John Clouse IMD HW 3

Table of Contents

Initialize

```
clearvars -except hw_pub function_list

CelestialConstants
```

Problem 1

```
JD_depart = 2454085.5;
JD_arrive = JD_depart + 830;
[r_p1, v_p1] = MeeusEphemeris(Mars, JD_depart, Sun);
[r_p2, v_p2] = MeeusEphemeris(Jupiter, JD_arrive, Sun);

fprintf('r_mars:\n');disp(r_p1); fprintf('\b\b km\n\n')
fprintf('r_jupiter:\n');disp(r_p2); fprintf('\b\b km\n\n')
```

```
r_mars:
   1.0e+08 *

   -1.2817
   -1.9059
   -0.0084 km

r_jupiter:
   1.0e+08 *

    4.8338
   -5.8746
   -0.0838 km
```

Problem 2

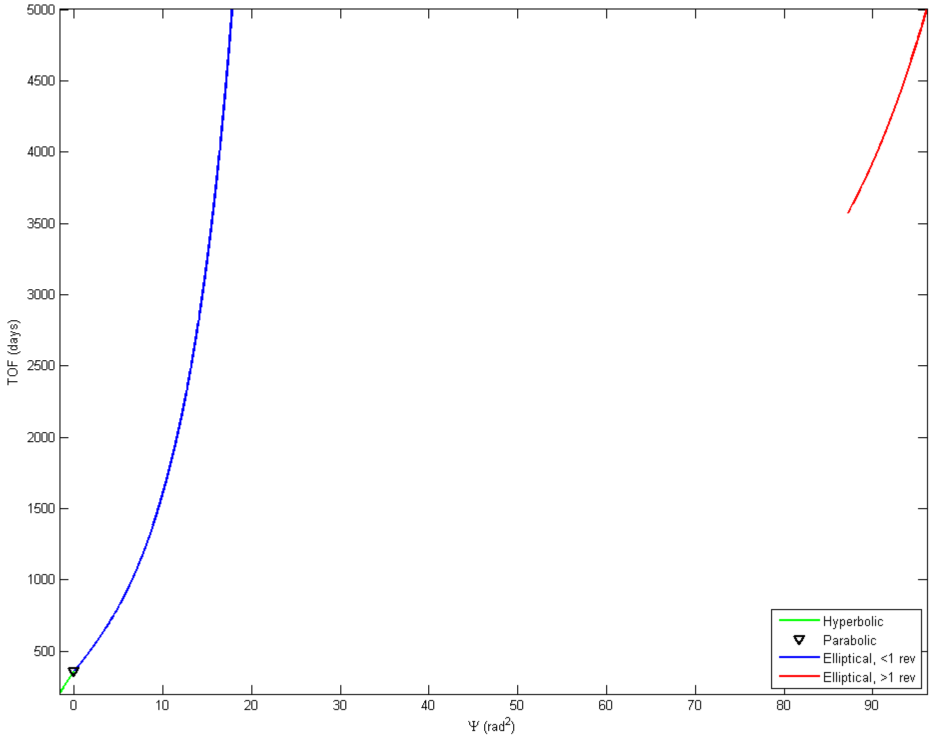
```
day_store = 200:5000;
psi_store = zeros(1,length(day_store));
% get psi out of Lambert
for ii = 1:length(day_store)
    [~, ~, psi_store(ii)] = lambert(r_p1, r_p2, day_store(ii)*24*3600, 1, Sun);
end
```

```
% Find the initial psi value that yields a multi-rev solution
psi_multi_rev = psi_store(end);
psi_out = psi_store(end);
while psi_out <= psi_store(end)+1
    psi_multi_rev = psi_multi_rev+10;
    [~, ~, psi_out] = lambert(r_p1, r_p2, day_store(end)*24*3600, 1, Sun,psi_multi
end

% Run multi-rev Lambert
psi_multirev_store = zeros(1,length(day_store));
for ii = length(day_store):-1:1
    [~, ~, psi_multirev_store(ii)] = lambert(r_p1, r_p2, day_store(ii)*24*3600, 1,
end

figure('Position', hw_pub.figPosn)
ell_plot = plot(psi_store, day_store,'LineWidth',hw_pub.lineWidth);
hold on
hyp_plot = plot(psi_store(psi_store < 0), day_store(psi_store < 0),'g',...
    'LineWidth',hw_pub.lineWidth);
para_plot = plot(max(psi_store(psi_store < 0)), ...
    max(day_store(psi_store < 0)),'kv','LineWidth',hw_pub.lineWidth);
mr_indices = psi_multirev_store > psi_store +1;
mr_plot = plot(psi_multirev_store(mr_indices), day_store(mr_indices),'r',...
    'LineWidth',hw_pub.lineWidth);

ylabel('TOF (days)')
xlabel('\Psi (rad^2)')
xlim([min(psi_store) max(psi_multirev_store)]);
ylim([day_store(1) day_store(end)]);
legend([hyp_plot para_plot ell_plot mr_plot],'Hyperbolic', 'Parabolic', ...
    'Elliptical, <1 rev', 'Elliptical, >1 rev','Location','SouthEast');
```



