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THE RADIATION ENVIRONMENT MONITOR

STRV–1B and MIR orbit tracking

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Contents

1 Introduction

In order to understand and interpret the REM measurements it is crucial to know the position of the satellite/spacestation at the moment of the data taking. L-value and magnetic field calculations are based on the assumed position in space.

In this report we discuss the methods applied in the REM project for the satellite/spacestation position determination.

2 Available orbit information

2.1 STRV–1B

The orbital parameters of the STRV satellites are regularly provided by DRA. The information is written on the files named bov****.txt, where **** is a number characterizing the time of epoch. In figure 1 and example of such a file is shown.

The files contain position and velocity in geocentric inertial coordinates (Orbit vector) at a given time (Epoch of orbit vector), the keplerian osculating elements and also the latest NORAD two-line element set (see section 2.3 for a discussion of the NORAD two–line element sets).

2.2 MIR

For each MIR–REM data file (tyymmddx.rem), a file containing MIR spacestation positions is provided (byymmddx.rem) which are created by the Russian Space Corporation ENERGIA in Moscow. An example of such a ballistic data file is shown in figure 2.

The ballistic data files contain besides the position in geocentric inertial coordinates also the orientation of the MIR–REM instrument which is given by the azimuth and elevation in a cartesian coordinate system, centered on the REM detectors with the z–axis parallel to the earth rotation axis and the x–axis directed towards equinox [1]. The last column of ones and zeros shows whether the REM instruments has been in the sun light (1) or not (0). One data point is normaly given per 320 sec.

```
**************************************************************
DRA Space and Communications Department
Flight Dynamics Service
**************************************************************
                       STRV ORBIT
**************************************************************

Satellite name: BEST ESTIMATE OF ORBIT VECTOR STRV-1B

Please quote the following number in all correspondence.

Element set number : STRB-48

Epoch of orbit vector
---------------------
Date:  MJD 49873  Mon 05 May 95
Hr/min/sec: 00:00:00.00

Orbit vector
------------
Coordinate frame: geocentric inertial,
                  true of date equator and equinox.
Units: distance-km, velocity-km/s, angles-degrees.

Position and velocity (x,y,z,dx/dt,dy/dt,dz/dt):

   -6094.493   -10400.051     -626.556   2.66354661  -6.46082999  -0.89344102

Keplerian osculating elements (semi-major axis, eccentricity,
inclination, right asc. of the ascending node, argument of
perigee, mean anomaly):

   24289.401  0.72609802       7.506      36.394     109.575      16.146

Latest NORAD two-line mean element set:

1 23126U 94034C   95154.64582650  .00000241  00000-0  17148-3 0  1504
2 23126   7.5020  37.0617 7263363 108.2779 337.1200  2.29543003  7380

Comments
--------

None.

**************************************************************
For further enquiries please contact Mr.P.Houchin on 01252-392006
or Miss A.Cant on 01252-393714.
**************************************************************
                           END
**************************************************************
```

