NASA TECHNICAL MEMORANDUM NASA TM-75684

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

V. I. Prokhorenko

(NASA-TM-75684) AUXILIARY SUBPROGRAMS FOR CALCULATING THE NAVIGATIONAL PARAMETERS OF ARTIFICIAL EARTH SATELLITES. FORTRAN IV (National Aeronautics and Space Administration) 60 p HC A04/MF A01 CSCL 22B G3/15

N82-16140

Unclas
07979

Translation of "Vspomogatel'nyye Podprogrammy dlya Rascheta Navigatsionnykh Parametrov Iskusstvennykh Sputnikov Zemli. Fortran IV." Academy of Sciences USSR, Institute of Space Research, Moscow, Report PR-301, 1976, pp 1-59

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 JUNE 1981

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OF POOR QUALITY

STANDARD TITLE PAGE

1. Report No. NASA TM-75684

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle AUXILIARY SUBPROGRAMS FOR CALCULATING THE NAVIGATIONAL PARAMETERS OF ARTIFICIAL EARTH SATELLITES. FORTRAN IV.

5. Report Date June 1981

6. Performing Organization Code

7. Author(s) V. I. Prokhorenko, Academy of Sciences USSR Institute of Space Research, Moscow

8. Performing Organization Report No.

10. Work Unit No.

9. Performing Organization Name and Address Leo Kanner Associates, Redwood City, California 94063

11. Contract or Grant No. NASW-3199

13. Type of Report and Period Covered Translation

12. Sponsoring Agency Name and Address National Aeronautics and Space Administration, Washington, DC 20546

14. Sponsoring Agency Code

15. Supplementary Notes
Translation of "Vspomogatel'nyye podprogrammy dlya rascheta navigatsionnykh parametrov iskusstvennykh sputnikov zemli. Fortran IV." Academy of Sciences, USSR, Institute of Space Research, Moscow, Report PR-301, 1976, pp. 1-59

16. Abstract
The work contains a description of subprograms for transforming coordinates and time, for determining the position of the moon and sun, and for calculating the atmosphere and disturbances, which are specified by anomalies of the Earth's gravitational field. The subprograms are written in Fortran IV and form a major part of the package of applied programs for calculating the navigational parameters of artificial Earth satellites.

17. Key Words (Selected by Author(s))

18. Distribution Statement Unclassified-Unlimited

19. Security Classif. (of this report) Unclassified

20. Security Classif. (of this page) Unclassified

21. No. of Pages 54

22.

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FOREWORD

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 auxilliary 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 paramaters (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. I.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.

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

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CHAPTER.I. THE ORGANIZATION OF THE SUBPROGRAM LIBRARY AND ITS FEATURES /5*

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, AOI, AO2,...). 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: /6

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)

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*Numbers in the margin indicate pagination in the foreign text.

3. Access
4. Input data
5. Results
6. Usage of the region COMMON
7. Limitations
8. Emergency outputs
9. Method or algorithm
10. References
11. 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). /7

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 EM, 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 EM 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). /8

The time T is measured in seconds (or in units determined by the scale factor ESEC). Only in the subprograms HMSSEC (B03) and SECHMS (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_z coincides with the rotational axis of the Earth and is oriented towards the North pole;
>
> the axis O_x 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 quadrate (equatorial, stellar) systems of coordinates OXYZ:

> the center O coincides with the center of the Earth;
>
> the axis OZ coincides with the Earth's rotational axis oriented towards the North pole;
>
> the axis OX is oriented towards the point of the vernal equinox (at the current moment);
>
> the axis OY 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);
Ω -the longitude of the ascending vertex of the orbit (calculated along the equatorial arc

from the direction towards the point of spring counterclockwise);

ω -argument of perigee (angular distance from the ascending vertex to the perigee);

τ -the time of passage through the perigee.

The position of the satellite in orbit is determined by the argument of latitude u (angular distance of the AES 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 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^h 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^h of ephemeris time.

$$RJD=JD-2415020.0$$

-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 quantitites more frequently encountered in the subprogram descriptions we will introduce constant designations (identifiers of these quantitites). /10

RJD-relative Julian date;

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

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);
YG-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;
XG-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 Y_6."

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.

CHAPTER 2
CONSTANTS (INDEX A)

2.1 Basic Constants (A01-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 AES, and translates the dimensional constants into any 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;

ESEC-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 ESEC=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 ESEC=1000.

2. Structure. Subprogram CONST.

The Common Units

/CAED/$_1$, /CA00/$_2$, /CA00A/$_2$, /CA22/$_4$, /CGR/$_1$, /CGRL/$_1$, /CGRS/$_2$, /CGM/$_1$, /CRE/$_1$, /CRZ/$_1$, /CAE/$_2$, /CAEL/$_1$, /CCLZ/$_1$, /COMZ/$_1$, /COMZP/$_2$, /CSDAY/$_1$, /CT3/$_1$, /CKDM/$_{13}$, /CDSJS/$_1$, /CPI/$_5$, /CDEGR/$_1$, /CHRAD/$_1$, /CE2/$_1$, /CE3/$_1$, /CE4/$_1$, /CE6/$_1$, /CC60/$_1$, /CC3600/$_1$, /BEM/$_2$, /CEV/$_1$, /CESB/$_1$, /CELB/$_1$, /CERO/$_1$, /CHA/$_{20}$.

3. Access: Call CONST (EM, ESEC).

4. Raw data: EM, ESEC.

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.

6. Text

```
 SUBROUTINE CONST(EM,ESEC)
 DIMENSION A(20),K(13)
 DATA A/1.E5,1.5E5,3.E5,6.E5,9.E5,.4141E-7,.2173E-9,.4801E-11
1      ,.8904E-13,.6407E-14,.1469E-6,.8004E-10,.7111E-11
2 ,.1931E-11,0.,.1787E-3,.3734E-4,.1547E-4,.9275E-5,.954E-3/
 DATA K/0,31,59,90,120,151,181,212,243,273,304,334,365/
 COMMON/CHA/HA(5),AA(5),Q1(5),Q2(5)
 COMMON/CA80/A80
 COMMON/CA00/A00,A20
 COMMON/CA00A/A00A,A20A
 COMMON/CA22/A22,B22,A30,A40
 COMMON/CGR/GR
 COMMON/CGRL/GRL
 COMMON /CGRS/ GRS,DGRS
 COMMON/CGM/GM
 COMMON/CRE/RE
 COMMON/CRZ/RZ
 COMMON/CAE/AE,AL
 COMMON /CAEL/AEL
 COMMON/CGLZ/GLZ
 COMMON/COMZ/OMZ
 COMMON/COMZP/OMZ2,OMZK
 COMMON /CSDAV/SDAV
 COMMON /CT3/T3
 COMMON/CKDM/KDM(13)
 COMMON/CDSJS/DSJS
 COMMON/CPI/PI,PID2,PI2
 COMMON /CDEGR/DEGR
 COMMON /CHRAD/HRAD
 COMMON/CE2/E2
```

```
 COMMON/CE3/E3
 COMMON/CE4/E4
 COMMON/CE6/E6
 COMMON /C60/C60
 COMMON/CC3600/C3600
 COMMON/CEM/EM1,ESEC1
 COMMON /CEV/EV
 COMMON /CERO/ERO
 COMMON/CESB/ESB
 COMMON/CELB/ELB
 E0=1+0600.E5/EM
 COM2=ESEC/EM
 ECOM2=COM2*COM2
 A00=62564950,4*ECOM2
 A20=-07886.473*ECOM2
 A00A=.425049349E5*ECOM2
 A20A=-.628913065E5*ECOM2
 A22=93,44765*ECOM2
 B22=-53,24096*ECOM2
 A30=139,7068*ECOM2
 A40=29,29772*ECOM2
 GR=.3986013E15*ECOM2/EM
 GRL=.4[illegible]/9713*ECOM2/EM
 GRS=.132[illegible]9172.1*ECOM2/EM
```

```
 OMZ2=OMZ*2.
 OMZK=OMZ*OMZ
 SDAV=86400./ESEC
 T3=10800./ESEC
 DO 1 J=1,13
1 KDM(J)=K(J)
 DSJS=36525.
 PID2=1.5707963
 PI=3.1415926
 PI2=6.2831853
 DEGR=57.2957795
 HRAD=DEGR/15
 E2=1E2
 E3=1E3
 E4=1E4
 E6=1E6
 C60=60.
 C3600=3600.
 EM1=EM
 ESEC1=ESEC
 EV=EM/ESEC
 ESB=EV*EV*EM
 ELB=EV/ESEC
 ERO=ESB*EM
```

