Table of Contents

Josh O

```
------------ HW2 - Josh Oates ------------
```

4.15

```
------------P4.15------------
My calculations have the following results:
Velocity in Perifocal Frame [km/s]:
         0   12.2156         0

Position in Perifocal Frame [km]:
        6678           0           0

Velocity in ECI Frame [km/s]:
  -10.3559   -5.7627    2.9611

Velocity in Perifocal Frame [km]:
   1.0e+03 *

   -1.9838    5.3488    3.4715

H/C: norms of r and v in either frame should be equal:
Norm veci: 12.2156  Norm vp: 12.2156
Norm reci: 6678  Norm rp: 6678
```

5.6

```
Warning: joshfLambert: This function may be useful but it is not well tested
 and
complete argument validation has not been implimented.
------------P5.6------------
My calculations have the following results:
V1 in km/s:
```

```
   -4.8864    6.0226    3.0479

V2 in km/s:
   -6.9168    1.2549   -1.3988

H/C: We should be using the short side and theta1 < theta2 so this makes sense
```

6.8

```
------------P6.8------------
My calculations have the following results:
dv [km/s]: 1.1977
transit time [s]: 59.6542
H/C: transfer time is halff of the tranfer period. This period makes sense for
 something LEO MEOish.
```

6.23

```
------------P6.23------------
My calculations have the following results:
dv [km/s]: 3.4054
H/C: The orbital period used in the calculation makes sense for a MEO orbit.
```

6.25

```
Warning: joshCOE will assume that R and V are normal if the inputs are scalar
ie: the craft is in a circular orbit or is at periapse or apoapse
------------P6.25------------
My calculations have the following results:
Delta gamma [degrees]: -8.1813
Delta v [km/s]: 0.91545
H/C: We would imagine a moderate delta v for a manuver like this. This seems
 to make sense for a small apseline rotation.
```

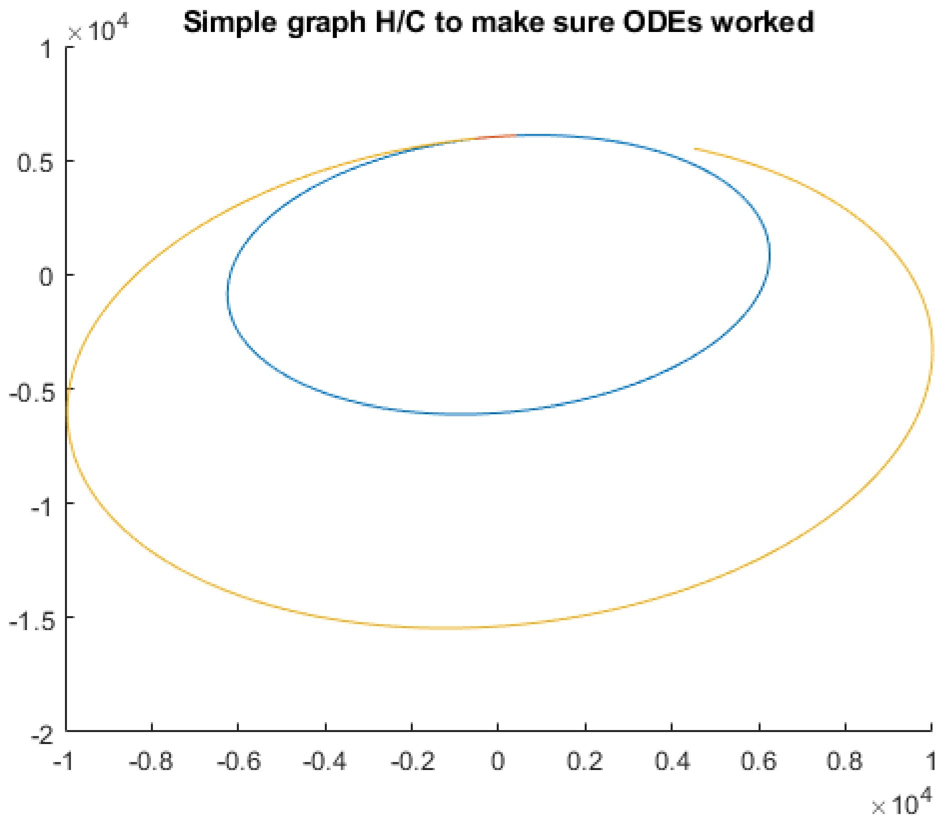
6.31

on paper

6.44

```
------------P6.44------------
My calculations have the following results:
A) dv [km/s]: 2.7927
B) dv [km/s]: 2.6951
C) dv [km/s]: 2.7835
H/C: We would expect the lowest delta v to be a combined manuver at a greater
 altitude, this way there is less velocity to change so to speak and a small
 dv will create a larger inc change.
```

