PROPOSAL FOR

STUDY OF SELENODETIC EXPERIMENTS FOR EARLY LUNAR SURFACE APOLLO MISSIONS

RFP MSC 64-993 P

GEONAUTICS, Inc.

APPLIED GEOPHYSICAL SCIENCES

GEODESY • OCEANOGRAPHY • HYDROGRAPHY • NAVIGATION • ASTRONOMY

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PROPOSAL FOR STUDY OF SELENODETIC EXPERIMENTS FOR EARLY LUNAR SURFACE APOLLO MISSIONS

RFP MSC 64-993 P

Prepared For

Lunar Surface Technology Branch
Advanced Spacecraft Technology Division

By

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TECHNICAL PROPOSAL

1. INTRODUCTION

Exhibit "A" of NASA, Manned Spacecraft Center Request for Proposal No. MSC 64-993P outlines scope of work and requirements for investigation of selenodetic experiments for the early Apollo missions to the lunar surface. As set forth in the RFP, specific objective of the study is to recommend measurements, experiments, procedures and techniques, modifications to equipment, and data recording and handling, in order for the astronauts to perform First Order, Class II, selenodetic measurements on the surface of the moon during early Apollo missions. While it is proposed to strive for the greatest precision possible, it should be noted that it is improbable that First Order, Class II accuracies will be attained. Anticipated environmental conditions will be severe at best, and it is unlikely that the standards of work on earth, which are realized only with difficulty under optimum conditions, can be matched. Control surveys of the quality specified, for example, have not been achieved in Antarctica after many years of extensive effort. Also, unless there are at least three stations in a net, occupied at one time or another by instruments, there will be no closing errors in angle or displacement, and no way to estimate the internal precision of a survey according to terrestrial standards. It seems doubtful that as many as three intervisible stations will be established during the Apollo mission, unless they are quite close together, thereby reducing their usefulness. It is then suggested that the statement of objectives of the study be broadened to provide determination of:

a) Type of selenodetic measurements or experiments desirable for establishing horizontal and vertical control for lunar mapping, consistent with requirements and standards of mapping techniques planned during approximately the same period and a reasonable period thereafter.

b) Measurements desirable for establishment of a selenodetic datum and control network that may be required to support future lunar operations.

c) Measurement or experiments desirable either on the lunar surface or within an orbital spacecraft to refine present estimates of size and shape of the moon which, when combined with gravitational data, will tell something about the internal structure of the moon.

d) Equipment, operational methodology, and data reduction procedures that would be desirable for early Apollo missions to assist in accomplishment of (a), (b) and (c) above.

2. TECHNICAL APPROACH

2.1 Constraints

Consequences of the nature, severity, extent and significance of a wide variety of environmental factors will be studied and carefully evaluated in determining system concept, procedures, and equipment. Many of them are obvious but will require the utmost attention; such as

a) Hard vacuum and extremes of heat and cold
b) Traversability of terrain and its ability to support various types of equipment.
c) High level of sun brightness; low degree of contrast between successive skylines, as viewed with the sun at one's back; illusions caused by shadows when terrain is backlighted.
d) Availability and distinguishability of sharp terrain features - sharp enough to be used as selenodetic targets, without the necessity of occupying them with instruments or targets.
e) Problems of dust adhering to instruments and operators.
f) The advantages of absence of atmospheric refraction, winds, and clouds, etc.
g) The relatively low gravitational effect.

Other problems or constraints will be involved in the Apollo concepts themselves, including:

a) Astronaut in LEM will have 120 degrees field of view to observe and support measurements by exterior astronaut, but possibly through a port only 1" in diameter.
b) Astronaut will remain outside LEM 4 hours each on first two missions, 24 hours each on next two; but only part of the time can be devoted to selenodetic measurements.
c) How far astronaut will roam from LEM is unknown; a maximum of 1 mile will be considered for first two missions.

d) CM will be in 50-100 miles lunar orbit, in line of sight of any point on the lunar surface no more than about 8 minutes in each hour.

These factors and many others will be studied and analyzed in the Research and Analysis phase of the study (see Management Section 3.3.1), and pertinent information developed by AMS Projects LAMP and HORIZON, as well as studies at NASA and elsewhere will be taken into account.

2.2 Establishment of Selenodetic Datum

A framework of coordinates and a lunar datum to a previously unattained degree of accuracy must be established along with an ability to relate points and features on the moon's surface to such a selenodetic reference system with equal accuracy. The full and complete datum would include the following parameters:

a) The semimajor axes of a triaxial ellipsoid a, b, c; or the equivalent as separate scale factors (e.g., the length in meters of a degree of latitude at the poles, at the ends of the greatest and least equatorial diameters, etc.); these quantities specify the size and shape of the moon.

b) Three angles or direction cosines (two for one axis and one for another) referred to astronomical inertial coordinates to give the orientation of the reference ellipsoid in space.

c) The time rates of change (which are non-linear) of these angles or direction cosines.

d) The selenodetic latitude, longitude, and height (above the reference ellipsoid) of a known point on the moon's surface (or its equivalent, e.g. the location on the ground of a pole of rotation), and the variations of these quantities with time.

e) The selenodetic azimuth of a line connecting the known point with another known point.

Since the reference ellipsoid would be fitted to the solid body of the moon, it would be subject to the same rotation rate and physical librations as the moon. Librations would affect items (b), (c), and (d) above. The direction of the moon's mean axis of rotation in space and the librations are at present imperfectly known. The uncertainty of these quantities is of the order of 0.01 degree. The amplitude of the librations is several hundredths of a degree. For comparison, 1 degree of latitude on the moon's surface is approximately 30 kilometers, so that the errors of reference between a selenodetic and a selenocentric astronomical coordinate system would amount to several hundred meters.

To refer any point on the moon's surface to a selenodetic datum by means of observations analogous to terrestrial astrogeodetic fixes, would require as a minimum the following items:

a) A star catalogue of selenocentric right ascensions and declinations of a number of stars, for the computation of which an arbitrary north celestial pole for the moon could be used in the beginning, with the idea of refining it later.
b) A means of determining the angular altitude of the moon's north celestial pole from the surface of the moon. This presents problems unfamiliar to the terrestrial surveyor; for instance, the exact location of the moon's pole is not known as it is on the earth; the physical librations of the moon cause the lunar pole to oscillate in a way analagous to terrestrial nutation, but with much greater amplitude and uncertainty; and the moon rotates at only approximately 1/30 the rate of the earth, so that, other things being equal, it would take thirty times as long to get a fix with a similar degree of accuracy.

Measurements of the moon's magnetic field would provide valuable data for geophysical purposes, but according to the best information available today would be useless for orientation purposes. The moon's field at the surface of the moon appears to be no greater than 1 or 2 X 10^{-6} gauss, and so would be completely overpowered by the interplanetary field, which is of the order of 10 to 100 x 10^{-6} gauss and highly variable in magnitude and direction. Gravity measurements taken on the surface of the moon would also be useful for geophysical purposes and, when combined with selenodetic information about the figure of the moon, or with seismological data, would provide a good deal of information about the interior of the moon.

As in the case of terrestrial surveys, information about the magnitude of the local gravity can be obtained with gravity meters. Information about the direction of the local gravity, (specifically the angle by which it deviates from the normal to the mean spheroid) can be obtained by comparing astronomical and selenodetic coordinates. These quantities can both be obtained from the gravitational potential, the chief coarse-grained features of which can be derived from satellite orbit perturbations. The departures of the actual figure from the equilibrium figure under self-gravity and rotation are a measure of the departure from isostatic equilibrium. Large-scale (global, or affecting a large region) departures from a symmetrical equilibrium figure imply deep-seated inhomogeneities in density or internal structure; if the departures are non-isostatic as well, they imply great mechanical strength. Very localized departures, on the other hand, imply inhomogeneities near the surface. Thus although the overall size and shape of the moon will give the mean density of the interior and set certain limits to the possible internal distribution of mass, gravity data are also required for a more detailed analysis. Gravity data taken on the surface of the moon would only be useful, however, for a selenodetic survey after a fairly large-area selenodetic net has been established.

Establishment of a complete and accurate selenodetic datum will require more steps than can be carried out during the successive Apollo landings, but the following should certainly be possible:

(a) establishment of an arbitrary datum, to be corrected as data accumulate; (b) provision of an accurate as possible scale for photogrammetric surveys (c) orientation and vertical control for limited regions around landing sites with respect to the arbitrary datum. The orientation can be extended to as much of the surrounding region as is covered by overlapping photographs taken from orbiting vehicle, although accuracy of the orientation would deteriorate towards the edge of the region covered by the overlapping photographs.

