Ground Segment

User Manual

Abstract:

The ground segment produces reference trajectories, Jupiter ephemeris and a performance criterion of the host trajectory.

The tool is fulfilling a number of specifications and its architecture has been designed so that its development can be effective in the next steps of the project.

In order to produce a reference trajectory, the tool uses a Runge-Kutta 4 numerical integration. Moreover, to guess a good approximation of the velocity at the moment of jettisoning from the host mission (especially apart form the Earth sphere of influence), the tool uses the resolution of the Lambert's problem.

The tool uses different reference frames that lead to creat some frame conversion functions.

Software requirements : Scilab V5.4.1 and its module Celestlab V3.0.0

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Applicability			Latest Confidence Levels		
STM	**PFM**	**FM1**			
X	X	X	**CL 2**	**Date** : 24-sep-2014	1
			CL 3	**Date** : dd-mmm-yyyy	<Version-Nb>
			CL 4	**Date** : dd-mmm-yyyy	<Version-Nb>

Checked By	Function	Internal Review to CL=3
Florent DELEFLIE	Technical Expert	**Date** : dd-mmm-yyyy

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I. - Introduction

I.1. - Context & Purpose

This part of the ground segment has to produce a reference trajectory and planets' ephemeris thanks to a host trajectory from a host mission available for BIRDY. These data will be stored in the memory of BIRDY and for the moment will be used by the Navigation part and the Navigation Test Bench.

Moreover, a performance criterion is needed to inform the projet team if a host mission available for BIRDY fit with the BIRDY mission needs : it has to give the GO/NOGO decision.

I.2. - List of abbreviations

TBD **T**o **B**e **D**etermined

EOD (mean equinox mean) **E**cliptic **O**f **D**ate

EME2000 **E**arth **M**ean **E**quator and Equinox at epoch J**2000**

ICRS **I**nternational **C**elestial **R**eference **S**ystem

BCF **B**ody **C**entered (body) **F**ixed

ECF **E**arth **C**entered (earth) **F**ixed

cjd modified julian date from 1950.0

TT **T**errestrial **T**ime

UTC **C**oordinated **U**niversal **T**ime

I.3. - Internal reference documents

[1] EME-001, "System Analysis", 21-Aug-2014 version 1.10

[2] EME-005, "Requirements Specification", 21-Aug-2014 version 1.2

I.4. - External reference documents

[3] "Rapport de stage : Méthode de calcul de trajectoire pour un libre retour Terre-Mars-Terre du CubeSat BIRDY", Audrey PORQUET, 09-Sep-2014

II. - The Ground Segment environment

II.1. - Ground Segment requirements

- BIRDY has to be jettisoned from the host mission once in interplanetary trajectory (reference trajectory start)

- The reference trajectory shall be able to make a Mars Flyby

- The reference trajectory shall be able to return to the Earth (or to be put on a disposal orbit)

- The DeltaV budget at the beginning of the mission will be TBD m/s (the upper limit of DeltaV will be 30m/s)

- The Ground Segment shall be able to produce data to be stored in the memory of the CubeSat

- The Ground Segment shall be able to produce a trade-off between the date of jettisoning and the required DeltaV (to give the performance criterion GO/NOGO).

II.2. - Software requirements

We use the Scilab software version 5.4.1 and its application/module Celestlab version 3.0.0 which is a CNES Space mechanics toolbox for mission analysis.

First the user has to install Scilab. Then, to install Celestlab on it, the user can go in the Scilab software then Applications/Gestionnaire de modules – ATOMS/Aerospace/Celestlab. Or the user can just execute in the Scilab software : --> atomsInstall("celestlab") . (checked only on PC linux and windows platform)

II.3. - Interfaces and format

II.3.a. Input file

The input file is the host trajectory. Its name has to be written in the subprogram "conf_file.sce" for the value of **Host_traj** (see section IV.2.a).