6.47



dependancies

```
------------Dependancies------------
My code uses the following functions:
    {'C:\AERO351\A351HW3\HW3.m'                       }
    {'C:\joshFunctionsMatlab\joshAnomalyCalculator.m'}
    {'C:\joshFunctionsMatlab\joshAxisRotation.m'     }
    {'C:\joshFunctionsMatlab\joshCOE.m'              }
    {'C:\joshFunctionsMatlab\joshHomann.m'           }
    {'C:\joshFunctionsMatlab\joshIsOnes.m'           }
    {'C:\joshFunctionsMatlab\joshLawCos.m'           }
    {'C:\joshFunctionsMatlab\joshStumpffCoeffs.m'    }
    {'C:\joshFunctionsMatlab\joshStumpffZ.m'         }
    {'C:\joshFunctionsMatlab\joshVazVr.m'            }
    {'C:\joshFunctionsMatlab\joshfLambert.m'         }
```

functions

```
------------P6.44------------
My calculations have the following results:
Max altitude [km]: 10433.3136
Max altitude time since t0 [min]: 194.9897
```

H/C: the time to get to apogee seems to be within range for 2ish orbits in LEO which is what the included graph seems to predict.

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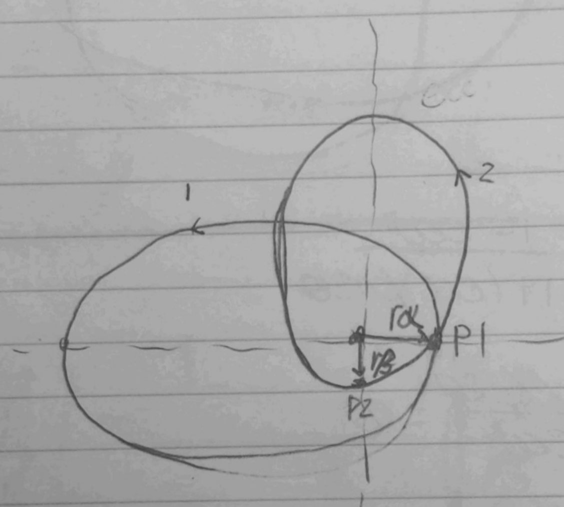
HW 3

6.31

$ecc1 = ecc2$



$$r_2(0^\circ) = r\beta$$
$$r_2(90^\circ) = r\alpha$$
$$r_1(0^\circ) = r\alpha$$

$$r = \frac{h^2}{\mu}\left(\frac{1}{1+ecc\cos\theta}\right)$$

$$r\beta = r_2(0^\circ) = \frac{h_2^2}{\mu}\left(\frac{1}{1+ecc}\right), \quad r\alpha = r_2(90^\circ) = \frac{h_2^2}{\mu}, \quad r\alpha = r_1(0^\circ) = \frac{h_1^2}{\mu}\left(\frac{1}{1+ecc}\right)$$

$$\frac{h_2^2}{\mu} = \frac{h_1^2}{\mu}\left(\frac{1}{1+ecc}\right), \quad \boxed{h_2 = \sqrt{h_1^2\frac{1}{1+ecc}} = h_1\frac{1}{\sqrt{1+ecc}}}$$

Table of Contents

Josh O

```
clear all
close all
clc

addpath('C:\joshFunctionsMatlab\')


% 4.15
% % % 5.6 - lambert
% 6.8
% 6.23
% 6.25
% 6.31 - rotation
% % 6.44 - HT and inc
% 6.47 - ODE


disp("------------ HW2 - Josh Oates ------------")
```

