DOTNET Framework Design Environment for System Integration of Planetary Probe Payload Sensors and Interplanetary Trajectory Optimization

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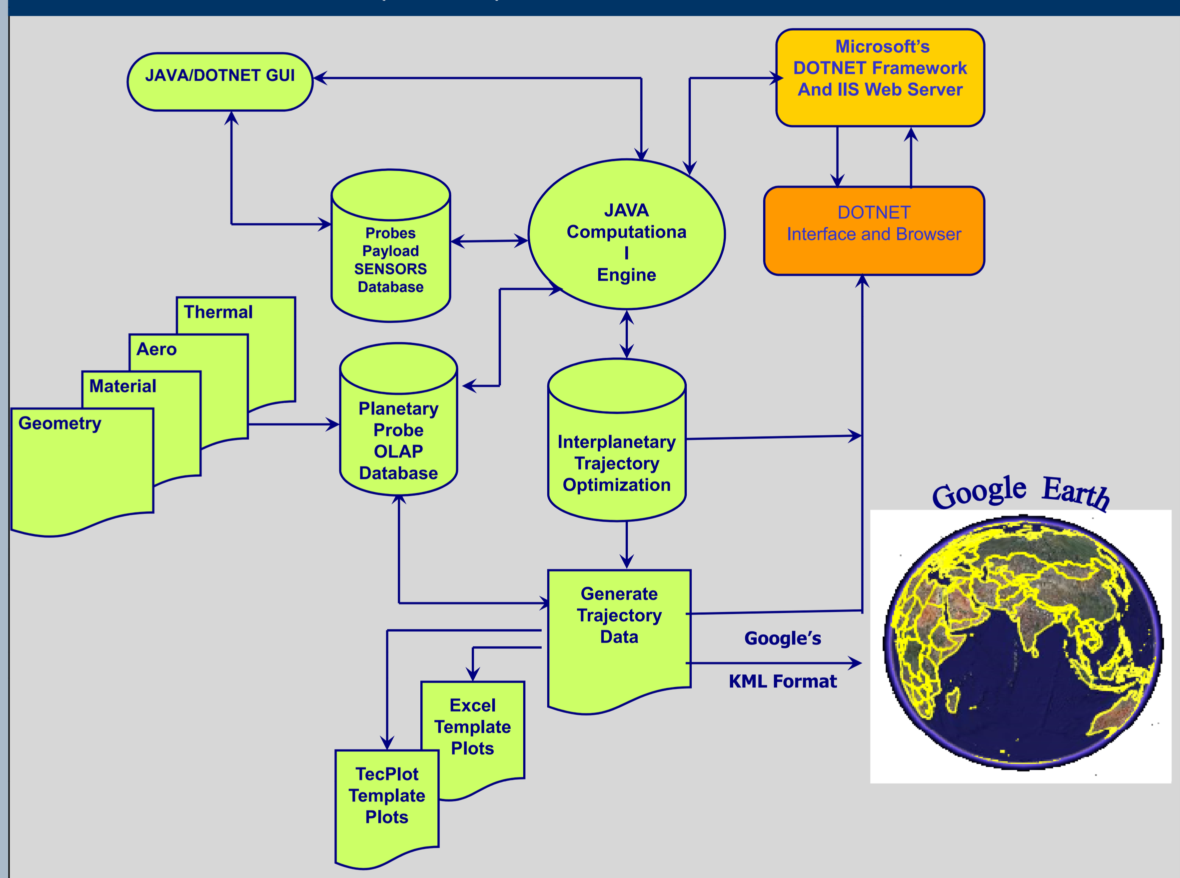
Software Framework Architecture



Interplanetary Payload Sensors and Mission Design Using Multi Disciplinary Design Optimization

- **Launch vehicle performance – The Energy equation**
- **Planetary orbital position – Keplerian orbit elements**
- **Interplanetary trajectories – Lambert's Problem**
- **ΔV computations – Patched-Conic Approximation**
- **PSM derivation – Rocket engine equation**
- **Optimum case determination – MDO Simplex and Matrix Experiment techniques**
- **Ability to calculate conic section between planets using the Lambert targeting technique**
- **Calculation of conic section from planet center to planet center in a specified time**
- **Ability to calculate the required velocity impulse at each of the planets**

