notes of the location furnished. The field man is called upon to plot the road on an outdated photo, and then to compare its location with the actual location given on the most recent photo. The close comparison sure to result will improve his confidence in aerial photographs as a forest management tool.

CLOSURE

This discussion has dealt with an ever-present problem in a forestry organization. This problem is encouraging the field man to use time-saving equipment and procedures. Aerial photographs fit into this category. Although they are not a direct function of forest management, they are a tool of such management and must be publicized as such. A local aerial photo training manual can provide this publicity in a personal manner through use of local aerial photographs.

Although the case discussed in this paper dealt with aerial photographs in a forest management setting, the points covered could be used to advantage in other disciplines. The need for a local photo training manual no doubt exists within many organizations, and when prepared, should provide a valuable reference for all field men in the organization.

*Geodesy's Newest Dimension**

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ABSTRACT: *Many methods and projects of three-dimensional geodesy have a common denominator—the photographing of a light source against a star back-background. Tested methods are Rocket-Flash Triangulation and Long Line Azimuth determination. The geodetic satellite ANNA is an example of a system whose observation program is just beginning. A proposed program which is now under study is Project SCORPIO, a satellite system primarily designed to calibrate range instrumentation equipment but which will also provide geodetic and geophysical data. LARGOS, a laser-activated reflecting geodetic optical satellite, also in the design stage, will be a passive type satellite. Undergoing feasibility studies is a geodetic equatorial synchronous satellite, which could provide valuable information on gravitational harmonics.*

INTRODUCTION

THE new dimension of geodesy is *space.* One of the basic keys to the utilization of this new dimension is photogrammetry. The principles of this science are employed with precision stellar cameras and a light source in space for the purposes of performing geodetic stereo-triangulation.

The various methods and uses of photographing a light source against a star background for geodetic purposes can best be appreciated if we look at our past performances and failures, our present systems, and our hopes and plans for the future.

The methods discussed here are techniques which have been fostered by Air Force Cambridge Research Laboratories as a part of our geodetic research activities. Rocket-Flash Triangulation and photogrammetric azimuth determination are examples of tested projects; ANNA, the geodetic satellite which on Oct. 31 was successfully injected into orbit; Projects SCORPIO and LARGOS are future programs under development; geodetic uses of synchronous satellites are still being studied.

ROCKET-FLASH TRIANGULATION

In 1946, Vaisala conceived the idea of rocket-flash triangulation (RFT); thus, geodesy moved into the new dimension of space.

Early experiments with this method used small balloon-borne or aircraft-borne photoflash cartridges as light sources which could be photographed by several cameras simultaneously. These images, measured against

* This paper was presented at the 1962 St. Louis ACSM-ASP Convention.

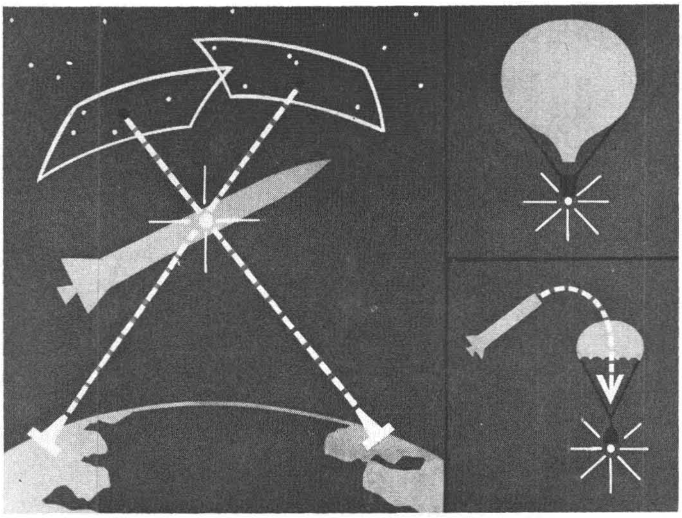

FIG. 1. Rocket-flash triangulation.

the stellar background, provided space positions of the flashes and from these, relative positions of the camera stations were derived.

Most noteworthy among the major tests of the RFT technique are Brown's Bermuda Tie in 1959 and more recently, AFCRL's Project Cambridge. While these experiments can't be termed unqualified successes, they do generate much hope for the use of rocket-flash triangulation for intervisible ties.

