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ANNEXES

Annex A: MATLAB codes of the computations

initSpicev function

```
function  initSPICEv(HOMESPICE,METAKR)

addpath(osi(strcat(HOMESPICE,'/src/mice/')))
addpath(osi(strcat(HOMESPICE,'/lib')))

for i=1:length(METAKR)
    if mod(i,2)==1
        url=METAKR{i};
        continue;
    end
    kfile=osi(sprintf('%s/kernels/%s',HOMESPICE,METAKR{i}));
    if exist(kfile,'file')~=2
        fprintf('downloading %s\n',url);
        websave(kfile,url);
    end
%     fprintf('cspice_furnsh(%s)\n',kfile);
    cspice_furnsh(kfile);
end


end
```

osi function

```
function [ fname ] = osi( fname )
% operating system independent
% given a path name
% changes / to \ or viceversa, only if needed, to suit the operating system
% eg osi('a/b/c') excuted in a windows machine will return 'a\b\c'

if ismac || isunix % to unix
    fname(fname=='\')='/';
else % windows
    fname(fname=='/')='\';
end

end
```

time computation function

```
function [times_sec, dates_plot] = time_computation(dates, STEP)

et = cspice_str2et(dates); % From date to ephemeris time
times_sec = (0:STEP-1) * ( et(2) - et(1) )/STEP + et(1); % Time of each
computation in seconds
times_dates = cspice_etcal(times_sec); % Time of each computation in dates
times_dates = cellstr(times_dates(:,1:11))';
dates_plot = [times_dates(STEP/STEP), times_dates(STEP/10),
times_dates(STEP/10*2), times_dates(STEP/10*3), ...
```

```
              times_dates(STEP/10*4), times_dates(STEP/10*5),
times_dates(STEP/10*6), times_dates(STEP/10*7), ...
              times_dates(STEP/10*8), times_dates(STEP/10*9),
times_dates(STEP)]; % Dates represented in the plots

end
```

Dawn heliocentric trajectory from Earth to Vesta

```
% CLEAN ENV
close all; clear; clc;

% Determination of the Dawn's total trajectory around Vesta, Dawn's range and
% relative velocity during the orbits

HOMESPICE='/Users/Álvaro/Desktop/MASE/2n QUATRI/TFM/SPICE/mice';

METAKR={'https://naif.jpl.nasa.gov/pub/naif/generic_kernels/lsk/naif0012.tls',
'naif0012.tls', ...

'https://naif.jpl.nasa.gov/pub/naif/generic_kernels/pck/pck00010.tpc','pck0001
0.tpc', ...

'https://naif.jpl.nasa.gov/pub/naif/generic_kernels/spk/planets/de432s.bsp','d
e432s.bsp' ,...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_070927-
070930_081218_v1.bsp','dawn_rec_070927-070930_081218_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_070930-
071201_081218_v1.bsp','dawn_rec_070930-071201_081218_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_071201-
080205_081218_v1.bsp','dawn_rec_071201-080205_081218_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_080205-
080325_081218_v1.bsp','dawn_rec_080205-080325_081218_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_080325-
080503_081218_v1.bsp','dawn_rec_080325-080503_081218_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_080503-
080601_081218_v1.bsp','dawn_rec_080503-080601_081218_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_080601-
080718_081218_v1.bsp','dawn_rec_080601-080718_081218_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_080718-
080910_081218_v1.bsp','dawn_rec_080718-080910_081218_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_080910-
081022_090218_v1.bsp','dawn_rec_080910-081022_090218_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_081022-
081109_090218_v1.bsp','dawn_rec_081022-081109_090218_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_081109-
090228_090306_v1.bsp','dawn_rec_081109-090228_090306_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_090228-
090501_090702_v1.bsp','dawn_rec_090228-090501_090702_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_090501-
090801_090916_v1.bsp','dawn_rec_090501-090801_090916_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_090801-
090915_090923_v1.bsp','dawn_rec_090801-090915_090923_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_090915-
091201_091202_v1.bsp','dawn_rec_090915-091201_091202_v1.bsp', ...
```

```
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_091201-
100208_100209_v1.bsp','dawn_rec_091201-100208_100209_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_100208-
100316_100323_v1.bsp','dawn_rec_100208-100316_100323_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_100316-
100413_100422_v1.bsp','dawn_rec_100316-100413_100422_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_100413-
100622_100830_v1.bsp','dawn_rec_100413-100622_100830_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_100622-
100824_100830_v1.bsp','dawn_rec_100622-100824_100830_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_100824-
101130_101202_v1.bsp','dawn_rec_100824-101130_101202_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_101130-
110201_110201_v1.bsp','dawn_rec_101130-110201_110201_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_110201-
110328_110328_v1.bsp','dawn_rec_110201-110328_110328_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_110328-
110419_110420_v1.bsp','dawn_rec_110328-110419_110420_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_110416-
110802_110913_v1.bsp','dawn_rec_110416-110802_110913_v1.bsp'};
%

initSPICEv(HOMESPICE,METAKR);

dates = {'Sep 28, 2007', 'Apr 16, 2011'} ; % Dates selected
STEP = 100000; % Determines the accuracy of the computations

[times_sec, dates_plot] = time_computation(dates, STEP); %From dates to
ephemeris time

[state, ltime]= cspice_spkezr( 'Dawn', times_sec, 'J2000', 'NONE', 'SUN'); %
Dawn's position and velocity computation

x = state(1,:); % Coordinates of the positions
y = state(2,:);
z = state(3,:);
range = sqrt(x.^2+y.^2+z.^2); % Dawn's range

vx = state(4,:); % Components of the velocity
vy = state(5,:);
vz = state(6,:);
v_tot = sqrt(vx.^2+vy.^2+vz.^2); % Dawn's relative velocity

figure(1);
plot3(x,y,z)
hold on
plot(0,0,'r*','MarkerSize',20)
title('Dawn trajectory around the Sun (km)');
xlabel('x (km)')
ylabel('y (km)')
zlabel('z (km)')

figure(2);
plot(range)
set(gca,'xticklabel',dates_plot.')
title('Dawn distance with respect to the Sun');
xlabel('Time (dates)');
```

```
ylabel('Distance (km)');

figure(3);
plot(v_tot)
set(gca,'xticklabel',dates_plot.')
title('Dawn relative velocity with respect to the Sun');
xlabel('Time (dates)');
ylabel('Relative velocity (km/s)');

cspice_kclear
```

