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GEOGRAPHIC INTELLIGENCE REPORT

SOVIET CAPABILITIES IN GEODESY AND CARTOGRAPHY FOR SUPPORT OF SOVIET GUIDED-MISSILE SYSTEMS

Provisional Report

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CENTRAL INTELLIGENCE AGENCY

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FOREWORD

This preliminary draft of the ORR/DGG contribution to NIE 11-6-54 was prepared to provide information on the geodetic and cartographic aspects of missile guidance for other analysts engaged in the preparation of their contributions.

This provisional estimate has not been coordinated with the surveying and mapping components of the Department of Defense or with intelligence personnel interested in the geodetic and cartographic capabilities of the Soviet Union. However, estimates of geodetic and cartographic positioning errors included are based in part on estimates provided by the U.S. Coast and Geodetic Survey and on preliminary estimates of the U.S. Geological Survey. In addition the report has been reviewed, with concurrence, [redacted] who is a consultant to the Geography Division, ORR, on gravity and higher geodesy.

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The report is organized in three parts. The first section summarizes the extent of the Soviet resource as reflected in the geodetic and cartographic organization, personnel, research, and activities. The second section describes in greater technical detail those Soviet activities and standards of performance in astronomy, triangulation, and gravity that bear directly on the range of error in the relative locations of widely spaced, intercontinental points which we consider attainable by the Soviets. The third section estimates additional cartographic errors that are inherent in the derivation of geographic positions of targets on large-scale topographic maps.

Comments or questions concerning this report are solicited by 19 July 1954 for consideration in the preparation of a final draft of the estimate. Comments are particularly solicited on the problem of determining the effects of gravity on the behavior of missiles and guidance systems in connection with the variation of gravity with altitude and with the geographic distribution of gravity anomalies over the entire earth.

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SOVIET CAPABILITIES IN GEODESY AND CARTOGRAPHY FOR SUPPORT OF SOVIET GUIDED-MISSILE SYSTEMS

A. Appraisal of Soviet Geodetic and Cartographic Organization, Personnel, Facilities, and Activities

The Soviets, building on a foundation of over a century of geodetic and cartographic development, have succeeded in establishing a modern organization and a corps of scientific and technical personnel sufficiently competent in all aspects of geodesy and map production to provide dependable support for the positioning of widely separated launching points and targets for missile guidance.

1. Geodesy and Cartography in the USSR

Early recognition by Lenin of the basic importance of geodesy and cartography to Soviet economic development and military defense led to a program of geodetic and cartographic development and activity unprecedented in the world history of surveying and mapping. Huge capital investments were made available for surveying and mapping and their allocation at any given time was limited only by the availability of scientific and technical personnel.

a. Organization

Basic surveying and mapping of the country at large is centralized in the Chief Administration of Geodesy and Cartography (commonly referred to as GUGK, from the Russian form of its name), which works in conjunction with the Military Topographic Administration (VTU) of the Army General Staff. Other surveying and mapping units function as parts of individual ministries, administrations, or trusts, but all are subject to the centralized plans, programs, supervision, and specifications of GUGK and VTU.

The GUGK is a vertically integrated organization comprising, in addition to the conventional technical and administrative units, the following: two policy bodies, one of which coordinates the work of other mapping organizations, including that of the military; a central archive for the custody of all data; a publishing unit for geodetic and cartographic literature; a central research institute; a factory for the production of geodetic and other mapping instruments; 12 aerial-photography and geodetic plants, and 12 cartographic plants. The VTU comprises a production service (VTS), a faculty for advanced geodesy at the Engineering Academy, a scientific research institute, an instrument-production plant, 12 topographic units, 7 geodetic units, 3 aerial-photography units, 12 geodetic and cartographic units, and a field training and testing camp.

b. Personnel

Heavy emphasis on training, dating back to 1779, has produced a corps currently estimated to number 6,000 engineers and 10,000 technicians in geodesy and cartography. The personnel of the Chief Administration of Geodesy and Cartography alone has increased from 469 in 1924 to 5,058 in 1940 and to an estimated 9,000 in 1953.

c. Education and Training

The training of engineers in geodesy and cartography is on a very high level, both in theoretical and practical aspects, and Soviet instruction and facilities compare very favorably with the best in Western

Europe. The Soviet effort, however, exceeds in magnitude that of any other country, and probably of all other countries combined.