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```
      URS=1L/G
      G1=9.31662
      RE=6378388./EM
      RZ=6371000./EM
      AE=6378140./EM
      AL=.335289187E-2
      AEL=AE*AL
      C24=.90533458
      OMZ=.72921157E-4*ESEC
      EM2=EM*EM
      U=EM2/ESEC2
      DO 2 J=1,5
      A0(J)=A(J)*EM
      AA(J)=A(J+5)*EM
      B1(J)=A(J+10)*EM
    2 B2(J)=A(J+15)*EM
      RETURN
      END
```

2.2 Coefficients of Expansion of the Earth's Gravitational Field in Spherical Functions (AOZ-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: $/BCONGR/_{546}$.

3. Access: CALL CONGR (EM, ESEC).

4. Raw Data: EM, ESEC /18

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 α_{nm} are dispatched to array ANM, and the values β_{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.

Units COMMON	Identifiers	Type	Designation	Values (kg, m, sec.)	Dimensions	Contents	
/CAED/ 1	AED	REAL	a.e.	149600 10^6	M		
/CA00/ 1	A00		α_{00}	62564030,6	M^2/sec^2	astronomical unit	
	A20		α_{20}	-67883,473	M^2/sec^2	parameters of the Earth's	
/CA00A/ 4	A00A		α'_{00}	62564934,9	M^2/sec^2	normal gravitational field	
	A20A		α'_{20}	-67891,3965	M^2/sec^2	resolution ratio of the	
/CA22/ 4	A22		α'_{22}	98,4[illegible]	M^2/sec^2	Earth's gravitational field	Additional
	B22		β'_{22}	-53,21586	M^2/sec^2	according to spherical functions	variant
	A30		α'_{30}	160,7068	M^2/sec^2		
	A40		α'_{40}	99,29772	M^2/sec^2	effect of the gravitational	
/CGR/ 1	GR		μ	0,3986013 10^{15}	M^3/sec^2	constant on masses accordingly	Earth
/CGRL/ 1	GRL		μ_{a}	0,49027779 10^{13}	M^3/sec^2		Moon
/CGRS/ 2	GRS		$\mu_{\odot}10^{-10}$	0,132712517 10^{11}	M^3/sec^2	scale factors for the	Sun
	DGRS			10^{10}		acceleration of the	
/CGM/ 1	GM		g	9,80665	M/sec^2	forces of gravity on the Earth's surface	
/CRE/ 4	RE		R_e	6378388	M	equatorial radius of	
/CRZ/ 4	RZ		R	6371000	M	semi-major axis of the Earth's Ellipsoid	
/CAE/ 2	AE		a_e	6378140	M	contraction of the Earth's ellipsoid	
	AL		α	0,00335289187			
/CAEL/ 1	AEL		$a_e\alpha$		M	$a_e\alpha$	
/CCLZ/ 1	CLZ		$(1-\alpha)^4$	0,993305458		$(1-\alpha)^4$	
/COMZ/ 1	OMZ		ω_3	0,729211575 10^{-4}	1/sec	angular velocity of the earths rotation.	
/COMZP/ 2	OMZ2		$2\omega_3$		1/sec	$2\omega_3$	
	OMZK		ω_3^2		$1/sec^2$	ω_3^2	

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Table 2.2 Constants used in the measurement of time.

№	Units COMMON	Identifiers	Type	Values	Content	
1	2	3	4	5	6	
I	/CSDAY/$_1$	SDAY	REAL	86400	1 days in seconds	
2	/CT3/$_1$	T3	REAL	I0800	3 hours in seconds	
3	/CKDM/$_{13}$	KDM$_{13}$	INTEGER ARRAY	0	interval of time in days from Greenwich midnight, Jan 1, of the current year to Greenwich midnight on the first day of the corresponding month:	January
				3I		February
				59		March
				90		April
				I20		May
				I5I		June
				I8I		July
				2I2		August
				243		September
				273		October
				304		November
				334		December
				365	number of days in the year	
4	/CDSJS/$_1$	[illegible]	REAL	36525	Julian centuries in ephemeris days	

Table 2.3 Auxilliary constants, scale factors

1	2	3	4	5	6	
I	/CPI/$_3$	PI	REAL	3;I4159265	π	
		PID2		I;57079633	π/2	
		PI2		6,2831853I	2π	
2	/CDEGR/$_1$	DEGR		57,2957795	radian in degrees	
3	/CHRAD/$_1$	HRAD		DEGR/15.	radian in hours	
4	/CE2/$_1$	E2		I00		
5	/CE3/$_1$	E3		I000		
6	/CE4/$_1$	E4		I0000		
7	/CE6/$_1$	E6		I000000		
8	/CC60/$_1$	C60		60		
9	/CC3600/$_1$	C3600		3600		
I0	/BEM/$_2$	EM		EM	scale factors	distance
		ESEC		ESEC		times
II	/CEV/$_1$	EV		EM/ESEC		velocity
I2	/CESB/$_1$	ESB		$EM^3/ESEC^2$		SB
I3	/CELB/$_1$	ELB		$EM/ESEC^2$		B
I4	/CERO/$_1$	ERO		$EM^4/ESEC^2$		density

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Table 2.4. Characteristics of the standard five-layer model of the Earth's atmosphere: h_i - - layer boundries by altitude, A_i, $k_{1,i}$, $k_{2,i}$ - - model coefficients (i = I, 2, . . . , 5)

№	Units COMMON	Identifiers	Specifications	Length of array	Designations	Values	Dimensions
I	/CHA/$_{20}$	HA	ARRAY	5	h_i (i = I÷5)	I00000	м
						I50000	м
						300000	м
						600000	м
						900000	м
		AA	ARRAY	5	A_i (i = I÷5)	0,4I4I IO^{-7}	кГсек^{2}м$^{-4}$
						0,2I73 IO^{-9}	кГсек^{2}м$^{-4}$
						0,486I IO^{-11}	кГсек^{2}м$^{-4}$
						0,8904 IO^{-13}	кГсек^{2}м$^{-4}$
						0,6497 IO^{-14}	кГсек^{2}м$^{-4}$
		Q1	ARRAY	5	$k_{1,i}$ (i = I÷5)	0,I469 IO^{-8}	м$^{-2}$
						0,8004 IO^{-10}	м$^{-2}$
						0,7III IO^{-11}	м$^{-2}$
						0,I83I IO^{-11}	м$^{-2}$
						0	м$^{-2}$
		Q2	ARRAY	5	$k_{2,i}$ (i = I÷5)	0,I787 IO^{-3}	м$^{-1}$
						0,3734 IO^{-4}	м$^{-1}$
						0,I547 IO^{-4}	м$^{-1}$
						0,9275 IO^{-5}	м$^{-1}$
						0,954 IO^{-5}	м$^{-1}$

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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).

n 2	m 3	ANM(i) (m^{2}/sec^{2})	BNM(i) (m^{2}/sec^{2})	i 1	n 2	m 3	ANM(i) (m^{2}/sec^{2})	BNM(i) (m^{2}/sec^{2})	i 1	n 2	m 3	ANM(i) (m^{2}/sec^{2})	BNM(i) (m^{2}/sec^{2})
2	0	0		27	7	I	0,III IO	0,554 IO	54	IO	I	0,4[illegible] IO	-0,[illegible] IO
2	I	0	0	28	7	2	0,I76 IO	0,I00 IO	55	IO	2	-0,II IO	-0,376 IO
2	2	0,9755 IO^{2}	-0,5505 IO^{2}	29	7	3	0,I78 IO^{0}	-0,204 IO^{0}	56	IO	3	-0,74 IO^{-2}	-0,5I6 IO^{-1}
3	0	0,I59 IO^{3}		30	7	4	-0,268 IO^{-1}	-0,I47 IO^{-1}	57	IO	4	-0,I9 IO^{-2}	-0,I50 IO^{-2}
3	I	0,I336 IO^{3}	0,I76 IO^{2}	31	7	5	0	0,223 IO^{-2}	58	IO	5	-0,3I IO^{-3}	-0,550 IO^{-3}
3	2	0,I9I IO^{2}	-0,I35 IO^{2}	32	7	6	-0,II4 IO^{-2}	0,438 IO^{-3}	59	IO	6	-0,I3 IO^{-4}	-0,878 IO^{-4}
3	3	0,604 IO	0,I252 IO^{2}	33	7	7	0,I87 IO^{-3}	-0,82 IO^{-4}	60	IO	7	0,32 IO^{-5}	0,I6 IO^{-5}
4	0	0,999 IO^{2}		34	8	0	0,78 IO		6I	IO	8	0,5I IO^{-6}	-0,58 IO^{-6}
4	I	-0,3I6 IO^{2}	-0,292 IO^{2}	35	8	I	0,I3 IO	0,I3 IO	62	IO	9	-0,I2 IO^{-7}	0,I2 IO^{-7}
4	2	0,464 IO	0,998 IO	36	8	2	0,26 IO^{0}	0,4I IO^{0}	63	IO	IO	0,3I5 IO^{-7}	-0,79 IO^{-8}
4	3	0,372 IO	-0,563 IO^{0}	37	8	3	-0,38 IO^{-1}	0,I3 IO^{-1}	64	II	0	-0,I2 IO^{2}	
4	4	-0,II IO^{0}	0,45I IO^{0}	38	8	4	-0,I24 IO^{-1}	0,66 IO^{-2}	65	II	I	0	0,II IO
5	0	0,I5 IO^{2}		39	8	5	-0,69 IO^{-3}	0,69 IO^{-3}	66	II	2	0,I6 IO^{0}	-0,30 IO^{0}
5	I	-0,27 IO	-0,539 IO	40	8	6	-0,88 IO^{-4}	0,458 IO^{-3}	67	II	3	-0,I8 IO^{-1}	-0,38 IO^{-1}
5	2	0,62I IO	-0,356 IO	4I	8	7	0,97 IO^{-5}	0,29 IO^{-4}	68	II	4	-0,80 IO^{-3}	0,I3 IO^{-2}
5	3	-0,894 IO^{0}	-0,I9 IO^{0}	42	8	8	-0,64 IO^{-5}	0,56 IO^{-5}	69	II	5	0,76 IO^{-4}	0,328 IO^{-3}
5	4	-0,I32 IO^{0}	0,39 IO^{-1}	43	9	0	0,55 IO		70	II	6	0,I0 IO^{-4}	0,25 IO^{-5}
5	5	0,20I IO^{1}	-0,930 IO^{-1}	44	9	I	0,575 IO	-0,82 IO^{0}	7I	II	7	0,I3 IO^{-5}	-0,368 IO^{-5}
6	0	-0,3I8 IO^{2}		45	9	2	0,44 IO^{-1}	-0,35 IO^{0}	72	II	8	0,I8 IO^{-6}	-0,60 IO^{-7}
6	I	-0,496 IO	0,20 IO	46	9	3	-0,478 IO^{-1}	-0,573 IO^{-1}	73	II	9	0,467 IO^{-7}	-0,39 IO^{-8}
6	2	0,39 IO^{0}	-0,274 IO	47	9	4	0,32 IO^{-2}	0,595 IO^{-2}	74	II	IO	-0,72I IO^{-8}	-0,I3 IO^{-8}
6	3	0,39 IO^{-1}	0,52 IO^{-1}	48	9	5	-0,65 IO^{-4}	0	75	II	II	0,I54 IO^{-8}	-0,5I IO^{-9}
6	4	0	-0,964 IO^{-1}	49	9	6	0,I7 IO^{-4}	0,I84 IO^{-3}	76	I2	0	0,32 IO	
6	5	-0,I07 IO^{-1}	-0,264 IO^{-1}	50	9	7	-0,60 IO^{-5}	-0,I57 IO^{-4}	77	I2	I	-0,I8 IO	-0,II IO
6	6	0,I3 IO^{-2}	-0,I0 IO^{-2}	5I	9	8	0,475 IO^{-5}	0,I2 IO^{-5}	78	I2	2	0,87 IO^{-1}	0,23 IO^{0}
7	0	0,22 IO^{2}		52	9	9	-0,39 IO^{-6}	0,44 IO^{-6}	79	I2	3	0,I4 IO^{-1}	0,I2 IO^{-1}
				53	10	0	0,23 IO^{2}						

Here ANM (1)÷α_{20} =0, in so far as the corresponding member of the resoultion is considered to be in the Earth's normal field (the value α_{20} is from table 2.1).

Table 2.5 (continued)

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1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
80	I2	4	-0,79 I0^{-3}	0,39 I0^{-3}	III	I4	8	-0,1 I0^{-7}	-0,22	[illegible]	[illegible]	[illegible]	0,2I3 I0	0,I9 I0^{-7}
81	I2	5	0,34 I0^{-4}	0,68 I0^{-4}	II2	I4	9	0,[illegible] I0^{-8}	0,30	[illegible]	[illegible]	[illegible]	-0,[illegible] I0^{-7}	0
82	I2	6	-0,30 I0^{-5}	0	II3	I4	I0	0,[illegible] I0^{-9}	-0,I2	[illegible]	[illegible]	[illegible]	[illegible]	-0,I03 [illegible]
83	I2	7	0,I7 I0^{-6}	0,I43 I0^{-6}	II4	I4	II	0,90 I0^{-11}	-0,24 I0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
84	I2	8	-0,I4 I0^{-7}	0,42 I0^{-7}	II5	I4	I2	0,3I I0^{-12}	-0,[illegible] I0	[illegible]	[illegible]	[illegible]	[illegible]	-0,3[illegible]
85	I2	9	-0,46 I0^{-8}	0,67 I0^{-8}	II6	I4	I3	0,[illegible] I0^{-13}	0,[illegible] I0	[illegible]	[illegible]	[illegible]	0,[illegible]	-0,I[illegible]
86	I2	I0	0,39 I0^{-9}	0	II7	I4	I4	-0,[illegible] I0^{-15}	-0,[illegible] I0	[illegible]	I6	[illegible]	0,I[illegible] I0	0,85
87	I2	II	0,II I0^{-9}	-0,I4 I0	II8	I5	0	0,I I0		[illegible]	I6	[illegible]	-0,4[illegible] I0^{-15}	0,[illegible]
88	I2	I2	0,II I0^{-10}	-0,24 I0	II9	I5	I	0	0,[illegible] I0	[illegible]	[illegible]	[illegible]	[illegible] I0^{-15}	[illegible]
89	I3	0	0,45 I0		I20	I5	2	-0,4[illegible] I0^{-1}	-[illegible] I0	[illegible]	[illegible]	[illegible]	-0,[illegible] I0	0,I[illegible]
90	I3	I	-0,2I I0	0,I0 I0	I2I	I5	3	0,I4 I0^{-2}	-0,I4 I0	[illegible]	[illegible]	[illegible]	[illegible]	
91	I3	2	-0,I3 I0^{-1}	0,52 I0^{-1}	I22	I5	4	0,9I I0^{-4}	0,64 I0	[illegible]	[illegible]	[illegible]	0,I5 I0	
92	I3	3	0,39 I0^{-2}	-0,59 I0^{-2}	I23	I5	5	0,I8 I0		[illegible]	[illegible]	[illegible]	-0,45 I0	0
93	I3	4	-0,30 I0^{-3}	0,89 I0^{-3}	I24	I5	6	0,30 I0^{-5}	-0,507 I0	I65	I7	I4	-0,29 I0^{-5}	0,43 I0
94	I3	5	0,II7 I0^{-4}	-0,59 I0^{-4}	I25	I5	7	0,360 I0^{-6}	0,I2 I0^{-6}	I69	I8	0	0,I6 I0^{2}	
95	I3	6	-0,76 I0^{-5}	0,57 I0^{-6}	I26	I5	8	-0,22I I0	-0,88 I0^{-7}	I8I	I8	I2	0,90 I0^{-14}	0,90 I0
96	I3	7	-0,40 I0^{-6}	0	I27	I5	9	0,34 I0^{-9}	0,5I I0^{-9}	I82	I8	I3	0	-0,27
97	I3	8	-0,29 I0^{-7}	-0,I4 I0^{-7}	I28	I5	I0	-0,29 I0	0	I83	I8	I4	-0,I6 I0^{-15}	-0,23
98	I3	9	-0,20 I0^{-8}	0,750 I0^{-8}	I29	I5	II	-0,37 I0	0,II I0^{-10}	I88	I9	[illegible]	0,I2 I0^{2}	
99	I3	I0	-0,64 I0^{-9}	-0,7I I0^{-9}	I30	I5	I2	0,I[illegible] I0	0,I2 I0^{-12}	200	I9	I2	0,3I I0^{-1}	-0,[illegible]
I00	I3	II	-0,25 I0^{-10}	0,50 I0^{-10}	I3I	I5	I3	-0,[illegible]	0	20I	I9	I3	0,33 I0^{-14}	-0,[illegible]
I0I	I3	I2	0	0,25 I0^{-11}	I32	I5	I4	0,[illegible]	-0,5I I0^{-14}	202	I9	I4		-0,[illegible]
I02	I3	I3	0,I6 I0^{-11}	0,I6 I0^{-12}	I33	I5	I5	0	-0,3I I0^{-15}	203	20	0	0	
I03	I4	0	-0,34 I0		I34	I6	0	-0,[illegible]		22I	20	I3	0,84 I0^{-13}	0,42
I04	I4	I	-0,67 I0	0,I7	I35	I6	I	-[illegible]	0,25 I0	222	20	I4	0,[illegible] I0^{-17}	-0,I9 I0
I05	I4	2	0,69 I0^{-1}	-0,I2 I0	I36	I6	2	0,3[illegible] I0^{-1}	0,57 I0^{-1}	229	2I	0	[illegible] I0	
I06	I4	3	0,32 I0^{-2}	0	I37	I6	3	-0,[illegible] I0^{-2}	0,35 I0^{-2}	242	2I	I3	0	-0,I4 I0
I07	I4	4	0,I2 I0^{-3}	-0,46 I0^{-3}	I38	I6	4	-0,[illegible] I0^{-3}	0,23 I0^{-3}	243	2I	I4	0,2I I0^{-1}	0
I08	I4	5	-0,25 I0^{-4}	-0,I7 I0^{-4}	I39	I6	5	-0,I[illegible] I0^{-4}	0,I4 I0^{-4}	265	22	I4	-0,30 I0^{-17}	0,[illegible] I0
I09	I4	6	0,I2 I0^{-5}	-0,37 I0^{-5}	I40	I6	6	-0,[illegible] I0^{-5}	-0,I2 I0^{-5}					
II0	I4	7	0,48 I0^{-7}	0,48 I0^{-7}										

6. Text

ORIGINAL PAGE IS
OF POOR QUALITY

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```
      SUBROUTINE CONGR(EM,ECEK)
      COMMON/BCONGR/AM(273),BM(273)
      DIMENSION A(273),B(273)
      DATA A/2*0.,.0785E2,.159E3,.135E3,.1.E2,.964E1,.[illegible]
     1     -.315E2,.372E1,-.11,.15E2,-.27E1,.591E1,-.894,-.142,
     2     .221E-1,-.315E2,-.496E1,.30,.39E-1,0.,-.107E-1,.13[illegible],
     3     .22E2,.111E2,.176E1,.178,-.258E-1,0.,-.114E-2,.18[illegible]-3,
     4 .[illegible]E1,.13E1,.26,-.39E-1,-.124E-1,-.69E-3,-.88E4,.97E-5/
     5     -.54E-5,.55E1,.575E1,.44E-1,-.478E-1,.32E-2,-.55E-4,
     6.1[illegible],.50E-5,.472E-5,-.39E-6,.23E2,.437,-.11,-.74E-2,
     7     -.19E-2,-.31E-3,-.13E-4,.32E-5,.51E-[illegible],-.12E-7,.315E-7,
     8     .315E-7,-.12E3,0.,.16,-.18E-1,-.80E-3,.76E-4,.10E-4,
     9     .13E-5,.14E-6,.467E-7,-.771E-8,.154E-8,.32E1,-.[illegible]E1,
     1     .37E-1,.14E-1,-.79E-3,.34E-4,-.30E-5,.14E-6,-.14E-7,
     2     -.46E-8,-.37E-9,-.11E-9,-.11E-10,.65E1,-.21E1,-.[illegible]
     3     .30E-2,-.30E-3,.117E-3,-.76E5,-.49E-6,-.20E-7,-.[illegible]
     4     .54E-9,-.25E-10,0.,-.16E-11,.34E1,-.67,.60E-1,.37E-2,
     5      [illegible]-4,-.29E-6,.12E-3,.[illegible]-7,-.[illegible]-7,.14E-8,.12E-[illegible]
     6 [illegible]-11,.14E-1[illegible],.23E-12,-.44E-13,.1[illegible],-.[illegible]-1,.[illegible]-2,
            [illegible],.30E-5,.36[illegible]-0,-[illegible]-7,.34[illegible],-.[illegible]-10,
        [illegible]-13,.[illegible],.2[illegible],.1[illegible]-13,.17[illegible].[illegible],.[illegible]E2,-.[illegible],
        [illegible]-4,-.10E-4,-.18E-[illegible],.21E[illegible],-.[illegible]-7,.[illegible]-1[illegible],
          [illegible]-12,.92E-13,.17E-1[illegible],-.[illegible],-.[illegible],
          [illegible],.38E1,11*0.,.10E-12,.[illegible],-.2[illegible]-12,[illegible],
          [illegible],11*0.,.70E-14,[illegible],-.15E-15,[illegible],.[illegible]E2,11*0.,
          [illegible],13*0.,.44E-15,.30E-[illegible],-.[illegible]E1,.3[illegible],
     4      [illegible],-.22E-17,4*0./
             [illegible],-.59[illegible]E2,0.,.176E2,-.135E2,.125E2,0.,-.22E2,
              [illegible],-.[illegible]E1,-.[illegible]E-1,-.3[illegible],.19,.39E-1,
               [illegible].27E1,-.27E1,.52E-[illegible],-.[illegible]E-1,-.26[illegible]E-1,
                 [illegible]E1,-.[illegible],-.14E-1,.223E-2,.[illegible]E-3,
          [illegible],.[illegible]E1,.41,.13E-1,.30E-2,.[illegible]E3,.[illegible]E-3,
                      [illegible],.22,-.59,-.57[illegible],.59[illegible]E-2,0.,[illegible]
          [illegible],.[illegible]-5,.64E-5,0.,-.5915E1,-.374,-.216E-1,
          [illegible]-5,.478E-4,.10E-5,-.[illegible]E-0,.12E-7,
          [illegible],-.31,-.38E-1,.13E-2,.328E-3,.25E-[illegible]
          [illegible],-.76E-8,-.12E-5,-.31E-[illegible],0.,-.[illegible]
          [illegible]-3,.68E-4,.14E-5,.42E-7,.[illegible]
          [illegible],.34E-10,[illegible],.13E1,.52E-1,-.59E-2,.89E-[illegible],
          [illegible]-7,.75E-8,-.71E-10,.50E-1[illegible],
          [illegible]E-11,.14E-1[illegible],.12E1,-.12E0,[illegible],-.40E-3,-.17E-4,
          [illegible]-7,[illegible],.33E-8,-.12E-9,-.24E-10,-.20E-11,
          [illegible],-.8[illegible],.13E1,-.42E-1,-.14E-2,.64E-3,[illegible],
          [illegible],.13E-6,-.38E-8,.51E-9,0.,.11E-10,.12E-12,0.,
          [illegible],-.31E-13,0.,.25E1,.57E-1,.35E-2,.29E-3,.14E-4,
     9  -.[illegible]E-5,-.10E-7,0.,-.103E-8,0.,-.38E-11,-.14E-12,.85E-14,
     1  -.70E-1,0.,.10E-15,14*0.,.43E-15,15*0.,.90E-14,-.27E-14,
     2  -.48E-15,15*0.,-.44E-14,-.18E-14,-.42E-6,18*0.,.42E-15,
     3     -.19E-16,19*0.,-.14E-15,22*0.,-.60E-17,8*0./
```

```
[illegible]
ECDH2=ECDH2*ECDH2
DO 3 I=1,273
ANM(I)=A(I)*ECDH2
BNM(I)=B(I)*ECDH2
RETURN
END
```