Dawn total trajectory around Vesta

```
% CLEAN ENV
close all; clear; clc;

% Determination of the Dawn's total trajectory from Earth to Vesta, Dawn's
% range and relative velocity during the trajectory.

HOMESPICE='/Users/Álvaro/Desktop/MASE/2n QUATRI/TFM/SPICE/mice';

METAKR={'https://naif.jpl.nasa.gov/pub/naif/generic_kernels/lsk/naif0012.tls',
'naif0012.tls', ...

'https://naif.jpl.nasa.gov/pub/naif/generic_kernels/pck/pck00010.tpc','pck0001
0.tpc', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_110416-
110802_110913_v1.bsp','dawn_rec_110416-110802_110913_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_110802-
110831_110922_v1.bsp','dawn_rec_110802-110831_110922_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_110831-
110928_111221_v1.bsp','dawn_rec_110831-110928_111221_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_110928-
111102_111221_v1.bsp','dawn_rec_110928-111102_111221_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_111102-
111210_120618_v1.bsp','dawn_rec_111102-111210_120618_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_111211-
120501_120620_v1.bsp','dawn_rec_111211-120501_120620_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_120501-
120611_120625_v1.bsp','dawn_rec_120501-120611_120625_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_120611-
120724_121101_v1.bsp','dawn_rec_120611-120724_121101_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_120724-
120913_121213_v1.bsp','dawn_rec_120724-120913_121213_v1.bsp'};
%

initSPICEv(HOMESPICE,METAKR);

dates = {'Jul 19, 2011', 'Sep 02, 2012'} ; % Dates selected
STEP = 100000; % Determines the accuracy of the computations

[times_sec, dates_plot] = time_computation(dates, STEP); %From dates to
ephemeris time
```

```
[state, ltime]= cspice_spkezr('Dawn', times_sec, 'J2000', 'NONE', 'VESTA'); %
Dawn's position and velocity computation

x = state(1,:); % Coordinates of the positions
y = state(2,:);
z = state(3,:);
range = sqrt(x.^2+y.^2+z.^2); % Dawn's range

vx = state(4,:); % Components of the velocity
vy = state(5,:);
vz = state(6,:);
v_tot = sqrt(vx.^2+vy.^2+vz.^2); % Dawn's relative velocity

figure(1);
plot3(x,y,z)
title('Dawn trajectory around Vesta (km)');
xlabel('x (km)')
ylabel('y (km)')
zlabel('z (km)')

figure(2);
plot(range)
set(gca,'xticklabel',dates_plot.')
title('Dawn distance with respect to Vesta');
xlabel('Time (dates)');
ylabel('Distance (km)');

figure(3);
plot(v_tot)
set(gca,'xticklabel',dates_plot.')
title('Dawn relative velocity with respect to Vesta');
xlabel('Time (dates)');
ylabel('Relative velocity (km/s)');

cspice_kclear
```

