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AUXILIARY SUBPROGRAMS FOR CALCULATING THE NAVIGATIONAL PARAMETERS OF ARTIFICIAL EARTH SATELLITES. FORTRAN IV.

V. I. Prokhorenko

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<td>V. J. Prokhorenko, Academy of Sciences USSR Institute of Space Research, Moscow</td>
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In the process of creating this packet of applied programs for calculating the navigational parameters of artificial Earth satellites (AES), the methods of use, whose possibilities and organization are described in Preprint [8], there arose a library of subprograms which have a sufficiently independent nature. The present work is devoted to a description of these subprograms. Because of the space limitation of a preprint, the description of the subprogram library has been divided into two parts. Included in the present preprint are the subprograms for transforming coordinates and time, for determining the position of the Moon and Sun, and for calculating atmospheric density on the basis of various models of the atmosphere and disturbances specified by anomalies of the Earth's gravitational field. In the library of subprograms of the packet mentioned above, these subprograms have indexes A-E.

The second part of the subprogram library (F-I) contains subprograms for the formation of the right parts of a system of differential equations for the motion of AES and for its integration by Adam's method, and subprograms for calculating the values of various functions from the parameters of the AES's motion.

The description of the master program and auxiliary subprograms, which guarantee the organization of information input, as well as the calculation and printing or recording on magnetic tape of an arbitrary set of navigational parameters (NP), makes up the content of an independent preprint.

There is a variant of the subprogram library for execution with binary precision of the calculations enumerated above.

When using the suggested library of subprograms or even one program of this library, one must keep in mind that all constants which are encountered in separate subprograms are located in a common region and values are assigned to them by a preliminary reference to the subprogram CONST (p. 2.1). Therefore, before turning to descriptions of actual subprograms, it is necessary to become familiar with points 1.2 and 2.1.

The systems of coordinates used and accepted when describing the subprogram library of designations are introduced in point 1.3.

The principle of the organization of the library of subprograms is described in p. 1.1.

The remaining points contained in the description of actual subprograms can be used independently of one another.

The author of subprograms VKMA and DENS (DO2) is M.I. Voyskovskiy, and of subprograms DEG2, DEG3, and DEG5 (EOI) it is Ye.Ye. Ryazanova.
The subprograms ADEN, AMBAR, GRAV, and TIOCAI are taken from [6] and are tested and modified for the Ye.Ye. Ryazanova's electronic computer (BESM-6). The remaining subprograms are those of the author of this work.

The author wishes to thank Ye.A. Chistyakova for help editing the tests of the programs for publication and I.V. Zaytseva and V.V. Smirnova for their help in preparing the manuscript.
1.1 Organization of the Subprogram Library

At the base of the organizational procedure of the subprogram library are the principles of organizing a subprogram library which are accepted at this time, and which are used, for example, in the joint Institute of Nuclear Research in Dubna.

To facilitate the review, the library is broken down into specific logical groups, each of which has its own index (A,B,C...). These indexes in a sense do not coincide with the indexes used in the joint Institute of Nuclear Research library but are used for the convenience of describing the library presented below.

The chapter names conform to the names of respective groups. Subprograms in each group are numbered (for example, A01, A02,...). Each individual subprogram is described in a separate point, and sometimes several subprograms which are linked to one another are described in one point. The names of points coincide with the names of subprograms. In such manner the indexing can be considered an inventory of subprograms which are grouped according to their meaning.

Besides this, in each section of the description of the subprogram library is a list of subprograms by their names in alphabetical order (together with indexes by which one can find a corresponding subprogram). In the last section is a full list of subprograms given by names.

When describing each individual subprogram the following format is used:

1. Function
2. Structure
   Subprograms, subprogram-function, and the packet of subprograms
   Identifier (identifiers) of the subprogram which is the input for the user.

   Internal inputs (subprograms inaccessible to the user)
   Peripheral subprograms used (access to other subprograms of the library)
   Peripheral devices (input and output devices)
   Common units (COMMON)

*Numbers in the margin indicate pagination in the foreign text.
Information on all of the above points is not contained in each description, and numeration according to these points is not strictly adhered to.

In order to save space in the description of structure (p.2) replies of the type "Peripheral devices not in use" or "Access to internal subprograms unavailable" are omitted.

1.2 Constants, dimensional variables

The proposed subprogram library is a complex of subprograms which have been developed on the basis of several general principles.

All constants, dimensional and non-dimensional, which are used in various subprograms, are taken out of the common region (COMMON), and values are assigned to these constants by accessing the subprogram CONST (for the majority of constants, see Tables 2.1-2.4) and the subprogram CONGR (for coefficients of anomalies of the Earth's gravitational field, see Table 2.5).

All dimensional constants which are originally given in the system of units kg, m, and sec, can be subjected to multiplexing with the scale factors EM and ESEC, which are given as actual parameters of the subprograms CONST and CONGR.

The problem is that for various AES it may be necessary to conduct the calculations in various systems of units: kg, m, sec; 1000000 m, 1000 sec, and so forth. The system of units chosen for calculations can be fixed by two scale factors: EM, ESEC -- the number of meters in the chosen unit of measuring distance and the number of seconds in the chosen unit of measuring time. In the case that the system of units is kg, m, and sec.-- EM=1, ESEC=1.

Dimensional reference data, such as T, s, y, z, v, v_x, v_y, v_z, a, SB and so forth, should be translated into the system of units which are fixed by the scale factors EN, ESGC, for which the scale factors from corresponding units of COMMON can be used (see Table 2.3).

In these subprograms for which the descriptions do not contain indication of the system of units in which the dimensional reference data should be fixed and resulting in dimensional results, it is
implied that it is a system of units fixed by the scale factors BM and ESEC. The current moment of time is given by the date and Moscow time $T$, figured from that particular date. The date can be given as the calendar date or as the RJD, the relative Julian date (see p. 1.2).

The time $T$ is measured in seconds (or in units determined by the scale factor ESEC). Only in the subprograms HMSSEC (B03) and BOCHMS (B04) is the time $T$ always measured in seconds.

In several of the subprograms of the library (usually the subprograms of other authors, for example DENS (D02), ADEN (D03)) the dimensional reference data should be given in definite units. This is discussed in the descriptions of the corresponding subprograms.

1.3 Systems of Coordinates, Time and Designations

1. The following system of coordinates is used.
Greenwich relative rectangular coordinate system $O_{xyz}$, coordinated with the rotating Earth:

the center $O$ coincides with the Earth's center;
the axis $O_x$ coincides with the rotational axis of the Earth and is oriented towards the North pole;
the axis $O_z$ is oriented towards the point of intersection of the Earth's equator and the Greenwich meridian;
the axis $O_y$ completes the system to the right.

The absolute rectangular quadrature (equatorial, stellar) systems of coordinates $O_{XYZ}$:

the center $O$ coincides with the center of the Earth;
the axis $O_Z$ coincides with the Earth's rotational axis oriented towards the North pole;
the axis $O_X$ is oriented towards the point of the vernal equinox (at the current moment);
the axis $O_Y$ completes the system to the right.

Oscillating system of coordinates (elements of the orbit). The elements of this system of coordinates are:

$a$ - the semimajor axis of the orbit;
$e$ - eccentricity;
$i$ - inclination (the angle of incline of the plane of orbit and the equatorial plane);
$\Omega$ - the longitude of the ascending vertex of the orbit (calculated along the equatorial arc.
from the direction towards the point of spring
counterclockwise);

\[ \omega \] - argument of perigee (angular distance from the
ascending vertex to the perigee);

\[ \tau \] - the time of passage through the perigee.

The position of the satellite in orbit is determined by the
argument of latitude \( \mu \) (angular distance of the AFS from the
ascending orbital vertex).

2. In descriptions of the subprogram library, the following
concepts are connected with the estimation of time [4].

- the Gregorian calendar (GU) -- contemporary
  \( \text{chronology} \)
- the Julian computation of time -- the system
  of continuous count of days from the beginning
  of the Julian period, year 4713 to the New era
  January 1, 12\(^{th}\) according to the Gregorian calendar.
- JD -- the Julian date, the number of days
  which have passed since the beginning of the
  Julian period.
- In many of the subprograms the relative Julian
  date (RJD) is used, the number of days which
  have passed since 1900, January 0.12\(^{nd}\) of
  ephemeris time.

\[ \text{RJD}=\text{JD}-2415020.0 \]

- The stellar local time [2] at the given
  meridian (S) is the time calculated from the
  moment of the upper culmination of the point
  of the vernal equinox to any other of its
  positions. Stellar time is numerically
  equal to the hour angle of the point of the
  vernal equinox.

3. For several of the quantities more frequently encountered in
the subprogram descriptions we will introduce constant designations (identifiers of these quantities).

\[ \text{RJD} \] - relative Julian date;

\[ T, TR \] - Moscow time, calculated from
a certain date in seconds (or in other
units fixed by the scale factor ES86);

\[ SO \] - stellar time on the Greenwich meridian
at midnight in Greenwich on the corresponding
date;

\[ ST \] - stellar time on the Greenwich meridian at
the moment of time \( T \);
YA-array containing $X, Y, Z, V_x, V_y, V_z$
(absolute systems of coordinates);
YB-array containing $x, y, z, v_x, v_y, v_z$
(Greenwich coordinate system);
Y-array containing coordinates and constituents of a vector of velocity in an arbitrary system of coordinates;
XA-array containing only $X, Y, Z$;
XB-array containing only $x, y, z$;
X-array containing AES coordinates in a random system of coordinates;
A-array containing elements of orbit
$a$, $e$, $i$, $\Omega$, $\omega$, $u$;
SB-ballistic coefficient;
P-atmospheric density.

When the size of an array is mentioned in the descriptions, instead of the words "array Y is reserved for 6 real values," it will be written "array Y6."

When the size of an area reserved in the COMMON/B/3 block is mentioned, the number 3 indicates the quantity of real values for which block B is reserved.
2.1 Basic Constants (AO1-CONST)

1. Function. The subprogram CONST dispatches to the common area (COMMON) the values of dimensional and non-dimensional constants which are used in the system of subprograms for computing navigational information which characterizes the position of the ATS, and translates the dimensional constants into an given system of units. In Tables 2.1-2.4 a list is introduced of corresponding constants, their standard designations, the values and dimensions in the units (kg, m, and sec). For an assignment of the needed system of units the following parameters are used:

- EM - number of meters in the unit of measuring distance;
- ESOC - number of seconds in the unit of measuring time.

For example, if for computations the chosen units are kg, m, and sec, then EM = 1, and ESOC = 1. In order to carry out computations in the systems of units, kg, 1000 km, 1000 sec then it is necessary to let EM = 1,000,000, and ESOC = 1000.