Figure 1: Example of an STRV–1B orbit information file (bov156a.txt)

```
95  4 30       Epoch Date(yy,mm,dd)
15 33 38.878   Universal Time[hh,mm,ss]
 5540.233      Period[s]
 6776.660      Semi Major Axis[km]
  .00172443    Eccentricity
  35.7654      RA of Node[gr]
  52.1168      Arg of Perigee[gr]
  51.6690      Inclination[gr]
  DATE       UT           Xa        Ya        Za       AL       DL
 [y,m,d]   [h,m,s]       [km]      [km]      [km]     [gr]     [gr]
     ATTITUDE s INDEX:i2
95  4 30 15 54   .000 -1415.723  4065.113  5220.463  272.194   75.278 1
95  4 30 15 59 20.000 -3404.531  2638.099  5221.813  272.110   75.267 1
95  4 30 16  4 40.000 -4949.436   867.363  4540.628  272.054   75.249 1
95  4 30 16 10   .000 -5849.661 -1015.844  3266.845  272.031   75.230 0
95  4 30 16 15 20.000 -5989.061 -2766.458  1567.435  272.030   75.216 0
95  4 30 16 20 40.000 -5350.688 -4157.560  -335.864  272.029   75.211 0
95  4 30 16 26   .000 -4018.327 -5009.555 -2195.615  272.006   75.215 0
95  4 30 16 31 20.000 -2165.161 -5212.929 -3770.661  271.950   75.223 0
95  4 30 16 36 40.000   -31.263 -4741.925 -4856.983  271.867   75.227 0
95  4 30 16 42   .000  2107.170 -3657.628 -5313.697  271.776   75.222 1
95  4 30 16 47 20.000  3973.061 -2100.175 -5081.094  271.701   75.209 1
95  4 30 16 52 40.000  5323.930  -271.026 -4188.521  271.656   75.189 1
95  4 30 16 58   .000  5983.274  1592.659 -2751.038  271.643   75.171 1
95  4 30 17  3 20.000  5863.860  3248.504  -955.039  271.644   75.160 1
  DATE       UT           Xa        Ya        Za       AL       DL
 [y,m,d]   [h,m,s]       [km]      [km]      [km]     [gr]     [gr]
95  4 30 17  8 40.000  4980.266  4480.065   964.904  271.633   75.160 1
95  4 30 17 14   .000  3445.866  5127.178  2759.237  271.599   75.166 1
95  4 30 17 19 20.000  1460.704  5104.387  4192.421  271.533   75.172 1
95  4 30 17 24 40.000  -715.928  4414.663  5076.721  271.445   75.174 1
95  4 30 17 30   .000 -2799.523  3148.512  5296.585  271.357   75.166 1
     ATTITUDE s INDEX:r
95  4 30 17 32   .000 -3500.167  2556.984  5199.058  271.329   75.161 1
95  4 30 17 35 20.000 -4518.065  1471.860  4823.877  256.650   68.679 1
95  4 30 17 37   .000 -4943.002   897.423  4541.666  253.277   64.967 1
     ATTITUDE s INDEX:o
95  4 30 17 40 40.000 -5647.884  -396.115  3721.287  250.356   55.889 0
95  4 30 17 46   .000 -6042.764 -2212.040  2133.598  252.143   42.614 0
95  4 30 17 51 20.000 -5652.526 -3740.231   268.246  257.437   30.008 0
95  4 30 17 56 40.000 -4528.885 -4783.133 -1632.012  265.052   18.672 0
.
.
.
```

Figure 2: Example of an MIR–REM ballistic data file (b9505011.rem)

2.3 NORAD two–line mean element sets

For each satellite the orbital parameters are regularly determined, updated and distributed in form of the NORAD two–line mean element sets. They can be downloaded from an anonymous server at the Air Force Institute of Technology, Ohio, USA. The internet address is **archive.afit.af.mil** and the latest list of elements are on **pub/space/tle.new**. The information for a satellite is contained in three lines, one containing the satellite name and the other two containing the orbit parameters. A more complete definition is given in the text below.

