



PRESENTATION

Launchers, What are they? & How are they controlled?

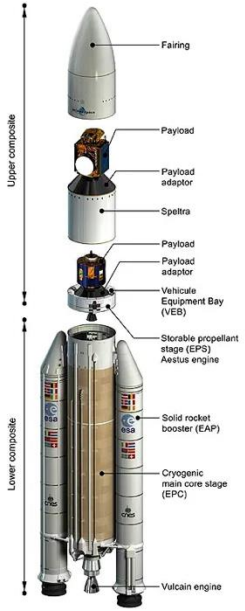
Andrés Marcos Esteban, Director of CSAT, MISE & ST3LLARsat

Department of Aerospace Engineering

What are Launch Vehicles (LVs)?

An LV is the vehicle used to send satellites / spacecraft / people into orbit or to other planets.





https://www.esa.int/es/articles/about-us/directorates/space-transportation/what-is-a-launcher

https://www.esa.int/articles/about-us/directorates/space-transportation/launcher-systems

Guiana Space Center (GSC)
https://centrespatialguyanais.cnes.fr/en/

CENTRE SPATIAL GUYANAIS
Port spatial de l'Europe
Europe's Spaceport
esa cnes



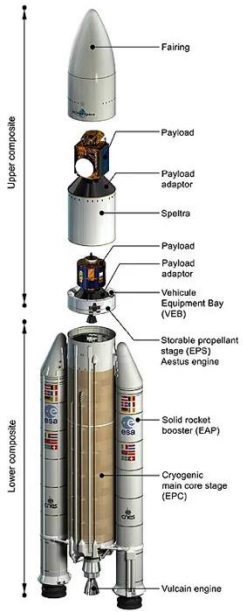


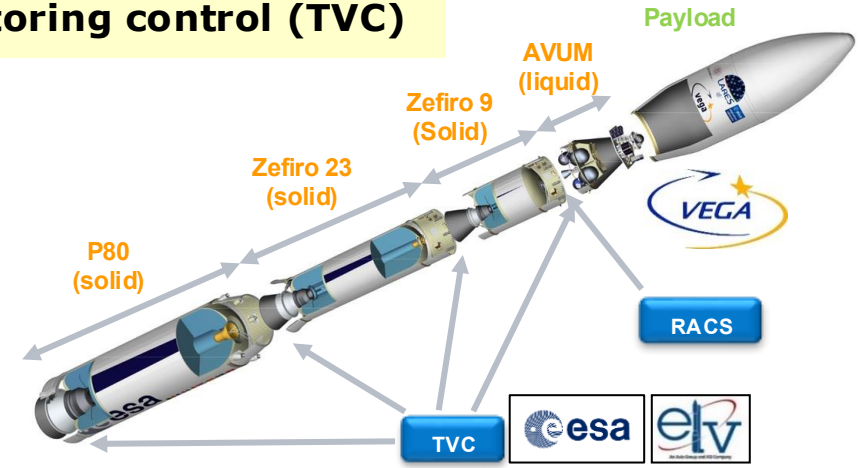
Image from **@Google Maps**



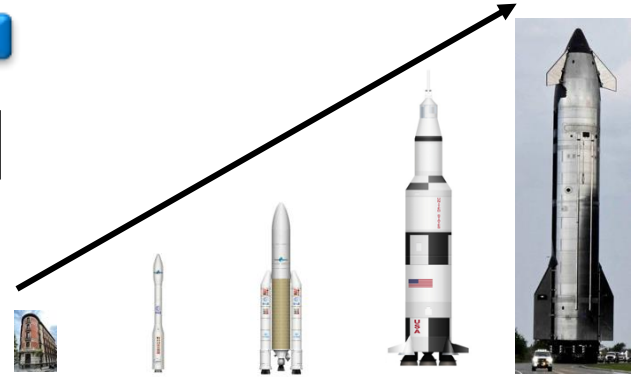
What are LVs like?

