Problem 1

```
addpath(genpath(fileparts(which('pathfile.m'))))
interr = 'latex';
% interr = 'none';
set(groot,'defaulttextinterpreter',interr);
set(groot, 'defaultAxesTickLabelInterpreter',interr);
set(groot, 'defaultLegendInterpreter',interr);
R_E = 6378.1363;
R_M = 1738.2;
mu_E = 398600.4415;
mu_M = 4902.8005821478;
a_M = 384400.00; % moon SMA around Earth
```

Part a)

Hohmann Transfer Characterisitcs

```
rp_T_mag = 250 + R_E, ra_T_mag = a_M
```

```
rp_T_mag = 6.6281e+03
ra_T_mag = 384400
```

```
a_T = (rp_T_mag + ra_T_mag)/2
```

```
a_T = 1.9551e+05
```

```
e_T = 1 - rp_T_mag/a_T
```

```
e_T = 0.9661
```

```
v1_n_mag = sqrt(mu_E*(2/rp_T_mag - 1/a_T))
```

```
v1_n_mag = 10.8737
```

```
v1_n = [v1_n_mag 0]'
```

```
v1_n = 2×1
   10.8737
         0
```

```
v2_0_mag = sqrt(mu_E*(2/ra_T_mag - 1/a_T))
```

```
v2_0_mag = 0.1875
```

```
v2_0_R = [0 v2_0_mag]'
```

```
v2_0_R = 2×1
         0
    0.1875
```

```
n_T = sqrt(mu_E/a_T^3)
```

```
n_T = 7.3030e-06
```

Moon Orbit about Earth

```
v_M_mag = sqrt((mu_E)/a_M)
```

```
v_M_mag = 1.0183
```

```
v_M_R = [0,v_M_mag]'
```

```
v_M_R = 2×1
         0
    1.0183
```

Departure Parking Orbit

```
r1_mag = 250 + R_E
```

```
r1_mag = 6.6281e+03
```

```
v1_0_mag = sqrt(mu_E/r1_mag)
```

```
v1_0_mag = 7.7548
```

```
v1_0 = v1_0_mag * [1 0]'
```

```
v1_0 = 2×1
    7.7548
         0
```

```
dv1 = v1_n-v1_0, dv1_mag = norm(dv1)
```

```
dv1 = 2×1
    3.1188
         0
dv1_mag = 3.1188
```

Arrival Parking orbit

```
rp_M = 195 + R_M
```

```
rp_M = 1.9332e+03
```

Arrival Hyperbolic Orbit

```
v_inf_M = v2_0_R - v_M_R
```

```
v_inf_M = 2×1
         0
   -0.8308
```

```
v_inf_M_mag = norm(v_inf_M)
```

```
v_inf_M_mag = 0.8308
```

```
v2_n_mag = sqrt(mu_M/rp_M)
```

```
v2_n_mag = 1.5925
```

```
dv2_mag = sqrt(v_inf_M_mag^2 + 2*mu_M/rp_M) - v2_n_mag
```

```
dv2_mag = 0.8080
```