Each satellite is given a unique **Satellite Number**.
STRV–1B has the number **94034C**, MIR spacestation has the number **86017A**.

```
To get the most recent NORAD two elemnt vectors:

> ftp archive.afit.af.mil
ftp>    cd pub/space
ftp>    get tle.new

As a service to the satellite user community, the following description of the
NORAD two-line orbital element set format is uploaded to sci.space.news and
rec.radio.amateur.space on a monthly basis.  The most current orbital elements
from the NORAD two-line element sets are carried on the Celestial BBS, *(205)
409-9280*, and are updated several times weekly.  Documentation and tracking
software are also available on this system.  The Celestial BBS may be accessed
24 hours/day at 300, 1200, 2400, 4800, or 9600 bps using 8 data bits, 1 stop
bit, no parity.  In addition, element sets (updated weekly) and some
documentation and software are also available via anonymous ftp from
archive.afit.af.mil (129.92.1.66) in the directory pub/space.

==============================================================================

Data for each satellite consists of three lines in the following format:

AAAAAAAAAAAAAAAAAAAAAA
1 NNNNNU NNNNNAAA NNNNN.NNNNNNNN +.NNNNNNNN +NNNNN-N +NNNNN-N N NNNNN
2 NNNNN NNN.NNNN NNN.NNNN NNNNNNN NNN.NNNN NNN.NNNN NN.NNNNNNNNNNNNNN

Line 0 is a twenty-two-character name (this change is being made to be
consistent with the name length in the NORAD SATCAT).

Lines 1 and 2 are the standard Two-Line Orbital Element Set Format identical
to that used by NORAD and NASA.  The format description is:

Line 1
Column     Description
 01-01     Line Number of Element Data
 03-07     Satellite Number
 10-11     International Designator (Last two digits of launch year)
 12-14     International Designator (Launch number of the year)
 15-17     International Designator (Piece of launch)
 19-20     Epoch Year (Last two digits of year)
 21-32     Epoch (Julian Day and fractional portion of the day)
 34-43     First Time Derivative of the Mean Motion
        or Ballistic Coefficient (Depending on ephemeris type)
 45-52     Second Time Derivative of Mean Motion (decimal point assumed;
           blank if N/A)
 54-61     BSTAR drag term if GP4 general perturbation theory was used.
           Otherwise, radiation pressure coefficient.  (Decimal point assumed)
```

```
 63-63     Ephemeris type
 65-68     Element number
 69-69     Check Sum (Modulo 10)
           (Letters, blanks, periods, plus signs = 0; minus signs = 1)

Line 2
Column     Description
 01-01     Line Number of Element Data
 03-07     Satellite Number
 09-16     Inclination [Degrees]
 18-25     Right Ascension of the Ascending Node [Degrees]
 27-33     Eccentricity (decimal point assumed)
 35-42     Argument of Perigee [Degrees]
 44-51     Mean Anomaly [Degrees]
 53-63     Mean Motion [Revs per day]
 64-68     Revolution number at epoch [Revs]
 69-69     Check Sum (Modulo 10)

All other columns are blank or fixed.

Example:

NOAA 6
1 11416U          86 50.28438588 0.00000140           67960-4 0  5293
2 11416  98.5105  69.3305 0012788  63.2828 296.9658 14.24899292346978
```

---

3 Orbit generator

The NORAD two–line elements can be used to calculate satellite positions at any time. There exist different computer programs for the calculation of satellite trajectories. The one we use is called SPACETRACK, is available from the same site as the NORAD elements (see section 2.3), and has been written by Dr. T.S. Kelso [2].

3.1 SPACETRACK

SPACETRACK is a well documented Fortran IV code. It calculates satellite positions x, y, z and velocities v_x, v_x, v_x in geocentric inertial coordinate system. It contains five different tracking models.

As input SPACETRACK normaly needs a set of NORAD two–line elements, a variable telling which tracking model shall be used, and three variables defining start, stop, and time increment for the tracking.

The original SPACETRACK code consist of ten Fortran subroutines:
driver (main program), sgp, sgp4, sdp4, sgp8, sdp8 (five tracking models), deep (used for long orbits), actan, fmod2p, and thetag.

3.2 REM–project implementation

For the use of SPACETRACK for the REM project, the input and output sections have been modified. In order to make it running on a DEC–Alpha station some minor changes had to be applied, which however do not affect the results. These changes are described in Appendix A.

As mentioned before SPACETRACK provides five tracking models. In order to guarantee consistency in orbit generation throughout the whole REM project, the liberty of model selection has been removed. We always use one and the same model. This restriction is justified by the comparison of the different models, which show no significant differences. We use the model which is recommanded in the SPACETRACK REPORT [2], the model called **SDP4**.

The PSI implementation takes information from two files and writes the results on a third one.