2. Structure. Subprogram CONST.

The Common Units

/CAED/1, /CA00/2, /CA00A/2, /CA22/4, /COR/1, /C30/1,
/CGRS/2, /COM/1, /CRE/1, /CRZ/1, /CAE/2, /CAEL/1, /CCLZ/1,
/COMZ/1, /C30Z/2, /CSDAY/1, /CT3/1, /CKDM/13, /CDSJS/1,
/CPI/5, /CDE/CR/1, /CHRAD/1, /CE2/1, /CE3/1, /CE4/1, /CE6/1, /CC60/1,
/CC3600/1, /BEM/2, /CEV/1, /CESB/1, /CEL/1, /CERO/1, /CHA/20.


4. Raw data: EM, ESOC.

5. Results, use of the area COMMON.

The values of constants in accordance with Tables 2.1-2.4 are dispatched to the units of Common enumerated in p. 2.
2.2 Coefficients of Expansion of the Earth's Gravitational Field in Spherical Functions (ACZ-CONGR)

1. Function: Subprogram CONGR dispatches the values of coefficients of expansion of the Earth's gravitational field in spherical functions (5) to the common region (COMMON) and translates these coefficients into the given system of units. Values of the coefficients are given in table 2.5. These coefficients are used only in subprograms for computing anomalies of the Earth's gravitational field.

2. Structure. Subprogram CONGR.

COMMON units: /BCONGR/ 546


4. Raw Data: EM, ESFC

5. Results, use of the area COMMON.

In the unit COMMON/BCONGR/ANM (273), BNM (273), in accordance with table 2.5, the values of $C_{nm}$ are dispatched to array ANM, and the values $\beta_{nm}$ are dispatched to array BNM.
Table 2.1 Astronomical units, gravitational characteristics, parameters of the Earth's ellipsoid, angular velocity of the Earth's rotation.

<table>
<thead>
<tr>
<th>Units</th>
<th>Identifiers</th>
<th>Type</th>
<th>Designation</th>
<th>Values (kg, m, sec.)</th>
<th>Dimensions</th>
<th>Contents</th>
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<tr>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td>149597.810^6</td>
<td>M^2/sec</td>
<td>astronomical unit</td>
</tr>
<tr>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td>6223750.473</td>
<td>M^2/sec</td>
<td>parameters of the Earth's normal gravitational field</td>
</tr>
<tr>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td>-67795.4965</td>
<td>M^2/sec</td>
<td>resolution ratio of the Earth's gravitational field</td>
</tr>
<tr>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td>931.4143</td>
<td>M^2/sec</td>
<td>Additional according to spherical functions</td>
</tr>
<tr>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td>160.7068</td>
<td>M^2/sec</td>
<td>effect of the gravitational constant on masses according to spherical functions</td>
</tr>
<tr>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td>199.29772</td>
<td>M^2/sec</td>
<td>scale factors for the acceleration of forces of gravity on the Earth's surface</td>
</tr>
<tr>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td>9.80665</td>
<td>M^2/sec</td>
<td>semi-major axis of the Earth's Ellipsoid</td>
</tr>
<tr>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td>6378388</td>
<td>M^2/sec</td>
<td>contraction of the Earth's ellipsoid</td>
</tr>
<tr>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td>6371000</td>
<td>M^2/sec</td>
<td>angular velocity of the earth's rotation.</td>
</tr>
<tr>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td>6378140</td>
<td>M^2/sec</td>
<td>2\omega_3</td>
</tr>
<tr>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td>0.00335289187</td>
<td>M^2/sec</td>
<td>\omega_3</td>
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</table>

**REAL**
Table 2.2 Constants used in the measurement of time.

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<th>Identifiers</th>
<th>Type</th>
<th>Values</th>
<th>Content</th>
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<tr>
<td>1</td>
<td>1/CSDAY/4</td>
<td>SDAY</td>
<td>REAL</td>
<td>66400</td>
<td>1 days in seconds</td>
</tr>
<tr>
<td>2</td>
<td>2/CT3/3</td>
<td>T3</td>
<td>REAL</td>
<td>10800</td>
<td>3 hours in seconds</td>
</tr>
<tr>
<td>3</td>
<td>3/CKDM/15</td>
<td>KDM</td>
<td>INTEGER ARRAY</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>interval of time</td>
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<td></td>
<td></td>
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<td></td>
<td>in days from Greenwich midnight, January 1, of the current year to Greenwich midnight on the first day of the corresponding month:</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>number of days in the year</td>
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<tr>
<td>4</td>
<td>4/CDSJS/8</td>
<td>DSJS</td>
<td>REAL</td>
<td>36525</td>
<td>Julian centuries in ephemeris days</td>
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Table 2.3 Auxilliary constants, scale factors

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<thead>
<tr>
<th>No.</th>
<th>PI</th>
<th>PID2</th>
<th>PI2</th>
<th>DEGR/15</th>
<th>DEGR</th>
<th>HRAD</th>
<th>E2</th>
<th>E3</th>
<th>E4</th>
<th>E6</th>
<th>C60</th>
<th>E3600</th>
<th>ESEC</th>
<th>ESEC</th>
<th>EM</th>
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<th>EM/ESEC^2</th>
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<td>3</td>
<td>1</td>
<td>1.57079533</td>
<td>6.28318531</td>
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<td>100</td>
<td>1000</td>
<td>1000000</td>
<td>60</td>
<td>3600</td>
<td>3;14159265</td>
<td>2π</td>
<td>radian in degrees</td>
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Table 2.4. Characteristics of the standard five-layer model of the Earth's atmosphere: $h_i$ - layer boundaries by altitude, $A_i$, $k_{1,i}$, $k_{2,i}$ - model coefficients ($i = 1, 2, \ldots, 5$)

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Table 2.5 Resolution ratios of the Earth’s gravitational field by spherical function (unit COMMON/BCONGR/ANM (273), BNM (273)).

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Here ANM (I) = $\alpha_2 = 0$, in so far as the corresponding member of the resolution is considered to be in the Earth’s normal field (the value $\alpha_2$ is from table 2.1).
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Table 2.5 (continued)
3.1 Transition from GU, the Calendar Date, to RJD, Relative Julian Date (BO1-DATDAY)

1. Function: the program determines the RJD, the relative Julian date, the number of days which have passed since the mean Greenwich midday, January 0, 1900 until the mean Greenwich midnight of the given calendar date.

2. Structure. Subprogram: DATDAY.
Common units: /CKDM/13, /CEZ/1.


4. Raw data: DTK-real variable containing the date GU which is given by the decimal fraction of the type: DD.MM.GG, where DD is the date, MM is the month's number and GG is the year's number minus 1900 (the two last numbers of the year).

5. Results: RJD-relative Julian date.

6. Use of the COMMON units. Constants are used from the units: /CKDM/13, /CEZ/1 (No. 3 Table 2.2., No. 4 Table 2.3).

7. Algorithm: \( \text{RJD} = 365 \cdot \frac{\text{GG}}{4} + \frac{(G - 1)}{4} - 0.5 + t \)
where GG is the number of years minus 1900, the number of days passed since January 0 of the current year until the given date. \([x]\) is the whole part of \(x\).

8. Text

```
SUBROUTINE DATDAY(DATDAY)
   COMMON/CKDM/13, /CEZ/1
   H=DATDAY
   H=H-1
   I=I+1001-E2
   J=J+1011-E2
   RETURN
   E1
```

3.2 Transition from RJD (the relative Julian date) to GU, the Calendar Date (BO2-DAYDAT)

1. Function. For the moment of time, given by RJD the relative Julian Date (see p. 1.3), the calendar date is determined.
The moment of time can also be given in the form of RJD and the time $T$ in seconds (or in units given by the scale factor $ESEC$, calculated from midnight of the RJD date (the interval of time $T$ may contain any number of days). A result of the operation of subprogram DAYDAT, the interval which is a multiple for whole days is excluded from the time $T$, $TR$ is obtained, and the days excluded from $T$ are added to the date RJD and the RJDR is obtained. The calendar date is determined for the RJDR date.

2. Structure. Subprogram DAYDAT
   Common units: \text{/CSDAY/1, /CKDM/13, /CCGO/1}.

3. Access: CALL DAYDAT (RJD, T, RJDR, TR, ND, NM, NG)

4. Raw data: RJD-relative Julian date. $T$-time (in seconds), calculated from the RJD date.

5. Results: RJDR-relative Julian date; $TR$-time in seconds, calculated from the RJDR date; ND, NM, NG-whole variables containing the corresponding number, month and year (minus 1900), corresponding to the RJDR date.

6. Use of the area COMMON. Constants are used from the units COMMON/CSDAY/1, /CKDM/13, /CCGO/1 (No. 1.3 of table 2.2, No. 3 of table 2.3).

7. Algorithm. Let RJD be the reference Julian date, $T$ the time in seconds calculated from midnight of the RJD date.

   $$ RJDR = RJD + \left\lceil \frac{T}{S\text{DAY}} \right\rceil; \quad TR = T - \left\lfloor \frac{T}{S\text{DAY}} \right\rfloor \cdot S\text{DAY}, $$

   where SDAY is the number of seconds in the days, $\left\lfloor x \right\rfloor$ is the whole part of $x$.

   $$ KVG = \left( RJDR - 365 \right) / 1491; \quad K = RJDR - KVG; \quad N = K / 365, $$

   where $KVG$ is the number of leap years which have passed since 1900 to the given moment.

   $$ NG = \begin{cases} 
   N, & \text{if } 4 \left( KVG + 1 \right) - k \geq 0 \\
   N - 1, & \text{if } 4 \left( KVG + 1 \right) - k < 0. 
   \end{cases} $$

   The number of days, calculated from the beginning of the present year:

   $$ KDTG = K - 365NG + 1. $$

   The month and day of an unknown date are determined with a comparison of KDTG with the array KDM; (i=1,13), in which the i element contains the number of days which have passed since the beginning of the present year (not a leap year) to the beginning of the i-month. In the case of a leap year, when KDTG $\geq 60$ a correction is made.
3.3 Conversion of Hours, Minutes, and Seconds into Seconds

3i3-HMSSSEC)

1. Function: Originating from the time given in hours, minutes, and seconds, the time is determined in seconds.

2. Structure. Subprogram HMSSSEC
   Common units: /CE2/1,/CCG/1,/GC3600/1.


4. Raw data: HMS—the real variable, containing the time given in hours, minutes and seconds in the following form:
   0. HHHMMSSSDS, where HH is the hours, MM the minutes, and SS the seconds with fractions.

5. Results: T—the time in seconds.

6. Use of the COMMON units. Constants are used from the units COMMON/CEZ/1,/CCG/1,/GC3600/1 (Nos. 8 and 9 of Table 2.3).

7. Text.
3.4 Conversion of Seconds into Hours, Minutes, and Seconds (BO4-SECHMS)

1. Function: Originating from the time given in seconds, the time is determined in hours, minutes, and seconds.

2. Structure: Subprogram SECHMS.
   Common units: \[/CGG0/1, CC 3600/1\].

3. Access: CALL SECHMS (T, KH, KM, SE0).

4. Raw data: T-time in seconds and fractions of seconds.

5. Results: KH-hours (whole variable), KM-minutes (whole \[/23\] variable), SE0-seconds and fractions of seconds (real variable).

