

Earth Observation  
Mission CFI Software  
**MISSION SPECIFIC CUSTOMIZATIONS**

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## 1 SCOPE

All features and conventions defined and used in the Earth Observation Mission CFI Software are described in the document "Earth Observation Mission CFI Software Conventions" [MCD].

This document covers all CFI SW mission specific customizations that are not described in [MCD], i.e. those features and conventions that are defined and used within specific missions.



## 2 ACRONYMS AND NOMENCLATURE

### 2.1 Acronyms

ADM/Aeolus	Atmospheric Dynamics Mission
ANX	Ascending Node Crossing
AOCS	Attitude and Orbit Control Sub-system
CFI	Customer Furnished Item
DRS	Data Relay Satellite
DORIS	Doppler Orbitography and Radio positioning Integrated by Satellite
ERS	European Remote Sensing Satellite
ESA	European Space Agency
ESTEC	European Space Technology and Research Centre
EO	Earth Observation
EOCFI	Earth Observation CFI Software
GOCE	Gravity Field and Steady-state Ocean Circulation Mission
GPS	Global Positioning System
METOP	Meteorological Operational Polar Satellite
OBT	On-Board Time
SBT	Satellite Binary Time
SIRAL	Synthetic-Aperture Interferometric Radar Altimeter
SMOS	Soil Moisture and Ocean Salinity Mission
TAI	International Atomic Time
TM	Telemetry
UTC	Coordinated Universal Time
YSM	Yaw Steering Mode

## 3 APPLICABLE AND REFERENCE DOCUMENTS

### 3.1 Applicable Documents

### 3.2 Reference Documents

ADM_AGL	AOCS Guidance Laws. AE.RP.ASU.PL.044
CRYO_ATT	CryoSat Star Tracker Data Usage for Attitude Determination. CS-TN-ESA-GS-0300. Issue 1.5.
S1_ATT	Sentinel-1: Roll Steering Law. EXPCFI-NOTE-042. Issue 1.2. 10/02/2010
CRYO_SRD	CryoSat System Requirements Document. CS-RS-ESA-SY-0006. Issue 6.
DRSENV_ICD	ICD between the DRS and the Envisat-1 System. CD/1945/mad. D/TEL/R. K. Falbe-Hansen. Issue 5. April 1996.
KLINKRAD	Semi-Analytical Theory for Precise Single Orbit Predictions of ERS-1. ER-RP-ESA-SY-004. H.K. Klinkrad (ESA/ESTEC/WMM). Issue 1.0. 28/06/87.
MCD	Earth Observation Mission CFI Software Conventions Document. EO-MA-DMS- GS-0001. Issue 4.13. 05/04/2017.
S2_ATT	Sentinel-2: AOCS Coordinate Systems Document. GS2.TN.ASD.SY.00035. Issue 2 30/09/2010
METOPSG_ATT	MOS.TCN.ASD.SYS.00836 "Satellite and Subsystem Reference Coordinate Systems" ABHP.TN.ASTR.AV.00005 "AS400 AOCS Coordinate Systems"

## 4 TIME REFERENCES AND MODELS

### 4.1 Earth Observation CFI Software Time Formats

Table 1 describes the time formats used within specific missions:

*Table 1: Earth Observation time formats*

Mission Name	Time format	Description	Usage
Cryosat	Transport CryoSat General TM	Three 32-bits integer numbers for days, milliseconds and microseconds	Time values exchange between computers
Cryosat	Transport CryoSat SIRAL TM	Four 32-bits integer numbers for days, milliseconds, microseconds and an extra counter of 80 MHz ticks	
SMOS	Transport SMOS Transport format	Three 32-bits integer numbers for week number, seconds of the week and fraction of seconds	
Envisat	ASCII Envisat	Text string: “dd-mmm-yyyy hh:mm:ss“	Readable output, such as file headers, log messages, ...
Envisat	ASCII Envisat with reference	Text string: “RRR=dd-mmm-yyyy hh:mm:ss“	
Envisat	ASCII Envisat with microseconds	Text string: “dd-mmm-yyyy hh:mm:ss.uuuuuu“	
Envisat	ASCII Envisat with reference and microseconds	Text string: “RRR=dd-mmm-yyyy hh:mm:ss.uuuuuu“	

