photography will be acquired on a priority basis where ground stations can be installed. Visual mapping photo and APR will be acquired in the clear weather area regardless of priority.

In conclusion, it can be stated that the sophisticated survey and mapping system presently under development, combined with this global operational concept, will rapidly gather the bulk of the data required for our 1/50,000 scale maps.

To further substantiate the basis for this concept, reference is made to a report on the value of 30-second vertical photography which was compiled by the Ohio State University Research Foundation and published in May 1962.

The noted photogrammetrist, Dr. Brandenberger, states in his conclusions that "One of the greatest advantages of vertical photography lies probably in a very simplified procedure of determining secondary ground-control." A savings of as much as 80% in ground-control data would be realized by combining the precise vertical photography with the electronic surveying system (Control Point Photography). Dr. Brandenberger also stated that "All first-order and most second-order stereoplotting instruments can readily absorb vertical data *without any modification.*" A savings in map compilation of up to 40% over present methods would be possible with true vertical photography.

In summary then, this new mapping concept will "jet propel" the ground surveyors laborious process of data acquisition by acquiring most of the control needed by the map maker along with the aerial photography. The precise vertical photography will also provide a short cut to map compilation which will elevate it to a new height of efficiency and production.