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AERO 351 FINAL PROJECT

HOUSEKEEPING

OBJECTS OF INTEREST

IRIDIUM 33 (LEO-1) - Iridium debris 1 24946U 97051C 20312.77658151 .00000096 00000-0 27434-4 0 9994 2 24946 86.3843 127.9418 0008700 151.1544 209.0134 14.33702974211628

IRIDIUM 33 (LEO - 2) - Iridium debris 1 33776U 97051P 20312.80323369 .00000235 00000-0 76976-4 0 9999 2 33776 86.4036 138.4324 0015334 156.4007 214.2811 14.34129899613840

GLONAS (MEO) - Rocket Body 1 13610U 82100H 20312.07351556 .00000096 00000-0 00000-0 0 9997 2 13610 64.0303 137.2256 0008118 199.9412 343.5184 2.14005188297957

INTELSAT 2-F2 (GEO) - Defunt GTO sat 1 02639U 67001A 20312.75954111 -.00000059 00000-0 00000+0 0 9999 2 02639 1.9465 287.8917 0009103 316.2065 67.8614 1.00312972 98739

FINDING R, V VECTORS; COES FROM TLE

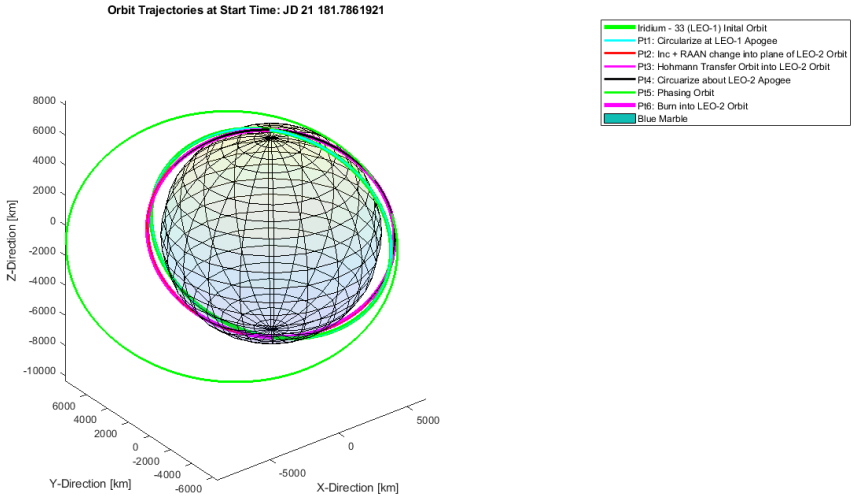
STATE VECTORS

ODE45 CALL FOR ORBIT TRAJECTORY

POSITION OF SATELLITES AT START

LEO1 TO LEO2 TRANSFER

LEO1 TO LEO2 TRANSFER ORBIT PLOTTING



LEO2 TO MEO TRANSFER

MEO TO GEO TRANSFER

FINAL NUMBERS

MISSION DEBRIEF WITH TWO IMPULSE

```
*****************************************

END OF MISSION DEBRIEF WITH 2 IMPULSE

TOTAL DELTA-V REQUIRED [km/s]: 16.695166
```

```
DELTA-V REQUIRED FOR LEO1 TO LEO2 [km/s]: 3.182477
DELTA-V REQUIRED FOR LEO2 TO MEO [km/s]: 4.402169
DELTA-V REQUIRED FOR MEO TO GEO [km/s]: 9.110520

TOTAL TIME REQUIRED [days]: 26.406684

DELTA-T REQUIRED FOR LEO1 TO LEO2 TFR [days]: 0.627558
DELTA-T REQUIRED FOR 5 LEO2 PERIODS [days]: 0.348643
DELTA-T REQUIRED FOR LEO2 TO MEO TFR [days]: 4.791667
DELTA-T REQUIRED FOR 5 MEO PERIODS [days]: 2.336392
DELTA-T REQUIRED FOR MEO TO GEO TFR [days]: 13.666667
DELTA-T REQUIRED FOR 5 GEO PERIODS [days]: 4.984400

INITAL JD WHILE ON LEO-1 OBJECT: JD 21 181.7861921
FINAL JD AFTER 5 GEO PERIODS: JD 21 208.192876

****************************************
```

