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A SUMMARY OF ESTIMATED SOVIET CAPABILITIES IN GEODESY, GRAVIMETRY, AND CARTOGRAPHY

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A SUMMARY OF ESTIMATED SOVIET CAPABILITIES IN GEODESY, GRAVIMETRY, AND CARTOGRAPHY

FOREWORD

The purpose of this paper is to provide some indications of currently estimated Soviet capabilities in geodesy, gravimetry, and cartography as they would affect accuracy at the target of Soviet-launched long-range missiles.

THE PROBLEM

Probable error (CEP) at the target of an ICBM involves two distinct and fundamental geodetic considerations. First is the static geodetic positioning error in relating the launching and target points, which generally are in different, widely separated geodetic systems or datums. Second are the gravity anomalies at the Earth's surface, which extend into outer space and affect dynamically the course of the missile during flight. Unless the magnitude of these anomalies along the projected flight path is known, the resulting cumulative error over long ranges could be even larger than the probable geodetic positioning error. The following analysis will consider these two sources of geodetic probable error at the target in relation to Soviet capabilities to direct ICBM's against Europe and North America.

THE EARTH AS A GEODETIC BODY

If the earth were homogeneous, without its familiar topographic irregularities and variations in crustal density, the task of the geodesist today would be boringly simple. The figure of the earth would then be a mathematical ellipsoid of revolution, and the plumb line at any point would represent the only true vertical that would have to be considered. This is not the case. The geoid, or sea-level surface, departs from such a mathematically ideal figure of revolution by elevations and depressions amounting to as much as 100 meters. The problem is to determine the relationship between the Earth's surface, and ellipsoid of reference, and the geoidal surface.

If this were known the world over, the discrepancies between different geodetic systems could be eliminated. A goal of long-standing, then, is the determination of geoidal undulations referred to an agreed upon ellipsoid of reference. Current efforts in gravity surveying and in the establishment of connection of large horizontal survey nets of the earth will provide the basic data for determining the undulations of the geoid and geoidal elevations.

GEODETIC VS. OPERATIONAL ERROR

Before proceeding with this analysis, it is important for us to distinguish between the total geodetic probable error due to positioning and gravity considerations and the operational errors expected with long-range missiles. Operational errors arise from the multiplicity of responses of the internal components of the missile to the commands of the computing and guidance systems, as well as in the aerodynamic behavior of the missile during free flight. At the present state of missile technology, the operational errors substantially exceed in magnitude the geodetic errors -- by a factor of 10 or more. If we assume a weapons system whose destructive capabilities extend radially 4 or 5 miles from the bursting point, the geodetic problem admittedly becomes less significant than in the case of conventional weapons. On the other hand, if we assume as plausible hypotheses that (1) type-of-war doctrine will continue to encompass highly selective destruction, (2) operational errors will in time be reduced to a point where geodetic errors become significant, and (3) there are weapons systems for targets of lower magnitude that are important to destroy but too numerous to warrant the expenditure of a large warhead, then geodetic errors take on sufficient importance to merit our careful consideration. Parenthetically, in this connection, it is important to note that geodetic and gravimetric surveys are by their nature so involved and long-drawn-out that years may be required to obtain the necessary survey data for any extensive areas for improving launch-site and target determination.

CURRENT GEODETIC AND GRAVIMETRIC REQUIREMENTS FOR MISSILES

At present the geodetic and cartographic data required for missile guidance and targeting (as well as for ultra-high-speed aircraft requiring coordinates to Initial Points and Aim Points) are: (1) coordinates of launch points and targets referred to a common system, and (2) the undulations of the geoid, which are obtainable only from gravity anomalies for the entire Earth.

ELEMENTS OF A GEODETIC SYSTEM AND THE PROBLEM OF DATUM COORDINATION

To make these two requirements understandable to a mixed audience, it is necessary to describe briefly the nature of the first requirement and the activities necessary to achieve the second. This will be followed by a summary of Soviet capabilities in general and with respect to the stated problems in particular.

A geodetic system consists of a network of points derived by triangulation and computed on a selected reference ellipsoid from a selected point of origin. The coordinated and correlated relationship between the triangulation points remains true only so long as they are computed from the same initial quantities, i.e. latitude, longitude, and azimuth, plus the equatorial radius and flattening of a given ellipsoid. A change in the value of any of these will change the datum and the coordinates of points on that datum. Over the past 300 years, many national geodetic systems have been developed, each with its own initial point based upon some selected ellipsoid. Consequently, positions referred to different datums are not directly comparable since we are still uncertain regarding the relative orientations of these datums and the distances between their initial points. In some cases, discrepancies between common points of adjoining countries have amounted to hundreds of meters on the Earth's surface, even to several kilometers.