CHAPTER 3
SUBPROGRAMS FOR THE TRANSFORMATION OF TIME AND COORDINATES
(INDEX B)

3.1 Transition from GU, the Calendar Date, to RJD, Relative Julian Date (B01-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/$_{13}$,/CE2/$_1$.

3. Access: CALL DATDAY (DTK, RJD).

4. Raw data: DTK-real variable containing the date GU which is given by the decimal fraction of the type: 0. DDMMGG, where DO 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: $RJD=365GG+\left[(GG-1)/4\right]-0,5+t$ 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. /20

8. Text

```
      SUBROUTINE DATDAY(DAT,DAY)
      COMMON/CE2/E2
      COMMON/CKDM/KDM(13)
      N=DAT*E2
      NDTN=N
      N=(N-NDTN)*E2
      NM=N
      N=(N-NM)*E2
      N=N+.5
      NG=N
      KDTG=KDM(NM)+NDTN
      KVG=(NG-1)/4
      IF((KVG+1)*4-NG)2,1,2
    1 IF(NM-2)2,2,3
    3 KDTG=KDTG+1
    2 DAY=NG*KDM(13)+KVG+KDTG-.5
      RETURN
      END
```

3.2 Transition from RJD (the relative Julian date) to GU, the Calendar Date (B02-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:/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 /21
units COMMON/CSDAY/$_1$,/CKDM/$_{13}$./CCG0/$_1$ (No. 1.3 of table 2.2, No. 8 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.

$$RJDR = RJD + [T/SDAY]; \quad TR = T - [T/SDAY] \cdot SDAY,$$

where SDAY is the number of seconds in the days, [x] is the whole part of x.

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

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

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

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 (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.

8. Text.

```
SUBROUTINE DAYDAT(DAY,T,DAYR,K,NT,NM,ND)
COMMON/C201/C201
COMMON/CKDM/KDM(13)
COMMON/CSDAY/SDAY
KG=T/SDAY
DAYR=DAY-KG
TD=T-KG*SDAY
KDN=INT(DAY)+KG
KVG=(KDN-KDM(13))/1461
K=KDN-KVG
NG=K/KDM(13)
IVG=(NG-1)*4-NG
IF(IVG)1,2,2
NG=NG-1
```

```
2 KDTG=K-1-NG*KDM(13)
  IF(IVG)3,3,6
3 IF(KDTG-C60)6,4,5
4 ND=29
  NM=2
  GOTO 10
5 KDTG=KDTG-1
6 DO 7 NM=1,13
  IF(KDTG-KDM(NM))8,7,7
7 CONTINUE
8 NM=NM-1
  ND=KDTG-KDM(NM)
10 RETURN
  END
```

3.3 Conversion of Hours, Minutes and Seconds into Seconds (BC3-HMSSEC)

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

2. Structure. Subprogram HMSSEC
Common units: $/CE2/_1, /CCG0/_1, /CC3600/_1$.

3. Access: CALL HMSSEC (HMS, T).

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

5. Results: T-the time in seconds.

6. Use of the COMMON units. Constants are used from the units $COMMON/CEZ/_1, /CCG0/_1, /CC3600/_1$ (Nos. 8 and 9 of Table 2.3).

