Review [redacted] [redacted]ellite Geodesy and Mapping Systems

Since its first proposed satellite geodetic system, ARGON, the Army has had to defend its space geodesy and mapping programs from other suggested "systems". Some of these rival "systems" were not systems at all but were only cameras. The claims made for end products were not backed up with data reduction sub systems and system error analyses. Many of the claims for performance were well beyond the state-of-the-art or beyond the possibilities of the weak geometry of the photography.

When the ARGON program was proposed by the Army, the Air Force said it had a panoramic camera in being which could accomplish the same thing as the ARGON camera. Many engineering man hours were expended to disprove the AF claims for its system. Next, the AF proposed the use of a 6" focal length camera instead of the 3" focal length camera of the ARGON system. The 6", E-4 system had a stellar camera at 90° the same as the ARGON camera sub-system and it had time recordings and telemetering very similar to the ARGON. Only the focal length was different, the claim being that larger scale photography was required to provide greater ground resolution. An Atlas-Agena vehicle would be required to put the E-4 data acquisition sub-system into orbit compared to the Thor-Agena required for ARGON. This seems to be a waste of power when, with the same vehicle, the Army's advanced mapping sub system could be put into orbit. Claims were even made that contours could be plotted from E-4 photography that would meet 1:250,000 scale map requirements. Such claims are unrealistic. Later it was suggested by AF personnel that combinations of E-4 photography and panoramic photography could produce contours meeting the 1:250,000 scale requirement (100 meter contour internal). Numbers were compiled to show that the E-4 panoramic combination could meet these

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requirements but the A-panoramic combination could not meet them. Recently the Air Force has proposed the use of a 1½" focal length frame camera in combination with a panoramic camera (KH-4 system) to produce contours meeting requirements for maps of scales 1:250,000 and larger. However, if the numbers formerly used for the E-4 and the ARGON photography in combination with panoramic photography were extrapolated, the following would be found:

* Estimated Contour Interval Possible Using Combinations of Fixed Frame & Panoramic Photography

Standard Map Scale No.	Desired Contour Interval	Relative Contour Interval 24" 30° Convergent Panoramic		
		E-4, 6"FL	ARGON, 3"FL	KH-4, 1½"FL
250,000	328 FT	272 FT	376 FT	480 FT (extrapolated)

The absolute contour intervals shown for the same systems were 332 ft for the 6"FL, E-4 and 484 ft for the 3" FL ARGON. By extrapolating to the 1½" FL, KH-4 the contour interval would be 636 feet. These values for the KH-4 system differ greatly for the ones now claimed.

Whereas the ARGON system was designed to achieve certain geodetic objectives, there is continual pressure for trying to use the A material for topographic map compilation. The Army does not believe that short focal length vertical photography can meet vertical accuracy requirements for 1:250,000 and larger scale maps. For meeting such requirements, the advance mapping system using 18"FL, 9"x18" format cameras in a 30° convergent mode was proposed by the Army in June 1960.

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* Table 7 - Report on the Sub Task Group on Pseudo Maps

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It has been delayed several times because of AF claims for other systems. First it was claimed that E-4 photography (6" fl. 9"x9" format) could be used for meeting the 1:250,000 scale requirements. Army studies showed that with present and future instruments the contour interval to be expected from E-4 material would be too large.

Later a contractor proposed the use of a convergent 8¼" focal length system, claiming that 1:250,000 scale maps could be made with "off the shelf cameras and existing data reduction equipment". Again it was necessary to demonstrate that such a system was not capable of meeting accuracy requirements.

Now it is being suggested that the Army's proposed system (18" F.L.) is <u>too</u> accurate for 1:250,000 scale mapping and that it should be considered for making maps of 1:50,000 scale and smaller. Also it is understood that the AF is considering a 24" F.L. frame camera for producing materials for 1:50,000 and smaller scale maps.

The Army's study of advanced mapping systems covers requirements for producing maps as scales from 1:25,000 to 1:250,000. Numbers are available for every part of the data acquisition and data reduction sub-systems showing the needed accuracies and the physical limitations. These studies are available for review and criticism. Studies of this type should be used in designing mapping systems instead of trying to devise makeshift data reduction sub-systems for producing maps from existing reconnaissance photography.