4.15

```
[Cx,Cy,Cz]=joshAxisRotation();

mu_e = 398600;
r_e = 6378; % km

ecc = 1.5;
zpapse = 300; % km

inc = 35; % degrees
raan = 130; % degrees
aop = 115; % degrees
```

```
inc = deg2rad(inc);
raan = deg2rad(raan);
aop = deg2rad(aop);
rpapse = zpapse + r_e;
theta = 0;
h = sqrt(mu_e*rpapse*(1+ecc*cos(theta)));

vpapse = h/rpapse;

rp = [1,0,0]*rpapse;
vp = [0,1,0]*vpapse;
clear vpapse rpapse zpapse

Q = Cz(raan)*Cx(inc)*Cz(aop);
Q = Q'; % Perifocal -> ECI

reci = rp*Q;
veci = vp*Q;



disp("------------P4.15------------")
disp("My calculations have the following results:")
disp("Velocity in Perifocal Frame [km/s]:")
disp(vp)
disp("Position in Perifocal Frame [km]:")
disp(rp)
disp("Velocity in ECI Frame [km/s]:")
disp(veci)
disp("Velocity in Perifocal Frame [km]:")
disp(reci)
disp("H/C: norms of r and v in either frame should be equal:")
disp("Norm veci: "+string(norm(veci))+"  Norm vp: "+string(norm(vp)));
disp("Norm reci: "+string(norm(reci))+"  Norm rp: "+string(norm(rp)));
```

5.6

```
clear all

coefs = 15;
[Cc,Sc]=joshStumpffCoeffs(coefs);
C = @(z) sum(Cc.*joshStumpffZ(z,coefs));
S = @(z) sum(Sc.*joshStumpffZ(z,coefs));

mu_e = 398600;

r1 = [5644,2830,4170]; % km
r2 = [-2240,7320,4980]; % km
dt = 20; % min
dt = dt*60; % sec

z = cross(r1,r2);
z = z(3);
```

```
theta1 = acos(dot(r1,r2)/(norm(r1)*norm(r2)));
theta2 = 2*pi - acos(dot(r1,r2)/(norm(r1)*norm(r2)));

[fz,y,A,z,flag,glag,gdotlag] =
 joshfLambert(norm(r1),norm(r2),dt,theta1,mu_e,Cc,Sc);

v1 = (1/glag)*(r2-flag*r1);
v2 = (1/glag)*(gdotlag*r2-r1);

disp("------------P5.6------------")
disp("My calculations have the following results:")
disp("V1 in km/s: ")
disp(v1)
disp("V2 in km/s: ")
disp(v2)
disp("H/C: We should be using the short side and theta1 < theta2 so this makes
 sense")
```

6.8

```
clear all;

mu_e = 398600;
r_e = 6378; % km

z1 = 300; % km
z3 = 3000; % km
r1 = r_e+z1;
r3 = r_e+z3;

v1 = sqrt(mu_e/r1);
v3 = sqrt(mu_e/r3);

ecc2 = (r3-r1)/(r3+r1);
a2 = (r3+r1)/2;

h2 = sqrt(a2*mu_e*(1-ecc2^2));

vp2 = h2/r1;
va2 = h2/r3;

dv = abs(va2-v3)+abs(vp2-v1);
P2 = (2*pi/sqrt(mu_e))*a2^1.5; % sec
tranfertime = P2/2;
tranfertime = tranfertime/60;

disp("------------P6.8------------")
disp("My calculations have the following results:")
disp("dv [km/s]: "+string(dv))
disp("transit time [s]: "+string(tranfertime))
disp("H/C: transfer time is halff of the tranfer period. This period makes
 sense for something LEO MEOish.")
```