6. Use of the area COMMON. Constants are used from the units COMMON/CGG0/1, CC3600/1 (Nos. B and 9 of Table 2.3).

7. Text.

3.5 Stellar Time (BO5-STTIME, STT)

1. Function: Subprogram STTIME determines the stellar time S0 on the Greenwich meridian at Greenwich midnight of the given RJD date.

   Subprogram STT according to the known S0 determines stellar time ST on the Greenwich meridian at any moment of time T on the RJD date.

2. Structure: The independent subprogram STTIME and the subprogram-function STT.

   Common units: /CSDJS/1, /CPI/3, /CMZ/1, /CT3/1, /BS0/3.
3. Description of the subprogram STTIME.
Raw date: RJD—relative Julian date.
Results: SO—stellar time on the Greenwich meridian in radians (SO ≤ 2π).

Use of the units COMMON. Constants are used from the units COMMON/CDSJS/1, COP/3 (No. 4 of Table 2.2, No. 1 of Table 2.3).

Algorithm:

\[ SO = 6^h38^m45.836 + 8640184.542 T + 0.0929 T^2 + 0.061164 \Delta \psi, \]
\[ \Delta \psi = -7.23 \sin \Omega, \]
\[ \Omega = 259^010^\prime59^\prime79 - 1934^008^\prime31^\prime23T + 7^\prime48T^2 + 0^\prime0080T^3, \]
\[ T = RJD / 36525, RJD \]

4. Text.

```
SUBROUTINE STTIME(DAV, SO)
COMMON/CDSJS/CSJS
COMMON/CPI/P1,P12,P12
T=DAV/DSJS
SO=514((1.387851E-7*T+.362645634E-4-33.75714625)*T
+4.523601516))
N=int(T*33.759)
N=N-P12
N=N+N*P12
SO=(6.755E-6*T+.19511E-21)*T+1.7399359-.766385E-4*SOM+N
N=SO/P12
SO=SO-N*P12
RETURN
END
```

5. Description of the subprogram—function STT.

Access: ST-STT(T).
Raw date: T is the present moment in time in seconds, Moscow time.
Results: ST—stellar time on the Greenwich meridian in radians.

Use of the region COMMON: in the unit COMMON/BS0/S0, TS, NS the following values should be initially placed:

So—stellar time at Greenwich midnight on the date RJD, TS=0, NS=0, if T is calculated from the same RJD date.
In most cases the RJDI date and the looking of time $T$ can be less than or equal to RJD. If RJDI < RJD, then TS and NS should contain (TS in seconds, and NS in days) the interval of time between the RJDI and RJD dates.

Constants are used from the units $\text{COMMON}/\text{COMZ}/_1/\text{CT3}/_1$ (No. 14 of Table 2.1 and No. 2, Table 2.2).

Algorithm. Stellar time $ST$ is calculated according to the following approximate formula:

$$ST = S_0 + \omega_3 (T - TS - 10800^8)$$

where $\omega_3$ is the absolute angular velocity of the Earth's rotation.

$S_0$ is the stellar time at Greenwich midnight on the RJD date,

$T$ is the Moscow time, figured from the RJDI date, usually different from the RJD (RJDI < RJD) date,

$TS = 86400^8 (RJD - RJDI)$.

Text:

```fortran
FUNCTION STT(T)
COMMON /S0/, TS, NS
COMMON /C-5/,
COMMON /COMZ/,
STT=S0 + W3*(T- TS - 10800^8)
RETURN
END
```

3.6 Transition from the Absolute System of Coordinates to the Greenwich and the Reverse; from the Greenwich System to the Absolute (BOE-AGIGA, AGIGAC)

1. Function. According to the known values $X,Y,Z,V_x,V_y,V_z$ in the absolute system of coordinates, the subprogram AGIGA determines the values of $x,y,z,v_x,v_y,v_z$ in the Greenwich relative system of coordinates; the transition back is also possible: $x,y,z,v_x,v_y,v_z \rightarrow X,Y,Z,V_x,V_y,V_z$. The subprogram AGIGAC makes the same conversion possible only with the coordinates: $X,Y,Z + x,y,z$ and $x,y,z + X,Y,Z$.

2. Structure. Subprograms: AGIGA, AGIGAX
Common units: $/\text{COMZ/}_1,/\text{CT3/}_1$. 


Raw data: T-Moscow time (in seconds).

SO-stellar time on the Greenwich meridian at Greenwich midnight; Y1-array of reference values of coordinates and constituents of the velocity vector; l-indicator of the transition.

Results: YR-array of values of coordinates and constituents of the velocity vector in the resulting system of coordinates.

4. Access to AGIGAC: CALL AGIGAC(ST, X1, l, XR).

Raw data: ST-stellar time on the Greenwich meridian at the present moment of time; X1-array of base coordinate values; l-indicator of the coordinate transition (which both by its meaning and values conforms to the l parameter in subprogram AGIGA).

Results: XR-array of coordinate values in the resulting system of coordinates.

5. Use of the area COMMON: in subprogram AGIGA constants are used from the units COMMON/COM2/1/CT3/1 (No. 14, Table 2.1, No. 2, Table 2.2).

5. Algorithm: a) transition from X, Y, Z, Vx, Vy, Vz to x, y, z, vx, vy, vz is conducted according to the formula:

\[
x = X \cos \beta + Y \sin \beta, \quad v_x = V_x \cos \beta + V_y \sin \beta + \omega_3 y,
\]

\[
y = -X \sin \beta + Y \cos \beta, \quad v_y = -V_x \sin \beta + V_y \cos \beta - \omega_3 x,
\]

\[z = z, \quad v_z = V_z,
\]

where \(\beta = SO + \omega_3 (T - 3^b)\),

SO-stellar time at Greenwich midnight.

\(\omega_3\)-angular velocity of the Earth's rotation,

T-Moscow time

b) transition back from x, y, z, vx, vy, vz to X, Y, Z, Vx, Vy, Vz is conducted according to the formula:

\[
X = x \cos \beta - y \sin \beta, \quad V_x = v_x \cos \beta - v_y \sin \beta - \omega_3 y,
\]

\[
Y = x \sin \beta + y \cos \beta, \quad V_y = v_x \sin \beta + v_y \cos \beta + \omega_3 x,
\]

\[Z = z, \quad V_z = v_x.
\]
3.7 Determination of Coordinates and Constituents of the Velocity Vector in the Absolute System of Coordinates According to the Elements of Orbit (NO/2, ABS)

1. Function: according to the known elements of orbit: \( \alpha, e, i, \Omega, \omega, u \), \( X, Y, Z, V_x, V_y, V_z \) are determined.

2. Structure. Subprogram EABS
Common units: \( / \text{GCR/1} \).

3. Access: CALL EABS \((A, YA)\).

4. Raw data: Array \( A \), containing values of the orbital elements in the following order: \( \alpha, e, i, \Omega, \omega, u \). All angles should be given in radians.

5. Results: Array \( Y \), containing values of \( X, Y, Z, V_x, V_y, V_z \) in the absolute system of coordinates.

6. Application of the area COMMON. Constants are used from the unit. \( / \text{GCR/1} \) (No. 5 table 3.1).

7. Algorithm: The following correlations are used:

\[
X = r (\cos \Omega \cos u - \sin \Omega \sin u \cos i),
\]
\[
Y = r \sin u \sin i,
\]
\[
Z = r \sin \Omega \cos u + \cos \Omega \sin u \cos i.
\]
\[ V_x = V_r (\cos \Omega \cos u - \sin \Omega \sin u \cos \lambda) - V_u (\cos \Omega \sin u + \sin \Omega \cos u \cos \lambda), \]
\[ V_y = V_r (\sin \Omega \cos u + \cos \Omega \sin u \cos \lambda) - V_u (\sin \Omega \sin u - \cos \Omega \cos u \cos \lambda), \]
\[ V_z = V_r \sin u \sin \lambda + V_u \cos u \sin \lambda, \]

where
\[ r = \frac{P}{1 + e \cos \nu}, \quad \nu = u - \omega, \]
\[ V_r = (\mu / P)^{1/2} e \sin \nu, \quad V_u = (\mu / P)^{1/2} (1 + \cos \nu), \quad P = a (1 - e^2), \]
\[ \mu = \text{product of the gravitational constant into the Earth's mass}. \]

8. Text.

3.8 Determination of Orbital Elements and the Position of Points on the Orbit According to Known Coordinates and Constituents of the Velocity Vector in the Absolute System of Coordinates (508-ABSEL)

1. Function: According to the known coordinates \( X, Y, Z \) and the constituents of the velocity vector \( V_x, V_y, V_z \) in the absolute system of coordinates, the elements of orbit \( a, e, i, \Omega, \omega \), are determined as well as their position in the orbit \( u \).

2. Structure. Subprogram ABSEL

   Common units: /CGR/, /CT1/3.

   Access: CALL ABSEL (YA, A).
4. Raw data:

Array $Y_A$, containing the values of $X, Y, Z, V_x, V_y, V_z$.

5. Results: Array $A$, which contains the values of orbital elements in the following order: $\alpha, e, i, \Omega, \omega$. The values of all angles are in radians.

6. Use of the area COMMON. Constants are used from units /OCR/1, /CPI/3 (No. 5 of Table 2.1, No. 1 of Table 2.3).

7. Algorithm.

$$a = \frac{r}{(2-k)}, \quad k = \frac{rV^2}{\mu}, \quad V^2 = V_x^2 + V_y^2 + V_z^2,$$

$$r^2 = X^2 + Y^2 + Z^2, \quad e = \sqrt{1 - k(2 - k)\cos^2 Q},$$

$$\sin Q = \frac{(XV_x + YV_y + ZV_z)}{rV}, \quad i = \frac{\pi}{2} - \arctan \frac{c_3}{\sqrt{c_1^2 + c_2^2}}, \quad 0 \leq i \leq \pi,$$

$$c_1 = YV_Z - ZV_Y, \quad c_2 = ZV_X - XV_Z, \quad c_3 = XV_Y - YV_X,$$

$$c = (c_1^2 + c_2^2 + c_3^2)^{1/2},$$

$$\Omega = \arctan \left( \frac{c_1}{-c_2} \right), \quad \nu = \arctan \frac{k \sin Q \cos Q}{k \cos^2 Q - 1},$$

$$\mu = \arctan \frac{ZG}{YC_1 - XC_2}, \quad \omega = \mu - \nu,$$

$\mu$ – product of the gravitational constant into the Earth's mass.
3.9 Standard Array of Initial Conditions
(B09-TRDATE)

1. Function. Subprogram TRDATE extracts from the initial conditions, which are given in the standard form, information which is necessary for conducting navigational computations.