7. Text.

```
SUBROUTINE HMSSEC(HMS,T)
COMMON/CE2/E2
COMMON/CC3600/C3600
COMMON/CC60/C60
H=HMS*E2
H=H+.1
[illegible]
IF(H) 1,2,2
[illegible]
```

```
  GOTO 3
2 ANS=H*E2
  M=ANS-.1
  ANS=ANS-M
  IF(ANS)3,4,4
3 ANS=0.
4 T=ANS*E2+M*C60+H*C3600
  RETURN
  END
```

3.4 Conversion of Seconds into Hours, Minutes, and Seconds (B04-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: /CCG0/$_1$,/CC 3600/$_1$.

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

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

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

6. Use of the area COMMON. Constants are used from the units COMMON/CCG0/$_1$,/CC3600/$_1$ (Nos. 8 and 9 of Table 2.3).

7. Text.

```
      [illegible] S[illegible] (T,KH,KM,SEC)
      COMMON/CCG0/C60
      COMMON/CC3600/C3600
      KH=T/C3600
      X1=T-KH*C3600
      KM=X1/C60
       SEC=X1-KM*C60
      I=SEC-C60+.0001
      IF(I)1,2,2
    2 KM=KM+1
        [illegible]
    1 RETURN
      END
```

3.5 Stellar Time (B05-STTIME, STT)

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

Subprogram STT according to the known SO 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/$_3$,/COMZ/$_1$,/CT3/$_1$,/BSO/$_3$.

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3. Description of the subprogram STTIME.
Access: CALL STTIME (RJD, SO).
Raw data:RJD-relative Julian date.
Results: SO-stellar time on the Greenwich meridian in radians($SO \leq 2\pi$).

Use of the units COMMON. Constants are used from the units COMMON/CDSJS/$_1$,/CPI/$_3$ (No. 4 of Table 2.2, No. 1 of Table 2.3). /24

Algorithm:

$$SO = 6^h38^m45^s{,}836 + 8640I84^s{,}542\ T + 0^s{,}0929\ T^2 + 0^s{,}06II64\Delta\psi,$$

$$\Delta\psi = -I7{,}23 \sin \Omega \quad ,$$

$$\Omega = 259^0I0'59''{,}79 - I934^008'3I''{,}23T + 7''{,}48T^2 + 0''{,}0080T^3,$$

$$T = RJD\ /36525,\ RJD$$

4. Text.

```
SUBROUTINE STTIME(DAY,SO)
COMMON/CDSJS/DSJS
COMMON/CPI/PI,PI32,PI2
T=DAY/DSJS
SOM=SIN(((.387851E-7*T+.362640634E-4-33.75714625)*T
+                  +4.523601516))
W=628.33*T
N=W/PI2
W=W-N*PI2
SO=(6.755E-6*T+.19511E-2)*T+1.7399359-.766385E-4*SOM+W
N=SO/PI2
SO=SO-N*PI2
RETURN
END
```

5. Description of the subprogram-function STT.

Access: ST=STT(T).
Raw data: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/BSO/SO, 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 locking 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. /25

Constants are used from the units COMMON/COMZ/$_1$,/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:

$$ST = SO + \omega_3(T - TS - 10800^s)$$

where ω_3 is the absolute angular velocity of the Earth's rotation.

SO-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 $\leq$ RJD) date,

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

Text:

```
FUNCTION STT(T)
COMMON/ESO/SO,TS,NS
COMMON/CT3/T3
COMMON/COMZ/OMZ
STT=SO+OMZ*(T-TS-T3)
RETURN
END
```

3.6 Transition from the Absolute System of Coordinates to the Greenwich and the Reverse: from the Greenwich System to the Absolute (B06-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: $X,Y,Z \rightarrow x,y,z$ and $x,y,z \rightarrow X,Y,Z$.

2. Structure. Subprograms: AGIGA, AGIGAX
Common units: /COMZ/$_1$,/CT3/$_1$.

3. Access to AGIGA: CALL AGIGA (SO, T, Y1, 1,YR). /26
Raw data: T-Moscow time (in seconds).

SO-stellar time on the Greenwich meridian at Greenwich midnight; $Y1_6$-array of reference values of coordinates and constituents of the velocity vector; I-indicator of the transition. I=1 during the transition from the absolute system of coordinates to the Greenwich, I=2 during the transition from the Greenwich system of coordinates to the absolute.

Results: YR_6-array of values of coordinates and constituents of the velocity vector in the resulting system of coordinates.

4. Access to AGIGAC: CALL AGIAC(ST, X1,1,XR).
Raw data: St-stellar time on the Greenwich meridian at the present moment of time; xl_3-array of base coordinate values; 1-indicator of the coordinate transition (which both by its meaning and values conforms to the I 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/COMZ/$_1$,/CT3/$_1$ (No. 14, Table 2.1, No. 2, Table 2.2).

6. Algorithm: a) transition from X,Y,Z,V_x,V_y,V_z to x, y,z, v_x, v_y, v_z is conducted according to the formula:

$$x = X\cos\beta + Y\sin\beta, \qquad v_x = V_X\cos\beta + V_Y\sin\beta + \omega_3 y,$$

$$y = -X\sin\beta + Y\cos\beta, \qquad v_y = -V_X\sin\beta + V_Y\cos\beta - \omega_3 x,$$

$$z = Z, \qquad v_z = V_Z;$$

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

SO-stellar time at Greenwich midnight.
W3-angular velocity of the Earth's rotation,
T--Moscow time /27

b) transition back from x,y,z,v_x,v_y,v_z to X,Y,Z,V_xV_y,V_z is conducted according to the formula:

$$X = x\cos\beta - y\sin\beta, \qquad V_X = v_x\cos\beta - v_y\sin\beta - \omega_3 Y,$$

$$Y = x\sin\beta + y\cos\beta, \qquad V_Y = v_x\sin\beta + v_y\cos\beta + \omega_3 X,$$

$$Z = z, \qquad V_Z = v_z.$$

In subprogram AGIGAC $ST = \beta$

7 TEXTS'

```
  [illegible]
  COMMON /CT3/-3
  B=B0+OM7*(T-T3)
  W(1)=SIN(B)
  W(2)=COS(B)
  W(3)=-W(1)
  A=OM7
  X=XI(1)
  Z=XI(4)
  GOTO(2,1),I
1 A=-A
  W(3)=-W(3)
  W(4)=-W(1)
2 DO 3J=1,2
  XR(J)=W(J+1)*X+W(J)*XI(2)
3 XR(J+3)=W(J+1)*Z+W(J)*XI(5)
  XR(4)=XR(4)+A*XR(2)
  XR(5)=XR(5)-A*XR(1)
  XR(3)=XI(3)
  XR(6)=XI(6)
  RETURN
  END
```

```
  SUBROUTINE AGISAC( ST,XI,I,XR)
  DIMENSION XI(3),XR(3)
  CB=COS( ST)
  SB=SIN( ST)
  GOTO(2,1),I
2 SB=-SB
1 U=XI(1)*SB
  XR(1)=XI(1)*CB-XI(2)*SB
  XR(2)=XI(2)*CB+U
  XR(3)=XI(3)
  RETURN
  END
```

3.7 Determination of Coordinates and Constituents of the Velocity Vector in the Absolute System of Coordinates According to the Elements of Orbit (B07-ELABS)

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

2. Structure. Subprogram ELABS
Common units: $/CGR/_1$.

3. Access: CALL ELABS (A, YA).

4. Raw data: Array A_6, containing values of the orbital elements in the following order: $a, e, i, \Omega, \omega, u$. All angles should be given in radians. /28

5. Results: Array Y_6, 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. $/CGR/_1$ (No. 5 table 2.1).

7. Algorithm: The following correlations are used:

$$X = r(\cos\Omega\cos u - \sin\Omega\sin u\cos i),$$

$$Y = r(\sin\Omega\cos u + \cos\Omega\sin u\cos i),$$

$$Z = r\sin u\sin i,$$

$$V_x = V_r(\cos\Omega\cos u - \sin\Omega\sin u\cos i) - V_u(\cos\Omega\sin u + \sin\Omega\cos u\cos i),$$

$$V_y = V_r(\sin\Omega\cos u + \cos\Omega\sin u\cos i) - V_u(\sin\Omega\sin u - \cos\Omega\cos u\cos i),$$

$$V_z = V_r\sin u\sin i + V_u\cos u\sin i,$$

where

$$r = P/(1+e\cos v), \quad v = u-\omega,$$

$$V_r = (\mu/P)^{1/2} e\sin v, \quad V_u = (\mu/P)^{1/2}(1+\cos v), \quad P = a(1-c)^2,$$

μ-product of the gravitational constant into the Earth's mass.

8. Text.

```
      SUBROUTINE ELABS(A,X)
      DIMENSION A(6),X(6),U(8)
      COMMON/CGR/GR
      P=A(1)*(1.-A(2)*A(2))
      A(5)=A(6)-A(5)
      DO 1 J=1,4
      U(J)=COS(A(J+2))
    1 U(J+4)=SIN(A(J+2))
      X(3)=U(8)*U(5)
      X(6)=-U(4)*U(5)
      VU=SQRT(GR/P)
      VR=VU*A(2)*U(7)
      R=1.+A(2)*U(3)
      VU=VU*R
      R=P/R
      P=U(8)*U(1)
      U(1)=U(4)*U(1)
      U(2)=U(8)
      U(7)=-U(8)
      DO 2 J=1,2
      X(J)=U(J+4)*U(4)-U(J+5)*P
    2 X(J+3)=U(J+4)*U(8)-U(J+5)*U(1)
      DO 3 J=1,3
      X(J+3)=X(J)*VR-X(J+3)*VU
    3 X(J)=X(J)*R
      A(5)=A(6)-A(5)
      RETURN
      END
```

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 (B08-ABSEL) /29

1. Function: According to the known coordinates X,Y,Z and the constitutents of the velocity vector V_x, V_y, V_z in the absolute system of coordinates, the elements of orbit a, e, i, Ω, ω, are determined as well as their position in the orbit u.

2. Structure. Subprogram ABSEL
Common units: $/CGR/_1$, $/CP1/_3$.

Access: CALL ABSEL (YA, A).

4. Raw data:

Array YA_6, containing the values of X, Y, Z, V_x, V_y, V_z.

5. Results: Array A_6, which contains the values of orbital elements in the following order: a, e, i, Ω, ω. The values of all angles are in radians.

