Assignment: Trajectory and Mission design for Reusable Launch Vehicle

1. Assume a launch vehicle of specifications provided in Table 1 to be launched from SDSC, SHAR to a Low Earth Orbit. With sufficient assumptions, calculate the following:
   a) ΔV required including all applicable losses and launch azimuth to reach a prograde, circular orbit at 400 km above the Earth's surface and 22 degrees above the equator.
   b) For the same altitude and tilt angle as specified in ***(1a)***, calculate the additional ΔV required for a retrograde orbit and the subsequent launch azimuth.
   c) Calculate the propellant and structural masses of both the stages and payload mass that can be carried to reach the orbit described in ***(1a)*** assuming direct ascent.
   d) Calculate the feasible payload mass assuming a Hohmann transfer with parking orbit at 250 km and compare with ***(1c)***.
   e) Calculate the time, altitude, velocity and downrange of the stages at burnout for the trajectory calculated in ***(1d)***.
   f) Calculate the propellant and liftoff mass for the same rocket to carry 1.4 times the payload as calculated in ***(1c)***.

Table 1

Liftoff mass (kg)	672470	
Max Rocket Diameter (m)	6.5	
	Stage 1	Stage 2
Thrust (kN)	8.2 MN	1.2 MN
No. of engines	1	4
Isp (s)	278	302
Structural coefficient	5.13%	4.04%

Tools allowed: Excel

2. Describe the equations of motion for the launch vehicle described in Table 1 under the influence of gravitational, aerodynamic and thrust forces in planar ascent. Using calculus of variations and Pontryagin's principle to devise an optimal control problem to minimize the fuel consumption while achieving the target orbit by assuming thrust-to-weight ratio as control variable in the vector form. Derive the Hamiltonian function along with the costates and its equations and explain the condition of optimality. Introduce variations in atmospheric density, thrust magnitude, wind disturbances and initial launch conditions using a Monte Carlo simulation approach. Discuss the sensitivity of initial launch parameters and optimal control law on the maximum Q and acceleration loads, rate of climb, and degree of climb to these uncertainties.

Submission requirements: Derivations, calculations, source codes, Statistical plots and histograms of key trajectory parameters.

Tools allowed: Excel / Python

Deliverables Expected

1. Prepare a **Design Document** for the entire system design, describing all the concepts, formulae, diagrams, flowcharts and calculations, ensuring clear and concise presentation of the documentation. Include any relevant notes, observations, or modifications made during the design and implementation process.
2. Prepare **Excel Sheets** representing all the calculations made with formulae included. **The use of softwares like MATLAB/ STK/ GPOPS/ GMAT is strictly not encouraged; any usage of the above-mentioned tools may lead to termination of candidature.**
3. Each section of the question must be included in the document with Heading 1 and Heading 2 styles used for the task and the sub-task respectively. Under the specific question, the solution for the section needs to be included.
4. Include these sections in the document:
   a) **Introduction**
   b) **Assumptions**: Specify the assumptions of numerical values, boundary conditions, environmental factors or any other parameters which have been assumed and not provided in the question. Include justifications for each assumption.
   c) **Solution Implementation Approach**: Specify the process followed in solving the assignment.
   d) **References**: List all references utilized.

Prepared by	SURYA S, Lead Aerodynamics Engineer
Verified by	PRASHANTH SHARMA, Director & CTO