Software Interface Specification

Small Forces File

for
MErcury Surface Space ENvironment GEochemistry and Ranging
(MESSENGER)

Version 1.3

Version for PDS Archive June 2015

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List of Acronyms

MESSENGER	MErcury Surface, Space ENvironment, GEochemistry and Ranging spacecraft
EME2000	Earth Mean Equator and Equinox of J2000 coordinate frame
GC	Guidance & Control subsystem (aka attitude control or ACS)
delta-V	Change in velocity
DSN	Deep Space Network
EME2000	Earth-Mean-Equator and Equinox of J2000 coordinate frame
ET	Ephemeris Time
JHU/APL	Johns Hopkins University/Applied Physics Laboratory
Kinetx	Kinetx Corp
MIRAGE	Orbit determination software developed at JPL and licensed to Kinetx
ODP	Orbit Determination Program
SIS	Software Interface Specification
SFF	Small Forces File
TCM	Trajectory Correction Maneuver

Change History

Version	Date	Reason
1.0	2003-09	First draft, for review
1.1	2008-06	Redacted and abridged for use with the Radio Science PDS data archive. Mike Reid, JHU/APL.
1.2	2009-09	Changed document custodian from Robin Vaughan to Dan O'Shaughnessy.
1.3	2015-06	Removed **Custodian** field from the title page. This document is derived from a more extensive mission document. No changes to the content of this document have been made since version 1.1, June 2008.

1. General Description

1.1 Purpose

The Small Forces File (SFF) provides the following information:
-an estimate of the cumulative delta-V effect of thruster firing
-an estimate of the cumulative spacecraft mass loss due to the use of propellant (fuel and oxidizer) while firing thrusters
-an estimate cumulative on-times for each individual thruster
The file provides the accumulated value of these quantities since a specified start time which is normally set to the time of MESSENGER launch. The intent is for each file to present the running history of thruster firing events since the start of the mission. For generality, the capability to specify a start time (or T0) other than launch is provided.

1.2. Scope

This Software Interface Specification (SIS) is applicable for the MESSENGER spacecraft. It covers both "predict" and "reconstruction" situations.

There are two planned activities where the propulsion system will be used for MESSENGER: trajectory correction maneuvers (TCMs) which intentionally impart a delta-V to alter the spacecraft's trajectory and commanded momentum dumps where thrusters are used to maintain spacecraft attitude while off-loading momentum from the reaction wheels. Momentum dumps do not intentionally impart a significant delta-V to the spacecraft, but a small residual delta-V will always be incurred whenever thrusters are fired since they are not perfectly balanced. The MESSENGER G&C system also has the capability to use thrusters autonomously to lower system momentum or for attitude control when 1 or more reaction wheels have failed or are otherwise unavailable. For either commanded or autonomous thruster use, the system should be configured to record appropriate telemetry from which the desired SFF information can be computed. The exception is mass flow rate during thruster firing. This is estimated by ground models maintained by the propulsion system engineers.

The MESSENGER propulsion system has 16 monopropellant thrusters, 12 4.4N thrusters designated A1-4, B1-4, S1 & 2, and P1 & 2 and 4 22N thrusters designated C1-4. There is also the LVA bi-propellant main engine which is used for very large delta-Vs, primarily Mercury Orbit Insertion (MOI). The location of each thruster is shown in Figure 1. There are two main fuel tanks and one oxidizer tank, all of the same size and one smaller auxiliary fuel tank. Mass flow rate depends on how many thruster of which type are firing and which set of fuel and/or oxidizer tanks are being used. There are 3 main propulsion system modes:

4.4N mono-prop thrusters are firing using the auxiliary tank. This mode is used for commanded and autonomous momentum dumps, TCMs with small delta-V targets, and for attitude control if too many wheels have failed.
22N mono-prop thrusters are firing using the main fuel tanks. This mode is used for TCMs with intermediate delta-V targets.
LVA bi-prop main engine is firing using fuel and oxidizer from the main fuel tanks. This mode is used for TCMs with large delta-V targets such as MOI and the DSMs.