Whatever datum is adopted as the arbitrary starting datum should take into account existing information on the figure and size of the moon, and the best fitting sphere (spheroid) used by the U.S. Naval Observatory to map the moon's limb.

In arriving at the most practicable means of determining an accurate datum, the possibility of using earth-based, highly precise tracking will ~~should~~ be considered to determine the location of the CM with respect to the center of gravity of the moon. If the determination is accurate enough, the position of the CM as a function of time could be used to acquire some data for the establishment of a selenodetic datum. If the CM could be tracked against the background of the stars by the LEM party on the surface of the moon, then a number of lines whose direction with respect to the stars and also with respect to the surface of the moon would be known. (If the CM could be fitted with a flashing light, it would greatly simplify ground operations on the moon.)*

Probably the only type of terrestrial tracking now potentially capable of giving the required accuracy would be Doppler tracking, using several frequencies to eliminate the effect of ionospheric refraction. The reduction of Doppler tracking data for circumlunar orbits would be similar to that used in the determination of the orbits of spectroscopic binary stars: that is, the semimajor axis of the orbit A, and the inclination of the orbital plane to the line of sight from the earth, sin I are indiviually indeterminate, but the product A sin I is known. This difficulty

*Study Constraints (Paragraph 3.1, Exhibit "A", Statement of Work) seem to be ambiguous in its wording concerning CM or LEM instrumentation.

can be circumvented by waiting a few hours, at which time the inclination, I, of the orbital plane to the line of sight from the earth would be changed, so that the semimajor axis A could be solved for. Furthermore, the inclination of the orbital plane of the CM around the moon could be established from angular fixes or lunar features taken from the CM. A certain amount of indeterminateness would arise from the fact that in the intended orbit the CM will go into eclipse behind the moon, so that no kind of tracking will cover a completely closed circuit of the CM around the moon.

(If a radar altimeter could be supplied on the CM to give the mean height above the terrain, such data would be extremely useful in tying the known position of the CM to the lunar surface.)* Absolute directions of the line to lunar features from the CM in space could be established by means of angular measurements to reference stars seen over the lunar horizon. (This would be much simpler to accomplish photographically, if equipment could be carried on the CM.)*

2.3 Scale Determination

Considerable knowledge of scale would be supplied by the tracking data discussed above, to the extent successful. A major objective of the astronaut's measurements, however, would be to further refine scale accuracy by surface techniques. Many of these will be studied including, but not limited to, the following:

a) Direct measurement of a line between base points with temperature and tension-calibrated tapes, even though such taping would be difficult with only one man on the ground. One astronaut, granted reasonable mobility, could measure to one or more points from the LEM by carrying out the end of a calibrated wire from a spool installed in the LEM. Investigation of this possibility is recommended because of its simplicity.

b) Lines to or between marked points could be determined by equipment of the tellurometer or geodimeter type, which would require the use of instruments at the base ends; or by radar, which would require only reflecting beacons or transponders placed manually or by rocket dispatch to the base ends. Targets so placed should carry some sort of conspicuous marker to render them visible in photographs. Use of natural unmarked features would be low in precision and probably impractical.

It should be noted that accuracy of measurement can only be assured by redundant and/or self-checking procedures which also permit mathematical adjustment to arrive at statistical answers; this aspect will be thoroughly studied in connection with possible techniques, field methods and equipment in order that accuracies of measurement can be verified to the fullest extent practicable.

2.4 Control Network

There follow examples of schemes for extension of surveys over limited areas of the moon, which should be examined in detail.

a) Conventional optical triangulation is probably too cumbersome, but will be given at least some consideration.

b) Trilateration using tellurometer-type instruments or possibly the geodimeter, suggests itself as reasonably fast and convenient, and of high accuracy. A great deal of effort would be required to miniaturize the instrument or instruments, and provide almost complete automation of use.

c) Photogrammetric methods appeal as possible solutions to the problem. Specially designed photo-theodolites to measure both horizontal and vertical angles might be used at base points for series of shots panning the horizon sky line; or all visible points within a radius of several kilometers of a pair of base-lines in cross configuration, each several hundred meters long, could thus be positioned by phototriangulation within 1/70,000 in horizontal and vertical directions. The ends of the base-lines should be easily identified points, and the lengths should be measured by one of the methods suggested above. This has the prospect of establishing control over whatever area is accessible from the landing site.

d) If the phototheodolite could be pointed to the celestial pole and the zenith it could also be used for the determination of astronomic position and astronomic azimuth orientation, subject <u>initially</u> to the uncertainties discussed above under "Establishment of a Selenodetic Datum". This system of survey could be operated by the roaming astronaut without support from the LEM or CM, except possibly for time signals in connection with the astronomic observations. It would require a minimum of time and effort, and virtually no special training for the details of operation.

The following selenodetic information could be observed from these observations:

a) Position: Photographs of the visible celestial pole and pairs of timed zenith photographs would provide the means of computing an astronomic position. (This might present a problem were the astronaut to land within about 30 miles of the sub-terrestrial point of the moon as we see it, for then the astronaut's zenith would be on the Earth.)

b) Azimuth: The zenith of each station (end of base-line) would give the zenith circle of the baseline and thereby provide an astronomic azimuth.

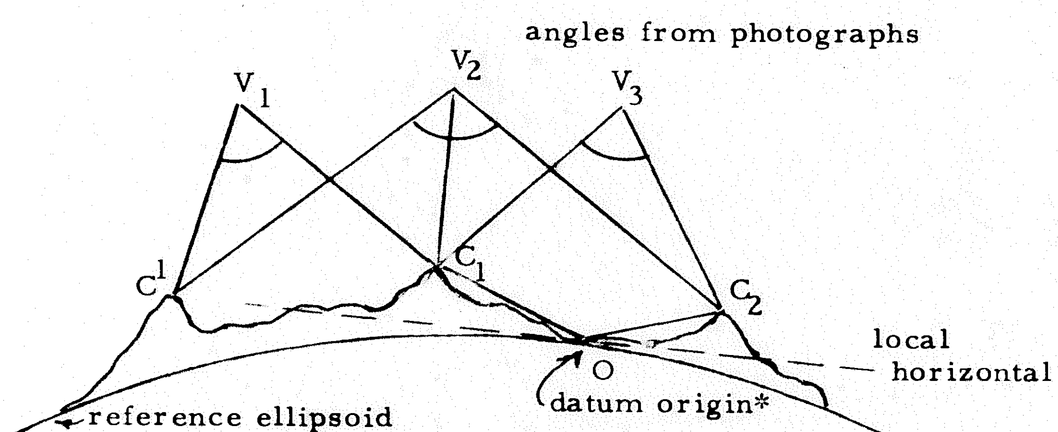
c) The Start of a Photo-triangulation Net: The position and azimuth determined astronomically can be used as the origin of a selenodetic datum. Coordinates of prominent features on the Moon's surface can be determined photogrammetrically, utilizing the length of the base-line and photographs from both camera positions. These positions may, if they are well defined features, be used as photo control points for subsequent mapping operations. Accuracy of photo-triangulation would be dependent, aside from limitations of equipment, upon length of the base-line used.

Methods of analytic photogrammetry are now sufficiently advanced that photogrammetrists are able to construct internal control of substantially 2nd order accuracy over extended areas. Base points are necessary, and for photo mapping of large areas they should be scattered widely over the project areas. This may not be fully realizable in the Apollo plan. Modern mapping cameras can record very minute detail even from great heights, and it is contemplated that good quality mapping photographs will be available from exploratory missions.

Possibly natural distinct point-like features will be found in sufficient abundance in the photographs. An important point to investigate, however, as already suggested, is the possibility of scattering signal objects over large areas. They might be conspicuous splash-marks, reflectorized mylar objects, or radio transponders, and possibly distributed by rocket dispatch from the LEM landing point, or by discharge from the CM. Such objects could assist the construction of the control network needed for photogrammetric techniques.

d) Vertical Datum: It should be possible to determine elevations of distant points to a high degree of accuracy. Because of the total lack of refraction, measurements of vertical angles should be considerably more accurate than similar measurements on Earth.

