Tutorial 4°
Modeling of a launcher nozzle dynamics

Vega, Figure 1, is the lightweight workhorse of Arianespace and the European Space Agency that made its first voyage in 2012 after 13 years of development and testing. The vehicle was built to haul small payloads into a variety of orbits including Low Earth, Sun Synchronous and Polar Orbits. Vega is a three-stage launch vehicle (with an optional fourth stage) which stands 29.9 meters tall, has a main diameter of 3.03 meters and a liftoff mass of 137 tons. The rocket can lift up to 2.5 tons of payloads – depending on the target orbit.

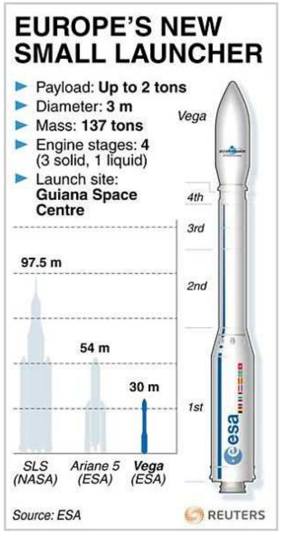

Figure 1 – Vega launcher

Figure 2 –The first stage of the Vega launcher (motor and the nozzle) – P80

Figure 3 – Validation test of the P80 thrust vector control system

The first stage (Figure 2) – P80 motor – provides the thrust for the launcher during the first 110 seconds. The thrust vector is controlled by gimbaling the nozzle, which is attached to the launcher via a flexible bearing (Figure 4), within a range of $\pm 5.7°$. This is achieved by two electromechanical actuators driving two perpendicular rotations of the nozzle.

Nozzle equation of motion

Before the integration on the launcher, several ground-based tests were conducted on the nozzle with its actuation system (Figure 3). For the design of the actuators and the control itself, engineers need the model of the nozzle motion submitted to the external forces. In the following we will study the ground-based motion of the nozzle on a single rotational axis, neglecting the coupling with the second axis.

1. Define the efforts acting on the nozzle with respect to its circular motion. Which will be the additional efforts during the fly?
2. Give the equation of motion of the nozzle (ground-based test).
3. The equation of motion makes use of different quantities such as nozzle inertia, lever arm of the actuation system and the distance from the CoR to the CoM.
   a. Determine the inertia of the nozzle if it is assumed that it can be assimilated to a hollow cone[1] of mass $M = 1616\ kg$, high $H = 2.5\ m$ and base radius $R = 1\ m$, which is turning about its point.
   b. Determine the center of mass of the nozzle.
   c. Express the lever arm of the actuator force acting on the nozzle as a function of the gimballing angle θ. The geometry of the setup is given in Figure 5.
4. Determine the maximal force that the actuator should develop in the following design scenarios:
   a. Scenario 1: Gimbal the nozzle from 0° to 1° in 0.19 s.
   b. Scenario 2: Gimbal the nozzle from 0° to 5.5° in 0.57 s.

The stiffness of the flexible bearing is $K = 10.85\ kNm/°$.

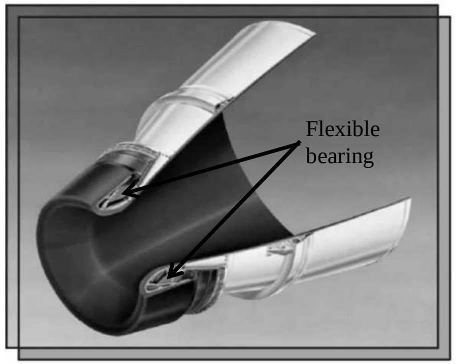

Figure 4. Natural geometry of the nozzle and its flexible bearing for the attachement on the launcher

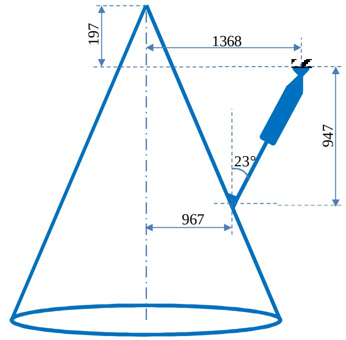

Figure 5. Nozzle with and its one axis actuator

[1] This assumption is made only for educational purpose. The results obtained for this geometry may vary significantly from the real nozzle.