The rocket launch for Project Cambridge took place on 8 Dec. '61. A 32-foot Astrobee 1500 rocket—equipped with three flare packages designed to eject at apogee minus 7 minutes, apogee, and apogee plus 7 minutes, during a 1,361 mile high flight over the Pacific Ocean—was launched from Pt. Arguello, Calif. By simultaneously photographing the ejected flares with precision stellar cameras, located on Johnston Island, the Hawaiian Islands, and on the West Coast of North America—Sitka, Alaska, Beale AFB, Calif., El Centro, Calif., Fairchild AFB, Wash.—it was hoped that analytical stereotriangulation techniques could be utilized to accurately determine the geodetic positions of Hawaii and Johnston Island relative to the North American datum.

Three bursts of seven Daisy photoflash cartridges provided the light source. The Daisy specifications are as follows:

Peak Intensity	60×10^6 candles
Time to peak	1.0 millisecond
Total duration	12 milliseconds
Integral light	$.150\times10^6$ candle seconds

Despite many equipment malfunctions and operational difficulties at most sites—probable flare package malfunctions and abnormal atmospheric conditions of the Sitka site—two points were triangulated. The large mean error of orientation of the Sitka plate made it impossible to associate any meaningful accuracy with the computed coordinates of these points. Although these data are not sufficient to accomplish the initial objective of the test, i.e., the determination of the positions at Hawaii and Johnston Island relative to the North American datum, the results are nonetheless encouraging.

The fact that flares were recorded by precision stellar cameras at ranges of approximately 1,500 nautical miles, definitely demonstrates the practicability of intercontinental geodetic rocket-flash triangulation. Also the high accuracy of the orientation calibration performed on the Johnston Island camera indicates that accuracies approaching ½ second of arc are attainable with this technique.

PHOTOGRAMMETRIC AZIMUTH DETERMINATION

Considering now short range work that could be accomplished by geodetic photogrammetry, we discover the problem of azimuth determination. The photogrammetric techniques appropriate for complementing HIRAN (electronic distance measuring equipment), are similar in some respects; however, there are important differences. The light source would consist of a pair of airborne, synchronized strobe lamps, beamed at the station at each end of the baseline. The strobe lights would be flashed at a moderate rate during a line crossing and would be recorded against the stellar background by cameras at the HIRAN ground stations.

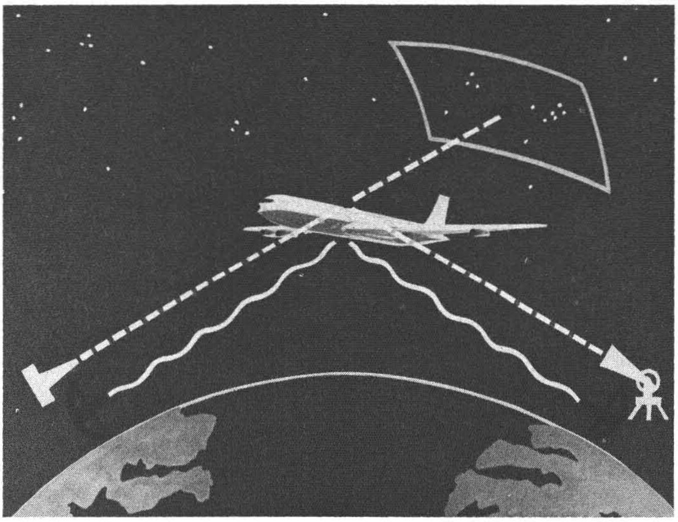

FIG. 2. Photogrammetric azimuth determination employed in conjunction with HIRAN trilateration.

Realizing the need for methods of determining azimuths accurate to ± 1.0 second of arc in order to strengthen HIRAN trilateration surveys over intermediate distances, a joint AFCRL-Air Photographic and Charting Service field test was performed in Florida in January '62. Due to unusual weather conditions, haze and equipment malfunctions, no satisfactory data were obtained. It is hoped that future tests will prove out this method.

PROJECT ANNA

A natural follow-up of the rocket-flash intervisible method is the geodetic satellite ANNA. Briefly ANNA is a joint effort of the Air Force, Army and Navy. The Air Force is responsible for the flashing light; the Navy has a doppler system which is similar to that used in their Transit satellite series. Secor, a ranging device is the Army's contribution to the ANNA program.