LVs have multiple stages, each controlled by a **thrust vectoring control (TVC)**







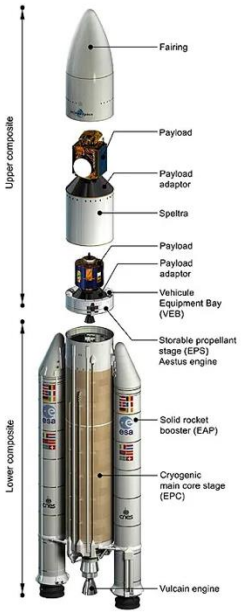


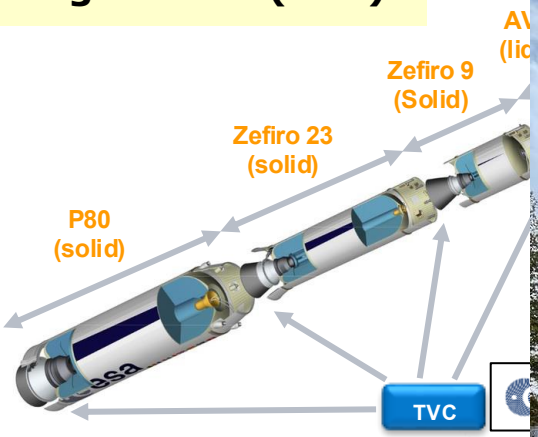


"Pirulí" de Madrid 232m/28-8m

What are LVs like?

LVs have multiple stages,
each controlled by a
thrust vectoring control (TVC)