Problem 3

I added an argument to make the initial guess for Psi to be larger. I also had to implement a bailout mechanism, as sometimes it would get stuck on some other local minimum and not converge.

Problem 4

```
min_days = min(day_store(mr_indices));
fprintf('Minimum time for multi-rev transfer is %d days.\n', min_days);
fprintf('Psi = %.3f rad^2\n',min(psi_multirev_store(mr_indices)));
```

```
Minimum time for multi-rev transfer is 3564 days.
Psi = 87.116 rad^2
```

Published with MATLAB® R2013b

CelestialConstants

Table of Contents

Description

All sorts of constants for orbital mechanics purposes

```
fcnPrintQueue(mfilename('fullpath')) % Add this code to code app
```

Celestial units

```
au2km = 149597870.7;
```

Physical constants

```
day2sec = 86400; % sec/day
speed_of_light = 299792458; %m/s
```

Earth

```
Earth.name = 'Earth';
Earth.mu = 3.986004415e5; %km3/s2
Earth.R = 6378; %km
Earth.a = 149598023; %km
Earth.spin_rate = 7.2921158553e-05; %rad/s
Earth.flattening = 1/298.25722; %WGS-84
Earth.oblate_ecc = 0.081819221456; %WGS-84
Earth.J2 = 0.0010826267;
Earth.P_days = 365.2421897; %days
Earth.P_years = 0.99997862; %days
Earth.m = 5.9742e24; %kg
% Meeus ephemeris parameters
```

```
Earth.Meeus.J200.L = [100.466449 35999.3728519 -0.00000568 0.0]; %deg
Earth.Meeus.J200.a = 1.000001018*au2km; %km
Earth.Meeus.J200.e = [0.01670862 -0.000042037 -0.0000001236 0.00000000004];
Earth.Meeus.J200.i = [0 0.0130546 -0.00000931 -0.000000034]; % deg
Earth.Meeus.J200.RAAN = [174.873174 -0.2410908 0.00004067 -0.000001327]; %deg
Earth.Meeus.J200.Pi = [102.937348 0.3225557 0.00015026 0.000000478]; %deg
```

Moon

```
Moon.name = 'Moon';
Moon.R = 1738.0; %km
Moon.J2 = 0.0002027;
Moon.P_days = 27.321582; %days
Moon.mu = 4902.799; %km3/s2
Moon.m = 7.3483e22; %kg
Moon.a = 384400; %km
```

Sun

```
Sun.mu = 1.32712428e11; %km3/s2
Sun.m = 1.9891e30; %kg
```

Mercury

```
Mercury.name = 'Mercury';
Mercury.R = 2439.0; %km
Mercury.J2 = 0.00006;
Mercury.P_days = 87.9666; %days
Mercury.mu = 2.2032e4; %km3/s2
```