We can operate with three modes: the intervisible, the short arc, and the orbital.*

PROJECT SCORPIO

SCORPIO—an acronym for "*S*atellite, *C*alibrator *O*f *R*anges, *P*hotographed *I*n *O*rbit"—is a satellite system being considered primarily to calibrate range instrumentation for the Atlantic Missile Range. While satisfying this mission, valuable geodetic and geophysical data will be natural by-products. It must be emphasized at this time that Project SCORPIO is still in the *proposal* stage.

The calibration technique will utilize a flashing-light system on a low-altitude satellite and precision camera systems to record light flashes against a star background. The observed data are reduced to supply predictions of satellite velocity and position. By analyzing these derived quantities with the actual measurements by the tracking systems, the calibration parameters can be determined.

The three transponders to be calibrated in this satellite system are Mistram, Glotrac and DPN-66. The Mistram transponder, developed by General Electric Co., is an X-band, C-W type system. Glotrac is a C-band, pulse-type system under development at General Dynamics. Motorola's DPN-66 is a general purpose, pulse system which can be used with C-band tracking radars such as an FPS-16, and SPG-56. It will have widespread utilization with the C-band radars presently operating around the world.

The flashing-light system will be quite similar to the one used in the ANNA satellite program. The specifications of the ANNA strobe light:

(1) Flash Duration: 1 millisec
(2) Flash Definition: 550 watt-seconds per flashtube into 2 flashtubes
(3) Optical Beam Pattern:

Intensity on axis	8,000 candle secs
Intensity 35° off axis:	10,000 candle secs
Intensity 70° off axis:	7,000 candle secs
Intensity 90° off axis:	3,500 candle secs
½ beam width 75°	

ANNA is magnetically stabilized. If SCORPIO were to have gravity stabilization, a smaller cone-angle could be tolerated, thus reducing intensity requirements.

* The program for the St. Louis meeting shows that Capt. Tavenner presented a paper on Project ANNA. Publication in *Surveying and Mapping* is under consideration.—EDITOR

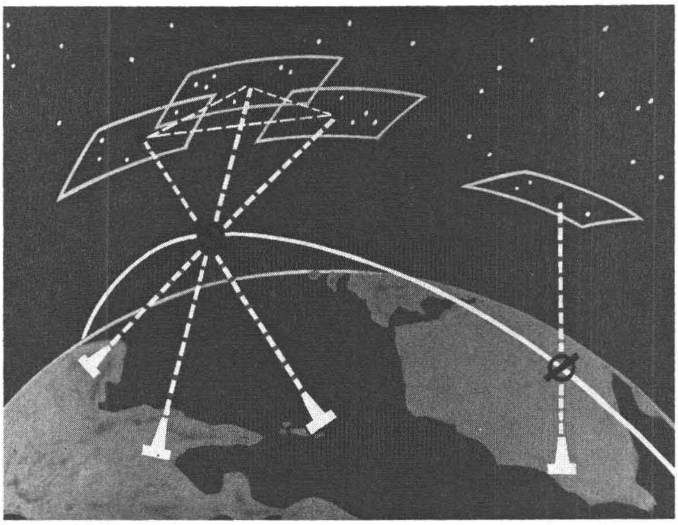

FIG. 3. Intervisible and orbital methods with a geodetic satellite.

We will now look at the desired orbital parameters and the vehicle we use to achieve the desired orbit.

We must satisfy two requirements when selecting the orbital parameters for SCORPIO:

(1) Maximize the number of observations for the tracking stations based on their geodetic positions.

(2) Minimize the uncertainties in the orbital predictions. An inclination of 40° fulfills the first requirement while an altitude of 500 n.m. would keep drag and bulge perturbations to a minimum. A near-circular orbit would best suit our purposes in that it would require less booster performance than would an eccentric orbit.

Two main possibilities exist for boosters to place SCORPIO in orbit.

(1) Launching the satellite with a special-purpose booster e.g. Thor-Ablestar.

(2) Riding "Piggy-back" on larger vehicles launched for suborbital tests.

The most interesting from the point-of-view of economy is the second consideration. An orbital pod, similar to scientific passenger pods now in use, but with its own propulsion and guidance system could be carried on Atlas R & D vehicles.

Using an orbital pod we would expect to achieve inclination to $\pm 5°$ and altitudes to ± 50 n.m. Depending of course on the specific mission of the test vehicle, a payload of from 200 to 400 lbs. could be used.

