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SPACE SCIENCE BOARD

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MEMORANDUM REPORT

To: Dr. Hugh L. Dryden, Deputy Administrator
National Aeronautics and Space Administration

From: Lloyd Berkner, Chairman
Space Science Board

On: NASA Tracking and Orbit Computation Services, and Distribution of Tracking and Orbital Data to the Scientific Community

This report constitutes a covering document for the much more detailed report submitted to the Space Science Board by its ad hoc Panel on NASA tracking and orbit computation services. The Panel's report is enclosed.

The present memorandum takes up the questions in your letter of 9 November 1960 one by one, and gives the Board's answer immediately after each question. As you predicted, answers to the more technical questions about requirements for data on positions, orbits, and other parameters, and on the required precision of these data and their mode of presentation, differ markedly with the type of investigation being carried out. These answers have accordingly been given separately for the several types of research. The types have been grouped as follows:

Geodesy and Gravitational Fields;

Meteorology (cloud cover interpretation and radiation balance studies);

Atmospheric physics (pressure, temperature, density, composition, winds, etc., except studies that belong under Meteorology, Air Density from Drag, and Ionospheric Physics);

Air Density from Drag (requirements given under this heading apply to any non-gravitational forces);

Ionospheric Physics (direct probe measurements and propagation studies);

Magnetic Fields (including auroral studies in which the influence of magnetic fields is emphasized);

Cosmic Rays and Trapped Radiation;

Electromagnetic Radiation (ultraviolet, X-ray, and gamma-ray studies);

The Interplanetary Medium (including micrometeorites).

As necessary, certain questions are followed by explanatory statements to indicate the Board's interpretation of the questions. Answers to each question are then developed -- if possible, by providing a specific answer applicable to each of several specific research areas.

1. "What do scientists really need in the way of satellite positions?"

/In some instances, answers refer to those features or aims of each type of investigation that determine the character of the requirements for positional or orbital data, etc. Topics such as specific estimates of the accuracy required, time intervals, etc., are given where relevant in answers to the other, more specific, questions below./

1.1. Geodesy and Gravitational Fields. Geometric studies (e.g., those using the satellite as a moving triangulation point) require instantaneous 3-dimensional coordinates of the satellite, with as great precision as possible and with correspondingly precise times. The number of such positions need not be very great, and they need not be spaced in any set time interval. Orbital elements are either completely unnecessary, as in the intervisible case; or an orbital arc may be required as a device for precise interpolation or extrapolation in order to relate observed points in one geographical region to observed points in another region (as in the case of "long ties" connecting well separated land areas).

Gravitational studies, based on dynamical treatments, require the instantaneous acceleration of the satellite as a function of time, as precisely and continuously as possible. For gross features of the gravitational field, orbital elements and their time variation are required; for fine structure of the gravitational field the raw observations (either corrected or uncorrected for observational effects such as refraction) are needed.

1.2. Meteorology. In general terms, the meteorology programs (cloud-cover and radiation balance analyses) require positions and orientations of the satellite good enough to establish the point from which the readings were taken and the direction of the cloud-cover picture or the radiometer scans. The degree of precision (discussed further under Question 4) depends on the scale of the images or the cone of acceptance of the radiometers, i.e., the intrinsic angular resolution of the equipment.

1.3. Atmospheric Physics. Experiments in this category require information regarding the position and orientation of the measurements, including information concerning the direction in which the sensors are pointed. As some sensors are affected by the velocity, 3-dimensional coordinates, orientation of the sensors and the velocity vector of the satellite corresponding to time intervals of the order of one or a small number of minutes are required.

1.4. Air Density from Drag. The velocity and acceleration of the satellite as a function of time and position are required in order to separate the non-gravitational forces (chiefly atmospheric drag) from the gravitational force. Such studies are, in practice, adjuncts to gravitational field studies and the requirements are essentially the same.

1.5. Ionospheric Physics. The analysis of the space and time structure of the ionosphere from probe measurements or propagation studies, including Faraday rotation, requires a knowledge of the geocentric position of the probes or of the transmitter in space as a function of the time.