GENERAL NOTES ON SATELLITE MAPPING

Maps can be divided generally into two classes; special purpose maps and maximum utility maps. Special pupose maps are, as the name implies, made to perform specific tasks. Such maps generally cover a limited area on the ground at the scale suited for the purpose, contain only information of interest to the purpose, and are not accurately related to other ground areas. They are not intended for general military application. On the other hand, maximum utility maps are produced in a family of scales. They are designed to meet the needs of many map users and are tied to a common datum so that one map of a series is properly related to all other maps of that series, within the accuracy of the control network.

An example of a special purpose map would be a controlled mosaic with contour overprints at a scale of one inch to one-half mile. All roads, railroads and bridges in the area might be annotated so they could be found easily. Perhaps a local grid overlay might be added so that points could be positioned by grid coordinates. Marginal information would contain only the scale, contour interval and the legend for roads, railroads and bridges. Such a map would be very useful for some purposes but its use would be very limited. Another example of special purpose maps or charts would be bombing target charts produced by the Air Force. The position or elevation of one object relative to another within a limited area is a requirement for these charts. Also, certain intelligence studies require accurate measurements of object sizes with the results shown on special purpose maps.

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A maximum utility map, on the other hand, would be produces at a standard scale, (1:250,000; 1:50,000; 1:1,000,000 for instance). A standard universal transverse mercator grid would be placed on the map. Standard annotations for roads, houses, towns, streams, mines, vegetation, elevations, names, etc., would be shown. All map sheets of the series would be related to each other to the accuracy of the control grid. Such maps would have many uses, both military and non-military.

The Department of the Army utilizes special purpose, or provisional, maps whenever the need arises and/or when adequate control material is not available. Many such maps were made during World War II from reconnaissance photography when the occasion did not require or permit standard maps. These maps generally were produced in small numbers and because of their limited positional accuracy and general information content were not retained in the Army's map inventory. The Army will continue to produce provisional maps to meet special needs; however, its primary mapping program must be geared to the production of maximum utility maps.

Any extensive mapping program must be carried out by means of a practical, well designed, systematic, mapping system. All parts of the system must be tailored to be compatible with the rest of the system. For instance, coverage of an area with high quality cartographic photography does not permit accurate mapping unless some means is available for controlling the photography. As a matter of fact, the Army Map Service has cartographic photography available for several critical areas but maps meeting requirements cannot be compiled because of the lack of adequate ground control. Another instance of insufficient source material

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for mapping is the availability of coverage consisting only of long focal length, high resolution photography. Because of the weak geometry of the photography (whether frame or panoramic) it is not possible to make accurate space resections or photogrammetric control extensions. The design of an adequate data acquisition sub-system for precision mapping must provide for strong geometric relationships between intersecting rays and sufficient ground resolution to identify items of interest. Mapping agencies have found supplemental photography of long focal length useful, in combination with cartographic photography of shorter focal length for identifying objects on the ground with greater accuracy. In all instances the cartographic photography with the strong internal geometry was used for all position and height measurements.

The term "photogrammetric control extension" is used quite often in connection with mapping in areas of limited ground control. Both cantilevering and bridging techniques are used. In reading isolated reports one might erroneously conclude that extensions of 20 to 50 models can be made without a great loss in accuracy. In practice, extensions are generally limited to a much smaller number of models, depending on the scale of the map being compiled, and these are bridging extensions and not cantilever extensions. Furthermore, such extensions are made with photography having high geometric fidelity and precision calibration.

The production of maps of denied territory is restricted in several ways including; the restriction of aircraft flying over the area, the lack of adequate identifiable ground control and the unreliability of long photogrammetric control extensions. To overcome these barriers the Army

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has designed an Advanced Satellite Topographic Mapping System. The data acquisition and the data reduction subsystems were designed together so that optimum utility of the recovered data could be realized. Studies were conducted on every phase of the proposed system with necessary error analyses to assure adequate design of each part of the system.

The proposed system provides for precision terrain photography to be made from a near polar earth satellite. At the instant of exposure a stellar photograph will be made with a camera rigidly attached to the terrain camera. Also, the time of exposure to ± one milisecond will be recorded on the film. After several days in orbit the exposed film will be recovered. Data reduction will include the accurate determination of the orbit from photographs exposed over mapped areas. The attitude of the camera to an accuracy of a few seconds of arc will be determined from stellar records and camera relative orientation calibration data. Next, the position and the angular orientation of each photograph will be computed, using the orbital parameters and time to find the former and stellar records and time to determine the latter. Special equipment will be used for measuring the stellar and terrain records prior to accomplishing the work just mentioned. Other special equipment will be used for drawing contours and for producing orthophotographs. Planimetric data will be drawn directly from the orthophotographs.