6.23

```
clear all

mu_e = 398600;
r_e = 6378; % km

theta1 = 150; % degrees
theta1 = deg2rad(theta1);
theta2 = 45;% degrees
theta2 = deg2rad(theta2);
ra1 = 18900;%km
rp1 = 8100;%km
a1 = (ra1+rp1)/2;
P1 = (2*pi/sqrt(mu_e))*a1^1.5; % sec

ecc1 = (ra1-rp1)/(ra1+rp1);
Me1 = joshAnomalyCalculator(ecc1,theta1);
n1 = sqrt(mu_e/a1^3);
t1 = Me1/n1; % time since periapse orbit 1 object B

Me2 = joshAnomalyCalculator(ecc1,theta2);
t2 = Me2/n1; % time since periapse orbit 1 object C

P2 = (P1-t1); % time till periapse object c
P2 = P2+t2; % time till rendezvous

h1 = sqrt(a1*mu_e*(1-ecc1^2));
r1_45 = (h1^2/mu_e)/(1+ecc1*cos(theta2)); % at theta 45 what is the radius of
 both orbits
rp2 = r1_45; % at a theta of 45, satalite B makes its location its new
 periapse

a2 = (P2*(sqrt(mu_e)/(2*pi)))^(2/3);
ra2 = a2*2-rp2;
ecc2 = (ra2-rp2)/(ra2+rp2);
h2 = sqrt(a2*mu_e*(1-ecc2^2));
vp2 = h2/rp2;
%
[vaz1_45,vr1_45] = joshVazVr(theta2,ecc1,h1,mu_e); % orignal vaz and vr

vr2 = 0;
vaz2 = vp2;

% v1_45 = sqrt(vaz1_45^2+vr1_45^2)
vp2 = [vaz2,vr2];
v1_45 = [vaz1_45,vr1_45];
dv = norm(v1_45-vp2)*2;

disp("------------P6.23------------")
disp("My calculations have the following results:")
disp("dv [km/s]: "+string(dv));
```

```
disp("H/C: The orbital period used in the calculation makes sense for a MEO
 orbit.")
```

6.25

```
clear all
mu_e = 398600;
r_e = 6378; % km
theta1 = deg2rad(100);

rp1 = 1270+r_e;
vp1 = 9;
[a1,ecc1,~,~,~,~,h1,T1,E1] = joshCOE(rp1,vp1,mu_e,"magnitude");

[vaz1,vr1,gamma1] = joshVazVr(theta1,ecc1,h1,mu_e);

r100 = h1^2/(mu_e*(1+ecc1*cos(theta1)));
ecc2 = .4;
a2 = r100*(1+ecc2*cos(theta1))/(1-ecc2^2);

h2 = sqrt(a2*mu_e*(1-ecc2^2));


[vaz2,vr2,gamma2] = joshVazVr(theta1,ecc2,h2,mu_e);

dgamma = rad2deg(gamma2-gamma1);
dv = norm([vaz2, vr2]-[vaz1, vr1]);

disp("------------P6.25------------")
disp("My calculations have the following results:")
disp("Delta gamma [degrees]: "+string(dgamma))
disp("Delta v [km/s]: "+string(dv))
disp("H/C: We would imagine a moderate delta v for a manuver like this. This
 seems to make sense for a small apseline rotation.")
```

6.31

on paper

6.44

```
clear all
mu_e = 398600;
r_e = 6378; % km

r1 = 300+r_e;
r2 = 600+r_e;

v1 = sqrt(mu_e/r1);
v2 = sqrt(mu_e/r2);

inc = deg2rad(20);
```

```
[dvh2,dvh1,dvh,~,~,~,vt1,vt2] = joshHomann(r1,v1,r2,v2,mu_e);

dvi = sqrt(2*(v2^2)-2*(v2^2)*cos(inc));
dva = dvi+dvh;

dvh1i = joshLawCos(v1,vt1,inc);
dvh2i = joshLawCos(v2,vt2,inc);

dvb = dvh1 + dvh2i;
dvc = dvh2 + dvh1i;

disp("------------P6.44------------")
disp("My calculations have the following results:")

disp("A) dv [km/s]: "+string(dva))
disp("B) dv [km/s]: "+string(dvb))
disp("C) dv [km/s]: "+string(dvc))

disp("H/C: We would expect the lowest delta v to be a combined manuver at a
 greater altitude, this way there is less velocity to change so to speak and a
 small dv will create a larger inc change.")
```