FIGURE 1: ALL ORBITS AND SATS AT START TIME

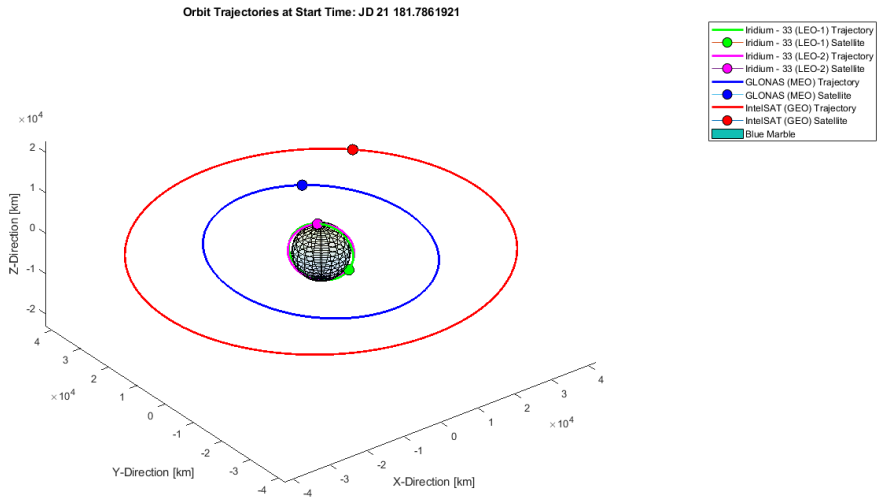


FIGURE 2: LEO1 AND LEO2

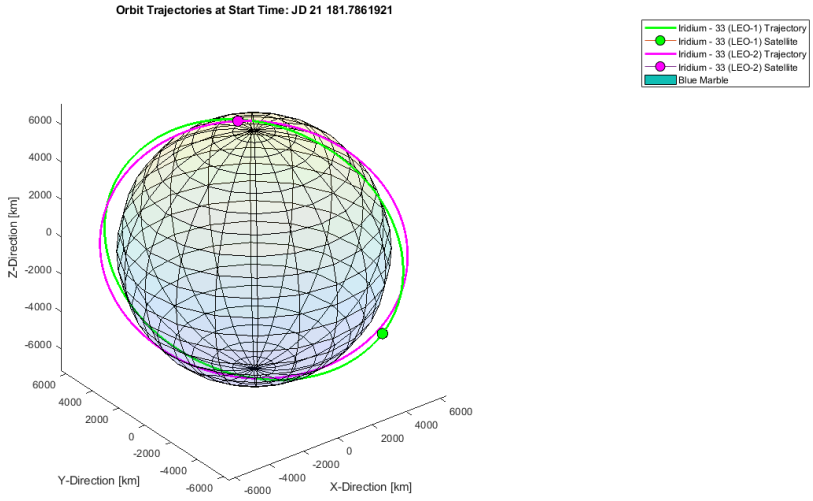


FIGURE 3: RENDEZVOUS AT LEO 2

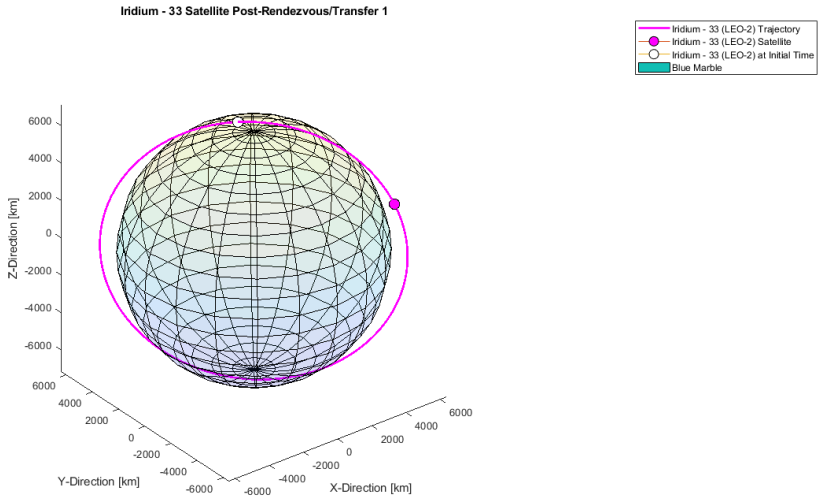


FIGURE 4: LEO2 AND MEO

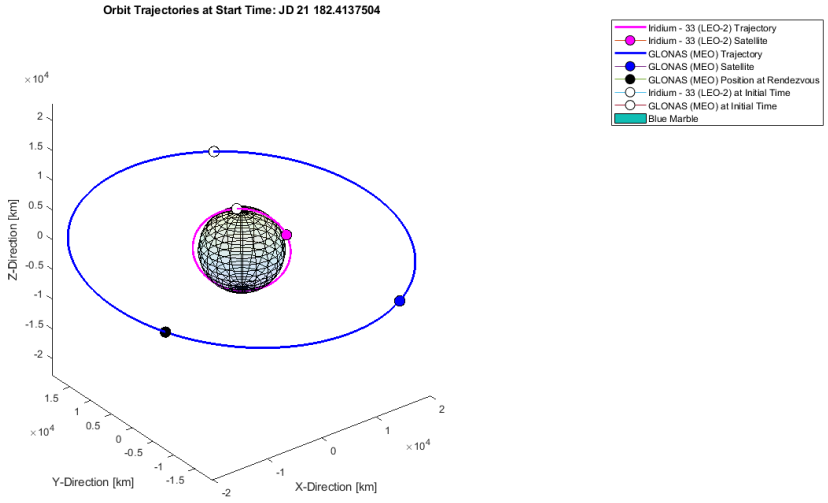


FIGURE 5: RENDEZVOUS AT MEO

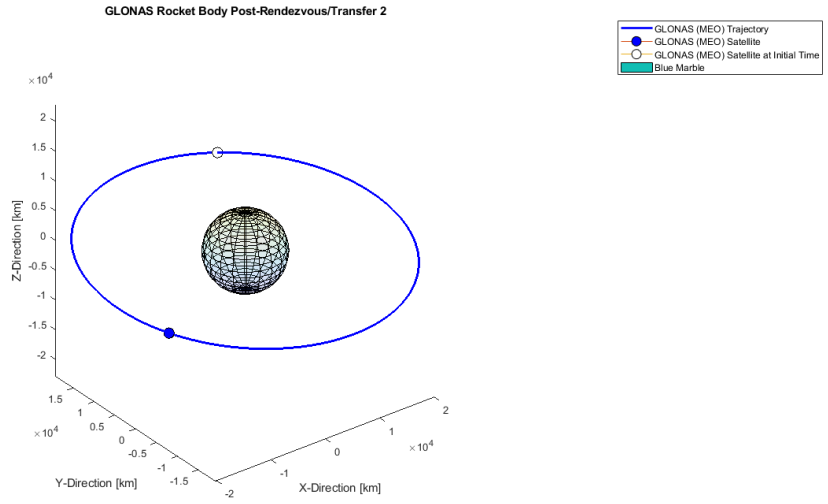


FIGURE 6: MEO AND GEO

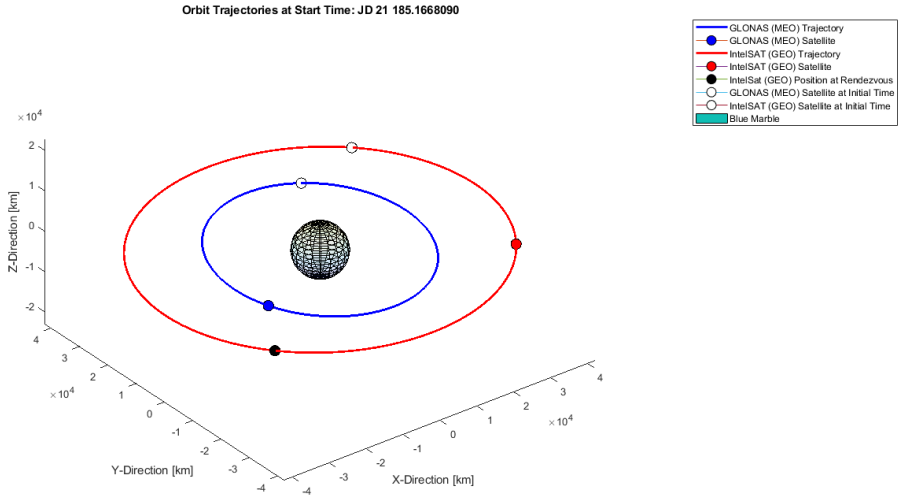
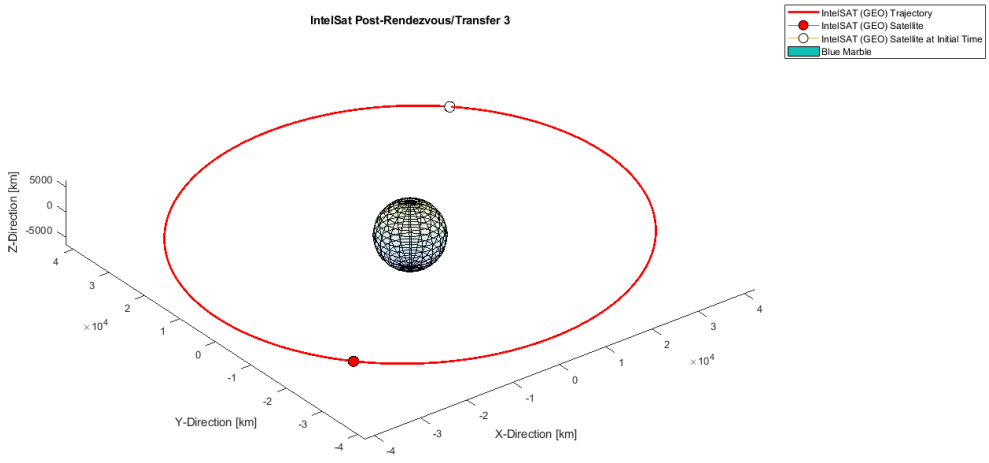