Planetary Position Benchmark NET Framework Vs JPL

Radius (km)	Mercury .NET FW	Mercury JPL	% Err	Venus .NET FW	Venus JPL	% Err
Rx	52638550.8	52638550.8	0.0%	-54092361.3	-54092361.3	0.0%
Ry	-22688214.2	-22688214.2	0.0%	92784072.7	92784072.7	0.0%
Rz	-6683556.1	-6683556.1	0.0%	4391857.2	4391857.2	0.0%

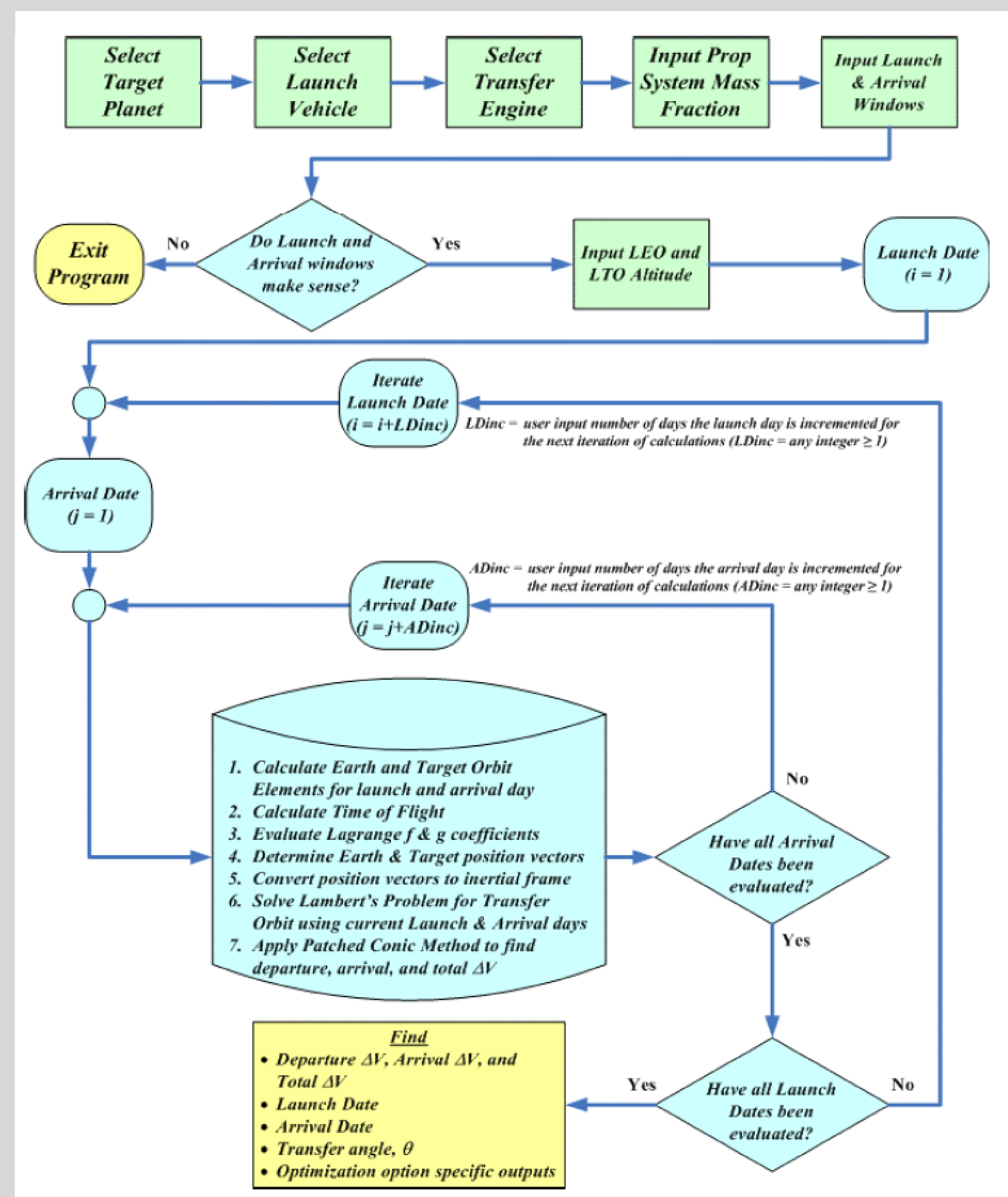
Radius (km)	Earth .NET FW	Earth JPL	% Err	Mars .NET FW	Mars JPL	% Err
Rx	95541839.9	95541839.9	0.0%	103303558.3	103303558.3	0.0%
Ry	-118007885.5	-118007885.5	0.0%	-182950046.9	-182950046.9	0.0%
Rz	2227.6	2227.6	0.0%	-6371754.3	-6371754.3	0.0%

