European Space Agency

Directorate of Technical and Operational Support

Ground Systems Engineering Department

ROSETTA / MARS EXPRESS

Mission Control System (MCS)
Data Delivery Interface Document
DDID
RO-ESC-IF-5003/MEX-ESC-IF-5003

Appendix H
FD Products

Issue 2

22 August 2003

ESOC *European Space Operations Centre*

Distribution List

Recipient	Organization	Recipient	Organization
J. Fertig	TOS-GFI		
V. Companys	TOS-GFI		
T. Morley	TOS-GFI		
J. Schoenmaekers	TOS-GFI		
M. Warhaut	TOS-OGR		
P. Ferri	TOS-OGR		
M. McKay	TOS-OGM		
M. Denis	TOS-OGM		
F Delhaise	TOS-GCM		
D. Koschny	SCI-SO		

Document Change Record

Date	Issue	Description
17/04/2000	Draft 0	Initial Draft
28/04/2000	Draft 1	Updated for comments received on Draft 0: new sections 3.4 and 8
08/05/2000	Draft 2	Updated for comments by J Fertig, V Companys, T Morley and J Schoenmakers on Draft 1: sections 3.4.1, 3.4.2, 3.5.1, 3.5.8 and 8. changed sections 3.5.5 to 3.5.7 added tables 1 and 2 changed
24/05/2000	Draft 3	Updated according to comments from MOD review 17/05/2000: sections 3.5.2, 3.5.3, 4.6.2, 4.6.3, 6.1, 7, 8 and 10 added sections 3.5.1, 4.2, 4.5, 4.6.1, 6 and 11 changed
24/07/2000	Draft 4	Updated according to comments from MOD S/W description added sections 1.1 and 7 added sections 3.3, 3.5.1, 5 and 6 changed
15/11/2000	Draft 5	Update of document title and number
31/05/2001	Issue 1	section 3.5.1 modified: new subroutine rrered.F added, subroutines hermite.de and lagrange.F replaced by hermde.F and lagrde.F section 4 modified: reconstituted attitude is based on downlinked on board estimator data section 5 modified: there are separate OWLT files for each GS section 6 modified: event id changed from 3 digit number to alphanumeric string, time format changed section 12 modified: ADID’s changed, file names added, summary of provided s/w added
06/06/2001	Issue 1.1	section 6.1 modified: milliseconds added to time format, extension of description field section 12.2 modified: table of software updated
13/06/2001	Issue 1.2	Structure changed to include Mars Express auxiliary data Event duration parameter in event file extended

Date	Issue	Description
01/03/2002	Issue 1.3	Rosetta and Mars Express: - event descriptions with underscores instead of white spaces - conjunction and opposition times provided w.r.t. G/S near the Earth - start time removed from name of event file - one way light time file removed - orbit and attitude files are delivered as ASCII files only Rosetta: - asteroid centric orbit files removed - LGA coverage times provided w.r.t. G/S near the Earth Mars Express: - description of lander file added - file naming convention of lander file added - operational orbit file split into several parts due to large amount of data - long term planning orbit file defined - long term planning event file defined - events KMDS and KMAS refer to height instead of radial distance Software: - description of software extended - description of ASCII file format added - description of low level subroutines removed
22/08/2003	Issue 2	Rosetta and Mars Express: - event descriptions for AOS and LOS changed to include G/S antenna identifier - event durations may be -1, if end events are outside the range of the event file - clarification on DDS file naming conventions (FDS replaced by FDL or FDR, RMS replaced by RMA or RMB for Rosetta and MMA or MMB for Mars Express) - clarification on file version numbering: after an update of files in the DDS, the version numbers may increase by more than one as the update frequency for the various file types is different. - only one type of attitude information is provided through the DDS (only based on commanded profiles, no reconstruction based on TM) Rosetta: - adaptions due to mission redesign - NAVCAM images removed, as images are available through the DDS Mars Express - clarification on formats of event descriptions for event types: SCDS, SCUS SOUS and end events, MPER, MAPO, KMDS, KMAS - new event types: NPSS, NPNS, EPSS, ALFn, ALRn, LLFn, LLRn Software: - clarification on S/C frames added in section 3.2.1 - clarification on sign convention of quaternions as returned by sub-routine rafop (section 3.2.3)

1 Introduction

This document describes the products from Flight Dynamics (FD) to be delivered via the Data Distribution System (DDS).

1.1 Abbreviations and Acronyms

AFM	Asteroid Flyby Mode
AOCMS	Attitude and Orbit Control and Measurement System
AOS	Acquisition of Signal
CVP	Commissioning and Verification Phase
DDS	Data Distribution System
DSN	Deep Space Network
FB	Flyby
FD	Flight Dynamics
FPAP	Fine Pointing Accuracy Phase
FPIP	Fine Pointing Inertial Phase
FPSP	Fine Pointing Stability Phase
GS	Ground Station
HGA	High Gain Antenna
LEOP	Launch and Early Orbit Phase
LGA	Low Gain Antenna
LOS	Loss of Signal
MCS	Mission Control System
MGA	Medium Gain Antenna
RMOC	Rosetta Mission Operations Centre
RSOC	Rosetta Science Operations Centre
RV	Rendezvous
S/C	Spacecraft
SB	Swingby
SESC	Sun/Earth/Spacecraft angle
SSCE	Sun/Spacecraft/Earth angle
STR	Star Tracker
TBC	To Be Comfirmed
TBD	To Be Defined
TC	Telecommand
TDB	Barycentric Dynamical Time
TM	Telemetry
UTC	Coordinated Universal Time
w.r.t	with respect to

1.2 Reference Documents

[RD-1] Explanatory Supplement to the Astronomical Almanac
1992, University Science Books

[RD-2] Rosetta System Requirements Specification,
RO-ESC-RS-5510, issue 6, October 1999

[RD-3] Description of the software for the support of the time correlation between internal clock of ROSETTA and UTC
RO-ESC-TN-5518, issue 2.1, 19 February 2001

[RD-4] ROSETTA Users Manual,
RO-DSS-MA-1001, issue 2a, 15/03/2001

[RD-5] Mars Express Flight Dynamics Support / Requirements Compilation
MEX-ESC-RS-6510, Draft 2, September 2000

[RD-6] MARS EXPRESS Mission Plan
MEX-MMT-RP-0221, issue 03, revision 1, February 2000

[RD-7] Interplanetary Software Facility (IPSF)
Description of the Software for Computing Apocentre and Pericentre Times and Orbital Revolution Numbers
MEX-ESC-TN-5504, issue 1.0, 11 December 2000

[RD-8] MARS EXPRESS
Auxiliary Data: Star Occultation Events
MEX-ESC-TN-5506, draft 0, 28/03/2001

[RD-9] American National Standard Programming Language FORTRAN,
ANSI X3.9-1978

[RD-10] Interplanetary Software Facility (IPSF), Description of the Software for Computing Solar Oppositions and Conjunctions Times,
RO-ESC-TN-5530 / MEX-ESC-TN-5507, issue 1.0, 05/06/2001

[RD-11] Consultative Committee for Space Data Systems, Orbit Data Messages, CCSDS 502.0-R-1 Red Book, June 2001

[RD-12] Coordinate Systems for Rosetta
RO-DSS-TN-1081, issue 6c, 21/10/2002

[RD-13] Mars Express User Manual, Volume 1, Section 3
MEX-MMT-MA-1091, issue 4.0, 15/05/2003

2 Rosetta Auxiliary Data

2.1 Mission Overview

The ROSETTA mission is designed to investigate in situ the nucleus of a comet and it's environment. The capability of the S/C requires a mission design where additional gravity assists at Mars and Earth provide the necessary energy for a transfer orbit to the comet. The original launch in January 2003 with flybys at Otawara and Siwa and the rendezvous at Churyumov-Gerasimenko could not be met. The new launch is now foreseen in February 2004. After the mission redesign, comet Churyumov-Gerasimenko was chosen as target. The new baseline orbit allows for additional flybys at asteroids. Up to now, no choice on the candidate asteroids has been made.

A simplified overview of the new main mission events (e.g. correction manoeuvres are not included) is given in the following table:

Start	Time after Launch (months)	Event
2004/02	0	LEOP/CVP
2005/03	13	Earth Swingby #1
2007/02	36	Mars Swingby
2007/11	45	Earth Swingby #2
2009/11	69	Earth Swingby #3
2014/05	123	RDV with Churyumov-Gerasimenko

Table 1 Rosetta Mission Phases

2.2 Orbit Data

2.2.1 Orbit Determination

Orbit determination is essentially a batch least squares procedure taking into account range and Doppler measurements from the ESA 35m antenna at Perth. During near Earth mission phases also the 15m Kourou station provides tracking data. During critical mission phases tracking data will additionally be provided by NASA/DSN stations.

The dynamical model of the S/C motion refers to the J2000 inertial reference frame with Barycentric Dynamical Time (TDB) as independent variable. In addition to the Newtonian attraction of the planets and the Moon the model includes :

- relativistic corrections to the gravitational fields

- perturbations of the Earth and Mars gravitational fields due to oblateness
- solar radiation pressure forces
- orbit manoeuvres
- small forces due to gas leaks or uncoupled control jets

At comet Churyumov-Gerasimenko, the central attraction and additional forces due to cometary activity will be included. Near the asteroids and at Churyumov-Gerasimenko the radiometric data will be augmented by optical data from the onboard cameras.

The centre of integration depends on the mission phase. Near Earth or Mars the orbit is integrated with respect to the planet. During cruise phases the centre is either the Sun or the barycentre of the solar system. The ephemerides of the planets and Moon are taken from the latest version DE405 of the JPL export ephemeris files. The orbits of the comet and the asteroids are also determined using optical angular measurements on the plane-of-sky, i.e. of right ascension and declination. The dynamic model for the comet includes nongravitational forces due to the sublimation of cometary material, mainly water ice.

Range and Doppler measurements are corrected for several effects:

- transponder delay
- signal delay due to the troposphere and ionosphere of the Earth
- signal delay due to interplanetary plasma

The result of the least squares procedure are best estimates of the state vector of the S/C and of several model parameters plus statistical information. The accuracy depends on the mission phase and is expected to be typically better than 100 km per AU distance from the Earth for the position. Relative to the Swing-by bodies, the accuracy is expected to be of the order of 1 km (Earth) and less than 5 km (Mars). During observation phases the orbits of the comet and the asteroids are also estimated. Relative to the comet, the orbital accuracy will improve with time as the gravitational and kinematic properties are better determined so that the order of metres is expected (TBC).

The number and frequency of batch runs for the orbit determination depends on the mission phase and the availability of tracking data. During cruise (except hibernation phases) a run every (TBD) days is expected whereas during observation phases several fits per day are likely to be performed.

2.2.2 Orbit Prediction

The orbit prediction uses the same dynamic model and similar integration techniques. But instead of fitting the S/C orbit in the past with received tracking data the future S/C orbit is integrated using the best estimate of the last orbit determination and optimized with respect to fuel consumption and mission constraints by suitable insertion of manoeuvres.

2.2.3 Orbit Data Delivery

The delivery of orbital data depends strongly on the mission phase. Up to the rendezvous with the comet the orbit of the S/C is essentially fixed and to some extent known in advance. Updates are made mainly after orbit determination is performed. Near the comet the future orbit is subject to detailed planning procedures with several operation centres and FD involved. Therefore the concept for delivery of orbital data is accordingly divided into two periods. The first period, which is referred to as ‘cruise phase’ in the following, comprises roughly the time up to the rendezvous with the comet and the second, called ‘comet observation’ begins with the start of near comet operations. The actual date defining the end of the cruise phase and the start of the comet observation phase is TBD.

2.2.3.1 Cruise Phase

For the cruise phase 5 files for the S/C orbit are available. The reference plane for all these files is the Earth mean equator of J2000. The first covers the whole mission up to the rendezvous with the comet and provides heliocentric states. Additionally for each of the phases corresponding to 2 Earth and 1 Mars swingbys a file is available providing states with respect to the respective target (Earth or Mars) and covering the time span around the respective event.

At the beginning of the mission the S/C orbit files contain only predicted states. During the mission, the files are updated according to results from orbit determination and manoeuvre optimisation. The updates may replace reconstructed states by more accurate reconstructed states, predicted states by reconstructed states or predicted states by more accurate predicted states, which depends on the date and number of measurements. The covered time span will not be affected considerably by the update. For each orbit file within this series of orbit files the latest version is available via the DDS. The specification of an epoch is not required in the retrieval request as these orbit files contain always all states of the time span described previously. Each version contains information on its version number, its generation date and the date of last processed measurement.

2.2.3.2 Comet Observation

During near comet operations two S/C orbit files are provided. The nominal orbit file contains comet centric states w.r.t. the Earth mean equator of J2000. As for the cruise phase the states in the file are either reconstructed or predicted depending on the last processed date of measurement. The file covers the S/C orbit from comet rendezvous up to the end of the current planning period. Additionally one orbit file covering the next planning period is provided which reflects the current status of the iterative medium term planning procedure carried out at the ROSETTA Science Operations Centre (RSOC) and the ROSETTA Mission Operations Centre/flight dynamics (RMOC/FD). After each iteration this orbit file is updated. After completion and as a result of the medium term planning cycle the nominal orbit file is augmented by the predicted orbit from the medium term planning file and the process starts again. Only medium term planning orbit files for the current planning cycle are provided. If the short term planning requires a change of the future S/C orbit the respective part of the nominal orbit file is updated. All S/C orbit states in this phase are given w.r.t. the comet. Again the latest versions of both of the orbit files are available for retrieval by the user.

2.2.3.3 Target Orbits

Heliocentric orbit files for Churyumov-Gerasimenko and the flyby asteroids are also provided. These orbits cover the history as well as the future. Updates to these files need be no more frequent than every one or two years. Close to the times of the flybys the respective asteroid orbits will be updated approximately every day. When ROSETTA is near the comet, it is likely that weekly updates of the comet orbit file will be sufficient.

2.3 Attitude Data

Attitude data are provided via the DDS for all mission phases apart from safe modes (SAM, SKM, SHM) and deep space hibernation (SPM and SBM). During all these phases (except in AFM during asteroid flybys), the S/C controls the attitude based on inertial Sun and Earth direction profiles stored on board, or ground commanded attitude guidance profiles uplinked from ground. The attitude calculated by the FD command generator subsystem is delivered as attitude information via the DDS. During AFM the attitude is derived from the estimated orbits of the S/C and the target. Under normal circumstances the S/C follows the guidance law within a predefined accuracy according to the requirement specifications (see [RD-2]). Nevertheless due to the autonomous behaviour of the S/C (wheel off loadings, transition into safe mode etc.), or due to short term replanning of activities, the actual attitude of the S/C may deviate from the attitude profile in the DDS. In that case, the attitude information in the DDS will be updated accordingly.

2.3.1 Attitude Data Delivery

The considerations concerning data delivery are for attitude data in several aspects different from those for orbit data.

- Orbit data are provided for the whole mission whereas attitude data are only provided for times when the S/C is operated in certain modes or phases
- For the attitude a larger amount of data per covered time span is expected compared with orbit data.

- Although there are many occasions during the cruise phase to the comet (especially during asteroid flyby) where the required attitude of the S/C is known in advance there is a greater flexibility for the operations planning to choose an attitude. The orbit however is nearly fixed during cruise.

