Preliminary design of a Satellite launcher

We wish to produce a first-order design of a 3-stage launch vehicle to place a 3 kg. nanosatellite in a circular equatorial of 500 km. altitude. Launch will be from the Equator, in an Easterly direction. All stages will use solid propellant rocket motors with $I_s = 270s$, and each will have a structural mass fraction $\varepsilon_i = M_{si}/M_{0i} = 0.1$ (i=1,2,3).

For a first approximation to the required stage ΔV's, assume two instantaneous impulses, one delivered near the ground ($r = R_E = 6730\ km$) at an average elevation angle $\alpha = 20°$, that will place the vehicle in an ascent trajectory with apogee at 500 km altitude, and the other at the apogee, to add enough velocity to reach orbital conditions. Use conservation of angular momentum and energy (kinetic plus potential) in the ascent trajectory to find the initial velocity v_1 after the first impulse and the apogee velocity v_a. The velocity v_1 will be regarded as made up of the sum of the two velocity increments $\Delta V_1 + \Delta V_2$ of the first and second stages, plus the Earth rotation velocity $\omega_E R_E \cos \alpha$, minus the full gravity loss ΔV_G and the full drag loss ΔV_D. This determines $\Delta V_1 + \Delta V_2$; assume $\Delta V_1 = \Delta V_2$ and calculate both.

To estimate the gravity loss, assume a variation of the elevation angle γ such that sin γ varies linearly in time <u>during the first stage burn</u>, from 1 (vertical launch) to 0. Of course, the 20° assumed for α above is a rough approximation of the average of γ during both, the first and second stage burns. To calculate the stage firing times, assume each motor provides an initial trust acceleration $F_i/M_{0i} = 3g$. One other piece of information for this time calculation is the propellant mass which itself depends on the stage ΔV; this is not really known until the gravity loss is estimated, but you can iterate a bit, or make a simple first cut for this purpose only.

The calculation of the drag loss is more involved, and depends on a trajectory calculation, plus the aerodynamic characteristics of the vehicle. For now, assume $\Delta V_D = 150m/s$.

With these assumptions, or some reasonable modification you may prefer (but if so, the new assumptions should be clearly stated and justified in some manner), calculate the initial mass of each of the stages, as well as their structural and propellant masses. Note that the payload for each stage is the initial mass of the next stage, except for the third stage, whose payload is the overall payload. Calculate also the firing time and the thrust of each motor.

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