This suggested program has many advantages over conventional mapping programs. Denied territory can be overflown to provide necessary photographic coverage. There is no error propogation along a flight line as in conventional photogrammetric aerotriangulation. Each photograph is positioned with respect to a world datum and the absolute angula[redacted]

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orientation of each photograph is known. Any two overlapping photographs will form a stereo model from which true contours can be drawn. The equipment and procedures have been designed for maximum speed and accuracy. Such a mapping system will permit the production of topographic maps of any area in the world in an orderly, economical and timely manner. The method is well understood and the results are not speculative.

Suggestions have been made that medium and large scale maps be produced from a combination of panoramic and frame photography. Although details are lacking, it is believed that the suggestion involves the use of 24" convergent (15°) panoramic photography with a format of 2."2 x 29."0 and a vertical frame camera with a 1½" focal length and 2¼" x 2¼" format. The frame photography would be used as a horizontal control base for the panoramic photography which would be used for identifying ground objects and for contouring. No attempt would be made to reference the final product to either a horizontal or vertical datum to which other maps were referenced. That is, horizontal and vertical positions would be relative to other positions within a given model or frame.

For the preparation of special purpose maps of small areas the panoramic-frame combination mentioned above probably is adequate. To consider such a combination for producing medium and large scale maps of a large area is operationslly unrealistic.

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As mentioned previously, the 1½" f.l. frame camera format is 2¼" x 2¼". The panoramic photography, reduced to the scale of the frame photography (approx 1:8,000,000) would be 1/8" x 2¼". Seventeen strips of panoramic photography (or 17 models) would be required for each frame camera exposure. The problem of tieing 17 strips of semi-controlled contour manuscript together would be formidable, not to mention the task of finding sufficient ground detail to permit accurate matching of the panoramic and frame photography. Even if this could be accomplished, the "control" information available from the frame photography would be useful only for horizontal ties and not for vertical ties.

To cover the same area with the system proposed by the Army would require only two models and all horizontal and vertical points would be referenced to a selected world datum. The time required to map the area would be much less than that required with the panoramic-frame technique and the accuracy would be higher.

The controversy concerning the need for absolute or relative horizontal and vertical accuracies seems to stem from erroneous assumptions. One of these assumptions is that it is much more difficult to provide accuracies related to a world or continental datum than to a local datum. This is untrue, if the data acquisition, the data reduction systems and the flight operations are properly correlated and if the mapping of large areas is required. The availability of stellar records and time recordings of each exposure and proper calibration of the camera system

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make it possible to determine an accurate orbit which then becomes a space tape line to which all stereo models are referenced. To fail to take full advantage of this natural control source, which never before has been available, would be gross negligence.

There seems to be a growing feeling that the production of maps of any areas in the world from satellite photography is relatively simple and an accomplished fact. Although it is important and necessary for research and development personnel to be progressive and optimistic it also is necessary to be realistic and to properly interpret scientific studies. Studies made to date showing that 1:250,000 scale maps with a 50 meter contour internal can be produced by the advanced mapping system proposed by the Army. This system requires two 18" focal length, convergent (30°) cameras with 9" x 18" formats. Studies also show that 1:100,000 scale maps can be produced from material from a 24" convergent cartographic camera sub-system and that a 36" convergent cartographic camera sub-system would be required for 1:50,000 scale maps. Prudent weight lifting and time in orbit (reliability) considerations lead to 1:100,000 - 1:250,000 scale mapping goals at this time.

The production of Class A maps from satellite photography will not be easy. Equipment accuracies, calibration exactness, mathematical sophistication and quality control far beyond that ever used before in mapping operations will be required. No part of the system can be permitted to contribute more than its alloted error or the required accuracies cannot be met. Some examples of the accuracies required are: the distance between exposure stations must be known to 25 feet (over a [redacted] [redacted]

distance of about 200 miles). The angular orientation must be known to 2 seconds in each axis, the angular pointing accuracy of the camera must not exceed 2½ seconds, the stereometer error including automatic correlation error must not exceed 10 microns and the errors in plotting contours and planimetry must not exceed 40 microns. (First order stereoplotting instruments in use today, Wild A-7 and Zeiss Stereoplanigraph, can make settings to about 32 seconds for angular orientation, compared to 2 seconds required for the proposed system). Angular orientation errors of more than one second cannot be tolerated in the 1:50,000 map system. Other sources of errors, such as atmospheric refraction, earth curvature, film distortion, and lens distortion must be taken into proper consideration in all precision satellites mapping operations.