Advanced scientific and technical education in surveying and mapping is provided by the largest system of special educational institutions in the world. Civilians and military personnel are given training in independent facilities. Advanced civilian training at a university level (with one-third of a 5-year course devoted to higher geodesy) is given in two institutes, which confer engineering degrees at the rate of about 400 per year. Graduate training is given not only at these two institutes but also at several scientific research institutions. Graduate degrees are awarded at a rate in excess of 7 doctorates and 21 predoctorates (master's degrees) per year. In addition, intermediate education for production personnel (topographers and cartographers) is provided by nine special schools with 4-year programs.

Military training in surveying and mapping leading to advanced degrees is given in the engineering and air academies. With engineer officers graduated in geodesy at the rate of 100 per year, the supply of highly trained officer personnel will be adequate to maintain a corps capable of supporting staff and operational requirements for all phases of guided-missile operations.

2. Soviet Research Facilities and Programs

a. Facilities

High-level research institutes in geodesy, photogrammetry and cartography function in both the GUGK and the VTU. These agencies in turn are supported by a vast array of scientific research institutes attached to the astronomical and geophysical observatories of the Academy of Sciences as well as in universities, in technical schools, and in the production and resource-development components of Soviet industry. GUGK alone has over 100 highly qualified scientists who devote their entire attention to the problems of geodesy and cartography.

b. Scope

The availability of unlimited funds combined with a large number of highly qualified geodesists, photogrammetrists, and cartographers has developed a scientific resource capable of undertaking any problem in geodesy and cartography. Current trends in Soviet research in higher geodesy reveal unmistakable evidence of a determined continuing program to increase geodetic precision and accuracy significantly in excess of practical domestic requirements, without any apparent regard to man-hour costs. This ever-present drive for refinements in precision and accuracy -- considered excessive by American standards -- may be designed to obtain the benefits of distance measurement and position determination on a worldwide scale, which could materially enhance the accuracy of Soviet intercontinental geodetic positioning.

A dynamic and widespread effort systematically surveys all foreign literature which then is widely disseminated to Soviet theoretical and practical geodesists and cartographers. As a result, Soviet scientific research reveals not only a thorough knowledge of Western geodetic advancements, but also indicates the willingness and the mature ability to pursue independent lines of study and experimentation.

c. Astronomy in Support of Geodesy

Vigorous Soviet scientific investigation of the earth as an astronomic body has provided significant support to the study of the size and shape of the earth. In addition, a large amount of Soviet astronomical research has been directed to the support of Soviet geodesy and cartography. A large-scale program for the compilation of an astronomic catalog listing about 20,000 stars was begun in 1932 to replace Western catalogs (Boss and FK3), which have been declared obsolete for Soviet requirements. Ten centers of time service have been established for the determination of longitude through an extensive program to increase precisions over the years.

The Europe Satellites are being integrated into Soviet astronomic plans and programs for geodetic purposes. The Poles have been incorporated in the Soviet astronomical program and are now engaged in the compilation of a catalog of "weak stars" to help "topographers to fix points on the earth's surface." Research on the motion of the terrestrial poles also has been begun in Poland.

Six Soviet observatories participate in a domestic research program on the variation of latitude. In addition, several conferences on this problem have been held. The 1949 conference at the Poltava Gravimetric Observatory was attended by representatives of 13 astronomic and geodetic organizations, including the military engineer academy and the hitherto unknown "Arktikrazvedka."

d. Instrumentation

We believe that the Soviets have the scientific and technical ability to design and construct geodetic, photogrammetric, and cartographic instruments. Information is lacking on the productive capacities of Soviet industry to meet requirements independent of Satellite or Western sources of supply.