1.6. Magnetic Fields. Geocentric positions are required of sufficient accuracy to map the Earth's magnetic field without degrading the information which can be derived from the magnetic record (1 gamma for current work). Mapping the static field requires more precise positions than the recording of dynamic changes.

1.7. Cosmic Rays and Trapped Radiation. Ephemerides of geocentric positions are required, together with enough magnetic data to determine the behavior of charged particles in the Earth's magnetic field (e.g., to ascertain the pattern of trapping as a function of space and time).

1.8. Electromagnetic Radiation. For radiation from extraterrestrial sources (Sun, cosmic sources), the position of satellite is relatively unimportant compared to information concerning the direction of arrival of the rays. However, for related measurements of the absorption (or emission) spectrum of the terrestrial atmosphere, positions as functions of time are important, as well as direction.

1.9. The Interplanetary Medium. Geocentric and heliocentric positions are needed to map the distribution of interplanetary matter in the solar system as a whole or as modified in the immediate environs of the Earth.

2. "In what form is the information desired? Are observed satellite positions sufficient or are orbital elements needed or, perhaps, computed positions over an arc of the orbit?"

/The word form has been interpreted in two senses: (i) mathematical form, e.g., ephemerides, elements, etc., and answers to the second part of the question cover this sense; (ii) physical form, e.g., printed tabular matter, magnetic tapes, punch cards, etc. The type of investigations has no particular relevance for the physical form of the data; rather it depends on whether the scientific user has access to an automatic computer. Thus, for convenience, data for all types of experiments should be available in any of the possible physical forms./

2.1. Geodesy and Gravitational Fields. Geometric problems primarily require observed positions. Gravitational problems require either (a) orbital elements and the time rates of change thereof, including all periodic terms deducible from the tracking data; or (b) a time sequence of orbital elements corresponding to a succession of short-arc fits from which the time variations of the orbital elements can be derived; or (c) in some instances, the original observations.

2.2. Meteorology. Cloud-cover images and radiation balance measurements require satellite positions at one-minute time intervals or orbital elements from which such an ephemeris can easily be computed.

2.3. Atmospheric Physics. These studies require the position of the satellite in geographical coordinates and height in metric units; angles should be given in decimals of a degree or radians. Many workers prefer that the time be given in only one unit (e.g., seconds), and multiples and decimal fractions thereof.

2.4. Air Density from Drag. These investigations require orbital elements and time variation thereof, or else sets of elements updated at, for example, 2-day intervals. Unsmoothed observed positions as functions of the time (especially on arcs near perigee) are needed to determine very short-term fluctuations.

2.5. Ionospheric Physics. Topocentric (altazimuth) ephemeris or crossing data are needed for satellite acquisition. Ephemeris of altazimth coordinates and slant range of the satellite at the receiver are needed for reduction of propagation data, or else geocentric coordinates from which the foregoing can be readily computed.

2.6. Magnetic Fields. Ephemeris or geocentric positions are required. For very eccentric orbits (like that of Explorer VI), time interval in the ephemeris should be about one minute for the arc near perigee and ten minutes near apogee.

2.7. Cosmic Rays and Trapped Radiation. These studies require an ephemeris of geocentric rectangular coordinates, given at one-minute intervals for low perigees (up to several hundred km), increasing to ten-minute intervals for measurements made at several Earth-radii. Also needed are revolution number or pass number; and date and time in UT. (Other items given in answer to the next question should be tabulated for the same tabular values of the time as are used in this ephemeris.)

2.8. Electromagnetic Radiation. These studies require an ephemeris of geocentric positions, given at one-minute time intervals for low altitudes, up to ten minutes at high altitudes (like last entry); also dates and times in UT.

2.9. The Interplanetary Medium. Studies in this area require an ephemeris of geocentric positions in either spherical or rectangular coordinates, with a time interval of one to ten minutes (like last two entries); this interval can be considerably increased for analyzing series of observations secured at large distances from the Earth.