Therefore the following guidelines for the delivery of attitude data were chosen:

- Attitude data are provided for the past and (only) for the near future.
- The distinction between cruise phase and comet observation as for the orbit data is not necessary here.
- The attitude is provided in segments, each covering a specific time span. These segments have no overlap. There may be gaps between segments and even gaps in the segments.
- During mission the number of segments is growing. As soon as the attitude profiles are available from the FD command generation subsystem corresponding segments are provided.

One additional attitude file is provided serving the medium term planning iteration cycle. The usage is the same as for the corresponding orbit file.

2.4 Events

An ASCII file containing information about events will be provided. For each event one line of information is given. The events occur in ascending order in time.

2.4.1 Event File Format

The following table shows the format of the event file.

Name	Format	Contents
EVTTID	A4	Event Type Identification
EVTCNT	(X2,I10)	Event Count
PREREC	(X2,A1)	single character flag indicating whether event is predicted (‘P’) or reconstituted (‘R’)
EVTTIM	(X2,A20)	Start Time of Event in the format ‘YY-DDDThh:mm:ss.dddZ’
EVTDUR	(X2,I8)	duration of event in seconds
EVTDES	(X2,A80)	description of event
LF	A1	single line feed character (ASCII 0Ahex)

Table 2 Rosetta Event File Format

The format definition refers to the ANSI FORTRAN notation for format statements.

EVTTID is a alphanumeric string of length 4 which is unique for each event type.

EVTCNT is a running number for each event type. It will always be in ascending consecutive order.

EVTTIM is always given in UTC. The format is ‘YY-DDDThh:mm:ss.dddZ’ where YY are the last two digits of the year, DDD is the day of the year and hh, mm, ss and ddd are hours, minutes, seconds and milliseconds of the day. All other symbols are fixed character constants. The provided numerical accuracy of all events is 1 second, i.e. the milliseconds are always 0. EVTDUR contains the duration of the event in seconds. Although the end of events can be derived from the start time of the event and its duration, the end of the event is additionally given for convenience. In this case EVTTIM refers to the end of the event and EVTDUR contains 0.

EVTDUR = -1 for an event indicates that the corresponding end event is not contained in the file (e.g. when the end event is later than the end time of the event file).

For the pericentre crossings (CPER), there is no duration related to the event. In that case EVTTIM refers just to the time of the event rather than the start time of the event and EVTDUR contains 0.

2.4.2 Event Types

The following tables show all event types.

The last column indicates whether a duration is related to the event or not.

The event types AxxH and LxxH refer to the event when the elevation of the line of sight from the GS to the S/C rises above or falls below the horizon mask. The horizon mask defines, depending on the azimuth, the minimum required elevation of the antenna for reception of a signal. In the event description, the elevation of the horizon mask is given in degrees as ‘nn’. The elevation for AxxH and LxxH may differ from each other.

For the event types AxxH, AxxT, LxxH and LxxT the xx and XXX in EVTTID and EVTDES indicate the antenna and the ground station complex as follows:

G/S Antenna	xx (EVTTID)	XXX (EVTDES)
Perth	73	PER
New Norcia	74	NNO
Kourou	75	KOU
DSN Goldstone 34m	13	GDS
DSN Goldstone 70m	14	GDS
DSN Goldstone 34m	15	GDS
DSN Goldstone 34m	24	GDS
DSN Goldstone 34m	25	GDS
DSN Goldstone 34m	26	GDS
DSN Madrid 34m	54	MAD
DSN Madrid 34m	61	MAD
DSN Madrid 70m	63	MAD
DSN Madrid 34m	65	MAD
DSN Canberra 34m	34	CAN
DSN Canberra 34m	42	CAN
DSN Canberra 70m	43	CAN
DSN Canberra 34m	45	CAN

The four event types LGPS, LGMS, LGPE and LGME referring to the coverage of the low gain antenna are only given when the S/C is within a distance of TBD km from the Earth. This event type is provided depending on the G/S when the S/C is near the Earth. Far from the Earth, only one event type refering to the centre of the Earth is provided. This is indicated by the acronym

‘XXX’ which is either a G/S (same definition as in the event description for acquisition and loss of signal is used) or ‘EAR’ for Earth.

Types SCDS and SCDE refer to the event, when the Sun/Earth/Spacecraft angle (SESC) falls below the limit where safe TM downlink is guaranteed. The nominal value for this estimate is 3 degrees according to the Rosetta Users Manual (see [RD-4]). The actually used value ‘n’ is provided in the event description. This event type is provided depending on the G/S when the S/C is near the Earth. Far from the Earth, only one event type refering to the centre of the Earth is provided. This is indicated by the acronym ‘XXX’ which is either a G/S (same definition as in the event description for acquisition and loss of signal is used) or ‘EAR’ for Earth. For details of the involved algorithms see [RD-10].

Types SCUS, SOUS, SCUE and SOUE refer to the event, when the Sun/Spacecraft/Earth angle (SSCE) falls below the limit where safe TC uplink via HGA or MGA is guaranteed. The nominal value for this estimate is 5 degrees according to the Rosetta Users Manual (see [RD-4]). The actually used value ‘n’ is provided in the event description. As for SCDS and SCDE, this event type is given either w.r.t. a G/S or the Earth depending on the S/C-Earth distance.

The event types KMDS and KMAS, ‘x km descend’ and ‘x km ascend’, refer to the radial distance of the S/C from the centre of the comet. The value of x is TBD.

EVTTID	Event Type	EVTDES	Duration until
AxxH	Acquisition of Signal at ground station with elevation angle nn	XXX_AOS_nn	XXX_LOS_nn
AxxT	Acquisition of Signal 10 degrees at ground station	XXX_AOS_10	XXX_LOS_10
LGPS	low gain antenna +Z coverage start	XXX_COV_LGA_+Z_START	XXX_COV_LGA_+Z_END
LGMS	low gain antenna -Z coverage start	XXX_COV_LGA_-Z_START	XXX_COV_LGA_-Z_END
OMAS	orbit manoeuvre start	ORB_MAN_START	ORB_MAN_END
SMAS	slew manoeuvre start	SLEW_MAN_START	SLEW_MAN_END
WOLS	wheel offloading start	WHEEL_OFFL_START	WHEEL_OFFL_END
FPAS	entry into FPAP	FPAP_START	FPAP_END
FPSS	entry into FPSP	FPSP_START	FPSP_END
HIBS	hibernation start	HIBERNATION_START	HIBERNATION_END
MOCS	Mars occultation start	OCC_MARS_START	OCC_MARS_END
COCS	comet occultation start	OCC_COMET_START	OCC_COMET_END
SCDS	S/C conjunction (SESC n degrees) start	XXX_CON_START_SESC_n	XXX_CON_END_SESC_n
SCUS	S/C conjunction (SSCE n degrees) start	XXX_CON_START_SSCE_n	XXX_CON_END_SSCE_n
SOUS	S/C opposition (SSCE n degrees) start	XXX_OPP_START_SSCE_n	XXX_OPP_END_SSCE_n
AL00	acquisition of signal 0 degree from lander to S/C	LSC_AOS_0	LSC_LOS_0
AL10	acquisition of signal 10 degrees from lander to S/C	LSC_AOS_10	LSC_LOS_10

EVTTID	Event Type	EVTDES	Duration until
VLMS	visibility landmark n start	VIS_n_START	VIS_n_END
KMDS	x km descend	x_KM_DESCEND	x_KM_ASCEND
LxxH	Loss of signal at ground station with elevation angle nn	XXX_LOS_nn	n/a
LxxT	Loss of signal 10 degrees at ground station	XXX_LOS_10	n/a
LGPE	low gain antenna +Z coverage end	XXX_COV_LGA_+Z_END	n/a
LPME	low gain antenna -Z coverage end	XXX_COV_LGA_-Z_END	n/a
OMAE	orbit manoeuvre end	ORB_MAN_END	n/a
SMAE	slew manoeuvre end	SLEW_MAN_END	n/a
WOLE	wheel offloading end	WHEEL_OFFL_END	n/a
FPAE	exit from FPAP	FPAP_END	n/a
FPSE	exit from FPSP	FPSP_END	n/a
HIBE	hibernation end	HIBERNATION_END	n/a
MOCE	Mars occultation end	OCC_MARS_END	n/a
COCE	comet occultation end	OCC_COMET_END	n/a
SCDE	S/C conjunction (SESC n degrees) end	XXX_CON_END_SESC_n	n/a
SCUE	S/C conjunction (SSCE n degrees) end	XXX_CON_END_SSCE n	n/a
SOUE	S/C opposition (SSCE ndegrees) end	XXX_OPP_END_SSCE n	n/a

EVTTID	Event Type	EVTDES	Duration until
LL00	loss of signal 0 degree from lander to S/C	LSC_LOS_0	n/a
LL10	loss of signal 10 degrees from lander to S/C	LSC_LOS_10	n/a
VLME	visibility landmark n end	VIS_n_END	n/a
KMAS	x km ascend	x_KM_ASCEND	n/a

2.5 Cometary Environment

TBD

2.6 Comet Characteristics

TBD

2.7 Comet Kinematics

TBD

2.8 Auxiliary Data Summary

The following table contains a summary of all auxiliary data files.

2.8.1 ADID

For each product there is a unique ADID assigned which is listed in the first column of the tables. The format of the ADID is

- for orbit files
  character 5 and 6: OR(=orbit file)
  character 7: H(=heliocentric) or E(= Earth centric 1. Earth flyby) or F(=Earth centric 2. Earth flyby) or G(=Earth centric 3. Earth flyby) or M(=Mars centric) or W(=comet centric) or P(=medium term planning)
  character 8: R(=Rosetta S/C) or W(=Churyumov-Gerasimenko) or O(=1st flyby asteroid) or S(=2nd flyby asteroid)
- for attitude files
  character 5 and 6: AT(=attitude file)
  character 7: N(=nominal) or P(=medium term planning)
  character 8: R(=Rosetta S/C)
- for the event file
  character 5 to 7: EVT(=event file)
  character 8: R(=Rosetta S/C)
- for the software (see 3.4)
  character 5 to 8: OASW (=orbit and attitude data access software)

2.8.2 Product Type

In the second column the product type is described.

2.8.3 Covered Time Span

The third column gives the covered time span of the product type.

2.8.4 Delivery

The entry in the fourth column states how long these files are updated.

2.8.5 Update Frequency

The update frequency in the fifth column is given as an estimated range. It depends on the mission phase as explained above. During hibernation no update will take place.

2.8.6 Format

The sixth column shows the format of the product. All orbit and attitude files are delivered as ASCII files.

2.8.7 File Name

The file name appears in the seventh column of the table. For all products the file names have the format ‘ffff_sssddd_txxxxxxxxxxxxxx_vvvvv.ROS’ where

- ffff is a 4 character file type mnemonic which is built from the last 4 characters of the ADID to which the file belongs, i.e. file ‘ffff....’ belongs to ADID ‘EROSffff’.
- sss is always ‘FDL’ or ‘FDR’. The acronym depends on whether the file has been sent from the FD ORATOS L platform or the R platform. In the table, only FDS is specified which stands for either FDL or FDR
- ddd is always ‘RMA’ or ‘RMB’. The acronym depends on whether the file has been sent from FD to the nominal Rosetta Mission Control System server romca or the backup server romcb. In the table, only RMS is specified which stands for either RMA or RMB.
- t is always ‘D’ for data
- ‘xxxxxxxxxxxxxx’ depends on the file type where
  character 1 is either A(= ASCII) or T(= tar file)
  character 2 is either P(=predicted) for attitude files, or ‘_’ for all other files
  and character 3 to 14 are either ‘____________’ for files without time span or ‘YYMMDDhhmmss’ for files with time span where the date specifies the start time of the data contained in the file
- vvvvv is the version number of the file

ADID	Product Type	Covered Time Span	Delivery	Update Frequency	Format	File Name
EROSORHR	S/C orbit, cruise, heliocentric	from launch to RV	until RV	1/week to 1/day	ASCII	ORHR_FDSRMS_DA______________vvvvv.ROS
EROSORER	S/C orbit, 1. Earth swingby, Earth centric	1. Earth SB +/- several days	until 1. Earth SB	1/week to 1/day	ASCII	ORER_FDSRMS_DA______________vvvvv.ROS
EROSORMR	S/C orbit, Mars swingby, Mars centric	Mars SB+/- several days	until Mars SB	1/week to 1/day	ASCII	ORMR_FDSRMS_DA______________vvvvv.ROS
EROSORFR	S/C orbit, 2. Earth swingby, Earth centric	2. Earth SB +/- several days	until 2. Earth SB	1/week to 1/day	ASCII	ORFR_FDSRMS_DA______________vvvvv.ROS
EROSORGR	S/C orbit, 3. Earth swingby, Earth centric	3. Earth SB +/- several days	until 3. Earth SB	1/week to 1/day	ASCII	ORGR_FDSRMS_DA______________vvvvv.ROS
EROSORPR	S/C orbit, medium term planning, comet centric	planning period	during comet observation	1/day	ASCII	ORPR_FDSRMS_DA______________vvvvv.ROS
EROSORWR	S/C orbit, comet centric	from RV	during comet observation	1/planning period	ASCII	ORWR_FDSRMS_DA______________vvvvv.ROS
EROSORHW	comet orbit, heliocentric	several years	whole mission	1/year to 1/week	ASCII	ORHW_FDSRMS_DA______________vvvvv.ROS
EROSORHO	1. FB asteroid orbit, heliocentric	several years	until FB	1/year to 1/day	ASCII	ORHO_FDSRMS_DA______________vvvvv.ROS
EROSORHS	2. FB asteroid orbit, heliocentric	several years	until FB	1/year to 1/day	ASCII	ORHS_FDSRMS_DA______________vvvvv.ROS
EROSATPR	S/C attitude, medium term planning	planning period	during comet observation	1/day	ASCII	ATPR_FDSRMS_DAPYYMMDDhhmmss_vvvvv.ROS
EROSATNR	S/C attitude	several days / segment	whole mission	1/month to 1/day	ASCII	ATNR_FDSRMS_DAPYYMMDDhhmmss_vvvvv.ROS
EROSEVTR	event file	TBD	whole mission	TBD	ASCII	EVTR_FDSRMS_DA______________vvvvv.ROS
EROSCENV	cometary environment	TBD	from RV	TBD	ASCII	CENV_FDSRMS_DA______________vvvvv.ROS
EROSCCHA	comet characteristics	TBD	from RV	TBD	ASCII	CCHA_FDSRMS_DA______________vvvvv.ROS
EROSCKIN	comet kinematics	TBD	from RV	TBD	ASCII	CKIN_FDSRMS_DA______________vvvvv.ROS
EROSOASW	orbit and attitude data access software	n/a	whole mission	one file for each release	tar file	OASW_FDSRMS_DT______________vvvvv.ROS

2 Mars Express Auxiliary Data

2.1 Mission Overview

MARS EXPRESS is the first 'flexible mission' in the revised ESA Long-Term Scientific Programme. Its objective is the remote observation of the Martian atmosphere, surface and subsurface from a nearly polar orbit with about 260 km pericentre altitude, 11600 km apocentre altitude and a period of about 7.6 hours. The S/C was launched in June 2003 by a Soyuz/Fregat launcher and is planned to be inserted into orbit around Mars in December 2003.

The S/C will also carry the lander probe Beagle 2. Five days before arrival at Mars Beagle 2 will be separated from the S/C by a spin eject spring system and follow a hyperbolic entry trajectory towards Mars. In orbit, the S/C will serve as data relay orbiter for the lander.

For each orbit, baseline operations are split into two phases. Around pericentre the S/C is nadir pointing allowing for close observation of the Martian surface. Between pericentre passages, the S/C is Earth pointing for transmission of scientific data down to Earth.