Method of Generation

The SFF will be created either from simulations (predict mode) or from spacecraft telemetered data (reconstruction mode). Any SFF can contain a mixture of predicted or reconstructed data.

2.1 Predict Mode

From a specification standpoint, the predict record need only contain valid data for the first 10 fields. Thruster on-times are not mandatory. But, in order to provide the change in mass, some first-order estimate of the on-times will be needed.

2.2 Reconstruction Mode

An SFF may be produced in "reconstruction" mode by a set of scripts and programs that obtain data packets returned from the spacecraft and post-process and/or reformat this data into an SFF. This process includes some computations of derived parameters.

3. Detailed Data Object Definition

3.1 General Structure

An SFF consists of two sections–header and data–separated by an end of header character flag on a line by itself:

<header>
$$EOH
<data>

where

<header> is a set of KEYWORD=VALUE assignments

$$EOH is end-of-header delimiter, on a line by itself

<data> is one or more small forces data records

There is no special end of file marker inserted at the end of the data section.

3.2 Header Section Structure

The header section consists of the following KEYWORD=VALUE assignments, each on a line by itself. Any amount of white space, including none, can appear on each side of the "=" symbol.

MISSION_NAME = <character string>
SPACECRAFT_NAME = <character string>
DSN_SPACECRAFT_ID = <positive integer>
PRODUCTION_TIME = YYYY-MM-DD HR:MN:SC[.XXX]
PRODUCER_ID = <character string>
FILE_TYPE = SFF
START_TIME = YYYY-MM-DD HR:MN:SC[.XXX]

where

MISSION_NAME	name of the mission (MESSENGER)
SPACECRAFT_NAME	name of the spacecraft (MSGR)
DSN_SPACECRAFT_ID	DSN ID for the spacecraft: (MESSENGER=236)
PRODUCTION_TIME	file production date and time, taken from the local computer clock
PRODUCER_ID	name/organization of the producer; example: JHU/APL
FILE_TYPE	always set to SFF to indicate that this is a small forces file

START_TIME	the "T0" time to which the deltaV and thruster on-time entries in all subsequent data records are referenced. Nominally this is set to the time of MESSENGER launch and not changed throughout the mission. The intent is for each SFF file to give a running history of constantly increasing accumulated deltaV and thruster on-times since the start of the mission. For flexibility and possible special applications, the software maintains the capability to change the start time to which all other records in a particular SFF are referenced. Note that while this is presented in a character string date/time format, it represents ET (ephemeris time) – not UTC or GMT.

3.3 Data Section Structure

The data section of an SFF consists of one or more data records, each record occupying a single line:

<data record 1>
<data record 2>
...
<data record N>

Data Record Structure

Each SFF data record consists of the following 31 items given in the order shown:

INDEX, RECTYPE, GENTIM, TIME, MET,
DMASS, DVX, DVY, DVZ,
ESTQUAT1, ESTQUAT2, ESTQUAT3, ESTQUAT4,
PROP_MODE,
THRA1_TIME, THRA2_TIME, THRA2_TIME, THRA4_TIME,
THRB1_TIME, THRB2_TIME, THRB3_TIME, THRB4_TIME,
THRS1_TIME, THRS2_TIME, THRP1_TIME, THRP2_TIME,
THRC1_TIME, THRC2_TIME, THRC3_TIME, THRC4_TIME,
THRLVA_TIME

The first 8 items are required and will always be present for each record. The last 23 items are optional and may not all be present in a single record. Missing items are indicated by two consecutive commas separated by any amount of white space (blanks). The last item, item 31, is missing if there is nothing in the record following the last comma.

A short description of each data item is given in the table below; more detailed explanations for some items are provided in the text sections following the table/

INDEX	Index of the record in the file (1...N)
RECTYPE	Type of the record, one character string: P = predicted, R = reconstructed, I = Intermediate
GENTIM	Record generation time; format: YYYY-MM-DD HR:MN:SC[.XXX]; taken from the local computer clock (implies UTC for TMOD computers)
TIME	Time tag for the record; format YYYY-MM-DD HR:MN:SC.XXX Given in a date/time character string format, but in the ET time frame (not UTC or GMT)
MET	Time tag given as spacecraft MET; if spacecraft attitude quaternion data is present, it

is the estimated attitude at MET-1 second?