Venus

```
Venus.name = 'Venus';
Venus.a = 108208601; %km
Venus.R = 6052.0; %km
Venus.J2 = 0.000027;
Venus.P_days = 224.6906; %days
Venus.mu = 3.257e5; %km3/s2
Venus.m = 4.869e24; %km
```

Mars

```
Mars.name = 'Mars';
Mars.a = 227939186; %km
Mars.R = 3397.2; %km
Mars.J2 = 0.001964;
Mars.P_days = 686.9150; %days
Mars.mu = 4.305e4; %km3/s2
Mars.m = 6.4191e23; %kg
```

```
% Meeus ephemeris parameters
Mars.Meeus.J200.L = [355.433275 19140.2993313 0.00000261 -0.000000003]; %deg
Mars.Meeus.J200.a = 1.523679342*au2km; %km
Mars.Meeus.J200.e = [0.09340062 0.000090483 -0.0000000806 -0.00000000035];
Mars.Meeus.J200.i = [1.849726 -0.0081479 -0.00002255 -0.000000027]; %deg
Mars.Meeus.J200.RAAN = [49.558093 -0.2949846 -0.00063993 -0.000002143]; %deg
Mars.Meeus.J200.Pi = [336.060234 0.4438898 -0.00017321 0.000000300]; %deg
```

Jupiter

```
Jupiter.name = 'Jupiter';
Jupiter.a = 778298361; %km
Jupiter.R = 71492; %km
Jupiter.J2 = 0.01475;
Jupiter.P_years = 11.856525; %days
Jupiter.P_days = Jupiter.P_years/Earth.P_years*Earth.P_days; %days
Jupiter.mu = 1.268e8; %km3/s2
Jupiter.m = 1.8988e27; %kg
Jupiter.Meeus.J200.L = [34.351484 3034.9056746 -0.00008501 0.000000004 ];
Jupiter.Meeus.J200.a = [5.202603191 0.0000001913 ]*au2km;
Jupiter.Meeus.J200.e = [0.04849485 0.000163244 -0.0000004719 -0.00000000197 ];
Jupiter.Meeus.J200.i = [1.303270 -0.0019872 0.00003318 0.000000092 ];
Jupiter.Meeus.J200.RAAN = [100.464441 0.1766828 0.00090387 -0.000007032 ];
Jupiter.Meeus.J200.Pi = [14.331309 0.2155525 0.00072252 -0.000004590 ];
```

Saturn

```
Saturn.name = 'Saturn';
Saturn.a = 1429394133; %km
Saturn.R = 60268; %km
Saturn.J2 = 0.01645;
Saturn.P_years = 29.423519; %days
Saturn.P_days = Saturn.P_years/Earth.P_years*Earth.P_days; %days
Saturn.mu = 3.794e7; %km3/s2
Saturn.m = 5.685e26; %kg
```

Uranus

```
Uranus.name = 'Uranus';
Uranus.R = 25559; %km
Uranus.J2 = 0.012;
Uranus.P_years = 83.747406; %days
Uranus.P_days = Uranus.P_years/Earth.P_years*Earth.P_days; %days
Uranus.mu = 5.794e6; %km3/s2
```

Neptune

```
Neptune.name = 'Neptune';
Neptune.R = 24764; %km
Neptune.J2 = 0.004;
Neptune.P_years = 163.7232045; %days
```

```
Neptune.P_days = Neptune.P_years/Earth.P_years*Earth.P_days; %days
Neptune.mu = 6.809e6; %km3/s2
```