The connection of elevations of selenodetic control points to an eventual common datum could be accomplished as follows:



*point with assumed coordinates and height above reference ellipsoid

The coordinates of O and its height above or below the reference ellipsoid are arbritrary. Points C_1 and C_2 are surveyed in by triangulation, or some combination of ranges, vertical angles, and azimuths. The angles C_1C_2 as viewed from successive positions of a vehicle are known. Even if the heights of the vehicle are not precisely known, the apices V_1, V_2, V_3 must fit a selenocentric orbit, which is known from tracking data. Therefore C^1 and all similar points can be placed on the same coordinate system (referred to as the same datum) as point 0.

A more sophisticated and difficult operation that might become extremely valuable when extended to the sites of later landings, is the so-called flare triangulation, using perhaps the CM itself as the sighting point. Such a technique would require simultaneous observations from more than one station, and presupposes accurately synchronized timekeeping at all stations. The logistics of the operation involving two or more fairly well separated surface stations appear to be prohibitive for any except very late missions.

A modification of this technique would be tracking of the CM against the star background, a system that would require good determination of the orbital motions of the CM, and would not necessarily require simultaneous sighting from different and distant points. This would be analogous to so-called satellite geodesy on earth.

2.5 Equipment To Be Considered

In recommending and/or designing equipment that will be required, every effort will be made to make all possible use of that presently planned for the Apollo missions, and thorough investigation will be made of all types of applicable equipment in order to make the best judgments, considering weight limitations and other constraints. The specific method and techniques of surveying and the type of equipment eventually selected will be compatible.

2.5.1 Distance Measuring Equipment

The following types of DME equipment will be investigated to determine feasibility of lunar-type equivalents. Tentative order of investigation and relative importance is as listed, under the assumption that the simplest and lightest would be the most feasible.

a) Chaining devices: Tapes similar to conventional metal tapes do not seem feasible for a one-man operation; more promising would appear to be calibrated wire on a reel attached to the LEM or instrument support. Consideration would have to be given to corrections for the coefficient of thermal expansion, but aside from that, the tape could be a simple, expendable device to establish a baseline of a predetermined length.

b) Angle measurement devices: To be considered here are stadia- or subtense-type targets to be measured either by a conventional theodolite or a photo-theodolite. Problems related to this type of measurement would be the extreme conditions of illumination and optical contrast or lack of it, as well as accuracy limitations. Present accuracy of the standard two-meter subtense bar or of the standard stadia rod is considerably below that indicated in the study. However, investigations may show that with lack of atmospheric disturbance and gravity, relatively long or tall targets can be plumbed and aligned rigidly and read accurately.

c) Rangefinders: These would appear not too promising, but lack of atmospheric disturbances may enable one to use relatively long bases, and the absence of refraction and low gravity will tend to increase the accuracy for any given base length.

d) Electronic distance measuring equipment: Tellurometer or geodimeter type equipment presently operational would provide the desired accuracy. The use of passive beacons would be investigated. These could be distributed by various means for distance-determination to several points. However, a drawback may be possible interference, and light waves (in Geodimeter) may be attenuated by ambient light conditions.

e) Laser distance measuring equipment: This would be ideal for both range and angle. State-of-art in perfecting this device may restrict its consideration for Apollo, although some recent developments are promising.

2.5.2 Angle Measuring Equipment

Consideration would be given to optical theodolite-type, phototheodolite-type, and electronic or laser-type angle measuring equipment.

a) Optical theodolites: These appear to be impractical because they (1) measure angles only, (2) require manual operation and visual reading, and (3) would require definable targets visible from two different points. Consideration would be given, however, to ways and means of automating some functions, such as having a recording circle, thus eliminating one operator function.

2nd b) Photo-theodolites: This appears to be a promising approach. Advantages are (1) ease of operation, (2) permanent record, which (3) will be valuable as well for allied lunar surface studies. Since undoubtedly one of the equipment requirements for the surface astronaut will be a camera, a photo-theodolite could serve in a dual capacity, thus conserving space and weight. Proper design would make it possible also to use the theodolite as a zenith camera or other astronomical photographic device.

If possible c) Electronic- or laser-type angle measuring equipment: As discussed in the section on distance measuring, state-of-the-art in perfecting this kind of equipment may restrict consideration for Apollo, but intriguing developments of a combined and automated laser ranging and angle measuring device with digital readout will be investigated.

2.6 Data Recording, Handling and Reduction

Problems of data recording, storage, read-out and reduction will constantly be considered in relation to all techniques, procedures and equipments that study phases indicate will be practicable in order that this important system phase will be compatible. Special attention will be given to simplicity, reliability and permanent storage of data, and appropriate use of the AGC. We feel, however, that these problems will be defined by other phases of the study, and solutions in harmony therewith will be straightforward.

Investigations will be made of all types of data recording and storage mediums, including photographic, electrical, and visual and verbal readout methods, to determine the most desirable methods for the Apollo missions. Recommendations will be made as to suitable computations and data reduction to be made while the LEM is on the lunar surface.

As part of this phase of the study, analytical evaluations will be made of reduction procedures necessary for LEM operation, and detailed computational tests will be conducted to ascertain accuracies obtainable from recommended observational data.

2.7 Human Factors

Throughout the study attention will be given to human factors affecting the performance by the astronauts of the recommended tasks. This means, of course, that every care will be exercised to ensure that both the equipment and the tasks and procedures to use it are the simplest possible so that they will impose the minimum burden on the astronauts' physical and mental resources, which will probably already be heavily taxed. For this purpose, services of a human factors engineer will be used throughout the study of equipment and procedures.

3. SUMMARY

Investigations and analyses along the lines described in preceding paragraphs to accomplish objectives of the study can be grouped in six phases, and it is proposed that staffing and effort be organized and directed accordingly. They are:

3.1 Review and analysis in detail of both MSC requirements and plans, and the very considerable amount of work already done by government agencies and private firms which are directly related to the problems. In this way, previous work will not be re-done, and recommendations will be in harmony with the broadest range of programs.

3.2 Analysis and recommendations of extent, accuracy and layout requirements of appropriate vertical and horizontal control network, considering:

- b a) Scale, resolution, format and focal length of best mapping photography expected to be obtainable during 1968-1970 period, including potential Manned Survey Mission
- c b) Photogrammetric and other control extension techniques.
- a c) Projected user programs in exploration, research, etc.

3.3 Analysis and recommendation of field techniques and procedures to achieve Item 3.1 above, considering time available, environmental conditions and instrument problems. Methods to be studied will include but not be limited to the following:

- a) Modified terrestrial surveying techniques.
- b) Radar and laser DME trilateration.

c) Terrestrial photogrammetric techniques.

d) Flash triangulation against star background.

e) Special experiments that could lead to improved methods.

3.4 Analysis and recommendation of equipment, equipment modifications and accuracies achievable thereby including, in addition to instruments planned for the CM and LEM:

a) Optical sighting instruments.

b) Radar and laser DME.

c) Terrestrial and aerial photographic equipment.

d) ~~Magnetometers~~, gravimeters, etc.

3.5 Investigate and recommend methods of recording, preserving and readout of data, by photographic, electronic or visual and verbal means. Analyze and recommend data reduction methods, including equipment (on board and terrestrial), tables, ephemerides computer programs, etc. Time estimate for data reduction will be furnished.

3.6 At the conclusion of analyses undertaken above, a complete Selenodetic system
system will be set forth, including suggestion for training instructions for the astronauts, and time estimates for field performance. Specifications for special or modified instruments will be provided, along with time and cost estimates for their construction.

SECTION II

MANAGEMENT PROPOSAL

1. INTRODUCTION

This management proposal is submitted in accordance with requirements set forth in NASA Request for Proposal No. MSC 64-993P, Study of Selenodetic Experiments.

The proposed investigation is one which captures our imagination, stimulates our thinking and offers opportunity to make fullest use of the unique capability available at Geonautics. We shall assign for this task a well-coordinated team of able, competent, and enthusiastic staff members and associates possessing all of the skills necessary for successful completion of the program. Our staff and consultants have become internationally known for their works in a number of scientific disciplines applicable to this study, and may be expected to contribute extensively from their broad backgrounds and considerable talent. We will devote our energy to the fullest extent in producing a comprehensive study resulting in a definitive design of feasible selenodetic operations for Project Apollo.

The following sections outline Geonautics' capabilities, qualifications, and experience, proposed organization for the study, and project schedule.