Dawn scientific orbits around Vesta

```
%% CLEAN ENV

close all; clear; clc;

%% Kernels loading

HOMESPICE='/Users/Álvaro/Desktop/MASE/2n QUATRI/TFM/SPICE/mice';

METAKR={'https://naif.jpl.nasa.gov/pub/naif/generic_kernels/lsk/naif0012.tls',
'naif0012.tls', ...

'https://naif.jpl.nasa.gov/pub/naif/generic_kernels/pck/pck00010.tpc','pck0001
0.tpc', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_110416-
110802_110913_v1.bsp','dawn_rec_110416-110802_110913_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_110802-
110831_110922_v1.bsp','dawn_rec_110802-110831_110922_v1.bsp', ...
```

```
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_110831-
110928_111221_v1.bsp','dawn_rec_110831-110928_111221_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_110928-
111102_111221_v1.bsp','dawn_rec_110928-111102_111221_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_111102-
111210_120618_v1.bsp','dawn_rec_111102-111210_120618_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_111211-
120501_120620_v1.bsp','dawn_rec_111211-120501_120620_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_120501-
120611_120625_v1.bsp','dawn_rec_120501-120611_120625_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_120611-
120724_121101_v1.bsp','dawn_rec_120611-120724_121101_v1.bsp', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_120724-
120913_121213_v1.bsp','dawn_rec_120724-120913_121213_v1.bsp'};
%

initSPICEv(HOMESPICE,METAKR);

%% Determination of the Dawn's trajectory around Vesta, Dawn's range and
relative velocity during the orbits

% Scientific orbits around Vesta: 1 --> SURVEY ORBIT
%                                 2 --> HIGH ALTITTUDE MAPPING ORBIT 1
%                                 3 --> LOW ALTITTUDE MAPPING ORBIT
%                                 4 --> HIGH ALTITTUDE MAPPING ORBIT 2

trajectory = 3; % Trajectory type

STEP = 100000; % Number of time steps

[x, y, z, range, vx, vy, vz, v_tot, dates_plot] = trajectory_Vesta(trajectory,
STEP);

figure(1);
plot3(x,y,z)
hold on
plot(0,0,'k*','MarkerSize',20)
title('Dawn trajectory around Vesta (km)');
xlabel('x (km)')
ylabel('y (km)')
zlabel('z (km)')

figure(2);
plot(range)
set(gca,'xticklabel',dates_plot.')
title('Dawn distance with respect to Vesta');
xlabel('Time (dates)');
ylabel('Distance (km)');

figure(3);
plot(v_tot)
set(gca,'xticklabel',dates_plot.')
title('Dawn relative velocity with respect to Vesta');
xlabel('Time (dates)');
ylabel('Relative velocity (km/s)');
```

```
cspice_kclear
```

trajectory Vesta function

```
function [x, y, z, range, vx, vy, vz, v_tot,dates_plot] =
trajectory_Vesta(trajectory, STEP)

% Scientific orbits around Vesta: 1 --> SURVEY ORBIT
%                                 2 --> HIGH ALTITTUDE MAPPING ORBIT 1
%                                 3 --> LOW ALTITTUDE MAPPING ORBIT
%                                 4 --> HIGH ALTITTUDE MAPPING ORBIT 2

    switch trajectory

            case 1 % Survey orbit
                dates = {'Aug 11, 2011', 'Aug 31, 2011'};

            case 2 % First High Altitude Mapping Orbit
                dates = {'Sep 29, 2011', 'Nov 02, 2011'};

            case 3 % Low Altitude Mapping Orbit
                dates = {'Dec 12, 2011', 'May 01, 2012'};

            case 4 % Second High Altitude Mapping Orbit
                dates = {'Jun 15, 2012', 'Jul 25, 2012'};

    end

    [times_sec, dates_plot] = time_computation(dates, STEP);

    [state, ~]= cspice_spkezr('Dawn', times_sec, 'J2000', 'NONE', 'VESTA'); %
Dawn's position and velocity computation

    x = state(1,:); % Coordinates of the positions
    y = state(2,:);
    z = state(3,:);
    range = sqrt(x.^2+y.^2+z.^2); % Dawn's range

    vx = state(4,:); % Components of the velocity
    vy = state(5,:);
    vz = state(6,:);
    v_tot = sqrt(vx.^2+vy.^2+vz.^2); % Dawn's relative velocity

end
```