Hopefully, having placed our satellite in orbit, let's look at the observation program. The main nucleus of the optical observation system will involve 16 PC-1,000 mm. cameras 6 BC-600 mm. cameras, and 7 BC-4 (300 mm.) cameras belonging to AFCRL, AMR, and APCS. It is felt that more cameras of a similar type could be enlisted from other government agencies.

The data acquisition and reduction would be a joint effort with APCS furnishing their experienced camera crews; AMR contributing their skills in the field of ballistic camera observations and data reduction; and ACIC performing plate measurements and adjustments as they will do on Project ANNA.

Air Force Cambridge Research Laboratories, in managing the program, would be responsible for reducing and analyzing all data and maintaining a current ranging system's calibration to determine precise orbital elements. Also, reduction and analysis of all data dealing with the geophysical and geodetic aspects of the program will be performed at AFCRL. The hope then, with SCORPIO, is to utilize experience gained on Project ANNA to efficiently and accurately calibrate electronic ranging equipment while also deriving important geodetic and geophysical data.

PROJECT LARGOS

Several methods of using light sources for geodetic determination have been discussed. One method stands apart from these by virtue of the light source location. LARGOS: The *L*aser-*A*ctivated *R*eflecting *G*eodetic *O*ptical *S*atellite is a system under development by AFCRL as suggested by M. S. Tavenner.

The theory is to reflect light energy from a satellite by placing a light source on the earth's surface and giving the satellite a reflecting surface. The satellite must reflect the light to a ground camera in sufficient quantity to expose a photographic emulsion with a very short exposure time to avoid unsuitably large images. A prismatic reflector will be used to maintain the required intensity.

The prismatic reflector is a device that reflects any incident light back to the source, parallel to the incident beam. The reflector is constructed by placing three first-surface mirrors together such that the face of each mirror is normal to the faces of the other two mirrors. Thus, as a beam of light approaches the reflector at any arbitrary angle (other than an angle exactly parallel with one of the faces) the light will be reflected once off each surface—a total of three reflections with the final direction of the reflected light beam being exactly opposite to that of the incident beam.

The light source to be utilized is the optical maser. The optical maser is called the LASER (Light Amplification by Stimulated Emission of Radiation). The laser itself is a relatively simple device. It applies principles of atomic excitation to provide light amplification in much the same manner that a radio tube is used to amplify radiowaves. The basic types are solid state and gaseous lasers.

One of the first solid state lasers was the ruby laser. The heart of this device is a synthetic ruby crystal, coated on each end with reflecting mirror surface. One end is completely reflective, while the other is slightly transparent to allow the output beam to emerge. While crystal size is not a critical factor, the ends must be flat and parallel to about a millionth of an inch. The ruby is surrounded by a spiral flash tube which pumps energy into the ruby. The white light from the flash tube is absorbed by chromium ions in the ruby where it is stored and then released as red light. Part of the red light is reflected back and forth by the mirror ends of the crystal, being amplified with each traversal. The amplification is due to the addition of more light released from other chromium atoms when stimulated by passage of the beam.

The light moving along the axis continues to build up through successive passes through the crystal until oscillation sets in. Thusly, the red light that comes through the partially silvered end is emitted in a very nearly parallel beam. With present state-of-the-science, using optical focusing, a beam width of 1 minute of arc can be achieved.

Tavenner has computed that a system using

(1) 600 nm orbit
(2) 30° elev. angle on clear night
(3) Energy of flash tube = 10,000 watt-secs

will give

$$1.24 \times 10^{-6} \frac{\text{lumen-sec}}{m^2}$$

of energy available at the camera for photographic exposure. The light required for image formation with a 5 inch aperture camera is

$$1 \times 10^{-9} \frac{\text{lumen-sec}}{m^2},$$

thus a system designed with the above parameters would be feasible.

The employment of LARGOS is seen as follows: Information from radar tracking sites observing the satellite would be fed to a computer. Acquisition data are then computed for at least three ground stations whose locations are approximately known. These data are relayed from the computer to the tracking mounts at the ground sites which will point the source laser in the desired direction. The lasers at the various ground stations would be triggered from a central control.

We believe that LARGOS will prove to be an entirely feasible method for geodetic position determination.

Geodetic Synchronous Satellite

A synchronous satellite is one which orbits the earth at an altitude of 22,300 miles, thus having a 24 hour period. Current synchronous satellites projects under development by NASA are *Syncom*, a communications satellite and *Aeros*, a weather satellite.