6. Use of the area COMMON. Constants are used from units $/CGR/_1$, $/CPI/_3$ (No. 5 of Table 2.1, No. 1 of Table 2.3).

7. Algorithm. $a = r/(2-k)$, $k = rV^2/\mu$, $V^2 = V_X^2 + V_Y^2 + V_Z^2$,

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

$$\sin Q = (XV_X + YV_Y + ZV_Z)/rV,$$

$$i = \pi/2 - \operatorname{arctg} \frac{c_3}{\sqrt{c_1^2 + c_2^2}}, \qquad 0 \leqslant i \leqslant \pi,$$

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

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

$$\Omega = \operatorname{arctg}\left(\frac{C_1}{-C_2}\right), \qquad v = \operatorname{arctg} \frac{k \sin Q \cos Q}{k \cos^2 Q - 1},$$

$$u = \operatorname{arctg} \frac{ZC}{YC_1 - XC_2}, \qquad \omega = u - v,$$

μ - product of the gravitational constant into the Earth's mass. /30

8. Text.

```
      SUBROUTINE ABSEL(X,A)
      DIMENSION X(6),A(6),C(4),S(4)
      DIMENSION Y(6)
      COMMON/CGR/GR
      COMMON/CPI/PI,PIO2,PI2
      R=0
      V=0
      XV=0
      DO 1 J=1,3
      R=X(J)*X(J)+R
      V=X(J+3)*X(J+3)+V
    1 XV=X(J)*X(J+3)+XV
      R=SQRT(R)
      AM=(R/GR)*V
      V=SQRT(V)
      DO 12 J=1,3
      Y(J)=X(J)/R
   12 Y(J+3)=X(J+3)/V
      C(1)=Y(2)*Y(6)-Y(3)*Y(5)
      C(2)=Y(3)*Y(4)-Y(1)*Y(6)
      C(3)=Y(1)*Y(5)-Y(2)*Y(4)
      CN=C(1)*C(1)+C(2)*C(2)+C(3)*C(3)
      CN=SQRT(CN)
      C(4)=0.
      IF(CN-1.E-8)14,14,13
   13 S(4)=C(1)*X(2)/CN-C(2)*X(1)/CN
   14 S(1)=SQRT(C(1)*C(1)+C(2)*C(2))
      S(4)=X(3)
      S(2)=C(1)
      S(3)=C(3)
      SQ=XV/R/V
      CQ=1.-SQ*SQ
      W=2.-AM
      A(1)=R/W
      C(3)=AM*CQ-1.
      A(2)=SQRT(1.-[illegible]*CQ)
      S(3)=AM*SQ*SQRT([illegible])
      C(2)=-C(3)
      DO 2 J=1,4
      IF(C(J))4,3,4
    3 A(J+2)=SIGN([illegible],S(J))
      GO TO 9
    4 A(J+2)=ATAN([illegible](J),C(J))
      IF(C(J))5,9,9
    5 A(J+2)=A(J+2)+[illegible]
    6 IF(A(J+2))7,9,9
    7 A(J+2)=A(J+2)+PI2
    9 CONTINUE
      IF(A(5)-[illegible])[illegible],10,[illegible]
   10 A(3)=A(3)-PI2
    8 A(5)=A(4)-A(3)
      IF(A(5))[illegible],11,11
    8 A(5)=A(5)+PI2
   11 RETURN
      END
```

3.9 Standard Array of Initial Conditions (B09-TRDATO)

1. Function. Subprogram TRDATO 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); /31

PN(2)-the current date in the form: 0.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 0.HHMMSSDS, where HH is the hour, MM the minutes, and SSDS 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. /32

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 (B01), HMSSEC(B03), STTIME(B05), AGIGA (B06), ELABS (B07), ABSEL (B08).

Common units:$/CDEGR/_1$, $/CE3/_1$,$/CC60/_1$.

3. Access:

CALL TRDATO (PN, NSP, DZ, RJD, NB, T, TD, SB, B, SO, A,YA, YG, EM, ESEC).

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4. Raw data: Array PN_{12}, which contains the initial conditions in one of the three forms described in p. 1;

EM, ESEC-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=o).

5. Results: NSP-the number of the satellite;
DZ-the launching date in the form: 0.DDMMGG;
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
$a, e, i, \Omega, \omega, u$
(angles in radians);
Array YA_6-which contains $X, Y, Z, V_x, V_y V_z$;
Array YG_6-which contains x, y, z, v_x, v_y, v_z.

6. Use of the area COMMON: Constants are used from the units: $/CDEGR/_1, /CE3/_1, /CCG0/_1$ (Nos. 2,5 and 8 of Table 2.3).

7. Text.

```
      SUBROUTINE TPRATP(PN,NSP,DZ,DT,NB,T,TD,SB,B,SO,A,XA,XG,
     *                  EM,ESEC)
      DIMENSION PN(12),A(6),XA(6),XG(6)
      COMMON/CE3/E3
      COMMON/CDEGR/DEGR
      COMMON/CCG0/CG0
      CALL DATDAY(PN(2),DT)
      CALL HMSSEC(PN(4),T)
      T=T/ESEC
      TR=PN(1)*E3
      NSP=TR
      DZ=(TR-NSP)
      V=EM/ESEC
      SB=PN(11)/V/V/EM
      NB=PN(5)+.1
      CALL STTIME(DT,SO)
      N=PN(12)+.1
      IF(N-1)3,1,3
    1 DO 4 J=1,3
      XG(J)=PN(J+4)/EM
    4 XG(J+3)=PN(J+7)/V
      CALL AGIGA(SO,T,XG,2,XA)
      GOTO 7
    3 IF(N-2)5,2,5
    2 DO 6 J=1,3
      XA(J)=PN(J+4)/EM
    6 XA(J+3)=PN(J+7)/V
      CALL AGIGA(SO,T,XA,1,XG)
    7 CALL ABSEL(XA,A)
      TD=0
      B=0
      GOTO 8
    5 DO 9 J=3,6
    9 A(J)=PN(J+2)/DEGR
      A(1)=PN(6)/EM
      A(2)=PN(7)
      A(6)=A(6)/DEGR
      TD=PN(3)*CG0/ESEC
      B=PN(10)/EM
      CALL ELABS(A,XA)
      CALL AGIGA(SO,T,XA,1,XG)
    8 RETURN
      END
```

3.10 Altitude of the AES over the Earth's Surface, the Geographic Latitude and Longitude, the Geocentric Latitude of a Sub-Satellite Point. (B10-GEOGRC, HEIGHT, GCLTIN)

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, φ, λ -- the geographical latitude and longitude of the sub-satellite point; subprogram HEIGHT determines only h; subprogram GCLTIN determines φ_{oc}, λ the geocentric latitude and longitude of the sub-satellite point. For subprograms HEIGHT and GCLTIN, 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, GCLTIN.
Common units: $/CAE/_2$,$/CAEI/_1$,$/CCIZ/_1$,$/CP1/_3$.

3. Access:

```
CALL GEOGRC (X,HC,ALT, ALN, XNG),
CALL HEIGHT (X, HC),
CALL GCLTIN (X, ALTC, ALN).
```

4. Raw data: Array X_3, which contains the values of x, y, z (for GEOGRC only in the Greenwich frame of axes). /3

5. Results:
HC-the altitude of the AES above the surface of the Earth's ellipsoid; ALT, ALN-the geographic altitude and longitude of the sub-satellite point; array XNG_3, which contains the cosines of the peripheral standard which is directed towards the Earth's ellipsoid; ALTC-the geocentric latitude of the sub-satellite point.

6. Use of the area COMMON.
In subprogram HEIGHT constants are used from the units COMMON$/CAE/_2$,$/CAEI/_1$,$/CCIZ/_1$$/CP1/_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: $/CAE/_z$,$/CAEI/_1$ and in subprogram GCLTIN from unit $/CP1/_3$.

7. Algorithm

$$h = r - a_e + a_e \alpha z^2/r^2,$$

$$\varphi = \mathrm{arctg}\{z/r_1(1-\alpha)^2\}, \quad -\pi/2 < \varphi < \pi/2,$$

$$\lambda = \mathrm{Arctg}(y/x), \quad 0 < \lambda < 2\pi,$$

where $r = (x^2 + y^2 + z^2)^{1/2}$, $r_1 = (x^2 + y^2)^{1/2}$,

α_e, α -is the semimajor axis and the contraction of the Earth's whole ellipsoid.

$\varphi_{oc} = \operatorname{arctg}(z/r_1)$ -the geocentric latitude.

$$x_N^o = x(1-\alpha)^2/r_2, \quad y_N^o = y(1-\alpha)^2/r_2, \quad z_N^o = z/r_2,$$

where x_N^o, y_N^o, z_N^o the cosines of the peripheral standards directing towards the Earth's ellipsoid,

$$r_2 = \{r_1^2(1-\alpha)^4 + z^2\}^{1/2}.$$

8. Texts.

```
    SUBROUTINE GEOGRC(X,HC,ALT,ALN,XE)
    COMMON/CCLZ/CLZ
    COMMON/CAE/AE,AL
    COMMON/CPI/PI,PID2,PI2
    COMMON /CAEL/AEL
    DIMENSION U(2),CU(2),X(6),XE(3)
    R12=X(1)*X(1)+X(2)*X(2)
    W=X(3)*X(3)
    R2=R12+W
    HC=SQRT(R2)-AE+AEL*W/R2
    CU(1)=X(1)
    CU(2)=CLZ*SQRT(R12)
    W=SQRT(W+CU(2)*CU(2))
    DO 1 J=1,2
    IF(CU(J))2,3,2
  3 U(J)=SIGN(PID2,X(J+1))
    GOTO 4
  2 U(J)=ATAN(X(J+1)/CU(J))
  4 XE(J)=X(J)*CLZ/W
  1 CONTINUE
    XE(3)=X(3)/W
    ALT=U(2)
    ALN=U(1)
    IF(CU(1))5,6,6
  5 ALN=ALN-PI
  6 IF(ALN)7,8,8
  7 ALN=ALN+PI2
  8 RETURN
    END
```

```
    SUBROUTINE HEIGHT(V,HC)
    DIMENSION V(6)
    COMMON /CAE/AE,AL
    COMMON/CAEL/AEL
    W=V(3)*V(3)
    R2=W+V(1)*V(1)+V(2)*V(2)
    HC=SQRT(R2)-AE+AEL*W/R2
    RETURN
    END
```

```
    SUBROUTINE GCLTLN(V,ALT,ALN)
    COMMON /CPI/PI,PID2,PI2
    DIMENSION V(3)
    R1=SQRT(V(1)*V(1)+V(2)*V(2))
    ALT=PID2
    IF(R1)1,1,2
  2 ALT=ATAN(V(3)/R1)
  1 ALN=ATAN2(V(2),V(1))
    IF(ALN)3,4,4
  3 ALN=ALN+PI2
  4 RETURN
    END
```

CHAPTER 4
POSITION OF THE MOON AND THE SUN
(INDEX C)

4.1 Position of the Moon (C01-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: $/CRE/_1, /CSDAY/_1, /CT3/_1, /CDSJS/_1, /CP1/_3$.

3. Access: CALL SELENA (RJD, T, XS, RS).

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

5. Results: Array XS_3, 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:
$/CRE/_1, /CSDAY/_1, /CT3/_1, /CDSJS/_1, /CP1/_3$ (No. 9 of Table 2.1, Nos. 1,2,4, of Table 2.2, No. 1 of Table 2.3).

7. Algorithm:

$$X_{☾}^{\circ} = \cos\alpha_{☾} \cos\delta_{☾} = \cos\beta_{\varepsilon} \cos\lambda_{\varepsilon} ,$$

$$Y_{☾}^{\circ} = \sin\alpha_{☾} \cos\delta_{☾} = \cos\beta_{\varepsilon} \sin\lambda_{\varepsilon} \cos\varepsilon - \sin\beta_{\varepsilon} \sin\varepsilon ,$$

$$Z_{☾}^{\circ} = \sin\delta_{☾} = \cos\beta_{\varepsilon} \sin\lambda_{\varepsilon} \sin\varepsilon + \sin\beta_{\varepsilon} \cos\varepsilon .$$

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:

$$\varepsilon = 23^{\circ}27'08'',26 - 46'',845T - 0'',0059T^2 + 0'',00181T^3;$$
$$\ell = 296^{\circ}06'16'',59 + 477198^{\circ}50'56'',79T + 33'',09T^2 + 0'',0518T^3;$$
$$\ell' = 358^{\circ}28'33'',04 + 35999^{\circ}02'59'',10T - 0'',54T^2 - 0'',0120T^3;$$
$$F = 11^{\circ}15'03'',20 + 483202^{\circ}01'30'',54T - 11'',56T^2 - 0'',0012T^3;$$

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$$D=350^{\circ}44'14'',95+445267^{\circ}06'51'',18T-5'',17T^{2}+0.0068T^{3};$$ /37

$$\lambda_{\varepsilon}=270^{\circ}26'02'',99+481267^{\circ}52'59'',31T-4'',08T^{2}+0.0068T^{3}+$$
$$+22639'',58\sin\ell-4586'',438\sin(\ell-2D)+2369'',899\sin 2D+$$
$$+769'',021\sin 2\ell-668'',944\sin\ell'-411'',614\sin 2F-$$
$$-211'',658\sin(2\ell-2D)-206'',219\sin(\ell+\ell'-2D)+191,954\sin(\ell+2D)$$
$$-165'',351\sin(\ell'-2D)+147'',878\sin(\ell-\ell')-124,785\sin D-$$
$$-109'',804\sin(\ell+\ell')-55'',174\sin(2F-2D)-45'',100\sin(\ell+2F)+$$
$$+39'',532\sin(\ell-2F)-38'',428\sin(\ell-4D)+36'',124\sin 3\ell-$$
$$-30'',773\sin(2\ell-4D)-28'',511\sin(\ell-\ell'-2D)-24'',451\sin(\ell'+2D);$$

$$\beta_{\varepsilon}=18461'',480\sin F+1010'',18\sin(\ell+F)-999'',695\sin(F-\ell)-$$
$$-623'',658\sin(F-2D)+199'',485\sin(F+2D-\ell)-166'',577\sin(\ell+F-2D)$$
$$+117'',262\sin(F+2D)+61'',913\sin(2\ell+F)-33'',359\sin(F-2D-\ell)-$$

$$\pi_{\varepsilon}=3422'',7+186'',5398\cos\ell+34'',3117\cos(\ell-2D)+28,2333\cos 2D$$
$$+10'',1657\cos 2\ell+3'',0861\cos(\ell+2D)+1'',9202\cos(\ell'-2D)+$$
$$+1'',4455\cos(\ell+\ell'-2D)+1'',1542\cos(\ell-\ell')-0'',9752\cos D-$$
$$-0'',9502\cos(\ell+\ell')-0'',7136\cos(\ell-2F)+0'',6215\cos 3\ell+$$
$$+0'',6008\cos(\ell-4D);$$

$$Z_{\leftmoon}=206\,264'',81R_{\text{э}}/\pi_{\varepsilon},$$

where $R_{\text{э}}$ is the equatorial radius of he Earth.