Dawn escape trajectory from Vesta

```
%% CLEAN ENV

close all; clear; clc;

%% Kernels loading

HOMESPICE='/Users/Álvaro/Desktop/MASE/2n QUATRI/TFM/SPICE/mice';

METAKR={'https://naif.jpl.nasa.gov/pub/naif/generic_kernels/lsk/naif0012.tls',
'naif0012.tls', ...

'https://naif.jpl.nasa.gov/pub/naif/generic_kernels/spk/asteroids/a_old_versio
ns/vesta_1900_2100.bsp','vesta_1900_2100.bsp', ...

'https://naif.jpl.nasa.gov/pub/naif/generic_kernels/pck/pck00010.tpc','pck0001
0.tpc', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_120724-
120913_121213_v1.bsp','dawn_rec_120724-120913_121213_v1.bsp'};

initSPICEv(HOMESPICE,METAKR);

%% Computations

STEP = 10000; % Determines the accuracy of the computations
dates = {'Aug 18, 2012', 'Sept 02, 2012'}; % Dates selected

[times_sec, dates_plot] = time_computation(dates, STEP); %From dates to
ephemeris time

[state, ltime]= cspice_spkezr( 'Dawn', times_sec, 'J2000', 'NONE', 'VESTA'); %
Dawn's position and velocity computation from Vesta

x = state(1,:); % Coordinates of the positions from Vesta (km)
y = state(2,:);
z = state(3,:);
range = sqrt(x.^2+y.^2+z.^2); % Dawn's range from Vesta

r(:,1) = x; % Position vector from Vesta
r(:,2) = y;
r(:,3) = z;

vx = state(4,:); % Components of the velocity relative to Vesta (km/s)
vy = state(5,:);
vz = state(6,:);
v_tot = sqrt(vx.^2+vy.^2+vz.^2); % Dawn's relative velocity to Vesta

v(:,1) = vx; % Velocity vector relative to Vesta
v(:,2) = vy;
v(:,3) = vz;

% Spacecraft trajectory reference system

for i=1:STEP

    h(i,:) = r(i,:)/norm(r(i,:)); % Radial vector
```

```
    b(i,:) = cross(r(i,:),v(i,:));
    b(i,:) = b(i,:)/norm(b(i,:)); % Elevation vector
    t(i,:) = cross(b(i,:),h(i,:)); % Tangential vector

    beta(i) = asind(dot(v(i,:),h(i,:))/(norm(v(i,:)))); % Angle from the
tangential vector to the projection on the thrust in the t-h plane

end

alpha_max = acosd(dot(b(1,:),b(STEP,:))); % Maximum angle between the thrust
vector and its projection in the t-h plane

[theta,~,~] = cart2sph(x,y,z);
theta = rad2deg(theta); % Theta angle of the orbit (radial)

[state_s, ~]= cspice_spkezr( 'Dawn', times_sec, 'J2000', 'NONE', 'SUN'); %
Dawn's position and velocity computation from the Sun

range_s = sqrt(state_s(1,:).^2+state_s(2,:).^2+state_s(3,:).^2); % Dawn's
range from the Sun
range_s_au = range_s/149597870.7; % In AU (to know the the input power given
by the solar arrays to know the throttle level)

throttle_level = 6; % From the input power of the solar arrays
[Ft_tot] = Dawn_thrust(throttle_level); % Total thrust

for i=1:STEP

    alpha(i) = alpha_max*sind(theta(i)); % Angle between the thrust vector and
its projection in the t-h plane

    Ft_h(i) = Ft_tot*cosd(alpha(i))*sind(beta(i)); % Components of the thrust
in the h-t-b reference system
    Ft_t(i) = Ft_tot*cosd(alpha(i))*cosd(beta(i));
    Ft_b(i) = Ft_tot*sind(alpha(i));

    Ft_x(i) = Ft_h(i)*h(i,1)+Ft_t(i)*t(i,1)+Ft_b(i)*b(i,1); % Components of
the thrust in the x-y-z reference system
    Ft_y(i) = Ft_h(i)*h(i,2)+Ft_t(i)*t(i,2)+Ft_b(i)*b(i,2);
    Ft_z(i) = Ft_h(i)*h(i,3)+Ft_t(i)*t(i,3)+Ft_b(i)*b(i,3);

end

figure(1);
plot3(x,y,z)
hold on
plot(0,0,'k*','MarkerSize',20)
title('Dawn trajectory around Vesta (km)');
xlabel('x (km)')
ylabel('y (km)')
zlabel('z (km)')

figure(2);
plot(range)
hold on
set(gca,'xticklabel',dates_plot.')
title('Dawn distance with respect to Vesta');
```

```
xlabel('Time (dates)');
ylabel('Distance (km)');

figure(3);
plot(v_tot)
hold on
set(gca,'xticklabel',dates_plot.')
title('Dawn relative velocity with respect to Vesta');
xlabel('Time (dates)');
ylabel('Relative velocity (km/s)');

figure(4)
plot(Ft_h)
hold on
plot(Ft_t)
hold on
plot(Ft_b)
set(gca,'xticklabel',dates_plot.')
xlabel('Time (dates)');
ylabel('Thrust force (N)');
legend('Radial','Tangential','Elevation')
title('Components of the thrust in the spacecraft trajectory reference
system')

cspice_kclear
```