Radius (km)	Jupiter .NET FW	Jupiter JPL	% Err	Saturn .NET FW	Saturn JPL	% Err
Rx	-772138493.7	-772138493.7	0.0%	635076135.5	635076135.5	0.0%
Ry	243284053.6	243284053.6	0.0%	-1355728654.5	-1355728654.5	0.0%
Rz	16269944.9	16269944.9	0.0%	-1671976.7	-1671976.7	0.0%

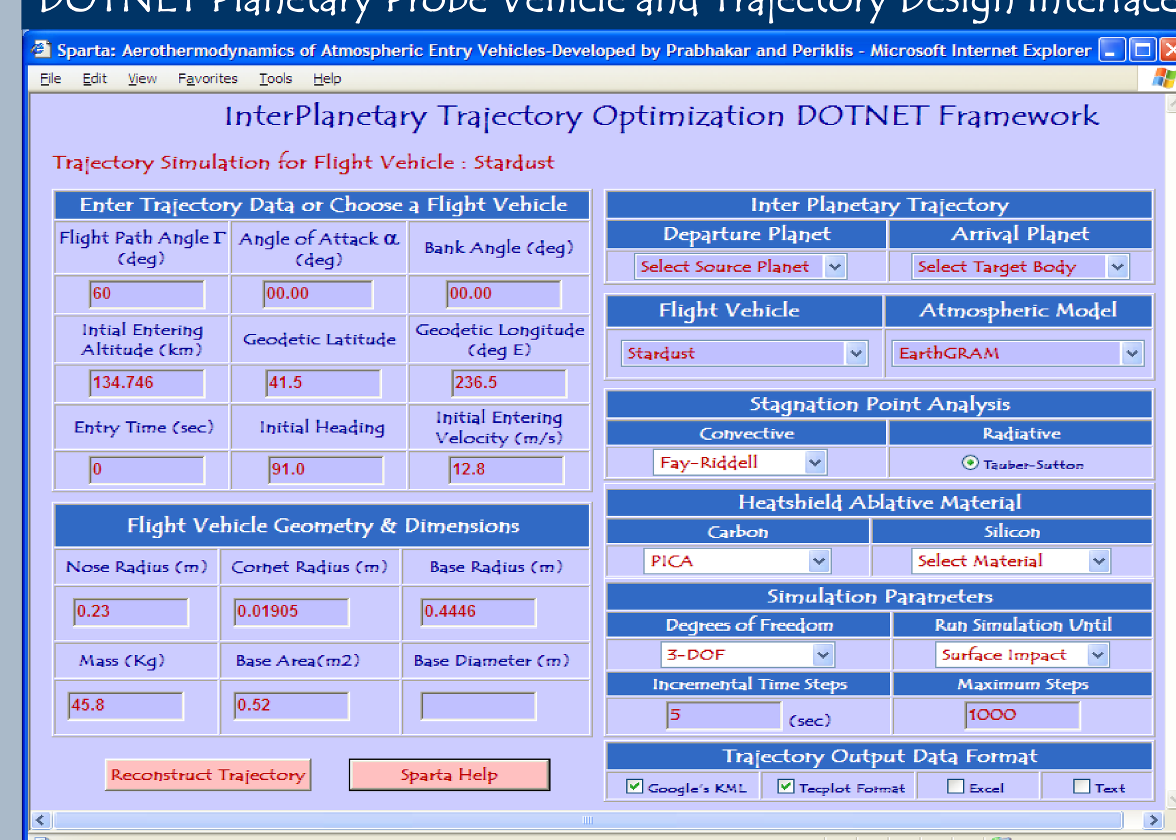
Radius (km)	Uranus .NET FW	Uranus JPL	% Err	Neptune .NET FW	Neptune JPL	% Err
Rx	2966641523.4	2966641523.4	0.0%	3704547277.0	3704547277.0	0.0%
Ry	-485416521.3	-485416521.3	0.0%	-2538175432.8	-2538175432.8	0.0%
Rz	-40136794.8	-40136794.8	0.0%	-33237926.6	-33237926.6	0.0%