The initial conditions can be given in three forms: as the elements of orbit; as the coordinates and constituents of the velocity vector in the absolute (b) and Greenwich (c) system of coordinates. We will designate as PN the array which contains the initial conditions in the standard form. There are 12 elements in this array. In all three cases the first four elements and the second elements of that array contain the following parameters:

PN(1)—the number of AES and the launching date in the form of a decimal fraction, the first three numbers after the decimal point are the number of the AES, the following six numbers are the date (the year is indicated by the last two numbers);

PN(2)—the current date in the form: C.DDMMGG, where DD is the day, MM the month, and GG the year;
PN(3) - the number of revolutions;

PN(4) - the present time in the form O.HHMMSSDS, where HH is the hour, MM the minutes, and SS the seconds and fractions of seconds;

PN(11) - is the ballistic coefficient \((m^3/kgsec^2)\).

The rest of the elements of array PN are different for all three cases.

In the case a): PN(5) is the Draconian period in minutes,
PN(6) - the semimajor axis of orbit (m).
PN(7) - eccentricity,
PN(8) - angle of inclination of the orbit from the equator (degrees),
PN(9) - vertex of the orbit (degrees),
PN(10) - argument of perigee (degrees),
PN(12) - minimum altitude of the orbit (m).

In the case b): PN(5)-PN(10) contain respectively values \(X, Y, Z, V_x, V_y, V_z\); PN(12)=2

In the case c): PN(5)-PN(10) contain values \(x, y, z, v_x, v_y, v_z\);
PN(12)=1.

In both cases the coordinates are given in meters, and the constituents of the velocity vector in m/sec.

In the work results of subprogram TRDATO the angles are translated into radians, the time into seconds, and the calendar date into the RJD. The stellar time is determined for Greenwich midnight on the current date, and the initial conditions are converted into all three systems of coordinates.

Dimensional quantities are converted into the system of units given by the scale factors: EM, ESEC.

Note: If EM=1, then the initial conditions remain in meters and seconds.

2. Structure. Subprograms TRDATO.
Access to the peripheral subprograms: DATDAY (BO1), HMSSEC(B03), STTIME(BO5), AGIGA (BO6), ELABS (BO7), ABSEI (BO8).

Common units: /CDEGR/1, /CE3/1, /CO60/1.

3. Access:
CALL TRDATO (PN, NSP, DZ, RJD, NB, T, TD, SB, B, SO, A, YA, YG, EM, ESEC).
4. Raw data: Array $P_n$, which contains the initial conditions in one of the three forms described in p. 1;

EM, BSEC-scale factors.

In the case of $a$, it is necessary to make the value of $A(6)-u$ (most often the initial conditions are given in the point of the ascending vertex of orbit, where $u=0$).

5. Results: NSP—the number of the satellite; DZ—the launching date in the form: 0.DDMG; RJD—the current date as the relative Julian date; NB—the number of revolutions; T—the current time in seconds; TD—the period in minutes; SB—the ballistic coefficient; $B$—minimum altitude of the orbit; SO—stellar time at Greenwich midnight on the current date;

Array $A_6$—which contains the elements of orbit $\alpha, e, \iota, \Omega, \omega, u$

(angles in radians);

Array $Y_A$—which contains $X, Y, \iota, V_x, V_y$;

Array $Y_G$—which contains $x, y, z, v_x, v_y, v_z$.

6. Use of the area COMMON: Constants are used from the units:
/CDEGR/1, /C23/1, /CCG/1 (Nos. 2, 5 and 8 of Table 2.3).

7. Text.

```
J = 1, 1, /PI, (0H, USO, DZ, T, IT, T2, T3, SR, R, SO, a, XA, XG, 
F, * E SEC) 
J = 1, 1, /PI, (0H, USO, DZ, T, IT, T2, T3, SR, R, SO, a, XA, XG, 
F, * E SEC) 
J = 1, 1, /PI, (0H, USO, DZ, T, IT, T2, T3, SR, R, SO, a, XA, XG, 
F, * E SEC) 
J = 1, 1, /PI, (0H, USO, DZ, T, IT, T2, T3, SR, R, SO, a, XA, XG, 
F, * E SEC) 
J = 1, 1, /PI, (0H, USO, DZ, T, IT, T2, T3, SR, R, SO, a, XA, XG, 
F, * E SEC) 
```

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```
3.10 Altitude of the AES over the Earth's Surface, the Geographic Latitude and Longitude, the Geocentric Latitude of a Sub-Satellite Point.

(BIO-GEORC, HEIGHT, GCITIN)

1. Function. Using the known Greenwich coordinates \( x, y, z \) of the AES, the subprogram GEOGRc determines \( h \) -- the altitude of the AES above the surface of the Earth's ellipsoid and, \( \varphi, \lambda \) -- the geographical latitude and longitude of the sub-satellite point; subprogram HEIGHT determines only \( h \); subprogram GCITIN determines \( \varphi_{GC}, \lambda \) the geocentric latitude and longitude of the sub-satellite point. For subprograms HEIGHT and GCITIN, \( x, y, \) and \( z \) can also be given in the absolute system of coordinates; in this case there is the right ascension of the AES.

2. Structure. Independent subprograms:

- GEOGRc, HEIGHT, GCITIN.
- Common units: /CAE/1, /CAE/1, /CC/1/2, /CPF/3.

3. Access:

- CALL GEOGRc (X, HC, AIT, AIN, XNG),
- CALL HEIGHT (X, HC),
- CALL GCITIN (X, AITC, AIN).

4. Raw data: Array X3, which contains the values of \( x, y, z \) (for GEOGRc only in the Greenwich frame of axes).

5. Results:

- \( h \) -- the altitude of the AES above the surface of the Earth's ellipsoid;
- \( \varphi, \lambda \) -- the geographic altitude and longitude of the sub-satellite point;
- array XNG3, which contains the cosines of the peripheral standard which is directed towards the Earth's ellipsoid;
- \( \varphi_{GC}, \lambda \) -- the geocentric latitude and longitude of the sub-satellite point.

6. Use of the area COMMON.

In subprogram HEIGHT constants are used from the units COMMON/CAE/1, /CAE/1, /CC/1/2, /CPF/3 (Nos. 11, 12 and 13 of Table 2.1 and No. 1 of Table 2.3), in subprogram HEIGHT constants are used from units: /CAE/2, /CAE/1 and in subprogram GCITIN from unit /CPF/3.

7. Algorithm

\[ h = r - a_e + a_e a z^2/r^2, \]
\[ \varphi = \arctan \left( \frac{z}{r_1 (1 - \alpha')} \right), \quad -\pi/2 < \varphi < \pi/2, \]
\[ \lambda = \arctan \left( \frac{y}{x} \right), \quad 0 < \lambda < 2\pi, \]

where \( r = (x^2 + y^2 + z^2)^{1/2} \), \( r_1 = (x^2 + y^2)^{1/2} \).
\( \alpha_c, \alpha \) is the semimajor axis and the contraction of the Earth's whole ellipsoid.

\[ \phi_{GC} = \arccos \left( \frac{z}{r_2} \right) \] - the geocentric latitude.

\[ x_0^0 = x_0 (1 - \alpha)^2 / r_2, \quad y_0^0 = y_0 (1 - \alpha)^2 / r_2, \quad z_0^0 = z / r_2, \]

where \( x_0^0, y_0^0, z_0^0 \) the cosines of the peripheral standards directing towards the Earth's ellipsoid,

\[ r_2 = \left\{ r_1^2 (1 - \alpha)^2 + z^2 \right\}^{1/2}. \]

8. Texts.

SUBROUTINE GECCRC(X,HC,AL;ALT;ALN;XE)
COMMON/CCLZ/CLZ
COMMON/CAE/AE=AL
COMMON/CPI/P1;PID2;P12
COMMON/CAEL/AEL
DIMENSION V(2),CU(2),X(6),XE(3)
R12=X(1)*X(1)+X(2)*X(2)
R=V(3)*V(3)
R2=R12+R
HC=SQR(R2)-AE+AEL*W/R2
CU(1)=X(1)
CU(2)=CLZ*SQR(R12)
W=SQR(V(2)+CU(2)+CU(2))
DO 1 J=1,2
IF(CU(J))2,3,2
2 U(J)=SIGN(PID2,X(J+1))
GOTO 4
1 CONTINUE
XE(J)=X(J+1)/CU(J)
AL=U(2)
ALN=U(1)
IF(CU(1))3,6,6
5 ALN=ALN+P1
6 IF(ALN)7,8,8
7 ALN=ALN+P12
8 RETURN
END

SUBROUTINE GECCRC(X,HC,AL;ALT;ALN;XE)
COMMON/CCLZ/CLZ
COMMON/CAE/AE=AL
COMMON/CPI/P1;PID2;P12
COMMON/CAEL/AEL
DIMENSION V(2),CU(2),X(6),XE(3)
R12=X(1)*X(1)+X(2)*X(2)
R=V(3)*V(3)
R2=R12+R
HC=SQR(R2)-AE+AEL*W/R2
CU(1)=X(1)
CU(2)=CLZ*SQR(R12)
W=SQR(V(2)+CU(2)+CU(2))
DO 1 J=1,2
IF(CU(J))2,3,2
2 U(J)=SIGN(PID2,X(J+1))
GOTO 4
1 CONTINUE
XE(J)=X(J+1)/CU(J)
AL=U(2)
ALN=U(1)
IF(CU(1))3,6,6
5 ALN=ALN+P1
6 IF(ALN)7,8,8
7 ALN=ALN+P12
8 RETURN
END

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4.1 Position of the Moon (COL-SELENA)

1. Function: The subprogram determines the position of the moon in the absolute geographical system of coordinates for the moment of time which is given by the relative Julian date and Moscow time in seconds.

2. Structure. Subprogram SELENA.

   Common units: /CRE/1,/CSDAY/1,/CT3/1,/CDSJS/1,/CPL/3.


4. Raw data: RJD-relative Julian date; T- Moscow time in seconds.

5. Results: Array XS, which contains the direction cosines of the radius vector of the Moon in the absolute system of coordinates; RS-the module of the Moon's radius vector.

6. Use of the area COMMON. Constants are used from the units: /CRE/1,/CSDAY/1,/CT3/1,/CDSJS/1,/CPL/3 (No. 9 of Table 2.1, Nos. 1,2,4, of Table 2.2, No. 1 of Table 2.3).