The end of the nominal mission is 30th November 2005. An optional extension of the mission may last up to November 2008.

A simplified overview of the mission phases is given in the following table.

Start	End	Duration (month)	Phase
2003/06	2003/07	1	LEOP/CVP
2003/07	2003/11	5	Cruise
2003/11	2004/01	2	Lander Ejection Mars Orbit Insertion
2004/01	2005/11	23	Routine Operations
2005/12	2008/11	36	Extended Operations

Table 1 Mars Express Mission Phases

2.2 Orbit Data

2.2.1 Orbit Determination

Orbit determination is essentially a batch least squares procedure taking into account range and Doppler measurements from the ESA 35m antenna at Perth. During critical mission phases tracking data will additionally be provided by ESA/Kourou and NASA/DSN stations.

The dynamical model of the S/C motion refers to the J2000 inertial reference frame with Barycentric Dynamical Time (TDB) as independent variable. In addition to the Newtonian attraction of the planets and the Moon the model includes :

- relativistic corrections to the gravitational fields
- perturbations of the Earth and Mars gravitational fields due to oblateness
- solar radiation pressure forces
- orbit manoeuvres
- small forces due to gas leaks or uncoupled control jets

The centre of integration depends on the mission phase. Near Earth or Mars the orbit is integrated with respect to the planet. During cruise phase the centre is either the Sun or the barycentre of the solar system. The ephemerides of the planets and Moon are taken from the latest version DE405 of the JPL export ephemeris files.

Range and Doppler measurements are corrected for several effects:

- transponder delay
- signal delay due to the troposphere and ionosphere of the Earth
- signal delay due to interplanetary plasma

The result of the least squares procedure are best estimates of the state vector of the S/C and of several model parameters plus statistical information. The accuracy depends on the mission phase and is expected to be typically better than (TBD) km for the position.

The number and frequency of batch runs for the orbit determination depends on the mission phase and the availability of tracking data. During cruise a run every (TBD) days is expected whereas during observation phases fits will be made after every pass.

2.2.2 Orbit Prediction

The orbit prediction uses the same dynamic model and similar integration techniques. But instead of fitting the S/C orbit in the past with received tracking data the future S/C orbit is integrated using the best estimate of the last orbit determination and optimized with respect to fuel consumption and mission constraints by suitable insertion of manoeuvres.

2.2.3 Orbit Data Delivery

Two types of orbit data are provided which correspond to two ADIDs in the DDS. One (EMEXORHM) covers the cruise phase from launch to Mars orbit insertion, the second (EMEXORMM) the operational orbit around Mars after orbit insertion. For all types, the reference plane is the Earth mean equator of

J2000. The orbital data are provided during cruise as heliocentric states, in the operational orbit as Mars centric states.

Data of the first type are all contained in one file. With each new orbit determination and/or manoeuvre optimisation, a new version of the file will be created.

Data of the second type are distributed over several files due to the large amount of data. The name of a file contains the start time YYMMDDhhmmss of the interval which is covered by the file. As there are no gaps between files, the corresponding end time of a file is given by the start time of the next file. The time interval will be typically about 1 month. With each new orbit determination and/or manoeuvre optimisation, new versions for all files of the second type will be created. Especially, the file names including start times will not change with a new update of orbit data. The start times in the file name will be given to an accuracy of a day (i.e. hhmmss = 000000) and will be accurate to one day compared to the actual time span covered by the data in the file. For example, the file with YYMMDDhhmmss = 040309000000 contains data starting at any time between 08/03/2004 and 10/03/2004. This is done in order to keep some freedom in the choice on the actual separation of data in time. This separation will take into account operational conditions like correction manoeuvres and may shift slightly (i.e. within +/- 1 day) with each new update.

For long term planning purposes, a long term planning file is available. This file provides Mars centric states after orbit insertion and is not split into several parts. Due to its large size (approximately 800 MB), the file is delivered not via the DDS but only on RDM (CD-ROM or DVD).

2.3 Attitude Data

Attitude data are provided via the DDS for all mission phases apart from safe modes (SAM and SHM).

Except for inital launcher separation and for backup modes the attitude is controlled in one of the following ways:

- The S/C takes a fixed inertial attitude commanded by ground
- The S/C follows a time dependent attitude profile commanded by ground
- The S/C x-axis is Earth pointing, the S/C y-axis is nearly perpendicular to the ecliptic. Time dependent inertial Earth and Sun direction profiles are commanded by ground

The attitude information in the DDS is based on commanded profiles.

2.3.1 Attitude Data Delivery

The considerations concerning data delivery are for attitude data different from those for orbit data.

- For the attitude a larger amount of data per covered time span is expected compared with orbit data.
- Although there are many occasions (e.g. during cruise phase, nadir pointing as baseline operation at pericentre) where the required attitude of the S/C is known in advance there is a greater flexibility for the operations planning to choose an attitude. The orbit however is nearly fixed.

Therefore the following guidelines for the delivery of attitude data were chosen:

- Attitude data are provided for the past and (only) for the near future.
- The distinction between cruise phase and operational orbit as for the orbit data is not necessary here.
- The attitude is provided in several files, called segments, each covering a specific time span. These segments have no overlap. There may be gaps between the segments and even gaps in the segments.
- During mission the number of segments is growing. As soon as the attitude profiles are available from the command generation subsystem corresponding segments are provided via the DDS.

As a consequence, the user has to retrieve one or more segments (attitude files) to cover a requested time span.

2.4 Events

Two ASCII files containing information about events will be provided. The file with ADID EMEXEVTM is the most up to date event file consistent with the orbit data from ADID EMEXORHM and EMEXORMM and contains events up into the near future. The file with ADID EMEXEVTF is a frozen event file consistent with orbit data from the long term planning orbit file and provides events covering the complete long term planning period. The frozen event file contains only a subset of all possible event types (see 2.4.2).

The format of both event files is the same:
For each event one line of information is given. The events occur in ascending order in time.

2.4.1 Event File Format

The following table shows the format of the event file.

Name	Format	Contents
EVTTID	A4	Event Type Identification
EVTCNT	(X2,I10)	Event Count
PREREC	(X2,A1)	single character flag indicating whether event is predicted (‘P’) or reconstituted (‘R’)
EVTTIM	(X2,A20)	Start Time of Event in the format ‘YY-DDDThh:mm:ss.dddZ’
EVTDUR	(X2,I8)	duration of event in seconds
EVTDES	(X2,A80)	description of event
LF	A1	single line feed character (ASCII 0Ahex)

Table 2 Event File Format

The format definition refers to the ANSI FORTRAN notation for format statements.

EVTTID is a alphanumeric string of length 4 which is unique for each event type.

EVTCNT is a running number for each event type. It will always be in ascending consecutive order.

The format of EVTTIM is ‘YY-DDDThh:mm:ss.dddZ’ where YY are the last two digits of the year, DDD is the day of the year and hh, mm, ss and ddd are hours, minutes, seconds and milliseconds of the day. All other symbols are fixed character constants. The provided numerical accuracy of EVTTIM depends on the event type. For pericentre passages, the event time is provided with a numerical accuracy of 3 decimal digits. For all other events, the

provided numerical accuracy is reduced to 1 second, i.e. the three decimal digits ‘ddd’ are ‘000’.
EVTTIM is always given in UTC.
If there is no duration related to the event (e.g. pericentre passage) then EVTTIM refers just to the time of the event rather than the start time of the event and EVTDUR contains 0. Although the end of events can be derived from the start time of the event and its duration, the end of the event is additionally given for convenience. In this case EVTTIM refers to the end of the event and EVTDUR contains also 0.

EVTDUR = -1 for an event indicates that the corresponding end event is not contained in the file (e.g. when the end event is later than the end time of the event file).

2.4.2 Event Types

The tables at the end of this section show all event types. The last column indicates whether a duration is related to the event or not.

The event types AxxH and LxxH refer to the event when the elevation of the line of sight from the GS to the S/C rises above or falls below the horizon mask. The horizon mask defines, depending on the azimuth, the minimum required elevation of the antenna for reception of a signal. In the event description, the elevation of the horizon mask is given in degrees as ‘nn’. The elevation for AxxH and LxxH may differ from each other.

For the event types AxxH, AxxT, LxxH and LxxT the xx and XXX in EVTTID and EVTDES indicate the G/S antenna and complex as follows:

G/S Antenna	xx (EVTTID)	XXX (EVTDES)
Perth	73	PER
New Norcia	74	NNO
Kourou	75	KOU
DSN Goldstone 34m	13	GDS
DSN Goldstone 70m	14	GDS
DSN Goldstone 34m	15	GDS
DSN Goldstone 34m	24	GDS
DSN Goldstone 34m	25	GDS
DSN Goldstone 34m	26	GDS
DSN Madrid 34m	54	MAD
DSN Madrid 34m	61	MAD
DSN Madrid 70m	63	MAD
DSN Madrid 34m	65	MAD
DSN Canberra 34m	34	CAN

G/S Antenna	xx (EVTTID)	XXX (EVTDES)
DSN Canberra 34m	42	CAN
DSN Canberra 70m	43	CAN
DSN Canberra 34m	45	CAN

The event types AxxH, AxxT, LxxH, LxxT indicate when the line of sight to the S/C reaches the given elevation at the G/S. These events do not indicate whether a TM/TC link is possible, as further events have to be considered like occultation, opposition or conjunction.

The event types ALHM and LLHM refer to the event when the elevation of the line of sight from the lander to the S/C rises above or falls below the horizon mask. The horizon mask defines, depending on the azimuth, the minimum required elevation of the orbiter direction for reception of a signal. In the event description, the elevation of the horizon mask is given in degrees as ‘nn’. In the beginning, the horizon mask is not known and ‘nn’ will always be zero. If a horizon mask derived from actual visibility times will become available, it will be used for these events. In that case, the elevation for ALHM and LLHM may differ from each other. AL10 and LL10 are given, when the elevation of the line of sight rises above and falls below 10 degrees. The entry ‘XXX’ in EVTDES of types ALHM, AL10, LLHM and LL10 gives the identification for the lander. BE2 is used for Beagle-2, MRA and MRB for Mars Rover A and Mars Rover B.

The event types ALFn and ALRn refer to the event when the forward link (i.e. Mars Express Melacom to Beagle2) or return link (i.e. Beagle2 to Mars Express Melacom) become available with a bit rate of 2^n kbps and, at the same time, the aspect angles on both antennas (i.e. line of sight from Beagle2 to Mars Express w.r.t. Beagle2 antenna boresight and line of sight from Mars Express to Beagl2 w.r.t. Melacom antenna boresight) are below 70 degrees. Possible values for n are 1 to 7 for the return link, and 1 and 3 for the forward link. Event types LLFn and LLRn are the corresponding end events, i.e. correspond to the times when the forward or return links become unavailable. The events are computed based on a default S/C nadir pointing attitude and on a Beagle2 antenna pointing direction towards the local zenith. In the event descriptions, bit rate in kbps (x= 2 ,4, 8, 16, 32, 64 or 128), range in km (rrrrr) and line of sight direction from lander to S/C as azimuth in degree (zzz.z) and elevation in degree (ee.e) at the corresponding event time are provided.

Type MOCS and MOCE refer to the event, when the line of sight from the centre of the Earth to the S/C starts and ends to be occulted by Mars. With MOCS some additional parameters are given:
rrr.rr,ddd.dd are right ascension from 0 to 360 and declination from -90 to +90 in degrees of the line of sight from the centre of the Earth to the S/C at start or end of occultation.

xxx.xx,yyy.yy are planetocentric longitude from 0 to 360 degrees eastward and planetocentric latitude from -90 to +90 degrees of the occulted Mars point. This is the point where the line of sight is tangential to the Martian surface at start or end of occultation. zzz is the Sun zenith angle in degrees for the occulted Mars point at start or end of occultation.

Types MO2S and MO2E refer to the event, when the smallest distance between the surface of Mars and the line of sight from the centre of the Earth to the S/C drops below or rises above 200 km. Additional parameters are given:
rr.rr,dd.dd are right ascension and declination in degrees of the line of sight from the centre of the Earth to the S/C at event time.
xxx.xx,yyy.yy are planetocentric longitude from 0 to 360 degrees eastward and planetocentric latitude from -90 to +90 degrees of the point on the line of sight where the distance to the surface of Mars is 200 km. zzz is the Sun zenith angle in degrees for that point at event time.

Types PENS and UMBS refer to the event, when the S/C enters the penumbra and umbra of the body indicated by xxx. The entry xxx can be either ‘MAR’ for Mars, ‘PHO’ for Phobos or ‘DEI’ for Deimos. The events PENE and UMBE indicate the exit from penumbra and umbra.

Types SCDS and SCDE refer to the event, when the Sun/Earth/Spacecraft angle (SESC) falls below the limit where safe TM downlink is guaranteed. The nominal value for this estimate is 3 degrees according to [RD-6]. The actually used value ‘n’ is provided in the event description. This event type is provided depending on the G/S when the S/C is near the Earth. Far from the Earth, only one event type refering to the centre of the Earth is provided. This is indicated by the acronym ‘XXX’ which is either a G/S (same definition as in the event description for acquisition and loss of signal is used) or ‘EAR’ for Earth. For details of the involved algorithms see [RD-10].

Types SCUS, SOUS, SCUE and SOUE refer to the event, when the Sun/Spacecraft/Earth angle (SSCE) falls below the limit where safe TC uplink via HGA or MGA is guaranteed. The nominal value for this estimate is 5 degrees. The actually used value ‘n’ is provided in the event description. As for SCDS and SCDE, this event type is given either w.r.t. a G/S or the Earth depending on the S/C-Earth distance.

The event types MPER and MAPO refer to the event, when the S/C crosses the line of apsides. This event is defined by the time when the osculating true anomaly measured from -180 degrees to +180 degrees changes sign (For a detailed description of this event type refer to [RD-7]). The number ‘nnnn’ in the event description provides the current orbit number. Orbit numbers are incremented by one with each apocentre passage starting from the first apocentre after orbit insertion. For each event of type MPER, also the subsatellite point (xxx.xx,yyy.yy) in planetocentric longitude from 0 to 360 degrees and planetocentric latitude between -90 and +90 degrees and the Sun zenith angle zz of the subsatellite point in degrees are given.

Types KMDS and KMAS, ‘x km descend’ and ‘x km ascend’, refer to the event when the height of the S/C position above the Mars reference ellipsoid drops below or rises above x km. Events are provided for heights of 800 km, 1200 km, 2000 km and 4000 km (i.e. x is either ‘800’, ‘1200’, ‘2000’ or ‘4000’).

All events of type AxxH, LxxH, AxxT, LxxT, MOCS, MOCE, SCDS, SCDE, SCUS, SCUE, SOUS, SOUE refer to a purely geometrical situation. All considerations concerning related start and end times of TM and TC have to take into account additionally the one way light time.

The long term planning event file (ADID=EMEXEVTF) contains only event types AxxH, AxxT, MO2S, MOCS, PENS, UMBS, SCDS, SCUS, SOUS, MPER, MAPO with their corresponding end times and KMDS, KMAS.