Radius (km)	Pluto .NET FW	Pluto JPL	% Err
Rx	671955176.4	671955176.4	0.0%
Ry	-4767573386.5	-4767573386.5	0.0%
Rz	315848193.6	315848193.6	0.0%

Interplanetary Trajectory Design Flow as employed in .NET Framework



DOTNET Planetary Probe Vehicle and Trajectory Design Interface



ΔV Benchmark

Item	Case 1 .NET FW	Case 1 LM	Case 1 % Diff	Case 2 .NET FW	Case 2 LM	Case 2 % Diff
Departure ΔV	5.989	5.989	0.00014%	3.839	3.840	0.00055%
Arrival ΔV	7.839	7.839	0.00000%	2.634	2.634	0.00000%
Total ΔV	13.828	13.828	0.00006%	6.473	6.473	0.00033%
TOF (days)	149	149	0.00000%	200	200	0.00000%
Launch Day	2/8/2018	2/8/2018		3/12/2016	3/12/2016	
Arrival Day	7/7/2018	7/7/2018		9/28/2016	9/28/2016	
Target	Mars	Mars		Mars	Mars	
Low Orbit Alt	400	400		400	400	

Item	Case 3 .NET FW	Case 3 LM	Case 3 % Diff	Case 4 .NET FW	Case 4 LM	Case 4 % Diff
Departure ΔV	10.369	10.369	-0.00009%	6.459	6.459	0.00017%
Arrival ΔV	10.699	10.699	-0.00006%	10.407	10.407	-0.00002%
Total ΔV	21.068	21.068	-0.00007%	16.866	16.866	0.00005%
TOF	289	289	0.00000%	956	956	0.00000%
Launch Day	12/7/2015	12/7/2015		7/19/2011	7/19/2011	
Arrival Day	9/21/2016	9/21/2016		3/1/2014	3/1/2014	
Target	Venus	Venus		Jupiter	Jupiter	
Low Orbit Alt	200	500		300	150000	

Payload Mass Calculation: Inputs

Departure Planet	Earth	Arrival Planet	Mars
Semi-major Axis a	42,238 km	Semi-major Axis a	20,000 km
Eccentricity e	0.0	Eccentricity e	0.2
Inclination i	0.0°	Inclination i	30.0°
Departure Date	5/1/2003	Heliocentric Time of Flight	200 days
Initial Mass	5,000 kg	Specific Impulse (Isp)	5,000 sec
Source Power S_J	100 kW	System Specific Mass β	0.020 kg/kW
System Efficiency η_T	0.50		

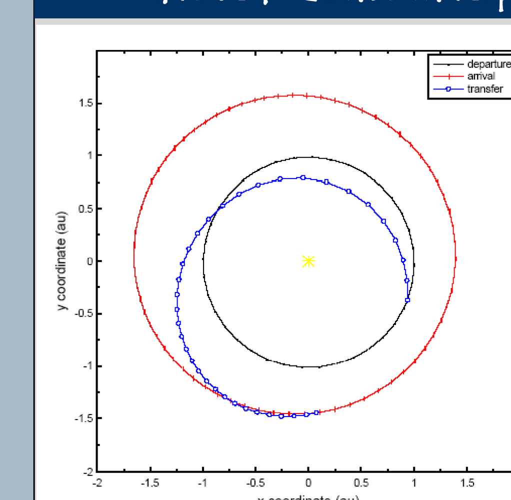
Payload Mass Calculation Output from the Sensors Database and the program

Thrust	2.03957 N	Initial Mass	5000.000 kg
Departure Spiral		Fuel Used for Heliocentric	718.820 kg
Trip Time	75.143 day	Total Propellant Mass	1117.830 kg
Fuel Consumed	270.070 kg	Final Mass	3882.169 kg
Arrival Spiral		Inert Mass	2000.000 kg
Trip Time	35.876 day	Payload Mass	1882.169 kg
Fuel Consumed	128.940 kg	Equivalent ΔV	12.407 km/s