Dawn thrust function

```
function [thrust] = Dawn_thrust(throttle_level)

% Determination of the total thrust depending on the throttle level in N

switch throttle_level

    case 0
        thrust = 20.9e-3;

    case 1
        thrust = 23.9e-3;

    case 2
        thrust = 26.3e-3;

    case 3
        thrust = 31.8e-3;

    case 4
        thrust = 37e-3;

    case 5
        thrust = 42.2e-3;

    case 6
        thrust = 47.4e-3;
```

```
    case 7
        thrust = 52e-3;

    case 8
        thrust = 57.2e-3;

    case 9
        thrust = 62.4e-3;

    case 10
        thrust = 67.2e-3;

    case 11
        thrust = 72.4e-3;

    case 12
        thrust = 77.1e-3;

    case 13
        thrust = 82.1e-3;

    case 14
        thrust = 86.8e-3;

    case 15
        thrust = 91.5e-3;

end

end
```

Dawn theoretical escape trajectory from Vesta

```
%% CLEAN ENV

close all; clear; clc;

%% Kernels loading

HOMESPICE='/Users/Álvaro/Desktop/MASE/2n QUATRI/TFM/SPICE/mice';

METAKR={'https://naif.jpl.nasa.gov/pub/naif/generic_kernels/lsk/naif0012.tls',
'naif0012.tls', ...

'https://naif.jpl.nasa.gov/pub/naif/generic_kernels/pck/pck00010.tpc','pck0001
0.tpc', ...
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_120724-
120913_121213_v1.bsp','dawn_rec_120724-120913_121213_v1.bsp'};


initSPICEv(HOMESPICE,METAKR);

%% Computations
mass_vesta = 2.59076e+20; % Mass of Vesta (kg)
grav_const = 6.6740831e-20; % Gravitational constant (km^3/(kg*s^2))
```

```
mu_vesta = mass_vesta*grav_const; % Gravitational parameter of Vesta

mass_dawn = 958.4; % Mass of Dawn spacecraft (kg)
thrust_dawn = 0.0474; % Total thrust (N)
acc_dawn = thrust_dawn/mass_dawn/1000; % Dawn acceleration from thrust
(km/s^2)

%% From SPICE

STEP = 10000; % Determines the accuracy of the computations
dates = {'Aug 18, 2012', 'Sept 02, 2012'}; % Dates selected

[times_sec, dates_plot] = time_computation(dates, STEP); %From dates to
ephemeris time

time_step = times_sec(2)-times_sec(1); % Time in seconds between steps

[state, ltime]= cspice_spkezr( 'Dawn', times_sec, 'J2000', 'NONE', 'VESTA'); %
Dawn's position and velocity computation from Vesta

x_spice = state(1,:); % Coordinates of the positions from Vesta from SPICE
(km)
y_spice = state(2,:);
z_spice = state(3,:);
range_spice = sqrt(x_spice.^2+y_spice.^2+z_spice.^2); % Dawn's range from
Vesta from SPICE

vx_spice = state(4,:); % Coordinates of the positions from Vesta from SPICE
(km)
vy_spice = state(5,:);
vz_spice = state(6,:);
v_tot_spice = sqrt(vx_spice.^2+vy_spice.^2+vz_spice.^2); % Dawn's relative
velocity to Vesta from SPICE

x_i = state(1,1); % Coordinates of the initial position from Vesta (km)
y_i = state(2,1);
z_i = state(3,1);
range_i = sqrt(x_i.^2+y_i.^2+z_i.^2); % Dawn's initial range from Vesta

r_i(1) = x_i; % Initial position vector from Vesta
r_i(2) = y_i;
r_i(3) = z_i;

r(1,:) = r_i; % Position vector from Vesta

x_f = state(1,STEP); % Coordinates of the final position from Vesta (km)
y_f = state(2,STEP);
z_f = state(3,STEP);
range_f = sqrt(x_f.^2+y_f.^2+z_f.^2); % Dawn's final range from Vesta

vx_i = state(4,1); % Components of the initial velocity relative to Vesta
(km/s)
vy_i = state(5,1);
vz_i = state(6,1);
v_tot_i = sqrt(vx_i.^2+vy_i.^2+vz_i.^2); % Dawn's initial relative velocity to
Vesta
```

```
v_i(1) = vx_i; % Initial velocity vector relative to Vesta
v_i(2) = vy_i;
v_i(3) = vz_i;

v(1,:) = v_i; % Velocity vector relative to Vesta

vx_f = state(4,STEP); % Components of the final velocity relative to Vesta
(km/s)
vy_f = state(5,STEP);
vz_f = state(6,STEP);