Total

```
dvtotal_mag = dv1_mag + dv2_mag
```

```
dvtotal_mag = 3.9268
```

Post Encounter Orbit

```
a_h = -mu_M/v_inf_M_mag^2
```

```
a_h = -7.1030e+03
```

```
e_h = 1 - rp_M/a_h
```

```
e_h = 1.2722
```

```
delta = 2*(asin(1/e_h)),delta_deg = rad2deg(delta)
```

```
delta = 1.8088
delta_deg = 103.6376
```

```
ths_inf = acos(-1/e_h), ths_inf_deg = rad2deg(ths_inf)
```

```
ths_inf = 2.4752
ths_inf_deg = 141.8188
```

```
v2_n_mag = sqrt(v_M_mag^2 + v_inf_M_mag^2 - 2*v_M_mag*v_inf_M_mag*cos(delta))
```

```
v2_n_mag = 1.4581
```

```
gamma_2_n = asin(v_inf_M_mag/v2_n_mag * sin(delta)), gamma_2_n_deg = rad2deg(gamma_2_n)
```

```
gamma_2_n = 0.5868
gamma_2_n_deg = 33.6223
```

```
v2_n_R = v2_n_mag*[sin(gamma_2_n);cos(gamma_2_n)]
```

```
v2_n_R = 2×1
    0.8074
    1.2142
```

```
v_2_0_R = [0 v2_0_mag]'
```

```
v_2_0_R = 2×1
         0
    0.1875
```

```
dveq_R = v2_n_R - v_2_0_R
```

```
dveq_R = 2×1
    0.8074
    1.0267
```

```
dveq_mag = norm(dveq_R)
```

```
dveq_mag = 1.3061
```

```
ths_2_n = atan((ra_T_mag * v2_n_mag^2 / mu_E)*sin(gamma_2_n)*cos(gamma_2_n)...
    /((ra_T_mag * v2_n_mag^2 / mu_E)*cos(gamma_2_n)^2-1))
```

```
ths_2_n = 1.1512
```

```
ths_2_n_deg = rad2deg(ths_2_n)
```

```
ths_2_n_deg = 65.9585
```

```
iCr2 = [cos(pi), -sin(pi); sin(pi) cos(pi)]
```

```
iCr2 = 2×2
   -1.0000   -0.0000
    0.0000   -1.0000
```

```
v2_0 = iCr2 * v2_0_R
```

```
v2_0 = 2×1
   -0.0000
   -0.1875
```

```
v2_n = iCr2 * v2_n_R
```

```
v2_n = 2×1
   -0.8074
   -1.2142
```

```
dveq = v2_n - v2_0
```

```
dveq = 2×1
   -0.8074
   -1.0267
```

```
a_post = -mu_E*(v2_n_mag^2 - 2*mu_E/ra_T_mag)^-1
```

```
a_post = -7.6283e+06
```

```
e_post = sqrt((ra_T_mag * v2_n_mag^2/mu_E -1)^2*cos(gamma_2_n)^2+sin(gamma_2_n)^2)
```

```
e_post = 1.0352
```

```
rp_post = a_post*(1-e_post)
```

```
rp_post = 2.6853e+05
```

```
dv_d = -dveq, dv_d_mag = norm(dv_d)
```

```
dv_d = 2×1
    0.8074
    1.0267
dv_d_mag = 1.3061
```

```
v2_d = v2_0
```

```
v2_d = 2×1
   -0.0000
   -0.1875
```

```
v2_o = v2_n
```

```
v2_o = 2×1
   -0.8074
   -1.2142
```

```
dgamma2 = 0 - gamma_2_n
```

```
dgamma2 = -0.5868
```

```
[alpha,beta] = alphabeta(norm(v2_o),norm(v2_d),norm(-dveq),dgamma2)
```

```
alpha = 3.0620
beta = 0.0796
```

```
alpha_deg = rad2deg(alpha), beta_deg = rad2deg(beta)
```

```
alpha_deg = 175.4411
beta_deg = 4.5589
```

Part b)

Transfer Orbit Characteritics

```
trans_angle = 173 * pi / 180;

r1_mag = R_E + 150
```

```
r1_mag = 6.5281e+03
```

```
r2_mag = a_M
```

```
r2_mag = 384400
```

```
ta1 = 0
```

```
ta1 = 0
```

```
ta2 = trans_angle
```

```
ta2 = 3.0194
```

```
e_T = (r2_mag/r1_mag - 1)*(1-r2_mag/r1_mag * cos(ta2))^-1
```

```
e_T = 0.9737
```

```
a_T = r1_mag/(1-e_T)
```

```
a_T = 2.4858e+05
```

```
rp = r1_mag
```

```
rp = 6.5281e+03
```

```
ra = a_T*(1+e_T)
```

```
ra = 4.9064e+05
```

```
n = sqrt(mu_E/a_T^3)
```

```
n = 5.0940e-06
```

```
period = 2*pi/n, period_hr = period/3600, period_day = period/3600/24
```

```
period = 1.2335e+06
period_hr = 342.6253
period_day = 14.2761
```

```
[TOF_T,dt1,dt2] = timeofflight(ta1,ta2,a_T,e_T,r1_mag,mu_E)
```

```
TOF_T = 2.6708e+05
dt1 = 0
dt2 = 2.6708e+05
```

```
TOF_T_day = TOF_T/3600/24
```

```
TOF_T_day = 3.0912
```

```
energy_T = -mu_E/(2*a_T)
```

```
energy_T = -0.8017
```

```
n_M = sqrt(mu_E/a_M^3)
```

```
n_M = 2.6491e-06
```

```
phase = pi - n_M*TOF_T, phase_deg = rad2deg(phase)
```

```
phase = 2.4341
phase_deg = 139.4630
```

```
v1_0_mag = sqrt(mu_E/r1_mag)
```

```
v1_0_mag = 7.8140
```

```
v1_n_mag = sqrt(mu_E*(2/r1_mag - 1/a_T))
```

```
v1_n_mag = 10.9779
```

```
dv1_mag = v1_n_mag - v1_0_mag
```

```
dv1_mag = 3.1639
```