It is only after one becomes acquainted with the exacting requirements of mapping from satellite photography can he fully appreciate the importance and necessity of an integrated data acquisition - data reduction mapping system. It then becomes abundently clear that Class A mapping of large areas cannot be accomplished from reconnaissance type photography in combination with extremely small scale frame photography. This combination falls short both technically and operationally.

The use of high resolution panoramic photography for supplementing cartographic photography for the identifying of ground objects appears to have great merit. As mentioned previously, the use of long focal length supplemental photography has been standard practice in the mapping profession for many years. There is every reason to believe that such practice will extend to satellite photography.

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DESIGN CONSIDERATIONS FOR A SATELLITE MAPPING SYSTEM

1. INTRODUCTION.

The justification for a mapping system utilizing a satellite as a camera carrying vehicle is that it is the only means for obtaining map information in militarily important areas of the world to which access by more conventional vehicles is denied, and where useful ground control points are not available. The minimum requirements that such a system must satisfy are:

a. It must be capable of obtaining a record with sufficient geometric fidelity so that the maps produced will meet the National Map Accuracy Standards.

b. It must provide an adequate ground resolution to permit recovery of the significant ground detail required for mapping at the selected scales.

c. It must be amenable to an efficient ground data processing system which will permit an orderly and rapid compilation of the required maps.

A camera system which produces a record that does not satisfy all three of these requirements will not be a mapping system at all. It will either produce a bad map whose consequences will not be known until a catastrophe occurs when it is used in the field. Or it will not produce any map because of the operational complexity which it imposes on the ground data processing system. Most important, by delaying the implementation of an adequate system, it may result in good maps never being available because of changes in the political climate and advances in anti-satellite techniques.

2. CONTROL REQUIRED FOR MAPPING.

Conventional photogrammetric mapping depends upon the presence of ground control points in each stereo model. These points must be:

a. Identifiable on the photographs.

b. Properly distributed over the area of the stereo model. .Two horizontal control points are required for completely locating and scaling the stereo model. A single point will permit location, but no scaling or azimuth control. Five vertical control points, located at the corners and center of the model, are required for a complete orientation. Three vertical control points will permit leveling of the model but no removal of model warping. One vertical control point will permit connection to sea level datum, but no leveling or distortion removal.

c. The horizontal control points must be given on (or convertable to) the selected geographic reference (UTM grid system). The vertical control points must be referenced to mean sea level.

Because the contour interval on maps is usually much smaller than the allowable planimetric error, the accuracy requirements for elevation are two to four times as severe as those for horizontal position. The allowable map errors for standard contour intervals and scales are:

Allowable Errors in Elevation

Contour interval (meters)	100	50	20	10
Standard error in elevation (meters)	30	15	6	3

Allowable errors in Position

Map scale	1:250,000	1:50,000
Standard error in position (meters)	60	12

In standard mapping practice control points are expected to have errors less than one tenth those allowed in the final map. It goes without saying that control of this density, distribution, accuracy, and identifiability will not be generally available in the areas for which the satellite mapping system is designed. Consequently, it is proposed to use the satellite orbit and stellar photography as a substitute for ground control.

Satellite orbits are currently established by observations made by electronic and optical tracking stations. Electronic systems require active transmission from the satellite, and the observations are of limited accuracy. Optical systems permit location of the satellite at the time of observation with a standard error of approximately 15 meters in each coordinate. However there are only a limited number of optical stations, and they can obtain observations only under optimum combinations of clear weather, satellite position, and illumination. Satellites may go for weeks without a single good optical observation. Under these conditions, existing tracking networks cannot be expected to provide orbital coordinates to any better than a standard error of 150 meters, which is inadequate for any scale mapping to National Map Accuracy Standards. Therefore the mapping satellite must be able to develop its own orbit by a bootstrap operation.