Types NPSS and NPNS indicate the times in the mission, when the pointing of the x-axis has to switch from North to South (NPSS) or from South to North (NPNS) in order to avoid Sun incidence on the S/C -x face in nadir pointing mode around Mars.
In nadir pointing mode, with the x-axis perpendicular to the ground track, the angle between the S/C -x axis and the Sun direction varies around the pericentre by some degrees (e.g. at the switching time around mid March 2004 about 5 degrees). This means that there is not a single date and time to switch to the correct x axis pointing or, conversely, depending on the duration of the nadir pointing, it might therefore not be possible, to avoid Sun incidence on the S/C -x face during a complete pericentre passage in nadir pointing mode (neither with North nor with South pointing option). Instead, the duration of the nadir pointing has to be reduced or a small Sun incidence must be tolerated.
The events are calculated as follows: At the beginning of the mission the S/C x axis must be North pointing, i.e. close to the orbital North pole. The Sun incidence on the S/C -x face is then calculated at each pericentre assuming nadir pointing mode and the first pericentre is noted when the x axis has to switch from North to South pointing to avoid Sun incidence on the -x face exactly at pericentre. An event ‘NPSS’ is then inserted at the time of the preceding apocentre that indates the required switch from North to South. The event ’NPNS’ for switching back to North is inserted at the apocentre time before the pericentre where the switch back to North is required

Type EPSS indicates the date and time, where the S/C y axis direction has to change from ecliptic North to South in order to minimise Sun incidence on the S/C +z face. There is a considerable time span around the switching time where a small Sun incidence angle can not be avoided, neither with North nor with South pointing option. The event is calculated such, that the option with the smallest incidence angle is chosen. The computation of the event time is based on the direction of the ecliptic pole which is used by the AOCMS onboard software, not on the true ecliptic pole.

Types NPSS, NPNS and EPSS refer only to the corresponding geometrical conditions as described above. The times may differ from the actual switching times as commanded by the Flight Control Team.

EVTTID	Event Type	EVTDES	Duration until
AxxH	Acquisition of Signal at ground station with elevation angle nn	XXX_AOS_nn	XXX_LOS_nn
AxxT	Acquisition of Signal 10 degrees at ground station	XXX_AOS_10	XXX_LOS_10
ALHM	Acquisition of signal at landing site from orbiter with elevation angle nn	xxx_AOS_nn	xxx_LOS_nn
AL10	Acquisition of signal 10 degrees at landing site from orbiter	xxx_AOS_10	xxx_LOS_10
ALFn	Acquisition of B2 forward link with 2^n kbps	BE2_AOS_TC_xKBPS_/_RN_rrrrr_/ _AZ_zzz.z_/_ELV_ee.e	BE2_LOS_TC_xKBPS_/_RN_rrrrr_/ _AZ_zzz.z_/_ELV_ee.e
ALRn	Acquisition of B2 return link with 2^n kbps	BE2_AOS_TM_xKBPS_/_RN_rrrrr_/ _AZ_zzz.z_/_ELV_ee.e	BE2_LOS_TM_xKBPS_/_RN_rrrrr_/ _AZ_zzz.z_/_ELV_ee.e
OMAS	orbit manoeuvre start	ORB_MAN_START	ORB_MAN_END
SMAS	slew manoeuvre start	SLEW_MAN_START	SLEW_MAN_END
WOLS	wheel offloading start	WHEEL_OFFL_START	WHEEL_OFFL_END
FPAS	entry into FPAP	FPAP_START	FPAP_END
FPIS	entry into FPIP	FPIP_START	FPIP_END
MO2S	Mars occultation 200 km start	OCC_MARS_200KM_START_/_ RA_rrr.rr_/_DE_ddd.dd_/_ OMP_(xxx.xx,yyy.yy)_/_SZA_zzz	OCC_MARS_200KM_END_/_ RA_rrr.rr_/_DE_ddd.dd_/_ OMP_(xxx.xx,yyy.yy)_/_SZA_zzz
MOCS	Mars occultation start	OCC_MARS_START_/_ RA_rrr.rr_/_DE_ddd.dd_/_ OMP_(xxx.xx,yyy.yy)_/_SZA_zzz	OCC_MARS_END_/_ RA_rrr.rr_/_DE_ddd.dd_/_ OMP_(xxx.xx,yyy.yy)_/_SZA_zzz
PENS	penumbra start	xxx_PENUMBRA_START	xxx_PENUMBRA_END
UMBS	umbra start	xxx_UMBRA_START	xxx_UMBRA_END

EVTTID	Event Type	EVTDES	Duration until
SCDS	S/C conjunction (SESC n degrees) start	XXX_CON_START_SESC_n	XXX_CON_END_SESC_n
SCUS	S/C conjunction (SSCE n degrees) start	XXX_CON_START_SSCE_n	XXX_CON_END_SSCE_n
SOUS	S/C opposition (SSCE n degrees) start	XXX_OPP_START_SSCE_n	XXX_OPP_END_SSCE_n
KMDS	x km descend	x_KM_DESCEND	x_KM_ASCEND
MPER	pericentre passage	PERICENTRE_PASSAGE_nnnn_/_ SSP_(xxx.xx,yyy.yy)_/_SZA_zzz	n/a
MAPO	apocentre passage	APOCENTRE_PASSAGE_nnnn	n/a
LxxH	Loss of signal at ground station with elevation angle nn	XXX_LOS_nn	n/a
LxxT	Loss of signal 10 degrees at ground station	XXX_LOS_10	n/a
LLHM	Loss of signal at landing site from orbiter with elevation angle nn	xxx_LOS_nn	n/a
LL10	Loss of signal 10 degrees at landing site from orbiter	xxx_LOS_10	n/a
LLFn	Loss of B2 forward link with 2^n kbps	BE2_LOS_TC_xKBPS_/_RN_rrrrr_/ _AZ_zzz.z_/_ELV_ee.e	n/a
LLRn	Loss of B2 return link with 2^n kbps	BE2_LOS_TM_xKBPS_/_RN_rrrrr_/ _AZ_zzz.z_/_ELV_ee.e	n/a
OMAE	orbit manoeuvre end	ORB_MAN_END	n/a
SMAE	slew manoeuvre end	SLEW_MAN_END	n/a
WOLE	wheel offloading end	WHEEL_OFFL_END	n/a

EVTTID	Event Type	EVTDES	Duration until
FPAE	exit from FPAP	FPAP_END	n/a
FPIE	exit from FPIP	FPIP_END	n/a
MOCE	Mars occultation end	OCC_MARS_END_/_ RA_rrr.rr_/_DE_ddd.dd_/_ OMP_(xxx.xx,yyy.yy)_/_SZA_zzz	n/a
MO2E	Mars occultation 200km end	OCC_MARS_200KM_END_/_ RA_rrr.rr_/_DE_ddd.dd_/_ OMP_(xxx.xx,yyy.yy)_/_SZA_zzz	n/a
UMBE	umbra end	xxx_UMBRA_END	n/a
PENE	penumbra end	xxx_PENUMBRA_END	n/a
SCDE	S/C conjunction (SESC n degrees) end	XXX_CON_END_SESC_n	n/a
SCUE	S/C conjunction (SSCE n degrees) end	XXX_CON_END_SSCE_n	n/a
SOUE	S/C opposition (SSCE n degrees) end	XXX_OPP_END_SSCE_n	n/a
KMAS	x km ascend	x_KM_ASCEND	n/a
NPSS	x-axis pointing switch from North to South	NADIR_POINTING_X_N_TO_S_SWITCH	n/a
NPNS	x-axis pointing switch from South to North	NADIR_POINTING_X_S_TO_N_SWITCH	n/a
EPSS	y-axis pointing switch from North to South	EARTH_POINTING_Y_N_TO_S_SWITCH	n/a

2.5 Lander

Information related to landers are provided in a lander file. It contains information for up to three landers. Its format is ASCII and it consists of three main parts, the main header, a daily header and a body part (see example below). The main header occurs at the top of the file and contains:

- start time of the time interval which is covered, the length of the covered time interval, the chosen stepsize for the discrete entries in the file
- general information of the S/C orbit around Mars, valid at the start time of the file: Mars centric state, orbital elements, osculating orbital period
- definition of Mars reference ellipsoid: equatorial radius, flattening coefficient
- Mars centric coordinates for up to three considered landers.

For each day, covered by the file, a daily header with subsequent body part is written. The daily header contains:

- the date in calender format
- S/C to Earth distance in AU at the time of the first entry in the following body part
- S/C to Sun distance in AU at the time of the first entry in the following body part

The body consists of a series of records provided at regular spaced discrete times. Each record contains columns with S/C data and columns with lander related data. The columns related to S/C data are (entries in brackets refer to the table header in the file):

- the time in UTC (HH:MM:SS)
- orbit number (ORB. REV.)
- osculating true anomaly in degrees of the S/C in its orbit (TA)
- direction of S/C as seen from the center of Mars in J2000 frame, given as right ascension in degrees (RA) and declination in degrees (DEC).
- Mars centric position of the S/C given in the rotating Mars frame as longitude in degrees (LONG), latitude in degrees (LAT) and height above reference ellipsoid in km (HEIGHT). The reference ellipsoid is defined by the constants given in the file header.The longitude is measured positive towards East.
- Sun-Mars-S/C angle in degrees (SMSC)

The columns related to lander data are:

- position of the S/C in the local lander horizon frame, i.e. azimuth in degrees (AZ), elevation in degrees (EL) and range in km (RANGE). The columns are empty, if the S/C is not visible from the lander.

- direction of the Sun as seen from the lander in the local horizon frame, i.e. azimuth in degrees (AZS) and elevation in degrees (ELS).
- local time at landing site given as difference of longitude between the lander and the sub solar point, measured in degrees positive towards East between -180 and +180 (LOT).

The following page shows an example file for two landers. The dots in the line after 13:36:00 UTC indicate that several lines from the printout are omitted.

```
          VISIBILITY OF PLANETARY ORBITER FROM LANDER(S)

     ORBITER: MEX

     EPOCH (UTC)          2004/01/10 13:30: 0.000     DURATION (DAYS):     5.000    INCREMENT (S):     120
     EPOCH (TDB)          2004/01/10 13:31: 4.184

     FRAME: PLANET EQUATOR WITH X-DIRECTION AT ASCENDING NODE WRT J2000 EQUATOR

     STATE RELATIVE TO   POSITION (KM)                =          195.498963          834.433946        -5377.880582
     CENTRE OF MARS      VELOCITY (KM/S)              =           -1.817572           -2.526305            1.188137

     ELEMENTS WRT        PERICENTRE DISTANCE (KM)     =         3645.942329
     MARS                APOCENTRE DISTANCE (KM)      =        14847.825506
                         SEMI MAJOR AXIS (KM)         =         9246.883917
                         ECCENTRICITY                 =            0.605711
                         INCLINATION (DEG)            =           86.296675
                         ASC. NODE (DEG)              =          232.850628
                         ARG. OF PERICENTRE (DEG)     =          344.616089
                         TRUE ANOMALY (DEG)           =          -82.884527
                         OSC. ORBITAL PERIOD (H)      =            7.499028

                         EQUATORIAL RADIUS OF MARS    =         3397.515000
                         FLATTENING COEFFICIENT OF MARS =          0.006500

     COORDINATES OF  3 LANDER(S)
              |------------------------MARSCENTRIC------------------------|
      LANDER   LONGITUDE   LATITUDE   RADIUS      X - KM     Y - KM     Z - KM   LANDER
      NUMBER     (DEG)*     (DEG)      (KM)                                      NAME
         1     90.000000   10.600000 3397.515      0.000   3339.538    624.977   BEAGLE 2
         2      6.010000   -1.990000 3396.188   3375.484    355.373   -117.933   ATHENA ROVER HEMATITE TM20B
      *LONGITUDE IS MEASURED POSITIVE TOWARDS THE EAST

                                                           ----------|DATE: 2004/01/10|----------
MEX      ORBIT G3UB          S/C TO EARTH IN AU:     1.19676     S/C TO SUN IN AU:     1.48660
SMSC = ANGLE SUN-MARS-S/C    AZS,ELS = AZIMUTH/ELEVATION SUN     LOT = LOCAL TIME
---------------------------------------------------------------------------------------------------------------------------------------
--------|----|---|-----------MARSCENTRIC-----------|         |--------------BEAGLE 2--------------|--------------ROVER   --------------|
UTC     |ORB.|TA |  RA     DEC    SMSC   LONG    LAT   HEIGHT |  AZ    EL RANGE   AZS   ELS    LOT |  AZ    EL RANGE   AZS   ELS    LOT |
HH:MM:SS|REV.|DEG| DEG     DEG    DEG    DEG*    DEG   KM     | DEG  DEG    KM   DEG   DEG    DEG | DEG  DEG    KM   DEG   DEG    DEG |
---------------------------------------------------------------------------------------------------------------------------------------
13:30:00|  17|277|134.82 -44.03  82.77 306.67 -80.90  2069.8 |                 226.5  57.6   23.4 |                 102.4  29.2  -60.6 |
13:32:00|  17|281|138.05 -47.10  79.64 321.85 -84.18  1876.0 |                 227.1  57.3   23.9 |                 102.5  29.6  -60.1 |
13:34:00|  17|285|141.96 -50.28  76.29   6.15 -86.26  1684.6 |                 227.7  56.9   24.4 |                 102.5  30.1  -59.6 |
13:36:00|  17|289|146.79 -53.54  72.70  58.89 -84.49  1496.9 |                 228.2  56.6   24.8 |                 102.6  30.6  -59.1 |
                                                     .............................................
13:56:00|  17|355|260.38 -46.05  34.32  94.98 -20.33   261.9 |                 233.4  52.8   29.7 |                 103.1  35.3  -54.3 |
13:58:00|  17|  3|266.69 -39.31  34.46  95.06 -12.19   257.8 |                 233.9  52.5   30.2 |                 103.2  35.8  -53.8 |
14:00:00|  17| 11|271.83 -32.35  36.24  95.11  -4.10   282.4 |160.7  8.4   998 234.3  52.1   30.7 |                 103.2  36.3  -53.3 |
14:02:00|  17| 19|276.15 -25.35  39.35  95.14   3.83   334.7 |142.7 28.0   623 234.8  51.7   31.2 |                 103.3  36.7  -52.8 |
14:04:00|  17| 27|279.86 -18.49  43.36  95.15  11.48   413.1 | 79.7 49.4   523 235.2  51.3   31.7 |                 103.4  37.2  -52.3 |
```

Example Lander File

2.6 Star Occultations

For a list of stars provided by the SPICAM experiment, star occultation events are given in a separate file. Four types of events are considered:

- 200 km descend
  This event refers to the time when the minimum distance of the line of sight between S/C and star from the Mars reference ellipsoid drops below 200 km.
- start occultation
  This event refers to the time when the line of sight starts to be occulted by the Mars reference ellipsoid.
- end occultation
  This event refers to the time when the line of sight ends to be occulted by the Mars reference ellipsoid.
- 200 ascend
  This event refers to the time when the minimum distance of the line of sight between S/C and star from the Mars reference ellipsoid rises above 200 km.

All events are sorted in ascending order in time. For each event one line of description is given. The format of each line is as follows:

Format	Field
I4	orbit number, counted from first apocentre after orbit insertion
(X3,A16)	event time in UTC in the format YY-DDDThh:mm:ssZ (for the format definition see definition of EVTTIM parameter in event file in section 2.4.1)
(X5,A8)	time until next pericentre in the format hh:mm:ss
(X9,A8)	time since last pericentre in the format hh:mm:ss
(X6,F8.3)	true anomaly in degrees between -180 deg and +180 deg
(X2,I5)	BSC star number
(X2,A19)	event description, one of the following four entries: 200 km, descending start occultation end occultation 200 km, ascending
(X2,A15)	occultation point in the format (xxx.xx,yyy.yy) where xxx.xx is planetocentric longitude in degrees from 0 to 360 eastward, and yyy.yy is planetocentric latitude in degrees from -90 to +90
(X3,F6.2)	solar zenith angle, i.e. the angular separation in degrees between the Sun direction and the direction of the occultation point as seen from the centre of Mars
(X7,F6.2)	local time, i.e. the difference in longitude in degrees between occultation point and Sun direction from -180 to 180 degrees

Table 3 Mars Express Star Occultation File Format

The format definition refers to the ANSI FORTRAN notation for format statements.