Since World War II, real progress has been achieved in reducing the number of different datums by integrating small systems with a major continental system. Examples of this are the European Datum, the North American Datum, and the Soviet Datum. These datums, however, are restricted to land areas of the Earth. With the development of long-range intercontinental missiles as well as ultra-high-speed manned aircraft, the intercontinental connection of datums into a World Geodetic System becomes increasingly urgent. When such a system is established, the computed geographic coordinates of points on any existing datum will be comparable without significant discrepancies. Moreover, if the gravimetric approach is used, it will make possible reasonably accurate mapping at the scale of 1:100,000 (and consequently geodetic coordinate determination) of unmapped areas in which launch or target sites may be required. Including the gravimetric method, there are three basic ways in which intercontinental connections of datums can be made: [redacted] The completion of a world gravity survey would also provide basic information for the study of the effects of the gravity anomalies on a missile in flight.

SOVIET GEODETIC AND GRAVIMETRIC PRODUCTION AND RESEARCH RESOURCES

Before taking up Soviet capabilities in the specific fields and problems just discussed, it is necessary to make some general remarks on the Soviet surveying and mapping organization, its research facilities, and its collection of foreign materials and data. Following this, we can examine quantitative estimates of Soviet capabilities.

The Soviets, building on a foundation of over a century of Czarist geodetic and cartographic development, have established a modern organization and a corps of scientific and technical personnel sufficiently competent in all aspects of geodesy and map production to provide highly qualified support in the solution of the basic geodetic and cartographic problems connected with missile guidance and target positioning.

Early recognition by Lenin of the basic importance of geodesy and cartography to Soviet economic growth and industrialization led to a geodetic and cartographic development unprecedented in any recent history of surveying and mapping. Over the years, huge capital investments have been made in surveying and mapping, with the result that the Soviet Union may now be considered topographically mapped at 1:100,000.

Basic surveying and mapping of the country as a whole is centralized in the Chief Administration of Geodesy and Cartography (GUGK), which is now attached to the Ministry of the Interior. GUGK works in close concert with the Military Topographic Administration (VTU) of the Army General Staff. Little is known of the nature of this collaboration and its relation to policy formation.

Relations between GUGK and the services of the Ministries of Defense are known to be regulated by a special statute, the text of which has not yet been obtained. It is also known that basic geodetic surveying of the first three orders is conducted by GUGK, the Army, and the Navy. Of the military services, the Army appears dominant, since it is the only service that has been identified as having right to serve as co-author with GUGK in the issuance of basic geodetic and cartographic specifications and regulations. It is believed that top-level coordination of policy occurs at the ministerial level in a group consisting of both civilian and military planners.

GUGK is an integrated organization that, in addition to the conventional technical and administrative units, includes two policy bodies -- a Collegium for broad program planning and research and another body for the coordination of interagency mapping projects and activities. The second group includes central archives for the custody of all data, a central publishing organization for geodetic and cartographic literature, a central research institute, a factory for the production of geodetic and mapping instruments, 12 photogrammetric and geodetic establishments, and 12 cartographic plants. The Military Topographic Administration includes a Military Topographic Service; a faculty for advanced geodesy at the Military-Engineering Academy im.

Kuybysheva (VIA); a scientific research institute; and, according to a prewar source, 12 topographic units, 7 geodetic units, 3 aerial photographic units, 12 geodetic and cartographic units, and a field training and testing camp.

Training in surveying and mapping, which dates back to 1779, has been particularly emphasized under the Soviet regime. Estimated conservatively, the Soviet Union currently has some 6,000 engineers and 10,000 technicians trained in geodesy and cartography. The ranks of GUGK (including its predecessor agencies) have increased from 469 in 1924 to 5,058 in 1940 and to an estimated 9,000 in 1953.

Training of engineers in geodesy is on a very high level, in both theoretical and practical aspects; and Soviet instruction and facilities compare very favorably with the best in Western Europe. Advanced scientific education and technical training is provided by the largest system of special educational institutions in the world. Civil and military personnel have independent training facilities. At the university level, advanced civilian training in which one-third of a 5-year course is devoted to higher geodesy is given in two institutes, which together are conferring 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. Between 1937 and 1955, forty-two Doctorates of Technical Sciences in geodesy were granted. In 1955 alone, no fewer than 40 Candidate's (i.e., Master's) dissertations and one Doctorate were presented by higher institutions of learning. With geodetic training of this depth, it can readily be seen that the Soviets already have a formidable reservoir of geodesists available to staff operational missile units.