2. COMPANY QUALIFICATIONS

Geonautics, Inc., was formed in 1957 by a group of scientists and engineers to provide independent professional counsel, technical services and research and development capabilities in the fields of geodesy, astronomy, high accuracy navigational systems, and certain aspects of oceanography. Its staff and associates include outstanding men in these fields. One of its specialties has become precise positioning and distance determination over land and water and in space, and the conduct of special surveys having unique or high order accuracy requirements. Its activities include field operations in geodesy and super-precise surveys, as well as theoretical and mathematical studies in orbital mechanics, geodetic mathematics and problems of precise tracking and positioning by satellite methods.

Geonautics is an independent professional firm not associated with any equipment manufacturer, but fully qualified to prepare conceptual equipment designs and specifications. It is the only company which specializes almost solely in the theory and field practice of geodesy, including its ramifications in space.

Detailed organization and personnel qualifications are set forth in the section which follows. It should be noted here that since Geonautics' inception, a large share of the technical leadership has been provided by four men: Carl I. Aslakson, who for six years was Geodetic Range Officer at the Atlantic Missile Range, is noted for his development of Hiran (the standard long range first order electronic geodetic measurement system being used today), a new determination of the velocity of light, numerous papers on alighment, first order surveys and related equipment, and is one of the three men who have received during the 100 years since its establishment, the Boyden

Premium from the Franklin Institute for achievements in precise measurements; Dr. Heinrich Karl Eichhorn, who is an international authority on star catalogues, and is noted for his work in determining geodetic positions and orbits by photographing against star backgrounds; Floyd W. Hough, known for the "Hough Ellipsoid" (one of the accurate definitions of the size and shape of the earth), consolidation of various National datums to a World datum, and who is currently President of the Section of Geodesy of the American Geophysical Union; and Dr. Edward R. Dyer, expert in celestial mechanics and mathematics of astronomy.

In view of their applicable backgrounds and close association with Geonautics, this group will be organized as a Technical Review Committee to guide the Project Manager in his decision-making, contributing from their vast experience to the development of entirely new concepts.

We are enclosing a list of projects completed or in process, but would like especially to mention the following:

1. In 1959-1960, Geonautics determined for NASA, Goddard Space Flight Center, geodetic parameters for Project Mercury tracking, and performed in the field necessary measurements for determination of latitude, longitude, elevations and deflections of the vertical for Mercury tracking radars in the United States, Hawaii, Mexico, Bermuda and the Canary Islands, including an evaluation of work done by the Australians for tracking sites in that country. In addition, Geonautics performed the precise alignment and orientation of certain of the tracking radars. This work has been the geodetic foundation of all project Mercury tracking subsequent thereto.

2. For approximately a year Geonautics has been working on a continuing contract with NASA, Goddard Space Flight Center, for the analysis of geodetic positioning accuracies and azimuths

of Minitrack, Mercury, Deep Space Probe, Baker-Nunn, Gemini and Apollo tracking sites throughout the world, including analysis of and specifications for precise alignment of tracking radars.

3. A contract similar to the two above has just been completed for U. S. Air Force Satellite Control Facility Tracking Stations throughout the World.

4. Research and development of a portable, simplified field system for determining first order geodetic measurements by means of photographing rocket ejected flares against star backgrounds, was successfully completed for the U. S. Army Geodetic Intelligence Mapping Research and Development Agency, Fort Belvoir, Virginia. Under this contract, Geonautics developed mathematical concepts resulting in an original method of computation which simplifies handling of the time parameter, and set forth system design of portable equipment for accomplishing such measurements, far less costly than conventional means.

5. Geonautics performed the necessary geodetic consultation and analysis of the problem, and actual field measurements for super precise geodetic surveys of latitude, longitude, elevation, deflection of the vertical for alignment and orientation of the Telstar tracking antenna at Andover, Maine for AT&T. Similar work was performed for certain transit sites for Westinghouse and an extensive analysis and appraisal of geodetic accuracies of the Florida Mistram tracking installation was completed for General Electric.

6. For Fairchild-Stratos an investigation was made of the state of the art of electronic distance measuring equipment; in connection with work for the Corps of Engineers and others, analysis has been made of means for accomplishing geodetic work by various photographic techniques; and during the last month a five month study was completed for Westinghouse of all techniques for obtaining geodetic measurements and accurate mapping control.

Members of Geonautics' staff are internationally recognized in the field of geodesy, are knowledgeable in the unique problems of NASA's projects, are acquainted with best sources of corollary and supporting information, and have the know-how to bring all state-of-the-art knowledge to bear on successful solution of this particular problem.

3. PROJECT ORGANIZATION

On the following page, Exhibit 1, is a project organization chart showing functional responsibilities for performance of the work, and principal individuals concerned, as described below:

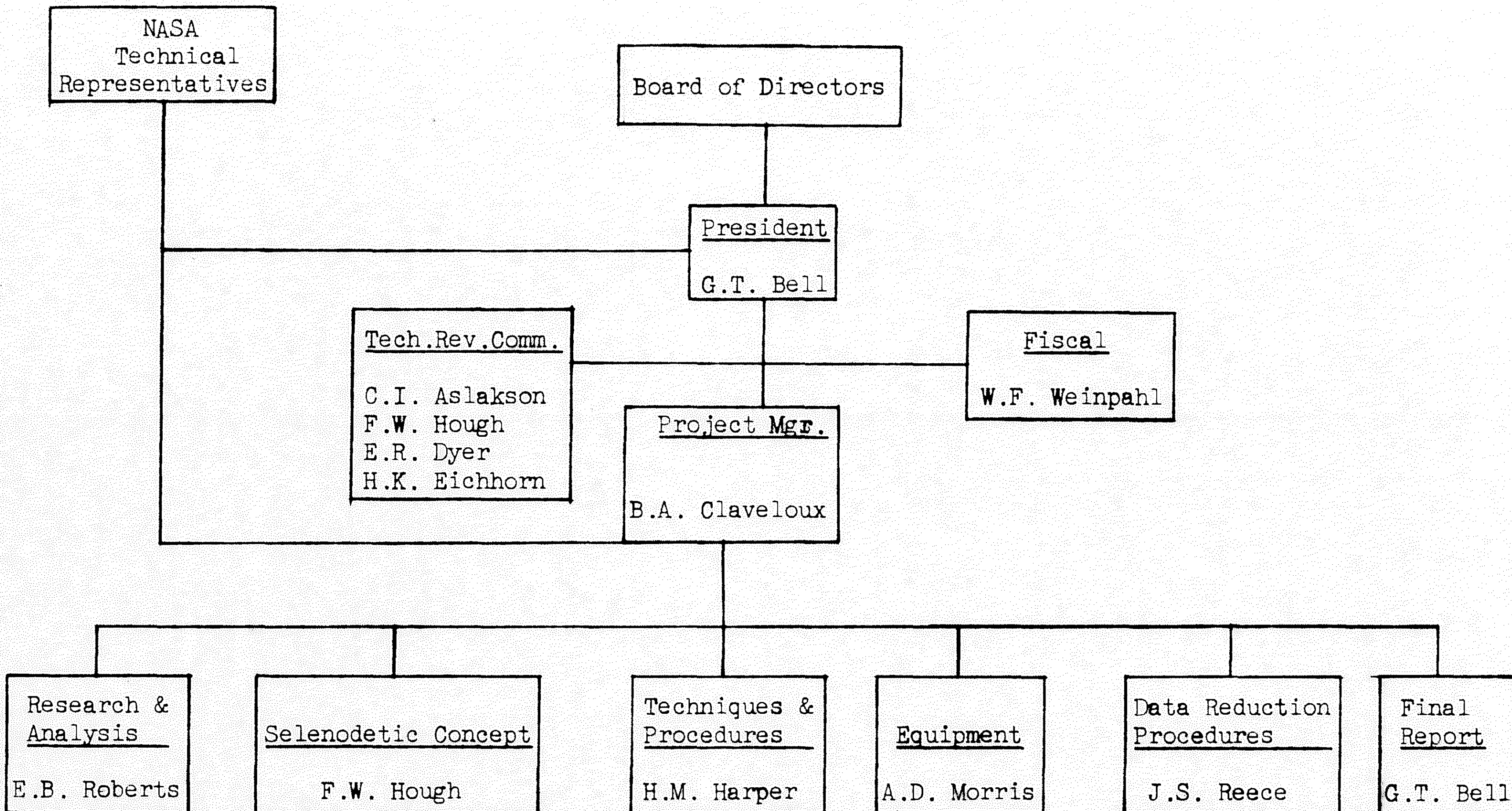
1. Project Manager will be Mr. B. A. Claveloux, Vice President, who has served as Senior Engineer of Geonautics since 1960. He is particularly qualified for this assignment, having directed and participated in studies of applications of geodesy to missile and satellite tracking, a state of the art study of geodetic techniques and equipment, an analysis of all electronic distance measuring systems suited to geodetic purposes, the photogrammetric flash triangulation research and development study for the U. S. Army Corps of Engineers, and others. Prior to his association with Geonautics, Mr. Claveloux served seven years with the research and development laboratories of the Corps of Engineers at Fort Belvoir, and at Chance Vought Aircraft as engineer on a series of projects involved in advanced survey and mapping techniques and equipment. He will be free of all other assignments to devote full time to this project.