FIGURE 7: RENDEZVOUS AT GEO



functions

Published with MATLAB® R2020b

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AERO 351 FINAL PROJECT

```
% HAYDEN BUSS
% FRANCISCO LEON-GOMEZ
% HECTOR DELGADO MARQUEZ
% GAGANDEEP THAPAR

% FALL QUARTER 2020
```

HOUSEKEEPING

```
clear
clc
close all
muE = 398600;
```

OBJECTS OF INTEREST

IRIDIUM 33 (LEO-1) - Iridium debris 1 24946U 97051C 20312.77658151 .00000096 00000-0 27434-4 0 9994 2 24946 86.3843 127.9418 0008700 151.1544 209.0134 14.33702974211628

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INTELSAT 2-F2 (GEO) - Defunt GTO sat 1 02639U 67001A 20312.75954111 -.00000059 00000-0 00000+0 0 9999 2 02639 1.9465 287.8917 0009103 316.2065 67.8614 1.00312972 98739

```
iri1tle =   [24946  86.3843 127.9418 0008700 151.1544 209.0134
 14.33702974211628];
iri2tle =   [33776  86.4036 138.4324 0015334 156.4007 214.2811
 14.34129899613840];
glonastle = [13610  64.0303 137.2256 0008118 199.9412 343.5184
 2.14005188297957];
inteltle =  [02639   1.9465 287.8917 0009103 316.2065  67.8614
 1.0031297298739];
```

FINDING R, V VECTORS; COES FROM TLE

```
[iri1R, iri1V] =        tle2RV(iri1tle, muE);
[iri2R, iri2V] =        tle2RV(iri2tle, muE);
[glonasR, glonasV] =    tle2RV(glonastle, muE);
[intelR, intelV] =      tle2RV(inteltle, muE);

[iri1h, iri1vr, iri1inc, iri1raan, iri1ecc,...
    iri1arg, iri1TA, iri1ra, iri1rp, iri1a, iri1T] =    RV2COE(iri1R,
 iri1V, muE);
[iri2h, iri2vr, iri2inc, iri2raan, iri2ecc,...
    iri2arg, iri2TA, iri2ra, iri2rp, iri2a, iri2T] =    RV2COE(iri2R,
 iri2V, muE);
[glonash, glonasvr, glonasinc, glonasraan,...
    glonasecc, glonasarg, glonasTA, glonasra,...
    glonasrp, glonasa, glonasT] =
 RV2COE(glonasR, glonasV, muE);
[intelh, intelvr, intelinc, intelraan,...
    intelecc, intelarg, intelTA, intelra,...
    intelrp, intela, intelT] =                          RV2COE(intelR,
 intelV, muE);

[iri1tsp] = TA2t(iri1ecc, iri1TA, iri1h, muE);
```

STATE VECTORS

```
iri1State =     [iri1R;iri1V];
iri2State =     [iri2R;iri2V];
glonasState =   [glonasR;glonasV];
intelState =    [intelR;intelV];
```

ODE45 CALL FOR ORBIT TRAJECTORY

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

iri1tspan =     [0 iri1T];
iri2tspan =     [0 iri2T];
glonastspan =   [0 glonasT];
inteltspan =    [0 intelT];
```

```
[iri1TIME, iri1New] =      ode45(@TwoBody, iri1tspan, iri1State,
 options, muE);
[iri2TIME, iri2New] =      ode45(@TwoBody, iri2tspan, iri2State,
 options, muE);
[glonasTIME, glonasNew] =  ode45(@TwoBody, glonastspan, glonasState,
 options, muE);
[intelTIME, intelNew] =    ode45(@TwoBody, inteltspan, intelState,
 options, muE);
```

POSITION OF SATELLITES AT START

```
tStart = 181.78619214501 + 365.25; % days

tsp1 = TA2t(iri1ecc, iri1TA, iri1h, muE);
tsp1 = tsp1/(24*3600); %days
tsp2 = TA2t(iri2ecc, iri2TA, iri2h, muE);
tsp2 = tsp2/(24*3600);
tsp3 = TA2t(glonasecc, glonasTA, glonash, muE);
tsp3 = tsp3/(24*3600);
tsp4 = TA2t(intelecc, intelTA, intelh, muE);
tsp4 = tsp4/(24*3600);

dT1 = tStart - (312.77658151 - tsp1); % days
dT1 = dT1*24*3600; %seconds

dT2 = tStart - (312.80323369 - tsp2);
dT2 = dT2 * 24*3600;

dT3 = tStart - (312.07351556 - tsp3);
dT3 = dT3 * 24*3600;

dT4 = tStart - (312.75954111 - tsp4);
dT4 = dT4 * 24*3600;

revs1 = dT1/iri1T;
frac1 = (revs1 - floor(revs1))*iri1T;
TA1atStart = t2TA(frac1, iri1h, muE, iri1ecc);

revs2 = dT2/iri2T;
frac2 = (revs2 - floor(revs2))*iri2T;
TA2atStart = t2TA(frac2, iri2h, muE, iri2ecc);

revs3 = dT3/glonasT;
frac3 = (revs3 - floor(revs3))*glonasT;
TA3atStart = t2TA(frac3, glonash, muE, glonasecc);

revs4 = dT4/intelT;
frac4 = (revs4 - floor(revs4))*intelT;
TA4atStart = t2TA(frac4, intelh, muE, intelecc);

[iri1rX, iri1rY, iri1rZ] = TA2Pos(TA1atStart, iri1arg, iri1inc,
 iri1raan, iri1h, muE, iri1ecc);
```

```
[iri2rX, iri2rY, iri2rZ] = TA2Pos(TA2atStart, iri2arg, iri2inc,
 iri2raan, iri2h, muE, iri2ecc);
[glonasrX, glonasrY, glonasrZ] = TA2Pos(TA3atStart, glonasarg,
 glonasinc, glonasraan, glonash, muE, glonasecc);
[intelrX, intelrY, intelrZ] = TA2Pos(TA4atStart, intelarg, intelinc,
 intelraan, intelh, muE, intelecc);
```

LEO1 TO LEO2 TRANSFER

```
% coast in LEO1 until apogee
tsincep = TA2t(iri1ecc, iri1TA, iri1h, muE);
tsp1 = tsincep;
t2Peri = iri1T - tsp1;
t2Apo = t2Peri + iri1T/2;

delT1 = t2Apo;  % delT for first phase in transfer (coast time)
delV1 = 0;      % delV for first phase in transfer (no burn)

% instant burn to circularize with rad = ra of LEO1
va1 = iri1h/iri1ra;
vcirc = sqrt(muE/iri1ra);

delT2 = 0;          % delT for second phase in transfer (instant burn)
delV2 = vcirc-va1;  % delV for second phase in transfer (circularize)

% instant burn to perform inc+raan change
calpha = cosd(iri1inc)*cosd(iri2inc) +
 sind(iri1inc)*sind(iri2inc)*cosd(iri2raan-iri1raan);
alpha = acos(calpha);

delT3 = 0;                      % delT for third phase in transfer
 (instand burn)
delV3 = 2*vcirc*sin(alpha/2);    % delV for third phase in transfer
 (inc+raan change)