3. "What information is needed other than the geometrical position, e.g., velocity components or magnetic field components?"

3.1. Geodesy and Gravitational Fields. The investigator needs velocities accurate enough to calculate the velocity-dependent non-gravitational forces and eliminate them, so that the error in the accelerations due to these causes is smaller than the observational error, although the computing facility need not necessarily supply these computations. In general, the velocity need not be known to many significant figures, and can easily be derived from the orbit itself; the investigator as a rule has done this for himself.

3.2. Meteorology. The investigator needs the satellite's attitude, with respect either to geocentric coordinates or to local horizontal coordinates.

3.3. Atmospheric Physics. The investigator needs the satellite attitude, in order to determine the direction of the Sun and the direction of the velocity vector with respect to body axes, to locate airglow pictures with respect to the Earth, and to construct "TV" pictures from the output of narrow-angle radiometers. For airglow studies, he also needs specification of the cone tangent to Earth, with vertex at satellite.

3.4. Air Density and Drag. The investigator needs the velocity of the satellite (easily deducible from orbital elements), also the spin and tumble rate and axes of rotation, as functions of the time.

3.5. Ionospheric Physics. No additional requirement was mentioned.

3.6. Magnetic Fields. The investigator needs the components of the magnetic field at satellite, computed according to a theoretical model; spin and tumble rate, if it is not readily calculable from attitude; and geomagnetic coordinates as function of the time (or at least times of crossing geomagnetic equator).

3.7. Cosmic Rays and Trapped Radiation. (Items should be tabulated in the same basic ephemeris asked for in answer to previous question, for the same values of UT.) The investigator needs heliocentric coordinates for elongated trajectories going out several Earth-radii; information whether the satellite is sunlit or shaded; the geomagnetic latitude and longitude; the three components of the magnetic field at satellite; and attitude of satellite as function of the time (to determine the look-angle of counters). A separate calculation is required for the loci of the function I = constant in terms of the geocentric coordinates of the "mirror points", where I is the integral invariant $\int_{M_1}^{M_2} v_{\parallel}\, dl$ along lines of force and M_1, M_2, are the mirror points (see page 15, Committee Report).

3.8. Electromagnetic Radiation. Information is required as to whether the satellite is in sunlight or shadow. Attitude information is critically important to determine direction of arrival of the radiation.

3.9. The Interplanetary Medium. These investigations require ephemerides of heliocentric coordinates, the three components of geocentric velocity (esp. for the reduction of micrometeorite energy and momentum data), the heliocentric velocity, and the satellite attitude, or spin and tumble rates and axes.

4. "To what accuracy are various types of data required?: (a) before the satellite pass (i.e., predicted orbits); (b) within a few weeks after the pass; (c) eventually?"

4.1. Geodesy and Gravitational Fields. Since time is not of the essence here, and since the unsmoothed satellite motions themselves constitute the observational data, there is no distinction between (b) and (c); in general, investigators in this field can use the best possible observed positions or orbital data for as a long a time as the satellite can be observed, without such smoothing as some "definitive orbits" have been subjected to.

The best current orbits, with higher-order harmonic terms included in the expression for the gravitational potential and with correction for air drag and radiation pressure, produce residuals that are not much larger than the smallest observational errors (one second of arc and two milliseconds of time), a fact which indicates that even better tracking and orbital data than are now available could be used with profit, as successive refinements become possible.

4.2. Meterology. (a) Predictions are required for the operational use of meteorological satellites, in lieu of real-time or immediate post-flight or observed positions, with accuracies like those given in (b) and (c) below.

(b) & (c) For research and analysis, the allowable error in positioning the small-scale cloud-cover pictures on the surface of the Earth is 100 km; for the large-scale pictures it is 50 km; for the analysis (and prediction) of the path of localized storms (e.g., tornadoes), it is 15 km. (These accuracies correspond to the internal position errors in the cloud-cover images, and are hard to achieve toward the edge of a picture because of the neglect of the height of the cloud above the surface and because of foreshortening. Large overlap between pictures compensates for this.)

