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Theoretical modeling and analysis of the launching process in an electromagnetic coil launcher

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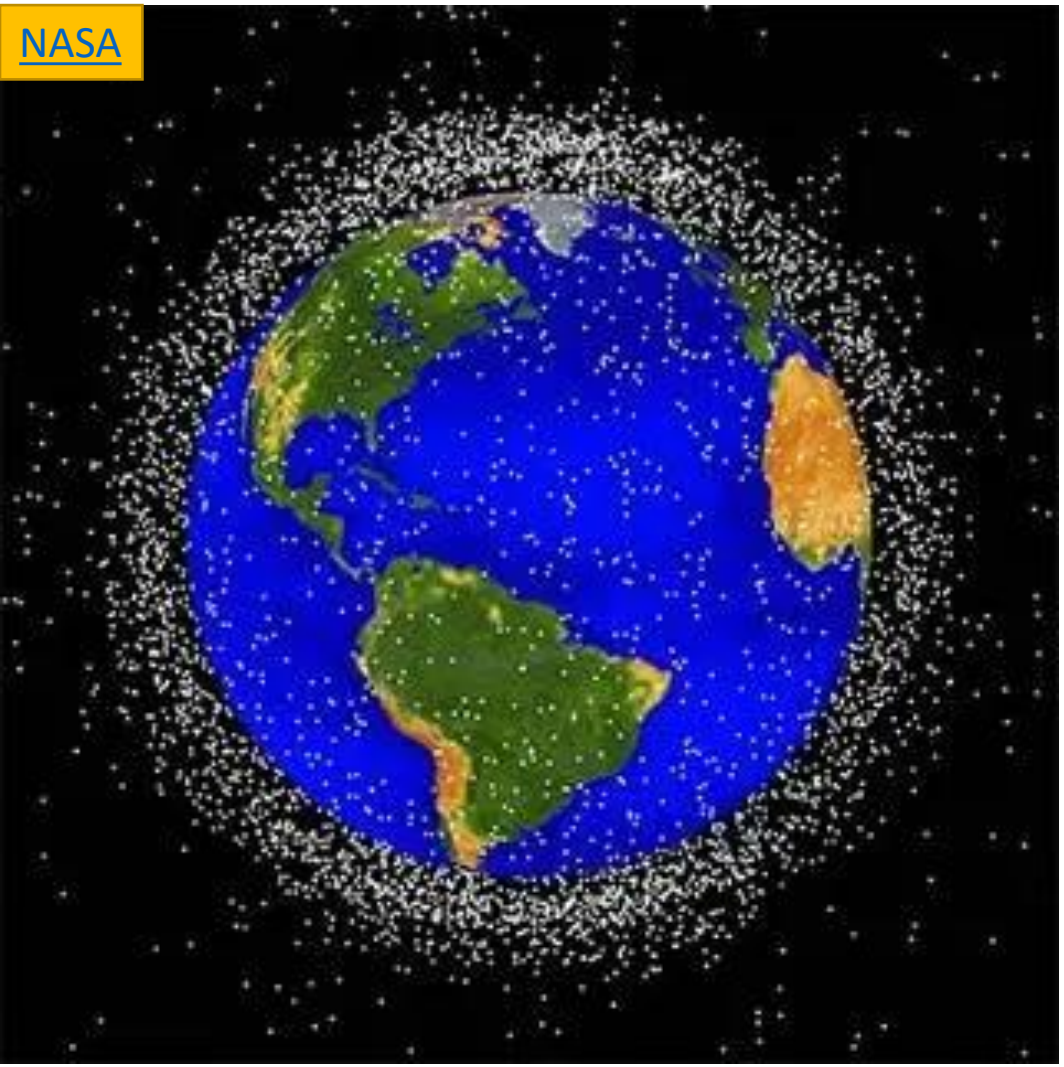
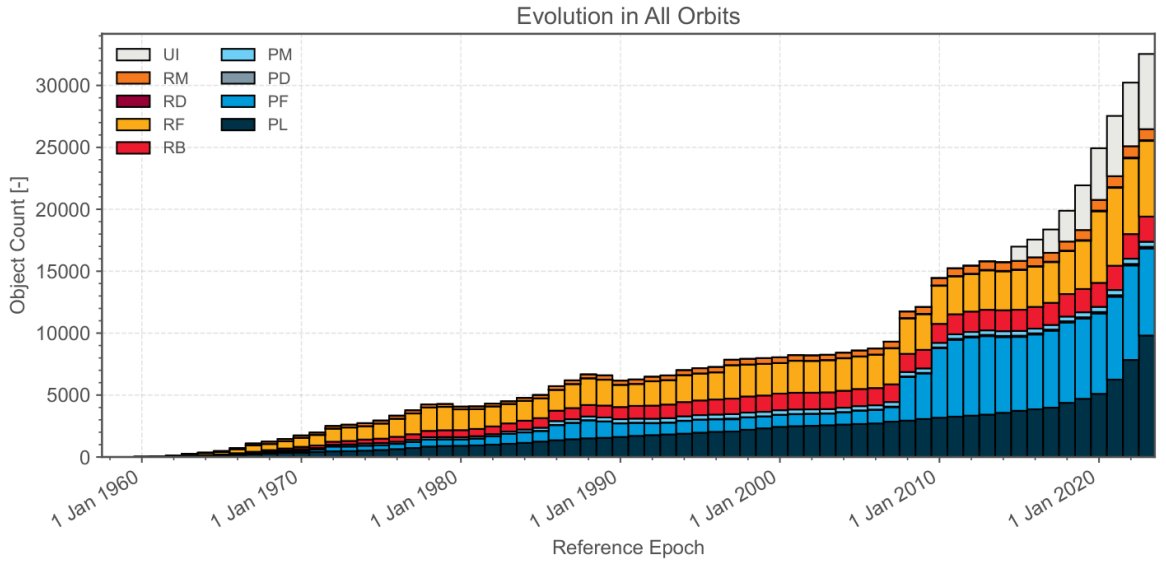
Background: on-orbit target capture