Published with MATLAB® R2013b

```
function [ r, v ] = MeeusEphemeris( planet, JD , Sun)
%MeeusEphemeris Calculate planetary ephemeris. Works with
%CelestialConstants.m file
%   Outputs PV in km, km/s
fcnPrintQueue(mfilename('fullpath')) % Add this code to code app

T = (JD - 2451545)/36525;

if length(planet.Meeus.J200.a) == 1
    a = planet.Meeus.J200.a;%*au2km;
else
    T_pow = 1;
    a = 0;
    for ii = 1:length(planet.Meeus.J200.a)
        a = a + planet.Meeus.J200.a(ii)*T_pow;
        T_pow = T_pow*T;
    end
end

L = planet.Meeus.J200.L(1) ...
    + planet.Meeus.J200.L(2)*T ...
    + planet.Meeus.J200.L(3)*T*T ...
    + planet.Meeus.J200.L(4)*T*T*T;
e = planet.Meeus.J200.e(1) ...
    + planet.Meeus.J200.e(2)*T ...
    + planet.Meeus.J200.e(3)*T*T ...
    + planet.Meeus.J200.e(4)*T*T*T;

i = planet.Meeus.J200.i(1) ...
    + planet.Meeus.J200.i(2)*T ...
    + planet.Meeus.J200.i(3)*T*T ...
    + planet.Meeus.J200.i(4)*T*T*T;

RAAN = planet.Meeus.J200.RAAN(1) ...
    + planet.Meeus.J200.RAAN(2)*T ...
    + planet.Meeus.J200.RAAN(3)*T*T ...
    + planet.Meeus.J200.RAAN(4)*T*T*T;

Pi = planet.Meeus.J200.Pi(1) ...
    + planet.Meeus.J200.Pi(2)*T ...
    + planet.Meeus.J200.Pi(3)*T*T ...
    + planet.Meeus.J200.Pi(4)*T*T*T;

% Convert everything to radians!
L = L*pi/180;
i = i*pi/180;
RAAN = RAAN*pi/180;
Pi = Pi*pi/180;

w = Pi - RAAN;

M = L - Pi;
```

```
e2 = e*e;
e3 = e*e2;
e4 = e*e3;
e5 = e*e4;

C_cen = (2*e-e3/4+5/96*e5)*sin(M) + (5/4*e2-11/24*e4)*sin(2*M) ...
    + (13/12*e3-43/64*e5)*sin(3*M) + 103/96*e4*sin(4*M) ...
    + 1097/960*e5*sin(5/M);

f = M + C_cen;

[r, v] = OE2cart(a, e, i, RAAN, w, f, Sun.mu);

end
```

Published with MATLAB® R2013b

```
function [r, v ] = OE2cart( a,e,i,RAAN,w,f,mu)
%cart2OE return classical orbital elements from cartesian coords
% Only valid for e < 1
% units in radians
fcnPrintQueue(mfilename('fullpath')) % Add this code to code app

% First find r,v in the perifocal coord system.
p = a*(1-e*e);
r_pqw = [p*cos(f);p*sin(f);0]/(1+e*cos(f));
v_pqw = [-sqrt(mu/p)*sin(f); sqrt(mu/p)*(e+cos(f));0];

r = Euler2DCM('313', -[w,i,RAAN])*r_pqw;
v = Euler2DCM('313', -[w,i,RAAN])*v_pqw;
```

Published with MATLAB® R2013b

```
function DCM = Euler2DCM( seq_string, angle_vector )
%Euler2DCM Turn an Euler Angle set into a DCM
%   Angle vector in radians
fcnPrintQueue(mfilename('fullpath'))

DCM = eye(3);
%get the trig functions
num_rot = length(seq_string);
c = zeros(num_rot,1);
s = zeros(num_rot,1);

for idx = 1:num_rot
c(idx) = cos(angle_vector(idx));
s(idx) = sin(angle_vector(idx));
end


for idx = num_rot:-1:1
    if strcmp(seq_string(idx),'1')
        M = [1 0 0; 0 c(idx) s(idx); 0 -s(idx) c(idx)];
        DCM = DCM*M;
    elseif strcmp(seq_string(idx),'2')
        M = [c(idx) 0 -s(idx); 0 1 0; s(idx) 0 c(idx)];
        DCM = DCM*M;
    elseif strcmp(seq_string(idx),'3')
        M = [c(idx) s(idx) 0; -s(idx) c(idx) 0; 0 0 1];
        DCM = DCM*M;
    else
        fprintf('%s is not a valid axis\n', seq_string(idx))
    end
end


end
```

