Tutorial 5°
Launcher's nozzle behavior during the ignition phase

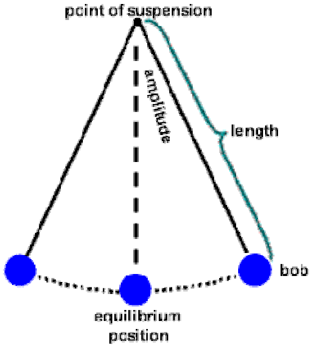

Figure 1. Classical pendulum

1 - Natural frequency of a classical pendulum

A classical pendulum is a mass (bob) suspended on a string or a rod of length l and negligible mass, oscillating about the equilibrium position (Figure 1). During the class lectures it was shown that for small amplitudes the period of oscillation is given by $T = 2\pi\sqrt{l/g}$. In the following consider the length $l = 50\ cm$.

1. Implement in Simulink the nonlinear and the linearized equation of motion of the pendulum.
2. Compute the free oscillation frequencies of the pendulum in both cases (linearized and nonlinear equation), starting with an initial angle $\theta_0 = [5°;\ 20°; 40°; 60°; 80°]$ and zero initial velocity. Plot the obtained frequencies as a function of the motion amplitude θ_{max}. Conclude on the usable range of the linearized solution.

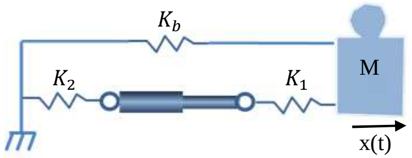

Figure 2. Equivalent translational model of the nozzle

2 - Modal analysis and shock simulation of a launcher nozzle

Consider the launcher's Thrust Vector Control (TVC) system studied in the previous tutorial. An important aspect of the system is its vibrational behavior, especially during the ignition phase. The specifications give a shock during the start which can be modeled by a half-sine effort of 24 MN amplitude during 0.2 ms applied on the equivalent translational mass of the nozzle (Figure 2).

1. Assuming that the actuator (which is controlled in position) is infinitely stiff, find the natural frequency of the nozzle. The equivalent translational stiffness of the flexible bearing is $K_b = 3.51E5\ N/m$, the anchorage stiffness on the sides of the actuator are $K_1 = 3.69E7\ N/m$ on the nozzle side and $K_2 = 5.58E7\ N/m$ on the structure side and

the equivalent translational mass of the nozzle is $M = 3083\ kg$. The mass of the actuator is neglected.

2. Determine, by simulation, the speed and calculate the kinetic energy of the equivalent mass just after the application of the shock.
3. Calculate the maximal displacement of the nozzle and the maximal transient effort on the actuator. Compare this effort with that calculated in the previous tutorial. Check this result by simulation.
4. In order to lower the effort applied on the actuator and to damp the oscillations of the nozzle during the ignition, the actuator is controlled so that it acts like a dumper (eventually with a spring in parallel). Calculate the equivalent damping coefficient to be emulated by the actuator. Estimate by simulation the maximal effort applied on the actuator.