The format of the host trajectory has to be made up of 7 columns separated by a tabulation and the reference frame has to be the heliocentric ecliptic J2000:

- the first column is the date (in Julian Day UTC)

- the second column is the position of the CubeSat along the X axis (in km)

- the third column is the position of the CubeSat along the Y axis (in km)

- the fourth column is the postion of the CubeSat along the Z axis (in km)

- the fifth column is the velocity of the CubeSat along the X axis (in km/s)

- the sixth column is the velocity of the CubeSat along the Y axis (in km/s)

- the seventh column is the velocity of the CubeSat along the Z axis (in km/s)

II.3.b. Output files

The reference trajectory:

The reference trajectory will be useful for the Navigation software (made by Oussema Sleimi) and the Navigation Test Bench (made by Sébastien Durand). The format was checked with them.

The format of the reference trajectory is then 8 columns of real double separated by a tabulation and the reference frame is the heliocentric ecliptic J2000 (in Celestlab: `'%.17f\t%.17f\t%.17f\t%.17f\t%.17f\t%.17f\t%.17f\t%.17f\n'`):

- the first column is the date (in Julian Day TT)

- the second column is the position of the CubeSat along the X axis (in km)

- the third column is the position of the CubeSat along the Y axis (in km)

- the fourth column is the postion of the CubeSat along the Z axis (in km)

- the fifth column is the velocity of the CubeSat along the X axis (in m/s)

- the sixth column is the velocity of the CubeSat along the Y axis (in m/s)

- the seventh column is the velocity of the CubeSat along the Z axis (in m/s)

- the eighth column is the radii of the CubeSat from the Sun (in km)

The ephemeris:

The ephemeris will be useful for the Navigation software. The format was cheked with Oussema.

The format of the ephemeris is then 4 columns of real double separated by a tabulation and the reference frame is the CubeSat-centered ecliptic J2000 (in Celestlab: `'%.17f\t%.17f\t%.17f\t%.17f\n'`):

- the first column is the date (in Julian Day TT)

- the second column is the latitude of the planet (in degree)

- the third column is the longitude of the planet (in degree)

- the fourth column is the radii of the planet from the CubeSat (in km)

Trajectory with more information (used for the trajectory analysis):

An other file with more information that is useful for trajectory analysis is generated. The format of this file is then 12 columns of real double separated by a tabulation and the reference frame is the CubeSat-centered ecliptic J2000 (in Celestlab: `'%.17f\t%.17f\t%.17f\t%.17f%.17f\t%.17f\t%.17f\t%.17f\t%.17f\t%.17f\t%.17f\t%.17f\n'`):

- the first column is the date (in Julian Day TT)

- the second column is the position of the CubeSat along the X axis (in km)

- the third column is the position of the CubeSat along the Y axis (in km)

- the fourth column is the postion of the CubeSat along the Z axis (in km)

- the fifth column is the velocity of the CubeSat along the X axis (in m/s)

- the sixth column is the velocity of the CubeSat along the Y axis (in m/s)

- the seventh column is the velocity of the CubeSat along the Z axis (in m/s)

- the eighth column is the radii of the CubeSat from the Sun (in km)

- the ninth column is the radii of the CubeSat from the Earth (in km)

- the tenth column is the radii of the CubeSat from Mars (in km)

-the eleventh column is the radii of Earth from the Sun (in km)

-the twelfth column is the radii of Mars from the Sun (in km)

Performance criterion:

The last file that is created by the software is the performance criterion. The format of this file is then 3 columns of real double separated by a tabulation and the reference frame is the heliocentric ecliptic J2000 (in Celestlab: `'%.17f\t%.17f\t%.17f\n'`):

- the first column is the date (in Julian Day TT)

- the second column is the minimum of the minima distances Mars-Cubesat (in m)

- the third column is the DeltaV to be applied to have the minimum of the minima distances Mars-Cubesat (in m/s)

III. - Frame

Different frames are used in the program for different reasons.

III.1. - The frame of the planets ephemeris from Celestlab (EOD)

Celestlab uses a function that recovers the ephemeris of the planets at a chosen date. The frame used is then the EOD frame Sun-centered.