Edificio 5 plantas 15m



VEGA 30m/3m

Ariane-5 52m/5m



Saturn V 111m/10m

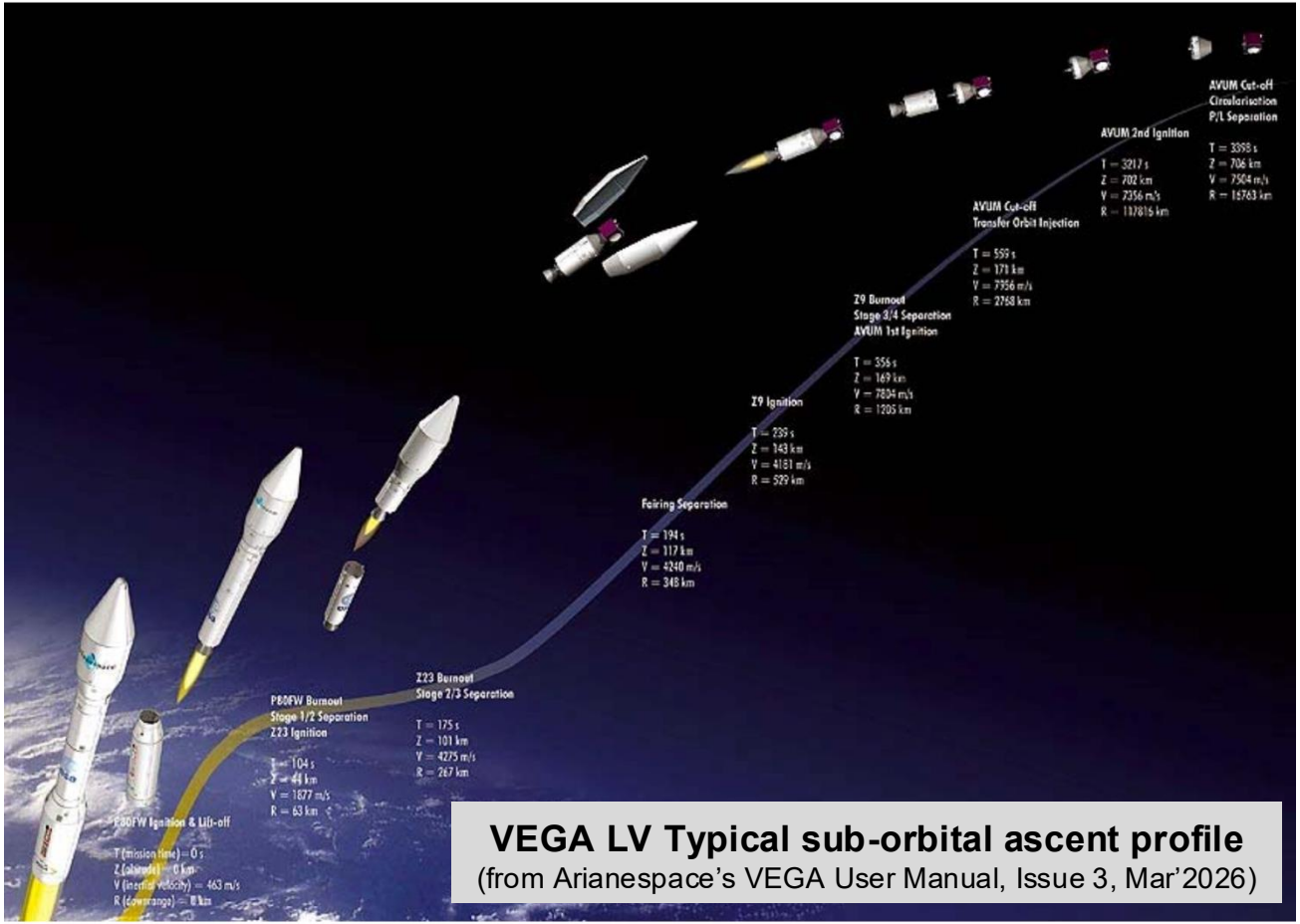


Starship 124m/10m



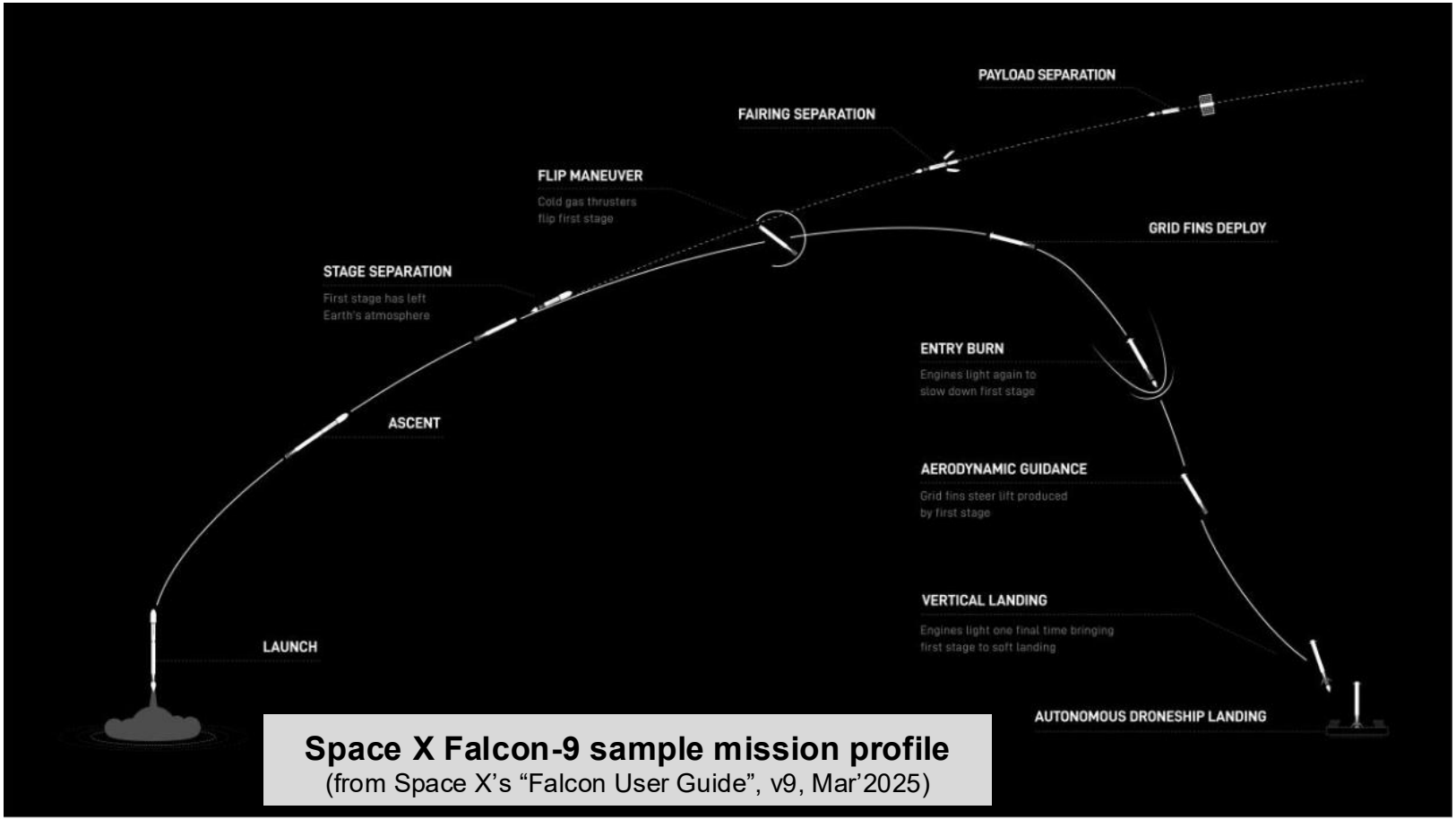
"Pirulí" de Madrid 232m/28-8m

Flight phases of the LVs