2. A very important part of the organizational concept proposed by Geonautics, is the Technical Review Committee to assist Mr. Claveloux in making decisions and trade-offs in connection with the study. This committee will be comprised of Mr. Aslakson and Mr. Hough and Drs. Dyer and Eichhorn and will provide top guidance for the project.

3. The study has been broken down into six phases for purposes of staffing and functional organization. These are:

   3.1 Research and Analysis.

   This phase, lead by Capt. Elliott B. Roberts, USC&GS



PROJECT ORGANIZATION

Exhibit 1

(ret), will represent the first and a very significant part of the contract and is necessary in order to take into account all MSC's programs, requirements and equipment planning which relate to this effort, state of the art in geodetic measurements and equipment, known environmental factors, and other studies which have already been made which directly relate to this endeavor.

3.2 Selenodetic Concepts

Under the direction of Floyd W. Hough this phase will establish the conceptual scheme which seems most practicable as determined from the research and analysis studies. Mr. Hough is uniquely qualified to be leader of this group having been for many years Chief of the Geodesy Division of the Army Map Service. He is an internationally recognized expert in the establishment of local datums and their consolidation into area and world datums.

3.3 Techniques and Procedures

This phase under the leadership of Mr. H. M. Harper will study, devise and recommend field techniques and procedures to be used by the astronauts to carry out measurements and experiments necessary to implement the selenodetic concepts established above. Mr. Harper has been in charge of and/or participated in field measurement phases of all Geonautics' geodetic programs for over 4 years, and is cognizant of the problems of environment and personnel in carrying out geodetic projects.

3.4 Equipment

Selection, modification and new design of equipment necessary to achieve the program objectives will be studied under the guidance of Dr. A. D. Morris, physicist and engineer with 10 years experience in the theory and design of optical, electronic and photographic equipment. This phase will be carefully coordinated with the study of techniques and procedures in order to set forth equipment recommendations to achieve field measurements in the simplest and most expeditious manner.

3.5 Data Handling and Reduction

During this phase, all problems of data recording, storage, handling and reduction, including analyses and assessment of expected accuracies will be considered under the direction of Mr. James Reece. Prior to joining Geonautics in early 1963, Mr. Reece served with the U. S. Coast & Geodetic Survey for years as Geodetic mathematician and is familiar with data handling problems, both by conventional and ADP applications.

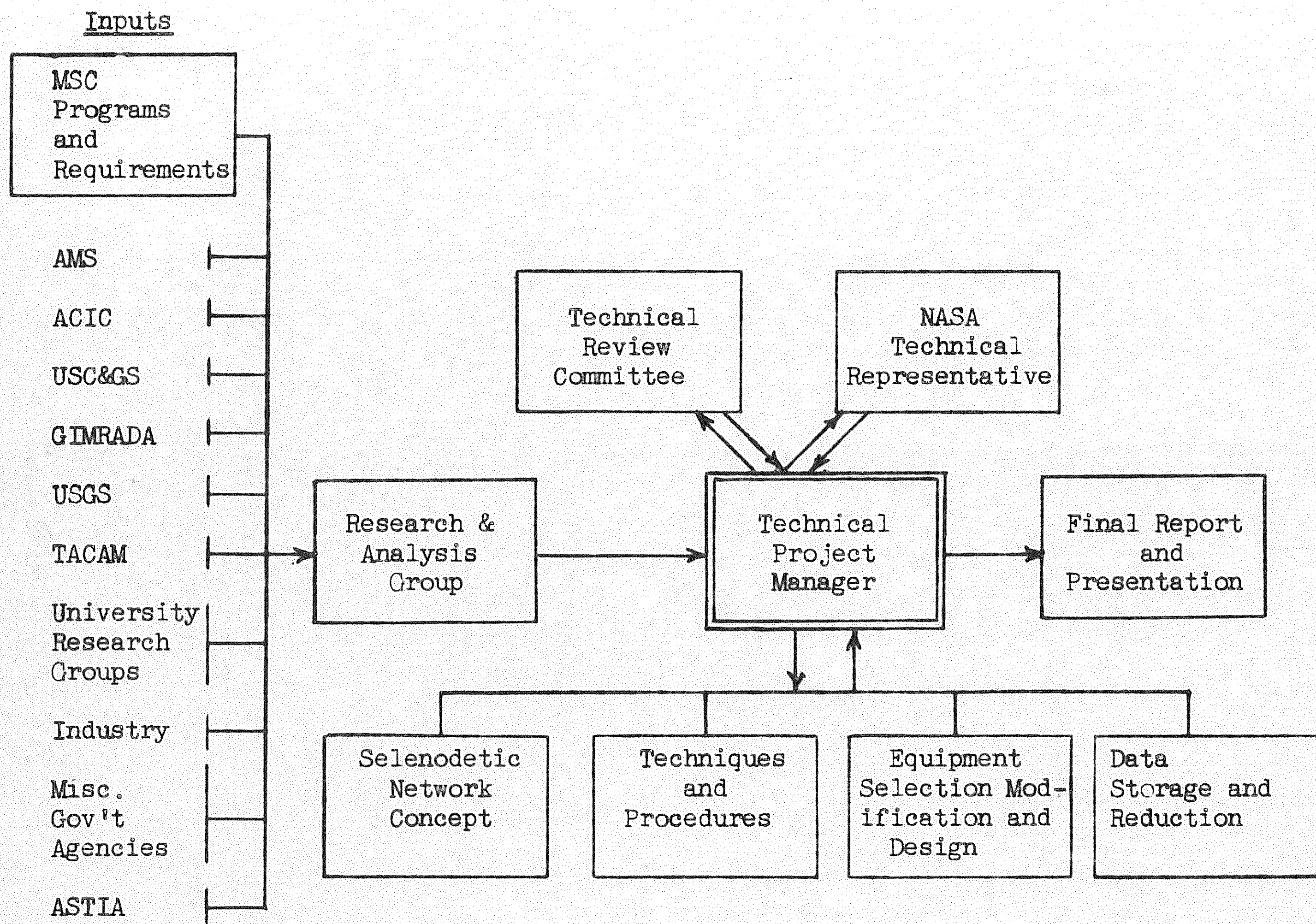
3.6 Final Report

Monthly reporting and preparation of the final report, to which all the groups will contribute, will be under the direction of G. T. Bell, President, of Geonautics. As the total benefit to MSC of the study must be contained in the reports, preparation of reports will receive top level attention, and is considered a major aspect of the study effort.

Exhibit 2 is the proposed work-flow diagram. It illustrates the sources of inputs to the study program and the inter-relationship of the component parts of the study group. The Technical Project Manager is a focal point in the organization of this effort, coordinating the work of his staff, while responsive to the thinking of the Technical Review Committee as well as requirements of the NASA Technical Representative.

The Research and Analysis Group will be the first to be activated, to analyze all available factors as well as pertinent Apollo mission concepts. Their digested data will be appropriately distributed for consideration and study, as indicated, with the final report and presentation representing the ultimate output.

Exhibit 3 contains an estimate of the amount of time to be devoted to this study by assigned members of our staff and associates. Time estimates are considered to be liberal and it is possible that all projected time charges may not be required to fulfill objectives of the study.