T-RJD/36525,
RJD relative Julian date in days,
T-the same interval of time in Julian centuries
ℓ -the median anomaly of the Moon,
ℓ' -the median anomaly of the Sun,
F -the median argument of the Moon's latitude,
D -the difference between the median longitudes of the Moon and Sun,
λ_{ε} -the Moon's longitude, /38
β_{ε} -the Moon's declination,
π_{ε} -the Moon's parallax

8. Text.

```
      SUBROUTINE SELENA(DT,T,S,P)
      DIMENSION S(3),A(32),B(17)
      COMMON /CT3/T3
      COMMON/CPI/PI,PID2,PI2
      COMMON/CDSJS/DSJS
      COMMON/CSDAY/SDAY
      COMMON/CRE/RE
      TR=DT/DSJS+(T-T3)/SDAY/DSJS
      S(1)=((.877512763E-8*TR-.286040072E-7)*TR
     *     -.227110969E-3)*TR+.4093197553
      W=8328.691*TR
      N=W/PI2
      W=W-N*PI2
      A(4)=((.231133487E-6*TR+.160424847E-3)*TR
     +     +.10556971E-3)*TR+5.168000347*W
      W=628.301*TR
      N=W/PI2
      W=W-N*PI2
      A(27)=((-.581776417E-7*TR-.261799388E-5)*TR
     +      -.942870201E-3)*TR+6.256583776*W
      W=8433.466*TR
      N=W/PI2
      W=W-N*PI2
      A(17)=((-.581776417E-8*TR-.560444615E-4)*TR
     +      +.293099557E-3)*TR+.1963655549*W

      W=7771.377*TR
      N=W/PI2
      W=W-N*PI2
      A(2)=((.329673303E-7*TR-.250645673E-4)*TR
     +     +.1297089207E-3)*TR+6.121523944*W
      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)
      DO 3 J=3,5
      L=2*(J-1)+14
      A(L)=A(17)+A(J)

    3 A(L+1)=A(17)-A(J)
      A(12)=A(27)-A(3)
      A(1)=3*A(4)
      A(24)=2*A(17)
      A(25)=A(24)-A(3)
      A(26)=A(4)+A(24)
      A(10)=A(4)-A(24)
      A(28)=A(15)+A(17)
      A(29)=A(6)+A(17)
      A(16)=A(4)+A(3)
      A(30)=A(18)-A(4)
      A(31)=A(27)+A(3)
```

```
      A(32)=A(21)-A(3)
      DO 4 J=1,16
    4 B(J+1)=COS(A(J))
      DO 5 J=1,32
    5 A(J)=SIN(A(J))
      B(1)=-.291276066E-5*B(9)+.301311706E-5*B(8)
     *-.345963043E-5*B(11)-.460669986E-5*B(12)-.479[illegible]028E-5*B(3)
     * +.559571021E-5*B(13)+.700798174E-5*B(14)+.9[illegible]
     * -.140616355E-4*B(17)+.492847844E-4*B(16)-.170878091E-5*B(4)
     * +.146347816E-3*B(7)+.904370471E-3*B(5)+.1699871[illegible]
      W=6399,704*TR
      W=W/PI2
      W=W-W*PI2
      B(1)=-.1[illegible]1793E-3*A(21)-.136222229E-3*A(16)
     * -.1[illegible]E-3*A(9)+.175134694E-3*A(1)-.186796821E-3*A(8)
     * -.1[illegible]165654E-3*A(20)-.21865097E-3*A(26)-.26749 11E-3*A(25)
     * -.[illegible]E-3*A(11) -.60[illegible]974752E-3*A(2)+.71[illegible]932776E-3*A(12)
     * -.[illegible]E-3*A(15)+.930619253E-3*A(10)-.9807[illegible]E-3*A(13)
     * -.[illegible]14094E-2*A(7)-.199556099E-2*A(24)-.3[illegible]293E-2*A(27)
     * -.[illegible]E-2*A(5)+.114895046E-1*A(3)-.222356789E-1*A(6)
     * +.1[illegible]759[illegible]*A(4)-((.320673303E-7*TR-.197[illegible]982E-4)*TR
     * +.1460[illegible]E-3)*TR+4.719965708*W

      B(5)=-.145936534E-3*A(28)-.15399137E-3*A(23)
     * -.161725945E-3*A(32)+.300162694E-3*A(22)+.568504219E-3*A(18)
     * -.[illegible]5E-3*A(29)+.967130572E-3*A(30)-.302357951E-2*A(19)
     * -.[illegible]13E-2*A(21)+.489749086E-[illegible]*A(20)+.805037808E-1*A(17)
      DO 3 J=1,5,2
      B(J+1)=COS(B(J))
    3 B(J)=SIN(B(J))
      S(3)=B(6)*B(3)
      S(2)=[illegible]*B(1)+B(5)*B(2)
      S(2)=B(6)*[illegible]*B(5)*B(1)
      S(1)=B(4)*B(6)
      R=RE/B(7)
      RETURN
      END
```

4.2 Position of the Sun (C02-SUN)

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/$_3$,/BIECL/$_2$

3. Access: CALL SUN (RJD, T, RS, AS, BS, XS).

4. 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. 240

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 $\cos\varepsilon$, $\sin\varepsilon$, which are defined below.

$$\Omega = 259^\circ 10' 59''{,}79 - 1934^\circ 08' 31''{,}23T + 7''{,}48T^2 + 0''{,}008T^3;$$
$$\varepsilon = 23^\circ 27' 08''{,}26 - 46''{,}845T - 0''{,}0059T^2 + 0{,}00181T^3 + 9''{,}21\cos\Omega;$$
$$e_\odot = 0{,}01675104 - 0{,}0000418T - 0{,}000000126T^2,$$

7. Algorithm

$$\alpha_\odot = \mathrm{Arctg}(\sin\lambda_\odot\cos\varepsilon/\cos\lambda_\odot)(0{,}061164\cdot 15\Delta\psi)'' - 20''{,}496;$$
$$\delta_\odot = \mathrm{arctg}(\sin\lambda_\odot\sin\varepsilon/(\cos^2\lambda_\odot + \sin^2\lambda_\odot\cos^2\varepsilon)^{1/2}) - 20''{,}496\sin\varepsilon\cos\alpha_\odot;$$
$$\lambda_\odot = \bar\lambda + 2e_\odot\sin(\bar\lambda - \bar\pi) + 5/4\, e^2_\odot \sin 2(\bar\lambda - \bar\pi);$$
$$r_\odot = a_\odot\{1 - e_\odot\cos M_\odot + e^2_\odot(1 - \cos 2M_\odot)/2\};$$
$$\bar\pi = 281^\circ 13' 15'' + 6189''{,}03T + 1''{,}63T^2 + 0''{,}12T^3;$$
$$\Delta\psi = -17{,}23\sin\Omega; \quad a_\odot = 1{,}00000023\, a.e.; \quad 1a.e. = 149600000\,\text{KM}$$
$$M = \bar\lambda - \bar\pi \qquad \bar\lambda = 279^\circ 41' 48''{,}04 + 129602768''{,}13T + 1''{,}089T^2$$

where T=RJD/36525

RJD-relative Julian date in days,

T-the same interval of time in Julian centuries,

$$X^\circ_\odot = \cos\alpha_\odot\cos\delta_\odot,$$
$$Y^\circ_\odot = \sin\alpha_\odot\cos\delta_\odot,$$
$$Z^\circ_\odot = \sin\delta_\odot.$$

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```
      SUBROUTINE SUN(DT,T,RS,AS,BS,XS)
      DIMENSION XS(3)
      COMMON /CT3/T3
      COMMON/CPI/PI,PID2,PI2
      COMMON/CRAD/RAD
      COMMON/CDSJS/DSJS
      COMMON/CSDAY/SDAY
      COMMON/CEPSL/CEP,SEP
      T1=DT/DSJS+(T-T3)/SDAY/DSJS
      P=((.5517[illegible]E-[illegible]*T1+.7902[illegible]E-[illegible])*[illegible]
     *+.3[illegible]00520420E-1)*T1+4.908229465
      W=628.33*T1
      N=W/PI2
      W=W-N*PI2
      AL=((.52[illegible]E-5*T1+.1051134E-2)*T1+4.881627935+W
      W=33.[illegible]57*T1
      N=W/[illegible]

      W=W-N*PI2
      OM=((.337[illegible]45E-[illegible]*T1+.36264063 4E-4)*T1[illegible]
     *+.[illegible]E-[illegible]*T1-[illegible]4.523601216
      ES=([illegible]*T1-.418E-4)*T1+.0167510[illegible]
      AM=AL-P
      ESK=ES*ES
      AL=AL-2.*ES*SIN(AM)+1.25*ESK*SIN(2*AM)
      SW=.7[illegible]7E-4*SIN(OM)
      EP=((.5[illegible]E-8*T1-.28[illegible]*T1
     *-.22711[illegible]E-3)*T1+.4465134E-4*COS([illegible]9319755
      CL=COS(AL)
      SL=SIN(AL)
      CEP=COS(EP)
      SEP=SIN(EP)
      U=SL*CEP
      IF(CL)2,3,2
    3 AS=SIGN(PID2,U)
      GOTO 5
    2 AS=ATAN(U/CL)
      IF(CL)6,6,5
    6 AS=PI+AS
    5 IF(AS)10,11,11
   10 AS=PI2+AS
   11 AS=AS-SW-.99367412[illegible]
      W=SQRT(CL*CL+U*U)
      U1=SL*SEP
      IF(W)7,8,7
    8 BS=SIGN(PID2,U1)
```