Part c)

```
r2_mag
```

```
r2_mag = 384400
```

```
v2_0_mag = sqrt(mu_E*(2/r2_mag - 1/a_T))
```

```
v2_0_mag = 0.6859
```

```
h_T = sqrt(mu_E*a_T*(1-e_T^2))
```

```
h_T = 7.1665e+04
```

```
gamma2_0 = asin(mu_E*e_T/v2_0_mag/h_T * sin(ta2)), gamma2_0_deg = rad2deg(gamma2_0)
```

```
gamma2_0 = 1.2955
gamma2_0_deg = 74.2271
```

```
pi-gamma2_0
```

```
ans = 1.8461
```

```
gamma2_0_check = acos(sqrt(mu_E*a_T*(1-e_T^2))/r2_mag/v2_0_mag)
```

```
gamma2_0_check = 1.2955
```

```
v2_n_mag = v2_0_mag
```

```
v2_n_mag = 0.6859
```

```
gamma2_n = -gamma2_0
```

```
gamma2_n = -1.2955
```

```
c = r2_mag*v2_n_mag^2/mu_E;
e_T2 = sqrt((c - 1)^2 * cos(gamma2_n)^2 + sin(gamma2_n)^2)
```

```
e_T2 = 0.9737
```

```
ta2_n = -ta2
```

```
ta2_n = -3.0194
```

```
ta2_n_deg = rad2deg(ta2_n)
```

```
ta2_n_deg = -173
```

```
dw = 2*pi + (ta2_n - ta2)
```

```
dw = 0.2443
```

```
v2_0 = v2_0_mag*[sin(gamma2_0); cos(gamma2_0)]
```

```
v2_0 = 2×1
    0.6600
    0.1864
```

```
v2_n = v2_n_mag*[sin(gamma2_n); cos(gamma2_n)]
```

```
v2_n = 2×1
   -0.6600
    0.1864
```

```
dv2_eq = v2_n-v2_0
```

```
dv2_eq = 2×1
   -1.3201
         0
```

```
dv2_eq_mag = norm(dv2_eq)
```

```
dv2_eq_mag = 1.3201
```

```
dgamma = gamma2_n - gamma2_0, dgamma_deg = rad2deg(dgamma)
```

```
dgamma = -2.5910
dgamma_deg = -148.4542
```

```
[alpha,beta] = alphabeta(v2_0_mag,v2_n_mag,dv2_eq,dgamma), alpha = - alpha
```

```
alpha = 2.8663
beta = 0.2753
alpha = -2.8663
```

```
alpha_deg = rad2deg(alpha)
```

```
alpha_deg = -164.2271
```

```
beta_deg = rad2deg(beta)
```

```
beta_deg = 15.7729
```

```
v_M_mag = sqrt(mu_E/a_M)
```

```
v_M_mag = 1.0183
```

```
v_M = v_M_mag*[0;1]
```

```
v_M = 2×1
         0
    1.0183
```

```
v2_inf_0 = v2_0 - v_M
```

```
v2_inf_0 = 2×1
    0.6600
   -0.8319
```

```
v2_inf_mag = norm(v2_inf_0)
```

```
v2_inf_mag = 1.0619
```

```
v2_inf_n = v2_n - v_M
```

```
v2_inf_n = 2×1
   -0.6600
   -0.8319
```

```
a_h = -mu_M/v2_inf_mag^2
```

```
a_h = -4.3478e+03
```

```
L = acos(dot(v2_inf_n,v2_inf_0)/v2_inf_mag^2)
```

```
L = 1.3414
```

```
% delta = pi-L
delta = 2*asin(v2_0_mag/v2_inf_mag * sin(gamma2_0))
```

```
delta = 1.3414
```

```
delta_deg = rad2deg(delta)
```

```
delta_deg = 76.8594
```

```
e_h = 1/sin(delta/2)
```

```
e_h = 1.6089
```

```
rp_h = a_h*(1-e_h)
```