### 4.2 Earth Observation CFI Software On-board times

#### 4.2.1 Envisat On-board clock ticks

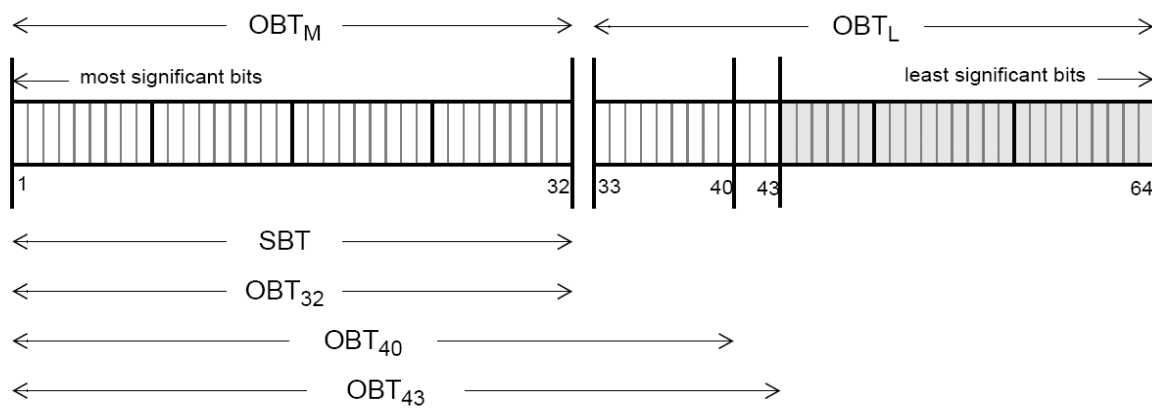
*Table 2: On-board clock ticks*

Time reference and format	Description	Usage
Satellite Binary Time (SBT)	32-bits integer number: · Count of 256 Hz clock ticks	Processing of satellite binary
On Board Time (OBT)	32-bits integer numbers: · obtm = most significant bits · obtl = least significant bits	Processing of instrument on-board time

The Satellite Binary Time (SBT) is a 32 bits counter, incremented by 1 at a frequency of about 256Hz (defined as the step-length  $PER_0$ ). It varies from **00000000** (Hexadecimal) to **FFFFFFFF** (Hexadecimal), the next value being again **00000000** (Hexadecimal) and so on. This reset of the counter after **FFFFFFFF** (Hexadecimal) is called the **wrap-around**.

The On Board Time (OBT) is a generic term to represent any of the instrument counters, used to date their source packets. Most instruments use a 32 bits counter synchronized with the SBT. Some instruments use a 40 or 43 bits counter, where the 32 most significant bits are synchronized with the SBT (i.e. they use a more precise clock).

Figure 1 shows the relationship between SBT and OBT.



**Figure 1: SBT and OBT relationship**

### 4.2.2 TAI time

If DORIS is used to perform the orbit determination, the satellite will work with TAI time reference using dedicated transport formats (Telemetry formats).<sup>1</sup>

### 4.2.3 CryoSat SIRAL extra counter

The main payload of CryoSat is the Synthetic-Aperture Interferometric Radar Altimeter (SIRAL). The way the SIRAL instrument performs the on-board datation of each TM packet is the following:

Every time SIRAL receives the 1 Hz PPS signal (Pulse-Per-Second) from the central computer, it reads and sets in its memory the first 3 time parameters (days / milliseconds / microseconds). These won't change until the next PPS tick.

At the same time, it resets the fourth time parameter (extra counter) to 0, and starts counting ticks of the internal 80MHz clock in it. Each tick of the 80 MHz clock is 12.5 nanoseconds. The extra counter actually has a lower resolution, it actually counts a multiple (165) of the 80 MHz. This results in a counter resolution of  $165 * 12.5 \text{ nanoseconds} = 2.0625 \text{ microseconds}$ .

1 Not applicable to ENVISAT

From then on, at each TM packet production (which is about every 46 ms), SIRAL dates using the "frozen" first 3 parameters, plus the counter of 2 microsec ticks in the fourth parameter.

The actual date of the packet can be calculated by adding up all four parameters (with the appropriate scaling for each, of course), as for any other format.

At the next PPS, the same sequence starts.

It has to be remarked that these TM transport formats use vectors of long integers in the CFI (according to CFI standard). This, however, does not match the TM packet time contents, in which byte efficiency is important. For example, days are on 16-bits, milli-seconds on 32-bits, micro-seconds on 16-bits, and the extra counter on 16-bits.