```
      GOTO 1
    2 BS=ATAN(Z1/R)
      BS=BS-SEP*COS(AS)*.993674121E-4
    1 RS=1.-ES*COS(AM)+ESK*(1.-COS(2.*AM))/2..
      AS=(RS*.23E-4*RS)*AE
      XS(3)=SIN(BS)
      XS(2)=COS(BS)
      XS(1)=COS(AS)*XS(2)
      XS(2)=SIN(AS)*XS(2)
      RETURN
      END
```

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CHAPTER 5
MODELS OF THE EARTH'S ATMOSPHERE
(INDEX D)

5.1 The Standard Five-Layer Model of the Earth's Atmosphere (DOI-RO)

1. Function: Subprogram RO calculators 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

$$p = A_i \exp(k_{1i}(h-h_i)^2 - k_{2i}(h-h_i)),$$

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 5.1 Values of the Coefficients A_i, k_{1i}, k_{2i}.

i	$h_i \leq h < h_{i+1}$ (м)	A_i (кГ $\cdot\ {}^2$м$^{-4}$)	k_{1i} (м$^{-2}$)	k_{2i} (м$^{-1}$)
I	$100000 \leq h < 150000$	0,4I4I IO^{-7}	0,I469 IO^{-8}	0,I757 IO^{-3}
2	$150000 \leq h < 300000$	0,2I73 IO^{-9}	0,8004 IO^{-10}	0,3734 IO^{-4}
3	$3000000 \leq h < 600000$	0,486I IO^{-11}	0,7III IO^{-11}	0,I547 IO^{-4}
4	$6000000 \leq h < 900000$	0,8904 IO^{-13}	0,I83I IO^{-11}	0,9275 IO^{-5}
5	$900000 \leq h$	0,6497 IO^{-14}	0	0,9540 IO^{-5}

8. **Text.**

```
      SUBROUTINE RO(HG,P)
      COMMON/CHA/HA(5),AA(5),Q1(5),Q2(5)
      I=1
      DO2J=2,5
      IF(HG-HA(J))3,1,1
    1 I=I+1
    2 CONTINUE
    3 W=HG-HA(I)
      P=AA(I)*EXP((Q1(I)*W-Q2(I))*W)
      RETURN
```

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]

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/$_{50}$,/SYEAR/$_{38}$.

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/OKOEF/A(50), are sent values of coefficients of the model according to Table 5.2, and into the unit COMMON/SYEAR/F_{38} is the set of numerical corrections on the semiannual effect according to Table 5.3.

---

[1] Author of the subprogram M.I. Voyskovskiy.

4. Access to DENS:
CALL DENS (HC,X,Y,Z,SUN,AP,$F10_7$,D,I,RO).
Raw data: HC-altitude above the Earth's surface in km; /44
X,Y,Z,-directing cosines of the radius-vector in the absolute system of coordinates; the array SUN, which contains the values $\alpha_\odot, \delta_\odot$ (right ascension and declination of the sun in radians);

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

$F10_7$-the F_{10_7}, at the moment of time $t-\Delta\tau_F$ where t is Moscow time (for isolating the calculation of the influence of solar activity it is sufficient to let $F_{10_7} < 0.5$);

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_6;
if $I=0$, then DE is not considered;
if $I > 0$, then DE is considered in its entirety.

Results: Array RO_6, 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:

$$RO(1)=k_4,$$

$$RO(2)=k_1, \; RO(3)=k_2, \; RO(4)=k_3, \; RO(5)=\rho_H, \; RO(6)=\rho_H k_1 k_2 k_3 k_4.$$

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 $/SYEAR/_{38}$.

6. Algorithm
The density p is calculated according to the formula:
$p = \rho_H \cdot k_1 k_2 k_3 k_4$, where ρ_H is the nightly vertical /45

cross 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.

$$\rho_h = \exp(a_1 - a_2 (h - a_3)^{1/2});$$

$$k_1 = 1 + (b_1 + b_2 h)(F - F_0)/F_0 \; ;$$

$$k_2 = 1 + \left(c_1 + c_2 h + c_3 \exp\left(-(h + c_4)^2/c_5^2\right)\right)\left(\cos^{m_1} \psi_1/2 + c_0 \cos^{m_2} \psi_2/2\right);$$

$$k_3 = 1 + (A_1 + A_2 h) A(d); \quad k_4 = 1 + (e_1 + e_2 h) \ln (a_p / \bar{a}_p),$$

where
$$\cos \psi_1 = Z^\circ \sin \delta_\odot + \cos \delta_\odot (X^\circ \cos \gamma_1 + Y^\circ \sin \gamma_1),$$
$$\cos \psi_2 = -Z^\circ \sin \delta_\odot + \cos \delta_\odot (X^\circ \cos \gamma_2 + Y^\circ \sin \gamma_2),$$
$$\gamma_1 = \alpha_\odot + \varphi_1, \quad \gamma_2 = \alpha_\odot + \varphi_2,$$

h -the altitude above the Earth's surface.

$X^\circ, Y^\circ, Z^\circ$ -the directing cosines of the radius-vector of a point in the absolute system of coordinates,

$\alpha_\odot, \delta_\odot$ -the right ascension and declination of the Sun.

d -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 vulumes 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, /46

a_p -the three hour index of geomagnetic disturbance.

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

In table 5.2 are also the coefficients of the model: $a_1, a_2, a_3, b_1, b_2, \ldots, \bar{a}_p$ 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 $F_0 10^{-22}$ W.m^{-2}Hz^{-1} (units COMMON/QKOEF/Q50)).

i	Designations	$Q(i)$	$Q(i)$	$Q(i)$	$Q(i)$
1	F_0	75	100	125	150
2	a_1	-14,030	-15,095	-17,028	-16,072
3	a_2	0,9108	0,8229	0,7198	0,7155
4	a_3	59,77	68,92	93,36	70,33
5	b_1	-0,630	-0,750	-0,710	-0,765
6	b_2	0,00506	0,00560	0,00562	0,00571
7	c_1	0,130	0,172	-0,274	-0,247
8	c_2	0,00014	0,00217	0,00257	0,00199
9	c_3	3,733	3,784	4,048	4,698
10	c_4	-507,95	-566,11	-632,63	-707,58
11	c_5	189,85	200,97	230,76	278,35
12	c_6	-0,041	-0,047	-0,038	-0,012
13	m_1	4,2	4,1	4,4	5,2
14	m_2	6,0	6,0	5,9	5,9
15	φ_1	37°,4	34°,2	34°,5	33°,8
16	φ_2	325°,9	318°,0	308°,0	322°,2
17	A_1	-0,602	-0,526	-0,513	-0,607
18	A_2	0,00669	0,00636	0,00631	0,00670
19	e_1	-0,132	-0,130	-0,128	-0,115
20	e_2	0,00108	0,00104	0,00095	0,00089
21	$\Delta\tau_F$	39^h	39^h	39^h	39^h
22	$\Delta\tau_{a_p}$	$10^h,5$	$10^h,5$	$10^h,5$	$10^h,5$
23	δt_F	4^h	4^h	4^h	4^h
24	δt_{a_p}	1^h	1^h	1^h	1^h
25	$\bar{a}_p$	2	2	3	4

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/SYEAR/P(38)).

i	d	$P(i)=A(d)$
I	0	-0,067
2	I0	-0,083
3	20	-0,094
4	30	-0,088
5	40	-0,063
6	50	-0,005
7	60	0,039
8	70	0,090
9	80	0,I23
I0	90	0,I33
II	I00	0,I26
I2	II0	0,099
I3	I20	0,059
I4	I30	0,0I7
I5	I40	-0,027
I6	I50	-0,065
I7	I60	-0,I03
I8	I70	-0,I36
I9	I80	-0,I56
20	I90	-0,I72
21	200	-0,I80
22	2I0	-0,I83
23	220	-0,I79
24	230	-0,I63
25	240	-0,I33
26	250	-0,085
27	260	-0,0I8
28	270	0,059
29	280	0,I23
30	290	0,I6I
3I	300	0,I70
32	3I0	0,I56
33	320	0,II9
34	330	0,073
35	340	0,027
36	350	-0,023
37	360	-0,055
38	370	-0,078

7. Text.

```
      SUBROUTINE VRMA (F)
      COMMON/CKOEF/A(50)/SYEAR/P(38)
      DIMENSION R(100),S(38)
      DATA S/-.067,-.083,-.094,-.088,-.063,-.005,.039,.09,.123,
     1       .133,.126,.099,.059,.017,-.027,-.065,-.103,-.136,-.156,
     2       -.172,-.18,-.183,-.179,-.163,-.133,-.085,-.018,.059,.123,
     3       .161,.17,.156,.119,.073,.027,-.023,-.055,-.078/
      DATA R/75.,-14.9,.5106,59.77,-.63,.00506,.130,.00014,3.733,
     1       -307.95,139.45,-.341,4.2,6.,37.4,325.9,-.602,.00569,
     2       -.132,.00108,59.,25.5,4.,1.,2.,100.,-15.095,.8299,68.92,
```

```
                                 .00217,3.784,-566,11,200.97,-.047,4.1,
        .2,518,-.526,.00636,-.13,.00104,39.,10.5,4,.1,.2,
     5  15.,-17.028,.7198,93.36,-.715,.005621,-.274,.00257,4.048,
     6  -532.63,230.76,-.035,4.415,9,34.5,308.,-.513,.00651,
     7  -.128,.00095,39.,10.5,4,.1,.3,.150.,-16.074,.7155,70.33,
     8  -.765,.00571,-.247,.00199,4.698,-707.58,278.35,-.012,5.2,
     9  5.9,33.8,322.2,-.607,.0067,-.115,.00080,39.,10.5,4,.1,.4./
      DO 6 J=1,38
    6 P(J)=S(J)
      DO 3 I=1,100,25
    1 IF(ABS(R(I)-F)-.1) 2,3,3
    3 CONTINUE
      PRINT 4
      STOP
    4 FORMAT ('НЕВЕРНО ЗАДАНО F')
    2 L=I+24
      DO 5 K=I,L
      N=K-I+1
    5 Q(N)=R(K)
      RETURN
      END