Syncom will have a synchronous, nonstationary orbit inclined 30° to the equator. It will sweep out a figure-eight track with respect to a point on the earth's surface. A follow-on more advanced communications satellite will be placed in a synchronous equatorial orbit. *Aeros*, also programmed for a 24 hour equatorial orbit, is scheduled for launch around 1966.

These factors which will make station keeping difficult for these communication and weather satellites are exactly those perturbative causes in which geodesists are interested.

Variance of a synchronous satellite from $X°$ longitude and 0° latitude will be caused by orbit perturbations. Grouping the perturbations in motion of a 24 hour satellite according to their orders of magnitude, we find the most important ones are due to:

(a) ellipticity of the equator
(b) gravitational gradient of the Sun and Moon
(c) oblateness of the Earth
(d) radiation pressure

What then could we hope to achieve with a geodetic synchronous satellite? The concept of using synchronous stationary (equatorial) and non-stationary orbits and non-synchronour equatorial orbits for accurately determining the coefficients of tesseral and sectorial harmonic terms in the earth's potential function appears feasible in principle. To apply the concept practically, however, it is necessary to accurately determine the lunar and solar perturbations and cancel their effects from observed satellite motions.

The relatively low angular rate of a 24 hour satellite and the moderate proximity to the Earth allows higher order terms in the potential to produce long term effects. Equatorial orbits are of value in determining the low-order potential terms whereas inclined orbits provide information relating to both low and high-order terms.

It will be necessary to utilize several satellites to obtain values for the higher order terms. The multiplicity of high-order effects make separation of the data difficult even though the period of the harmonic effects is known by definition. Low satellites and early synchronous ones shall be used to refine the first-order terms in the potential which can then be isolated from further observational data. Analysis of the remaining data for synchronous orbits should provide values for higher order terms whose real time periods are longer than those of near satellites.

The second sectorial term (2, 2) causes an oscillation of the "stationary" point (in a stationary synchronous orbit) about the minor axis of the Earth's equatorial section. On an inclined (non-stationary, synchronous) orbit this effect would cause the satellite's projection to trace out a series of shifting figure-eight patterns on the earth's surface. Such a slow-moving pattern with a period on the order of one or more years would provide complete coverage of large sectors of the earth. By properly injecting various satellites, complete earth coverage could be obtained, thus providing information relating to the short period tesseral and sectorial terms.

Nearly synchronous satellites could be used to produce a secular rather than periodic shift in the trace. The shift rate of the trace could be controlled by varying the orbital period of the satellite in this latter case.

If the effects of higher order tesseral and sectorial harmonics are measurable at synchronous orbit distances and *if* the lunisolar perturbations can be isolated, then synchronous satellite orbits would be of value in obtaining values for these harmonics. The advantage of the higher satellite orbits lies in the longer time allowed to observe the perturbations as well as the longer time over which the perturbation occurs.

Summary

While it might seem that satellite geodesy will eliminate the need for RFT and photogrammetric azimuth determination, this is not the case. All the methods discussed here utilizing light sources photographed against star backgrounds—RFT, photogrammetric azimuth determination, ANNA type geodetic satellites, LARGOS type projects, and synchronous satellites—could conceivably complement one another. Regardless, we must bear one point in mind, geodetic photogrammetry has been and will continue to be one of the primary tools of geodetic science.

References

1. Tavenner, M. S., "LARGOS: A Suggested Method for Stereotriangulation," Air Force Cambridge Research Laboratories, 1962.
2. Mancini, A., Kahler, H. R., and Warner, C., "Project SCORPIO," Air Force Cambridge Research Laboratories, 1962.
3. Tavenner, M. S., and Swenson, P. B., "Operational Concepts of Photogrammetric Determination of Azimuths Over Intermediate Distances," Air Force Cambridge Research Laboratories, 1962.
4. Interavia, August, 1962.
5. "Results of the Reduction of Photogrammetric Data Plates Acquired on Operation Cambridge," ICF, 1962.
6. Blitzer, L., Boughton, E., Kang, G., and Page, R. M., "Effect of Ellipticity of the Equator on 24 Hour Nearly Circular Satellite Orbits," *Journal of Geophysical Research*, January, 1962.
7. *Aviation Week & Space Technology*, July 1962.
8. Ouellette, G. A., "Synchronous and Equatorial Satellites for Earth Potential Analysis," Wolf Research and Development Corporation.