% hohmann tfr to circular orbit with rad = ra of LEO2\
rptfr = iri1ra;
ratfr = iri2ra;
vp = sqrt(muE/iri1ra);
va = sqrt(muE/iri2ra);

ecctfr = (ratfr - rptfr)/(ratfr+rptfr);
htfr = sqrt(rptfr*muE*(1+ecctfr));
atfr = (ratfr+rptfr)/2;
Ttfr = 2*pi*atfr^1.5/sqrt(muE);

vDtfr = htfr/rptfr;
vAtfr = htfr/ratfr;
delV4a = vDtfr - vp;
delV4b = va - vAtfr;

delT4 = Ttfr/2;             % delT for fourth phase in transfer
 (hohmann period)
```

```
delV4 = delV4a + delV4b;    % delV for fourth phase in transfer
 (hohmann burns)

% coast from peri-side apse line 1 to apo-side apse line 2

TAi = 0;
TAf = 180+(iri2arg - iri1arg);
delTA = TAf-TAi;
hcirc2 = sqrt(iri2ra*muE);

[tToTAf] = TA2t(0, delTA, hcirc2, muE);

delT5 = tToTAf;     % delT for fifth phase in transfer (coast time)
delV5 = 0;          % delV for fifth phase in transfer (no burn)

% burn to decircularize into LEO2 orbit at apogee
va2 = iri2h/iri2ra;
vcirc2 = sqrt(muE/iri2ra);

delT6 = 0;              % delT for sixth phase in transfer (instant
 burn)
delV6 = vcirc2 - va2;   % delV for sixth phase in transfer
 (decircularize)

% coast into perigee of LEO2 orbit

delT7 = iri2T/2; % delT for seventh phase in transfer (coast time)
delV7 = 0;       % delV for seventh phase in transfer (no burn)

% calculating TA of object 2 since start

Tpast = delT1+delT2+delT3+delT4+delT5+delT6+delT7;
revs = Tpast/iri2T;
tInNew = (revs - floor(revs))*iri2T;
TANew = t2TA(tInNew, iri2h, muE, iri2ecc);

% choose to rendezvous with object 2 after it completes orbit + 1
 extra
% orbit

tRemain = iri2T - tInNew;
tRendez = tRemain + (1*iri2T);

% find phasing orbit such that 1 period = time til rendezvous
 (tRendez)

rpPhase = iri2rp;
aPhase = (tRendez*sqrt(muE)/(2*pi))^(2/3); %need ra; rpPhase = rpLeo2
raPhase = 2*aPhase - rpPhase;
eccPhase = (raPhase - rpPhase)/(raPhase + rpPhase);
hPhase = sqrt(rpPhase*muE*(1+eccPhase));

% get onto Phase Orbit
```

```
vDphase = hPhase/rpPhase;
vi = iri2h/iri2rp;

delT8 = 0;              % delT for eigth phase in transger (instant
 burn)
delV8 = vDphase - vi;   % delV for eigth phase in transfer (get onto
 phase orbit)

% stay on Phase Orbit for 1 period

 TPhase = 2*pi*aPhase^1.5 / sqrt(muE);

 delT9 = TPhase;    % delT for ninth phase in transfer (coast time)
 delV9 = 0;         % delV for ninth phase in transfer (no burn)

% get off Phase Orbit back on to LEO2 (Rendezvous'd with Object 2!)

vAphase = hPhase/rpPhase;
vf = iri2h/iri2rp;

delT10 = 0;             % delT for tenth phase in transfer (instant
 burn)
delV10 = vAphase - vf;  % delV for tenth phase in transfer (get off
 phase orbit)

% stick with object 2 for 5 periods

delT11 = 5*iri2T;   % stay in orbit with object for 5 periods
delV11 = 0;         % no burn; coasting

delT = [delT1 delT2 delT3 delT4 delT5 delT6 delT7 delT8 delT9 delT10
 delT11];
DeltaT = sum(delT);

delV = [delV1 delV2 delV3 delV4 delV5 delV6 delV7 delV8 delV9 delV10
 delV11];
DeltaV = sum(delV);

% final JD
% JD = 21 182.4137503600938
[iri2FrX, iri2FrY, iri2FrZ] = TA2Pos(0,iri2arg,iri2inc,iri2raan,
 iri2h, muE, iri2ecc);
[iri2FvX, iri2FvY, iri2FvZ] = TA2Vel(0, iri2arg, iri2inc, iri2raan,
 iri2h, muE, iri2ecc);

% R, V vectors after rendezvous1
RpostTFR1 = [iri2FrX, iri2FrY, iri2FrZ];
VpostTFR1 = [iri2FvX, iri2FvY, iri2FvZ];

% calc position of Object 3 at JD = 21 182.4137503600938

tsincep = TA2t(glonasecc, glonasTA, glonash, muE);
tperirendez = tsincep +((181.78619214501 + 365.25 -
 312.07351556)*24*3600)  + DeltaT;
```

```
revs = tperirendez/glonasT;
tInNew = (revs-floor(revs))*glonasT;
TANEW = t2TA(tInNew, glonash, muE, glonasecc);
[glonasrXpost1, glonasrYpost1, glonasrZpost1] =
 TA2Pos(TANEW,glonasarg,glonasinc,glonasraan, glonash, muE,
 glonasecc);
[glonasvXpost1, glonasvYpost1, glonasvZpost1] =
 TA2Vel(TANEW,glonasarg,glonasinc,glonasraan, glonash, muE,
 glonasecc);
```

LEO1 TO LEO2 TRANSFER ORBIT PLOTTING

```
% circularize at orbit 1 ra
timespan = [0 2*iri1T];
[X Y Z] = sphere;
X = X*6378;
Y = Y*6378;
Z = Z*6378;
circ1h = vcirc*iri1ra;
[circ1rX, circ1rY, circ1rZ] = TA2Pos(180,iri1arg,iri1inc,iri1raan,
 circ1h, muE, 0);
[circ1vX, circ1vY, circ1vZ] = TA2Vel(180,iri1arg,iri1inc,iri1raan,
 circ1h, muE, 0);
statecirc1= [circ1rX;circ1rY;circ1rZ;circ1vX;circ1vY;circ1vZ];
options = odeset('RelTol',1e-8,'AbsTol',1e-8);
[~,circrF] = ode45(@TwoBody, timespan, statecirc1, options, muE);

% circular orbit w/ r = orbit2ra
circ2h = vcirc2*iri2ra;
[circ2rX, circ2rY, circ2rZ] = TA2Pos(180,iri2arg,iri2inc,iri2raan,
 circ2h, muE, 0);
[circ2vX, circ2vY, circ2vZ] = TA2Vel(180,iri2arg,iri2inc,iri2raan,
 circ2h, muE, 0);
statecirc2= [circ2rX;circ2rY;circ2rZ;circ2vX;circ2vY;circ2vZ];
options = odeset('RelTol',1e-8,'AbsTol',1e-8);
[~,circ2rF] = ode45(@TwoBody, timespan, statecirc2, options, muE);

