Thomas Todaro
Professor Hart
ME 356
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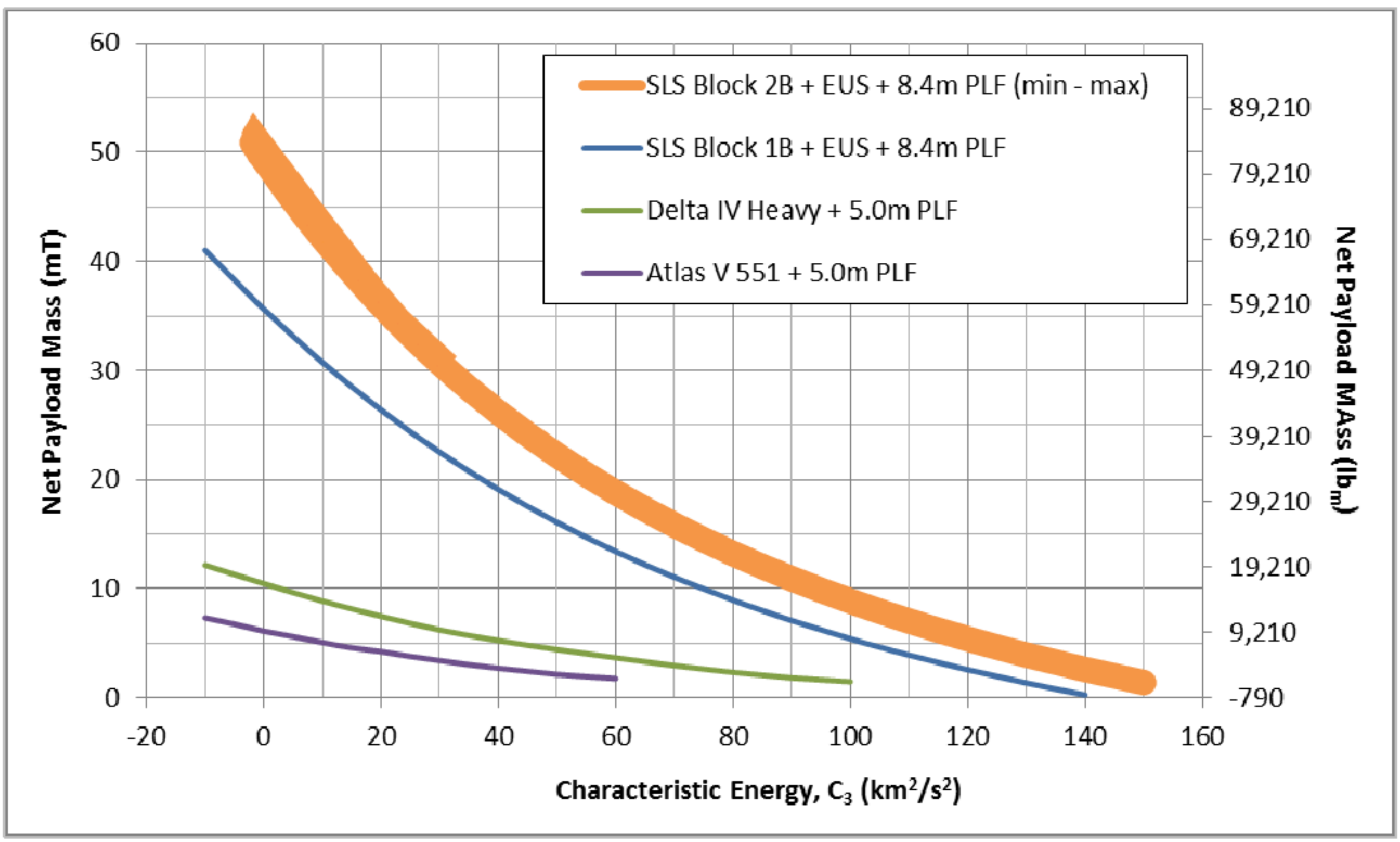
Project 2- Earth to Saturn Mission

1) **Launch Vehicle Data**

Using the Ames Trajectory Browser along with the following C3 vs Payload Mass chart from Lecture 18, I found that the necessary C3 for this mission is 108.6 km^2/sec^2 and that the maximum C3 of the Delta IV Heavy is 100 km^2/sec^2. This means that the Delta IV Heavy is too small of a launch vehicle for this mission and would likely only support a payload of <1000 kg. In terms of C3 and payload mass, my suggestion for another launch vehicle would be the SLS block 1B. The SLS would be able to deliver to Saturn with plenty of mass capacity, approximately 4 metric tons. Assuming the fuel mass would be 50% of the total payload mass and the Specific Impulse approximately 300 seconds, the maximum, reasonable delta V would be 2.03924 km/sec.