Published with MATLAB® R2013b

```
function [vi, vf, psi] = lambert(ri_vec, rf_vec, dt, DM, Sun, psi_in)
%lambert Solve lambert problem using universal variables method
%   Output initial and final velocities given respective position vectors
%   Inputs in km, Results in km/s
%   DM = Direction of Motion (short way or long way)

fcnPrintQueue(mfilename('fullpath')) % Add this code to code app

tol = 1e-6;

ri = norm(ri_vec);
rf = norm(rf_vec);

cos_df = dot(ri_vec, rf_vec)/(ri*rf);

A = DM*sqrt(ri * rf * (1+cos_df));

if nargin < 6
    psi = 0;
else
    psi = psi_in;
end
c2 = 1/2;
c3 = 1/6;
psi_up_i = 4*pi*pi + psi; % Doubled from Vallado for higher TOF
psi_low_i = -4*pi; % Doubled from Vallado for lower TOF

dt_calc = 0;

first_pass = true;
% while abs(dt_calc-dt) > tol
    if first_pass
        psi_up = psi_up_i;
        psi_low = psi_low_i;
        first_pass = false;
%     elseif psi_up < 0% hit the lower boundary
%         psi_up_i = psi_low_i; % Upper bound is last time's lower bound
%         psi_low_i = 4*psi_low_i; % decrease lower bound
%         psi_up = psi_up_i;
%         psi_low = psi_low_i;
%     elseif psi_low > 0 %hit upper boundary
%         psi_low_i = psi_up_i; % lower bound is last time's upper
%         psi_up_i = 4*psi_up_i; % increase upper
%         psi_up = psi_up_i;
%         psi_low = psi_low_i;
    end


    while abs(dt_calc-dt) > tol
        y = ri + rf + A*(psi*c3-1)/sqrt(c2);
        if A > 0 && y < 0
            while y < 0
```

```
                psi = psi + 0.1;
                y = ri + rf + A*(psi*c3-1)/sqrt(c2);
            end
        end

        X = sqrt(y/c2);
        dt_calc = (X*X*X*c3 + A*sqrt(y))/sqrt(Sun.mu);

%          y_prime = A*(c3-1)/sqrt(c2);
%          psi = psi - y/y_prime;
        if (dt_calc <= dt)
            psi_low = psi;
        else
            psi_up = psi;
        end

%          if abs(psi_up_i - psi_low) < 1e-10 || abs(psi_low_i - psi_up) < 1e-10
%              break; %we hit one of the boundaries
%          end

        psi = (psi_up + psi_low)/2;

        if psi > 1e-6
            c2 = (1-cos(sqrt(psi)))/psi;
            c3 = (sqrt(psi) - sin(sqrt(psi)))/sqrt(psi*psi*psi);
        elseif psi < -1e6
            c2 = (1-cosh(sqrt(psi)))/psi;
            c3 = (sinh(sqrt(-psi)) - sqrt(-psi))/sqrt(-psi*psi*psi);
        else
            c2 = 1/2;
            c3 = 1/6;
        end

        if (psi_up-psi_low) < 1e-10 && abs(dt_calc-dt) > 100
            %Get out of here! fell into a bad minimum.
            psi = 0;
            vi = zeros(3,1);
            vf = zeros(3,1);
            return
        end
    end

    f = 1-y/ri;
    g_dot = 1-y/rf;
    g = A*sqrt(y/Sun.mu);

    vi = (rf_vec-f*ri_vec)/g;
    vf = (g_dot*rf_vec-ri_vec)/g;
% end


end
```

Published with MATLAB® R2013b

```
function fcnPrintQueue( filename )
global function_list;
if exist('function_list', 'var')
    file_in_list = 0;
    for idx = 1:length(function_list)
        if strcmp(function_list(idx), filename);
            file_in_list = 1;
            break
        end
    end
    if ~file_in_list
        function_list = [function_list, filename];
    end
end
end
```

Published with MATLAB® R2013b