%inc+ raan change into plane of orbit 2
[circ3rX, circ3rY, circ3rZ] = TA2Pos(180,iri2arg,iri2inc,iri2raan,
 circ1h, muE, 0);
[circ3vX, circ3vY, circ3vZ] = TA2Vel(180,iri2arg,iri2inc,iri2raan,
 circ1h, muE, 0);
statecirc3= [circ3rX;circ3rY;circ3rZ;circ3vX;circ3vY;circ3vZ];
options = odeset('RelTol',1e-8,'AbsTol',1e-8);
[~,circ3rF] = ode45(@TwoBody, timespan, statecirc3, options, muE);

% hohmann from neworbit1 to orbit2
[hohrX, hohrY, hohrZ] = TA2Pos(0,iri2arg,iri2inc,iri2raan, htfr, muE,
 ecctfr);
[hohvX, hohvY, hohvZ] = TA2Vel(0,iri2arg,iri2inc,iri2raan, htfr, muE,
 ecctfr);
hoh= [hohrX;hohrY;hohrZ;hohvX;hohvY;hohvZ];
options = odeset('RelTol',1e-8,'AbsTol',1e-8);
```

```
[~,hohrF] = ode45(@TwoBody, timespan, hoh, options, muE);

% phasing orbit
[phaserX, phaserY, phaserZ] = TA2Pos(0,iri2arg,iri2inc,iri2raan,
 hPhase, muE, eccPhase);
[phasevX, phasevY, phasevZ] = TA2Vel(0,iri2arg,iri2inc,iri2raan,
 hPhase, muE, eccPhase);
phase= [phaserX;phaserY;phaserZ;phasevX;phasevY;phasevZ];
options = odeset('RelTol',1e-8,'AbsTol',1e-8);
[~,phaserF] = ode45(@TwoBody, timespan, phase, options, muE);

figure('units','normalized','outerposition',[0.25 0.25 0.75 0.75])
plot3(iri1New(:,1),iri1New(:,2),iri1New(:,3), 'g', 'linewidth', 4);
hold on
plot3(circrF(:,1),circrF(:,2),circrF(:,3),'c', 'linewidth', 2)
plot3(circ3rF(:,1),circ3rF(:,2),circ3rF(:,3),'r','linewidth',2)
plot3(hohrF(:,1),hohrF(:,2),hohrF(:,3),'m','linewidth',2)
plot3(circ2rF(:,1),circ2rF(:,2),circ2rF(:,3),'k', 'linewidth', 2)
plot3(phaserF(:,1),phaserF(:,2),phaserF(:,3),'g','linewidth',2)
plot3(iri2New(:,1),iri2New(:,2),iri2New(:,3),'m', 'linewidth', 4);
surf(X,Y,Z);
alpha 0.1;
axis equal;
hold off

legend('Iridium - 33 (LEO-1) Inital Orbit',...
    'Pt1: Circularize at LEO-1 Apogee',...
    'Pt2: Inc + RAAN change into plane of LEO-2 Orbit',...
    'Pt3: Hohmann Transfer Orbit into LEO-2 Orbit',...
    'Pt4: Circuarize about LEO-2 Apogee',...
    'Pt5: Phasing Orbit',...
    'Pt6: Burn into LEO-2 Orbit',...
    'Blue Marble')
xlabel('X-Direction [km]');
ylabel('Y-Direction [km]');
zlabel('Z-Direction [km]');
title('Orbit Trajectories at Start Time: JD 21 181.7861921')
```

LEO2 TO MEO TRANSFER

```
Rchase2 = RpostTFR1';
Vchase2 = VpostTFR1';
Rtarget3 = [glonasrXpost1;glonasrYpost1;glonasrZpost1];
Vtarget3 = [glonasvXpost1;glonasvYpost1;glonasvZpost1];

[dVTfr2, dTTfr2, Vbounce2] = twoImpulse(Rchase2, Vchase2, Rtarget3,
 Vtarget3);

timespan = [0 dTTfr2]; %sec

state = [Rtarget3;Vtarget3]; %state vectorR3
options = odeset('RelTol',1e-8,'AbsTol',1e-8);
[~,Rf] = ode45(@TwoBody, timespan, state, options, muE);
```

```
dTpers = 5*glonasT;

dTtotal = dTTfr2 + dTpers;
```

MEO TO GEO TRANSFER

```
% dTTfr2 measured starting at end of TFR1
% Need pos,vel of GLONAS, INTEL at end of TFR + 5 periods

% Pos of MEO post-(tfr2+periods)

timespan = [0 dTtotal]; %sec
state = [Rtarget3;Vtarget3]; %state vectorR3
options = odeset('RelTol',1e-8,'AbsTol',1e-8);
[~,statenew] = ode45(@TwoBody, timespan, state, options, muE);
RGloPreTFR3 =[statenew(end,1);statenew(end,2);statenew(end,3)];
VGloPreTFR3 = [statenew(end,4);statenew(end,5);statenew(end,6)];

% Pos of GEO post-(tfr2 + periods)

dTtotal = dTtotal + DeltaT; %Time since start of mission

[intelvX, intelvY, intelvZ] = TA2Vel(TA4atStart, intelarg, intelinc,
 intelraan, intelh, muE, intelecc);

Rintel = [intelrX;intelrY;intelrZ];
Vintel = [intelvX;intelvY;intelvZ];

timespan = [0 dTtotal]; %sec
state = [Rintel;Vintel]; %state vectorR3
options = odeset('RelTol',1e-8,'AbsTol',1e-8);
[~,statenew] = ode45(@TwoBody, timespan, state, options, muE);
RIntelPreTFR3 =[statenew(end,1);statenew(end,2);statenew(end,3)];
VIntelPreTFR3 = [statenew(end,4);statenew(end,5);statenew(end,6)];

% function
Rchase = RGloPreTFR3;
Vchase = VGloPreTFR3;
Rtarget = RIntelPreTFR3;
Vtarget = VIntelPreTFR3;
[dVTfr3, dTTfr3, Vbounce3] = twoImpulse(Rchase, Vchase, Rtarget,
 Vtarget);

timespan = [0 dTTfr3]; %sec
state = [Rtarget;Vtarget]; %state vectorR3
options = odeset('RelTol',1e-8,'AbsTol',1e-8);
[tnew,Rf4] = ode45(@TwoBody, timespan, state, options, muE);
```

FINAL NUMBERS

```
DVFINAL = DeltaV+dVTfr2+dVTfr3;
DTFINAL = DeltaT+dTTfr2+(5*glonasT)+dTTfr3+(5*intelT);
```