Input:
The input files are NORAD.DAT, containing the NORAD two–line elments and TIMES.DAT containing the start time of the trajectory calculation and a list of time stamps relativ to the start time in seconds. In figure 3 and 4 examples of the input files are shown.

```
STRV-1B
1 23126U 94034C   95303.45317932  .00010142  00000-0  17715-2 0  1890
2 23126   7.5434 335.6090 7268060 230.4033  38.9956  2.30926582 10816
```

Figure 3: Example of a NORAD.DAT file used as input for the REM–project orbit generator.

```
31-Oct-95, 06:37:01
   200.1
   300.2
   450.3
   550.5
   700.7
   800.8
   951.0
  1051.0
  .
  .
  .
```

Figure 4: Example of a TIMES.DAT file used as input for the orbit generator

Output:
The results are written on the file ORBIT.DAT.
Output in geocentric inertial, geographic, or geocentric solar ecliptic coordinates can be produced.

3.2.1 eci.exe

The program eci.exe calculates positions in geocentric inertial coordinates. An example of the output file ORBIT.DAT for the STRV–1B satellite is shown in figure 5.

```
31-Oct-95, 06:37:01
   200.1  -2876.8325  -6656.6426   -957.9106  1
   300.2  -2127.7673  -7242.3384   -986.4588  1
   450.3   -970.9195  -7999.0454  -1012.8232  1
   550.5   -187.6928  -8428.8359  -1020.7784  0
   700.7    987.1566  -8971.3252  -1020.4567  0
   800.8   1764.4730  -9272.0752  -1013.2680  0
   951.0   2914.8206  -9643.4121   -993.7876  0
  .
  .
  .
```

Figure 5: Example of a result file ORBIT.DAT produced with eci.exe. The five colums are (l.t.r.) time relative to start time (31-Oct-95, 06:37:01) in seconds , x, y, and z in km, eclipse

3.2.2 lla.exe

The program lla.exe calculates positions in geographic coordinates. An example of the output file ORBIT.DAT is shown in figure 6. lla.exe computes the geocentric inertial coordinates first and then transfers them to the geographic coordinate system following an algorithm described in Russell, 1971 [3].

```
31-Oct-95, 06:37:01
   200.1    107.4391     -7.5249   7314.6870  1
   300.2    114.0211     -7.4454   7612.6187  1
   450.3    122.8458     -7.1642   8121.1592  1
   550.5    128.0722     -6.9035   8492.4961  0
   700.7    134.9996     -6.4507   9082.9775  0
   800.8    139.0766     -6.1275   9492.7051  0
   951.0    144.4925     -5.6338  10123.2002  0
  1051.0    147.6893     -5.3079  10549.5576  0
  .
  .
  .
```

Figure 6: Example of an result file ORBIT.DAT produced with lla.exe. The five colums are (l.t.r.) time relative to start time (31-Oct-95, 06:37:01) in seconds , longitude and latitude in degrees, distance from earth center in km, eclipse

3.2.3 gse.exe

The program gse.exe calculates positions in geocentric solar ecliptic coordinates. An example of the output file ORBIT.DAT is shown in figure 7. gse.exe computes the geocentric inertial coordinates first and then transfers them to the geocentric solar ecliptic coordinate system following an algorithm described in Russell, 1971 [3].

```
31-Oct-94, 05:23:10
     0.0      -8.6419   2375.1468   6336.0132  0
   320.0  -2410.3750   2251.4965   5907.1665  1
   640.0  -4498.2572   1836.1177   4708.7400  1
   960.0  -6000.7943   1182.7277   2896.2399  1
  1280.0  -6721.9722    375.9981    705.5543  1
  1600.0  -6567.6889   -479.3839  -1577.6873  1
  1920.0  -5558.3481  -1272.4553  -3655.7890  1
  2240.0  -3826.4604  -1900.4016  -5257.8967  1
  .
  .
  .
```

Figure 7: Example of an result file ORBIT.DAT produced with gse.exe. The five colums are (l.t.r.) time relative to start time (31-Oct-94, 05:23:1) in seconds , x, y, and z in km, eclipse

3.3 Distribution and installation

The REM–project orbit generators have been compiled and tested on the following computer configurations:
DEC–Alpha/OSF1, VAX/VMS, and SPARC STATION 1+/Unix.