2) Matlab Analysis

Using Matlab and building off of example code 8.8, I have determined that the necessary Delta V for our mission requirements. The values are as follows:

```
Delta V Earth to Saturn Transfer (km/s) = 7.44657
Delta V to Capture Circular about Saturn (km/s) = 4.22988
Delta V to Lower Periapsis (km/s) = 2.89504
```

```
clear all; clc
global mu
mu  = 1.327124e11;
deg = pi/180;

%...Data declaration for Example 8.8:

%...Departure
planet_id = 3;
year      = 2029;
month     = 7;
day       = 29;
hour      = 0;
minute    = 0;
second    = 0;
depart = [planet_id  year  month  day  hour  minute  second];

%...Arrival
planet_id = 6;
year      = 2034;
month     = 7;
day       = 25;
hour      = 0;
minute    = 0;
second    = 0;
arrive = [planet_id  year  month  day  hour  minute  second];
```

In the code above, I took example 8.8 from class and adjusted the planet and date data to reflect the specifications of this mission. This includes the departure date of July 29, 2029, the arrival date of July 25, 2034, and the targeted planet, Saturn.

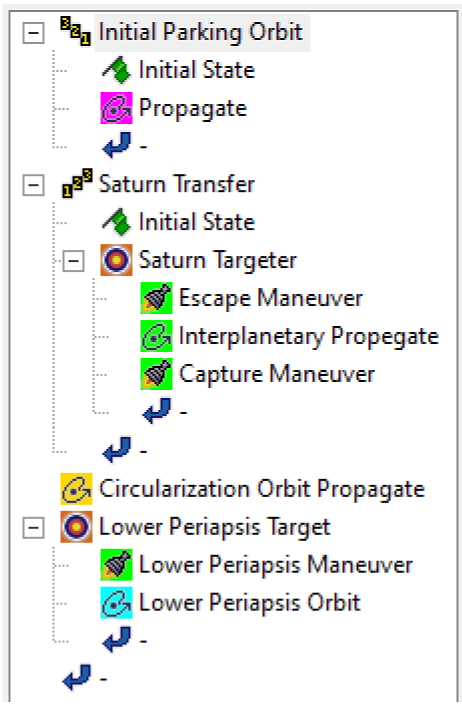
The following code is what I added to the results of example 8.8. It calculates the delta V's of Earth escape, Saturn capture/circularization, and the lowering periapsis maneuver in that order, based on the Vinf data from 8.8. Additionally, I manually included the delta V data from STK to calculate percent difference for comparison.

```
%Thomas Todaro
%Project 2 Matlab Calulations
%Built Using Example 8.8

%Earth to Saturn Transfer Dveta V Calculation
muearth=3.986*10^5;
rp=200+6378;                              %km
vp=sqrt(norm(vinf1)^2+2*muearth/rp);      %km/s
vc=sqrt(muearth/rp);                      %km/s
deltaVTransfer=vp-vc;                     %km/s

%Saturn Capture and Circularization Orbit Delta V Calculation
muSaturn=3.7931187*10^7;
rpSaturn=1200000;                                             %km
vphyperbola=sqrt((norm(vinf2))^2+2*muSaturn/rpSaturn);        %km/s
vpcirc=sqrt(muSaturn/rpSaturn);
%km/s
deltaVCapture=+vphyperbola-vpcirc;                            %km/s
deltaVTotal=deltaVTransfer+deltaVCapture;                     %km/s

%Saturn Periapsis Lowering Manuever
a=(1200000+160000)/2;                                         %km
deltaVLower=vpcirc-sqrt(muSaturn*(2/1200000-1/a));            %km/s

%Percentage Difference from STK Answers Calculation
percentage1=((deltaVTransfer-7.39785)/deltaVTransfer)*100;
percentage2=((deltaVCapture-0.19481)/deltaVCapture)*100;
percentage3=((deltaVLower-2.89481)/deltaVLower)*100;


fprintf('\n')
fprintf('\n  Delta V Earth to Saturn Transfer (km/s) = %g',...
                                                          deltaVTransfer)
fprintf('\n  Delta V to Capture Circular about Saturn (km/s) = %g',...
                                                          deltaVCapture)
fprintf('\n  Delta V to Lower Periapsis (km/s) = %g',...
                                                          deltaVLower)
fprintf('\n')
fprintf('\n')
fprintf('\n')
```