Urgent need for active removal of space objects

- ❑ Earth’ s orbital environment as a finite resource
- ❑ Possible collisions with orbital devices

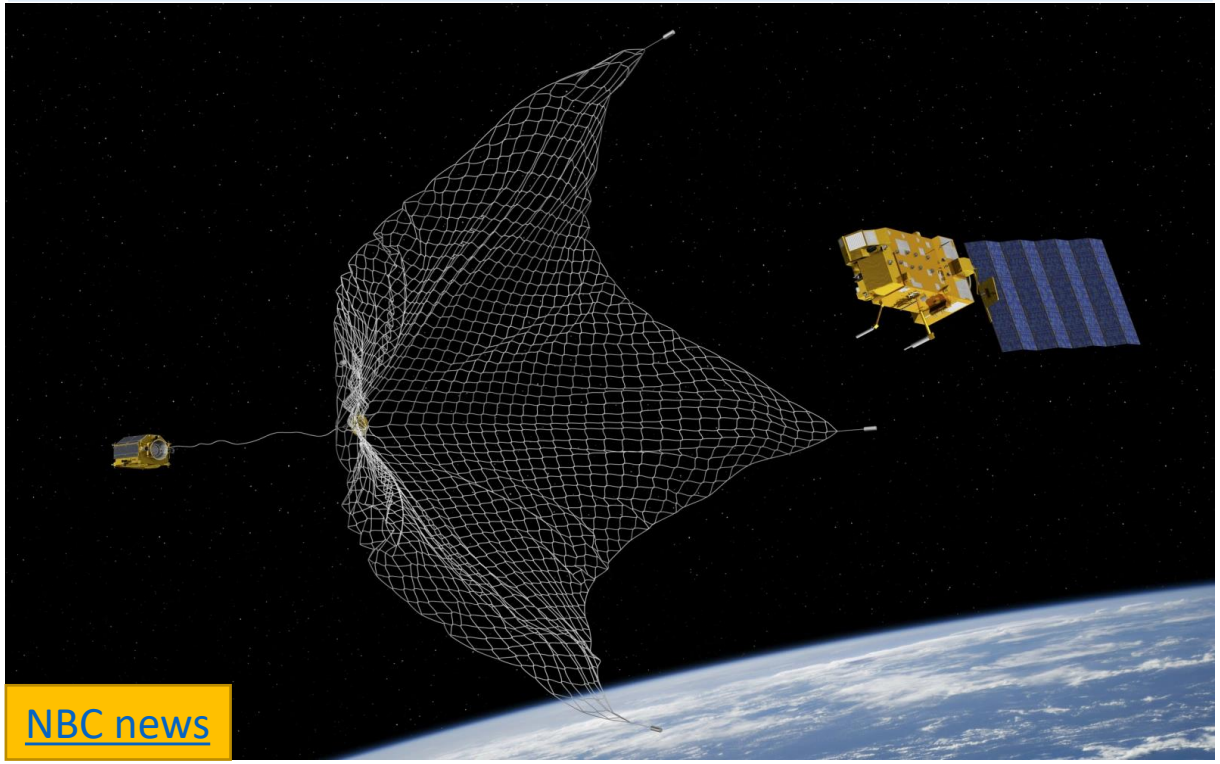
Background: on-orbit target capture

Active Removal of Space Objects

Robotic manipulators for **cooperative objects**

ISS

Tethered nets for **non-cooperative objects**

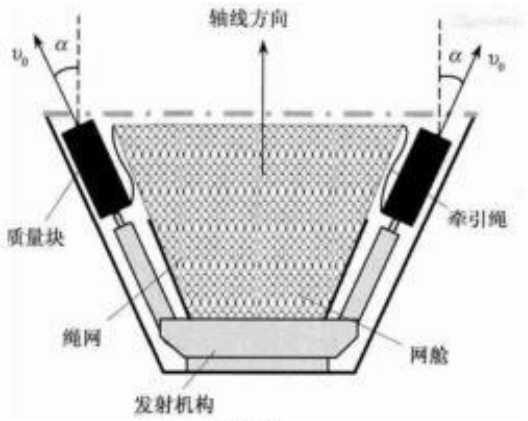