PROPOSED WORK FLOW

Exhibit 2

HOURLY TIME ESTIMATES

	Man Mo.	Research, Analysis	Selenodetic Concept	Tech. & Proced.	Equipment	Data Handling	Reports	Total
C.I. Aslakson, Princ. Eng.	3	100	100	100	100	40	40	480
F.W. Hough, Princ. Geodesist	3	100	160	100	40	40	40	480
H.K. Eichhorn, Astronomer	3	40	40	40	120	200	40	480
E.D. Dyer, Physicist	3	80	80	40	160	80	40	480
E.B. Roberts, Geodesist	3	160	160	80			80	480
A.D. Morris, Physicist	3	40			400		40	480
B.A. Claveloux, Sen. Eng.	7	290	140	170	220	40	260	1,120
J.S. Reece, Mathematician	4	40	40	40	40	440	40	640
H.M. Harper, Geodesist	6	160	40	520	160	40	40	960
G.T. Bell, Sen. Eng.	3	120	40	80	40		200	480
T.I. Gunther, Geodetic Eng.	5	160	40	320	200	40	40	800
H.A. Edgerton, Human Factors	1			80	40	40		160
Draftsman	1				80		80	160
	45	1290	840	1570	1600	960	940	7200

ESTIMATED TIME FOR PROJECT PERSONNEL

Exhibit 3

4. PROGRAM SCHEDULE

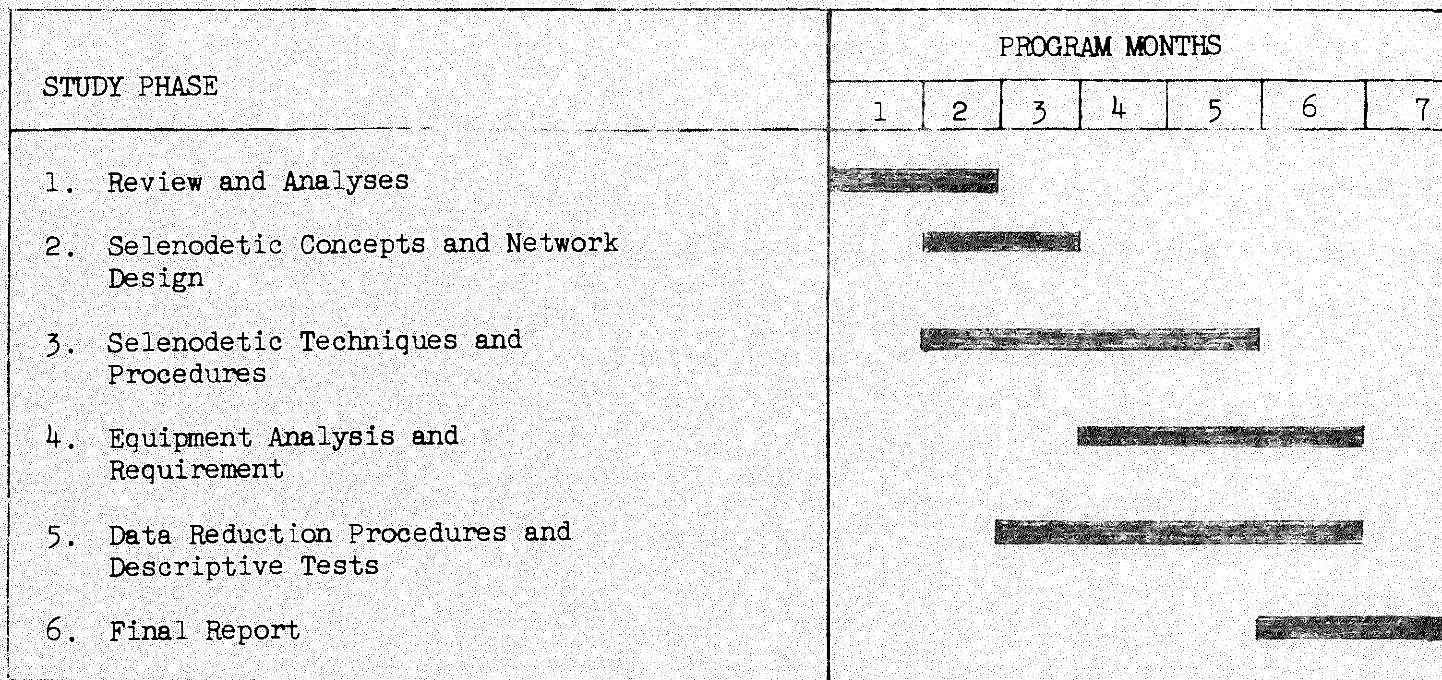
Geonautics, Inc. proposes to complete the work described in the RFP Statement of Work in accordance with the schedule shown in Exhibit 4. We believe that this systematic time-frame is reasonable, efficient and attainable. The various phases of the work are fitted together to ensure a logical sequence of events with minimal lost time as the program moves toward completion.

As shown, a six-month period is scheduled for study with a final technical report to be submitted to NASA, MSC at the end of the seventh month.

Attention is invited to the scheduled intensive review and analysis which is intended to bring sharply into focus all MSC programs related to this study and to insure elimination of duplication of effort. This work will extend into the second month of the study, but in the interests of efficiency will be overlapped by phases in which selenodetic concepts and network design, techniques and procedures are considered. At the end of the third month the selenodetic network design and equipment concepts will be defined in detail and reviewed in collaboration with MSC Technical Representatives with a view toward ensuring that objectives are mutually understood.

During the fourth, fifth and sixth months, phases of the program will be devoted to a thorough analysis of the procedures and instrumentation needs for the proposed selenodetic measurements and their reduction.

A final report covering all pertinent technical areas of the study with supporting analysis, tests and conclusions will be initiated during the sixth month of this study and submitted to MSC at the end of the seventh month.



PROPOSED TIME SCHEDULE

Exhibit 4

The following pages provide resumes of personnel assigned to this project. A list of contracts completed is also included.

GEORGE T. BELL, JR. PRESIDENT

Mr. Bell has over twenty-five years experience in all phases of business management and technical project administration. He was graduated from Lehigh University with a BS in Business Administration, and also received two years college training in Industrial Engineering. During five years at General Electric Company he completed both GE's Business Training and Test Engineering programs.

With Geonautics Mr. Bell has served as vice president and now chief executive of the company, combining his extensive business experience with an understanding of the company's technical operations to assure sound administrative and fiscal practices with efficient project control.

Prior to association with Geonautics, which began in 1959, Mr. Bell for 8 years was vice president and general manager of Air Survey Corporation, one of the major firms performing photogrammetric surveys and cartography for military and civilian government agencies. He is thoroughly familiar with technical, equipment and production aspects of photogrammetry, and necessary control measurements for photogrammetric processes.

During World War II, Mr. Bell served from Private to Major, AUS, at Army Finance Schools at Duke University and Wake Forest College, and for two years at the Army Industrial College in Washington, D. C., where he taught contract negotiation, cost and price analysis, allowable costs under cost-plus-fixed-fee contracts, and other courses related to government contract administration.

Mr. Bell is a member of the American Geophysical Union, American Society of Photogrammetry, National Rocket Club, American Congress of Surveying and Mapping, and others.

CARL I. ASLAKSON PRINCIPAL ENGINEER

Captain Aslakson, USC&GS (ret.), is in charge of geodetic field surveys and instrumentation projects of Geonautics. Upon graduation from the University of Minnesota with a BS Degree in Civil Engineering, he joined the U. S. Coast and Geodetic Survey, and for nineteen years his work throughout the United States and its territories included responsible charge of surveys in hydrography, geophysics and geodetic control. Later he directed gravimetric expeditions in Peru and Colombia.

During World War II he served as a Colonel in the Air Force where he was in charge of astronomic parties in Brazil, Uruguay, Paraguay and the interior of China. Upon completion of this work he initiated the development of geodetic distance measurement with SHORAN equipment. His extensive work led to the wide acceptance of SHORAN methods (later called HIRAN) for geodetic distance measurement of long lines.

During establishment and early operations of Cape Canaveral Missile Range, Captain Aslakson was in charge of geodetic operations and served as geodetic advisor to the Air Force on range instrumentation problems. He was responsible for HIRAN surveys throughout the Bahamas and Antilles, a new determination of the velocity of light, and extensive gravimetric work along the range.

Noted for numerous technical papers on precise alignment, theodolite circles, micrometers and their errors, deflection of the vertical, radio meteorology and others, Captain Aslakson holds the Department of Commerce Gold Medal Award for major contributions to science and technology in the measurement of distance by electronic methods.