```
JDFINAL = 181.7861921 + (DTFINAL/(24*3600));
```

MISSION DEBRIEF WITH TWO IMPULSE

```
fprintf('*****************************************\n\n')
fprintf('END OF MISSION DEBRIEF WITH 2 IMPULSE \n\n')
fprintf('TOTAL DELTA-V REQUIRED [km/s]: %f\n\n',DVFINAL);
fprintf('DELTA-V REQUIRED FOR LEO1 TO LEO2 [km/s]: %f\n',DeltaV);
fprintf('DELTA-V REQUIRED FOR LEO2 TO MEO [km/s]: %f\n',dVTfr2);
fprintf('DELTA-V REQUIRED FOR MEO TO GEO [km/s]: %f\n\n',dVTfr3);
fprintf('TOTAL TIME REQUIRED [days]: %f\n\n',DTFINAL/(24*3600));
fprintf('DELTA-T REQUIRED FOR LEO1 TO LEO2 TFR [days]: %f\n',DeltaT/
(24*3600));
fprintf('DELTA-T REQUIRED FOR 5 LEO2 PERIODS [days]: %f\n',(5*iri2T)/
(24*3600));
fprintf('DELTA-T REQUIRED FOR LEO2 TO MEO TFR [days]: %f\n',dTTfr2/
(24*3600));
fprintf('DELTA-T REQUIRED FOR 5 MEO PERIODS [days]: %f\n',(5*glonasT)/
(24*3600));
fprintf('DELTA-T REQUIRED FOR MEO TO GEO TFR [days]: %f\n',dTTfr3/
(24*3600));
fprintf('DELTA-T REQUIRED FOR 5 GEO PERIODS [days]: %f\n\n',
(5*intelT)/(24*3600));
fprintf('INITAL JD WHILE ON LEO-1 OBJECT: JD 21 181.7861921\n')
fprintf('FINAL JD AFTER 5 GEO PERIODS: JD 21 %f\n',JDFINAL)
fprintf('\n*****************************************\n')
```

FIGURE 1: ALL ORBITS AND SATS AT START TIME

```
[X,Y,Z] = sphere;
X = X*6378;
Y = Y*6378;
Z = Z*6378;

figure('units','normalized','outerposition',[0.25 0.25 0.75 0.75])
plot3(iri1New(:,1),iri1New(:,2),iri1New(:,3), 'g', 'linewidth', 2);
hold on
plot3(iri1rX, iri1rY, iri1rZ, '-
o','markeredgecolor','k','markerfacecolor','g', 'markersize', 10)
plot3(iri2New(:,1),iri2New(:,2),iri2New(:,3),'m', 'linewidth', 2);
plot3(iri2rX, iri2rY, iri2rZ, '-
o','markeredgecolor','k','markerfacecolor','m', 'markersize', 10)
plot3(glonasNew(:,1),glonasNew(:,2),glonasNew(:,3),'b', 'linewidth',
 2);
plot3(glonasrX, glonasrY, glonasrZ, '-
o','markeredgecolor','k','markerfacecolor','b', 'markersize', 10)
plot3(intelNew(:,1),intelNew(:,2),intelNew(:,3),'r', 'linewidth', 2);
plot3(intelrX, intelrY, intelrZ, '-
o','markeredgecolor','k','markerfacecolor','r', 'markersize', 10)
```

```
surf(X,Y,Z);
alpha 0.1;
axis equal;
hold off

legend('Iridium - 33 (LEO-1) Trajectory', 'Iridium - 33 (LEO-1)
 Satellite',...
    'Iridium - 33 (LEO-2) Trajectory', 'Iridium - 33 (LEO-2)
 Satellite',...
    'GLONAS (MEO) Trajectory', 'GLONAS (MEO) Satellite',...
    'IntelSAT (GEO) Trajectory', 'IntelSAT (GEO) Satellite',...
    'Blue Marble')
xlabel('X-Direction [km]');
ylabel('Y-Direction [km]');
zlabel('Z-Direction [km]');
title('Orbit Trajectories at Start Time: JD 21 181.7861921');
```

FIGURE 2: LEO1 AND LEO2

```
figure('units','normalized','outerposition',[0.25 0.25 0.75 0.75])
plot3(iri1New(:,1),iri1New(:,2),iri1New(:,3), 'g', 'linewidth', 2);
hold on
plot3(iri1rX, iri1rY, iri1rZ, '-
o','markeredgecolor','k','markerfacecolor','g', 'markersize', 10)
plot3(iri2New(:,1),iri2New(:,2),iri2New(:,3),'m', 'linewidth', 2);
plot3(iri2rX, iri2rY, iri2rZ, '-
o','markeredgecolor','k','markerfacecolor','m', 'markersize', 10)
surf(X,Y,Z);
alpha 0.1;
axis equal;
hold off

legend('Iridium - 33 (LEO-1) Trajectory','Iridium - 33 (LEO-1)
 Satellite','Iridium - 33 (LEO-2) Trajectory', 'Iridium - 33 (LEO-2)
 Satellite','Blue Marble')
xlabel('X-Direction [km]');
ylabel('Y-Direction [km]');
zlabel('Z-Direction [km]');
title('Orbit Trajectories at Start Time: JD 21 181.7861921')
```

FIGURE 3: RENDEZVOUS AT LEO 2

```
figure('units','normalized','outerposition',[0.25 0.25 0.75 0.75])
plot3(iri2New(:,1),iri2New(:,2),iri2New(:,3),'m', 'linewidth', 2);
hold on
plot3(iri2FrX, iri2FrY, iri2FrZ, '-
o','markeredgecolor','k','markerfacecolor','m', 'markersize', 10)
plot3(iri2rX, iri2rY, iri2rZ,'-
o','markeredgecolor','k','markerfacecolor','w', 'markersize', 10)
surf(X,Y,Z);
alpha 0.1;
axis equal;
```

```
hold off

legend('Iridium - 33 (LEO-2) Trajectory', 'Iridium - 33 (LEO-2)
 Satellite',...
    'Iridium - 33 (LEO-2) at Initial Time',...
    'Blue Marble')
xlabel('X-Direction [km]');
ylabel('Y-Direction [km]');
zlabel('Z-Direction [km]');
title('Iridium - 33 Satellite Post-Rendezvous/Transfer 1')
```

FIGURE 4: LEO2 AND MEO

```
figure('units','normalized','outerposition',[0.25 0.25 0.75 0.75])
plot3(iri2New(:,1),iri2New(:,2),iri2New(:,3),'m', 'linewidth', 2);
hold on
plot3(iri2FrX, iri2FrY, iri2FrZ, '-
o','markeredgecolor','k','markerfacecolor','m', 'markersize', 10)
plot3(glonasNew(:,1),glonasNew(:,2),glonasNew(:,3),'b', 'linewidth',
 2);
plot3(glonasrXpost1, glonasrYpost1, glonasrZpost1, '-
o','markeredgecolor','k','markerfacecolor','b', 'markersize', 10)
plot3(Rf(end,1),Rf(end,2),Rf(end,3), '-
o','markeredgecolor','k','markerfacecolor','k', 'markersize', 10)
plot3(iri2rX, iri2rY, iri2rZ,'-
o','markeredgecolor','k','markerfacecolor','w', 'markersize', 10)
plot3(glonasrX, glonasrY, glonasrZ, '-
o','markeredgecolor','k','markerfacecolor','w', 'markersize', 10)
surf(X,Y,Z);
alpha 0.1;
axis equal;
hold off

legend('Iridium - 33 (LEO-2) Trajectory', 'Iridium - 33 (LEO-2)
 Satellite',...
    'GLONAS (MEO) Trajectory', 'GLONAS (MEO) Satellite',...
    'GLONAS (MEO) Position at Rendezvous',...
    'Iridium - 33 (LEO-2) at Initial Time',...
    'GLONAS (MEO) at Initial Time',...
    'Blue Marble')
xlabel('X-Direction [km]');
ylabel('Y-Direction [km]');
zlabel('Z-Direction [km]');
title('Orbit Trajectories at Start Time: JD 21 182.4137504');
```

FIGURE 5: RENDEZVOUS AT MEO