NBC news

Launch and control of the tether-net system in orbit

Background: on-orbit target capture

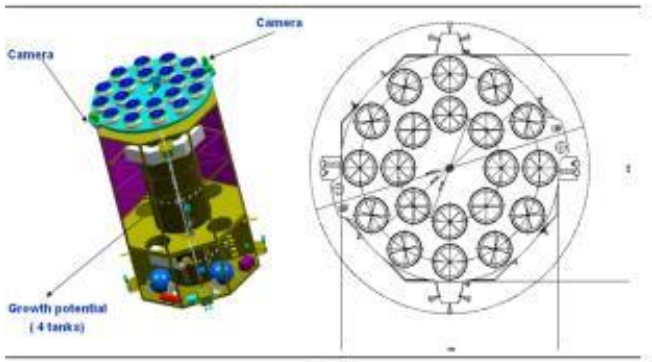
Launch of the tether-net system in orbit: accelerating a mass block in a short time



(a)


(b)

- ✓ **Gunpowder**
- ✓ **Compressed air**
- ✓ **Springs**
- ✓ **Electric motor**

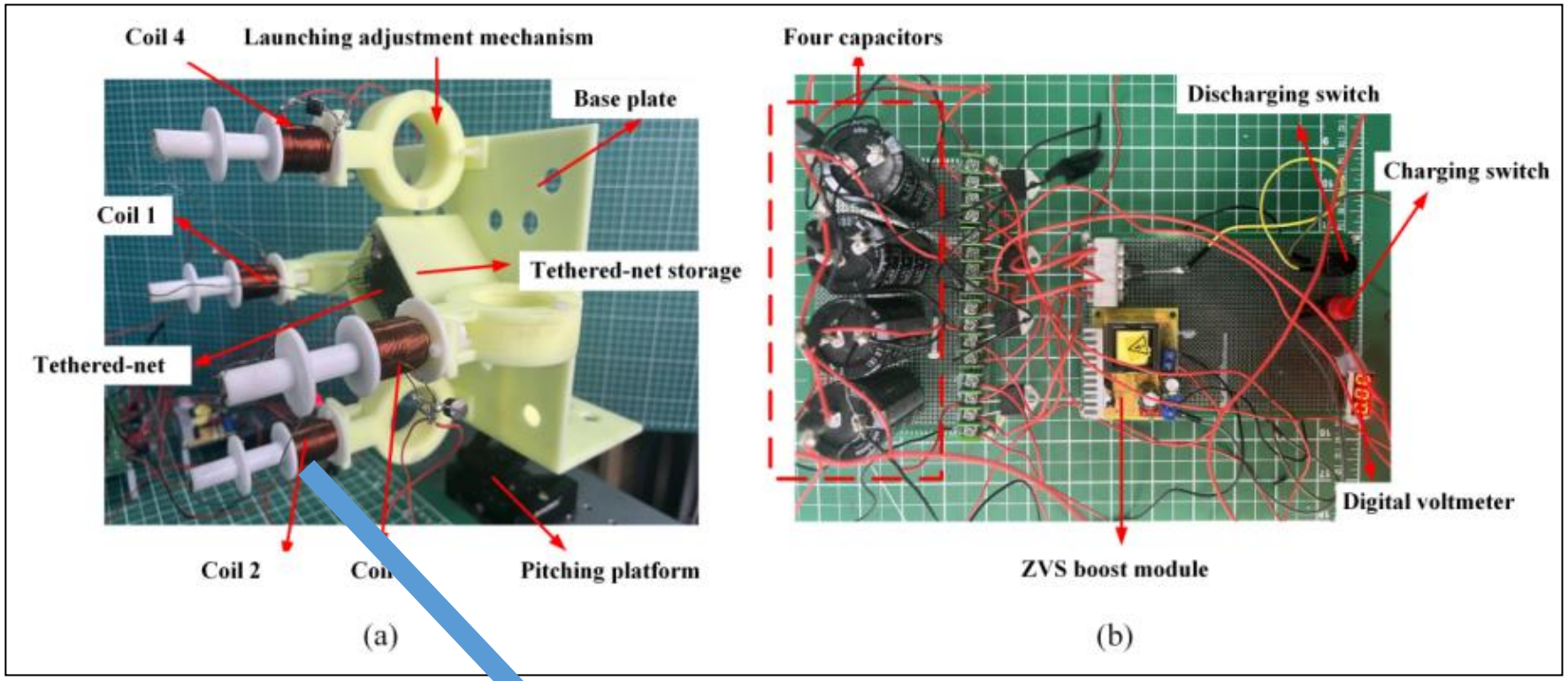


(c)