3. Soviet Achievements in Geodesy

a. The Astronomic-Geodetic Net

The Soviets began a modernization of their geodetic net in 1928. Computation of this modern astronomic-geodetic net, extending across the USSR to the Bering Strait and Vladivostok, was completed in 1946. It is based on the new Krasovskiy ellipsoid and referenced to a new datum, "Pulkovo 1942." This new geodetic system may give the Soviets a considerable potential advantage in the form of a reliable, widespread network to which Soviet launching bases could be referenced. We are unable to evaluate this advantage because the new catalog of the astronomic-geodetic net is not available to us. However, there are indications that high standards of accuracy are prescribed for field observations and that unusual, rigorous methods of adjusting triangulation observations are used. If these high standards have been successfully applied, the advantage to the Soviets of this new modern network could be significant.

b. The Krasovskiy Ellipsoid

The Krasovskiy ellipsoid has been computed from more geodetic arc measurements than have been utilized in the derivation of the ellipsoids used by the remainder of the world up to the present time. The Krasovskiy ellipsoid is recognized internationally as an outstanding geodetic contribution. Notwithstanding the completion of this laborious task, however, Soviet geodetic and astronomic theoretical research continues to determine a general terrestrial ellipsoid that will best represent the earth as a whole. In this connection, the Soviet goal to improve its values of size and shape will be significantly advanced by the free access to the observational data of the Inter-American Geodetic Survey of South America, the data from the completion of the 30th meridian survey of Africa by the Army Map Service, and the data of the gravity program being conducted at the Mapping and Charting Research Laboratory for the U.S. Air Force.

c. A Soviet World Datum

The Soviets have taken further steps in the direction of establishing a Soviet world datum. Plans for this achievement date back to 1936, when work was begun along the Sea of Okhotsk area to tie with North America via Alaska. In 1952 the Soviets pressed a program on the European Satellites to transform the diverse national geodetic systems to the "Pulkovo 1942" system and to recompile the various national topographic map series to bring them into accord with the Soviet series. This program is scheduled for completion by 1959, and it is estimated that it may be achieved by 1965. We can further assume that by 1965 the Soviets will also have readjusted the geodetic networks of western Europe. Thus, since it is likely that a tie with Alaska has been achieved, the Soviets will by 1965 have a common geodetic datum encompassing all of Europe, northern Asia, and North America.

d. Gravimetric and Magnetic Surveys

Systematic gravimetric and magnetic surveys, initiated in 1932 and 1931, respectively, are estimated to cover the entire USSR, and work is now continuing on increasing the density of these observations. These data will (a) probably lead to an earlier compilation of a more representative world map of gravity anomalies and undulations of the geoid than can be attained by the Western nations, and (b) provide the means to establish related geodetic positions in difficult regions devoid of triangulation, without resorting to the time-consuming methods of triangulation.

e. The Soviet Gravimetric Network

The Soviets have established a unified network of gravity stations that is somewhat similar to a triangulation network. With an available gravity net the Soviets can extend new positions (in conjunction with astronomic observations) more rapidly than can be done by conventional triangulation. This technique can increase the Soviets' range and mobility in the choice of additional launching sites. Although the intercontinental accuracies of such positions cannot be ascertained at present, it is possible that reported Soviet surveying of the China-Burma frontier may provide a triangulation chain to which the gravimetrically derived geodetic positions could be referenced and adjusted.

4. Soviet Mapping Intelligence

a. Free Access to Data

Soviet geodetic and cartographic capabilities have profited materially over the years by free access to information on Western research and development and to Western equipment and geodetic data. In marked contrast to Western liberality, keen Soviet awareness of the vital importance of geodetic and cartographic materials has been reflected in an effective security system that has prevented this vital information from reaching the West.

b. Soviet Cognizance of Developments

The Soviets are well informed on the basic organization of United States and other surveying and mapping organizations. There is no significant Western geodetic development or program (including the USAF gravity program) that is not thoroughly known to Soviet geodesists and cartographers. This has resulted from an avid and thorough Soviet collection effort that included an extended visit to the United States 25 years ago by three Soviet geodesists for the study of U.S. methods. The information obtained has been thoroughly assimilated in the evolution of Soviet geodetic and cartographic development.