For a detailed description of relevant algorithms and model assumptions (e.g. reference ellipsoid, rotational elements) refer to [RD-8].

2.7 Auxiliary Data Summary

The following table contains a summary of all auxiliary data files.

2.7.1 ADID

For each product there is a unique ADID assigned which is listed in the first column of the tables. The format of the ADID is

- for orbit files
  character 5 and 6: OR(=orbit file)
  character 7: H(=heliocentric) or M(=Mars centric)
  character 8: M(=Mars Express S/C) or F(=frozen)
- for attitude files
  character 5 and 6: AT(=attitude file)
  character 7: N(=nominal)
  character 8: M(=Mars Express S/C)
- for the event file
  character 5 to 7: EVT(=event file)
  character 8: M(=Mars Express S/C) or F(=frozen)
- for the star occultation file
  character 5 to 7: STO(=star occultation file)
  character 8: M(=Mars Express S/C)
- for the lander visibility file
  character 5 to 7: VIL(=visibility lander)
  character 8: M(=Mars Express S/C)
- for the software (see 3.4)
  character 5 to 8: OASW (=orbit and attitude data access software)

2.7.2 Product Type

In the second column the product type is described.

2.7.3 Covered Time Span

The third column gives the covered time span of the product type.

2.7.4 Delivery

The entry in the fourth column states how long these files are updated.

2.7.5 Update Frequency

The update frequency in the fifth column is given as an estimated range.

2.7.6 Format

The sixth column shows the format of the product. All orbit and attitude files are delivered as ASCII files.

2.7.7 File Name

The file name appears in the seventh column of the table. For all products the file names have the format ‘ffff_sssddd_txxxxxxxxxxxxxx_vvvvv.MEX’ where

- ffff is a 4 character file type mnemonic which is built from the last 4 characters of the ADID to which the file belongs, i.e. file ‘ffff....’ belongs to ADID ‘EMEXffff’.
- sss is always ‘FDL’ or ‘FDR’. The acronym depends on whether the file has been sent from the FD ORATOS L platform or the R platform. In the table, only FDS is specified which stands for either FDL or FDR
- ddd is always ‘MMA’ or ‘MMB’. The acronym depends on whether the file has been sent from FD to the nominal Mars Express Mission Control System server memca or the backup server memcb. In the table, only MMS is specified which stands for either MMA or MMB.
- t is always ‘D’ for data
- ‘xxxxxxxxxxxxxx’ depends on the file type where
  character 1 is either A(= ASCII) or T(= tar file)
  character 2 is either P(=predicted) for attitude files, or ‘_’ for all other files and character 3 to 14 are either ‘____________’ for files without time span or ‘YYMMDDhhmmss’ for files with time span where the date specifies the start time of the data contained in the file
- vvvvv is the version number of the file

ADID	Product Type	Covered Time Span	Delivery	Update Frequency	Format	File Name
EMEXORHM	S/C orbit, cruise, heliocentric	from launch to orbit insertion	until orbit insertion	1/week to 1/day	ASCII	ORHM_FDSMMS_DA______________vvvvv.MEX
EMEXORMM	S/C orbit, operational, Mars centric	approximately 1 month per segment	whole mission	1/week to 1/day	ASCII	ORMM_FDSMMS_DA_YYMMDDhhmmss_vvvvv.MEX
n/a (only distributed on RDM)	S/C orbit, operational, Mars centric, long term planning	whole mission from orbit insertion	whole mission	1/long term planning period	ASCII	ORMF_FDSMMS_DA______________vvvvv.MEX
EMEXATNM	S/C attitude	several days / segment	whole mission	1/month to 1/day	ASCII	ATNM_FDSMMS_DAPYYMMDDhhmmss_vvvvv.MEX
EMEXEVTM	event file	TBD	whole mission	TBD	ASCII	EVTM_FDSMMS_DA______________vvvvv.MEX
EMEXEVTF	event file, long term planning	TBD	whole mission	TBD	ASCII	EVTF_FDSMMS_DA______________vvvvv.MEX
EMEXSTOM	star occultations	from orbit insertion up to 1 medium term planning period (i.e. 1 month TBC) into the future	during operational orbit	TBD	ASCII	STOM_FDSMMS_DA______________vvvvv.MEX
EMEXVILM	lander visibility	TBD	during operational orbit	TBD	ASCII	VILM_FDSMMS_DA______________vvvvv.MEX
EMEXOASW	orbit and attitude data access software	n/a	whole mission	one file for each release	tar file	OASW_FDSMMS_DT______________vvvvv.MEX

3 Software

This section describes the software delivered via the DDS. The description is applicable for Rosetta and Mars Express.

3.1 Orbit Data Access

3.1.1 Data Storage

Orbit data are stored in a binary direct data access file in a format that is tailored with respect to numerical accuracy, access performance, common application interface and storage requirements. This applies to the S/C reconstructed and predicted orbits as well as to the asteroid and comet orbits. Although the low level architecture of data storage is quite sophisticated the retrieval of data is made very easy by use of a simple access routine.

The orbit file contains orbital information at discrete times. The corresponding epochs are not equidistant in time but are chosen by the numerical integrator. The whole orbit is partitioned into blocks which comprise a mission phase or a part of it. For each block and for the whole file there is additional information stored in block headers and the file header. All data are stored in logical records containing either orbital, block header or file header information. The logical records are in turn grouped together into the physical records of the binary direct access file.

There are two types of orbit files, L-type and H-type. For the L-type file the orbital information consists of the epoch and the S/C state. So one logical record of orbital information contains the epoch, 3 position and 3 velocity components. In the H-type file the orbital information is augmented by the S/C state time derivative at the epoch.

Read access is established by a layer of low level FORTRAN subroutines on top of which a very simple FORTRAN access subroutine resides. This subroutine (see description below) needs just the identifier of the orbit file and an arbitrary epoch as input and delivers the state of the S/C together with information on the central body and reference frame which the state refers to. The state is computed from the stored discrete orbital information by interpolation. The type of interpolation depends on the file type and user supplied input. For L-type files each position and velocity component is derived by Lagrangian interpolation. So for a given epoch a number of discrete states just before the epoch and an equal number of states just after the epoch are retrieved from the file. For each component a polynomial is computed which fits the retrieved states. As result the values of the polynomials at the required epoch are returned. For H-type files the components are derived by Hermite interpolation. In this case not only the state but also the state derivative is fitted by the polynomials resulting in a better interpolation accuracy. The number of discrete values chosen for the fit depends on the information which the user supplies in form of the interpolation order as input to the interface routines (see description of subroutine rofop.f). As the number of grid points for the interpolation is always even, the actual degree of the interpolating polynomial is sometimes greater than the user supplied input. The following table shows the number of grid points and the actual interpolation degree for the two file types for input orders from 6 to 12..

	L-Type		H-Type	
Input order	**# of grid points**	**polynomial degree**	**# of grid points**	**polynomial degree**
6	8	7	4	7
7	8	7	4	7
8	10	9	6	11
9	10	9	6	11
10	12	11	6	11
11	12	11	6	11
12	14	13	8	15

Table 4 Order of Interpolation

Usually an input order of 8 is recommended for both types of orbit files. It must be noted that the order of interpolation is decreased when the epoch for which the state is required approaches the boundary of a block as the interpolation is never done across block boundaries. So if there aren't enough grid points available in the block the order of interpolation is reduced. The access S/W automatically recognizes the type of orbit file and chooses the interpolation algorithm accordingly.

The access software reads the data only from binary direct access files. To allow the transfer of data between machines which are not binary compatible, orbit data are made available in ASCII format together with a FORTRAN utility for conversion into the required binary format on the target platform.

3.1.2 Access Software

To access an orbit state at a certain epoch from a FORTRAN application program the following steps are necessary:

- 3 top level FORTRAN subroutines (rofcl.f, rofop.f and rofrr.f) and a series of low level subroutines have to be transferred from the DDS. The subroutines have to be compiled on the target platform and linked together with the application program.
- An orbit file covering a period which contains the desired epoch has to be transferred and converted into binary format by using the FORTRAN program as2bin.f.
- The application program has to open the orbit file by a call to rofop.f.

- By a call to subroutine rofrr.f the state is found.
- After retrieval of all required states the orbit file is closed by a call to subroutine rofcl.f.

The low level subroutines are only called by top level subroutines and thus remain invisible to the user.

For a description of the top level subroutines, the headers from the source code are given in the following sections. They contain information on the functionality and the calling sequence of the routine. Also the conversion routine as2bin.f, the example program readof.f and the contents of the ASCII file is described.

The software code is compliant with the FORTRAN77 standard [RD-9] with a few minor exceptions (non standard declaration statements REAL*8 and INTEGER*4 and conversion function DFLOAT).

3.1.2.1 Subroutine rofop.f

```
SUBROUTINE ROFOP (IUNIT, FNAME, IORDER, NVARS, IFRAME, IBODY,
     .                         ITSCAL, TBEG, TEND,IF, IER)
C +----------------------+-------------------------+
C |   PROJECT ROS        |  MODULE ROFOP           |
C +----------------------|-------------------------+
C |   FDD                |  V. Companys            |
C +----------------------+-------------------------+------------------+
C |  FUNCTIONAL DESCRIPTION :                                         |
C |  ------------------------                                         |
C |  OPENS AN ORBIT FILE FOR READING AND GIVES RELEVANT INFORMATION.   |
C +-------------------------------------------------------------------+
C |  INPUT DESCRIPTION  :                                             |
C |  --------------------                                             |
C |  IUNIT(3)       I*4       UNIT TO WHERE FILE SHALL BE OPENED      |
C |                           IF IUNIT(1) GREATER THAN 0:             |
C |                             FILE SHALL BE OPENED TO UNIT IUNIT(1) |
C |                           IF IUNIT(1) EQUALS 0:                   |
C |                             FILE SHALL BE OPENED TO A FREE UNIT   |
C |                             BETWEEN IUNIT(2) AND IUNIT(3)         |
C |                           IUNIT(1) LESS THAN 0 IS NOT ALLOWED     |
C |  FNAME          C*132     NAME OF THE FILE TO BE OPENED.          |
C |  IORDER         I*4       ORDER OF INTERPOLATION REQUIRED. THE    |
C |                           NUMBER OF POINTS TO BE TAKEN TO THE LEFT |
C |                           AND TO THE RIGHT IS COMPUTED FROM THIS  |
C |                           ORDER. IN GENERAL, THE ACTUAL ORDER     |
C |                           USED WILL BE GREATER OR EQUAL IORDER.   |
C |                           ONLY IF NOT ENOUGH  POINTS ARE AVAILABLE,|
C |                           THE ORDER MAY BECOME LESS THAN IORDER   |
C |                           (E.G AT START AND END OF INTERVALS)     |
C |                           ORIGINATING SOME DEGRADATION IN THE     |
C |                           QUALITY OF INTERPOLATION                |
C +-------------------------------------------------------------------+
C |  OUTPUT DESCRIPTION  :                                            |
C |  ---------------------                                            |
C |  NVARS          I*4       NUMBER OF VARIABLES STORED IN ORBIT FILE |
C |                           3:  ONLY POSITION IS STORED             |
C |                           6:  POSITION AND VELOCITY ARE STORED    |
C |                           42: POSITION, VELOCITY AND VARIATIONALS |
C |                               ARE STORED                          |
C |  IFRAME         I*4       DEFAULT REFERENCE FRAME ID (FOR INFO)   |
C |                           0: MEAN EQUATOR AND EQUINOX OF J2000.0  |
C |                           1: MEAN ECLIPTIC AND EQUINOX OF J2000.0 |
C |                           2: MEAN EQUATOR AND EQUINOX OF B1950.0  |
C |                           3: MEAN ECLIPTIC AND EQUINOX OF B1950.0 |
C |  IBODY          I*4       DEFAULT REFERENCE BODY ID (FOR INFO)    |
C |                           0: BARY-CENTRE OF THE SOLAR SYSTEM      |
C |                           1: MERCURY                              |
C |                           2: VENUS                                |
C |                           3: EARTH                                |
C |                           4: MARS                                 |
C |                           5: JUPITER                              |
C |                           6: SATURN                               |
C |                           7: URANUS                               |
C |                           8: NEPTUNE                              |
C |                           9: PLUTO                                |
C |                           10: MOON                                |
C |                           11: SUN                                 |
C |  ITSCAL         I*4       TIME SCALE ID                           |
C |                           0 : TDB (BARYCENTRIC DYNAMICAL TIME)    |
C |                               IN MJD2000 FORMAT                   |
C |  TBEG           R*8       EARLIEST TIME IN THE ORBIT FILE         |
C |  TEND           R*8       LATEST TIME IN THE ORBIT FILE           |
C |                           ATTENTION: ORBIT FILE MAY HAVE GAPS     |
```

```
C |  IF             I*4       FILE IDENTIFIER TO BE USED IN SUBSEQUENT |
C |                           CALLS TO ORBIT FILE ACCESS SUBROUTINES   |
C |                           0 IF FAILED TO OPEN FILE                 |
C |  IER            I*4       ERROR CODE, NON-ZERO IF ERROR            |
C |                           1 = UNABLE TO OPEN FILE                  |
C |                           2 = UNABLE TO GET ADDITIONAL PARAMETERS  |
C |                           3 = TOO MANY FILES OPEN                  |
C +--------------------------------------------------------------------+
C |  COMMON DESCRIPTION   :                                            |
C |  ----------------------                                            |
C |  SEE INCLUDE FILES                                                 |
C +--------------------------------------------------------------------+
C |  INCLUDE FILES   :                                                 |
C |  -----------------                                                 |
C |  rofsh.inc   TO RESOLVE FORTRAN UNITS AND INTERPOLATION FILE IDS   |
C |  debugf.inc   ERROR PRINTING OPTIONS                               |
C +--------------------------------------------------------------------+
C |  REFERS TO  :                                                      |
C |  ------------                                                      |
C |  RIFOP, RGETHE, RINFO, RIFCL                                       |
C +--------------------------------------------------------------------+
C |  REFERENCES :                                                      |
C |  ------------                                                      |
C |  NONE                                                              |
C +--------------------------------------------------------------------+
C
```