SOVIET CONCEPT OF RESEARCH ON THE EARTH AS A WHOLE

An estimate of Soviet research in geodesy and gravity would be purposeless if it did not underscore the comprehensive nature of Soviet research on the Earth as a unit body -- its motion, interior, crust, oceans, and atmosphere. Soviet sources emphasize the integrated nature of this broad effort and, indeed, stress that one of the objectives of geodetic research is its work on a General Terrestrial Ellipsoid, to which seismic and astronomic research is joined. Thus, one finds an amazing interweaving of geodetic research in the curricula of astronomic and geophysical institutes and some inclusion of geophysical and astronomic studies in the programs of geodetic institutes. Technical geodetic research is centered in the GUGK organizations, which include the Central Scientific Research Institute of Geodesy, Photogrammetry and Cartography; and the Aero-Geodetic Enterprises. Geodetic research is also conducted at the

Moscow and Novosibirsk Institutes of Engineers of Geodesy, Photogrammetry and Cartography. Extensive basic research on problems of geodetic astronomy is in progress at Pulkovo and other observatories, at the dozen time-service stations now in the Central Research Institute of Radio Measurements, and at four observatories comprising the Soviet Latitude Service, which is designed to supplement the work of the International Latitude Service. Some of the objectives of this extensive effort are related to the study of the variation of latitude, the variable rate of rotation of the earth, and the compilation of star catalogues.

Extensive research on gravity problems is conducted at more than a dozen amply staffed research institutes and observatories. Although many of the problems are related primarily to geophysical prospecting, to determining the characteristics of the Earth's crust, and to refinement of instruments and methods, it must be recognized that all these are of great benefit to the solution of basic geodetic problems. The number of people engaged in research is not known, but some indication is provided by an estimate that the personnel of the former Geophysical Institute of the Academy of Science, USSR -- now reorganized into three institutes -- once numbered over 1,000.

SOVIET ACHIEVEMENTS IN GEODESY AND CARTOGRAPHY

Against this brief background of organization and research resources available to the USSR, we may now examine Soviet achievement in geodesy and its relationship to Soviet positioning capabilities -- in other words, to determine the estimated error in displacement between a launch site in the Soviet Union and a target outside the USSR.

The first requisite in the achievement of a minimum geodetic target error is a well-distributed, highly accurate horizontal network to which launch sites can be referenced and which can be tied to other geodetic systems. The Soviet triangulation network was explicitly devised not only to serve as a primary framework of points for topographic surveying and mapping but also to serve the needs of higher geodesy for the study of the size and shape of the Earth.

The Soviets inherited from the Czarist regime an obsolete horizontal network covering about 10 percent of the country. New triangulation was started in the European USSR about 1923, and a new comprehensive program was developed in 1928. By 1936 the triangulation system, based on two datums, extended from the western to the eastern borders of the USSR. This triangulation network, however, was computed on the Bessel Ellipsoid, which was found unsuitable for the vast extent of the USSR. The computation of a new ellipsoid was completed by Krasovskiy in 1940, and it was adopted as the reference ellipsoid in 1946. This ellipsoid is claimed by the Soviets to be not only the most suitable for the USSR but also the best for the whole world. (The US Army Map Service, however, has stated that its own newly computed ellipsoid is superior to the Krasovskiy.) A new readjustment of the first-order horizontal control occurred during the period 1942-45. Following this readjustment the Soviets found displacements in positions amounting to 2,500 feet in latitude and 100 feet in longitude in western USSR, and to 3,000 feet in latitude and -1,200 feet in longitude in Siberia. In order to raise the standards and quality of the continually expanding triangulation network, more rigorous field specifications were devised in 1948, and were adopted in 1954.

In this connection, it is necessary to emphasize an enigmatic Soviet drive, verging on the obsessive, to attain refinements in geodesy that far exceed the practical requirements of topographic and engineering problems. We cannot claim as yet that these refinements are motivated by problems of missile guidance; but we must recognize that continued refinements in geodesy, combined with geodetic gravimetry and seismology, will eventually lead to continued improvements in determining the dimensions and shape of the Earth and departures of the geoid from the ellipsoid of reference.