This does not allow users to simply copy the sequence of bytes into memory and point the time vector to it, they will have to read each time component and set it into a long integer (and vice-versa for users producing test data).

#### 4.2.4 SMOS On-board time

SMOS will manage two time sources:

- OBET: This value is derived by a HW counter 48 bits wide which is increased at a frequency of 65536 KHz, starting in 0 after power-on.
- UTC provided by Proteus each second.

The following tables shows the format for the OBET and the UTC-Proteus times:

**Table 3: SMOS OBET time**

P-Field			T-Field		
Extension Flag	Time Code identification	Details Bits for the information on the code		Coarse Time	Fine Time Note
1 bit	3 bits	4 bits		32 bits	24 bits
0	110	01	10	(Seconds from epoch)	(2-24 seconds)
1 byte			4 bytes		3 bytes

**Table 4: UTC Proteus time format**

Week Number	Unused	H3	Second of Week	Fraction of Seconds
12 bits	3 bits	1 bit	32 bits	16 bits
	000		(Seconds from epoch)	(2-16 seconds)
2 bytes			4 bytes	2 bytes

Where “Week Number” is weeks elapsed since January 6-12, 1980. This week is numbered (0). LSB=1 Week.

H3 represents the time source from which the payload is synchronised to the platform.

#### **4.2.5 Aeolus On-board Time**

The OBTime format for Aeolus is given in CCSDS Unsegmented time code (CUC), that is defined as: the time from a defined epoch in seconds coded on 4 octets and sub-seconds coded on 2 octets.

According to this the time is:

$$\text{Time} = C_0 * 256^3 + C_1 * 256^2 + C_2 * 256 + C_3 + F_0 * 256^{-1} + F_1 * 256^{-2}.$$

OBTime is set to GPS Time such that the UTC zero time-point reference of OBTime is the same as that of GPS, i.e. midnight on the night of January 5 1980 / morning of January 6 1980. At this UTC zero time-point reference there had been 19 leap seconds applied.

Therefore, the conversion from OBTime (in CUC) to UTC is:

$$\text{UTC} = (\text{CUCseconds} + \text{CUCsub-seconds} * 256^{-2}) - \text{GPST} + \text{UTC}_0$$

Where:

CUCseconds is the 4 most significant octets of OBTime ( $C_0$  to  $C_3$ )

CUCsub-seconds is the 2 least significant octets of OBTime ( $F_0$  to  $F_1$ )

GPST is the number of leap seconds between UTC and GPS Time (see section 3.2);

UTC<sub>0</sub>: UTC time at 06-01-1980 00:00:00.000000

#### **4.2.6 GOCE On-board Time**

The OBTime for GOCE is provided by telemetry as two parameters, the coarse OBTime in 32 bits and the fine OBTime in 16 bits. The OBTime time is therefore  $\text{OBTime} = (\text{Coarse OBTime}) + (\text{Fine OBTime})/2^{16}$ .

The conversion from a given OBTime to UTC is given by:

$$\text{UTC}_0 = (\text{Coarse UTC}_0) + (\text{Fine UTC}_0)/2^{16}$$

$$\text{OBTime}_0 = (\text{Coarse OBTime}_0) + (\text{Fine OBTime}_0)/2^{16}$$

$$\text{UTC} = \text{Gradient} * (\text{OBTime} - \text{OBTime}_0) + \text{Offset} + \text{UTC}_0$$

The result is the number of seconds from 1st of January 2000 at 00:00:00.000000, without counting the leap seconds (i.e. to convert into a calendar date and time, one has to assume that all days have 86400 seconds).

## 5 ORBIT CONSISTENCY CHECKS

The EO CFI software checks that the orbit supplied as input complies with a set of tolerances on the main osculating Kepler elements (in function `xo_osv_check` and internally when the propagation with an OSF file is computed).

Two categories of tolerance requirements are checked:

- Tight requirements
- Loose requirements

If the tight tolerance requirements are not satisfied, but the loose ones are, then a warning will be returned. If even the loose tolerance requirements are not satisfied, then an error will be returned.

These consistency checks are mission specific.