MASS	Total mass decrement since the start time given in the header record (usually set to launch), given in kg. This is computed from estimated mass flow rate (parameter updated after each major maneuver) and either predicted or reconstructed thruster on times.
DVX	Accumulated delta-V in EME2000 frame X direction since the start time given in the header record (usually set to launch), given in m/sec.
DVY	Accumulated delta-V in EME2000 frame Y direction since the start time given in the header record (usually set to launch), given in m/sec
DVZ	Accumulated delta-V in EME2000 frame Z direction since the start time given in the header record (usually set to launch), given in m/sec.
ESTQUAT1	First element of the vector part of the quaternion giving estimated spacecraft attitude at TIME or MET –1 second.
ESTQUAT2	Second element of the vector part of the quaternion giving estimated spacecraft attitude at TIME or MET – 1 second.
ESTQUAT3	Third element of the vector part of the quaternion giving the estimated spacecraft attitude at TIME or MET –1 second.
ESTQUAT4	Scalar element of the quaternion giving the estimated spacecraft attitude at TIME or MET – 1 second.
PROP_MODE	Propulsion system operational mode given as one of the following integer codes: Mode 1 commanded event – TCM with small delta-V or momentum dump using 4.4N mono-prop thrusters and auxiliary fuel tank Mode 2 autonomous event – autonomous momentum dump or attitude control using 4.4N mono-prop thrusters and auxiliary fuel tank Mode 3 commanded TCM – intermediate delta-V using 22N mono-prop thrusters and main fuel tanks Mode 4 commanded TCM – large delta-V using LVA 660N main engine and main fuel and oxidizer tanks
THRA1_TIME	Cumulative on-time for thruster 0 (A1) since the start time given in the header record, given in seconds
THRA2_TIME	Cumulative on-time for thruster 1 (A2) since the start time given in the header record, given in seconds.
THRA3_TIME	Cumulative on-time for thruster 2 (A3) since the start time given in the header record, given in seconds.
THRA4_TIME	Cumulative on-time for thruster 3 (A4) since the start time given in the header record, given in seconds.
THRB1_TIME	Cumulative on-time for thruster 4 (B1) since the start time given in the header record, given in seconds.
THRB2_TIME	Cumulative on-time for thruster 5 (B2) since the start time given in the

	header record, given in seconds.
THRB3_TIME	Cumulative on-time for thruster 6 (B3) since the start time given in the header record, given in seconds.
THRB4_TIME	Cumulative on-time for thruster 7 (B4) since the start time given in the header record, given in seconds.
THRS1_TIME	Cumulative on-time for thruster 8 (S1) since the start time given in the header record, given in seconds.
THRS2_TIME	Cumulative on-time for thruster 9 (S2) since the start time given in the header record, given in seconds.
THRP1_TIME	Cumulative on-time for thruster 10 (P1) since the start time given in the header record, given in seconds.
THRP2_TIME	Cumulative on-time for thruster 11 (P2) since the start time given in the header record, given in seconds.
THRC1_TIME	Cumulative on-time for thruster 12 (C1) since the start time given in the header record, given in seconds.
THRC2_TIME	Cumulative on-time for thruster 13 (C2) since the start time given in the header record, given in seconds.
THRC3_TIME	Cumulative on-time for thruster 14 (C3) since the start time given in the header record, given in seconds.
THRC4_TIME	Cumulative on-time for thruster 15 (C4 since the start time given in the header record, given in seconds.
THRLVA_TIME	Cumulative on-time for thruster 16 (LVA) since the start time given in the header record, given in seconds.

RECTYPE - an intermediate record is a record that was generated based solely on the available telemetry at the time the record was generated. These records will eventually be manually edited once the analysis is complete and marked 'R' (reconstructed). A record marked 'I' is subject to change, while a record marked 'R' should be considered final.