Initial Mass Calculations

Thrust	2.03957 N	Payload Mass	1999.993 kg
Departure Spiral		Fuel Used for Heliocentric	718.820 kg
Trip Time	76.670 day	Total Propellant Mass	1119.580 kg
Fuel Consumed	275.560 kg	Initial Mass	5119.573 kg
Arrival Spiral		Inert Mass	2000.000 kg
Trip Time	34.818 day	Final Mass	3999.993 kg
Fuel Consumed	125.200 kg	Equivalent ΔV	12.099 km/s

Patched-Conic Interplanetary Trajectory Optimization

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departure planet              Earth
departure calendar date       September 1, 1998
departure universal time      00 h 00 m 00 s
departure julian date         2451057.5

arrival planet                Mars
arrival calendar date         August 15, 1999
arrival universal time        00 h 00 m 00 s
arrival julian date           2451405.5

transfer time                 348  days

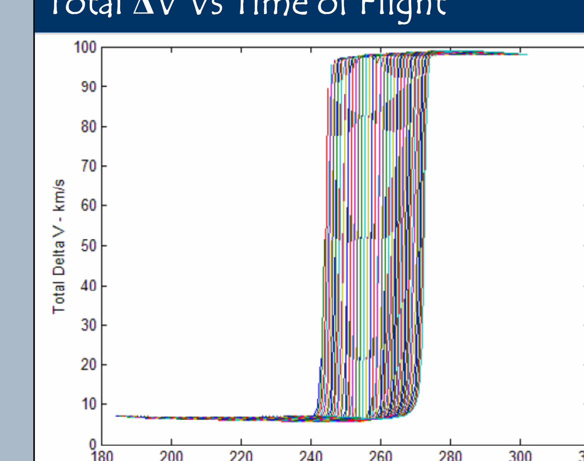
optimum launch delta-v

departure planet              Earth
departure calendar date       December 27, 2013
departure universal time      16 h 1 m 11.6099 s
departure julian date         2456654.1675

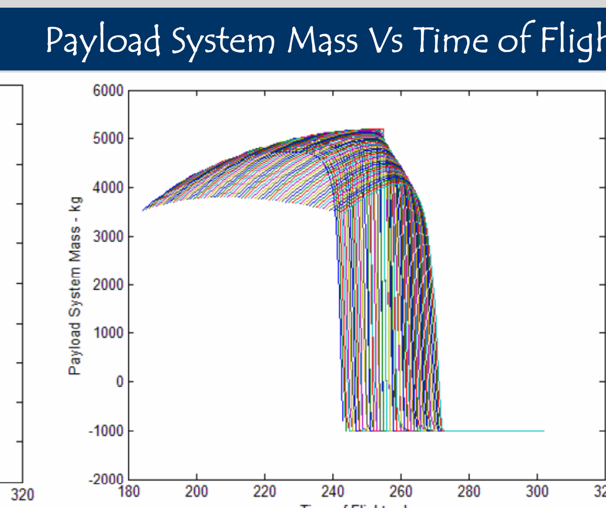
arrival planet                Mars
arrival calendar date         July 23, 2014
arrival universal time        12 h 4 m 50.3438 s
arrival julian date           2456862.00336