6.47

```
clear all
mu_e = 398600;
r_e = 6378; % km

r0 = [436;6083;2529];
v0 = [-7.340;-.5125;2.497];
m0 = 1000;
X0 = [r0;v0;m0];

options = odeset('RelTol', 1e-8,'AbsTol',1e-8);

tspan = [0,89]*60;%s
[t1,X1] = ode45(@XdotFunCoast,tspan,X0,options);

tspan = [0,120];
X0 = X1(end,:);
[t2,X2] = ode45(@XdotFunBurn,tspan,X0,options);

X = [X1;X2];
t = [t1;t2+t1(end)];

v3 = X(end,4:6);
r3 = X(end,1:3);

% [a,ecc,theta,inc,raan,aop,h,T,E] = joshCOE(r3,v3)

X0 = X2(end,:);
tspan = [0,200]*60;%s
```

```
[t3,X3] = ode45(@XdotFunCoast,tspan,X0,options);

X = [X1;X2;X3];
t = [t1;t2+t1(end);t3+t2(end)+t1(end)];

close all
figure
hold on
plot3(X1(:,1),X1(:,2),X1(:,3))
plot3(X2(:,1),X2(:,2),X2(:,3))
plot3(X3(:,1),X3(:,2),X3(:,3))
title("Simple graph H/C to make sure ODEs worked")

n = length(X);
rmag = zeros(n,1);
for i = 1:n
    rmag(i) = norm([X(i,1),X(i,2),X(i,3)]);
end

[rmax,i] = max(rmag);
zmax = rmax - r_e;
tmax = t(i);
tmax = tmax/60;

disp("------------P6.44------------")
disp("My calculations have the following results:")
disp("Max altitude [km]: "+string(zmax))
disp("Max altitude time since t0 [min]: "+string(tmax))
disp("H/C: the time to get to apogee seems to be within range for 2ish orbits
 in LEO which is what the included graph seems to predict.")
```

dependancies

```
disp("------------Dependancies------------")
disp("My code uses the following functions: ")
depends = matlab.codetools.requiredFilesAndProducts('C:\AERO351\A351HW3\HW3');
disp(depends')
```

functions

```
% 6.47 dX
function dX = XdotFunBurn (t,X)
    mu_e = 398600;
    isp = 300; % s
    g0 =  9.80665; % m/s^2
    g0 = g0/1000; % km/s^2
    T = 10000; % kg.m/s^2
    T = T/1000; % kg.km/s^2

    r = X(1:3);
    v = X(4:6);
    m = X(7);
    a = (-mu_e*r)/norm(r)^3 + (T/m)*(v/norm(v));
```

```
    dm = (-T/(isp*g0));

    dX = [v;a;dm];
end

function dX = XdotFunCoast (t,X)
    mu_e = 398600;
    isp = 300; % s
    g0 =  9.80665; % m/s^2
    g0 = g0/1000; % km/s^2
    T = 0; % kg.m/s^2
    T = T/1000; % kg.km/s^2

    r = X(1:3);
    v = X(4:6);
    m = X(7);
    a = (-mu_e*r)/norm(r)^3 + (T/m)*(v/norm(v));
    dm = (-T/(isp*g0));

    dX = [v;a;dm];
end

% for lamberts
function out = fp_zcheck(z,fp,fpz0)
    if z == 0
         out = fpz0;
    else
        out = fp;
    end
end
```

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```
function [M,E] = joshAnomalyCalculator(ecc,theta)
% M will be Me,Mp or Mh depending on ecc
% E will be Eccentric Anomoly when applicable or F: hyperbolic Ecctric
% anomoly. E will be set to
% values in Rads
arguments
    ecc (1,1) double {mustBeReal}
    theta (1,1) double {mustBeReal}
end