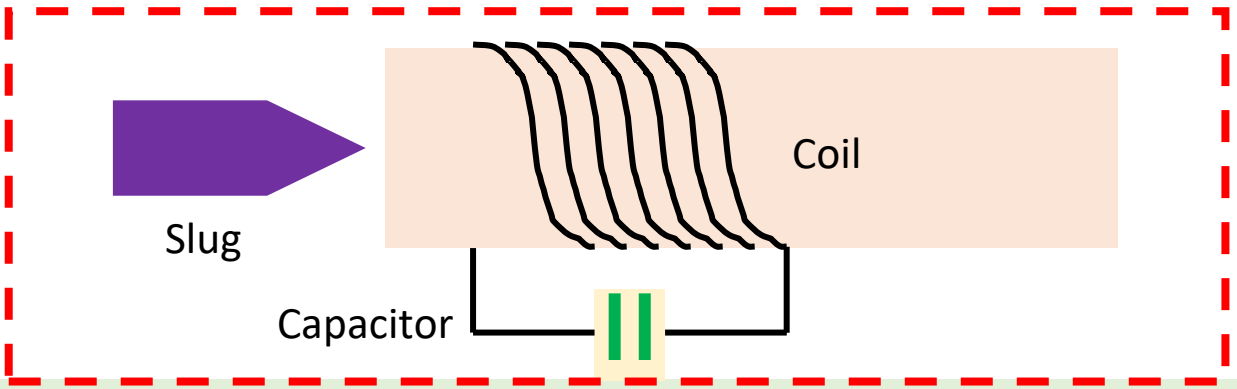

(d)

Alternatively, **electromagnetic launching** is promising in terms of its controllability and adaptability. In this contribution, **coil launcher** is focused on.

Coil launcher

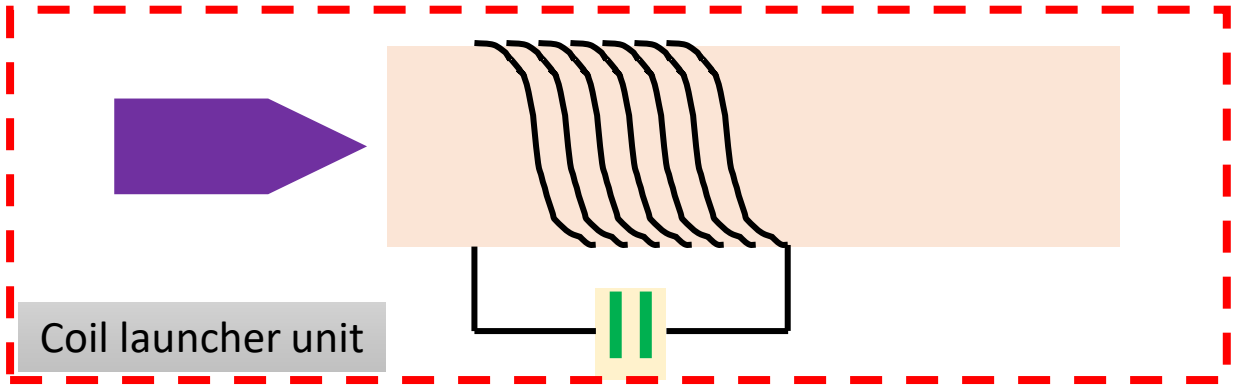


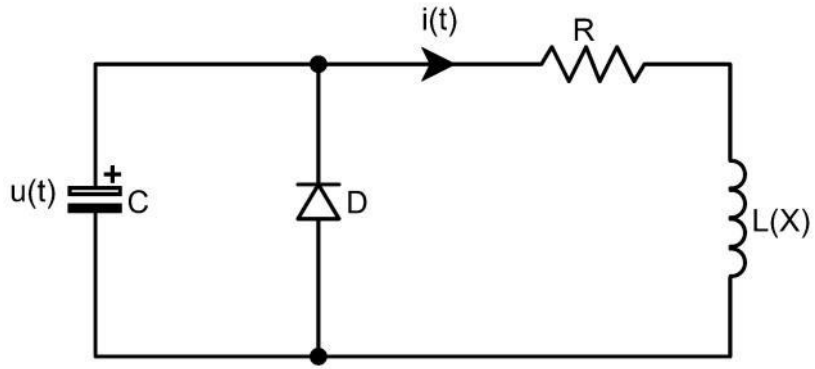
Four coil launcher units



Coil launcher

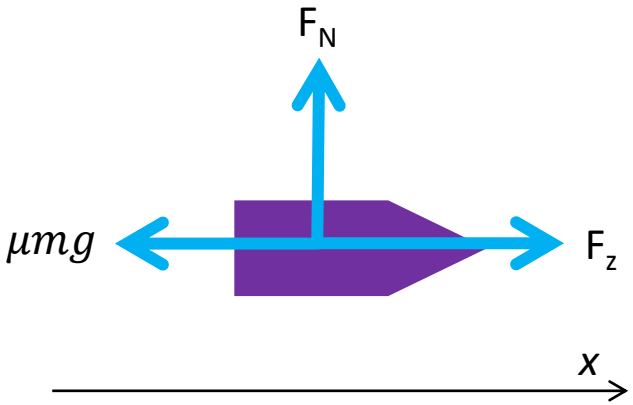
Mathematical description of the coil launcher:
an inductor-capacitor circuit for the coil and the electromagnetically pulled slug





