Limits of ion pathline control using electric field

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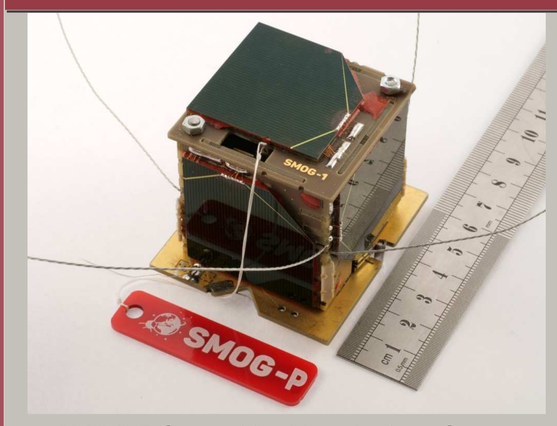
Motivation of work

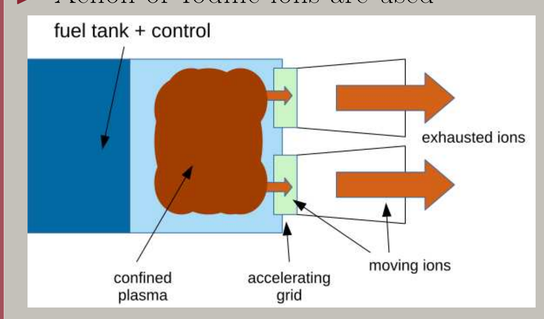


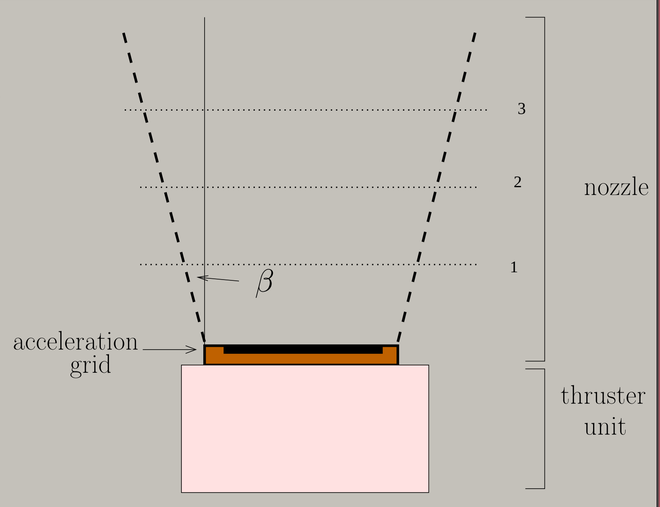
▶ SMOG-P [https://gnd.bme.hu/smog] PocketQube (5x5x10 cm) at the department

- small satellites becoming popular (CubeSat or PocketQube sized)
- a propulsion system is needed to control the motion of the satellite
- electric propulsion is a low-weight choice
- Can a single thruster steer a satellite or do we need multiple thrusters?

Ion propulsion system

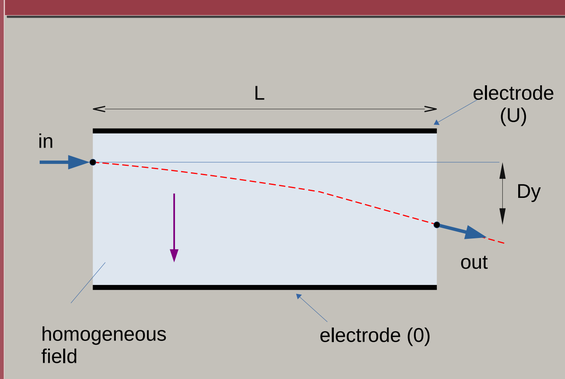
- a type of electric propulsion
- generated ions are accelerated towards the nozzle
- outflying ions push the satellite forward
- Xenon or Iodine ions are used