3.1.2.2 Subroutine rofrr.f

```
SUBROUTINE ROFRR (IF, TIME, STATE, IFRAME, IBODY, IER)
C +----------------------+-------------------------+
C |   PROJECT ROS        |  MODULE ROFRR           |
C +----------------------|-------------------------+
C |   FDD                |  V. Companys            |
C +----------------------+-------------------------+------------------+
C |  FUNCTIONAL DESCRIPTION :                                         |
C |  ------------------------                                         |
C |  RETRIEVES STATE FROM ORBIT FILE. THE ORBIT FILE HAS BEEN OPENED  |
C |  WITH SUBROUTINE ROFOP.                                           |
C +-------------------------------------------------------------------+
C |  INPUT DESCRIPTION  :                                             |
C |  --------------------                                             |
C |  IF             I*4       IDENTIFIER FOR ORBIT FILE, AS RETURNED  |
C |                           BY ROFOP                                |
C |  TIME           R*8       TIME TO RETRIEVE THE STATE IN TDB TIME  |
C |                           SCALE AND MJD2000 TIME FORMAT           |
C +-------------------------------------------------------------------+
C |  OUTPUT DESCRIPTION  :                                            |
C |  ---------------------                                            |
C |  STATE(6)       R*8       STATE VECTOR GIVEN IN REFERENCE FRAME   |
C |                           'IFRAME' AND RELATIVE TO REFERENCE BODY |
C |                           'IBODY'.                                |
C |                           STATE(1..3):                            |
C |                           POSITION IN KM                          |
C |                           STATE(4..6):                            |
C |                           VELOCITY IN KM/S                        |
C |  IFRAME         I*4       REFERENCE FRAME ID FOR RETURNED STATE   |
C |                           0: MEAN EQUATOR AND EQUINOX OF J2000.0  |
C |                           1: MEAN ECLIPTIC AND EQUINOX OF J2000.0 |
C |                           2: MEAN EQUATOR AND EQUINOX OF B1950.0  |
C |                           3: MEAN ECLIPTIC AND EQUINOX OF B1950.0 |
C |  IBODY          I*4       REFERENCE BODY ID  FOR RETURNED STATE   |
C |                           0: BARY-CENTRE OF THE SOLAR SYSTEM      |
C |                           1: MERCURY                              |
C |                           2: VENUS                                |
C |                           3: EARTH                                |
C |                           4: MARS                                 |
C |                           5: JUPITER                              |
C |                           6: SATURN                               |
C |                           7: URANUS                               |
C |                           8: NEPTUNE                              |
C |                           9: PLUTO                                |
C |                           10: MOON                                |
C |                           11: SUN                                 |
C |  IER            I*4:      RETURN CODE. ZERO IF OK                 |
C |                           1:  TIME TO EARLY                       |
C |                           2:  TIME TO LATE                        |
C |                           3:  TIME IN A GAP                       |
C |                           4:  ERROR GETTING ADDITIONAL PARAMETERS |
C |                           5:  ERROR CAN'T READ BLOCK HEADER       |
C |                           6:  INVALID IDENTIFIER                  |
C +-------------------------------------------------------------------+
C |  COMMON DESCRIPTION   :                                           |
C |  ---------------------                                            |
C |  SEE INCLUDE FILES                                                |
C +-------------------------------------------------------------------+
C |  INCLUDE FILES   :                                                |
C |  ----------------                                                 |
C |  rofsh.inc debugf.inc                                             |
C +-------------------------------------------------------------------+
C |  REFERS TO  :                                                     |
C |  -----------                                                      |
```

```
C |  RREREC, RGETBL                                                   |
C +------------------------------------------------------------------+
C |  REFERENCES :                                                     |
C |  ------------                                                     |
C |  NONE                                                             |
C +------------------------------------------------------------------+
C
```

3.1.2.3 Subroutine rofcl.f

```
SUBROUTINE ROFCL (IF, IER)
C +----------------------+-------------------------+
C |   PROJECT ROS        |  MODULE ROFCL           |
C +----------------------|-------------------------+
C |   FDD                |  V. Companys            |
C +----------------------+-------------------------+------------------+
C |  FUNCTIONAL DESCRIPTION :                                         |
C |  ------------------------                                         |
C |  CLOSES AN ORBIT FILE PREVIOUSLY OPEN FOR READING WITH ROFOP. THE |
C |  TOTAL NUMBER OF ORBIT FILES IS LIMITED, BECAUSE OF CONSTANT      |
C |  LENGTH OF FORTRAN ARRAYS. USING THIS SUBROUTINE, FREES MEMORY    |
C |  USED BY THE CURRENT ORBIT FILE.                                  |
C +-------------------------------------------------------------------+
C |  INPUT DESCRIPTION  :                                             |
C |  --------------------                                             |
C |  IF             I*4       IDENTIFIER FOR ORBIT FILE, AS RETURNED  |
C |                           BY ROFOP                                |
C +-------------------------------------------------------------------+
C |  OUTPUT DESCRIPTION  :                                            |
C |  ---------------------                                            |
C |  IER            I*4       ERROR CODE, NON-ZERO IF ERROR           |
C |                           1 = NOT ABLE TO CLOSE FILE              |
C |                           2 = INVALID IDENTIFIER                  |
C +-------------------------------------------------------------------+
C |  COMMON DESCRIPTION   :                                           |
C |  ----------------------                                           |
C |  SEE INCLUDE FILES                                                |
C +-------------------------------------------------------------------+
C |  INCLUDE FILES   :                                                |
C |  -----------------                                                |
C |  rofsh.inc debugf.inc                                             |
C +-------------------------------------------------------------------+
C |  REFERS TO  :                                                     |
C |  ------------                                                     |
C |  RIFCL                                                            |
C +-------------------------------------------------------------------+
C |  REFERENCES :                                                     |
C |  ------------                                                     |
C |  NONE                                                             |
C +-------------------------------------------------------------------+
```

3.1.2.4 Conversion Program as2bin.f

```
PROGRAM AS2BIN
C
CP  The program transforms ASCII versions of orbit or attitude files
CP  into binary versions.
C
CC  PROJ=GEN,SUBJ=AUX,UTIL=GEN,AUTH=G.PICKL TOS-G/FDD/IMSS
CC  07/12/2000
C
C
CV  The user is prompted to give the name of the ASCII version of the
CV  interpolation file to be transformed and the name of the target
CV  binary version of the file.
C
C   COMMON blocks used
CB  (only via called functions)
C
C   SUBROUTINES called
CS  WOFOP   opens a new binary orbit file
CS  WAFOP   opens a new binary attitude file
CS  WOFNB   creates a new block in binary orbit file
CS  WAFNB   creates a new block in binary attitude file
CS  WOFNR   writes a new record to a block in orbit file
CS  WAFNR   writes a new record to a block in attitude file
CS  WOFCL   closes binary orbit file
CS  WAFCL   closes binary attitude file
C
```

3.1.3 Example Program readof.f

```
PROGRAM READOF
C +----------------------+-------------------------+
C |   PROJECT ROS        |  MODULE READOF          |
C +----------------------|-------------------------+
C |   FDD                |  M. LAUER / G. PICKL    |
C +----------------------+-------------------------+------------------+
C |  FUNCTIONAL DESCRIPTION :                                         |
C |  ------------------------                                         |
C |  SAMPLE PROGRAM TO DEMONSTRATE THE USAGE OF ORBIT FILE ACCESS.    |
C |                                                                   |
C |  THIS IS AN INTERACTIVE PROGRAM.                                  |
C |  FIRST THE USER IS PROMPTED TO GIVE THE NAME OF THE ORBIT FILE AND |
C |  THE UNIT NUMBER WHICH IS TO BE USED FOR OPENING.                 |
C |  THEN THE USER IS PROMPTED IN A LOOP TO GIVE THE EPOCH FOR WHICH  |
C |  THE STATE IS REQUESTED. THE LOOP ENDS WHEN THE USER GIVES 0 AS   |
C |  EPOCH.                                                           |
C +-------------------------------------------------------------------+
C
```

3.1.4 Remarks

The formats are abbreviated. I*4 means INTEGER, R*8 means DOUBLE PRECISION, C*n means CHARACTER*n and (m) means array of length m.

The TDB time scale is the barycentric dynamical time.

The time format used for the orbit files is MJD2000 which is a continous time format used at ESOC. The time in this format is given in days since the reference epoch 2000 January 1. (Note that the reference epoch is **not** J2000.0 =

January 1, 2000 12h but January 1, 2000 0h!).

The reference frame J2000 is the mean earth equator frame of equinox J2000.0 (= 2000 January 1, 12h TDB = JD 2451545.0 TDB).

All epochs refer to the TDB time scale in MJD2000 format. (Detailed information on time scales and reference frames is given [RD-1])

The design of the software allows the user to access several (up to 8) orbit files at the same time. For this he has to call rofop.f with every file he wants to open as input in the calling sequence. Of course for each call a new unit has to be provided. From the calls to rofop.f the user gets for every orbit file a corresponding internal identifier which he can use to retrieve an orbit state from the respective orbit file.

3.1.5 ASCII version of orbit file

Orbit data are available in a ASCII file to allow the transfer between computer systems even when they are not binary compatible. After retrieval of the ASCII file, the conversion routine as2bin.f creates a corresponding FORTRAN binary direct access file which is required for the usage with the access software.

Although content and structure of the ASCII file is completey transparent to the user (only the conversion with as2bin.f is required to create a valid binary orbit file), a short description follows.

The ASCII version is designed similar to the Ephemeris Message (EPM) as defined in the CCSDS draft recommendation on orbit data messages (see [RD-11]), but contains more information (e.g. derivative of orbital states). It contains one or more blocks of data. Each block has a leading descriptive part, called meta data, consisting of a list of keyword value pairs surrounded by the identifying META_START and META_STOP keywords and the orbital data part proper. The following keywords appear in the meta data:

- CREATION_DATE — Date and time of file creation
- OBJECT_NAME — Identification of object (ROSETTA or MARS EXPRESS)
- TIME_SYSTEM — always TDB, i.e. barycentric dynamical time
- REF_FRAME — reference frame, always ‘EME 2000’ = mean Earth equator of J2000
- CENTER_NAME — identification of central body, e.g. SUN, EARTH, MARS
- START_TIME — start of time interval covered by the following block of data

- STOP_TIME — end of time interval covered by the following block of data
- FILE_TYPE — always ‘ORBIT FILE’
- VERSION_NUMBER — indicates the version of the file format
- VARIABLES_NUMBER — always 6
- DERIVATIVES_FLAG — either 0, when only states (position and velocity) are provided in the orbit file, or 1, when state and state derivative are provided

The orbital data proper are just lines providing at discrete time steps the epoch of the state, the state (position in km, velocity in km/s) and, if applicable, the state derivative (w.r.t time scale in days).

An example of the beginning of an ASCII orbit file is given on the next page. The dots at the end of each line in the data part indicate that the line is not completely displayed.

```
META_START
CREATION_DATE    = 2001-11-29T17:46:54
OBJECT_NAME      = MARS EXPRESS
TIME_SYSTEM      = TDB
REF_FRAME        = EME 2000
CENTER_NAME      = MARS
START_TIME       = 2004-01-07T01:32:05.98763521
STOP_TIME        = 2004-02-02T06:54:18.37968542
FILE_TYPE        = ORBIT FILE
VERSION_NUMBER   = 1.0
VARIABLES_NUMBER = 6
DERIVATIVES_FLAG = 1
META_STOP

2004-01-07T01:32:05.98763521, -0.19019092511143964D+03, -0.28018919435166326D+04, -0.23626369196080709D+04,  0.21802865477078974D+01, ...
                               0.18837675772196255D+06, -0.21625313829995826D+06,  0.24047491261359141D+06,  0.14476749104555944D+02, ...
2004-01-07T01:32:24.70741453, -0.14934916643297422D+03, -0.28483177463181560D+04, -0.23101770566857936D+04,  0.21830893147441532D+01, ...
                               0.18861891679389504D+06, -0.21228701194045902D+06,  0.24376320238851756D+06,  0.11393553693577617D+02, ...
2004-01-07T01:32:43.43025469, -0.10845451034937221D+03, -0.28938847330634471D+04, -0.22570042043943240D+04,  0.21852234783543074D+01, ...
                               0.18880330852981238D+06, -0.20825733305949951D+06,  0.24697572451046793D+06,  0.83027654371988699D+01, ...
2004-01-07T01:33:02.16134620, -0.67508125219888356D+02, -0.29385914957645095D+04, -0.22031198258102545D+04,  0.21866881596867218D+01, ...
                               0.18892985699693297D+06, -0.20416652345468398D+06,  0.25011061940409706D+06,  0.52097351372552039D+01, ...
2004-01-07T01:33:20.90588509, -0.26511166632081849D+02, -0.29824364209899295D+04, -0.21485252135576802D+04,  0.21874830826301936D+01, ...
                               0.18899853833924895D+06, -0.20001705776433428D+06,  0.25316609896974996D+06,  0.21198132633545272D+01, ...
2004-01-07T01:33:39.66907533,  0.14535218249952914D+02, -0.30254176849861155D+04, -0.20932214954417022D+04,  0.21876085737769806D+01, ...
                               0.18900938077433134D+06, -0.19581145998030229D+06,  0.25614044904103369D+06, -0.96166875411458330D+00, ...
2004-01-07T01:33:58.45613123,  0.55629886323953485D+02, -0.30675332489478624D+04, -0.20372096402118568D+04,  0.21870655611091161D+01, ...
                               0.18896246447982785D+06, -0.19155229985116282D+06,  0.25903203168975751D+06, -0.40294171562519931D+01, ...
2004-01-07T01:34:17.27227977,  0.96771694177537299D+02, -0.31087808544406034D+04, -0.19804904634505885D+04,  0.21858555714040997D+01, ...
                               0.18885792136931443D+06, -0.18724218918636034D+06,  0.26183928736988371D+06, -0.70781942985826687D+01, ...
2004-01-07T01:34:36.12276301,  0.13795949370758274D+03, -0.31491580189750634D+04, -0.19230646335837469D+04,  0.21839807263622943D+01, ...
                               0.18869593475770243D+06, -0.18288377807268835D+06,  0.26456073689268186D+06, -0.10102836790604442D+02, ...
2004-01-07T01:34:55.01284047,  0.17919212773152205D+03, -0.31886620317340139D+04, -0.18649326780116394D+04,  0.21814437374649094D+01, ...
                               0.18847673891696837D+06, -0.17847975101519123D+06,  0.26719498322596261D+06, -0.13098273219652954D+02, ...
2004-01-07T01:35:13.94779150,  0.22046842559034539D+03, -0.32272899494503135D+04, -0.18060949893604627D+04,  0.21782478995781980D+01, ...
                               0.18820061852355651D+06, -0.17403282301517544D+06,  0.26974071311106178D+06, -0.16059541349864599D+02, ...
```

...

<u>Example of orbit file ASCII version</u>

3.2 Attitude Data Access

3.2.1 Representation of Attitude Data

The attitude of the S/C refers always to the attitude of the S/C frame (i.e. S/C mechanical frame for Rosetta as defined in [RD-12] section 7.2 and S/C reference frame for Mars Express as defined in [RD-13] section 1.2) with respect to the J2000 frame. So, if u_i, v_i, w_i, i=1,2,3, are the components of the three orthogonal unit vectors $\vec{u}$, $\vec{v}$ and $\vec{w}$ in the J2000 inertial frame defining the S/C frame, the rows of the S/C attitude matrix $A_{S/C}$ are given by the transposition of the three unit vectors:

$$A_{\mathbf{S/C}} = \begin{bmatrix} u_1 & u_2 & u_3 \\ v_1 & v_2 & v_3 \\ w_1 & w_2 & w_3 \end{bmatrix}$$

This attitude matrix $A_{S/C}$ is represented in the form of four quaternions q_i, i=1,4:

$$A_{\mathbf{S/C}} = \begin{bmatrix} q_1^2 - q_2^2 - q_3^2 + q_4^2 & 2(q_1q_2 + q_3q_4) & 2(q_1q_3 - q_2q_4) \\ 2(q_1q_2 - q_3q_4) & -q_1^2 + q_2^2 - q_3^2 + q_4^2 & 2(q_2q_3 + q_1q_4) \\ 2(q_1q_3 + q_2q_4) & 2(q_2q_3 - q_1q_4) & -q_1^2 - q_2^2 + q_3^2 + q_4^2 \end{bmatrix}$$

The attitude of a payload instrument can be derived by applying the rotation between the instrument frame and the S/C frame. So, if x_i, y_i, z_i, i=1,2,3, are the components of the three orthogonal unit vectors $\vec{x}$, $\vec{y}$ and $\vec{z}$ in the S/C frame defining the payload instrument frame, the rows of the payload instrument attitude matrix A_I with respect to the S/C is:

$$A_{\mathbf{I}} = \begin{bmatrix} x_1 & x_2 & x_3 \\ y_1 & y_2 & y_3 \\ z_1 & z_2 & z_3 \end{bmatrix}$$

This matrix is constant apart from possible improvements due to calibration procedures.