The errors in picture location are the combined result of errors in satellite position and attitude, of which attitude error has the greater effect. Estimated allowable errors: ± 5 or 10 km in position, and ± 10° in attitude for an error of ± 100 km on the ground, correspondingly less for ± 50 km and ± 15 km.

(NIMBUS attitude control to 1° accuracy will allow much greater tolerance in position error for that satellite.)

4.3. Atmospheric Physics. For the most stringent case (spectroscopy of terrestrial atmospheric absorption lines), geocentric coordinates to ± 0.5 km and height to ± 1 km at minimum satellite altitudes are required. For most other purposes, subsatellite point to ± 10 km and height to 1% are sufficient.

Components of velocity vector with accuracy of 1 to 5 parts in 10^3 are also needed.

4.4. Air Density from Drag. For the more detailed analysis that are now becoming possible, all data should be given as precisely as possible. Like Geodesy-Gravity, the results are based on a close comparison of observed and computed positions and accelerations, and can benefit from unlimited precision.

4.5. Ionospheric Physics. (a) No stringent requirement is given; these investigations need advance positions for acquisition purposes only. (b) & (c) The following precisions have been asked for: three-dimensional positions for probe experiments, precisions of ± to 5 km, time to 0.1 to 0.5 sec; for Doppler measurements or for direction of signal observations, ± 10 km and ± 0.5 sec; for Faraday rotation experiments, several 10's of kilometers and a few seconds of time (based on the present intrinsic accuracy of such experiments). The precision of all these methods is steadily improving and the methods can make good use of more accurate data in the future.

4.6. Magnetic Fields. (a) Predictions good enough for telemetry acquisition are needed. (b) Positions with accuracy as near as possible to that in the final data in (c) below. (c) Since the magnetic field can be measured to 1 gamma, and the gradient of field is such that a change of 1 gamma corresponds to a few 10's of meters at 200 km height, about 1 km at 1 Earth-radius, and some 10's of km at 4 to 5 Earth-radii, positions should be equally good in order to avoid losing information.

4.7. Cosmic Rays and Trapped Radiation. (a) Predictions good enough for acquisition of telemetry signals are needed. (b) & (c) The data reduction requires a retrospective ephemeris with accuracy of ±5 km at low altitudes (i.e., several hundred kilometers), decreasing accuracy with increasing altitude.

4.8. Electromagnetic Radiation. (a) Predictions good enough for acquisition of telemetry signals are required. (b) & (c) For extraterrestrial radiation, precise positions are not important. For terrestrial radiation or absorption spectrum, positions to ±0.5 km would be useful. Precision of attitude data should match angular resolving power (cone of acceptance) of radiation sensors to avoid degradation of information.

4.9. The Interplanetary Medium. (a) Predictions good enough for acquisition of telemetry signals are required. (b) & (c) Positions need not be especially accurate, so long as position errors are small compared to scale of the region being mapped.

5. "For which vehicles are the accurate positions needed and what data should be supplied for all U. S. satellites?"

In order to avoid an unduly narrow interpretation of this question, which seems to apply to specific vehicles, past, present, and future, the answers should be understood as applying to any vehicle that can be useful in the kind of investigation described in the heading. For this purpose, the precision of the data required has been coded as follows:

A: as accurate as possible
B: ±1 to ±10 km
C: 10 km is permissible at low altitudes, with larger tolerances at several Earth-radii.

Data at least as precise as grade C should be supplied for all satellites.

5.1. Geodesy and Gravitational Fields: A - accurate positions for any satellites that can be observed.
5.2. Meteorology: B
5.3. Atmospheric Physics: A for absorption spectroscopy; B for rest.
5.4. Air Density from Drag: A
5.5. Ionospheric Physics: B
5.6. Magnetic Fields: A close in, to B at several Earth-radii
5.7. Cosmic Rays and Trapped Radiation: B
5.8. Electromagnetic Radiation: C for extraterrestrial radiation; A-B for terrestrial radiation.
5.9. The Interplanetary Medium: C

6. "Is there any requirement for orbit information referenced to the Sun?"