7. Algorithm:

   \[ X_\alpha = \cos \alpha \cos \delta = \cos \beta \cos \lambda, \]
   \[ Y_\alpha = \sin \alpha \cos \delta = \cos \beta \sin \lambda \cos \varepsilon - \sin \beta \sin \varepsilon, \]
   \[ Z_\alpha = \sin \delta = \cos \beta \sin \lambda \sin \varepsilon + \sin \beta \cos \varepsilon. \]

In accordance with Brown's theory of approximation, presented in [7], which guarantees a prediction of the Moon's position with an accuracy to 30'', the following correlations are used:

\[ \varepsilon = 23^\circ 27' 08'' 26 - 46^\circ 845 T^2 + 0',0059 T^2 + 0',00181 T^3; \]
\[ \ell = 296^\circ 06' 16'' 59 + 4779850' 56'' 79 T + 33',09 T^2 + 0',0548 T^3; \]
\[ \ell' = 358^\circ 28' 33',04 + 35999' 02' 59',10 T - 0',54 T^2 - 0',0120 T^3; \]
\[ F = 11^\circ 45' 03'' 20 + 483202' 01'',30' 54 T - 11'',56 T^2 - 0',0012 T^3; \]
\[ D = 350^{0} 44^{\prime} 14^{\prime\prime} 95 + 445267^{0} 06^{\prime} 51^{\prime} 18T - 5^{\prime} 17T^{2} + 0.0068T^{3} \]

\[ \lambda_{e} = 270^{0} 26^{\prime} 02^{\prime\prime} 99 + 481267^{0} 52^{\prime} 59^{\prime} 31T - 4^{\prime} 08T^{2} + 0.0068T^{3} + 22639^{\prime} 58 \sin \ell - 4586^{\prime} 438 \sin (\ell - 2D) + 2369^{\prime} 899 \sin 2D + 769^{\prime} 021 \sin 2\ell - 668^{\prime} 944 \sin \ell' - 411^{\prime} 614 \sin 2F - 244^{\prime} 658 \sin (2\ell - 2D) - 206^{\prime} 219 \sin (\ell + \ell' - 2D) + 191^{\prime} 954 \sin (\ell + 2D) - 165^{\prime} 351 \sin (\ell' - 2D) + 147^{\prime} 878 \sin (\ell' - \ell) - 124^{\prime} 785 \sin D - 109^{\prime} 804 \sin (\ell + \ell') - 55^{\prime} 174 \sin (2F - 2D) - 45^{\prime} 100 \sin (\ell + 2F) + 39^{\prime} 532 \sin (\ell - 2F) - 38^{\prime} 428 \sin (\ell - 4D) + 36^{\prime} 124 \sin 3\ell - 30^{\prime} 773 \sin (2\ell - 4D) - 28^{\prime} 511 \sin (\ell' - 2D) - 24^{\prime} 451 \sin (\ell' + 2D); \]

\[ \beta_{e} = 18461^{\prime} 480 \sin F + 1010^{\prime} 18 \sin (\ell + F) - 999^{\prime} 695 \sin (F - \ell) - 623^{\prime} 658 \sin (F - 2D) + 199^{\prime} 485 \sin (F + 2D - \ell) - 166^{\prime} 577 \sin (\ell + F - 2D) + 117^{\prime} 262 \sin (F + 2D) + 61^{\prime} 913 \sin (2\ell + F) - 33^{\prime} 959 \sin (F - 2D - \ell); \]

\[ \pi_{e} = 342^{\prime} 7 186^{\prime} 5898 \cos \ell + 34^{\prime} 317 \cos (\ell - 2D) + 28,233 \cos 2D + 10^{\prime} 1657 \cos 2\ell + 5^{\prime} 0861 \cos (\ell + 2D) + 1^{\prime} 9202 \cos (\ell' - 2D) + 1^{\prime} 4455 \cos (\ell + \ell' - 2D) + 1^{\prime} 1542 \cos (\ell - \ell') - 0^{\prime} 9752 \cos D - 0^{\prime} 9502 \cos (\ell + \ell') - 0^{\prime} 7136 \cos (\ell - 2F) + 0^{\prime} 6215 \cos 3\ell + 0^{\prime} 6008 \cos (\ell - 4D); \]

\[ Z_{e} = 206264,81 R_{\oplus} / \pi_{e}, \]

where \( R_{\oplus} \) is the equatorial radius of the Earth.

\[ \frac{T - RJD}{36525}, \]

\[ RJD \text{ relative Julian date in days}, \]

\[ T \text{ - the same interval of time in Julian centuries} \]

\[ \ell \text{ - the median anomaly of the Moon}, \]

\[ \ell' \text{ - the median anomaly of the Sun}, \]

\[ F \text{ - the median argument of the Moon's latitude}, \]

\[ D \text{ - the difference between the median longitudes of the Moon and Sun}, \]

\[ \alpha \text{ - the Moon's longitude}, \]

\[ \beta_{e} \text{ - the Moon's declination}, \]

\[ \pi_{e} \text{ - the Moon's parallax} \]
8. Text.
SUBROUTINE SELENA(DT,T,S,P)
DIMENSION S(3),A(32),B(17)
COMMON/CT3/T3
COMMON/CP1/P1,P102,P12
COMMON/CDSJS/DSJS
COMMON/CDAY/SDAY
COMMON/CRE/RE
TR=DT/DSJS+(T-T3)/SDAY/DSJS
S(1)=((.677912763E-8*TR-.286040072E-7)*TR
  -.227110969E-3)*TR+.409319753
W=6326.691*TR
N=N/P12
W=W*P12
A(4)=((.25113487E-6*TR+.16424847F-3)*TR
  +.1056971E-3)*TR+.168000347*W
N=N/P12
W=W*P12
A(27)=((.81776417E-7*TR-.261799388E-5)*TR
  +.942570201E-3)*TR+.296583776*W
N=N/P12
W=W*P12
A(17)=((.601776417E-8*TR-.5604441E-4)*TR
  +.295093537E-3)*TR+.1963655349*W
N=N/P12
W=W*P12
A(3)=2.*A(2)
A(5)=2.*A(4)
DO 1 J=4,7
1 A(J-2)=A(J)-A(3)
DO 2 J=4,6,2
A(J+7)=A(J)+A(27)
2 A(J+5)=A(J)-A(27)
J J=3,2
L=L+(J=1)*14
A(L)=A(17)+A(J)
3 A(L+1)=A(17)+A(J)
A(L+2)=A(27)+A(3)
A(L+3)=3.*A(4)
A(L+4)=2.*A(17)
A(L+5)=A(L+4)-A(3)
A(L+6)=A(4)+A(L+4)
A(L+7)=A(4)-A(L+4)
A(L+8)=A(L+7)+A(17)
A(L+9)=A(L+6)+A(17)
A(L+10)=A(L+6)+A(13)
A(L+11)=A(L+6)+A(4)
A(L+12)=A(L+2)+A(3)
1. Function: The subprogram determines the position of the sun in the absolute geographic frame of axes for the moment of time, which is given as the RJD and as Moscow time in seconds.

2. Structure. Subprogram SUN.

Common units: /CAED/1, /CSDAY/1, /CT3/1, /CDSJS/1, /CP1/3, /BIECI/2

4.2 Position of the Sun (CO2-SUN)

```
41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60
```

5. Raw data: RJD-relative Julian date;
   T-Moscow time in seconds

5. Results: RS-the module of the Sun's radius vector; AS, BS-
   the corresponding right ascension and declination of the Sun; array
   XS$_3$-directing cosines of the Sun's radius-vector.

6. Use of the area COMMON. Constants are used from the units:
   /CAED/1, /CSDAY/1, /CT3/1, /CDSJS/1, /CP1/3 (No. 1 of Table 2.1, Nos. 1,2, 4, of Table 2.2, No. 1 of Table 2.3). Into the unit COMMON/BIECL/2 are dispatched the values \( \cos\psi, \sin\psi \), which are defined below.

\[
\begin{align*}
\Omega &= 239^\circ 10' 59.79 - 1934^\circ 08' 31'' 23T + 7.48T^2 + 0.008T^3; \\
\psi &= 23^\circ 27' 08''.26 - 46.845T - 0.0059T^2 + 0.00181T^3 + 9.21\cos\Omega; \\
\theta &= 0.01675104 - 0.0000418T - 0.00000126T^2,
\end{align*}
\]

7. Algorithm
\[
\begin{align*}
\alpha &= \arctan(\sin\lambda_0 \cos\psi / \cos\lambda_0) (0.0611164.17\Delta \psi) - 20^\circ 496; \\
\delta &= \arctan(\sin\lambda_0 \sin\psi / (\cos^2\lambda_0 + \sin^2\lambda_0 \cos^2\psi))^{1/2} - 20^\circ 496 \sin\psi \cos\alpha_0; \\
\lambda &= \lambda + 2e_0 \sin(\lambda - \pi) + \frac{5}{4} e_0 \sin 2(\lambda - \pi); \\
r &= \alpha \{ 1 - e_0 \cos M_0 + e_0 \left( 1 - \cos 2M_0 \right) / 2 \}; \\
\pi &= 281^\circ 13' 15'' + 6189''.037 + 1.63T^2 + 0.12T^3; \\
\Delta \psi &= -17.23 \sin\Omega; \\
\alpha &= 1.00000023 \alpha_c; \\
M_0 &= \bar{\lambda} - \pi = 279^\circ 41' 48'' 04 + 129602768'' 13T + 1'' 089T^2; \\
\end{align*}
\]

where \( T = \text{RJD/36525} \)

RJD-relative Julian date in days,
T-the same interval of time in Julian centuries,
\( X_0 = \cos\alpha_0 \cos\delta_0 \),
\( Y_0 = \sin\alpha_0 \cos\delta_0 \),
\( Z_0 = \sin\delta_0 \).
\begin{verbatim}
UCTU 1
\end{verbatim}
5.1 The Standard Five-Layer Model of the Earth's Atmosphere (DC1-RO)

1. Function: Subprogram RO calculates values for the density of the Earth's atmosphere \( p \) at the point given by the altitude above the Earth's surface.

2. Structure. Subprogram RO.
   Common units: /CHA/20.

3. Access: RO (HC\( _1 \)P).

4. Raw data: HC-altitude above the Earth's surface.

5. Results: \( p \)-the atmospheric density.

6. Use of the area COMMON. Constants are used from the unit /CHA/20 (Table 2.4).

7. Algorithm

\[
p = A_i \exp \left( k_{1i} (h - h_i)^2 - k_{2i} (h - h_i) \right),
\]

where \( h \) is the altitude over the Earth's surface, \( A_i, k_{1i}, k_{2i} \) are the coefficients depending on the altitude \( h \) (Table 5.1).

<table>
<thead>
<tr>
<th>( i )</th>
<th>( h_i \leq h &lt; h_{i+1}(M) )</th>
<th>( A_i(\times 10^{-7}) )</th>
<th>( k_{1i}(\times 10^{-9}) )</th>
<th>( k_{2i}(\times 10^{-9}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100000 \leq h &lt; 150000</td>
<td>0.4141</td>
<td>0.1469</td>
<td>0.1767</td>
</tr>
<tr>
<td>2</td>
<td>150000 \leq h &lt; 300000</td>
<td>0.2173</td>
<td>0.8004</td>
<td>0.3734</td>
</tr>
<tr>
<td>3</td>
<td>300000 \leq h &lt; 600000</td>
<td>0.4861</td>
<td>0.7111</td>
<td>0.1547</td>
</tr>
<tr>
<td>4</td>
<td>600000 \leq h &lt; 900000</td>
<td>0.3904</td>
<td>0.1831</td>
<td>0.9275</td>
</tr>
<tr>
<td>5</td>
<td>900000 \leq h</td>
<td>0.6497</td>
<td>0.8540</td>
<td>10^{-5}</td>
</tr>
</tbody>
</table>

38
5.2. Model of the Earth's Atmosphere, with a Calculation for the Influence of Solar Radio Emission at Wavelength 10.7 cm of Geomagnetic Disturbance, Daily and Semiannual Effects (DO2-VKMA, DENs)

1. Function. According to the given positions of the point and Sun, and according to the values of the indexes $F_{10.7}$ (the intensity of solar radio emission at wave 10.7 cm) and $a_p$ (three hour indexes of the geomagnetic disturbance), the subprogram DENS determines the atmospheric density at the given moment of time.