c. Soviet Collection Efforts

Collection of readily available Western geodetic data and large-scale maps probably spans the length of Soviet history. Such materials have been used in the production of large-scale maps of foreign countries dating as far back as 1930. Since World War II the Soviets, using the Satellites in some instances, are again reported to be collecting large-scale maps of Western Europe. Reports also indicate that production of large-scale maps of European countries bordering on the Satellites is now in progress.

d. Target Location

In view of the advanced geodetic and cartographic educational program and facilities in the Soviet engineer and air academies, we believe that the Soviets have a corps of officers available for duty as military attachés who are highly qualified not only for the collection of geodetic data and large-scale maps but especially for accurate plotting of the locations of targets. Soviet military attachés have been active within the past year in such widely scattered areas as Texas, Minnesota, Pennsylvania, New York, California, Ohio, Illinois, and Wisconsin. Soviet Embassy personnel have recently purchased complete topographic map coverage of the states of Michigan, Illinois, and Kentucky. Whether these persons are specifically engaged in target location has not been ascertained.

B. Soviet Capabilities in Geodesy Through 1965

1. Soviet Triangulation

The initial point for geodetic control of first-order triangulation in the USSR is in the Rotunda of the Pulkovo Observatory, with geodetic coordinates 59°46'18".55 N; 30°19'42".09 E. First-order triangulation extends the full breadth of the Soviet Union from its western borders with the Satellites to the Sea of Japan, the Sea of Okhotsk, and the Bering Strait on the east. The network is extensive throughout the European USSR, but east of the 90th meridian it narrows in the south to essentially two east-west arcs, laterally connected at intervals, extending to Nikolayevsk and Vladivostok. As of 1944, a single arc extended northward from Khabarovsk to beyond Magadan. There are very good reasons to believe that Soviet triangulation now extends from Magadan to the Bering Strait. Although this extension has not appeared on Soviet maps available to us or been confirmed in Soviet literature, it was the announced plan as far back as 1936 to make this extension and eventually to connect across the Bering Strait with the North American datum. There are several arcs of lower-order triangulation along the northern river valleys and the Arctic coast.

Soviet first-order triangulation arcs generally run in the direction of geographic meridians and parallels with no regularity of spacing, which may vary from 150 to more than 500 kilometers. The total length of all known first-order arcs exceeds 75,000 kilometers and today may actually be as much as 100,000 kilometers. The intersecting arcs of first-order triangulation form a pattern of polygons or loops, about 90 of which are known to exist. Base lines and Laplace stations are located at all vertices of the polygons to maintain uniformity of scale and proper orientation of the net. Some insight into the general accuracy of Soviet first-order geodetic triangulation can be had from their specifications controlling field work. A comparison of specifications limiting the probable errors for first-order triangulation in the USSR and the USA follows:

[redacted]

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In angle measurement and astronomic azimuth, Soviet specifications for accuracy exceed those of the U.S. It would be most desirable to check Soviet computations and adjustments of observations, starting with raw field data. Unfortunately we are lacking the data as well as the computations. We know that in 1947 the Central Computing Bureau of the Chief Administration of Geodesy and Cartography completed the compilation of a catalog of 4,733 control points in the astronomic-geodetic network of the USSR. The catalog fills five volumes and represents the last word in current Soviet first-order triangulation. For each control point are given --

(1) Rectangular coordinates

(2) Geographic coordinates

(3) Astronomic coordinates and components of deflection of the vertical

(4) Description of the triangulation point

Our inability to obtain the catalog is a serious handicap in estimating Soviet geodetic capabilities. The extreme care that the

Soviets have exercised in preventing a basic work of this kind from reaching the outside scientific world indicates their appreciation of the military potentialities associated with geodetic control.