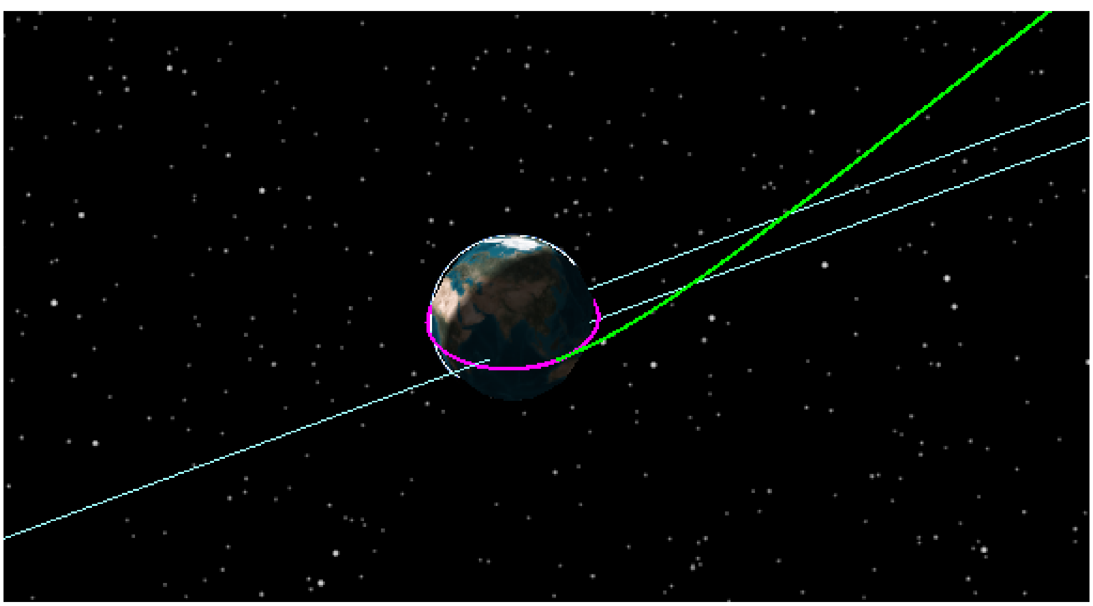
3) STK Analysis

Using STK and building the scenario from scratch, I determined the required Delta V for each maneuver. The values are as follows:

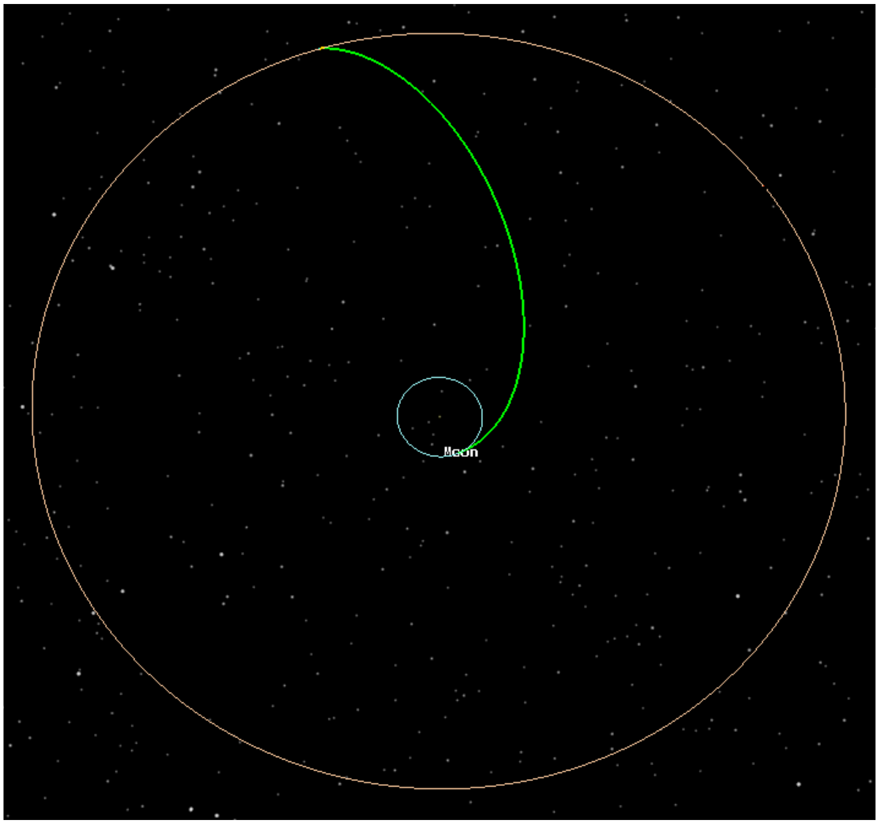
- Earth to Saturn Transfer Orbit: 7.39785 km/s
- Saturn Injection and Circularization Maneuver: 194.81 m/s
- Lowering of the Saturnian Periapsis: 2.89481 km/s