v_tot_f = sqrt(vx_f.^2+vy_f.^2+vz_f.^2); % Dawn's final relative velocity to
Vesta

TOF_real = (times_sec(STEP)-times_sec(1))/3600/24; % Real time of flight
(days)

%% From theoretical models

% Considers that the spacecraft escapes from Vesta at the final position

a_rad = mu_vesta/((range_f-range_i)*2*range_i); % Radial acceleration (km/s^2)
gravity_vesta = mu_vesta/((range_f+range_i)/2)^2; % Average gravity during
trajectory (km/s^2)
a_tan = range_i*v_tot_i^2/(sqrt(20)*range_f^2); % Tangential acceleration
(km/s^2)
a_tot = sqrt((a_rad-gravity_vesta)^2+a_tan^2); % Thrust acceleration (km/s^2)
f_tot = a_tot*mass_dawn*1000; % Total thrust (N) --> 0.0474N (real)

TOF_MIT = v_tot_i/a_tan*(1-(2*a_tan*range_i/v_tot_i^2)^(1/4))/3600/24; % Time
of flight (days)
TOF_et = v_tot_i/a_tan*(1-(20*a_tan^2*range_i^2/v_tot_i^4)^(1/8))/3600/24; %
Time of flight (days)

time = 0;

for i=1:STEP

    % Spacecraft trajectory reference system
    h(i,:) = r(i,:)/norm(r(i,:)); % Radial vector
    b(i,:) = cross(r(i,:),v(i,:));
    b(i,:) = b(i,:)/norm(b(i,:)); % Elevation vector
    t(i,:) = cross(b(i,:),h(i,:)); % Tangential vector

    time = time + time_step;

    v_circ(i) = sqrt(mu_vesta/norm(r(i,:)));
    v_rad(i) = 2*range_i*acc_dawn/(v_tot_i*(1-acc_dawn*time/v_tot_i));
    climb_angle(i) = atand(v_rad(i)/(v_circ(i))); % Angle between total and
tangential velocities

    vx(i) = v_rad(i)*h(i,1)+v_circ(i)*t(i,1);
    vy(i) = v_rad(i)*h(i,2)+v_circ(i)*t(i,2);
    vz(i) = v_rad(i)*h(i,3)+v_circ(i)*t(i,3);
    v(i,1) = vx(i); % Velocity vector relative to Vesta
    v(i,2) = vy(i);
    v(i,3) = vz(i);
```

```
    a_h(i) = acc_dawn*sind(climb_angle(i))-(mu_vesta/norm(r(i,:))^2); %
Components of the acceleration in the h-t reference system
    a_t(i) = acc_dawn*cosd(climb_angle(i));

    a_x(i) = a_h(i)*h(i,1)+a_t(i)*t(i,1);
    a_y(i) = a_h(i)*h(i,2)+a_t(i)*t(i,2);
    a_z(i) = a_h(i)*h(i,3)+a_t(i)*t(i,3);
    a(i,1) = a_x(i); % Acceleration vector relative to Vesta
    a(i,2) = a_y(i);
    a(i,3) = a_z(i);

    if (i<STEP)

        r(i+1,:) = r(i,:)+v(i,:)*time_step+a(i,:)*time_step^2; % Position
vector from Vesta
        v(i+1,:) = v(i,:)+a(i,:)*time_step; % Velocity vector relative to
Vesta

    end

end

x = r(:,1); % x, y and z components of the position vector
y = r(:,2);
z = r(:,3);
range = sqrt(x.^2+y.^2+z.^2); % Dawn's range from Vesta

v_tot = sqrt(vx.^2+vy.^2+vz.^2); % Dawn's relative velocity to Vesta

v_circ_i = sqrt(mu_vesta/range(1)); % Initial tangential velocity
v_circ_f = sqrt(mu_vesta/range(STEP)); % Final tangential velocity

TOF_co_theo = (v_circ_i-v_circ_f)/acc_dawn/3600/24; % Time of flight
considering theoretical velocities (days)
TOF_co_real = (v_tot_i-v_tot_f)/acc_dawn/3600/24; % Time of flight considering
real velocities (days)

figure(1);
plot3(x,y,z)
hold on
plot3(x_spice,y_spice,z_spice)
hold on
plot(0,0,'k*','MarkerSize',20)
title('Dawn exit trajectory around Vesta (km)');
xlabel('x (km)')
ylabel('y (km)')
zlabel('z (km)')
legend('From theoretical computations','From SPICE','Location','best')

figure(2);
plot(range)
hold on
plot(range_spice)
set(gca,'xticklabel',dates_plot.')
title('Dawn distance with respect to Vesta');
xlabel('Time (dates)');
ylabel('Distance (km)');
```

```
legend('From computations','From SPICE')

figure(3);
plot(v_tot)
hold on
plot(v_tot_spice)
set(gca,'xticklabel',dates_plot.')
title('Dawn relative velocity with respect to Vesta');
xlabel('Time (dates)');
ylabel('Relative velocity (km/s)');
legend('From computations','From SPICE')

cspice_kclear
```