Table 5 and Table 6 list, for each supported mission, the loose and tight requirements:

**Table 5: Loose tolerance requirements**

Mission Name	Semi-major axis (m)		Eccentricity		Inclination (deg)	
	A min	A max	E min	E max	I min	Imax
ERS1	7000000	7300000	0	0.1	98	99
ERS2	7000000	7300000	0	0.1	98	99
Envisat	7000000	7300000	0	0.1	98	99
METOP1	7000000	7300000	0	0.1	97	100
METOP2	7000000	7300000	0	0.1	97	100
METOP3	7000000	7300000	0	0.1	97	100
CryoSat	1000000	10000000	0	0.5	60	120
Aeolus	6600000	6860000	0	0.1	95.4	98.3
GOCE	1000000	10000000	0	0.5	60	120
SMOS	7040000	7220000	0	0.1	97.1	99.7
TerraSAR	6915000	7095000	0	0.1	96.6	99.2
EarthCARE	6720000	6830000	0	0.5	96.62	97.43
SwarmA	6500000	6975000	0	0.5	85	89
SwarmB	6500000	6975000	0	0.5	85	89
SwarmC	6500000	6975000	0	0.5	85	89



Sentinel1A	7000000	7140000	0	0.5	97.7	98.7
Sentinel1B	7000000	7140000	0	0.5	97.7	98.7
Sentinel2	7120000	7210000	0	0.5	98.16	98.98
Sentinel3	7100000	7250000	0	0.5	98.22	99.04
SEOSAT	7000000	7090000	0	0.5	97.68	98.49
Sentinel1C	7000000	7140000	0	0.5	97.7	98.7
Sentinel2A	7120000	7210000	0	0.5	98.16	98.98
Sentinel2B	7120000	7210000	0	0.5	98.16	98.98
Sentinel2C	7120000	7210000	0	0.5	98.16	98.98
Sentinel3A	7100000	7250000	0	0.5	98.22	99.04
Sentinel3B	7100000	7250000	0	0.5	98.22	99.04
Sentinel3C	7100000	7250000	0	0.5	98.22	99.04
JasonCSA	7660000	7760000	0	0.5	65.62	66.45
JasonCSB	7660000	7760000	0	0.5	65.62	66.45
MetOpSGA1	7140000	7240000	0	0.5	98.29	99.11
MetOpSGA2	7140000	7240000	0	0.5	98.29	99.11
MetOpSGA3	7140000	7240000	0	0.5	98.29	99.11
MetOpSGB1	7140000	7240000	0	0.5	98.29	99.11
MetOpSGB2	7140000	7240000	0	0.5	98.29	99.11
MetOpSGB3	7140000	7240000	0	0.5	98.29	99.11
Sentinel5P	7150000	7250000	0	0.5	98.34	99.15
Biomass	6940000	7090000	0	0.5	97.45	98.48
Sentinel5	7140000	7240000	0	0.5	98.29	99.11
Saocom-CS	6940000	7050000	0	0.5	97.48	98.29
FLEX	7100000	7250000	0	0.5	98.22	99.04
Generic satellite	1000000	10000000	0	0.5	60	120



Generic Geostationary satellite	30000000	50000000	0	0.9	-20	20
MTG	30000000	50000000	0	0.9	-20	20
Generic Medium Earth Orbit satellite	1000000	40000000	0	1	0	180

**Table 6: Tight tolerance requirements**

Mission Name	Semi-major axis (m)		Eccentricity		Inclination (deg)	
	A min	A max	E min	E max	I min	Imax
ERS1	7118050	7194056	0	0.507	98.4475	98.6226
ERS2	7118050	7194056	0	0.507	98.4475	98.6226
Envisat	7118050	7194056	0	0.007	98.4475	98.6226
METOP1	7154298	7230343	0	0.007	98.5613	98.8165
METOP2	7154298	7230343	0	0.007	98.5613	98.8165
METOP3	7154298	7230343	0	0.007	98.5613	98.8165
CryoSat	1000000	10000000	0	0.5	60	120
Aeolus	6640000	6810000	0	0.007	96.4	97.3
GOCE	6500000	6700000	0	0.5	96	97
SMOS	7090000	7170000	0	0.007	98.1	98.7
TerraSAR	6965000	7045000	0	0.007	97.6	98.2
EarthCARE	6750000	6790000	0	0.007	96.72	97.33
SwarmA	6500000	6925000	0	0.007	85.85	88.15
SwarmB	6550000	6925000	0	0.007	85.85	88.15
SwarmC	6550000	6925000	0	0.007	85.85	88.15
Sentinel1A	7035000	7105000	0	0.007	97.8	98.6
Sentinel1B	7035000	7105000	0	0.007	97.8	98.6
Sentinel2	7140000	7190000	0	0.007	98.26	98.88