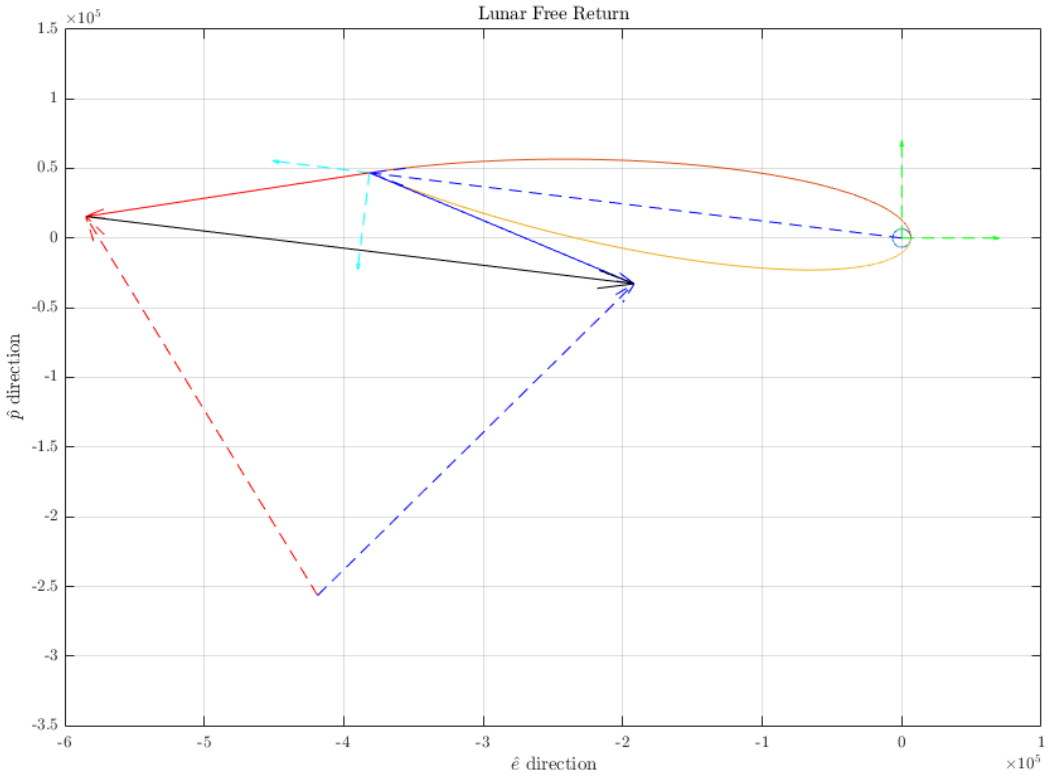
```
rp_h = 2.6472e+03
```

```
alt_p = rp_h - R_M
```

```
alt_p = 909.0458
```

Part d)

```
% plotorbit(ai,ei,ths1,ths2,rotate) % plot orbit inputs
plotorbit(rp,0,0,2*pi,0) % parking orbit
hold on
% plotorbit(a_M,0,0,2*pi,0) % Moon orbit
plotorbit(a_T,e_T,0,ta2,0)
plotorbit(a_T,e_T,-ta2,0,dw)
plotunit([0,0],0,'g--',10)
plotpos(a_T,e_T,ta2,'b--',0,10)
plotvel(a_T,e_T,ta2,v2_0,'r',0,0,3e5)
plotvel(a_T,e_T,ta2,v2_n,'b',0,0,3e5)
plotvel(a_T,e_T,ta2,dv2_eq,'k',[1;v2_0],0,3e5)
plotvel(a_T,e_T,ta2,v2_inf_0,'r--',[1;v_M],0,3e5)
plotvel(a_T,e_T,ta2,v2_inf_n,'b--',[1;v_M],0,3e5)
xlim([-6 1]*1e5),ylim([-3.5 1.5]*1e5)
set(gcf,'position',[0,0,1000,1000])
title('Lunar Free Return')
xlabel('$\hat{e}$ direction')
ylabel('$\hat{p}$ direction')
```


Lunar Free Return
×10^5
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-6
-5
-4
-3
-2
-1
0
1
×10^5
p̂ direction
ê direction