if ecc <1 % Me & E
    E = 2*atan(sqrt((1-ecc)/(1+ecc))*tan(theta/2)); % definintion of E,
 rewriten to solve E
    M = E-ecc*sin(E); % definition of M
elseif ecc > 1 % Mh & F
    E = log((sqrt(ecc+1)+sqrt(ecc-1)*tan(theta/2))/(sqrt(ecc+1)-
sqrt(ecc-1)*tan(theta/2)));
    M = ecc(sinh(F)-F);
else % ecc == 1 Mp
    E = nan; % This is a rare case and E doesnt have a definition for ecc == 1
    M = .5*tan(theta/2)+(1/6)*tan(theta/2)^3;
end
end
```

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```
function [Cx,Cy,Cz] = joshAxisRotation(opt)
arguments
        opt {mustBeMember(opt,{'degree','radian'})} = 'radian'
end


if strcmp(opt,'degree')
Cx = @(theta)...
    [[1 0 0];...
    [0 cosd(theta) sind(theta)];...
    [0 -sind(theta) cosd(theta)]];

Cy = @(theta)...
    [[cosd(theta) 0 -sind(theta)];...
    [ 0 1 0];...
    [sind(theta) 0 cosd(theta)]];

Cz = @(theta)...
    [[cosd(theta) sind(theta) 0];...
    [-sind(theta) cosd(theta) 0];...
    [0 0 1]];
else
Cx = @(theta)...
    [[1 0 0];...
    [0 cos(theta) sin(theta)];...
    [0 -sin(theta) cos(theta)]];

Cy = @(theta)...
    [[cos(theta) 0 -sin(theta)];...
    [ 0 1 0];...
    [sin(theta) 0 cos(theta)]];

Cz = @(theta)...
    [[cos(theta) sin(theta) 0];...
    [-sin(theta) cos(theta) 0];...
    [0 0 1]];
end
end
```

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```
function [a,ecc,theta,inc,raan,aop,h,T,E] = joshCOE(R,V,u,magOrVec)

%%%%%%%%%%%%%%%%%%
% Revamped to do rads and fit new naming convention %
%%%%%%%%%%%%%%%%%%


%COESOATESJOSHUA Takes postion and velocity vector and returns COES, all in
%ECI frame of reffrenece, km and seconds as units and degrees
% a = semi major axis
% ecc = eccentricity
% i = inclination
% raan = right accention acending node
% aop = argument of periapsis
% theta = true anomaly

% will return T in s as a period
% and E (sometimes epsilon) in km^2/s^2 as specific mechanical energy
% h is agular momentum

% magOrVec is a parameter that can be set for vector inputs to return
% vector h and ecc

% scalar entry should only be used if the spacecraft is at apoapse or
% periapse

arguments
    R {mustBeNumeric, mustBeReal}
    V  {mustBeNumeric, mustBeReal}
    u (1,1) {mustBeNumeric, mustBeReal, mustBePositive} = 3.986004418 *
 (10^5) %km^3/s^2
    magOrVec {mustBeMember(magOrVec,{'magnitude','vector'})} = 'magnitude'
end

[m1,n1] = size(R);
[m2,n2] = size(V);

if joshIsOnes([m1 n1 m2 n2])
    magOrVec = 'magnitude';
    R = [0 0 R];
    V = [V 0 0];
    warning("joshCOE will assume that R and V are normal if the inputs are
 scalar ie: the craft is in a circular orbit or is at periapse or apoapse")
elseif (~joshIsOnes([m1 n1] == [m2 n2]))|~((n1==1&m1==3)|(n1==3&m1==1))
    throw(MException("COEsOatesJoshua:invalidInput","R and V must be either
 1x3 vectors or scalars"))
end

% uearth = 3.986004418(8) x 10^14 m^3/s^2
ihat=[1,0,0];
khat=[0,0,1];
```

```
Rm = norm(R);
Vm = norm(V);

%calculate orbital constants
h = cross(R,V); %angular momentum vector
hm = norm(h);
E = ( ( Vm^2 ) / 2) - ( u / Rm ) ; %specfic mechanical energy
%calculate COEs

a = -u / (2 * E ); %semi major axis in km
T = 2*pi*sqrt((a^3)/u); %period in s

e = (1/u) * (((Vm^2)-(u/Rm) ) * R - (dot(R,V) * V)); %eccentricity vector
em = norm (e); %magnitude of e

inc = acos((dot(khat,h))/hm); %inclination
n = cross(khat,h); %node vector
nm = norm(n); %magnitude n

%raan
raan = acos(dot(ihat,n)/nm);
if n(2) < 0  %checks the vector relative to j to see if angle is positive or
 negative
    raan = 360 - raan;
end