EST_QUAT1,2,3,4:
Spacecraft attitude is provided in the form of a quaternion specifying the orientation of the spacecraft body frame relative to the EME2000 inertial reference frame. The MESSENGER s/c body frame is shown in Figure 2. The quaternion specifies an axis of rotation and the angle of rotation about that axis that is needed to transform from EME2000 to the s/c body frame. The first 3 elements represent the rotation axis as a unit vector, $\left[i_x \ i_y \ i_z\right]^T$, multiplied by the cosine of ½ of the rotation angle, ϕ. The fourth element represents the sine of ½ of the rotation angle. The quaternion is always unitized so that the sum of the squares of its four elements equals 1.

THRXX_TIME (XX = A1,A2, … LVA):
The MESSENGER G&C software tracks thruster on-times as a running count of 0.02 sec cycles that the thruster was commanded on by the software (control task runs at 50 Hz).

DVX,Y,Z:

The MESSENGER G&C software computes accumulated delta-V from accelerometer data. This is provided in the inertial reference frame (EME2000) in units of m/sec. It uses a constant s/c mass value to convert sensed acceleration to delta-V.

MASS:
This field shall now report the current spacecraft mass (at MET), instead of the delta mass. For intermediate records, there will be no ground modeling of mass flow rate to provide an estimated change in mass. Therefore, intermediate records will report the predicted mass. For autonomous momentum dumps, the intermediate record will report no change in mass.