Coefficients of the model of the atmosphere are chosen with the help of subprogram VKMA depending on $F_0$, the mean level of solar activity.

2. Structure. The packet of subprograms:

VKMA, DENS.
Peripheral devices: printer
Common units: /AKOEF/50, /SYBAR/38.

3. Access to VKMA: CALL VKMA (F).

Raw data: $F$ - the mean value of solar activity.
Possible values of $F$: 75, 100, 125, 150. If $F$ differs from the indicated values, then a stop should occur, whereupon the printer reads: "F incorrectly given."

Results: Into the unit COMMON/OKO EF/A(50), are sent values of coefficients of the model according to Table 5.2, and into the unit COMMON/SYBAR/F38 is the set of numerical corrections on the semiannual effect according to Table 5.3.

Author of the subprogram M.I. Voyskovskiy.
4. Access to DENS:
 CALL DENS (HC,X,Y,Z,SUN,AP,F107,D,I,RO).
Raw data: HC-altitude above the Earth's surface in km; X,Y,Z-directing cosines of the radius-vector in the absolute system of coordinates; the array SUN, which contains the values \( \alpha, \delta \) (right ascension and declination of the sun in radians);

AP-the value \( AP \) at the moment of time \( t - \Delta T_{AP} \), where \( t \) is Moscow time (for isolating the calculation of the influence of geomagnetic disturbance it is sufficient to let \( AP < 0.5 \));

F107-the \( F_{107} \), at the moment of time \( t - \Delta T_{F} \), where \( t \) is Moscow time (for isolating the calculation of the influence of solar activity it is sufficient to let \( F_{107} < 0.5 \));

D-the date and Moscow time in the form of the number of days from the beginning of the year (for isolating the calculation of the semiannual effect it is sufficient to let \( D < 0 \));

I-the parameter controlling the calculation of the daily effect (DE):
if \( I < 0 \), then DE is considered memberless with the coefficient \( C_i \);
if \( I = 0 \), then DE is not considered;
if \( I > 0 \), then DE is considered in its entirety.

Results: Array RO, which contains values of five factors, each of which takes into consideration its effect in the modes of atmospheric density (see p. 6) and the value of the density:

\[
RO(1) = k_4,
RO(2) = k_2, \quad RO(3) = k_3, \quad RO(4) = k_5, \quad RO(5) = \rho_H, \quad RO(6) = \rho_H k_1 k_2 k_3 k_4.
\]

5. Use of the area COMMON:
In subprogram DENS coefficients of the atmosphere model and corrections for semiannual effects, whose values are assigned by a preliminary accessing to subprogram VKMA, are used from the common units /QKOEF/50 and /SYEAP/38.

6. Algorithm
The density \( \rho \) is calculated according to the formula:
\[
\rho = \rho_H \cdot k_1 k_2 k_3 k_4, \quad \text{where} \quad k_4 \quad \text{is the nighty vertical}
\]
$c_{ioss}$ section of the atmospheric density.

$k_1$ - is the factor which allows for the influence of measurements of the intensity of solar radio emission $F$ at wavelength 10.7 cm relative to certain mean levels of solar radio emission.

$k_2$ - the factor which allows for daily effects in the dispersion of the atmosphere.

$k_3$ - correction for the semiannual effect.

$k_4$ - the factor which allows for the correlation between changes in the atmospheric density and geomagnetic disturbances.

\[
f_{i} = c \exp\left(\alpha_1 - \hat{a}_2 (h - \alpha_3)^{1/2}\right);
\]

\[
k_1 = 1 + \left(b_1 + b_2 h\right)\left(F - F_0\right) / F_0;
\]

\[
k_1 = 1 + \left(c_1 + c_2 h + c_3 \exp\left(-\left(h + c_4\right)^2/c_5^2\right)\right) \left(\cos^m \gamma_1 / 2 \cdot c_6 \cos^m \gamma_2 / 2\right);
\]

\[
k_2 = 1 + \left(A_1 + A_2 h\right) A(d);
\]

where

\[
\cos \psi_1 = Z^* \sin \delta_\od + \cos \delta_\od (\lambda^* \cos \gamma_1 + Y^* \sin \gamma_1);
\]

\[
\cos \psi_2 = -Z^* \sin \delta_\od + \cos \delta_\od (\lambda^* \cos \gamma_2 + Y^* \sin \gamma_2);
\]

\[
\gamma_1 = \alpha_\od + \varphi_1, \quad \gamma_2 = \alpha_\od + \varphi_2,
\]

\[\gamma_1 \]

- the altitude above the Earth's surface.

- the directing cosines of the radius-vector of a point in the absolute system of coordinates.

- the right ascension and declination of the Sun.

- the date and time in the form of the number of days, counted from the beginning of the year.

$A(d)$ - correction for the semiannual effect (the volumes of are shown in Table 5.3, with 10 day increments of time, the intermediate moments of time $A(d)$ exists as a linear interpolation).

$F$ - the intensity of solar radio emission at 10.7 cm.

$\alpha_p$ - the three hour index of geomagnetic disturbance.

The values $F$ and $\alpha_p$ should be at the moment of time, respectively: $t_F = t - \Delta t_F$ and $t_{\alpha_p} = t - \Delta \tau_{\alpha_p}$ where $t$ is Moscow time, $\Delta t_F$ and $\Delta \tau_{\alpha_p}$ are the "time lags" of changes in the density of the atmosphere which correlate to a
corresponding change of the quantities \( F \) and \( \alpha_p \). The values \( \Delta \tau_{\alpha_p} \) and \( \Delta \tau_F \) are shown in Table 5.2, and also are \( \Delta t_F \), \( \Delta t_{\alpha_p} \), the duration of intervals in the course of which the quantities \( F \) and \( \alpha_p \) are maintained by the constants and tabular values which are equal to them.

In table 5.2 are also the coefficients of the model: \( a_1, a_2, a_3; b_1, b_2, \ldots, \bar{\alpha}_p \), which depend on the mean level of solar radio emission \( F_0 \).

Table 5.2 Values of coefficients of the atmospheric model depending on the mean level of solar radio emission \( F_0 \times 10^{-2} \) W.m\(^{-2}\)Hz\(^{-1}\) (units COMMON/QKOEF/Q50).

<table>
<thead>
<tr>
<th>Designations</th>
<th>( Q(i) )</th>
<th>( Q(i) )</th>
<th>( Q(i) )</th>
<th>( Q(i) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F_0 )</td>
<td>75</td>
<td>100</td>
<td>125</td>
<td>150</td>
</tr>
<tr>
<td>2 ( a_1 )</td>
<td>-10,030</td>
<td>-15,095</td>
<td>-17,028</td>
<td>-16,072</td>
</tr>
<tr>
<td>3 ( a_2 )</td>
<td>0,9108</td>
<td>0,8229</td>
<td>0,7198</td>
<td>0,7155</td>
</tr>
<tr>
<td>4 ( a_3 )</td>
<td>59,77</td>
<td>68,82</td>
<td>93,36</td>
<td>70,33</td>
</tr>
<tr>
<td>5 ( b_1 )</td>
<td>-0,630</td>
<td>-0,750</td>
<td>-0,710</td>
<td>-0,765</td>
</tr>
<tr>
<td>6 ( b_2 )</td>
<td>0,00506</td>
<td>0,00560</td>
<td>0,00562</td>
<td>0,00571</td>
</tr>
<tr>
<td>7 ( e_1 )</td>
<td>0,130</td>
<td>0,172</td>
<td>-0,274</td>
<td>-0,247</td>
</tr>
<tr>
<td>8 ( e_2 )</td>
<td>0,00014</td>
<td>0,00217</td>
<td>0,00257</td>
<td>0,00199</td>
</tr>
<tr>
<td>9 ( c_2 )</td>
<td>3,733</td>
<td>3,784</td>
<td>4,048</td>
<td>4,698</td>
</tr>
<tr>
<td>10 ( c_3 )</td>
<td>-507,95</td>
<td>-566,71</td>
<td>-632,63</td>
<td>-707,58</td>
</tr>
<tr>
<td>11 ( c_4 )</td>
<td>189,85</td>
<td>200,97</td>
<td>230,76</td>
<td>278,35</td>
</tr>
<tr>
<td>12 ( c_5 )</td>
<td>0,041</td>
<td>0,047</td>
<td>-0,038</td>
<td>-0,012</td>
</tr>
<tr>
<td>13 ( m_1 )</td>
<td>4,2</td>
<td>4,1</td>
<td>4,4</td>
<td>5,2</td>
</tr>
<tr>
<td>14 ( m_2 )</td>
<td>6,0</td>
<td>6,0</td>
<td>5,9</td>
<td>5,9</td>
</tr>
<tr>
<td>15 ( q_1 )</td>
<td>37°4,4</td>
<td>34°5,5</td>
<td>33°8</td>
<td>33°8</td>
</tr>
<tr>
<td>16 ( q_2 )</td>
<td>325°9</td>
<td>318°0</td>
<td>308°0</td>
<td>322°2</td>
</tr>
<tr>
<td>17 ( A_1 )</td>
<td>-0,602</td>
<td>-0,526</td>
<td>-0,513</td>
<td>-0,607</td>
</tr>
<tr>
<td>18 ( A_2 )</td>
<td>0,00636</td>
<td>0,00636</td>
<td>0,00631</td>
<td>0,00670</td>
</tr>
<tr>
<td>19 ( c_1 )</td>
<td>-0,132</td>
<td>-0,137</td>
<td>-0,128</td>
<td>-0,115</td>
</tr>
<tr>
<td>20 ( c_2 )</td>
<td>0,00108</td>
<td>0,00104</td>
<td>0,00095</td>
<td>0,00089</td>
</tr>
<tr>
<td>21 ( \Delta \tau_F )</td>
<td>39h</td>
<td>39h</td>
<td>39h</td>
<td>39h</td>
</tr>
<tr>
<td>22 ( \Delta \tau_{\alpha_p} )</td>
<td>10h,5</td>
<td>10h,5</td>
<td>10h,5</td>
<td>10h,5</td>
</tr>
<tr>
<td>23 ( \delta )</td>
<td>4h</td>
<td>4h</td>
<td>4h</td>
<td>4h</td>
</tr>
<tr>
<td>24 ( \delta_{\alpha_p} )</td>
<td>1h</td>
<td>1h</td>
<td>1h</td>
<td>1h</td>
</tr>
<tr>
<td>25 ( \bar{\alpha}_p )</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>
Table 5.3 Corrections for the semiannual effect in dependence on \( d \) and the number of days since the beginning of the year (unit COMMON/SY"BAR/P(38)).