Soviet capabilities in triangulation may be estimated after first considering the accuracy obtainable in any well-adjusted first-order net. Observations of angles and measurements of distances with modern instruments lead to a very high order of precision in the positioning of widely separated points of a net. At a distance of several thousand miles the error may be as small as 1 part in 200,000. The European part of the Soviet first-order net very probably has such accuracy. [redacted] claims that accuracy of 1:350,000 in the measurement of 200-kilometer arcs of the first-order net has been attained. In view of the character of the trans-Siberian arcs and the rugged nature of the terrain, it is doubtful, however, if better than 1:100,000 accuracy is held in that part of the net.

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Assuming that 1:200,000 accuracy is possible everywhere on the earth's surface, the maximum probable error in the relative positions of two points diametrically opposite on the earth's surface would be about 300 feet. If the continents were wholly covered and connected by well-adjusted first-order triangulation, no more serious error in positioning than 300 feet would be expected at any distance. Only a small part of the land surface is covered by first-order triangulation, however, and the continents are far from being satisfactorily connected.

A tie-in with the North American datum across the Bering Strait was suggested by Krasovskiy as far back as 1936. We believe the

Soviets have made this connection across the Bering Strait -- probably years ago, when suspicions were less easily aroused and our Alaskan geodetic information was readily available.

The westward extension of the Soviet geodetic system to include the widely divergent systems of the Satellites was initiated in 1952 at a geodetic congress held in Sofia. In view of the fact that adjacent countries sometimes find their border positions in disagreement by as much as 200 meters, it was not unnatural that the USSR undertook to correct the situation with respect to the Satellites. The readjustment of all Satellite geodetic control to conform with the Soviet system is now under way, and the major part of it is scheduled for completion by 1957. Aside from the obvious advantage of replacing many small obsolete systems with a single system, this integration of geodetic systems will make it possible for the Soviets to establish launching sites for long-range missiles anywhere in the Satellites with all geodetic and cartographic hurdles already behind them.

2. Astronomic Observations

Determining the precise geodetic coordinates of positions on the earth's surface is a problem closely related to positional astronomy, which measures very accurately the right ascension and declination of the stars. Stellar proper motion in general is so small (the highest proper motion of any star is about 10" of arc per year) that the relative positions of the stars as seen from the earth remain practically unaltered from one year to another. Thus the stars provide essentially a fixed frame of reference with respect to which the angular separation of positions on the earth's surface can be measured. It is necessary, of course, to know accurately the celestial coordinates of the bright stars. In general use throughout Europe and the United States are the star catalogs of Boss and FK3. These catalogs are known to be subject to systematic errors sometimes as large 0".3, corresponding to a displacement on the earth's surface of about 30 feet. This is more error than the Soviets considered tolerable with first-order triangulation in the USSR.

Recognizing the shortcomings of Boss and FK3, the Soviets in 1932 undertook an extensive program at five large observatories to redetermine the right ascension and declination of bright stars for a more accurate star catalog. In 1948 they published a "Catalog of 2957 Bright Stars between declinations -10° and $+90^{\circ}$." This catalog is now used exclusively in Soviet geodetic work, but it is not available outside the USSR. It is reasonable to conclude that it represents improved accuracy over Boss and FK3. Since the probable error contributed by inaccuracy of star catalogs may be in the order of only 10 or 15 feet, the making of a new catalog by the Soviets is important as another example of their constant effort to achieve greater accuracy.

In preparation for any long-range missile attack on the United States, the Soviets would surely determine the astronomic coordinates of the launching point by repeated observations with the best field equipment. Standards of precision for astronomic work in the USSR indicate the probable error that might be expected at the launching point. [redacted]

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[redacted]

These specifications of accuracy are relaxed in lower orders of triangulation. In the Soviet Arctic, climatic conditions affect the instruments so adversely and present such obstacles for observation that precision of astronomic work is considerably less. Our estimate of probable circular error in Soviet astronomic work, including errors in the star catalog, expressed as displacement upon the earth's surface, ranges from 30 feet to 150 feet, the smaller figure being applicable to a launching site.