This will be accomplished by matching the images on the terrain photographs with existing maps. Each such match, coupled with the time at which the terrain photograph was exposed and the angular orientation obtained from the stellar photography, serves as an observation for use in calculating the satellite orbit. The accuracy of this observation, and consequently of the orbital positions over unsurveyed territory, will depend primarily upon the ground resolution and geometric fidelity of the terrain photograph. Tests have shown that the accuracy of satellite positions obtained from map comparison will be about equal to the measuring ability of the photography or to the accuracy of the map, whichever is smaller. Satellite positions over unmapped territory will have errors of approximately three times this amount.

This means that in addition to satisfying the resolution requirement for mapping, the photography must provide high ground resolution and geometric integrity in order to permit an adequate orbit to be obtained.

3. TYPES OF CAMERA SYSTEMS AVAILABLE.

There are three principal types of camera systems considered for use in a satellite:

a. Long focal length panoramic cameras.

b. Wide angle, frame type cameras used in the near vertical mode.

c. Normal angle, long focal length, frame type cameras used in the convergent mode.

It is expedient to examine these camera systems in terms of how well they satisfy the criteria for mapping and orbit determination.

4. LONG FOCAL LENGTH PANORAMIC CAMERAS.

Panoramic cameras are capable of producing the highest possible photographic resolution. In order to accomplish this, however, they are subject to a number of severe drawbacks.

a. They produce a very long and narrow format which cannot be handled as an integral unit in any existing or proposed ground mapping instruments.

b. The scale of the images changes from a maximum at the flight line to a minimum at the ends of the format. Since the photo resolution is essentially constant over the format, the <u>ground</u> resolution decreases away from the flight line. At the limits of the format the ground resolution may be less than that provided by comparable frame type cameras.

c. The high resolution is achieved by relative motion of the film with respect to the lens. This requires a total exposure time of approximately $\frac{1}{2}$ second. Any variation of the vehicle attitude during this exposure causes a real geometric error in the position of images on the film.

d. The image motion compensation depends upon the ratio of vehicle velocity to altitude, and is designed for straight and level flight.

Any variation in either velocity, altitude, or attitude produces real geometric distortions in the position of images on the film.

e. During the time required for exposure, a satellite will travel about 2 miles. . Consequently no single point in space can be considered as the exposure station, and no single angular orientation can be effective for the total panoramic exposure.

The lack of geometric fidelity is sufficient to eliminate the panoramic camera as the principal record for a mapping operation. Attempts which have been made at mapping from panoramic cameras have utilized a multiplicity of ground control points. Based upon these control points the errors in the record have been backed put. However this is certainly not a fair test of the operational capability of panoramic photography. In the first place, the ground control will not be available in the area of interest. In the second place, the set of errors will be unique to each exposure, so that for the most part, they cannot be eliminated by calibration of the camera over a known well controlled area.

Consideration has also been given to using the panoramic photography in conjunction with frame type photography. It is proposed to use the frame photography to establish a network of control points on the ground, and the panoramic photography to fill in the details of the map. However, the basic accuracy of the map could not be better than that provided by the frame photography. Utilizing the high acuity of the panoramic photography might permit drawing additional contour lines or the interpolation of additional planimetric detail. However, the information would be deceitful because it would give the impression of more accuracy than exists. The field commander would be better off with a standard accuracy map, produced from the frame photography, and a stereo pair of high resolution panoramic photographs for interpretation, not measurement, of the details.

Finally the combination of panoramic photography with frame photography imposes a frightful burden on the smooth efficient operation of a ground data processing system. Instead of being able to proceed with the orderly compilation of a complete stereo model, an operator would be faced with the requirement to continually interrupt his work and reorient a different part of the panoramic record. The prospect of automating such a procedure seems remote indeed.

5. WIDE ANGLE FRAME TYPE PHOTOGRAPHY.

Modern lens design techniques can produce lenses of cartographic quality with an acceptance angle of approximately 90°. When used with a square format this means that the picture frame dimensions will be $1\frac{1}{2}$ times the focal length of the lens. Three different configurations have been proposed:

a. A $1\frac{1}{2}$ inch focal length with a 2-1/4 inch square format.

b. A 3 inch focal length with a 4-1/2 inch square format.