          SUBROUTINE DENS(H,X,Y,Z,SUN,AP,F107,D,ISUT,RO)
          DIMENSION RO(6),V(5),SUN(2)
          COMMON /QKOEF/Q(50)/SVEAR/P(38)
          C6=0.
          PI=3.1415926/180.
          DO 7 J=1,4
        7 RO(J)=1.
           RO(5)=EXP(Q(2)-Q(3)*SQRT(H-Q(4)))
          IF (AP-.5) 2,2,1
        1 RO(1)=1.+(Q(19)+Q(20)*H)*ALOG (AP/Q(25))
        2 IF (F107-.5) 3,3,4
        4 RO(2)=1.+(Q(5)+Q(6)*H)*(-1+F107/Q(1))
        3 IF (D) 5,6,6
        6 I=INT(D/10.)+1
          RO(3)=AMOD (D,10.)/10.
          RO(3)=P(I)+(P(I+1)-P(I))*RO(3)
          RO(3)=1.+RO(3)*(Q(17)+Q(18)*H)
        5 ASSIGN 11 TO M
          IF(ISUT) 8,9,10
       10 ASSIGN 12 TO M
        8 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))**2)
          V(4)=SUN(1)+Q(15)*PI
          V(3)=SIN(V(4))
          V(4)=COS(V(4))
          V(5)=Z*V(1)+V(2)*(X*V(4)+Y*V(3))
          V(5)=((1.+V(5))/2.)**(Q(13)/2.)
          GO TO M,(11,12)
       12 V(4)=SUN(1)+Q(16)*PI
          V(3)=SIN(V(4))
          V(4)=COS(V(4))
          C6=-Z*V(1)+V(2)*(X*V(4)+Y*V(3))
          C6=((1.+C6)/2.)**(Q(14)/2.)
          C6=Q(12)*C6
       11 RO(4)=1.+RO(4)*(V(5)+C6)
        9 RO(6)=RO(5)*RO(4)*RO(3)*RO(2)*RO(1)
          RETURN
           END
```

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5.3 Yakkia-72 Model of the Earth's Atmosphere (DO3-ADEN, AMBAR, GRAV, TLOCAL)[1] /49

1. Function. Acording to the given location of a point, of the Sun, the values of F_{107}, 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 voume, 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_{107}(the time lag-1.7 days),
GEO(2)-the value of the geomagnetic index k_p , considering that 3^- =2.667, 3^+ =3.333 and so forth, the time delay τ_{k_p} =0.279 days. /50

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;

---

[1] 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^3).

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 F)

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6.1 The Acceleration Vector, Determined By the Influence of Anomalies of Earth's Gravitational Field (E01-DEG2, DEG3, DEG4)[1]

1. Function. For a point in space fixed by the Greenwich coordinates: x,y,z, one determines the constituents Δg_r, Δg_m and Δg_l, Δg of the acceleration vector which is specified by the influence of anomalies of the Earth's gravitational field 1.2 :

Δg_r --the radial constituent of vector Δg (project on the radius-vector of a point with a minus sign), Δg_m the merdional constituent (the meridian directed to the north),

Δg_l -the projection of Δg on the perpendicular to the plane of the meridian (directed to the east).

Supbrogram DEG2 determines the acceleration vector which is determined by the influence only of zonal harmonics of anomalies of the Earth's gravitational field. Subprogram 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: $/RAD/_2./CRZ/_1,/BCONGR/_{546},/CAZZ/_4$.

3. Access: CALL DEG2 (X,DG, NM),
CALL DEG3 (XG,DG,NM),
CALL DEG 4 (XG,DG).

4. Raw data. Array XG_3, which contains x,y,z--the Greenwich coordinates of a point;
NM-the number of harmonics considered ($NM \leq 22$).

Note. When accessing subprogram DEG_2 one may use coordinates of a point both in the Greenwich and absolute system of coordinates. /52

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 $R1=(x^2+y^2)^{\frac{1}{2}}$ into the unit COMMON/RAD/R,R1.

---

[1] Author--Ye.Ye. Ryazanova.

In the unit COMMON/CRZ/RZ the value RZ 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 2.5) by means of a preliminary accessing of subprogram CONGR(AO2). In subprogram DEG4 an additional variant of coefficient values of the Earth's gravitational field is used from unit COMMON/CAZZ/$_4$ (No. 4 of Table 2.1).

7. Algorithm.

a) calculation of zonal harmonics

$$\Delta g_r = 1/r \sum_{n=3}^{n_{max}} (R/r)^{n+1} (n+1)\alpha_{no}P_{no}(\sin\psi);$$

$$\Delta g_m = 1/r \sum_{n=3}^{n_{max}} (R/r)^{n+1} \alpha_{no}P_{n1}(\sin\psi); \quad \Delta g_\ell = 0.$$

b) calculation of zonal, tesseral, and sectoral harmonics:

$$\Delta g_r = 1/r \sum_{n=2}^{n_{max}} (R/r)^{n+1} (n+1) \sum_{m=0}^{n} (\alpha_{nm}\cos mL + \beta_{nm}\sin mL) P_{nm}(\sin\psi);$$

$$\Delta g_m = 1/r \sum_{n=2}^{n_{max}} (R/r)^{n+1} \sum_{m=0}^{n} (\alpha_{nm}\cos mL + \beta_{nm}\sin mL)(P_{n,m+1}(\sin\psi) - m\,\mathrm{tg}\,\psi P_{nm}(\sin\psi));$$

$$\Delta g_\ell = 1/r_1 \sum_{n=2}^{n_{max}} (R/r)^{n+1} \sum_{m=0}^{n} (-\alpha_{nm}\sin mL + \beta_{nm}\cos mL)\, m P_{nm}(\sin\psi);$$

x, y, z - the Greenwich coordinates of a point,

where $r = (x^2+y^2+z^2)^{1/2}$, $r_1 = (x^2+y^2)^{1/2}$, R = 6371 KM, / 53

ψ, L - the geocentric latitude and longitude of a point,

$\sin L = y/r_1$, $\cos L = x/r_1$, $\sin\psi = z/r$, $\cos\psi = r_1/r$,

$P_{n,m}(\sin\psi)$ - Legendre's joined functions

$P_{n+1,m} = ((2n+1)\sin\psi P_{nm} - (n+m)P$ [illegible], when n > m,

$P_{nn} = (2n-1)\cos\psi P_{n-1,n-1}$,

when n m, Pnm=0

$\sin mL = \sin(m-1)L\cos L + \cos(m-1)L\sin L$,

$\cos mL = -\sin(m-1)L\sin L + \cos(m-1)L\sin L$,

$P_{00} = 1$, $P_{10} = \sin\psi = z/r$, $P_{11} = \cos\psi = r_1/r$, $P_{20} = (3\sin^2\psi - 1)/2$,

$P_{21} = 3\sin\psi\cos\psi = 3zr_1/r^2$, $P_{22} = 3\cos^2\psi$,

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α_{nm}, β_{nm} -anomaly coefficients

n_{max} - -the greatest number of harmonics considered.

c) calculation of only the first four harmonics

$$\Delta g_r = \frac{1}{r}\left(\frac{R}{r}\right)^3\left(9\frac{x^2-y^2}{r^2}\alpha_{22} + 18\frac{xy}{r^2}\beta_{22} + \right.$$

$$\left. + \frac{Rz}{r^2}\left(10\frac{z^2}{r^2}-6\right)\alpha_{30} + \left(\frac{R}{r}\right)^2\left(\frac{175}{8}\left(\frac{z^2}{r^2}\right)^2 - \frac{150}{8}\frac{z^2}{r^2} + \frac{15}{8}\right)\alpha_{40}\right);$$

$$\Delta g_m = \frac{1}{r}\left(\frac{R}{r}\right)^3\frac{r_1}{r}\left(-6\frac{z}{r}\frac{x^2-y^2}{r_1^2}\alpha_{22} + 2\frac{xy}{r_1^2}\beta_{22}\right.$$

$$\left. + \frac{3}{2}\frac{R}{r}\left(\frac{5z^2}{r^2}-1\right)\alpha_{30} + \frac{5}{2}\frac{R^2}{r^2}\frac{z}{r}\left(7\frac{z^2}{r^2}-3\right)\alpha_{40}\right);$$

$$\Delta g_l = \frac{1}{r}\left(\frac{R}{r}\right)^3\frac{r_1}{r}\left(-12\frac{xy}{r_1^2}\alpha_{22} + 6\frac{x^2-y^2}{r_1^2}\beta_{22}\right).$$

8. Texts.

```
      SUBROUTINE DEG2(X,DG,NM)
      DIMENSION X(3),DG(3),PN0(3),PN1(3),A(19)
      COMMON/BCONGR/ANM(273),BNM(273)
      COMMON/RAD/R1,R
      COMMON/CRZ/RE
      A(1)=ANM(4)
      A(2)=ANM(8)
      A(3)=ANM(13)
      A(4)=ANM(19)
      A(5)=ANM(26)
      A(6)=ANM(34)
      A(7)=ANM(43)
      A(8)=ANM(53)
      A(9)=ANM(64)
      A(10)=ANM(76)
      A(11)=ANM(89)
      A(12)=ANM(103)
      A(13)=ANM(118)
      A(14)=ANM(134)
      A(15)=ANM(151)
      A(16)=ANM(169)
      A(17)=ANM(188)
      A(18)=ANM(208)
      A(19)=ANM(229)
      C1=RE/R
      C2=X(3)/R
      PN0(1)=C2
      PN0(2)=(3.0*C2*C2-1.0)/2.0
      PN1(1)=R1
      PN1(1)=PN1(1)/R
      PN1(2)=3.0*C2*PN1(1)
      DG(1)=0.0
      DG(2)=0.0
      U=0.0
      DO 10 N=3,NM
      U=N
      C3=(2.0*U-1.0)*C2
      PN0(3)=(C3*PN0(2)-(U-1.0)*PN0(1))/U                          /54
      PN1(3)=(C3*PN1(2)-U*PN1(1))/(U-1.0)
      C3=(C1**(N+1))*A(N-2)
      DG(1)=DG(1)+C3*(U+1.0)*PN0(3)
      DG(2)=DG(2)+C3*PN1(3)
      PN0(1)=PN0(2)
      PN0(2)=PN0(3)
      PN1(1)=PN1(2)
      PN1(2)=PN1(3)
   10 CONTINUE
      DG(1)=DG(1)/R
      DG(2)=DG(2)/R
      DG(3)=0.0
      RETURN
      END
```

```
      SUBROUTINE DEG3(X,DG,NM)
      DIMENSION X(3),DG(3),SG(3)
      DIMENSION P(23,24),SML(23),CML(23)
      COMMON/BCONGR/ANM(273),BNM(273)
      COMMON/RAD/R1,R
      COMMON/GRZ/RE
      SFI=X(3)/R
      CFI=R1/R
      NM1=NM+1
      SML(1)=0.0
      SML(2)=X(2)/R1
      CML(1)=1.0
      CML(2)=X(1)/R1
      DO 1 I=3,NM1
      SML(I)=SML(I-1)*CML(2)+CML(I-1)*SML(2)
    1 CML(I)=-SML(I-1)*SML(2)+CML(I-1)*CML(2)
      UM=0.0
      UN=0.0
      P(1,1)=1.0
      P(2,1)=SFI
      P(2,2)=CFI
      NM2=NM1+1
      DO 2 I=2,NM2
    2 P(1,I)=0.0
      DO 3 I=3,NM2
    3 P(2,I)=0.0
      DO 4 M=1,NM2
      UM=M-1
      DO 4 N=3,NM1
      UN=N-1
      W=(2.0*UN-1.0)
      IF(N-M)5,6,7
    5 P(N,M)=0.0
      GO TO 4
    6 P(N,M)=W*CFI*P(N-1,M-1)
      GO TO 4

    7 P(N,M)=(W*SFI*P(N-1,M)-(UN+UM-1.0)*P(N-2,M))/(UN-UM)
    4 CONTINUE
      RHOR=RE/R
      UN=0.0
      DO 8 I=1,3
    8 DG(I)=0.0
      DO 9 N=3,NM1
      UN=N
      DO 10 I=1,3
   10 SG(I)=0.0
      UM=0.0
      DO 11 M=1,N
      IS=0
      NS=N-3
      NAB=M
      IF(NS.LT.1)
                      GO TO 13
      DO 12 JS=1,NS
   12 NAB=NAB+JS+2
   13 C1=ANM(NAB)*CML(M)+BNM(NAB)*SML(M)
      UM=M
      W=(UM-1.)*P(N,M)
      SG(1)=SG(1)+C1*P(N,M)
      SG(2)=SG(2)+C1*(P(N,M+1)-W*(X(3)/R1))
   11 SG(3)=SG(3)+(-ANM(NAB)*SML(M)+BNM(NAB)*CML(M))*W
      C2=RHOR**N
      DG(1)=DG(1)+C2*UN*SG(1)
      DG(2)=DG(2)+C2*SG(2)
      DG(3)=DG(3)+C2*SG(3)
      DG(1)=DG(1)/R
      DG(2)=DG(2)/R
      DG(3)=DG(3)/R1
      RETURN
      END
```

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```
SUBROUTINE DEG4(X,DG)
DIMENSION X(3),DG(3)
COMMON/RAD/R1,R
COMMON/GRZ/RE
COMMON/GA22/A22,B22,A30,A40
C1=RE/R
C2=C1*C1
C3=C2*C1/R
C4=C3*C1/R
U1=X(3)/R
U2=U1*U1
U3=X(1)*X(1)-X(2)*X(2)
R2=R*R
R12=R1*R1
U4=U3/R12
U5=X(1)*X(2)/R12
DG(1)=C3*(9,0*U3*A22/R2+18,0*X(1)*X(2)*B22/R2+C1*U1
*   *(10,0*U2-6,0)*A30+(175,0*U2*U2-150.0*U2+15.0)*C2*A40/8.0)
DG(2)=C4*(-6,0*U1*(U4*A22+2,0*U5*B22)+1,5*C1
*   *(5,0*U2-1,0)*A30+2,5*C2*U1*(7,0*U2-3,0)*A40)
DG(3)=C4*6,0*(-2,0*U5*A22+U4*B22)
RETURN
END
```

List of Subprograms by Name.

Name	Index	Page *
ABSEL	B 08	29
ADEN	D 03	50
AGIOA	B 06	25
AGIOA3	B 06	25
AMBAR	D 03	50
CONGR	A 02	15
CONST	A 01	11
DATDAY	B 01	19
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DENS	D 02	43
ELABS	B 07	27

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