3. Deflections of the Vertical

The small angle between the direction of the normal to the ellipsoid and the plumb line is the station error, or deflection of the vertical. Usually amounting to only several seconds of arc in flat terrain, the deflection angle may become even greater than 1 minute of arc in mountainous regions. In the Soviet Union, the value of the deflection angle ranges up to 75 seconds. The geodetic coordinates of a point are obtained by subtracting the components of the deflection angle from the observed astronomic coordinates of latitude and longitude. Since 1 second of arc at the center of the earth subtends an arc approximately 100 feet on the surface, geodetic positioning is directly affected by knowledge of the station errors.

When the spirit levels of a theodolite are in final adjustment, the direction of the plumb line (the normal to the geoid) coincides with the vertical axis of the instrument. The direction of the plumb line thus can be established anywhere on the earth's surface. On the other hand, it is impossible to observe or set up an instrument in alignment with the normal to some arbitrarily selected ellipsoid. In short, deflections of the vertical depend upon the datum and cannot be observed in the field. These must be computed from many astronomic observations at control points of the triangulation net, or from gravimetric observations at many points in the surrounding area. In the United States, deflections of the vertical have been computed almost entirely from astronomic observations. The Soviets derived deflections of the vertical from gravity determinations, of which more than 20,000 are known to have been made in all parts of the USSR. Although there are more than 8,000 astro stations in the USSR, some associated with the triangulation net and others existing as isolated control points in remote areas, reliance is placed upon gravity determinations for the computation of station errors.

It is beyond the scope of this estimate to indicate and weigh the relative merits of these two different methods for calculating station errors. Of greater significance is the question of how well station errors are known in the USA and in the USSR. It is obviously necessary that the Soviets consider our probable error of deflection angle in any calculation that involves a target in this country.

25X9 The values assigned by the United States to the geodetic coordinates at Meades Ranch, Kansas (selected as the initial point because of its central location) are:

[redacted]

According to recent reliable estimates by U.S. geodetic authorities, the deflection angle at Meades Ranch may be in error by as much as 1 second of arc, or 100 feet. Uncertainty in the magnitude of this error is due in part to the chronology of geodetic development in this country. There was extensive triangulation along our eastern seaboard long before station errors were realized to be of such magnitude that they necessitated geodetic recognition. At the time of the selection of Meades Ranch as our initial point, there was no practical need for independently determining with great precision the components of the deflection angle at the datum point.

When the Krasovskiy ellipsoid and the geodetic system of "Pulkovo 1942" were adopted for the Soviet Union in 1946, the components of the deflection angle at Pulkovo were given as:

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[redacted]

Soviet estimates of accuracy in determining deflections of the vertical for the USSR by gravimetric methods indicate a probable error of 0".4 of arc. A considerable number of gravity stations exist in the area around Pulkovo, so that it is quite possible to accept this order of accuracy at the datum point. The astronomic coordinates of the Pulkovo Observatory are known with high precision. In preparing to set up the datum at Pulkovo the Soviets would determine the deflection angle as precisely as possible in order to insure the smallest error in the geodetic coordinates of the initial point. In areas of less concentration of gravity measurements the probable error in determining deflections of the vertical may increase to 2 seconds or more. At any launching point for long-range missiles in the USSR we would have to assume that the most refined preliminary geodetic observations of all types would be made, so that $0\overset{''}{.}4$, or 40 feet, is the probable error we may associate with determining the deflection of the vertical.

Recently announced technical improvements in timing the meridian transit of stars at the Pulkovo Observatory indicate a longitude shift of the datum point there of about 7 feet. Although accurate observations at large observatories reveal slight variations in longitude for reasons as yet unknown, it is uncertain whether such studies at Pulkovo are routine or are possibly motivated by Soviet desire for further refinement of values at the datum point.

Should the Krasovskiy ellipsoid replace the Clarke 1866 ellipsoid at Meades Ranch in some Soviet calculation, the component of the deflection angle in the meridian at Meades Ranch would change by a few tenths of a second of arc. For this reason alone the geodetic latitude of our initial point would change, as would the geodetic coordinates of all points in our system. These shifts in position are small as compared with other probable errors and will not be considered further.