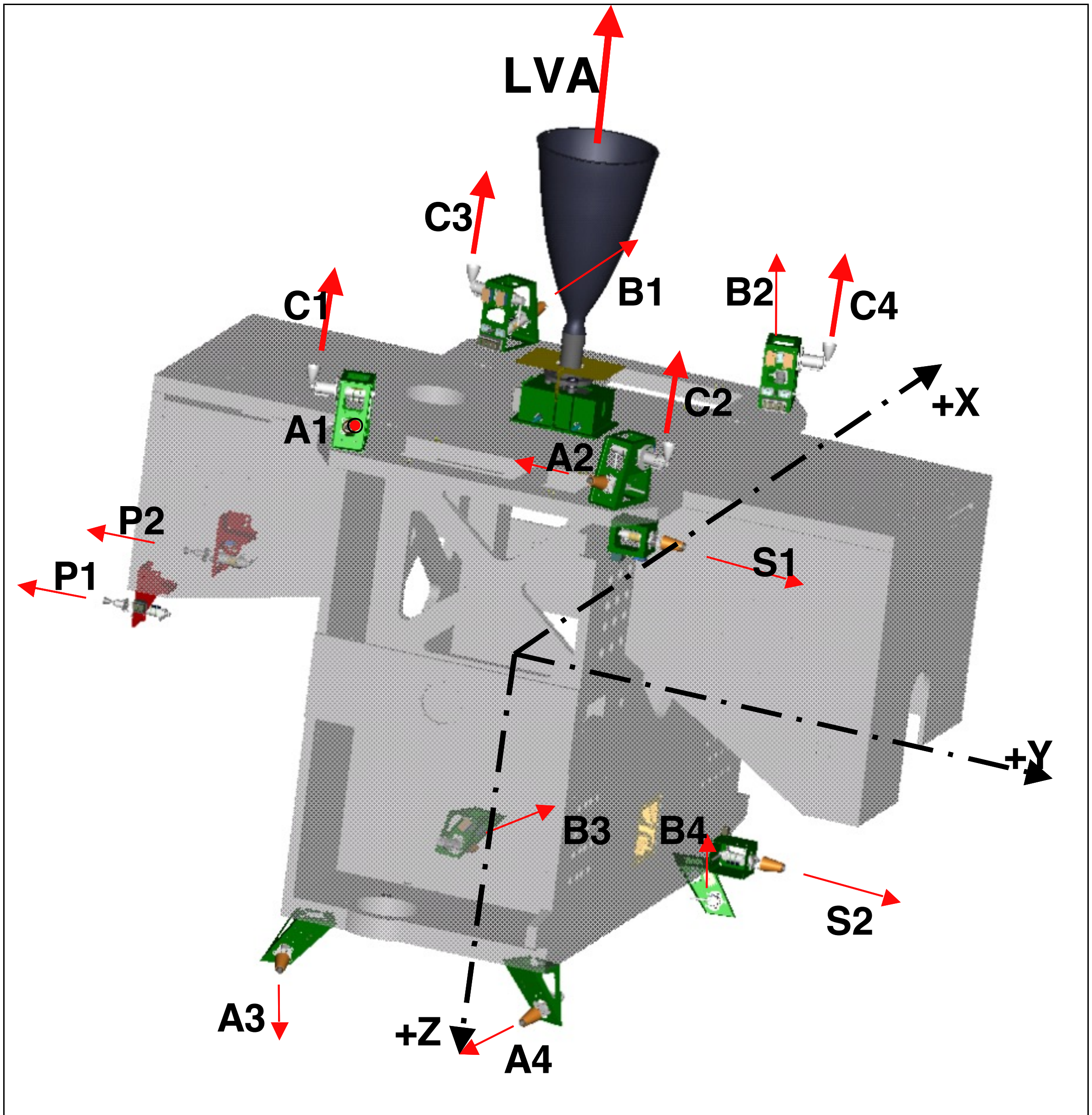

Figure 1 Thruster Locations and Thrust Directions

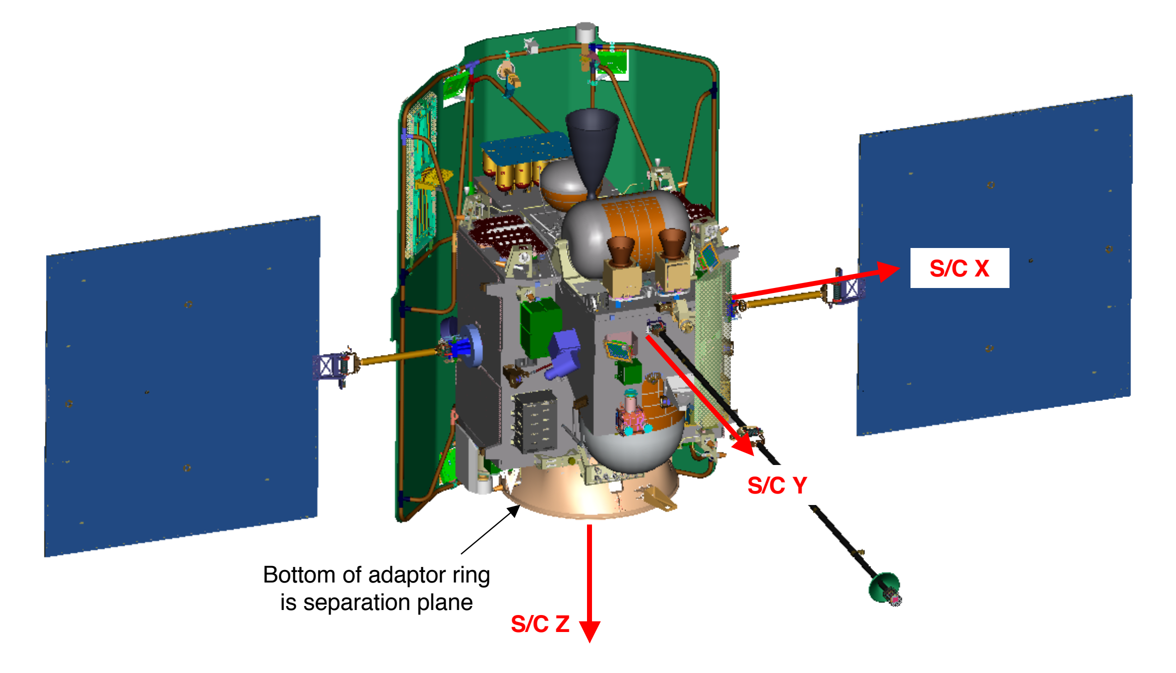

Figure 2 MESSENGER Spacecraft Body Coordinate Frame