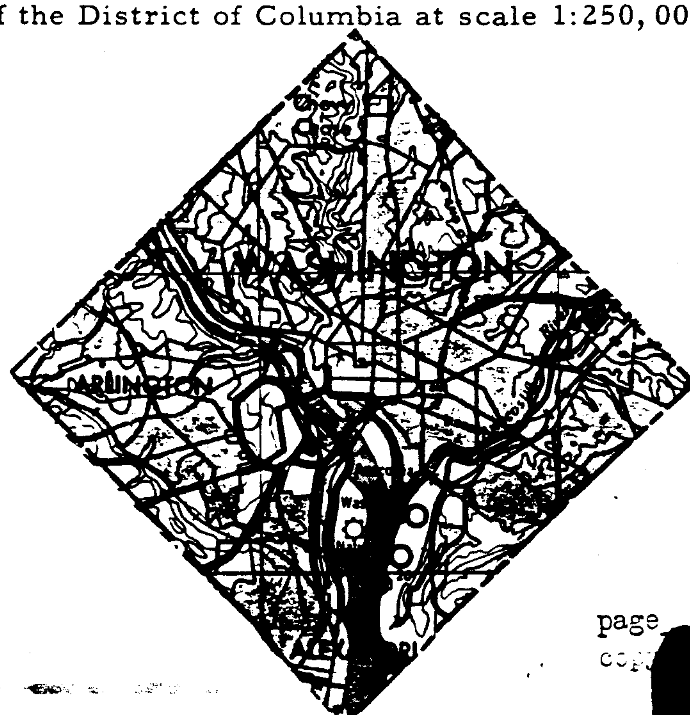
c. A 6 inch focal length with a 9 inch square format.

The principal advantage of the two smaller systems is that, because of their small weight and volume, they can be placed in orbit by the Thor-Agena booster, whereas the 6 inch system would require a booster of capacity comparable to the Atlas-Agena.

There is no question of the geometric fidelity of any of these systems. By careful calibration of the cameras and the use of a reseau in the focal plane it is possible to assure that the correct positions of all images may be recovered within the limits of resolution of the photography.

Neither is there much question of the efficiency of a ground data handling system for any of these systems. The processing of square format frame type records is the standard procedure in photogrammetry. The questions that remain are: will the photography provide sufficient information for compilation of a useful map; will the planimetric and topographic accuracy be sufficient for National Map Accuracy Standards.

A map of the District of Columbia at scale 1:250,000 is shown below:



It is approximately $2\frac{1}{2}$ inches square; it contains about 13 linear inches of railroads, about 50 linear inches of highways, about 15 inches of shoreline, etc. Now consider what this would look like on each of the proposed photographs.

a. On the 1-1/2 inch focal length photography it would be less than 3/32 inches square.

b. On the 3 inch focal length it would be less than 3/16 inches square.

c. On the 6 inch focal length it would be less than 3/8 inches square.

It seems quite obvious that it would be enormously difficult, if not totally impossible to take this amount of information from any of the proposed records.

Another way of looking at the same problem is in terms of the ground dimensions which can be resolved on the photography. The ground resolution is equal to the photo resolution multiplied by the image scale. An optimistic estimate of the ground resolution produced by each of these systems is:

200 meters for the 1-1/2 inch system

144 meters for the 3 inch system

62 meters for the 6 inch system.

It is again pretty obvious that these values are marginal at best.

The question of accuracy is not quite so easy to answer. The standard error of planimetric measurement is about one fourth the ground resolution. The topographic measuring accuracy depends also upon the Base-Height ratio, which is 0.6 for all these systems. This means that the topographic measuring accuracy is 1.6 times the planimetric accuracy. These values are:

	Planimetric	Topographic
1-1/2 inch focal length	50 meters	83 meters
3 inch focal length	36 meters	60 meters
6 inch focal length	15 meters	25 meters

These numbers are a measure of precision only. They give the relative accuracy of two adjacent points. They have very little to do with the accuracy of a map produced from these photographs, because they do not relate the details to their true positions and elevations. If the stereo models were completely controlled by ground control points these values would be indicative of the map accuracy.