In March of 1960 he was awarded the Boyden Premium by Franklin Institute for his original work on wave propagation in space.

With Geonautics, Captain Aslakson has served as a director of field projects, including positioning Project MERCURY tracking radars, the TELSTAR antenna at Andover, Maine, and in establishing a local geodetic control network for the 140-foot NRAO Radiotelescope. Additionally he has directed numerous geodetic studies and analyses carried out by Geonautics staff members.

Captain Aslakson is a Registered Professional Engineer in the District of Columbia, a member of the Cosmos Club, the Washington Academy of Sciences, American Society of Civil Engineers, American Geophysical Union and other professional organizations.

FLOYD W. HOUGH PRINCIPAL GEODESIST

Floyd W. Hough is internationally recognized as an authority in geodesy. His over thirty years experience includes extensive consulting work, direction of first-order geodetic control, precise alignment projects, international boundary and foreign oil concession definition, eleven years service with the U. S. Coast and Geodetic Survey and twelve years as Chief, Geodetic Division, U. S. Army Map Service.

During World War II he served as Chief of Geodetic Branch, Office of Chief of Engineers, Washington, and in the European Theatre of Operations as Commanding Officer of HOUGHTEAM, a geodetic and mapping intelligence unit which obtained extraordinarily valuable data and began the European Datum adjustment. For this accomplishment he received the Legion of Merit.

While Chief of the Geodetic Division, U. S. Army Map Service, he received the Department of the Army Decoration for Exceptional Civilian Service for his achievements in arranging for a unified world-wide geodetic system that resulted in the development of an accurate and more simple means of positioning, and determination of more exact dimensions for the figure of earth (Hough Ellipsoid).

Mr. Hough is widely known for his successful efforts to organize international cooperation in geodetic programs for adjustment and coordination of world geodetic control. He has served as official representative at numerous NATO and other international geodetic and mapping meetings in Europe, and to consultations in the Middle East, Africa, Ethiopia and South America.

Mr. Hough has been associated with Geonautics since its formation, serving as President from 1957 until 1962, when he resigned that position in order to devote his time to geodetic projects of the company.

He has contributed significantly to the analysis of geodetic positioning accuracies of MINITRACK, MERCURY, Baker-Nunn, and DSP tracking stations for NASA, and to the analysis of similar USAF satellite control facility tracking stations. He has also been a principal in numerous investigations, such as a theoretical study and design concept determination for a geodetic satellite, and in analysis and theoretical studies of computer programming for geodetic purposes.

He is President of the Section of Geodesy, American Geophysical Union; Fellow, American Society of Civil Engineers; member of the Cosmos Club, American Congress of Surveying and Mapping, Society of American Military Engineers and others; and a Registered Professional Engineer, District of Columbia.

HEINRICH KARL EICHHORN STAFF ASSOCIATE

Dr. Eichhorn studied mathematics, physics and astronomy at Vienna University in Austria where he received his Doctorate of Philosophy (summa cum laude) in 1949. He joined the Vienna University Observatory as an assistant, following graduation, and then attended Glasgow University (Scotland) under a scholarship grant by the British Council.

A fellowship grant by the Scientists Research Project, Foreign Operations Administration, brought him to the United States where he joined the McCormick Observatory Staff at the University of Virginia. With the McCormick Staff, Dr. Eichhorn concentrated his studies on long focus astronomy, celestial mechanics and theoretical stellar dynamics.

Dr. Eichhorn was Assistant Professor of Astronomy at Georgetown University where his abilities in the field of higher mathematics and work in celestial mechanics received international recognition, and is now Associate Professor of Astronomy at Wesleyan University. He has served as a Geonautics Staff Assistant since 1959, and has, among other projects, been engaged in the theoretical aspects of an R&D study of photogrammetric flash triangulation.

He is the author of numerous articles published in the scientific publications of Europe and America, including several papers on celestial mechanics, with emphasis on the determination of orbits.

EDWARD R. DYER STAFF CONSULTANT

Dr. Dyer attended the University of Virginia where he received his B.A. in Mathematics and Physics in 1938, and his M.A. and PhD. in Astronomy, the latter in 1948.

His research activities have included work under a Vanderbilt Research Fellowship, 1938-1940; assignment at Ultracentrifuge Laboratory of Rouss Physics Laboratory, 1941; and Carnegie Post-doctorate Fellowship at Mt. Wilson and Palomar Observatories, 1948-1950.

Dr. Dyer has taught General Astronomy (technical), Astrophysics, Celestial Mechanics, Statistical Astronomy, Practical and Spherical Astronomy, and others, at the University of Virginia and Georgetown University. He is the author of many papers on stellar photometry (photographic and photoelectric), stellar statistics (motions, radial velocities, magnitude, spectral types), astrometrics (stellar parallaxes, proper motions, radial velocities) and geodetic astronomy.

As a Special Consultant to Geonautics since 1960, Dr. Dyer has contributed extensively from his broad knowledge of mathematics and astronomy to insure successful and logical conclusion of highly complex analytical efforts. His work in orbit determination methods and error analysis in determination of ephemerides of orbiting satellites have been particularly noteworthy. His theoretical study of the effects of gravity on trajectories and orbits did much to advance the state-of-the-art, as did his theoretical investigation of navigation systems using artificial satellites.

ELLIOTT B. ROBERTS — STAFF ASSOCIATE

After receiving his B.S. degree from the Massachusetts Institute of Technology, Mr. Roberts had over thirty-five years experience with the U. S. Coast & Geodetic Survey in a wide area of applied geophysics rising to the commissioned rank of Captain. There he served in many capacities from party chief to commanding officer executing geodetic control surveys and hydrographic investigations in the continental United States, Alaska and the Philippine Islands, including organizing the seismic sea wave warning system in the Pacific, aeromagnetic surveys of the North American Arctic, and technical missions in South America.

In 1945 he became Chief of the Geophysics Division in charge of geomagnetic surveys, observatory operation, and general and engineering seismology. From 1959 until March of 1962 he was Assistant Director of the USC&GS for Research and Development. He is the inventor of the Roberts Radio Current Meter, a deep sea tide gage, and recipient of the Department of Commerce Meritorious Service Medal.

Captain Roberts has served as a staff associate to Geonautics since 1962 and has been actively engaged in a number of projects.

Most interesting among these was a survey of requirements for development of advanced geodetic survey and mapping instruments and equipment for a leading electronics manufacturer. Captain Roberts carried out an extensive research project in this regard before making a most comprehensive report. He also made an investigation of factors influencing the accuracy of optical sightings through multiple media and lent support to the development of a means of calibrating radio telescope antennas.

DR. ALAN D. MORRIS STAFF ASSOCIATE

Dr. Morris, Assistant Professor of Physics at American University, has been a consultant to Geonautics, Inc., since 1961. At the University, he teaches optics and directs the senior level Optics Laboratory. While on active duty as Aeronautical Engineering Officer, USNR, he designed and built the MX-2153/APQ-50 Radar Indicator Viewer and Camera Training Aid Optical system installed in fleet F4D Skyrays. He also designed radar viewers for the F3H and F8U aircraft, re-designed the functional arrangement of the Aero-13 Radar Antenna Hand Control, and modified the camera recorder optics of the ASB bombsight. He was a member of the Navy team which evaluated the North American "windshield display", a device which used a trichroic mirror combiner.

He has conducted reliability analysis of the infra-red and television sensors aboard the Numbus Satellite; participated in operations research studies of the effectiveness of reconnaissance satellites; and conducted studies of scientific experimentation aboard the MORL and MOL vehicles.

Dr. Morris received his engineering degrees from the Johns Hopkins University. He is a Registered Professional Engineer in Maryland and the District of Columbia, and he is a member of IEEE, Sigma Xi, Tau Beta Pi, NSPE, and the Naval Reserve.

DR. HAROLD A. EDGERTON STAFF ASSOCIATE

He was a member of the faculty of Ohio State University from 1928 to 1947. During that time, he was Professor of Psychology, Counselor in the College of Arts and Sciences, and Director of the Occupational Opportunities Service. On leave of absence (1935-37) he was Chief of the Statistical Unit and Statistical Consultant, Occupational Research Program of the United States Employment Service. During World War 1 1, he was Expert Consultant in Personnel Research to the Secretary of War, and later served on the Training Devices Panel, Research and Development Board, Department of Defense.