VEGA LV Typical sub-orbital ascent profile
(from Arianespace's VEGA User Manual, Issue 3, Mar'2026)

Flight phases of Reusable Launchers (RLVs)

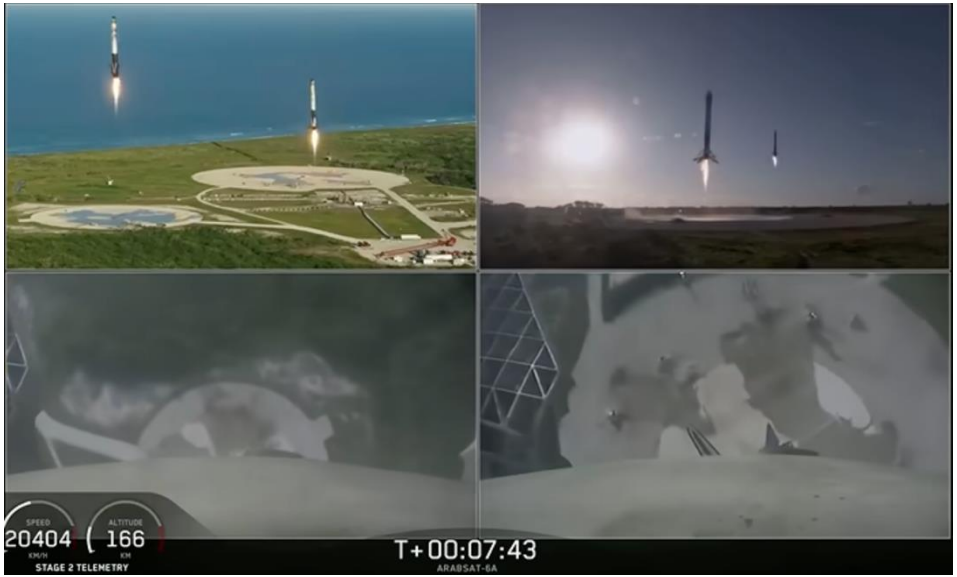


Space X Falcon-9 sample mission profile
(from Space X's "Falcon User Guide", v9, Mar'2025)