Coil

$$u(t) = R \cdot i(t) + \frac{d\Phi}{dt}$$



Slug

$$F_z - \mu mg = m\frac{d^2x}{dt^2}$$

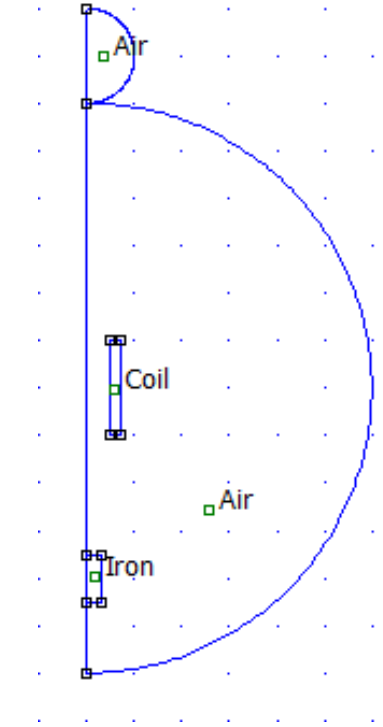
$$F_z = \frac{d}{dx}\left(\frac{1}{2}L \cdot i^2\right)$$

$$\frac{d\Phi}{dt} = \frac{d}{dt}(L \cdot i)$$

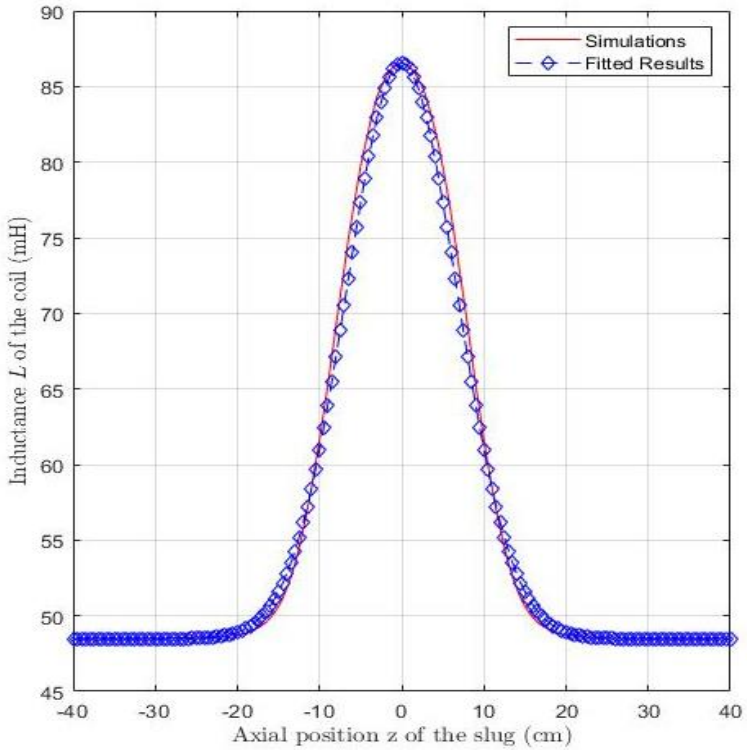
Axial magnetic forces F_z upon the slug and **equivalent inductance L** of the coil is highly dependent upon slug position z

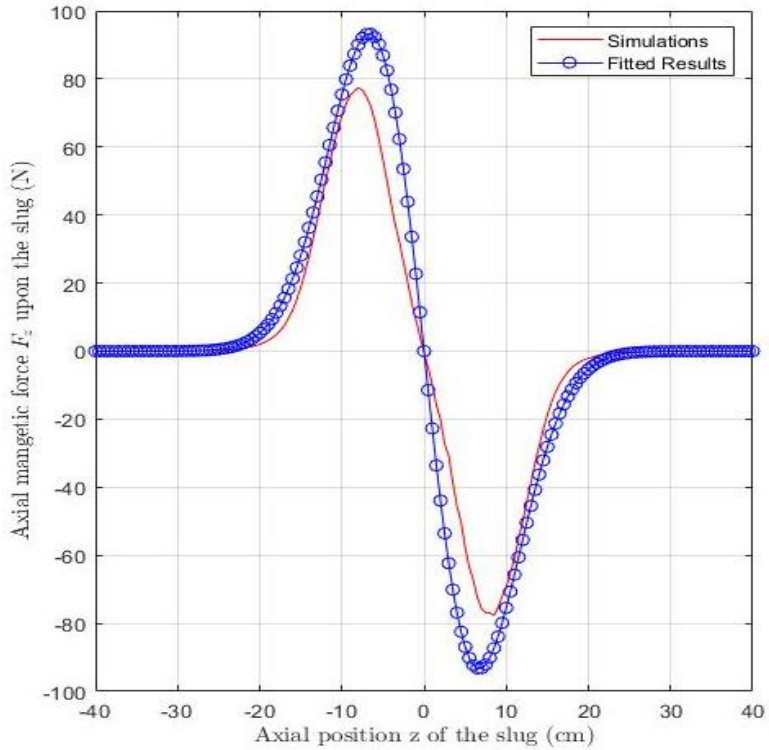
Coil launcher

Mathematical model of the coil launcher: an inductor-capacitor circuit for the coil and the electromagnetically pulled slug