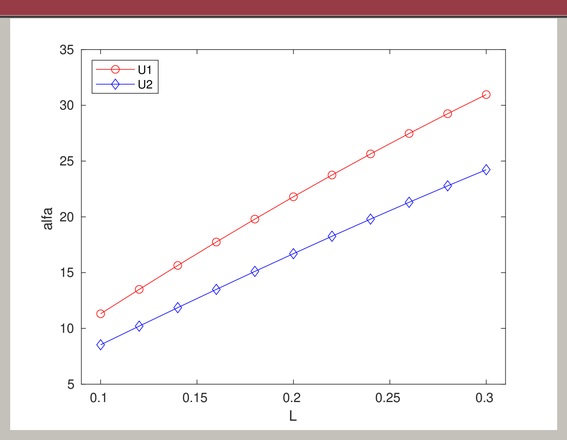


possible outline of a nozzle attached to the top of a 1U sized thruster-unit

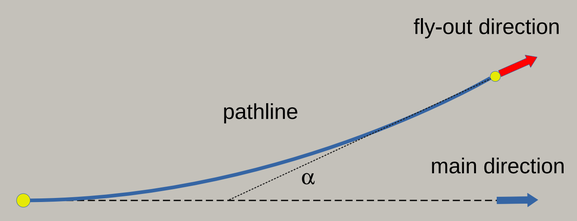
Single layer effect

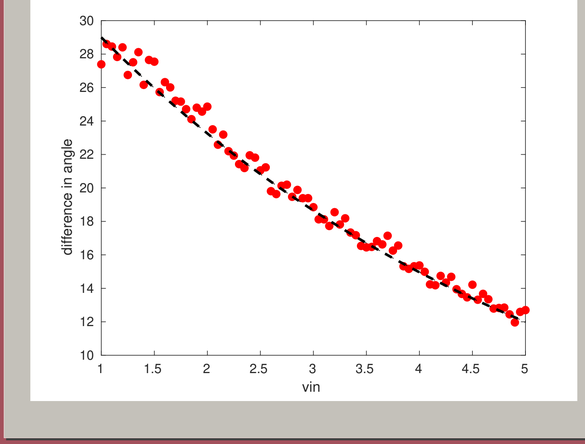


simple model (plane capacitor) to estimate deflection angle



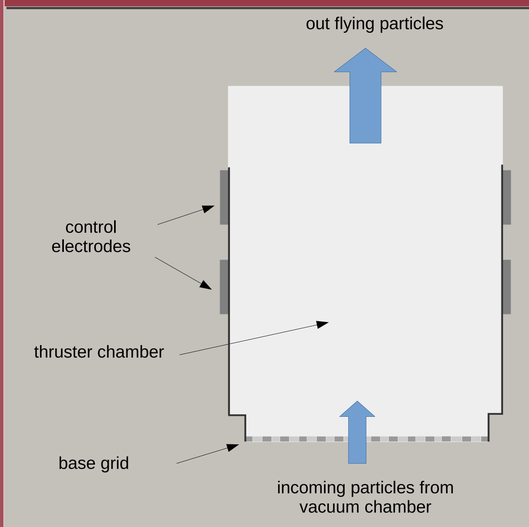
▶ effect of electrode length (L) and potential difference at small input velocity





- deflection angle of long electrode length
- red dots - different (random) starting point near center of accel. grid
- slashed line - simple model's calculated deflection angle
- simple model is surprisingly good

Physical model of the problem



- coupled problem of electromagnetics and motion of charged particles
- EM is modeled as electrostatic

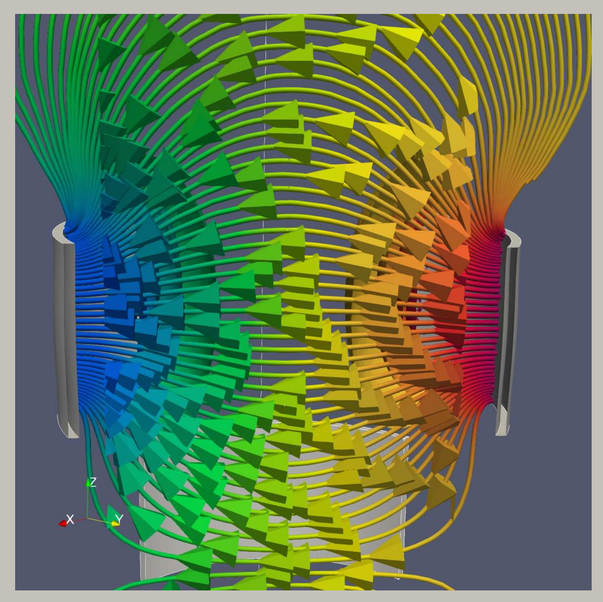
$$\nabla(\varepsilon\nabla\varphi) = 0$$

- proper BCs : $\dfrac{\partial\varphi}{\partial n} = 0$ and $\varphi = U_{el.}$
- trajectory is pathline of ions