The attitude matrix $A_{I/J2000}$ of the payload instrument with respect to the J2000 inertial frame is then given by multiplication:

$$A_{\mathbf{I/J2000}} = A_I A_{\mathbf{S/C}}$$

Additionally three components of the angular rate vector expressed in the S/C mechanical frame are given. Thus the quaternion vector $\vec{q}$ and the angular rate vector $\vec{\omega} = \begin{bmatrix}\omega_1 & \omega_2 & \omega_3\end{bmatrix}^t$ are coupled by the kinematic relation:

$$\frac{d}{dt}\begin{bmatrix}q_1\\q_2\\q_3\\q_4\end{bmatrix} = \frac{1}{2}\begin{bmatrix}0 & \omega_3 & -\omega_2 & \omega_1\\ -\omega_3 & 0 & \omega_1 & \omega_2\\ \omega_2 & -\omega_1 & 0 & \omega_3\\ -\omega_1 & -\omega_2 & -\omega_3 & 0\end{bmatrix}\begin{bmatrix}q_1\\q_2\\q_3\\q_4\end{bmatrix}$$

3.2.2 Attitude Data Storage

The storage of attitude data follows the same lines as for the orbit data (see 3.1.1). In fact the same low level architecture is used. Instead of storing discrete states, discrete quaternions are stored. Attitudes for arbitrary epochs are derived by interpolation. A simple FORTRAN access subroutine is provided (see below) which allows to retrieve attitude and angular rates from the attitude file.

3.2.3 Software Description

To access an attitude at a certain epoch from a FORTRAN application program the following steps are necessary:

- In addition to the subroutines mentioned in 3.1.2 the FORTRAN subroutines rafcl.f, rafop.f, rafrr.f have to be transferred from the DDS. The subroutines have to be compiled on the target platform and linked together with the application program.
- An attitude file covering a period which contains the desired epoch has to be transferred and converted into binary format by using the FORTRAN program as2bin.f.

- The application program has to open the attitude file by a call to rafop.f. The subroutine returns a file identifier 'IF' to be used subsequently in calls of subroutine rafrr.f.
- Call subroutine rafrr.f with the identifier 'IF' of the attitude file to be used and the time for which the attitude is needed. The subroutine returns in the first 4 elements of the array 'STATE' the attitude quaternion. The first 3 elements contain the vector part, the last element the scalar part. Using the formula above, the quaternion can be converted to an attitude matrix by the user application.
  The quaternions returned by the subroutine do **not** follow a specific rule concerning the sign of the elements (quaternions q and -q, i.e. with all entries multiplied with -1, represent the same attitude)! It may therefore happen, that, after retrieval of a quaternion q1 at time t1, a quaternion q2 at time t2 close to t1 is returned by the subroutine that is 'closer' (w.r.t. to the elements of the vector and scalar part) to -q1 than to q1.
- After retrieval of all required attitudes the attitude file is closed by a call to subroutine rafcl.f.

For a description of the additional three attitude related subroutines, the headers from the source code are given in the following sections. An example program and the contents of the ASCII version of the attitude file is also described.

3.2.3.1 Subroutine rafop.f

```
SUBROUTINE RAFOP (IUNIT, FNAME, IORDER,NVARS, IFRAME,
     .                          ITSCAL, TBEG, TEND,IF, IER)
C +----------------------+-------------------------+
C |   PROJECT ROS        |  MODULE RAFOP           |
C +----------------------|-------------------------+
C |   FDD                |  V. Companys            |
C +----------------------+-------------------------+------------------+
C |  FUNCTIONAL DESCRIPTION :                                         |
C |  ------------------------                                         |
C |  OPENS AN ATTITUDE FILE FOR READING. AND GIVES RELEVANT           |
C |  INFORMATION.                                                     |
C +-------------------------------------------------------------------+
C |  INPUT DESCRIPTION  :                                             |
C |  --------------------                                             |
C |  IUNIT(3)       I*4       UNIT TO WHERE FILE SHALL BE OPENED      |
C |                           IF IUNIT(1) GREATER THAN 0:             |
C |                             FILE SHALL BE OPENED TO UNIT IUNIT(1) |
C |                           IF IUNIT(1) EQUALS 0:                   |
C |                             FILE SHALL BE OPENED TO A FREE UNIT   |
C |                             BETWEEN IUNIT(2) AND IUNIT(3)         |
C |                           IUNIT(1) LESS THAN 0 IS NOT ALLOWED     |
C |  FNAME          C*132     NAME OF THE FILE TO BE OPENED.          |
C |  IORDER         I*4       ORDER OF INTERPOLATION REQUIRED. THE    |
C |                           NUMBER OF POINTS TO BE TAKEN TO THE LEFT |
C |                           AND TO THE RIGHT IS COMPUTED FROM THIS  |
C |                           ORDER. IN GENERAL, THE ACTUAL ORDER     |
C |                           USED WILL BE .GE. IORDER. ONLY IF NOT   |
C |                           ENOUGH POINTS ARE AVAILABLE, THE ORDER  |
C |                           MAY BECOME .LT. IORDER (START           |
C |                           AND END OF INTERVALS) ORIGINATING SOME  |
C |                           DEGRADATION OF THE QUALITY OF           |
C |                           INTERPOLATION                           |
C +-------------------------------------------------------------------+
C |  OUTPUT DESCRIPTION  :                                            |
C |  ---------------------                                            |
C |  NVARS          I*4       NUMBER OF VARIABLES                     |
C |  IFRAME         I*4       DEFAULT REFERENCE FRAME                 |
C |                           0: MEAN EQUATOR AND EQUINOX OF J2000.0  |
C |  ITSCAL         I*4       TIME SCALE ID                           |
C |                           0: TDB (BARYCENTRIC DYNAMICAL TIME)     |
C |                               IN MJD2000 FORMAT                   |
C |  TBEG           R*8       EARLIEST TIME IN THE ATTITUDE FILE      |
C |  TEND           R*8       LATEST TIME IN THE ATTITUDE FILE        |
C |                           ATTENTION: ATTITUDE FILE MAY HAVE GAPS  |
C |  IF             I*4       FILE IDENTIFIER TO BE USED IN SUBSEQUENT |
C |                           CALLS OF ATTITUDE FILE ACCESS SUBROUTINES|
C |                           0 IF FAILED TO OPEN FILE                |
C |  IER            I*4       ERROR CODE, NON-ZERO IF ERROR           |
C |                           1 = FAILED OPENING FILE                 |
C |                           2 = UNABLE TO GET ADDITIONAL PARAMETERS |
C +-------------------------------------------------------------------+
C |  COMMON DESCRIPTION   :                                           |
C |  ----------------------                                           |
C |  SEE INCLUDE FILES                                                |
C +-------------------------------------------------------------------+
C |  INCLUDE FILES   :                                                |
C |  -----------------                                                |
C |  rafsh.inc   TO RESOLVE FORTRAN UNITS AND INTERPOLATION FILE IDS  |
C |  debugf.inc   ERROR PRINTING OPTIONS                              |
C +-------------------------------------------------------------------+
C |  REFERS TO  :                                                     |
C |  ------------                                                     |
C |  RIFOP, RGETHE, RINFO                                             |
```

```
C +----------------------------------------------------------------------+
C |  REFERENCES :                                                        |
C |  ------------                                                        |
C |  NONE                                                                |
C +----------------------------------------------------------------------+
C
```

3.2.3.2 Subroutine rafrr.f

```
SUBROUTINE RAFRR (IF, TIME, STATE, IFRAME,IER)
C +----------------------+-------------------------+
C |   PROJECT ROS        |  MODULE RAFRR           |
C +----------------------|-------------------------+
C |   FDD                |  V. Companys            |
C +----------------------+-------------------------+
C |   MODIFIED BY U. HERFORT TO CALCULATE ANGULAR   |
C |   RATES FROM DERIVATIVES OF QUATERNIONS IF THEY |
C |   ARE NOT INCLUDED IN THE FILE.                 |
C +----------------------+-------------------------+-------------------+
C |  FUNCTIONAL DESCRIPTION :                                          |
C |  ------------------------                                          |
C |  RETRIEVES ATTITUDE QUATERNION AND RATES FROM ATTITUDE FILE.       |
C |  THE ATTITUDE FILE HAS BEEN OPENED WITH SUBROUTINE RAFOP           |
C +--------------------------------------------------------------------+
C |  INPUT DESCRIPTION  :                                              |
C |  --------------------                                              |
C |  IF              I*4       IDENTIFIER FOR ATTITUDE FILE, AS        |
C |                            RETURNED BY RAFOP                       |
C |  TIME            R*8       TIME TO RETRIEVE DATA IN                |
C |                            TDB TIME SCALE AND MJD2000 TIME FORMAT  |
C +--------------------------------------------------------------------+
C |  OUTPUT DESCRIPTION  :                                             |
C |  ---------------------                                             |
C |  STATE(7)        R*8       STATE(1..4):                            |
C |                            ATTITUDE QUATERNION SPECIFYING THE      |
C |                            ROTATION FROM 'IFRAME' TO S/C MECHANICAL |
C |                            FRAME.                                  |
C |                            SCALAR COMPONENT OF QUATERNION          |
C |                            IS STATE(4).                            |
C |                            UNIT: NONE                              |
C |                            STATE(5..7):                            |
C |                            ANGULAR RATE OF S/C MECHANICAL FRAME    |
C |                            W.R.T. 'IFRAME' EXPRESSED IN S/C FRAME. |
C |                            UNIT: 1/S                               |
C |  IFRAME          I*4       REFERENCE FRAME ID FOR RETURNED DATA    |
C |                            0: J2000                                |
C |  IER             I*4:      RETURN CODE.                            |
C |                            0:  OK                                  |
C |                            2:  TIME TO EARLY                       |
C |                            3:  TIME TO LATE                        |
C |                            4:  TIME IN A GAP                       |
C |                            5:  ERROR GETTING ADDITIONAL PARAMETERS |
C |                            6:  INVALID IDENTIFIER                  |
C +--------------------------------------------------------------------+
C |  COMMON DESCRIPTION   :                                            |
C |  ----------------------                                            |
C |  SEE INCLUDE FILES                                                 |
C +--------------------------------------------------------------------+
C |  INCLUDE FILES   :                                                 |
C |  -----------------                                                 |
C |  rafsh.inc debugf.inc                                              |
C +--------------------------------------------------------------------+
C |  REFERS TO  :                                                      |
C |  ------------                                                      |
C |  RREREC, RGETBL                                                    |
C +--------------------------------------------------------------------+
C |  REFERENCES :                                                      |
C |  ------------                                                      |
C |  NONE                                                              |
C +--------------------------------------------------------------------+
C
```

3.2.3.3 Subroutine rafcl.f

```
SUBROUTINE RAFCL (IF, IER)
C +---------------------+-------------------------+
C |   PROJECT ROS        |  MODULE RAFCL           |
C +---------------------|-------------------------+
C |   FDD                |  V. Companys            |
C +---------------------+-------------------------+------------------+
C |  FUNCTIONAL DESCRIPTION :                                        |
C |  -----------------------                                         |
C |  CLOSES AN ATTITUDE FILE PREVIOUSLY OPEN FOR READING WITH RAFOP. |
C |  THE TOTAL NUMBER OF ORBIT FILES IS LIMITED, BECAUSE OF CONSTANT |
C |  LENGTH OF FORTRAN ARRAYS. USING THIS SUBROUTINE, FREES MEMORY   |
C |  USED BY THE CURRENT ATTITUDE FILE.                              |
C +------------------------------------------------------------------+
C |  INPUT DESCRIPTION  :                                            |
C |  --------------------                                            |
C |  IF             I*4       IDENTIFIER FOR ATTITUDE FILE, AS       |
C |                           RETURNED BY RAFOP                      |
C +------------------------------------------------------------------+
C |  OUTPUT DESCRIPTION  :                                           |
C |  ---------------------                                           |
C |  IER            I*4       ERROR CODE, NON-ZERO IF ERROR          |
C |                           1 = NOT ABLE TO CLOSE FILE             |
C |                           2 = INVALID IDENTIFIER                 |
C +------------------------------------------------------------------+
C |  COMMON DESCRIPTION   :                                          |
C |  ----------------------                                          |
C |  SEE INCLUDE FILES                                               |
C +------------------------------------------------------------------+
C |  INCLUDE FILES   :                                               |
C |  -----------------                                               |
C |  rafsh.inc debugf.inc                                            |
C +------------------------------------------------------------------+
C |  REFERS TO  :                                                    |
C |  ------------                                                    |
C |  RIFCL                                                           |
C +------------------------------------------------------------------+
C |  REFERENCES :                                                    |
C |  ------------                                                    |
C |  NONE                                                            |
C +------------------------------------------------------------------+
```

3.2.4 Example Program readaf.f

```
PROGRAM READAF
C +---------------------+-------------------------+
C |   PROJECT ROS        |  MODULE READAF          |
C +---------------------|-------------------------+
C |   FDD                |  M. LAUER / G. PICKL    |
C +---------------------+-------------------------+------------------+
C |  FUNCTIONAL DESCRIPTION :                                        |
C |  -----------------------                                         |
C |  SAMPLE PROGRAM TO DEMONSTRATE THE USAGE OF ATTITUDE FILE ACCESS. |
C |                                                                  |
C |  THIS IS AN INTERACTIVE PROGRAM.                                 |
C |  FIRST THE USER IS PROMPTED TO GIVE THE NAME OF THE ATTITUDE FILE |
C |  AND THE UNIT NUMBER WHICH IS TO BE USED FOR OPENING.            |
C |  THEN THE USER IS PROMPTED IN A LOOP TO GIVE THE EPOCH FOR WHICH |
C |  ATTITUDE DATA IS REQUESTED. THE LOOP ENDS WHEN THE USER GIVES 0 |
C |  AS EPOCH.                                                       |
C +------------------------------------------------------------------+
C
```

3.2.5 ASCII version of attitude file

Attitude files are delivered via the DDS in ASCII version to allow the transfer of data between computer systems even when they are not binary compatible. After retrieval of the ASCII file, the conversion routine as2bin.f creates a corresponding binary direct access file which is required for the usage with the access software.

Although content and structure of the ASCII version is completey transparent to the user (only the conversion with as2bin.f is required to create a valid binary attitude file), a short description follows.