Aside from these added refinements, however, the new program will be expanded into areas not covered at all or inadequately covered -- that is, primarily into the Arctic and sub-Arctic regions north of the 65th parallel. Even without these extensions the Soviets have a first-order triangulation network that covers two-thirds of the country from Murmansk to Vladivostok, excluding only the area east of the Urals and north of the 65th parallel.

According to standards of accuracy outlined in their specifications, the Soviet geodetic standards are comparable to those of Western Europe and America. Postwar catalogues are not available to us for analysis and checking. It is reasonable to assume, however, that the Soviets can attain an order of positioning accuracy of 1:100,000 for long arcs. If a Soviet tie has been effected with North America, then launching sites established several hundred miles inland from the Bering Strait could cover every part of the US with missiles having a 5,000-mile range. The launching site, tied over a short distance to the Soviet triangulation, could be referenced to the North American Datum. By this method the Soviets might expect to achieve a CEP of 300-500 feet against US targets.

[redacted]

angles and geoidal heights. Under such conditions, it is doubtful if the Soviets can do better than a CEP of 1,000 feet against targets in the US.

Because of the shorter range, Soviet geodetic targeting errors will be smaller for Central and Western Europe. Since 1952 the USSR has been forcing the extension of its own geodetic datum and topographic-mapping system upon the European Soviet Satellites. This will unify the independent datums and eliminate discrepancies between common points, which in some instances have amounted to over 650 feet. The major part of the field work and mathematical readjustment is scheduled for completion by 1957. Large-scale-map production, at 1:25,000, is scheduled for completion by 1959-60 and has already been completed for East Germany. Recent reports indicate that the Soviets themselves are determining the geodetic coordinates of some basic control points in the overall program -- probably to ensure satisfaction with the end results and possibly because of reluctance to entrust the fundamental geodetic data and methods of the Soviet system to Satellite geodesists. [redacted]

[redacted]

Intercontinental geodetic connections by celestial triangulation employing solar eclipses, star occultations, and moon-position camera methods are currently being tested by the US. There is some suggestion that the Soviets also may be observing solar eclipses to obtain intercontinental ties. The 1947 eclipse in Brazil was observed by a Soviet party, which maintained off-limits restrictions for its inner observation area. The Soviets are also planning to observe the 1958 eclipse in the South Pacific from the Tokelau Islands. The path of totality continues to the western coast of South America. If a Soviet observation program is also undertaken in South America, it would provide strong evidence that an intercontinental tie is contemplated. If this were the case and if the complete results of the programs of the Western World were to be freely provided, it would be quite probable that by 1965 the Soviets could at least narrow their intercontinental positioning error to the order of 500 feet for any launching point in the USSR.

This summary of Soviet technical capabilities for effecting intercontinental connections of US and European datums would be incomplete if no mention were made of the significant contribution to Soviet capabilities resulting from the open availability of geodetic catalogues and large-scale topographic maps of nearly all countries outside the Soviet Bloc. Furthermore, a corresponding advantage in positioning is denied to the Western World by the Soviet policy of effectively withholding comparable postwar catalogues and maps of the USSR and the post-1952 results of the East European readjustment and remapping programs.

SOVIET GRAVIMETRY AND THE DEVELOPMENT OF A SOVIET WORLD GEODETIC SYSTEM

The estimates of Soviet positioning by means of the intercontinental connections of datums just described are limited to the positioning of targets within the areas covered by a given triangulation network. Such methods would be of no avail, however, for the great bulk of continental areas not covered by triangulation or for isolated areas with small unconnected triangulation systems. The gravimetric method offers a means of converting diverse geodetic datums into a World Geodetic System, and at the same time offers a means for the rapid establishment of geodetic control in unsurveyed areas without the necessity of a time-consuming geodetic survey. Such a control, although it would not be of first-order accuracy, would be adequate for mapping at scales of 1:100,000. For its most effective application, the method requires a gravity survey of the entire Earth. Once such data are processed into a world map of gravity anomalies -- showing lines of equal departure of observed gravity from normal gravity values for each latitude -- the results would also be extremely valuable to the second or dynamic problem: the determination of the effect of gravity anomalies upon long-range missiles, particularly over the extended areas of free flight. World gravity surveys are being undertaken by both the US and the Soviet Union. One could view this as a kind of race, with the odds favoring the Soviets somewhat.

Achievement of this ideal, however, is far from realization. Gravity data are notably lacking (for both the US and USSR) over the oceans, and to a lesser degree over the land areas of the Southern Hemisphere. Almost no horizontal control has been established for the Antarctic Continent, except for scattered observations around the coast. In the land areas of the Northern Hemisphere, the US is at a decided disadvantage vis-a-vis the USSR because the latter, on the one hand, has undertaken a most comprehensive gravity survey program and, on the other hand, has withheld these data from the Western World.