III.2. - The frame EME2000

This frame is useful to change the ephemeris of the planets from EOD frame to ECLIPJ2000.

As the ECLIPJ2000 frame is not known in Celestlab, the tool has to creat it from the EME2000 frame.

III.3. - The frame ECLIPJ2000

This frame is useful for the reference trajectory and the planets ephemeris for the navigation function and the navigation test bench.

The tool creats this frame thanks to the frame EME2000 using the matrix transformation Meme2eclip define with the obliquity of the ecliptic (=23°26'21,4096"), as follows:

$$\begin{bmatrix} x_{ecliptique} \\ y_{ecliptique} \\ z_{ecliptique} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\epsilon) & \sin(\epsilon) \\ 0 & -\sin(\epsilon) & \cos(\epsilon) \end{bmatrix} \begin{bmatrix} x_{equatorial\_terrestre} \\ y_{equatorial\_terrestre} \\ z_{equatorial\_terrestre} \end{bmatrix}$$

III.4. - The frame ICRS

This frame is used for the numerical integration and is necessary to use the other frames BCF (Body Centered Fixed) if the acceleration component in J_2 is required.

III.5. - The frame BCF (for the Sun and Mars)

This frame gives the orientation of the north pole (rotation axe) according to the ICRS frame for the Sun, Mars and the other planets except the Earth.

III.6. - The frame ECF (for the Earth)

This frame gives the orientation of the north pole (rotation axe) for the Earth according to the ICRS frame.

IV. - Program

IV.1. - Principle

The main program needs the 5 subprograms to run.

The main program uses the different moments of jettisoning from the host mission.

With one date, position and velocity giving by the host trajectory, the program will estimate the velocity needed to reach Mars (for 10 dates of arrivals to Mars). Then it uses these velocities (and no the initial velocity of the host trajectory), the initial position and date selected to make 10 numerical integrations. This gives 10 minimum distances Mars-CubeSat and so 10 DeltaV to be applied to the initial velocity to reach these distances for one moment of jettisoning. To get a performance criterion, we choose the minimum of these 10 miminum distances Mars-CubeSat, and so the corresponding deltaV and the initial date (moment of jettisoning). The program uses the deltaV chosen and makes a last numerical integration with the initial date and position and the velocity "initial velocity+deltaV chosen". The program generates then one trajectory and so 2 output files that contain information about this trajectory. Then it uses the subprograms "traj_analys" and "ephemeris" to make graphs and Jupiter ephemeris (another output file) according to this trajectory.

The program iterates for different moments of jettisoning from the host mission. At the end of the iteration, the program generates the output file for the performance criterion for the host trajectory.

IV.2. - SubPrograms

IV.2.a. Conf_file.sce

In this subprogram are put some user parameters which can be changed and some constant values.

User parameters:

Host_traj: the name of the host trajectory (input file). Example: 'GL-01_sun_58122.xyzv'

hpas: the step for the numerical integration in seconds. Example: 8000

npas: the total number of dates compute by the numerical integration. Example: 5400

deltaV: velocity vector that we can add directly to the host trajectory. Example: [0;0;0]

Constant values:

muEarth, muSun, muMars: the gravitational constants for the Earth, the Sun and Mars respectively (in m^3s^{-2}).

eqRadEarth, eqRadSun, eqRadMars: the equatorial radii for the Earth, the Sun and Mars respectively (in m).

J2Sun, J2Mars: the J_2 of the Sun and Mars respectively.

Meme2eclip: the transformation matrix from the equatorial coordinates to ecliptic coordinates (see section III.3).

IV.2.b. frame_change.sce

In this subprogram are gathered different functions that make frame changes and that use these frame changes.

Functions that make frame change:

EOD2ICRS: thanks to the position and the velocity in EOD frame and the date (in cjd TT), this function returns the position and velocity in the ICRS frame and the jacobian and the transform matrix from EOD to ICRS.