Sentinel3	7130000	7210000	0	0.007	98.32	98.94
SEOSAT	7016000	7076000	0	0.007	97.78	98.39
Sentinel1C	7035000	7105000	0	0.007	97.8	98.6
Sentinel2A	7140000	7190000	0	0.007	98.26	98.88
Sentinel2B	7140000	7190000	0	0.007	98.26	98.88
Sentinel2C	7140000	7190000	0	0.007	98.26	98.88
Sentinel3A	7130000	7210000	0	0.007	98.32	98.94
Sentinel3B	7130000	7210000	0	0.007	98.32	98.94
Sentinel3C	7130000	7210000	0	0.007	98.32	98.94
JasonCSA	7670000	7750000	0	0.007	65.72	66.35
JasonCSB	7670000	7750000	0	0.007	65.72	66.35
MetOpSGA1	7150000	7230000	0	0.007	98.39	99.01
MetOpSGA2	7150000	7230000	0	0.007	98.39	99.01
MetOpSGA3	7150000	7230000	0	0.007	98.39	99.01
MetOpSGB1	7150000	7230000	0	0.007	98.39	99.01
MetOpSGB2	7150000	7230000	0	0.007	98.39	99.01
MetOpSGB3	7150000	7230000	0	0.007	98.39	99.01
Sentinel5P	7160000	7240000	0	0.007	98.44	99.05
Biomass	6950000	7080000	0	0.007	97.55	98.38
Sentinel5	7150000	7230000	0	0.007	98.39	99.01
Saocom-CS	6950000	7040000	0	0.007	97.58	98.19
FLEX	7130000	7210000	0	0.007	98.32	98.94
Generic satellite	1000000	10000000	0	0.5	60	120
Generic Geostationary satellite	42000000	43000000	0	0.1	-0.1	0.1
MTG	42000000	43000000	0	0.1	-0.1	0.1

Generic Medium Earth Orbit satellite	1000000	30000000	0	1	0	180
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## 6 PROPAGATION MODES

### 6.1 Envisat Operational mode

The effect of the latitude and longitude dependent geoid anomalies up to degree and order 36 (GEM-10B), as well as the effect of a medium air drag (MSIS'77) and luni-solar perturbations, have been modeled in the form of second order correction terms to the satellite position and velocity components (radial, along track, and across track).

These correction terms are function of the longitude of the true ascending node in the Earth fixed reference frame, and of the true latitude of the propagated state vector using the longitude independent mode, expressed in the True of Date reference frame.

This mode is based on the equations derived in KLINKRAD reference.

## 7 ATTITUDE MODES

The Attitude modes supported in the EO CFI SW are described in [MCD].

The following are mission specific attitude modes that are implemented and supported in the EO CFI:

**Table 7: Attitude modes**

Mission Name	Attitude Law	Reference documentation
Envisat	Envisat attitude law	TBD
Cryosat	Cryosat attitude law	CRYO_ATT
ADM-Aeolus	ADM-Aeolus attitude law	ADM_AGL
Sentinel 1	Sentinel 1 attitude law	S1_ATT
Sentinel 2	Sentinel 2 attitude law	S2_ATT
MetOp SG	Metop SG attitude law	METOPSG_ATT

### 7.1 Sentinel-1 attitude law

The Sentinel-1 attitude is defined by the Roll Steering Law described in the document S1\_ATT.

The law for the roll steering is:

$$\theta_{\text{offNadir}} = \theta_{\text{ref}} - \alpha_{\text{roll}} (H - H_{\text{ref}})$$

where the parameters are:

**Table 8: Definition of Sentinel-1 roll steering law**

Parameter	Description	Value	Units
$\Theta_{\text{offNadir}}$	Antenna bore sight off nadir angle as function of altitude		
$\Theta_{\text{ref}}$	Antenna bore sight off nadir angle at reference altitude	29.450	deg
$\alpha_{\text{roll}}$	Roll steering sensitivity versus altitude	0.05660	deg/km
H	Actual satellite altitude		
$H_{\text{ref}}$	Reference altitude	711.700	km