But, as has been mentioned, in the areas for which the satellite mapping systems are designed, the control will be provided by the orbital parameters and stellar photographs. The accuracy of the orbital positions over unmapped territory is related to the measuring accuracy of the photography by a factor of about 3. The angular orientation accuracy depends upon the geometric configuration of the stellar cameras employed. In general, the stellar cameras selected are compatible with the terrain cameras, and higher orientation accuracy is obtainable with the larger systems. Furthermore the errors in the exposure station coordinates and angular orientation are related to the errors in the map by fairly complicated functions. This error propagation has been studied extensively, and the final results are:

	1-1/2 inch	3 inch	6 inch
Standard error of elevation	158 meters	112 meters	53 meters
Minimum contour interval	520 meters	370 meters	175 meters
Standard error of position	198 meters	141 meters	60 meters
Maximum map scale	1:825,000	1:590,000	1:250,000

Quite obviously only the largest system comes anywhere near meeting the minimum requirements. In such a case the question might reasonably be asked, "Why not bump up the scale another notch and use a 12 inch focal length?" The reason why not is that a 12 inch focal length would require an 18 inch square photograph. This would be unwieldy and would require a camera of large dimensions and weight. Furthermore all of its advantages, and more besides, would be provided by the third kind of system, which is:

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6. LONG FOCAL LENGTH, FRAME TYPE, CONVERGENT CAMERAS.

A long focal length, frame type, convergent camera system has the following immediate advantages:

a. It provides the same degree of geometric fidelity as the vertical frame type camera.

b. It provides a larger image scale without requiring exorbitant frame dimensions. A standard 9 × 18 inch rectangular format provides adequate coverage.

c. By virtue of the smaller acceptance angle, it provides greater image resolution. Ground resolution is therefore raised by the double factor of increased film resolution and increased image scale.

d. It provides an optimum Base-Height ratio of 1.2 . As a consequence elevation measuring accuracy is greater than planimetric accuracy rather than the reverse as with vertical photography. This is more directly in accord with the requirements of mapping.

The single disadvantage is one that is shares with panoramic photography. That is the variation of scale over the format. However this in no way inhibits the usefulness or the accuracy of the frame type photography.

The proposed convergent system will utilize cameras of 18 inch focal length and 9 × 18 inch format. This will provide an average image scale of about 1:770,000--almost three times as large as the largest feasible vertical camera. This means that its measuring ability will be higher, and consequently that the orbital positions over unmapped territory will be more accurate. The accuracy of the proposed stellar camera will also be superior so that more precise angular orientations can be obtained. The error propagation for this system has been studied with the same intensity as the vertical systems. The significant values are:

Planimetric measuring ability	5 meters
Topographic measuring ability	4 meters
Standard error of elevation	11 meters
Minimum contour interval	36 meters
Standard error of position	49 meters
Maximum map scale	1:200,000

Thus it is seen that this system can adequately meet all the requirements of a Standard Accuracy Map at scale 1:250,000.

The camera configuration has been very carefully integrated with the satellite orbit. For a satellite in a polar orbit at an altitude of 10^6 feet the equatorial longitude difference between passes of the satellite on two succeeding days will be 2.5 degrees. The equatorial longitude difference covered by a stereo model of the proposed system is 2.8 degrees. Thus the most efficient coverage is obtained. An increase in focal length and scale would result in gaps in coverage; a decrease in focal length and scale would result in lower accuracy and inefficient duplication of coverage.

It should be noted also that the 18 inch convergent system can be placed in orbit with the same booster required for the 6 inch vertical system.

7. CONCLUSIONS.

All of the investigations which have been conducted lead to one final conclusion:

Provided geometric fidelity is maintained in the record, there is absolutely no substitute for scale in order to provide adequate accuracy, content, and efficiency of processing.

If mapping of these vital areas by means of a satellite system is considered a useful objective, it would be extremely short-sighted, and in the long run more costly and time consuming, to send up a system whose capability was in any way marginal. The 18 inch focal length, 9 × 18 inch format, frame type, 30° convergent system is nearly optimum for satisfying all of the mapping requirements.

Brief and Evaluation of the K.C. [redacted] [redacted]

Brief

The Report on ACIC Procedures for Utilizing TKH Materials in Long Line Extensions was prepared by the Techniques Office, Missile Support Division, ACIC, and published in March 1962. The report describes subsequent investigations into the geometry of TKH materials and the procedures developed by ACIC for its exploitation to prepare target data and target and strike graphics in support of USAF requirements. In particular the report presents the detailed results of a test in the Kansas City area and an evaluation of these results. Consequently it is informally titled, K.C. Report.

The operation of the Wild Pub II and the Benson-Lehner "Giant" (Graphical Information Analog Numerical Translator) are described, and the effects of dynamic motions of the earth and the vehicle on panoramic imagery detailed. It is determined that distortion patterns are carried from one photograph to the next in a uniform and continuous manner. A standard frame was established by statistical reference to avoid the effects of elastic strain in the photographic materials.