4. Ellipsoids of Reference

Although geodesy as an earth science should be removed from the influence of arbitrary international boundaries on the earth's surface, the history of its growth indicates close attention to the requirements of individual nations. Every country engaged in geodetic work has computed or borrowed some ellipsoid of reference that supposedly agrees very closely with the geoidal configuration throughout its area. In the United States the Clarke ellipsoid of 1866 is used for referencing all triangulation control, starting from Meades Ranch as the initial point. In the table below are listed the parameters which determine the Clarke and Krasovskiy ellipsoids, as well as the Bessel and International ellipsoids, which are all that need concern us now:

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[redacted]

By comparing corresponding values in the table, some insight into the magnitude of error to be expected in selecting an ellipsoid is gained. The Bessel, although appearing often in the literature and still in use in some parts of the world, was considered too small by the Soviets, who abandoned it for the Krasovskiy ellipsoid. The semi-major axis of the Clarke ellipsoid is just 39 meters shorter than that of the Krasovskiy, and present opinions based on American experience are that the Clarke is too small rather than too large.

Determining the earth's semi-major axis from arc measurements in various parts of the world presents a problem of such a nature that it is hardly possible to reduce the probable error below 60 meters. The question of which measured arcs to include and which to reject in any attempt to compute an ellipsoid becomes of less practical concern when it is realized that there are no arc measurements representing the vast ocean areas that cover more than two-thirds of the earth's surface. In using any of the four ellipsoids it will be understood that the semi-major axis may be in error by $\pm$100 meters.

The flattening of the earth can be ascertained by astronomic, geodetic, or gravimetric methods. There is considerable range in the value of the reciprocal of flattening, as noted in the table, but it is a reasonable estimate that 297 is not in error by more than 1 unit. Although every one of the ellipsoids has been found usable when confined to the needs of some particular country, we must keep in mind the concept of a "best fitting ellipsoid" for world geodetic study, even though such an ideal is out of our reach. When dealing with problems hemispheric in scope, such as relating the positions of two points which might be the launching and target points for long-range missiles, the values used for the parameters of the ellipsoid of reference affect the accuracy of positioning very considerably.

Changing the value of the semi-major axis of any ellipsoid by 100 meters while retaining its flattening would change the relative distance between two points 5,000 miles apart by 400 feet. If the Krasovskiy value of the semi-major axis is retained but the flattening is changed to 1:297, the distance from Pulkovo to Meades Ranch (approximately 5,000 miles) would be less by about 300 feet. In the absence of triangulation connecting the Soviet and American triangulation nets, it is impossible to escape the large probable errors in long-range positioning due to uncertain knowledge of the earth's equatorial axis and flattening. The uncertainty might very well be in the order of 600 feet for the Soviets should they attempt to launch 5,000-mile missiles toward the USA today.

5. Estimate of Soviet Capability in Geodetic Positioning

The following estimate of current and future Soviet capability with respect to positioning of long-range intercontinental missiles is based on the assumption that the highest attainable accuracy in geodetic field observations and computations will prevail at the launching point. We are led to two different estimates of positioning accuracy by considering the alternatives of a possible Soviet connection of their first-order triangulation with the North American datum across the Bering Strait.

In the event that such a connection has been made, which we believe to be probable, the Soviets would benefit from the considerably greater accuracy inherent in first-order triangulation. Launching sites established several hundred miles back from the Bering Strait could cover every part of the United States with missiles of 5,000-mile range. Triangulation on the Soviet side of the Strait could be referenced to the North American datum for the short distance to the launching site. By this method, the best positioning the Soviets might be expected to achieve at the present time at 5,000-mile range between the USSR and the USA would be a circular probable error between 300 and 500 feet.

Should there be no connection across the Bering Strait, the problem becomes a matter of transforming the geodetic coordinates of one system to the other, encountering the uncertainties connected with the datums and the parameters of the ellipsoids. Other smaller errors resulting from observations, calculation of deflection angles, geoidal heights, and variations in latitude and longitude contribute further to the over-all uncertainty. It is very doubtful if by this method the Soviets at present can do better than a circular probable error of 1,000 feet at the target. This estimate of error would apply to a launching point in the Moscow area of the USSR for a target in the United States.