transfer time                 207.835864976  days
```

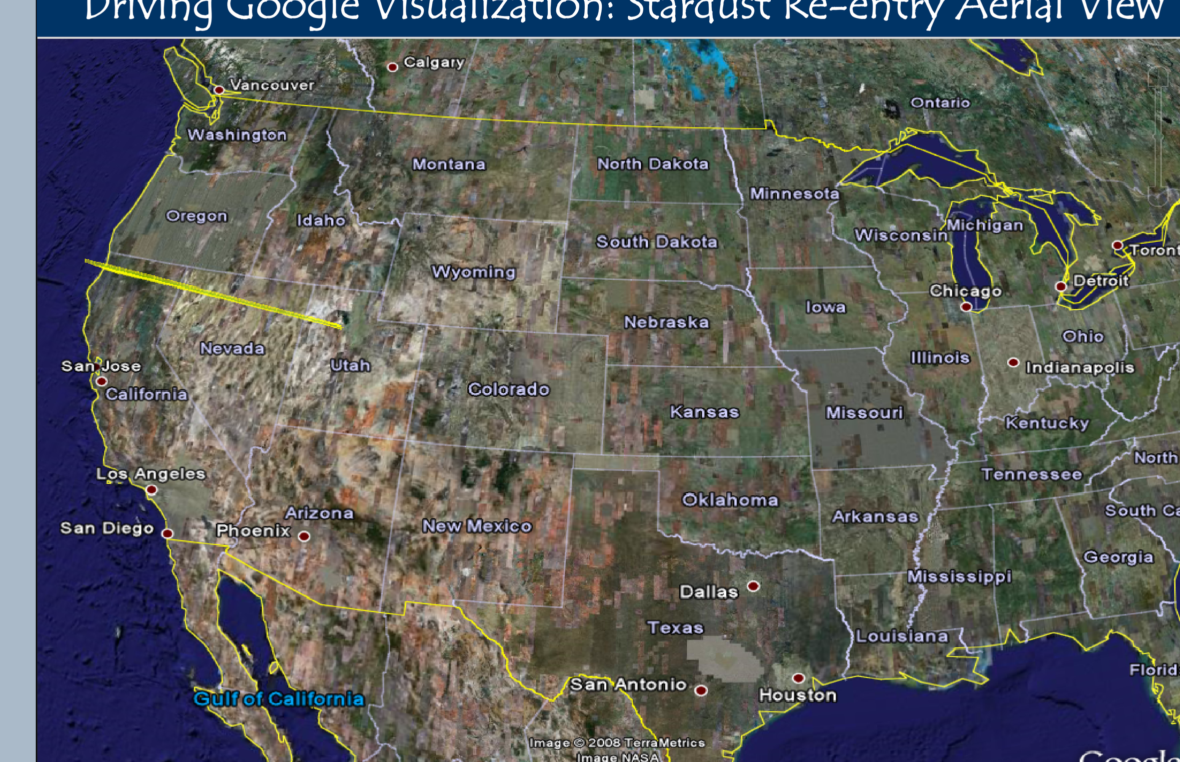
Total ΔV Vs Time of Flight



Payload System Mass Vs Time of Flight



Driving Google Visualization: Stardust Re-entry Aerial View



Payload Sensors and Planetary Probe Relational Database Management

- Developed a Payload Sensors RDBMS and Integrated DB with .NET Framework for Web accessibility
  - Database manager allows selective data retrieval through .NET web application user interface
- Comprehensive database of existing planetary probe designs and Sensors
  - Features tables for aerothermal, geometry, trajectory, sensors, etc.. information
- Users can modify existing vehicle designs by changing geometric features available in GUI, Update the database for their custom test probe architectures. Add/Modify sensors in the UI based on the initial selection by the system driven by Planetary body/Mission

Framework Entry Design Environment

- SPARTA Design environment is an Automation Package for Sensor design
  - Choose a Target Planetary body and the Sensors are automatically loaded into the DOTNET design interface
  - The total power, thermal, mass requirements and other parameters are automatically calculated from the database and populated in the user interface
  - The user is empowered with an option to add or delete a sensor for packaging into the probe
- The TOF, **ΔV** are all calculated and the user is alerted.
  - For Earth (Re) Entry, user is presented with KML format for reentry visualization in Google Earth

Driving Google from DOTNET Framework

- Earth (Re)-Entry Trajectory Data converted to Keyhole Markup Language (KML)
- Framework converts the trajectory data and produces a fresh KML file for every trajectory array set.
- Google Earth interprets it's native KML format and produces fly-by visualization along the entry trajectory
- Google Earth provides rich interactive and attractive platform for visualizing geospatial data.
- The framework employs a pure Java library which generates KML output to display the most commonly interesting forms of geospatial data.
- No prior knowledge of KML is required for the end-user.
- They are presented with a very simple API which expects data in the form of arrays, in which it is likely to already exist, and will create graphical elements of the sort which users are most likely to want.

Driving Google Visualization from DOTNET: Stardust Trajectory