```
figure('units','normalized','outerposition',[0.25 0.25 0.75 0.75])
plot3(glonasNew(:,1),glonasNew(:,2),glonasNew(:,3),'b', 'linewidth',
 2);
hold on
plot3(Rf(end,1), Rf(end,2), Rf(end,3), '-
o','markeredgecolor','k','markerfacecolor','b', 'markersize', 10)
```

```
plot3(glonasrX, glonasrY, glonasrZ, '-
o','markeredgecolor','k','markerfacecolor','w', 'markersize', 10)
surf(X,Y,Z);
alpha 0.1;
axis equal;
hold off

legend('GLONAS (MEO) Trajectory', 'GLONAS (MEO) Satellite',...
    'GLONAS (MEO) Satellite at Initial Time',...
    'Blue Marble')
xlabel('X-Direction [km]');
ylabel('Y-Direction [km]');
zlabel('Z-Direction [km]');
title('GLONAS Rocket Body Post-Rendezvous/Transfer 2');
```

FIGURE 6: MEO AND GEO

```
figure('units','normalized','outerposition',[0.25 0.25 0.75 0.75])
plot3(glonasNew(:,1),glonasNew(:,2),glonasNew(:,3),'b', 'linewidth',
 2);
hold on
plot3(RGloPreTFR3(1), RGloPreTFR3(2), RGloPreTFR3(3), '-
o','markeredgecolor','k','markerfacecolor','b', 'markersize', 10)
plot3(intelNew(:,1),intelNew(:,2),intelNew(:,3),'r', 'linewidth', 2);
plot3(RIntelPreTFR3(1), RIntelPreTFR3(2), RIntelPreTFR3(3),'-
o','markeredgecolor','k','markerfacecolor','r', 'markersize', 10)
plot3(Rf4(end,1),Rf4(end,2),Rf4(end,3),'-
o','markeredgecolor','k','markerfacecolor','k', 'markersize', 10)
plot3(glonasrX, glonasrY, glonasrZ, '-
o','markeredgecolor','k','markerfacecolor','w', 'markersize', 10)
plot3(intelrX, intelrY, intelrZ, '-
o','markeredgecolor','k','markerfacecolor','w', 'markersize', 10)
surf(X,Y,Z);
alpha 0.1;
axis equal;
hold off

legend('GLONAS (MEO) Trajectory', 'GLONAS (MEO) Satellite',...
    'IntelSAT (GEO) Trajectory', 'IntelSAT (GEO) Satellite',...
    'IntelSat (GEO) Position at Rendezvous',...
    'GLONAS (MEO) Satellite at Initial Time',...
    'IntelSAT (GEO) Satellite at Initial Time',...
    'Blue Marble')
xlabel('X-Direction [km]');
ylabel('Y-Direction [km]');
zlabel('Z-Direction [km]');
title('Orbit Trajectories at Start Time: JD 21 185.1668090');
```

FIGURE 7: RENDEZVOUS AT GEO

```
figure('units','normalized','outerposition',[0.25 0.25 0.75 0.75])
plot3(intelNew(:,1),intelNew(:,2),intelNew(:,3),'r', 'linewidth', 2);
hold on
```

```
plot3(Rf4(end,1), Rf4(end,2), Rf4(end,3),'-
o','markeredgecolor','k','markerfacecolor','r', 'markersize', 10)
plot3(intelrX, intelrY, intelrZ, '-
o','markeredgecolor','k','markerfacecolor','w', 'markersize', 10)
surf(X,Y,Z);
alpha 0.1;
axis equal;
hold off

legend('IntelSAT (GEO) Trajectory', 'IntelSAT (GEO) Satellite',...
    'IntelSAT (GEO) Satellite at Initial Time',...
    'Blue Marble')
xlabel('X-Direction [km]');
ylabel('Y-Direction [km]');
zlabel('Z-Direction [km]');
title('IntelSat Post-Rendezvous/Transfer 3');
```

functions

```
function [R,V] = tle2RV(CP7, muE)

inc = CP7(2);
raan = CP7(3);
ecc = CP7(4) /(10^7);
arg = CP7(5);
Me = CP7(6);
n = CP7(7);

Me = deg2rad(Me);

if Me < pi
    E_0 = Me - ecc;
else
    E_0 = Me + ecc;
end

f = @(E) Me - E + ecc*sin(E);
fp = @(E) -1 + ecc*sin(E);

E_1 = E_0 - (f(E_0)/fp(E_0));

err = abs(E_1 - E_0);

while err > 1*10^-8
    E_0 = E_1;
    E_1 = E_0 - (f(E_0)/fp(E_0));
    err = abs(E_1 - E_0);
end

E_1 = mod(E_1, 2*pi);

TA = 2*atand((sqrt((1+ecc)/(1-ecc)) * tan(E_1/2)));
```

```
T = (n/(24*3600))^-1;

a = (T*sqrt(muE)/(2*pi))^(2/3);

r = a*(1-ecc^2)/(1+ecc*cosd(TA));

h = sqrt(a*muE*(1-ecc^2));

Rmatr = r*[cosd(TA);sind(TA);0];
Vmatr = muE/h * [-sind(TA); ecc + cosd(TA); 0];

Q1 = [cosd(arg) sind(arg) 0; -sind(arg) cosd(arg) 0; 0 0 1];
Q2 = [1 0 0; 0 cosd(inc) sind(inc); 0 -sind(inc) cosd(inc)];
Q3 = [cosd(raan) sind(raan) 0; -sind(raan) cosd(raan) 0; 0 0 1];

Q = Q1*Q2*Q3;

R = Q'*Rmatr;
V = Q'*Vmatr;

end

function dstate = TwoBody(time, state, mu)

x = state(1); % defining position elements in state vector
y = state(2);
z = state(3);
vx = state(4); % defining velocity elements in state vector
vy = state(5);
vz = state(6);

rad = norm([x y z]); % def. of "radius"

ax = -mu*x/rad^3; % two body equation
ay = -mu*y/rad^3;
az = -mu*z/rad^3;

dstate = [vx; vy; vz; ax; ay; az]; % new state vector

end

function [h,vr,inc,raan,ecc,arg,TA,ra,rp,a,T] = RV2COE(R,V, muE)

hbar = cross(R,V);
h = norm(hbar);
vr = dot(R,V)/norm(R);

inc = acosd(hbar(3)/h);

N = cross([0 0 1], hbar);
raan = acosd(N(1)/norm(N));

if N(2) < 0
    raan = 360-raan;
```

```
end

eccbar = cross(V,hbar)/muE - R/norm(R);
ecc = norm(eccbar);

arg = acosd((dot(N,eccbar))/(norm(N)*ecc));