<table>
<thead>
<tr>
<th>( i )</th>
<th>( d )</th>
<th>( i \times P(i) - A(d) )</th>
<th>( i \times d )</th>
<th>( P(i) - A(d) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>-0.067</td>
<td>0</td>
<td>-0.067</td>
</tr>
<tr>
<td>1</td>
<td>10</td>
<td>-0.083</td>
<td>100</td>
<td>-0.183</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>-0.094</td>
<td>300</td>
<td>-0.183</td>
</tr>
<tr>
<td>3</td>
<td>40</td>
<td>-0.093</td>
<td>400</td>
<td>-0.183</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
<td>-0.035</td>
<td>500</td>
<td>-0.035</td>
</tr>
<tr>
<td>5</td>
<td>60</td>
<td>0.039</td>
<td>600</td>
<td>0.039</td>
</tr>
<tr>
<td>6</td>
<td>70</td>
<td>0.090</td>
<td>700</td>
<td>0.090</td>
</tr>
<tr>
<td>7</td>
<td>80</td>
<td>0.123</td>
<td>800</td>
<td>0.123</td>
</tr>
<tr>
<td>8</td>
<td>90</td>
<td>0.133</td>
<td>900</td>
<td>0.133</td>
</tr>
<tr>
<td>9</td>
<td>100</td>
<td>0.126</td>
<td>1000</td>
<td>0.126</td>
</tr>
<tr>
<td>10</td>
<td>110</td>
<td>0.099</td>
<td>1100</td>
<td>0.099</td>
</tr>
<tr>
<td>11</td>
<td>120</td>
<td>0.059</td>
<td>1200</td>
<td>0.059</td>
</tr>
<tr>
<td>12</td>
<td>130</td>
<td>0.017</td>
<td>1300</td>
<td>0.017</td>
</tr>
<tr>
<td>13</td>
<td>140</td>
<td>-0.027</td>
<td>1400</td>
<td>-0.027</td>
</tr>
<tr>
<td>14</td>
<td>150</td>
<td>-0.065</td>
<td>1500</td>
<td>-0.065</td>
</tr>
<tr>
<td>15</td>
<td>160</td>
<td>-0.103</td>
<td>1600</td>
<td>-0.103</td>
</tr>
<tr>
<td>16</td>
<td>170</td>
<td>-0.136</td>
<td>1700</td>
<td>-0.136</td>
</tr>
<tr>
<td>17</td>
<td>180</td>
<td>-0.155</td>
<td>1800</td>
<td>-0.155</td>
</tr>
</tbody>
</table>

7. Text.

SUBROUTINE VK01A (I)
COMMON/CK0DR/C(50)/SKEA/P(38)
DIMENSION R(100), S(36)
DATA 5/-, 0.97, -1.01, -0.65, -0.35, 0.4, 1.25,
      0.133, 0.125, 0.09, 0.057, 0.017, 0.007, 0.003, 0.001,
      -0.133, -0.125, -0.09, -0.057, -0.017, -0.007, -0.003, -0.001,
      0.133, 0.125, 0.09, 0.057, 0.017, 0.007, 0.003, 0.001,
      -0.133, -0.125, -0.09, -0.057, -0.017, -0.007, -0.003, -0.001,
      0.133, 0.125, 0.09, 0.057, 0.017, 0.007, 0.003, 0.001,
      -0.133, -0.125, -0.09, -0.057, -0.017, -0.007, -0.003, -0.001,
      0.133, 0.125, 0.09, 0.057, 0.017, 0.007, 0.003, 0.001,
      -0.133, -0.125, -0.09, -0.057, -0.017, -0.007, -0.003, -0.001,
      0.133, 0.125, 0.09, 0.057, 0.017, 0.007, 0.003, 0.001,
      -0.133, -0.125, -0.09, -0.057, -0.017, -0.007, -0.003, -0.001,
      0.133, 0.125, 0.09, 0.057, 0.017, 0.007, 0.003, 0.001,
      -0.133, -0.125, -0.09, -0.057, -0.017, -0.007, -0.003, -0.001,
      0.133, 0.125, 0.09, 0.057, 0.017, 0.007, 0.003, 0.001,
      -0.133, -0.125, -0.09, -0.057, -0.017, -0.007, -0.003, -0.001,
      0.133, 0.125, 0.09, 0.057, 0.017, 0.007, 0.003, 0.001,
      -0.133, -0.125, -0.09, -0.057, -0.017, -0.007, -0.003, -0.001,
      0.133, 0.125, 0.09, 0.057, 0.017, 0.007, 0.003, 0.001,
      -0.133, -0.125, -0.09, -0.057, -0.017, -0.007, -0.003, -0.001,
      0.133, 0.125, 0.09, 0.057, 0.017, 0.007, 0.003, 0.001,
      -0.133, -0.125, -0.09, -0.057, -0.017, -0.007, -0.003, -0.001,
      0.133, 0.125, 0.09, 0.057, 0.017, 0.007, 0.003, 0.001,
      -0.133, -0.125, -0.09, -0.057, -0.017, -0.007, -0.003, -0.001,
      0.133, 0.125, 0.09, 0.057, 0.017, 0.007, 0.003, 0.001,
      -0.133, -0.125, -0.09, -0.057, -0.017, -0.007, -0.003, -0.001,
      0.133, 0.125, 0.09, 0.057, 0.017, 0.007, 0.003, 0.001,
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      0.133, 0.125, 0.09, 0.057, 0.017, 0.007, 0.003, 0.001,
      -0.133, -0.125, -0.09, -0.057, -0.017, -0.007, -0.003, -0.001,
SUBROUTINE OBNS(H, X, Y, Z, SUN, AP, P, L, O, ISUT, RO)
DIMENSION RO(6), V(9), SUN(2)
COMMON /AKOEF/R(90)/SVEAR/P(38)
C6=0.
PT=3.1415926/180.
UN 7 J=1+4
7. RO(J)=1.
   RO(5)=EXP(Q(2)-Q(3)*SQRT(H-L(1))
   IF (AP=-5) 2, 2, 1
1. RO(1)=V(1), (Q(10)+Q(20)*H)/4, LOG (4/P/Q(2))
2. IF (L107=1) 3, 3, 4
3. IF (7) 5, 6, 6
6. I=INT(D/10.)*1
   RO(3)=4, (Q(17)+Q(18)+H)
5. ASSIGN 11 TO M
   IF(ISUT) 8, 9, 10
10. ASSIGN 12 TO M
   V(1)=SIN(SUN(2))
   V(2)=COS(SUN(2))
   RO(4)=Q(7)+Q(8)*H+Q(9)*EXP(-(H+Q(10))/Q(11))*P
   V(4)=SUN(1)+Q(15)*P
   V(3)=SIN(V(4))
   V(4)=COS(V(4))
   V(3)=Z+V(1)*V(2)+X*V(4)+Y*V(3)
   V(3)=((1+V(4))/2)+S(Q(13)/2).
   GO TO 11, 11, 11, 11
11. V(4)=SUN(L)-Q(16)*P
   V(3)=SIN(V(4))
   V(4)=COS(V(4))
   CO=-2+V(1)+V(2)+X*V(4)+Y*V(3)
   CO=(1,-C6)/2)+S(Q(14)/2.)
   CO=R(12)*C6
12. RO(4)=1+RO(4)*(V(5)+C6)
9. RO(0)=RO(5)*(RO(4)+RO(3)+RO(2)+RO(1))
RETURN
END
5.3 Yakkia-72 Model of the Earth's Atmosphere

1. Function. According to the given location of a point, of the Sun, the values of $F_{0}$, $k_{p}$ at a given moment in time determine the temperature at a given point, the exospheric temperature, the density of the atmosphere, the number of molecules of nitrogen, oxygen, argon, helium and hydrogen in a single volume, and also the mean molecular weight of constituents of the atmosphere (presuming that it consists only of the elements listed above).

2. Structure. Subprogram ADEN.
   Internal access: AMBAR, GRAV, TLOCAL.

3. Access:
   CALL ADEN (AMJD, SUN, SAT, GEO, TEMP, ALION, AMHW, RHO).

4. Raw data:
   AMJD-date & time in modified Julian days and fractions of days;
   SUN-the array which consists of two elements:
      SUN(1)-the direct ascension of the Sun in radians, 
      SUN(2)-the Sun's declination in radians; 
   SAT-the array consisting of three elements:
      SAT(1)-the longitude of a point in radians, 
      SAT(2)-geocentric latitude of a point in radians; 
      SAT(3)-the altitude of the point in kilometers; 
   GEO-an array consisting of three elements:
      GEO(1)-the value of the index $F_{0}$ (the time lag 1.7 days), 
      GEO(2)-the value of the geomagnetic index $k_{p}$, 
      $k_{p} \gg 50$ considering that $3^{-}=2.667$, $3^{+}=3.333$ and so forth, the time delay =0.279 days.

5. Results: TEMP-an array consisting of two elements TEMP (1)--the exospheric temperature over a given point (in Kelvin degrees); TEMP (2)--the temperature at a given point (in Kelvin degrees).

   ALION-an array consisting of six elements:
      ALION(1)-common logarithm of the number of nitrogen molecules in $M^{3}$, 
      ALION(2)-common logarithm of the number of oxygen molecules in $M^{3}$; 
      ALION(3)-common logarithm of the number of oxygen atoms in $M^{3}$;

---

The subprograms used are from [6] and were tested and modified for a high speed electronic computer BESM-6 by Ye.Ye. Ryazanova.
ALION(4)-common logarithm of the number of argon molecules in M$^3$;  
ALION(5)-common logarithm of the number of helium molecules in M$^3$;  
ALION(6)-common logarithm of the number of hydrogen molecules in M$^3$;  
AMHW-mean molecular weight;  
RHO-density (in Kg/m$^2$).

6. Due to a lack of space there can be no description of the Yakkia-72 atmospheric model or of the texts of subprograms which were published in [6].
CHAPTER 6
ANOMALIES OF THE EARTH'S GRAVITATIONAL FIELD
(INDEX ?)

6.1 The Acceleration Vector, Determined
by the Influence of Anomalies of
Earth's Gravitational Field
(SOL, DEG2, DEG3, DEG4)

1. Function. For a point in space fixed by the Greenwich
coordinates: x, y, z, one determines the constituents \( \Delta g_r \), \( \Delta g_m \), and \( \Delta g_l \) of the acceleration vector which is specified by the influence of anomalies of the Earth's gravitational field 1.2:

- \( \Delta g_r \) -- the radial constituent of vector \( \Delta g \) (project on the radius-vector of a point with a minus sign),
- \( \Delta g_l \) -- the meridional constituent (the meridian directed to the north),
- \( \Delta g_m \) -- the projection of \( \Delta g_l \) on the perpendicular to the plane of the meridian (directed to the east).