The orbit generators are avaiable on a tar–file orbgen.tar containing the following files: actan.f, deep.f, fmod2p.f, sdp4.f, thetag.f (used SPACETRACK subroutines), eci.f, gse.f, lla.f (main programs), conversions.f (coordinate transformations), eclipse.f (eclips calculations), timelib.f (some routines to handle dates and times), NORAD.DAT, TIMES.DAT (example input files), .forli (command file for the installation on a Unix machine), forli.com (command file for the installation under VMS).

The installation is very simple:

Table 1: Installation procedure for the REM–project orbit generators.

	Unix	VMS
1.	put the file orbgen.tar in the directory you want the programs to be installed	
2.	tar -xvf orbgen.tar	tar extract /archive=orbgen.tar *
3.	.forli	@forli.com

Thats it! The executables eci.exe, lla.exe, and gse.exe are ready now.

4 Accuracy and consistency check

In order to prove the correctitude of the computed spacecraft positions and to estimate the errors we compare values from different sources.

4.1 bov****.txt <–> SPACETRACK

We compare the orbit vector given in a bov****.txt file with positions calculated with SPACETRACK (see table 2). The relative differences are less than 0.5 %. This is very small compared to the path the STRV–1B satellite travels during a typical REM data accumulation time of ≈100 sec (see figure 5).

Table 2: Comparision of some STRV orbit vectors with SPACETRACK calculations.

bov****.txt	epoch of orbit	orbit vector			SPACETRACK results			relative
	00:00:00	x	y	z	x_S	y_S	z_S	difference[1]
			[km]			[km]		[%]
bov237a	20-Aug-94	-36278.9	-21248.4	3965.2	-36278.6	-21219.2	3972.6	0.071
bov340a	06-Dec-94	-16785.4	-2992.3	2080.4	-16795.8	-3069.6	2082.8	0.454
bov086a	27-Mar-95	13350.8	-38336.5	-3716.4	13372.8	-38308.7	-3722.1	0.088
bovx299	26-Oct-95	14275.1	23963.1	3660.6	14305.2	23961.5	3651.4	0.112
bovx015	15-Jan-96	27711.0	16873.5	4273.9	27694.2	16951.3	4275.9	0.243

[1] $\sqrt{(x-x_S)^2+(y-y_S)^2+(z-z_S)^2}/\sqrt{x^2+y^2+z^2}$

4.2 byymmddn.rem <–> SPACETRACK

We compare the MIR spacestation positions given in the ballistic data files byymmddn.rem with SPACETRACK calculations (see table 3). Also here we find a good agreement. The differences are much smaller than the MIR spacestation travels in a REM data accumulation time of 30 sec (see figure 2).

Table 3: Comparision of MIR spacestation positions from ballistic data files with SPACETRACK calculations.

byymmddn.rem	time	ballistic data			SPACETRACK results			relative
		x	y	z	x_S	y_S	z_S	difference[1]
			[km]			[km]		[%]
b9411011	31-Oct-94, 05:23:10	1427.0	-4262.9	5065.4	1454.5	-4243.0	5066.3	0.501
b9501161	15-Jan-95, 07:00:00	994.2	-4124.0	5275.1	923.7	-4149.4	5259.2	1.130
b9505051	04-Mai-95, 12:15:20	-485.1	4206.5	5277.8	-492.4	4204.4	5270.0	0.160
b9510121	11-Oct-95, 16:36:20	3134.6	3024.7	5187.1	3140.6	3012.8	5179.7	0.225

[1] $\sqrt{(x-x_S)^2+(y-y_S)^2+(z-z_S)^2}/\sqrt{x^2+y^2+z^2}$

We have also compared SPACETRACK results with values produced with other orbit generators (SAPRE from ESA's UNIRAD package [4], STSORBIT PLUS from David Ransom Jr. [5]) and obtain the same good agreement.