TA = acosd((dot(eccbar, R))/(norm(R)*ecc));
if vr < 0
    TA = 360-TA;
end

ra = h^2/muE * (1/(1-ecc));
rp = h^2/muE * (1/(1+ecc));
a = (ra+rp)/2;

T = 2*pi*a^1.5 / sqrt(muE);

end

function [rX, rY, rZ] = TA2Pos(TA,arg,inc,raan, h, muE, ecc)

Q1 = [cosd(arg) sind(arg)   0;...
    -sind(arg)  cosd(arg)   0;...
    0           0           1];

Q2 = [1 0           0;...
    0   cosd(inc)   sind(inc);...
    0   -sind(inc)  cosd(inc)];

Q3 = [cosd(raan)    sind(raan)  0;...
    -sind(raan)     cosd(raan)  0;...
    0               0           1];

Q = Q1*Q2*Q3;

Rmatr = h^2/(muE*(1+ecc*cosd(TA))) * [cosd(TA);sind(TA);0];

R = Q'*Rmatr;
rX = R(1);
rY = R(2);
rZ = R(3);


end

function [vX, vY, vZ] = TA2Vel(TA, arg, inc, raan, h, muE, ecc)

Q1 = [cosd(arg) sind(arg)   0;...
    -sind(arg)  cosd(arg)   0;...
    0           0           1];

Q2 = [1 0           0;...
    0   cosd(inc)   sind(inc);...
```

```
    0   -sind(inc)  cosd(inc)];

Q3 = [cosd(raan)    sind(raan)  0;...
    -sind(raan)     cosd(raan)  0;...
    0               0           1];

Q = Q1*Q2*Q3;

Vmatr = muE/h * [-sind(TA); ecc + cosd(TA); 0];
V = Q'*Vmatr;

vX = V(1);
vY = V(2);
vZ = V(3);

end

function [tsp] = TA2t(ecc, TA, h, muE)

E = 2*atan((sqrt((1-ecc)/(1+ecc)) * tand(TA/2)));

E = mod(E,2*pi);

Me = E - ecc*sin(E);

tsp = Me*h^3 / (muE^2 * (1-ecc^2)^1.5);

end

function [TA] = t2TA(t, h, muE, ecc)

Me = muE^2 * (1-ecc^2)^1.5 * t /h^3;

f = @(E) Me - E+ecc*sin(E);
fp = @(E) -1 + ecc*cos(E);

if Me < pi
    E_0 = Me - ecc;
else
    E_0 = Me + ecc;
end

E_1 = E_0 - (f(E_0)/fp(E_0));
err = abs(E_1 - E_0);

while err > 1*10^-8
    E_0 = E_1;
    E_1 = E_0 - (f(E_0)/fp(E_0));
    err = abs(E_1 - E_0);
end

E_1 = mod(E_1, 2*pi);

inner = tan(E_1/2);
```

```
inner = sqrt((1+ecc)/(1-ecc)) * inner;

TA = 2*atand(inner);

TA = mod(TA, 360);

end

function [V1, V2] = Lambert(R1, R2, delT, tol, muE)

r1 = norm(R1);
r2 = norm(R2);

traj = cross(R1,R2);
delTA = acosd((dot(R1,R2))/(r1*r2));

if traj(3) < 0
    delTa = 360-delTA;
end

A = sind(delTA)*sqrt((r1*r2)/(1-cosd(delTA)));
Z_0 = 1;

C = @(z) (1-cos(sqrt(z)))/z;
S = @(z) (sqrt(z) - sin(sqrt(z)))/((sqrt(z))^3);

y = @(z) r1 + r2 + (A*z*S(z)-A)/(sqrt(C(z)));
T = @(z) A*sqrt(y(z)/muE);

F = @(z) ((y(z)/C(z))^1.5)*S(z) + A*sqrt(y(z)) - sqrt(muE)*delT;
Fp = @(z) (y(z)/C(z))^1.5 * (1/(2*z)*(C(z) - (3*S(z)/(2*C(z)))) +
 (3*(S(z))^2 / (4* ((C(z))))) + A/8 * (3*S(z)/C(z) * sqrt(y(z)) +
 A*(sqrt(C(z)/y(z))));

Z_1 = Z_0 - (F(Z_0)/Fp(Z_0));
err = abs(Z_1 - Z_0);

while err > tol
    Z_0 = Z_1;
    Z_1 = Z_0 - (F(Z_0)/Fp(Z_0));

    err = abs(Z_1 - Z_0);
end

f = @(z) 1-y(z)/r1;
fdot = @(z) sqrt(muE)/(r1*r2) * sqrt(y(z)/C(z))*(z*S(z) - 1);
g = @(z) A*sqrt(y(z)/muE);
gdot = @(z) 1- y(z)/r2;

V1 = 1/(g(Z_1)) * (R2 - (f(Z_1)*R1));
V2 = 1/(g(Z_1)) * (gdot(Z_1)*R2 - R1);

end
```

```
function [dVTfr, dTTfr, Vbounce] = twoImpulse(Rchase, Vchase, Rtarget,
 Vtarget)

ihat = Rtarget/norm(Rtarget);
jhat = Vtarget/norm(Vtarget);
khat = cross(ihat,jhat);

Q = [ihat';jhat';khat'];

delR = Rchase - Rtarget;

nTarget = norm(Vtarget)/norm(Rtarget);
raantarget =  nTarget*khat;

delV = Vchase - Vtarget - cross(raantarget, delR);

delR0 = Q*delR;
delV0min = Q*delV;

dv = zeros(500,5);

for i = 1:500

    dv(i,1) = i;

    t = i*3600;

Phirr = [4-3*cos(nTarget*t) 0 0; 6*(sin(nTarget*t) - nTarget*t) 1 0; 0
 0 cos(nTarget*t)];

Phirv = [sin(nTarget*t)/nTarget 2*(1-cos(nTarget*t))/nTarget 0;
 2*(cos(nTarget*t) - 1)/nTarget (4*sin(nTarget*t) - 3*nTarget*t)/
nTarget 0; 0 0 sin(nTarget*t)/nTarget];

Phivr = [3*nTarget *sin(nTarget*t) 0 0; 6*nTarget*(cos(nTarget*t) -1)
 0 0; 0 0 -nTarget*sin(nTarget*t)];

Phivv = [cos(nTarget*t) 2*sin(nTarget*t) 0; -2*sin(nTarget*t)
 -4*cos(nTarget*t)-3 0; 0 0 cos(nTarget*t)];

delvI = -inv(Phirv)*Phirr*delR0;

delv0plus = Phivr*delR0 + Phivv*delvI;

delvFmin = Phivr*delR0 + Phivv*delv0plus;

deltavI = delv0plus - delV0min;
deltavF = [0;0;0] - delvFmin;

DELTAV = norm(deltavI) + norm(deltavF);

dv(i,2) = deltavI(1);
dv(i,3) = deltavI(2);
dv(i,4) = deltavI(3);
```

```
dv(i,5) = DELTAV;
end

[val,idx] = min(dv(:,5));% t = 59hour

dVTfr = val; % km/s
dTTfr = idx*3600; % sec
delVF = [dv(idx,2);dv(idx,3);dv(idx,4)];
Vbounce = Vchase + delVF;

end
```

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