Supprogram DEG2 determines the acceleration vector which is determined by the influence only of zonal harmonics of anomalies of the Earth's gravitational field. Supprogram DEG3 determines the acceleration vector, allowing for the influence of zonal, tesseral and sectorial harmonics of the Earth's gravitational field. Subprogram DEG4 determines the acceleration vector allowing for the influence of only the harmonics 22, 30 and 40.

2. Structure. The packet of subprograms:
DEG2, DEG3, DEG4.
Common units: /RAD/2, /ORZ/1, /BGR/546, /CAZ/2.

3. Access:
CALL DEG2 (XG, NM),
CALL DEG3 (XG, DG, NM),
CALL DEG4 (XG, DG).

4. Raw data. Array XG3, which contains x, y, z -- the Greenwich coordinates of a point;
NM -- the number of harmonics considered (NM ≤ 22).

Note. When accessing subprogram DEG, one may use coordinates of a point both in the Greenwich and absolute system of coordinates.

5. Results. Array DG, which contains the components:
\( \Delta g_r, \Delta g_m, \Delta g_l \) of the acceleration vector.

6. Use of the area COMMON:
Before accessing any of the subprograms it is necessary to put the values \( R = (x^2 + y^2 + z^2)^{\frac{1}{2}} \) and \( R_l = (x^2 + y^2)^{\frac{1}{2}} \) into the unit COMMON/RAD/R, Rl.

Author -- Ye.Ya. Ryazanova.
In the unit COMMON/CR2/2 the value R2 should be fixed.
(No. 10 of Table 2.1).

In order to secure the work of subprograms DEG2 and DEG3, the
values of coefficients of the resolution ratio of the Earth's
gravitational field (according to Table 2.3) by means of a pre-
liminary accessing of subprogram CONGR(A02). In subprogram DEG4
an additional variant of coefficient values of the Earth's gravi-
tational field is used from unit COMMON/CA2Z/4 (No. 4 of Table 2.1).

7. Algorithm.
   a) calculation of zonal harmonics
\[ \Delta g_r = \frac{1}{r} \sum_{n=3}^{n_{\text{max}}} (R/r)^{n+1} (n+1) \alpha_{n0} P_{n0}(\sin \psi); \]
\[ \Delta g_m = \frac{1}{r} \sum_{n=3}^{n_{\text{max}}} (R/r)^{n+1} \alpha_{n0} P_{n1}(\sin \psi); \quad \Delta g_\xi = 0. \]
   b) calculation of zonal, tesseral, and sectoral harmonics:
\[ \Delta g_r = \frac{1}{r} \sum_{n=2}^{n_{\text{max}}} (R/r)^{n+1} \sum_{m=0}^{n} (\alpha_{nm} \cos m \xi + \beta_{nm} \sin m \xi) P_{nm}(\sin \psi); \]
\[ \Delta g_m = \frac{1}{r} \sum_{n=2}^{n_{\text{max}}} (R/r)^{n+1} \sum_{m=0}^{n} (\alpha_{nm} \cos m \xi + \beta_{nm} \sin m \xi)(P_{n,m}(\sin \psi) - m g \xi P_{n,m}(\sin \psi)); \]
\[ \Delta g_\xi = \frac{1}{r} \sum_{n=2}^{n_{\text{max}}} (R/r)^{n+1} \sum_{m=0}^{n} (-\alpha_{nm} \sin m \xi + \beta_{nm} \cos m \xi) m P_{nm}(\sin \psi); \]

\( x, y, z \) - the Greenwich coordinates of a point,
\( r = (x^2 + y^2 + z^2)^{1/2}, \quad r_1 = (x^2 + y^2)^{1/2}, \quad R = 6371 \text{ km}, \)
\( \psi, \xi - \) the geocentric latitude and longitude of a point,
\( \sin L = y / r_1, \quad \cos L = x / r_1, \quad \sin \psi = z / r, \quad \cos \psi = r_1 / r, \)

\( P_{n,m}(\sin \psi) - \) Legendre's joined functions
\[ P_{n+1,m} = (2n+1) \sin \psi P_{n,m} - (n + (n+1)/2) (\sin \psi) P_{n,m}; \quad \text{when } n > m, \]
\[ P_{nn} = (2n-1) \cos \psi P_{n-1,n-1}; \]
when \( n = m, P_{nn} = 0. \)

\[ \sin m \xi = \sin((m-1) \xi) \cos L + \cos((m-1) \xi) \sin L, \]
\[ \cos m L = -\sin((m-1) \xi) \cos L + \cos((m-1) \xi) \sin L, \]
\[ P_{00} = 1, \quad P_{10} = \sin \psi = z / r, \quad P_{11} = \cos \psi = r_1 / r, \quad P_{20} = (3 \sin^2 \psi - 1) / 2, \]
\[ P_{21} = 3 \sin \psi \cos \psi = 3 z r_1 / r^2, \quad P_{22} = 3 \cos^2 \psi. \]
\begin{align*}
\Delta g_r & = \frac{1}{r} \left( \frac{R}{r} \right)^3 \left( 9 \sqrt{\frac{y^2}{r^2}} \ \alpha_{22} + 18 \ \frac{xy}{r^2} \ \beta_{22} + \\
& \quad + \frac{Rz}{r^2} \left( 10 \ \frac{z^2}{r^2} - 6 \right) \ \alpha_{30} + \left( \frac{R}{r} \right)^2 \left( \frac{17y^2}{8r^2} - \frac{150}{8} \frac{z}{r} + \frac{15}{8} \right) \ \alpha_{40} \right); \\
\Delta g_m & = \frac{1}{r} \left( \frac{R}{r} \right)^3 \frac{R}{r} \left( -6 \frac{z}{r} - \frac{y^2}{r^2} \ \alpha_{22} + 2 \ \frac{z}{r^2} \ \beta_{22} \right); \\
\Delta g_\ell & = \frac{1}{r} \frac{R}{r} \left( -12 \ \frac{z^2}{r^2} \ \alpha_{22} + 6 \ \frac{z^2}{r^2} \ \beta_{22} \right). 
\end{align*}
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8. Texts.

SUBROUTINE DEG2(x, dG, NK)
DIMENSION X(3), DS(3), PMN(3), PN1(3)
COMMON /ECOHET/ ANM(273), BK, SETS
COMMON /RAD/R1, R
COMMON /CRZ/ RE
A(1) = ANM(1)
A(2) = ANM(3)
A(3) = ANM(13)
A(4) = ANM(19)
A(5) = ANM(26)
A(6) = ANM(34)
A(7) = ANM(63)
A(8) = ANM(5)
A(9) = ANM(64)
A(10) = ANM(6)
A(11) = ANM(60)
A(12) = ANM(103)
A(13) = ANM(118)
A(14) = ANM(134)
A(15) = ANM(3)
A(16) = ANM(167)
A(17) = ANM(189)
A(18) = ANM(203)
A(19) = ANM(227)
WRITE/R
C2 = X(3)/R
PNU(1) = L2
PNU(2) = (3.0 + C2 - C2 - 1.0) / 2.0
PN1(1) = R1
PN1(1) = PN1(1) / R
P01(1) = 3.0 + C2 * PN1(1)
G(1) = 0.0
G(2) = 0.0
S = 0, 0
GO 10, 1; = 3 * ?1
R = N
C3 = (2.0 - 1.0) * C2
P11(1) = C3 * P01(1) * (U - 1.0) * PMN(1) / U
P11(1) = (C3 * P01(1) - U * PN1(1)) / (U - 1.0)
C3 = C3 * (U - 1.0) * U
G(1) = G(1) + C3 * (U - 1.3) * PMN(1)
G(2) = 0.1(2) - C3 * PN1(1)
p(1) = P01(1)
p(2) = P01(2)
p(3) = P01(3)
CYCLE
G(1) = G(1) / R
G(2) = G(2) / R
S = 0, 0
RETURN
END
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```
SML = X(2)/N1
CFL = 1/N1
SML(1) = 0, 0
SML(2) = X(2)/N1
CFL(1) = 1, 0
CFL(2) = X(1)/N1
DO 1 N = 3, N11
SML(1) = SML(1) - 1) * CFL(2) * CFL(1 - 1) * SML(2)
1 CFL(1) = -SML(1) - 1) * SML(2) + CFL(1 - 1) * CFL(2)
UN: = 0, 0
UN: = 0, 0
P(1, 1) = 1, 0
P(2, 1) = SFI
P(2, 2) = CF1
UN: = UN: + 1
DO 2 I = 2, N12
2 P(1, I) = 0, 0
10 J = 1, N12
3 P(2, I) = 0, 0
DO 4 I = 3, N11
UN: = I - 1
DO 4 I = 3, N11
UN: = UN: - 1
J = (2, J = UN: - 1, 0)
IF (N, N1) = 5, 7
5 P(N, N1) = 0, 0
GO TO 6
6 P(N, N1) = CFI + P(N - 1, N - 1)
I GO TO 4
4 CONTINUE
14 RH = RE/R
UN: = 0, 0
DO 8 I = 1, 3
9 DG(I) = 0, 0
DO 9 I = 3, N11
UN: = N
DO 10 I = 1, N
10 SG(I) = 0, 0
UN: = 0, 0
DO 11 I = 1, N
UN: = I
11 SG(I) = SG(I - 1) + C2 * UN * SG(I)
IS = 0
JS = 3
IF (LS, LT, 1)
13 C1 = A1 * UN * UN * UN + 2 * C2 * UN * SG(I)
G1 = UN + 1
UN: = UN + 1
SG(I) = SG(I) + C2 * UN * SG(I)
DO 1 = DG(I) + C2 * UN * SG(I)
DG(0) = DG(0) + C2 * SG(I)
DG(1) = DG(1) + C2 * SG(I)
DG(2) = DG(2) + C2 * SG(I)
DG(3) = DG(3) + C2 * SG(I)
C2 = A2 * UN * UN * UN + 2 * C3 * UN * SG(I)
C3 = A3 * UN * UN * UN + 2 * C4 * UN * SG(I)
DG(0) = DG(0) + C3 * SG(I)
DG(1) = DG(1) + C3 * SG(I)
DG(2) = DG(2) + C3 * SG(I)
DG(3) = DG(3) + C3 * SG(I)
RETURN
END
```
SUBROUTINE DEG4(X,Y,G)
DIMENSION X(3),Y(3)
COMMON/K1/K1,R1
COMMON/CR2/RE
COMMON/C22/22,22,30,40
C1=E=0
C2=Cl+C1
C3=Cl+C1/R
C4=C1+C1/R
U1=X(1)/R
U2=U1+U1
U3=X(1)*X(1)-X(2)*X(2)
R2=R*H
R1=ER1F1
N4=U3/N12
U4=X(1)*X(2)/PI2
J1(1)=X3(3),X(3)4+32/R2+14,0*X(1)*X(2)+2/R2+C1*U1
J1(2)=X3(3),X(3)4+32/R2+14,0*X(1)*X(2)+2/R2+C1*U1
J1(3)=X3(3),X(3)4+32/R2+14,0*X(1)*X(2)+2/R2+C1*U1
RETURN
END

List of Subprograms by Name.

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