In 1932 the USSR began a systematic gravity survey to provide coverage with a minimum density of 1 point per 1,000 sq.kms. of area for the entire country. This survey was probably initiated not only for geodetic purposes but also for its more immediate contribution to the geophysical prospecting program for minerals and fuels. By 1938, over 10,000 determinations had been completed, and by 1947 the number had increased to 15,000. It is estimated that this minimum program of observations has already been completed. The total number of observations is much greater than the prescribed minimum because geophysical prospectors are required to make their observations adaptable to the national gravity net; this is not the case in Western countries. The number of gravity observations contributed by Soviet geophysical prospectors is now reckoned by one authority to amount to "hundreds of thousands."

Included in this vast total are gravity values collected in the Arctic Basin since the 1930's, which have not been disseminated. The US has no postwar Soviet gravity catalogues. The most recent Soviet catalogue in US possession is an unofficial 1935 compilation containing 6,000 observation points, most of which were taken from a variety of uncoordinated surveys. For all practical purposes the US holds only a small fraction of the Soviet data for the largest contiguous land mass in the world, especially if we include China, which is also withholding its data. In contrast to this denial, the USSR has been systematically collecting the freely available (noncommercial) gravity data for the rest of the world. In 1951 the Soviet foreign catalogue contained over 25,000 determinations, as well as gravimetric maps. It was not without reason that one source proudly claimed that the Soviets hold a larger coverage of gravity data than the rest of the world combined. And it is not without some significance that, when the Soviets announced their intention to participate in the IGY, they called for an expansion in gravimetric and seismic observations. However, the Soviets are neither expanding their program (except in the Antarctic) nor willing to share their past survey data.

The Soviet IGY program is limited to two Earth-tide stations to collect data showing minute gravity variations in time, which have no military value whatsoever. When the Soviets were specifically confronted with their exclusion of gravity data from a recent declassification of other Arctic geophysical data, they pointed out that gravity data are still considered strategic and are known to be of interest to the US Air Force. Underscoring the attempt to push the collection of gravity data beyond the borders of the USSR, the Soviets are planning an expansion of their worldwide connections under the IGY. As evidence of this, the Soviets (1) are undertaking an extension of their highly developed gravity network from the North Pole via Novaya Zemlya, Salekhard, Novosibirsk, Garm, and Kabul to New Delhi; (2) are undertaking a survey from New Delhi via Saigon, Shanghai, Khaborovsk, and Tiksi to the North Pole; and (3) have indicated a keen interest in two drift stations to be launched by the US and have offered to exchange data on condition that US gravity instruments be made available. This exchange would provide the Soviets with coverage of the Western Hemisphere Sector of the Arctic Basin and, coupled with the freely disseminated Canadian gravity data, would go a long way toward tying North American gravity observations to Eurasian.

At a 1956 IGY meeting, the Soviets showed a keen interest in submarine gravity data obtained by the US and used the fact that the US data were not published as evidence that the US considers these data strategic. They argue, therefore, that the US cannot accuse the USSR of being the only country that withholds such data. More recently, Soviet gravimetrists manifested exceptional interest in arranging for a release of gravity data obtained by American oil companies but generally unpublished because they constitute valuable commercial secrets. From all evidence, it is readily apparent that the Soviets are making good progress in their efforts to establish their own World Gravity System and at the same time to make it an exclusively Soviet system by denying data to the rest of the world.

That such a World Gravity System would be of value not only to the geodetic problem of missile guidance but also to the dynamic problem has been indicated. Currently, the greatest need is for values of the absolute deflection of the vertical at launch points. The next most urgent need is for gravity anomalies over likely areas of free flight. If the theoretical findings are borne out by future test-flight operations, we can assume that the long-standing Soviet interest in gravity will have yielded an unexpected bonus through its value to missile guidance. That there is some connection between the keen current Soviet interest in a world gravity program and missile guidance is further suggested by known Soviet studies on the variation of gravity with altitude. One of these studies concludes that it is quite possible to determine mean values of vertical gradients for small areas by using planes and that "the construction of apparatus at the present level of Soviet science and industry does not present especial difficulty." If any such apparatus were developed, it would represent a major break-through that could have far-reaching effects in reducing the error due to the dynamic factor. So far as we know, no comparable studies directed toward the development of such an instrument have been made elsewhere.