6. Eclipse and Lunar Methods

The possibility of improving the accuracy of intercontinental geodetic connections by using methods involving eclipses, occulations of stars, and lunar photography is now being investigated. Active programs for observation and photography are now in progress under the auspices of the United States and other Western nations. It is not to be expected that any improvement in intercontinental positioning by these methods will exceed the accuracy of first-order triangulation.

Only slight improvement in Soviet positioning capability from present levels can be foreseen by 1965.

7. Positioning Submarine-Launched Missiles

The possibility of attempted missile launchings from Soviet submarines deserves attention from the standpoint of positioning. Under the most favorable conditions, a submarine beyond the horizon from land by stellar observations might establish its position relative to a coastal target within 1,500 feet. The star-tracking method which the U.S. has recently developed gives more accurate astronomic positions,

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[redacted]

8. Positioning Air-Launched Missiles

Low-level launching of a missile from the air, pre-supposing release at an IP (initial point) (which may be a specified geodetic or astronomic position, or visually identified feature, within 50 to 100 miles of the target), requires accurate referencing of the initial point to the target. Granting .02 inch maximum relative cartographic error between initial point and target on topographic maps of the United States at the scale of 1:24,000, the positional error at the target would be in order of the 40 to 100 feet. For launching from an airplance over ocean areas, the errors would be comparable to those estimated for submarine positioning.

9. Gravity Effects in Flight

The effect on the flight of a missile of the varying force of the earth's attraction due to gravity anomalies is still an unsettled question among geodesists. A more precise knowledge of the earth's exterior gravitational field is required to solve this problem. It is significant to note that the Soviets have been devoting considerable effort to the study of the external gravity field of the earth. A recent Soviet study reveals a lack of sufficient observational data. It is not possible to make this theoretical extension of the earth's gravitational field with accuracy sufficient for the guidance of long-range missiles. The great need is for representative gravity values for the whole earth, now principally from the vast ocean areas, where submarine measurements will be necessary. Since it is known that the Soviets have made gravity surveys at sea, employing not only submarines in the Black Sea, the Sea of Okhotsk, and the Sea of Japan but ice floes in the Arctic Ocean, it is possible for a survey of principal oceans to be completed by 1965.

C. Soviet Capabilities for Cartographic Location of Targets Through 1965

1. Target Plotting

It can be assumed that the Soviets have a corps of officer personnel specially trained in geodesy and cartography available for the field plotting of targets in relation to geodetic control in Europe and North America. The accuracy of this plotting is essentially a cartographic and cartometric problem, dependent on the quality and available coverage of large-scale topographic maps or town plans referenced to a standard geographic or military grid. In cartometry, the Soviets have devoted considerable study to the problem of determining the relative accuracies of control points on maps and the cultural and physical features related thereto. Such specialized interest in mathematics, usually in Western cartographic practice and experience, is especially advantageous to the targeting function of locating targets to control points on maps.

2. Estimates of Cartographic Errors

All printed maps have a cartographic positioning error that arises in the compilation and drafting of the original copy and is contributed to by paper stretch and possibly by imperfect registration in the printing. On first-class topographic maps, this cartographic error is seldom more than 0.02 inch at any scale for 90 percent of the cultural features shown. It is a fair assumption that the majority of potential targets in the United States are to be found on first-class topographic maps. At the scale of 1:24,000, the positional error would be 40 feet. Although some targets might be located on older, less accurate, or smaller-scale maps, it is quite unlikely that the cartographic error would ever exceed 100 feet for any military target in the United States. We estimate that Soviet use of our maps for the purpose of establishing the geodetic coordinates of targets would result in a positional error ranging from 40 to 100 feet, with probability favoring the smaller figure.

Western Europe is well covered with large-scale topographic maps, which it is believed the Soviets have succeeded in obtaining. The cartographic error in relating targets to geodetic control on maps of western Europe would generally be the same or slightly less than for the United States.