Let's watch some videos



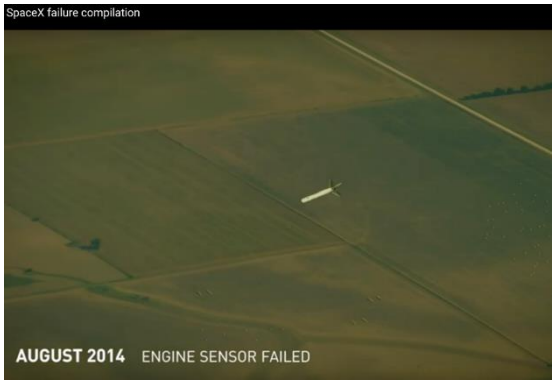
Vega VV05 LV launch (2015)
https://www.youtube.com/watch?v=9oiwVtselrE



Space X – 1st Vertical LV Landing (2019)
https://www.youtube.com/watch?v=mY-fSnKTLqw

Looks easy... but it is not

Space X – Failure compilation https://www.youtube.com/watch?v=ambXDKFZhN8





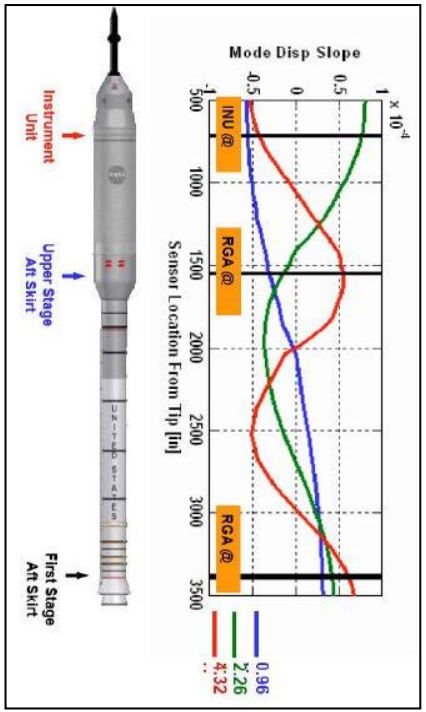






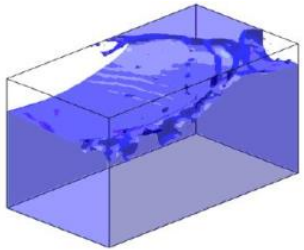
Why are they so difficult to control? Internal issues

- **Vehicle:**
  - Unstable
  - Flexible structure
  - Liquid engines

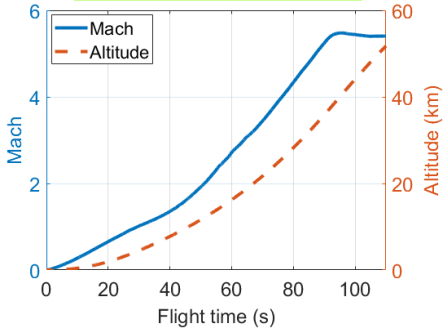


- **High variation of flight parameters**
- **Large number and range of Δ**

Sloshing

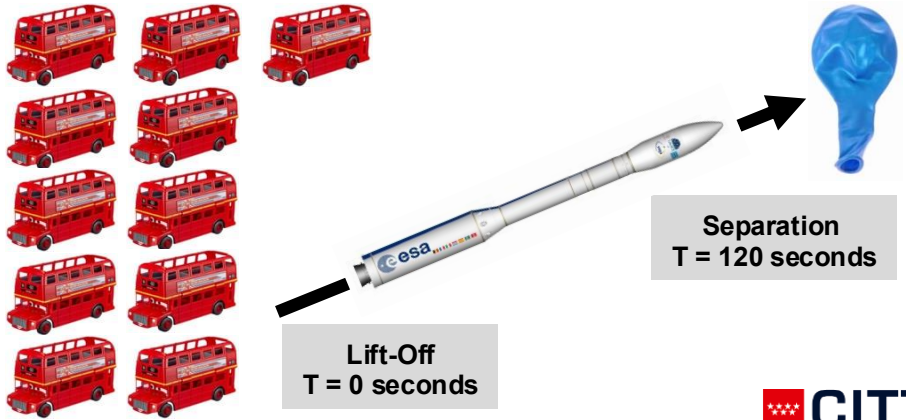


VEGA V005 mission





VEGA 1st Stage P80: consumes 88 Tons fuel in ~100secs!!