Magnetostatic FEM model in Femm 4.2



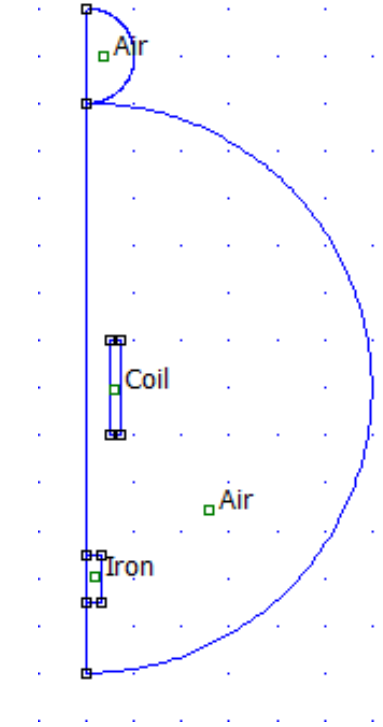


In a magnetostatic sense, **the current through the coil i is held constant**:

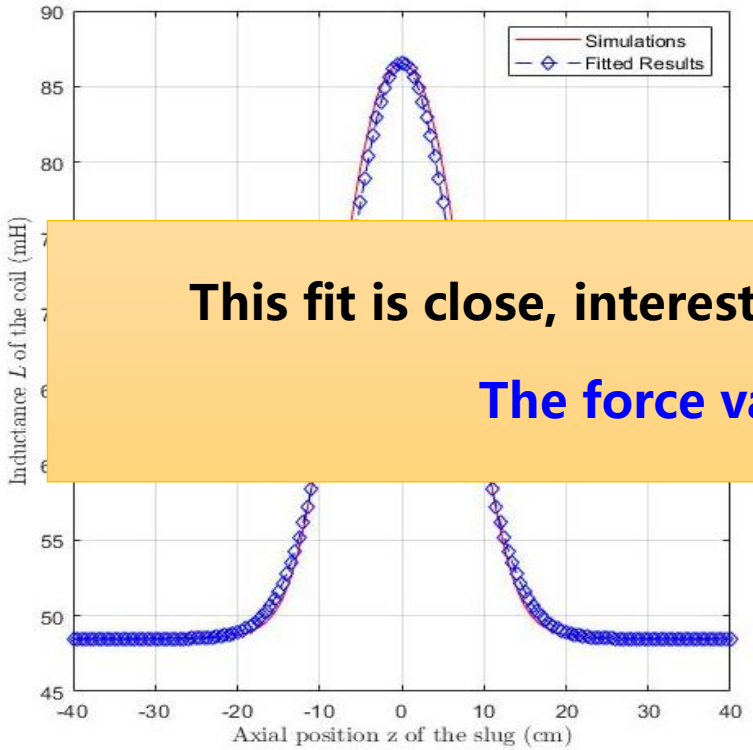
- the equivalent inductance L exhibits **an approximate Gaussian bell shape: $L = a + be^{-z^2/c}$**,
- the axial magnetic force F_z is **proportional to the axial derivative of L : $F_z \propto -\frac{2bz}{c}e^{-z^2/c}$**.

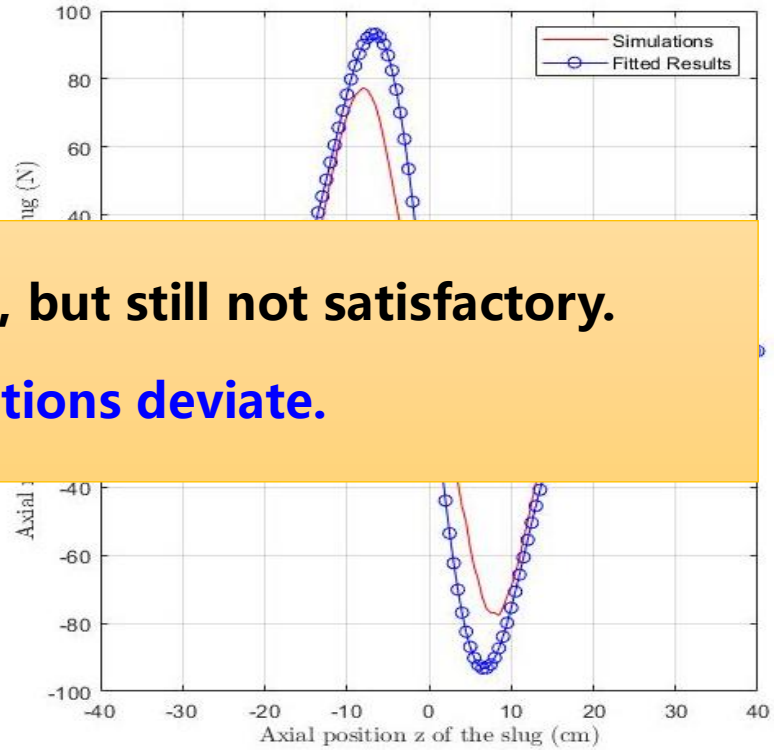
Coil launcher

Mathematical model of the coil launcher:
an inductor-capacitor circuit for the coil and the electromagnetically pulled slug



Magnetostatic FEM model in Femm 4.2





This fit is close, interesting, but still not satisfactory.