[In this connection, it should be noted that when each of the following types of studies are extended to the Moon and planets by means of space probe fly-bys or permanent orbiters, orbits referenced to these bodies will be required. This remark applies to all the disciplines noted below, with the possible exception of certain studies of cosmic rays, electromagnetic radiation, or the interplanetary medium.]

6.1. Geodesy and Gravitational Fields. When problems similar to those in this category are extended to the Solar System as a whole, e.g., measurements of the distance between circumsolar orbits to derive a better value of the Astronomical Unit, then heliocentric orbits will be required.

6.2. Meteorology; 6.3. Atmospheric Physics; 6.4. Air Density from Drag; 6.5. Ionospheric Physics; 6.8. Electromagnetic Radiation. Only the altitude of the Sun is required. (This may be computed by the experimenter himself from the time and position of the satellite.)

6.6. Magnetic Fields; 6.7. Cosmic Rays and Trapped Radiation. Heliocentric coordinates are not needed except for measurements in the interplanetary medium several Earth-radii out from the Earth, or farther.

6.9. Interplanetary Medium. Both heliocentric coordinates and velocities are needed.

Two questions asked by the National Aeronautics and Space Administration require generalized answers; they are not susceptible of specific replies for fields of scientific research of the type provided above.

7. "What is still needed to complete our IGY commitment? What is required beyond this for later commitments: (a) domestic and (b) international?
As indicated in the attached report of the SSB Ad Hoc Committee, the Board believes that all IGY requirements for distribution of tracking information and orbital data and similar post-IGY requirements as specified by COSPAR have been faithfully fulfilled.

8. "What estimate do the members of the Space Science Board give of the use that has been made of the orbital and positional data which NASA has distributed: (a) domestically and (b) internationally? What do they believe the scientific community has received from this service?"
The Board's answer to this question must obviously be subjective in character. Members of the Board consider that the actual number of scientific users of tracking information and orbital and positional data, whether obtained directly from NASA or SAO, or indirectly through World Data Center A, has been rather small. However, the Board stresses that the availability of these data has been absolutely indispensable to scientists analyzing scientific data from on-board satellite experiments as well as to those utilizing the satellite and its transmissions for other basic research such as air drag measurements, propagation analyses, etc.

It is the Board's distinct impression that a very large majority of the users of these data for scientific purposes have been U. S. scientists. Use of these data by scientists abroad appears to have been nominal: in the Board's view, practically all of the use of tracking and positional data by foreign scientists has occurred as a result of special arrangements between the National Aeronautics and Space Administration and scientists in other countries whom NASA has specifically solicited to assist in observing its satellites or in recording telemetered data therefrom. In addition, it is likely that a small number of scientists abroad have acquired such data through special arrangements taken on their own initiative; but it appears quite unlikely that much use of these data has been made from information distributed through generally available channels (e.g., SPACEWARN).

Despite the foregoing remarks, the Board urges that no thought be given to curtailing present arrangements for distribution of these data; rather, steps should be taken to improve their use and application by expanding NASA services in accordance with recommendations provided in earlier sections of this report and in the appended report of the SSB Ad Hoc Committee.

Moreover, the Board strongly believes that there is a large potential of scientific interest and use, both domestically and internationally, which could be invoked to the scientific advantage of the NASA program by the timely publication of detailed telemetry transmission schedules, codes and frequencies, for specific experiments and possibly by the use of continuous telemetry. The Board wishes to emphasize its believe that much could be achieved through such steps to interest scientists in this country, and particularly scientists in other countries, in the space research program. (The recent success of Dr. Herbert Friedman in achieving international participation in observing and analyzing Solar Radiation Experiment III indicates the potentialities of possible similar programs conducted by the NASA.) If this can be accomplished, orbital and positional data, also distributed on a timely basis and in detail, must obviously be provided.