Separation
T = 120 seconds

Lift-Off
T = 0 seconds

Why are they so difficult to control? External issues

- **Challenging environment**:
  - Wind disturbances
  - Structural loads (Qα)

40% Launches delayed due to weather

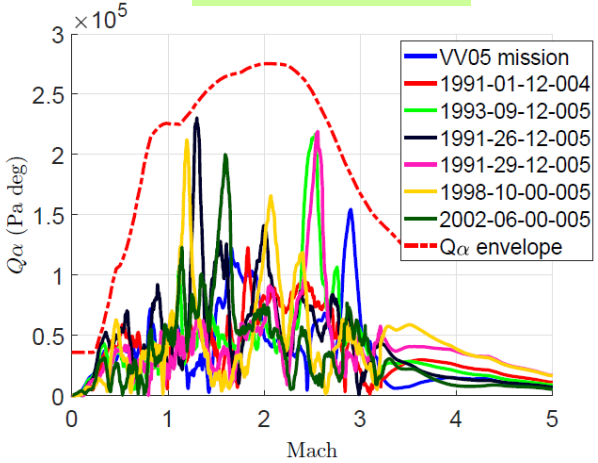
https://www.vaisala.com/en/expert-article/did-you-know-that-40-percent-of-space-launches-are-delayed-due-to-the-weather

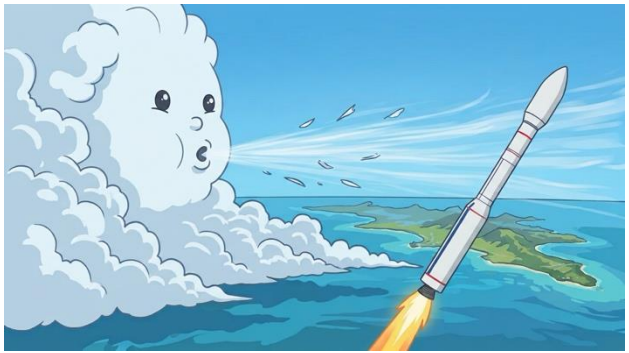
https://www.spacelaunchschedule.com/news/rocket-launch-delays-explained/

Qα is a very important parameter. It connects speed with angle of attack (think of a weathercock-vane).

It indicates **possibility of breaking up LV structure when speed is high and wind is strong**

VEGA Qα wind effect

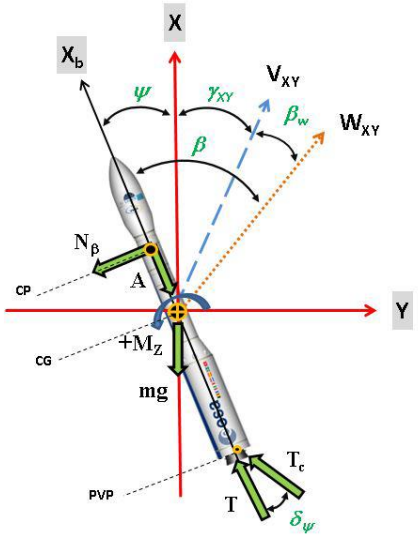


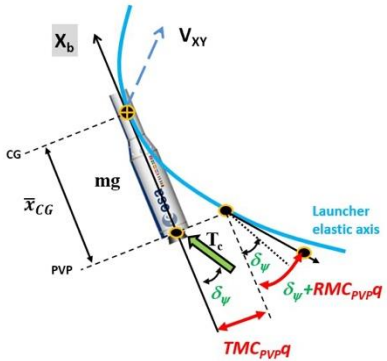




Images created by authors' prompts using **AI-Gemini**

How do engineers understand? the difficult way





Rigid & Flexible forces and moments:

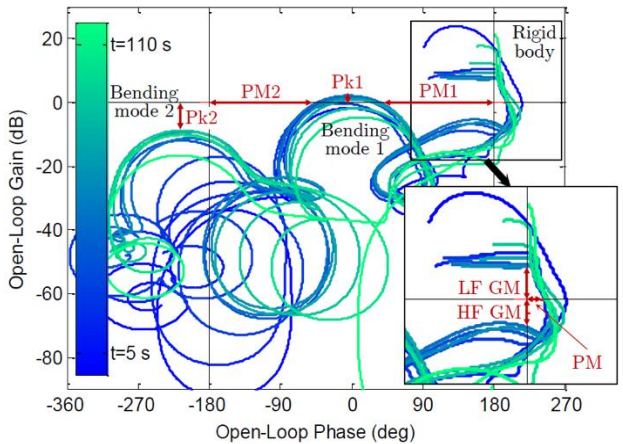
$$F_r = As_\psi - N_\beta c_\psi - Ts_\psi - T_c(c_{\delta_\psi}s_\psi + s_{\delta_\psi}c_\psi)$$
$$M_r = N_\beta(x_{CP} - x_{CG}) - T_c s_{\delta_\psi}(x_{CG} - x_{PVP})$$

$$F_f = T_c \sum_{i=1}^{k} RMC_{PVP_i}\, q_i$$
$$M_f = -T_c(\bar{x}_{CG} \sum_{i=1}^{k} RMC_{PVP_i} + \sum_{i=1}^{k} TMC_{PVP_i})\, q_i$$

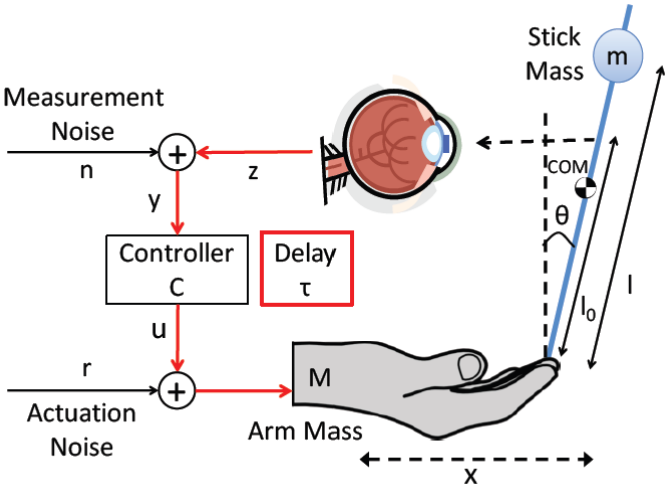
Complex mathematical representations of the equations of motion:

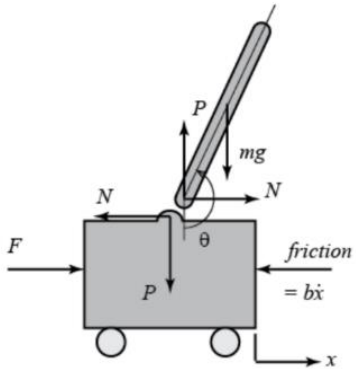
$$\begin{bmatrix} \dot{z} \\ \ddot{z} \\ \dot{\psi} \\ \ddot{\psi} \\ \dot{\mathbf{q}} \\ \ddot{\mathbf{q}} \end{bmatrix} = \left[\begin{array}{cccc:cc} 0 & 1 & 0 & 0 & \mathbf{0_{1k}} & \mathbf{0_{1k}} \\ 0 & a_1 & a_3 & a_2 & \mathbf{a_{zq}} & \mathbf{0_{1k}} \\ 0 & 0 & 0 & 1 & \mathbf{0_{1k}} & \mathbf{0_{1k}} \\ 0 & a_4 & a_6 & a_5 & \mathbf{a_{\psi q}} & \mathbf{0_{1k}} \\ \hdashline \mathbf{0_{k1}} & \mathbf{0_{k1}} & \mathbf{0_{k1}} & \mathbf{0_{k1}} & \mathbf{0_{kk}} & \mathbf{I_k} \\ \mathbf{0_{k1}} & \mathbf{0_{k1}} & \mathbf{0_{k1}} & \mathbf{0_{k1}} & \mathbf{a_{qq}} & \mathbf{a_{q\dot{q}}} \end{array}\right] \begin{bmatrix} z \\ \dot{z} \\ \psi \\ \dot{\psi} \\ \mathbf{q} \\ \dot{\mathbf{q}} \end{bmatrix} + \left[\begin{array}{ccc} 0 & 0 & 0 \\ a_p & k_2 & -a_1 \\ 0 & 0 & 0 \\ k_1 & k_3 & -a_4 \\ \hdashline \mathbf{0_{k1}} & \mathbf{0_{k1}} & \mathbf{0_{k1}} \\ \mathbf{a_{q\beta}} & \mathbf{a_{q\ddot{\beta}}} & \mathbf{0_{k1}} \end{array}\right] \begin{bmatrix} \beta_\psi \\ \ddot{\beta}_\psi \\ v_w \end{bmatrix}$$

$$\begin{bmatrix} Q\alpha \\ \psi_{INS} \\ \dot{\psi}_{INS} \\ z_{INS} \\ \dot{z}_{INS} \end{bmatrix} = \left[\begin{array}{cccc:cc} 0 & Q/V & Q & 0 & \mathbf{0_{1k}} & \mathbf{0_{1k}} \\ 0 & 0 & 1 & 0 & \mathbf{-a_{\psi' q}} & \mathbf{0_{1k}} \\ 0 & 0 & 0 & 1 & \mathbf{0_{1k}} & \mathbf{-a_{\psi' q}} \\ 1 & 0 & -l_{INS} & 0 & \mathbf{a_{\psi q}} & \mathbf{0_{1k}} \\ 0 & 1 & 0 & -l_{INS} & \mathbf{0_{1k}} & \mathbf{a_{\psi q}} \end{array}\right] \begin{bmatrix} z \\ \dot{z} \\ \psi \\ \dot{\psi} \\ \mathbf{q} \\ \dot{\mathbf{q}} \end{bmatrix} + \left[\begin{array}{ccc} 0 & 0 & -Q/V \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{array}\right] \begin{bmatrix} \beta_\psi \\ \ddot{\beta}_\psi \\ v_w \end{bmatrix}$$



How do engineers understand? the easier way





Nonlinear equations of motion of 'ruler'

$$(M+m)\ddot{x} + ml(\ddot{\theta}\cos\theta - \dot{\theta}^2\sin\theta) = u + r$$

$$m(\ddot{x}\cos\theta + l\ddot{\theta} - g\sin\theta) = 0$$

$$z = x + l_0\sin\theta \qquad y = z + n$$

Inverted pendulum controlled with a cart

$$(M+m)\ddot{x} + b\dot{x} - ml\ddot{\phi} = u$$

$$(I+ml^2)\ddot{\phi} - mgl\phi = ml\ddot{x}$$





ACTIVITY

“Do-It-Yourself (DYI)”: Control a “Launcher”

DYI Activity: Control a “Launcher”

- **Let us use a stick (which is equivalent to a launcher during ascent) to demonstrate the mathematical/engineering concepts of observability and controllability:**

  - **Take two sticks of markedly different lengths**
    (i.e., small like a pen and long like a 1-meter ruler)

  - **<u>First</u>: try to balance the smaller one in your hand**
    ➔ Can you do it?

  - **<u>Second</u>: do the same for the larger one, but …**
    - **2-a: looking at the base of the ruler in your hand**
    - **2-b: looking at the top of the ruler**

    ➔ Which one is easier? Why?