%aop
aop = acos(dot(n,e)/(nm*em));
if e(3) < 0
    aop = 360 - aop;
end

%theta
theta = acos(dot(e,R)/(em*Rm));
if(dot(R,V) < 0) % cehck flight path angle to see if it is postive or negative
    theta = 360 -theta;
end

if strcmp(magOrVec, 'magnitude') %for magnitude mode, vectors will not be
 returned
    h = hm;
    e = em;
    if joshIsOnes([m1 n1 m2 n2]) % for scalar inputs it is not possible to
 calculate these values
        theta = NaN;
        inc = NaN;
        raan = NaN;
        aop = NaN;
    end
end
ecc = e;

end
```

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```
function mx = joshCross(m)
% takes a column vector and returns the associated 'cross' matrix such that
% mx*b == cross(m,b)
arguments
    m (3,1)
end
if isa(m,"double") % overloaded to handle either symbolic or double type
 vectors
    mx = zeros(3);
elseif isa(m,"sym")
    syms mx [3 3]
else
    throw(MException("joshCross:invalidInput","m must be type sym or double"))
end
    for i = 1:3
        mx(i,i) = 0;
    end
    mx(1,2) = -m(3);
    mx(1,3) =  m(2);
    mx(2,3) = -m(1);

    mx(2,1) =  m(3);
    mx(3,1) = -m(2);
    mx(3,2) =  m(1);
end
```

Published with MATLAB® R2022a

```
function [isOnes] = joshIsOnes(M)
% takes a value (persumably a logical type matrix) and returns true iff all
% entries are true
[m,n] = size(M);
isOnes = true;
for i = 1:m
    for j = 1:n
        if M(i,j) ~= 1
            isOnes = false;
        end
    end
end
end
```

Published with MATLAB® R2022a

```
function [C,S] = joshStumpffCoeffs(n)
% AERO 351 code
% Generates the first n terms of the stumpff coeffcients for @S(z) and @C(z)
 in a vector

% these coeffs are used for the universal variable approach to orbital
 mechanics

% for use as companion function with joshStrumpffZ
% coeffs should be saved to workspace and reused to save compute time
% @S(z) == sum(S.*Z) == polyval(flip(S),z) : where Z = [z^0 z^1 ... z^n]
% @C(z) == sum(C.*Z) == polyval(flip(C),z) : where Z = [z^0 z^1 ... z^n]
arguments
    n (1,1) {mustBePositive,mustBeInteger} = 15;
end

C = zeros(1,n);
S = C;
for i = 1:n
    k = i-1;
    C(i) = (-1)^k*(1/factorial(2*k+2));
    S(i) = (-1)^k*(1/factorial(2*k+3));
end
end
```

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```
function [Z] = joshStumpffZ(z,n)
% AERO 351 code
% Generates the first n terms of the stumpff coeffcients for @S(z) and @C(z)
 in a vector
% for use as companion function with joshStrumpffCoeffs
% @S(z) == sum(S.*Z) == polyval(flip(S),z) : where S given by (-1)^k*(1/
factorial(2*k+2))
% @C(z) == sum(C.*Z) == polyval(flip(C),z) : where C given by (-1)^k*(1/
factorial(2*k+3))
arguments
    z (1,1)
    n (1,1) {mustBePositive,mustBeInteger} = 15;
end
Z = ones(1,n);
for i = 2:n
    Z(i) = z*Z(i-1);
end
end
```

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```matlab
function [Cx,Cy,Cz] = joshAxisRotation(opt)
arguments
        opt {mustBeMember(opt,{'degree','radian'})} = 'radian'
end


if strcmp(opt,'degree')
Cx = @(theta)...
    [[1 0 0];...
    [0 cosd(theta) sind(theta)];...
    [0 -sind(theta) cosd(theta)]];

Cy = @(theta)...
    [[cosd(theta) 0 -sind(theta)];...
    [ 0 1 0];...
    [sind(theta) 0 cosd(theta)]];

Cz = @(theta)...
    [[cosd(theta) sind(theta) 0];...
    [-sind(theta) cosd(theta) 0];...
    [0 0 1]];
else
Cx = @(theta)...
    [[1 0 0];...
    [0 cos(theta) sin(theta)];...
    [0 -sin(theta) cos(theta)]];

Cy = @(theta)...
    [[cos(theta) 0 -sin(theta)];...
    [ 0 1 0];...
    [sin(theta) 0 cos(theta)]];

Cz = @(theta)...
    [[cos(theta) sin(theta) 0];...
    [-sin(theta) cos(theta) 0];...
    [0 0 1]];
end
end
```

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