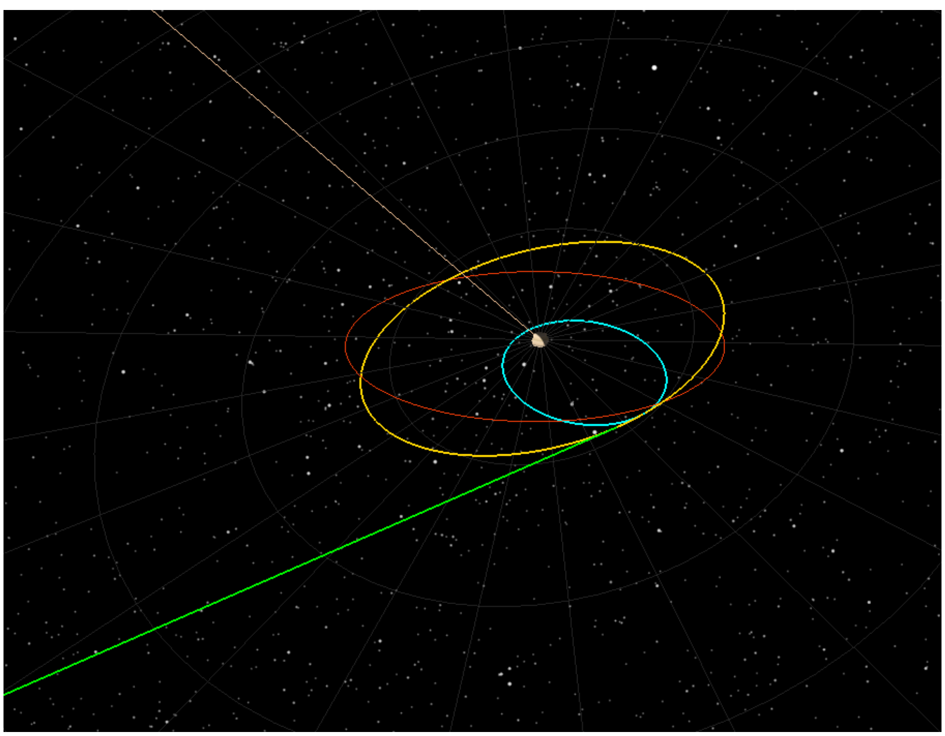
This is the mission control sequence for my STK scenario. The initial step was to create an Earth to Saturn Lambert Transfer sequence. This created the path from Earth to Saturn, as well as the required delta V's for the escape and capture maneuvers. The next step was to do a reverse sequence to simulate the parking orbit the satellite leaves from. Last, I performed a propagation of the capture orbit for approximately 1 period, then added a target sequence to guide a maneuver to lower the radius of periapsis of the capture orbit from 1,200,000 km to 160,000 km.



STK Figure 1: Earth parking orbit and escape maneuver



STK Figure 2: Earth to Saturn trajectory



STK Figure 3: Saturn Injection and Lowered Periapsis Elliptical Orbit
*Note: The red orbit displayed here is the Titan orbit about Saturn for reference.

Conclusion

The data received through STK and Matlab are extremely similar in all except the circularization maneuver. Using Matlab, I compared the values from both softwares to solve for percentage differences. These values are the following:

```
Percentage Differences
  Delta V Earth to Saturn Transfer (Percent) = 0.654204
  Delta V to Capture Circular about Saturn (Percent) = 95.3944
  Delta V to Lower Periapsis (Percent) = 0.00798272
```

The error seen in the second maneuver is likely due to the limitations of the patched conics calculation style of Matlab, whereas STK can more precisely calculate the orbital path geometrically. This implies that the actual maneuver delta V is likely closer to the STK solution.

Outside of calculation, one limitation of this project's parameters is that it would be impossible to inject into an equatorial orbit to Titan. This means that adjusting the inclination to match Titan would require another maneuver and more delta V, meaning more fuel. A solution to this would be to launch and arrive at a different date where the transfer orbit and Titanian orbit are in the same plane, allowing for the satellite to inject directly into an equatorial orbit.

Another limitation to this particular project is that the reasonable, maximum delta V from part 1 does not exceed the required delta V for the complete Saturn maneuvers. This can be solved by using higher Isp thrusters, however, the drawback to that is thrusters of higher Isp would have to be ion or nuclear thrusters. These require very long thrust times to make substantial maneuvers and would likely not be fast enough to capture a circular orbit as specified. Another potential solution would be to change the mission requirements to settle for less expensive orbital changes.