The actual altitude of the satellite is approximated by the following function:

$$H(t) = h_0 + \sum_{n=1}^N h_n \cdot \sin(n \cdot \omega_{\text{orb}} \cdot (t - t_{\text{ANX}}) + \phi_n)$$

where

**Table 9: Sentinel-1 numerical values describing altitude versus time by a series of four terms**

Parameter	Description	Value	Units
$t_{ANX}$	Time of ascending node crossing		
$\omega_{orb}$	Orbital frequency	$\omega_{orb} = 2\pi / T_{orb}$	
$h_0$		707714.8 <sup>*a)</sup>	m
$h_1$		8351.5 <sup>*a)</sup>	m
$h_2$		8947.0 <sup>*a)</sup>	m
$h_3$		23.32 <sup>*a)</sup>	m
$h_4$		11.74 <sup>*a)</sup>	m
$\varphi_1$		3.1495 <sup>*a)</sup>	rad
$\varphi_2$		-1.5655 <sup>*a)</sup>	rad
$\varphi_3$		-3.1297 <sup>*a)</sup>	rad
$\varphi_4$		4.7222 <sup>*a)</sup>	rad
$T_{orb}$	12 days / 175 orbits	5924.57 <sup>*a)</sup>	sec

\*a) These values may have to be recalculated, depending on actual orbit data

## 7.2 MetOp-SG attitude law

This attitude law is similar to YSM apart from the Z axis that is computed with an approximation for the local normal vector using a correction factor.

**Table 10: Parameters of MetOp-SG attitude law**

Parameter	Value	Units
Local normal pointing coefficient	0.005958	-
Earth's rotation velocity	-0.0000729211585	rad/s

With the values for the parameters shown in table 10, the difference with respect to YSM is below 1 mdeg.

## 8 DRS-ARTEMIS ORBIT

The EO CFI allows for Envisat the visibility computation of the DRS-Artemis Satellite:

### 8.1 DRS-Artemis Orbit Definition

The initial DRS space segment comprises the Artemis Satellite located in the GEO orbit over Europe (16.4° E). Artemis was launched the 12<sup>th</sup> of July 2001 reaching its operational orbit in xxxxx and is planned to be moved to 59° E when the first DRSS is launched (DRSENV\_ICD reference).

The orbit of the DRS is known on ground to an accuracy corresponding to the following errors  $\pm 20.0$  Km along track,  $\pm 15.0$  Km across track and  $\pm 15.0$  Km radial. These accuracies are achieved for a 24 hour prediction and are achieved when UT is the time reference (DRSENV\_ICD reference)

Due to launch failure the North-South station keeping is not operationally implemented. The inclination drift has not been modeled in the EO CFI Software. However it has been modelled in the Envisat CFI Software.

The CFI software will check the compliance of the DRS orbit supplied on input with a set of requirements on the main osculating Kepler elements:

**Table 11: DRS orbit tolerance requirements**

Osculating Kepler element	Tight tolerance	Loose tolerance
Semi-major axis	42000 / 43000 Km	30000 / 50000 Km
Eccentricity	0.0 / 0.1	0.0 / 0.9
Inclination	- 0.1 / + 0.1 deg	- 1.0 / + 1.0 deg

If the tight tolerance requirements are not satisfied, but the loose ones are, then a warning will be returned by the CFI software.

If even the loose requirements are not satisfied, then an error will be returned.

### 8.2 DRS-Artemis Orbit Propagation Model

The 24-hour prediction of DRS will be available in equinoctial elements at a given epoch valid for certain validity period, and assuming that the user will propagate this state vector, within the validity period using the following algorithm:

$$\mathbf{a} = \mathbf{a}_{\text{initial}}$$

$$\mathbf{e}_x = (\mathbf{e}_x)_{\text{initial}}$$

$$\mathbf{e}_y = (\mathbf{e}_y)_{\text{initial}}$$

$$\dot{\mathbf{i}}_x = (\dot{\mathbf{i}}_x)_{\text{initial}}$$

$$\dot{\mathbf{i}}_y = (\dot{\mathbf{i}}_y)_{\text{initial}}$$

$$\lambda = \lambda_{\text{initial}} + (t - t_{\text{initial}}) \frac{d\lambda_{\text{initial}}}{dt}$$

$$\frac{d\lambda_{\text{initial}}}{dt} = (\mu/a^3)^{1/2}$$

$$\mu = 3,9860044 \cdot 10^5 \text{ km}^3/\text{s}^2$$

where  $a_{\text{initial}}$ ,  $(e_x)_{\text{initial}}$ ,  $(e_y)_{\text{initial}}$ ,  $(i_x)_{\text{initial}}$ ,  $(i_y)_{\text{initial}}$  and  $\lambda_{\text{initial}}$  are the equinoctial elements at  $t_{\text{initial}}$ .