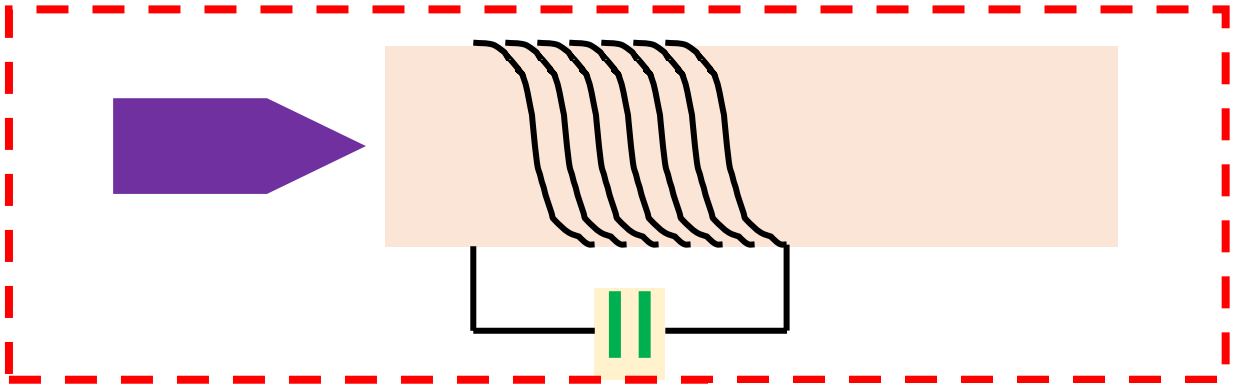
The force variations deviate.

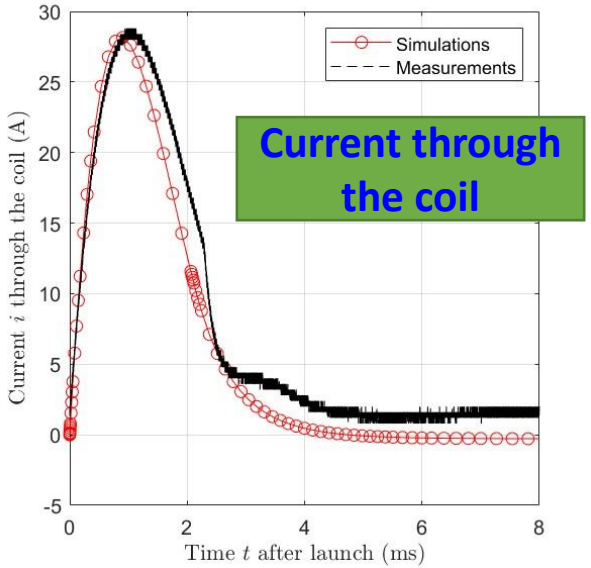
In a magnetostatic sense, **the current through the coil i is held constant**:

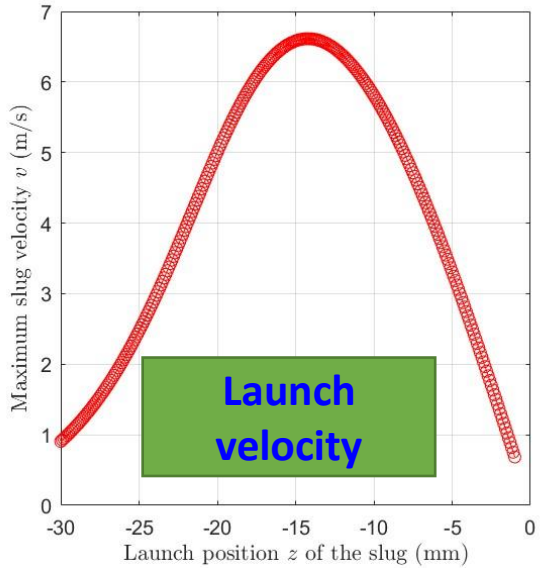
- the equivalent inductance L exhibits **an approximate Gaussian bell shape: $L = a + be^{-z^2/c}$**,
- the axial magnetic force F_z is **proportional to the axial derivative of L : $F_z \propto -\frac{2bz}{c} e^{-z^2/c}$**.

Coil launcher

Mathematical model of the coil launcher:
an inductor-capacitor circuit for the coil and the electromagnetically pulled slug