ICRS2BCFSun: thanks to the position and velocity in the ICRS frame and the date (in cjd TT), this function returns the position and velocity in the BCF frame of the Sun and the jacobian and the transform matrix from ICRS to BCFSun.

ICRS2BCFMars: thanks to the position and velocity in the ICRS frame and the date (in cjd TT), this function returns the position and velocity in the BCF frame of Mars and the jacobian and the transform matrix from ICRS to BCFMars.

ICRS2ECFTerre: thanks to the position and velocity in the ICRS frame and the date (in cjd TT), this function returns the position and velocity in the ECF frame of the Earth and the jacobian and the transform matrix from ICRS to ECFEarth.

Functions which compute the J_2 term of the acceleration:

ACCJ2Sun: thanks to the position and velocity in the ICRS frame and the date (in cjd TT), this function returns the acceleration in J_2 for the Sun. It uses the function "ICRS2BCFSun".

ACCJ2Mars: thanks to the position and velocity in the ICRS frame and the date (in cjd TT), this function returns the acceleration in J_2 for Mars. It uses the function "ICRS2BCFMars".

ACCJ2Terre: thanks to the position and velocity in the ICRS frame and the date (in cjd TT), this function returns the acceleration in J_2 for the Earth. It uses the function "ICRS2ECFTerre".

IV.2.c. Runge_Kutta_4.sce

In this subprogram there are the 2 functions used for the numerical integration.

integrale: thanks to the position and velocity in the EME2000 frame and the date (in cjd UTC) (initial conditions), this function returns the positions and velocities in the ECLIPJ2000 frame, the dates (in cjd TT), the distance Sun-CubeSat, the distance Earth-CubeSat, the distance Mars-CubeSat, the distance Sun-Earth and the distance Sun-Mars. It uses the function "fct" where there is the force model used.

fct: It is the force model function for the numerical integration. Thanks to the date (in cjd TT) and the vector that is composed of the position and the velocity in the ICRS frame, this function returns a vector composed of the velocity and the acceleration. The force model used the contribution of the Sun, the Earth and Mars (keplerian motion + J_2).

IV.2.d. traj_analys.sce

This subprogram uses a file generated by the program (12 columns) which is composed of information about the trajectory. This subprogram makes different graphs:

- a 3D graph of the reference trajectory with the Earth and Mars orbits plus the Sun in the center.

- a graph (in logarithmic scale) of the distance Mars-CubeSat (in km) according to the date (in day after the moment of jettisoned from the host mission (giving in julian day TT)).

- a graph (in logarithmic scale) of the distance Earth-CubeSat (in km) according to the date (in day after the moment of jettisoned from the host mission (giving in julian day TT)).

- a graph (in logarithmic scale) of the distance Sun-CubeSat (in km) according to the date (in day after the moment of jettisoned from the host mission (giving in julian day TT)).

IV.2.e. ephemeris.sce

This subprogram uses a file generated by the program (8 columns) which is composed of information about the trajectory (dates, positions, velocities and distances Sun-CubeSat). This subprogram computes the ephemeris of Jupiter according to the CubeSat in the ECLIPJ2000 frame. It produces an output file for the Jupiter ephemeris composed of 4 columns.

IV.3. - The main Program BIRDY-GSE-006.sce

There are 2 other functions in the program :

arrivals_Mars: thanks to the initial date and position of the CubeSat (=moment and position at the jettisoning), this function returns different velocities needed at this moment of jettisioning to go to Mars at different moments of arrivals : date of jettisoning + [210,220,...,300] days. These velocities are given thanks to the resolutions of Lambert's problem.

DVLambert: thanks to the velocities computing by the function "arrivals_Mars", the position, the velocity and the date (in cjd TT) from the host trajectory (initial conditions) and the deltaV of the subprogram "conf_file.sce", this function returns the date of jettisoning (in Julian Day TT), the minimun of distance Mars-CubeSat, the minimum of the Earth-CubeSat and the DeltaV applied to the host trajectory.