A REM project specific modifications of SPACETRACK

In the following all the REM project specific modifications of the SPACETRACK programs are listed. The modifications are clearly marked in the distributed files (see section 3.3). All these changes do not influence the results but are necessary to make the programs to be compiled with the DEC Fortran (Fortran–77) compiler.

A.0.1 COMMON data block E1

In the used spacetrack routines deep, sdp4, and thetag a common data block E1 is defined.

```
      COMMON/E1/XMO,XNODEO,OMEGAO,EO,XINCL,XNO,XNDT2O,
     1          XNDD6O,BSTAR,X,Y,Z,XDOT,YDOT,ZDOT,EPOCH,DS50
```

This has to be replaced in all these files by

```
      COMMON/E1/EPOCH,DS50,XMO,XNODEO,OMEGAO,EO,XINCL,XNO,XNDT2O,
     1          XNDD6O,BSTAR,X,Y,Z,XDOT,YDOT,ZDOT
```

A.0.2 deep

- Variables siniq and cosiq have to be defined as real, at the beginning of the subroutine

  ```
  REAL SINIQ, COSIQ
  ```

- Variable T has to be defined as double precision. Statement

  ```
  DOUBLE PRECISION EPOCH, DS50
  ```

  is replaced by

  ```
  DOUBLE PRECISION EPOCH, DS50, T
  ```

- In entry dpsec parameters siniq and cosiq are added. Statement

  ```
  ENTRY DPSEC(XLL,OMGASM,XNODES,EM,XINC,XN,T)
  ```

  is replaced by

  ```
  ENTRY DPSEC(XLL,OMGASM,XNODES,EM,XINC,XN,T,SINIQ,COSIQ)
  ```

- In entry dpper parameters t, siniq, and cosiq are added. Statement

  ```
  ENTRY DPPER(EM,XINC,OMGASM,XNODES,XLL)
  ```

  is replaced by

  ```
  ENTRY DPPER(EM,XINC,OMGASM,XNODES,XLL,T,SINIQ,COSIQ
  ```

A.0.3 sdp4

- Variable TSINCE has to be defined as double precision. Statement

```
DOUBLE PRECISION EPOCH, DS50
```

  is replaced by

```
DOUBLE PRECISION EPOCH, DS50, TSINCE
```

- In call to dpsec the parameters sinio and cosio are added. Statement

```
CALL DPSEC(XMDF,OMGADF,XNODE,EM,XINC,XN,TSINCE)
```

  is replaced by

```
CALL DPSEC(XMDF,OMGADF,XNODE,EM,XINC,XN,TSINCE,SINIO,COSIO)
```

- In call to dpper the parameters tsince, sinio, and cosio are added. Statement

```
CALL DPPER(E,XINC,OMGADF,XNODE,XMAM)
```

  is replaced by

```
CALL DPPER(E,XINC,OMGADF,XNODE,XMAM,TSINCE,SINIO,COSIO)
```

References

[1] Lebedev, O., Antonov, V. Shvetz, N., Adams, L., Zehnder, A. Final report on results of REM experiment preparation and realisation on MIR station. Technical report, Rocket and Space Corporation ENERGIA, 1995.

[2] Hoots, F.R. and Röhrich, R.L. SPACETRACK REPORTS NO. 3, Models for Propagation of NORAD Element Sets. Technical report, defense Documentation Center, Cameron Station, Alexandria VA 22314, USA, 1988.

[3] Russell, T.Ch. Geophysical coordinate transformations. *Cosmic Electrodynamics*, 2:184, 1971.

[4] Heynderickx, D. and Lemaire, J. UNIRAD User Manual. Technical report, Belgian Institute for Space Aeronomy, Ringlaan 3, B–1180 Brussels, Belgium, 1995.

[5] Ransom, D. Jr. STSORBIT PLUS. Technical report, 7130 Avenida Altisima Rancho Palos Verdes, CA 90275, 1996. http://www.traveller.com/w̃intrak/stsplus.html.