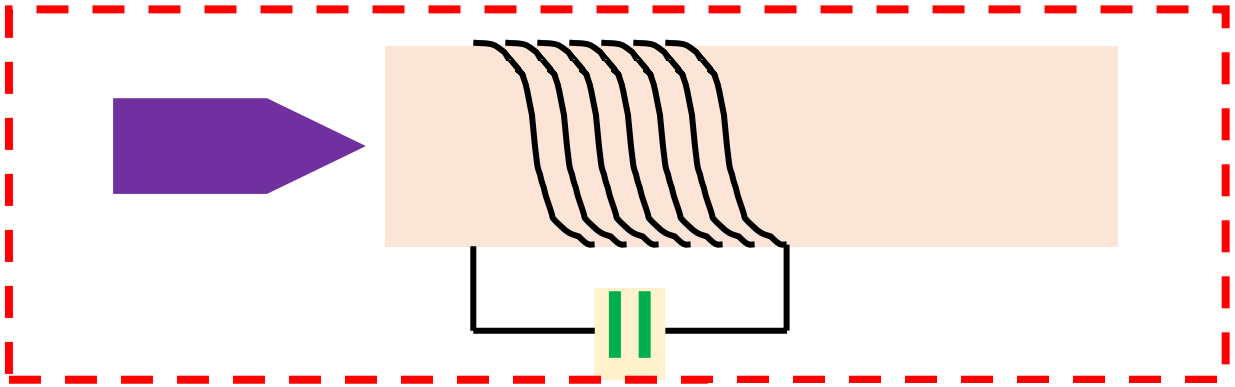




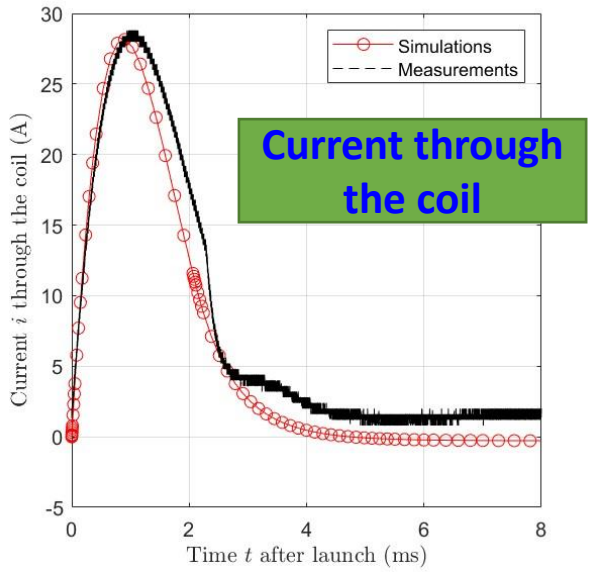


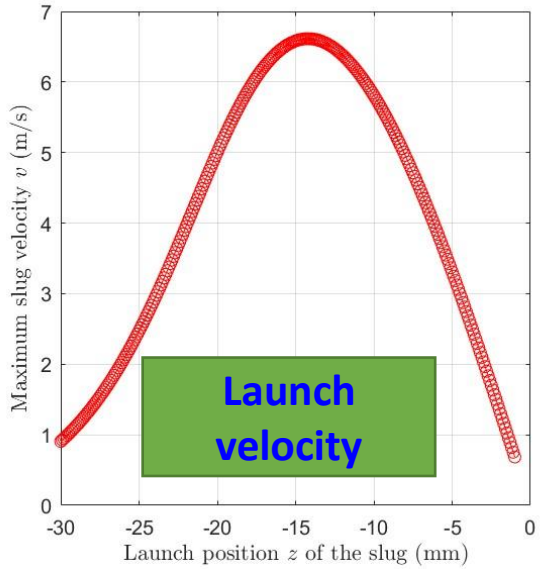
Coil launcher

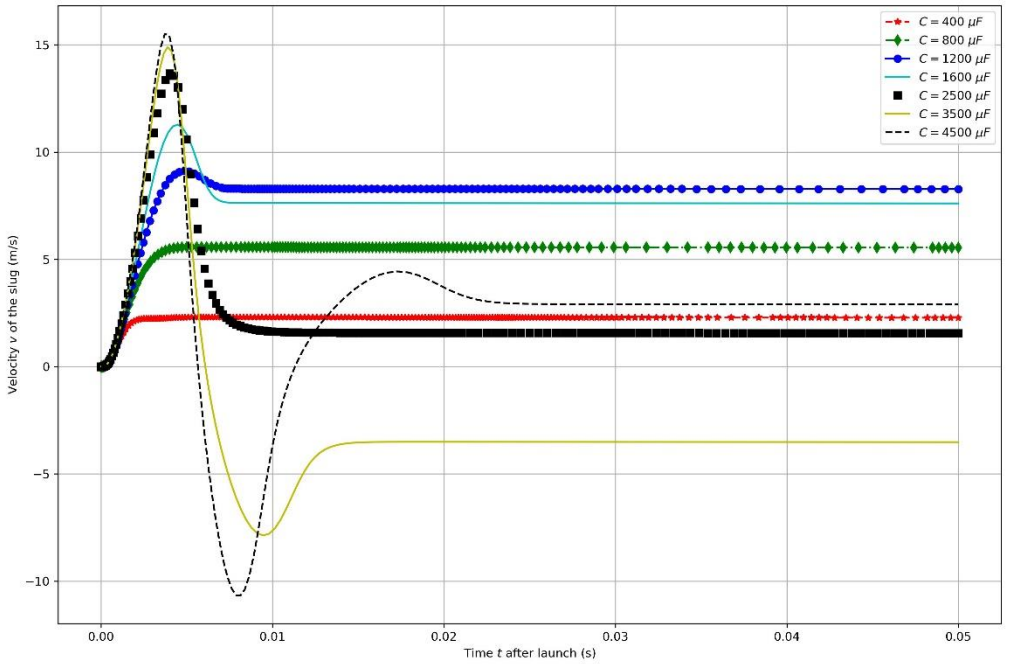
Mathematical model of the coil launcher:
an inductor-capacitor circuit for the coil and the electromagnetically pulled slug



- A **pulse current** is fed into the coil to launch the slug
- There exists an **optimal launching position**
- **The supercapacitor matters** …







Thanks for your attention