Since 1947, Dr. Edgerton has been Vice-President (1947-1959) and President (1959-1962) of Richardson, Bellows, Henry and Company, Inc., industrial psychologists and management consultants. ; During this period, he has been a consultant on problems of selection, performance evaluation and special programs to companies in such industries as oil, chemicals, mining, public utilities and banking. He has directed research for the Department of Defense in the areas of training methods, training devices and research utilization; and for the National Science Foundation, studying the impacts of their Summer Science Training Program for high ability secondary school students. He is a Chairman of the Board of Judges of the Annual Science Talent Search for the Westinghouse Scholarship and Awards, and is Professor of Psychology (part-time) at the University of Maryland.

Dr. Edgerton has published 3 books and over 100 technical papers, articles, monographs and research reports.

In addition to professional memberships, he is a Diplomate in Industrial Psychology, American Board of Examiners in Professional Psychology; has been President of the Divisions of Industrial Psychology and Consulting Psychology of the American Psychological Association; and is a past President of the Psychometric Society.

BERNARD A. CLAVELOUX, JR. SENIOR ENGINEER

Mr. Claveloux attended Catholic University where he received his B.C.E. degree in 1950. Since then he has completed graduate work in electronics, photogrammetry, optics and statistics at Southern Methodist University and George Washington University.

He served as a Project Engineer and Senior Project Engineer at the Engineer Research and Development Laboratories, Fort Belvoir, for seven years where he was engaged in the development of Shoran mapping techniques, analytical photogrammetry, target location techniques and advanced radar mapping equipment. Prior to joining Geonautics in 1960, Mr. Claveloux was a Lead Weapons Systems Engineer for two years at Chance Vought Aircraft, Inc. engaged in the development of the radar map matching guidance system and range instrumentation systems for the Regulus II missile program.

With Geonautics, Mr. Claveloux has served as project director of a study of geodetic factors related to positioning global range facilities; a comparative analysis of electronic distance measuring systems; an R&D study of photogrammetric flash triangulation for U. S. Army Corps of Engineers field use; and a photogrammetric calibration system for determination of configuration of radio telescope antennas.

Mr. Claveloux is a member of the American Society of Photogrammetry.

JAMES S. REECE MATHEMATICIAN

Mr. Reece was graduated with a B.S. in mathematics from Memphis State University in 1957 after having served as a 1st Lieutenant in artillery in Korea. From 1957 until coming with Geonautics early in 1963, he was a geodetic mathematician with the U. S. Coast & Geodetic Survey.

During that period he became thoroughly familiar with all types of geodetic computations and adjustments as well as programming such computations for digital computers. He has undertaken special research on the mathematics of triangulation in space, and the distribution of theodolite errors. In addition, he devised a method of locating earthquake hypocenters which is now used at the U. S. Coast & Geodetic Survey for all such determinations.

With Geonautics Mr. Reece has been engaged in reduction and adjustment of field geodetic data both by conventional and ADP applications, and written special computer programs for geodetic purposes. He has lent invaluable support to mathematical investigation of highly complex geodetic and astronomic problems. His analyses of geodetic positioning accuracies in connection with NASA and Air Force projects have been particularly noteworthy.

H. MacDONALD HARPER SENIOR GEODETIC ENGINEER

Mr. Harper has been with Geonautics since 1960, coming to this organization from the Standard-Vacuum Oil Company with whom he had been employed as a geologist in Indonesia for five years. With Stanvac he served as party chief of a large structural drilling party and later as subsurface geologist responsible for mapping numerous horizons in a highly complex oil field.

Educated both abroad and in the United States, Mr. Harper received his A.B. degree (Geology) from Princeton University. On graduation he was employed by the U. S. Navy Hydrographic Office, where for over four years he served extensively aboard the USS MAURY and other Navy hydrographic and oceanographic survey vessels as a civilian scientist. Additionally he was chief of independent parties establishing geodetic control in support of military projects. His experience with the Navy also included general and detailed bathymetric data collection and processing for scientific, engineering, and general navigational uses.

With Geonautics, Mr. Harper has been engaged in a wide range of efforts. Notable has been his work in determinations of first order astronomic position, azimuth, reference and deflection of the vertical for a star tracker laboratory, and for AT&T's Telstar tracker. Geodetic surveys, deflection and gravity observations for an inertial guidance laboratory, bathymetric studies and special chart preparation, special drone application of electronic DME are representative of the types of projects which have been included in his assignments.

Mr. Harper is a member of the American Congress on Surveying and Mapping.

THORSTEN L. GUNTHER GEODETIC ENGINEER

Mr. Gunther who joined Geonautics in 1963 is a graduate of Pomona College where he received a B. A. degree, and has completed three years full time graduate work in Civil Engineering at Harvard University. He was with the U. S. Army Corps of Engineers in the European Theater during World War II and then associated with several engineering companies on return to civilian life.

From 1957 to 1963 Mr. Gunther was Head of the Engineering Department of Air Survey Corporation, where he was in charge of planning aerial photography and ground control with emphasis on the geodetic aspects and associated computations.

With Geonautics Mr. Gunther, who has had 16 years experience in geodetic field operations, has been engaged almost exclusively in research projects related to positioning problems of space tracking facilities for NASA and the Air Force.

Projects Completed or in Process

Ship-board Hydrographic Survey, 800-Mile Cable Route

Verification of Pointing Azimuths, Mediterranean Tropo Antennas

Orbit Determination Methods and Trade-offs Among Them

Study of Technical Areas for R&D of Geodetic and Mapping Equipment

Desirable Geodetic Positioning and Pointing Standards for Tracking Radars

Analysis of Geodetic Positioning Accuracies and Boresighting of USAF Satellite Control Facility Tracking Stations

Error Analysis in Determination of Ephemerides of Orbiting Satellites

Study of Orbit Determination Methods, and Limitations on the Accuracies of Ephemerides Calculations

Geodetic Factors Related to Positioning Global Range Facilities

Analysis of Geodetic Positioning Accuracies of MINITRACK, MERCURY and DSP Tracking Sites; positioning GEMINI and APOLLO Sites; Analysis of Boresight Requirements and Procedures

Determination of First Order Astronomic Position and Azimuth Reference, Deflection of the Vertical, and Gravity for Star Tracker Laboratory

Study of Geodetic Aspects of AROD Navigation System for SATURN Vehicles

Positioning and Pointing of Twenty-one Tropo Antennas in Spain, Italy, Greece, Libya and Turkey

Bathymetric Study and Special Chart Preparation

Comparative Analysis of Electronic Distance Measuring Systems

Special Drone Applications

Consultation, Conduct and Analysis of Precise Geodetic Surveys for Latitude, Longitude, Elevation, Deflection of the Vertical; Precise Alignment and Orientation of TELSTAR Tracking Station

Oceanographic & Environmental Problems in Placement and Positioning Determination of Underwater Objects, Project ARTEMIS

Geodetic Surveys for Position, Alignment & Calibration of Precise Tracking Radars

Geodetic Surveys for Position and Elevation of Project TRANSIT Antennas

Theoretical Investigations of Practical Navigation Systems Using Artificial Satellites

Projects Completed or in Process - Continued

Study of Geodetic Parameters of MISTRAM System

Theoretical Study of the Effects of Gravity on Trajectories and Orbits

Determination of Latitude, Longitude, Elevations, Deflection of the Vertical and Gravity for Inertial Guidance Laboratory

Consultation, Analysis and Theoretical Studies of Geodetic Datum Relationship, Survey Errors and Geodetic Parameters for Computer Programming

Consultation, Analysis & Error Study of Proposed Airborne Radar Telescope Calibration System

Determination of Latitude, Longitude, Elevations and Deflection of the Vertical for Tracking Radars, Project MERCURY in U.S., Hawaii, Mexico, Bermuda and Canary Islands

Precise Alinement and Orientation of Radar Antennas, Project MERCURY

Very Precise Geodetic Control Network for 140-foot NRAO Radiotelescope, Green Bank, West Virginia

Phogrammetric Calibration System for Determination of Configuration of Radio Telescope Antenna

Research & Development Study, Photogrammetric Flash Triangulation for U. S. Army Corps of Engineers' Field Use

Pacific Missile Range Instrumentation Studies

Study of Station-Keeping Problems for Instrumentation of Tracking/Communication Ships

Oceanographic Aspects of Submarine Cable Laying

Target Array Emplantment Proposal Study

Theoretical Study and Design Concept for Satellite for Geodetic Purposes