Analytical aerial triangulation was accomplished by cantilevering and placing an unconditional restraint upon pitch. The triangulation is run in a free coordinate system and then adjusted to control. Mensuration and processing were done at the 20 to 50μ level. In this extension control data are employed. Trial adjustment was by means of a non-conformal parabolic equation, and does not utilize any sophistication based upon orbit theory.

The Kansas City Test involved the extension of 37 panoramic photographs adjusted by use of 240 control points. In the cantilever extension approximately six pass points were used in each area of overlap. The residual errors indicated a measurement precision around a standard error of 40μ. The curves showing the propagation of tilt components and differences in the consecutive exposure station position followed a consistent and regular trend indicating strip integrity.

Using a non-conformal (parabolic) adjustment standard errors in the remaining 212 points were 75 meters in line of flight and 43 meters transverse to the line of flight. A non-conformal cubic adjustment reduced these values slightly. With the control employed there were certain local areas of high correlation between closely grouped points. After reducing the control to 35 points, standard errors of 78 meters and 51 meters were obtained. ACIC estimated the reliability throughout the strip as lying between 105 and 145 meters.

The estimated overall time required to complete this test was one man-year. The report emphasized, however, that even with the complexities in the Kansas City extension, it would not be comparable to the activity which would be required to process a long line extension over the Eurasian continent. Moreover, the author emphatically states "that it is not meant to be conveyed in this report that panoramic materials are an adequate substitute for good cartographic photography obtained by means of a cartographic camera, to extend control and build up a geodetic control net to meet all Air Force needs".

The report concludes that:

"a.......the ACIC processes have been verified as to their adequacy to produce positional information and the evaluation of this information.

[redacted]

"b. Pan materials are not in general satisfactory for developing control beyond the accuracies which have been indicated in this report.

"c. If further exploitation of panoramic photography is to be achieved it must be in conjunction with a frame camera system which has sufficient geometric precision and stability to control the effects of local distortion in the panoramic materials.

Evaluation

This report describes a satisfactory test of analytical aerial triangulation with panoramic photography utilizing adequate ground control. It represents a system calibration in an area in which the quantity and quality of control were as good as could be expected. However, more than ten percent of these points were eliminated as a result of adjustment to a second degree polynomial. How often will we feel entitled to abandon more than ten percent of our control in unmapped areas?

The exercise was one of extension of position. Here the definition of positional information must be assumed to be qualified as horizontal position, for no mention is made of elevation and, of course, in any extension it is more difficult to carry the vertical. This method cannot carry the vertical, nor would it be expected; but to produce positional information most certainly includes elevation.

The quality control employed was the monitoring of the record differential of position and orientation parameters, and this seems suitable if these data are not to be used as input. And why were these parameters not employed as input? The author says that "this is due to the fact that there are no sophisticated orbit reduction programs currently available within ACIC, hence adaptation had to be made [redacted] already available". This implies that if only the programs were available, they would have been employed.

The writer suggests a possible application of panoramic photography for improving our knowledge of the horizontal position of points in the Eurasian Continent. Also he states that the use of frame and panoramic material in combination "possess great potential for improving horizontal position and heightening accuracy far beyond what can be achieved using either material by itself".

It should be noted that these are only statements of opinion and are not substantiated by test data. Proper combinations of frame and panoramic materials will certainly provide more information to the user than either of the materials alone. However, frame and panoramic materials in combination are not necessarily complementary. It depends on the problems being solved by these combined materials. Short focal length frame photography cannot materially aid long focal length photography in vertical height measurements. Also, long focal length panoramic photography will be of limited help to frame photography for horizontal control extensions. The best use of long focal length panoramic photography in a mapping program is in the identification of ground detail in selected areas. For this purpose the photographic coverages do not have to be made simultaneously and no geometric fidelity in the panoramic camera is required.

The writer confidently states that using this photography by itself nearly all information applying to control extension has been extracted by this process. This does appear to be so. A credible job of extension of horizontal control has been done with material unsuited for this purpose.

But as the author states pan materials are not an adequate substitute for good carographic photography. The writer states the Air Force needs to extend control and build up a geodetic control net. There is also a need for topographic mapping. And now that this need is recognized there seems to be no reason for delay in procuring good cartographic photography. Let the play begin.

[redacted]
Chief, Photogrammetry Division
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