Dawn solar arrays

```
close all; clear; clc;

HOMESPICE='/Users/Álvaro/Desktop/MASE/2n QUATRI/TFM/SPICE/mice';

METAKR={'https://naif.jpl.nasa.gov/pub/naif/generic_kernels/lsk/naif0012.tls',
'naif0012.tls', ... % ephemeris data of solar system bodies

'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/ck/dawn_sa_120813_120819.bc',
'dawn_sa_120813_120819.bc',... % orientation data of DAWN solar array

'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/ck/dawn_sa_120820_120826.bc',
'dawn_sa_120820_120826.bc',... % orientation data of DAWN solar array

'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/ck/dawn_sa_120827_120902.bc',
'dawn_sa_120827_120902.bc',... % orientation data of DAWN solar array
        'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/spk/dawn_rec_120724-
120913_121213_v1.bsp','dawn_rec_120724-120913_121213_v1.bsp',... % orientation
data of DAWN spacecraft

'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/fk/dawn_v15.tf','dawn_v15.tf'
,...% Frame information from Dawn spacecraft and Dawn solar arrays.

'https://naif.jpl.nasa.gov/pub/naif/generic_kernels/spk/asteroids/a_old_versio
ns/vesta_1900_2100.bsp','vesta_1900_2100.bsp', ...

'https://naif.jpl.nasa.gov/pub/naif/generic_kernels/pck/pck00010.tpc','pck0001
0.tpc', ...

'https://naif.jpl.nasa.gov/pub/naif/DAWN/kernels/sclk/DAWN_203_SCLKSCET.00091.
tsc','DAWN_203_SCLKSCET.00091.tsc' }; % SCLK information

initSPICEv(HOMESPICE,METAKR);

STEP = 10000; % Determines the accuracy of the computations
dates = {'Aug 18, 2012', 'Sept 02, 2012'}; % Dates selected

[times_sec, dates_plot] = time_computation(dates, STEP); %From dates to
ephemeris time
```

```
[state, ltime]= cspice_spkezr( 'Dawn', times_sec, 'J2000', 'NONE', 'SUN'); %
Dawn's position and velocity computation


for i=1:STEP

    Matsa1=cspice_pxform('DAWN_SPACECRAFT','DAWN_SA+Y',times_sec(i)); % gets
the position rotation matrix of the frame of the solar array +Y from the
spacecraft frame.
    Matsa2=cspice_pxform('DAWN_SPACECRAFT','DAWN_SA-Y',times_sec(i)); % gets
the position rotation matrix of the frame of the solar array -Y from the
spacecraft frame.

    boresightsa= [0;
                  0;
                  1]; % Normal vector.

    boresitesa1=Matsa1*boresightsa; % computes the normal vector from the
SOLAR ARRAY +Y.
    boresitesa2=Matsa2*boresightsa; % computes the normal vector from the
SOLAR ARRAY -Y.


    x = state(1,i); % Coordinates of the positions
    y = state(2,i);
    z = state(3,i);

    vectsundawn = [x,y,z]; % Dawn's vector from the Sun

    anglesa1(i)=acosd((vectsundawn*boresitesa1)/(norm(vectsundawn)))-90; %
gets the angle between the sun and the solar array +Y
    anglesa2(i)=acosd((vectsundawn*boresitesa2)/(norm(vectsundawn)))-90; %
gets the angle between the sun and the solar array -Y

    range = sqrt(x.^2+y.^2+z.^2); % Dawn's range from Vesta in km
    range_au = range/149597870.7; % In AU
    range_earth = 1; % In AU

    solar_ir_earth = 1361; % Solar irradiance on Earth in W/m^2
    sa_surf = 18.2; % Solar array surface in m^2
    sa_eff = 0.27; % Solar array efficiency
    PPU_eff = 0.92; % PPU efficiency

    solar_ir(i) = solar_ir_earth*range_earth^2/range_au^2; % Solar irradiance
on Dawn
    sa_power(i) =
solar_ir(i)*(sa_surf*cosd(anglesa1(i))+sa_surf*cosd(anglesa2(i))); %
    IPS_input_power(i) = sa_power(i)*sa_eff;

end

figure(1);
plot(anglesa1)
hold on
plot(anglesa2)
hold on
set(gca,'xticklabel',dates_plot.')
```

```
title('Dawn solar arrays orientation with respect to the Sun');
xlabel('Time (dates)');
ylabel('Orientation angle (°)');
legend('+Y SA','-Y SA')

figure(2);
plot(IPS_input_power)
set(gca,'xticklabel',dates_plot.')
title('Dawn input power (IPS + non-IPS systems)');
xlabel('Time (dates)');
ylabel('Dawn input Power (W)');

% Unload kernels
cspice_kclear
```