The ASCII version is designed similar to the orbital data exchange format EPM as defined in the CCSDS draft recommendation on orbit data messages (see [RD-11]). It contains one or more blocks of data. Each block has a leading descriptive part, called meta data, consisting of a list of keyword value pairs surrounded by the identifying META_START and META_STOP keywords and the attitude data part proper. The following keywords appear in the meta data:

- CREATION_DATE — Date and time of file creation
- OBJECT_NAME — Identification of object (ROSETTA or MARS EXPRESS)
- TIME_SYSTEM — always TDB, i.e. barycentric dynamical time
- REF_FRAME — reference frame, always ‘EME 2000’ = mean Earth equator of J2000
- START_TIME — start of time interval covered by the following block of data
- STOP_TIME — end of time interval covered by the following block of data
- FILE_TYPE — always ‘ATTITUDE FILE’
- VERSION_NUMBER — indicates the version of the file format
- VARIABLES_NUMBER — always 4
- DERIVATIVES_FLAG — always 0

The attitude data proper are just lines providing at discrete time steps the epoch of the state and the quaternion describing the rotation from the inertial to the S/C frame. An example of the beginning of an ASCII version is given on the next page.

```
ESOC_TOS_GFI_ATTITUDE_FILE_VERSION = 1.0

META_START
CREATION_DATE    = 2001-11-29T15:44:28
OBJECT_NAME      = MARS EXPRESS
TIME_SYSTEM      = TDB
REF_FRAME        = EME 2000
START_TIME       = 2004-01-11T00:00:00.00000000
STOP_TIME        = 2004-01-11T03:13:48.10351191
FILE_TYPE        = ATTITUDE FILE
VERSION_NUMBER   = 1.0
VARIABLES_NUMBER = 4
DERIVATIVES_FLAG = 0
META_STOP

2004-01-11T00:00:00.00000000,  0.14828983393822739D+00, -0.54000782193788777D+00, -0.82309351863136038D+00,  0.94439064922933399D-01,
2004-01-11T00:18:06.63636364,  0.14834690207759446D+00, -0.54000099319000583D+00, -0.82308337480966509D+00,  0.94476886642819988D-01,
2004-01-11T00:36:13.27272726,  0.14840340037022212D+00, -0.53999423218229614D+00, -0.82307329889358871D+00,  0.94514573568488455D-01,
2004-01-11T00:54:19.90909090,  0.14845933000893116D+00, -0.53998753845722680D+00, -0.82306329629684083D+00,  0.94552080533339397D-01,
2004-01-11T01:12:26.54545455,  0.14851468517555574D+00, -0.53998091239058976D+00, -0.82305337369812093D+00,  0.94589357673964147D-01,
2004-01-11T01:30:33.18181819,  0.14856945280451131D+00, -0.53997435518857817D+00, -0.82304353952575837D+00,  0.94626346632208563D-01,
2004-01-11T01:48:39.81818181,  0.14862361204318170D+00, -0.53996786890950454D+00, -0.82303380464650777D+00,  0.94662975326470764D-01,
2004-01-11T02:06:46.45454545,  0.14867713355014017D+00, -0.53996145648040783D+00, -0.82302418340339345D+00,  0.94699149985878334D-01,
2004-01-11T02:24:53.09090909,  0.14872997912402425D+00, -0.53995512162344650D+00, -0.82301469525540305D+00,  0.94734741969524347D-01,
2004-01-11T02:42:59.72727273,  0.14878210340360012D+00, -0.53994886842446843D+00, -0.82300536747476927D+00,  0.94769564215821056D-01,
2004-01-11T03:01:06.36363636,  0.14883346404884809D+00, -0.53994269962636121D+00, -0.82299623968098179D+00,  0.94803325734814287D-01,
2004-01-11T03:13:48.10351191,  0.14886901263418945D+00, -0.53993842332797215D+00, -0.82298999098695225D+00,  0.94826108360557410D-01,

META_START
OBJECT_NAME      = MARS EXPRESS
TIME_SYSTEM      = TDB
REF_FRAME        = EME 2000
START_TIME       = 2004-01-11T03:13:48.10351191
STOP_TIME        = 2004-01-11T03:16:20.77349478
META_STOP

2004-01-11T03:13:48.10351191,  0.14886901263421237D+00, -0.53993842332829312D+00, -0.82298999098669090D+00,  0.94826108360506450D-01,
2004-01-11T03:13:58.10351191,  0.14893762842444741D+00, -0.53792563371586744D+00, -0.82410180610624251D+00,  0.96487349445991077D-01,
2004-01-11T03:14:08.10351191,  0.14913166317986656D+00, -0.53185039956854208D+00, -0.82740958701300493D+00,  0.10143113345988961D+00,
2004-01-11T03:14:18.10351191,  0.14941777503723799D+00, -0.52160387536951403D+00, -0.83282956027483412D+00,  0.10953834595634665D+00,
2004-01-11T03:14:28.10351191,  0.14973812106675027D+00, -0.50701164621945638D+00, -0.84022117706768062D+00,  0.12060704500250891D+00,
2004-01-11T03:14:38.10351191,  0.15000701267521863D+00, -0.48784440114756067D+00, -0.84938590750064358D+00,  0.13434774488819307D+00,
2004-01-11T03:14:48.10351191,  0.15010636826867035D+00, -0.46383321561519042D+00, -0.86006591961605106D+00,  0.15037765862075111D+00,
2004-01-11T03:14:58.10351191,  0.14988012641404436D+00, -0.43468970037821475D+00, -0.87194300524216761D+00,  0.16821476659456883D+00,
2004-01-11T03:15:08.10351191,  0.14912786838489528D+00, -0.40013122719753769D+00, -0.88463820834161966D+00,  0.18727284969930644D+00,
2004-01-11T03:15:18.10351191,  0.14759801128066921D+00, -0.35991130284934425D+00, -0.89771269204554938D+00,  0.20685889801410973D+00,
2004-01-11T03:15:28.10351191,  0.14498107422892553D+00, -0.31385491060060516D+00, -0.91067043963141248D+00,  0.22617456441616723D+00,
2004-01-11T03:15:38.10351191,  0.14090368982177501D+00, -0.26189825468571154D+00, -0.92296341086694123D+00,  0.24432354898382011D+00,
2004-01-11T03:15:48.10351191,  0.13492422591449874D+00, -0.20413181623431609D+00, -0.93399975426502957D+00,  0.26032693655309130D+00,
```

Example of attitude file ASCII format

3.2.6 Remarks

The same remarks from section 3.1.4 apply here accordingly.

3.3 Utilities

Subroutines and functions for converting time formats and time scales are provided. For a description of the subroutines, the headers from the source code are given in the following sections. They contain information on the functionality and the calling sequence of the routine (input variables are described in lines starting with 'CI', output variables in lines starting with 'CO').

3.3.1 Time Format Conversion

The following subroutines allow to convert a date between the MJD2000 and the calender date time formats.

3.3.1.1 Subroutine jd2000.f

```
SUBROUTINE JD2000(DAY,JEAR,MONTH,KDAY,JHR,MI,SEC)
CP GIVES THE NEW MOD. JULIAN DAY (MJD=0.0 ON 2000/JAN/1 AT 0:00:00)
CP FOR INPUT CALENDAR DATES BETWEEN 1950/JAN/1 AND 2099/DEC/31.
C
C   MJD(2000) = MJD(1950) - 18262.0
C
CI  (INT*4) JEAR = YEAR WITH 2 OR 4 DIGITS; 2 DIGITS => 1950 TO 2049
CI  (INT*4) MONTH = MONTH
CI  (INT*4) KDAY = DAY
CI  (INT*4) JHR = HOUR
CI  (INT*4) MI = MINUTE
CI  (REAL*8) SEC = SECOND.
CO  (REAL*8) DAY = MOD. JUL. DAY, REFERRED TO 2000.
```

3.3.1.2 Subroutine dj2000.f

```
SUBROUTINE DJ2000(DAY,I,J,K,JHR,MI,SEC)
CP  COMPUTES CALENDER DATE FROM MODIFIED JULIAN DAY 2000
C   VALID FOR DATES BETWEEN 1950/JAN/1 AND 2099/DEC/31.
C   MJD(2000) = MJD(1950) - 18262.0 IS = 0 ON 2000/01/01 AT 00:00:00.
C
CI  (REAL*8) DAY = MOD. JULIAN DAY, REFERRED TO 2000 (MAY BE NEGATIVE).
CO  (INTEGERS): I=YEAR, J=MONTH, K=DAY, JHR=HOUR, MI=MINUTE
CO  (REAL*8): SEC=SECOND.
```

3.3.2 Time Scale Conversion

The following FORTRAN functions allow to convert between the TDB and the UTC time scale. Please note that the function TAIUTC contains the list of leap seconds from January 1, 1972, in a DATA statement. As soon as a new leap second is announced, the DATA statement in the function will be updated and a new version will be available via the DDS.

3.3.2.1 Function TDBUTC

```
DOUBLE PRECISION FUNCTION TDBUTC (DAY,KEY)
C
CP  CONVERTS BARYCENTRIC DYNAMICAL TIME (TDB) TO UTC OR VICE VERSA
C
CC  PROJ=GEN,SUBJ=TIM,UTIL=GEN,AUTH=T.A.MORLEY TOS-G/FDD/IMSS
CC  00/06/29
C
CN  VALID FOR THE SPAN OF VALIDITY OF ORBIT LIBRARY FUNCTION TAIUTC,
CN  I.E. FROM 1972 JAN 1 UNTIL CURRENT TIME. (TAIUTC MUST BE
CN  UPDATED WHEN A LEAP SECOND IS INSERTED).
C
C   CALLING SEQUENCE:
C   INPUT:
CI  DAY = MJD2000 IN TDB (KEY=1) OR UTC (KEY=2)                    R*8
CI  KEY .LE. 1 TO CONVERT TDB INTO UTC                             I*4
CI      .GE. 2 TO CONVERT UTC INTO TDB
C
CO  OUTPUT:
CO  TDBUTC = MJD2000 IN UTC (KEY=1) OR TDB (KEY=2)                 R*8
C
C   SUBPROGRAMS CALLED:
CS  TDBTDT: CONVERTS BARYCENTRIC DYNAMICAL TIME (TDB) TO TERRESTRIAL
CS          DYNAMICAL TIME (TDT) OR VICE VERSA (DOUBLE PRECISION
CS          FUNCTION).
CS  TDTUTC: CONVERTS TERRESTRIAL DYNAMICAL TIME (TDT) TO UTC OR
CS          VICE VERSA (DOUBLE PRECISION FUNCTION) (USES TAIUTC
CS          FROM THE ORBIT LIBRARY).
C
```

3.3.2.2 Function TDBTDT

```
DOUBLE PRECISION FUNCTION TDBTDT (DAY,KEY)
C
CP  CONVERTS BARYCENTRIC DYNAMICAL TIME (TDB) TO TERRESTRIAL
CP             DYNAMICAL TIME (TDT) OR VICE VERSA
C
CC  PROJ=GEN,SUBJ=TIM,UTIL=GEN,AUTH=T.A.MORLEY TOS-G/FDD/IMSS
CC  00/06/29
C
CR  REF(1) "EXPLANATORY SUPPLEMENT TO THE ASTRONOMICAL ALMANAC",
CR         P. SEIDELMANN (ED.), UNIVERSITY SCIENCE BOOKS, 1992.
CR  REF(2) "AMFIN - MATHEMATICAL DESCRIPTION OF THE AMFIN SUBROUTINES",
CR         PRE-DRAFT, 2000/03/23.
C
CN  ONLY THE MAIN ANNUAL TERM, WITH AMPLITUDE 1.66 MILLISECONDS,
CN  IS RETAINED. ALL NEGLECTED TERMS HAVE AMPLITUDES LESS THAN
CN  21 MICROSECONDS.
C
C   CALLING SEQUENCE:
C   INPUT:
CI  DAY = MJD2000 IN TDB (KEY=1) OR TDT (KEY=2)                      R*8
CI  KEY .LE. 1 TO CONVERT TDB INTO TDT                               I*4
CI      .GE. 2 TO CONVERT TDT INTO TDB
C
CO  OUTPUT:
CO  TDBTDT = MJD2000 IN TDT (KEY=1) OR TDB (KEY=2)                   R*8
C
C   DATA STATEMENT: VARIABLES FOR COMPUTING TIME DIFFERENCE
CV  COF = COEFFICIENT OF MAIN TERM (SECONDS)                         R*8
CV  ECC = MEAN ECCENTRICITY OF ORBIT OF EARTH-MOON BARYCENTRE        R*8
CV  RME = MEAN MEAN ANOMALY OF ORBIT OF EARTH-MOON BARYCENTRE        R*8
CV        AT 2000/01/01 00:00:00 TDB.
CV  RMD = MEAN MOTION OF THE ORBIT OF THE EARTH-MOON BARYCENTRE      R*8
CV        WITH RESPECT TO DYNAMICAL TIME.
C
```

3.3.2.3 Function TDTUTC

```
DOUBLE PRECISION FUNCTION TDTUTC (DAY,KEY)
C
CP  CONVERTS TERRESTRIAL DYNAMICAL TIME (TDT) TO UTC OR VICE VERSA
C
CC  PROJ=GEN,SUBJ=TIM,UTIL=GEN,AUTH=T.A.MORLEY TOS-G/FDD/IMSS
CC  00/06/29
C
CN  FUNCTION IS DERIVED FROM ETUTC OF THE ORBIT LIBRARY.
CN  VALID FOR THE SPAN OF VALIDITY OF ORBIT LIBRARY FUNCTION TAIUTC,
CN  I.E. FROM 1972 JAN 1 UNTIL CURRENT TIME. (TAIUTC MUST BE
CN  UPDATED WHEN A LEAP SECOND IS INSERTED).
C
C   CALLING SEQUENCE:
C   INPUT:
CI  DAY = MJD2000 IN TDT (KEY=1) OR UTC (KEY=2)                      R*8
CI  KEY .LE. 1 TO CONVERT TDT INTO UTC                               I*4
CI      .GE. 2 TO CONVERT UTC INTO TDT
C
CO  OUTPUT:
CO  TDTUTC = MJD2000 IN UTC (KEY=1) OR TDT (KEY=2)                   R*8
C
C   SUBPROGRAMS CALLED:
CS  TAIUTC: CONVERTS ATOMIC TIME (TAI) TO UTC OR VICE VERSA
CS          (DOUBLE PRECISION FUNCTION).
C
```

3.3.2.4 Function TAIUTC

```
DOUBLE PRECISION FUNCTION TAIUTC(DAY,KEY)
CP   CONVERTS ATOMIC TIME (TAI) TO UTC OR VICE VERSA.
C
CI  DAY = TAI (KEY=1) OR UTC (KEY=2) EXPRESSED AS MJD2000.
CI  KEY = 1 TO CONVERT TAI INTO UTC
CI      = 2 TO CONVERT UTC INTO TAI
C
CO  TAIUTC = UTC (KEY=1) OR TAI (KEY=2) EXPRESSED AS MJD2000.
C
C  LEAPSECONDS ARE REGISTERED FROM 1972 JAN 1 TO 1999 JAN 1.
C
```

3.4 Software Summary

The orbit and attitude data access software is delivered in the form of FORTRAN source code. Each software release is archived together in one tar file. This archive contains (current status)

- the ‘readme’ file
- the conversion routine ‘as2bin.f’ source code file
- the sample routine ‘readof.f’ source code file
- the sample routine ‘readaf.f’ source code file
- the file ‘OASWlib’ containing all source code of the orbit and attitude access software subroutines and functions, including utilities.

The archive is available in the DDS under the ADID ‘OASW’ (= orbit and attitude data access software). The filename is
OASW_FDSRMS_DT______________vvvvv.ROS for Rosetta and
OASW_FDSMMS_DT______________vvvvv.MEX for Mars Express
where ‘T’ in the free field indicates that the file is a tar file.

The ‘readme’ file contains information on the installation and on the release changes of the software. During the long mission duration, software updates due to enhancements, improvements or bug fixes have to be expected. With each new release, the version number in the file (indicated by vvvvv in the filename) increases by one. The readme file contains a summary of the updates and how the user is affected by them.