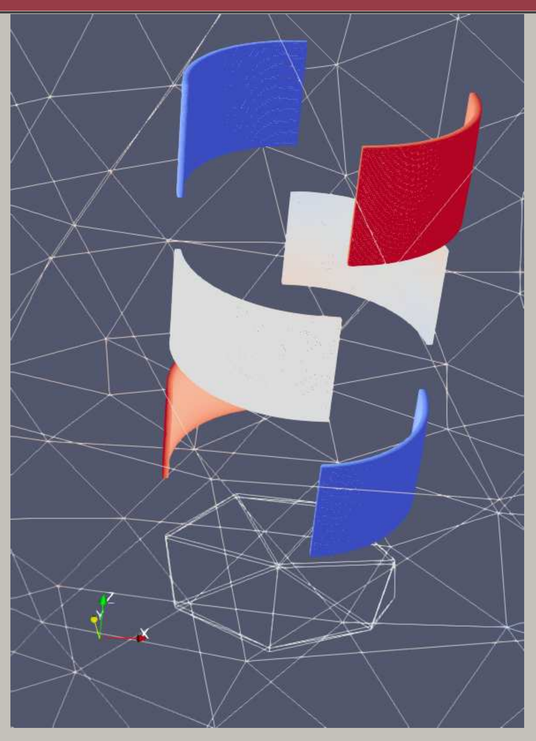
$$\frac{\mathrm{d}^2\tilde{\mathbf{p}}}{\mathrm{d}t^2} = \tilde{\mathbf{F}} = -\nabla\varphi$$

What requirements did we set for the EM-simulator?

- use only open-source/free programs
- gmsh - geometry creation and meshing
- Python-based (NumPy) solver for FEM
- Visualization is made by ParaView
- MATLAB-PDETool were used to testing and analysis of speed and memory usage

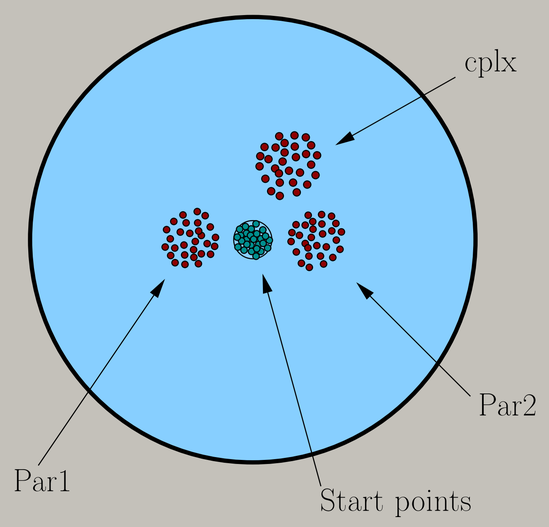


3D effects



outline of a nozzle with 3 layers of electrodes

random start points with same velocity



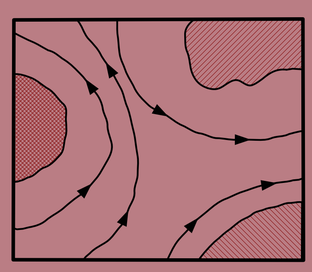
Electrode potentials 1,2,3,4,5,6

- Par1 : -1000,1000,0,0,-1000,1000
- Par2 : 1000, -1000,0,0,1000,-1000
- Cplx : 1000, -1000,1000,-1000,1000,-1000

Conclusions and remarks

- low speed ions can be controlled
- nonlinearity effects caused by non-planar electrodes
- simple model surprisingly good at low speed
- at high velocity only electric field is not enough
- in case of CubSat-sized satellite at least 2-3U needed
- control voltages are limited that limits deflection angles
- line of outflying is not always progresses through center of mass of satellite (torque effect on satellite)

Bibliography
- SMOG-P, Official Site, http://gnd.bme.hu/smog
- H. Henke, Elektromagnetische Felder, 6th Ed., Springer Verlag, Berlin, 2020
- R. Hockney, J. Eastwood, "Computer Simulation Using Particles", IOP, New York, 1989.
- Jahn, Robert G. (1968). "Physics of Electric Propulsion" (1st ed.). McGraw Hill Book Company
- A. Reichardt et al., "Optimization of particle trajectories inside an ion-thruster", Proc. of 19th International IGTE Symposium, Graz, 2020.



http://nanoelsim.hvt.bme.hu/IGTE2022