Annex B: Quality self-assessment

STUDENT'S NAME: Álvaro Boix	DATE: 20/06/2019
DEGREE: Master's Degree in Space and Aeronautical Engineering	
CALL : SPRING YEAR 2019	

PARAMETER TO VERIFY: FORMAL ASPECTS – CONTINENT	**RESULT**			
	1	**2**	**3**	**REMARKS**
A1 – Cover formats			X	
A2 – Summary of contents			X	
A3 - Summary of tables, figures			X	
A4 – Spelling/Units			X	
A5 – Tables/Figures			X	
A6 – Format of documents			X	
A7 – Length of the report			X	
A8 – Bibliography			X	
A9 – List of documents			X	
PARAMETER TO VERIFY: FORMAL ASPECTS – CONTENTS	**RESULT**			
	1	**2**	**3**	**REMARKS**
B1 – Approach to the problem			X	
B2 – Background and state of the art			X	
B3 – Approach and justification of the proposed solutions			X	
B4 – Fulfilment of scope and requirements			X	
B5 – Economic, environmental and safety aspects			X	Not applicable
B6 – Time-related aspects			X	Not applicable
B7 – Conclusions and recommendations			X	

Annex C: Thesis budget

This annex contains the budget related to the development and execution of this thesis. As it is a study, there are no bought resources or laboratory tools, only the ones required to work with MATLAB and SPICE in a PC.

There are two types of costs, the fixed and the time-based ones. The fixed costs are the PC itself and the MATLAB license. Then, the time-based costs are the elecetricity and the Internet required to make the PC work and the availability of the SPICE database kernel files and toolkit.

The time that determines the cost of this time-based budget is based on the ECTS credits of this Master's Final Thesis, which are 14 in this case. Converted to hours, each ECTS credit mean between 25 and 30 hours so, taking into account the meetings with the directors, each credit represents 25 hours.

The table below exposes these mentioned costs and contains their economical value.

RESOURCES	TIME	TOTAL COST (COST PER HOUR)
Electricity	350 h	24.85 € (0.071 €)
Internet	350 h	50.05 € (0.143 €)
PC	-	500 €
MATLAB license	-	119 €
TOTAL	350 h	**693.90 €**