Comparison of Methods for Numerical Modelling of Electric Propulsion Plume-Spacecraft Interaction

MSc. Thesis in Electromagnetics, Fusion and Space Engineering.

Presentation for the 28th SPINE Conference, 2021

K. Rikard Siljeströmer, MSc. Student in Aerospace Engineering
KTH Royal Institute of Technology

Presentation Agenda

Summary

- Introduction
  - *w*hy a comparison of methods?
- Simulation modeling
  - *Explain briefly about software being used*
- Simulation steps
- Numerical Results
- Discussion & Conclusion

Introduction

Computational models have been developed to **better understand** and **help manage** plume-spacecraft interactions,

- Calculations include
  - Current density
  - Ion energy
  - Plasma potential
  - Charge density

In this work, results from different plume-simulation software are compared, highlighting the impact of the different calculation methods.

Simulation Modeling

The software chosen for the comparison is SPIS (Spacecraft Plasma Interaction Software) developed by ONERA and ESA, and openPlumeEP, developed by the OHB Group.

- SPIS for its computational heavy Particle-in-Cell (PIC) algorithm, using super-particles to represent the actual particles being simulated.
- openPlumeEP for its quick and efficient Ray-Tracing algorithm, using rays to simulate the paths of the particles being simulated. (1/r^2 rule)

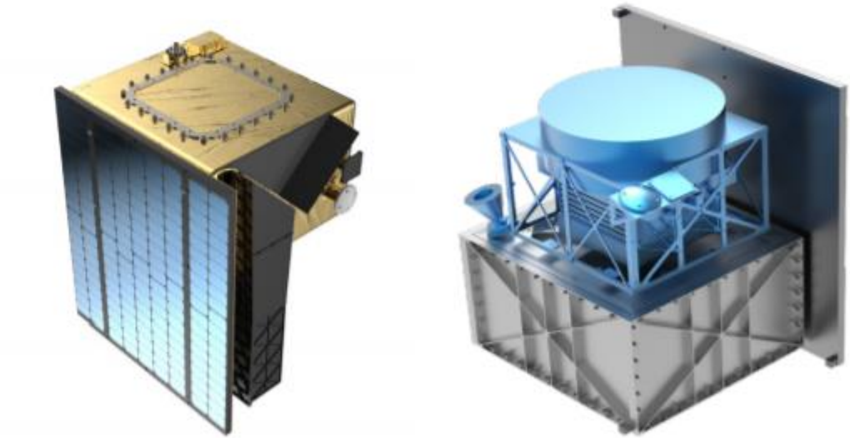
Simulation steps

The set-up for this thesis is defined into four phases

- Mesh geometry via GMSH interface
- Input thruster characteristics
- Defining parameters (SPIS and openPlumeEP)
  - Temporal
  - Geometric
  - Measuring instruments (only SPIS)
  - Etc
- Running the simulation

Mesh Geometry

Mesh geometry was based on the InnoSat medium satellite platform developed by OHB Sweden in 2012.



InnoSat Platform, image credit: OHB Sweden, 2018.

Mesh Geometry

A mesh was created using the GMSH platform since both SPIS and openPlumeEP relies on GMSH to construct their geometries.

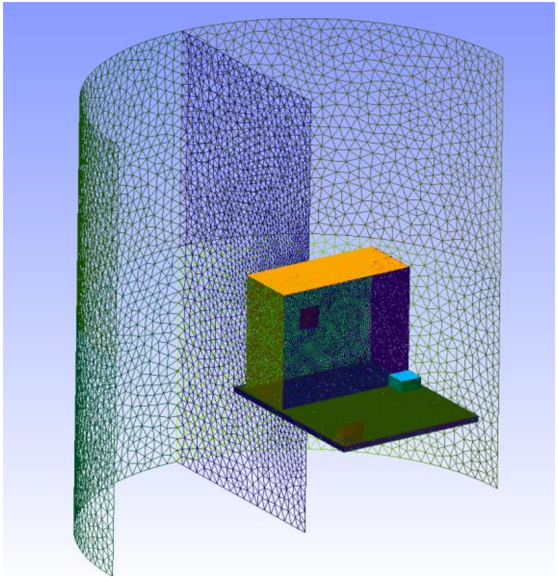
- A 2D mesh of surface shells to be used by openPlumeEP, containing the different satellite surfaces, important instruments to be included, thruster and measuring surface.
- A 3D mesh based on the one of openPlumeEP mesh but included an external boundary and a computational volume, used by SPIS.

The mesh needs to be more refined around the thruster exhaust in order to capture the particle interactions, and transitions into a more coarse grid further from the thruster exit

Total number of nodes could not be too small (**not enough resolution**) nor too big (**immense computation time**). Mesh size 30k – 120k is optimal. (no issues with openPlumeEP).

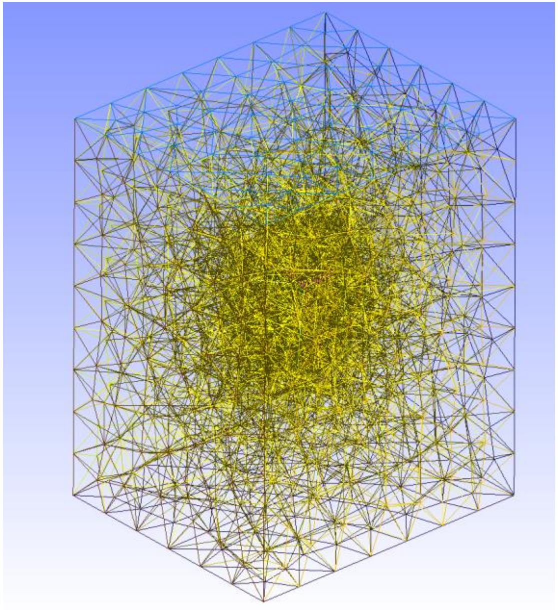
Mesh Geometry

2D



openPlumeEP Mesh, 132k surf. nodes

3D

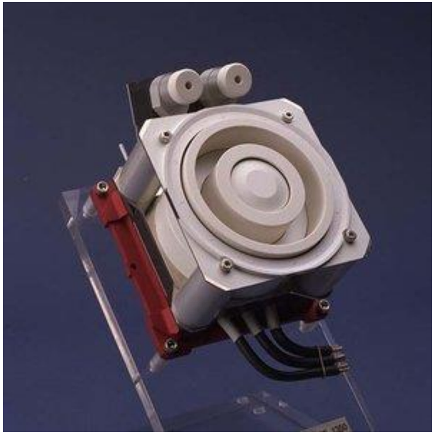


SPIS Mesh, ~39k vol. nodes

Input thruster characteristics

The thruster chosen for this comparison is the SPT-100 (Stationary Plasma Thruster) Hall-Effect Ion Thruster, using Xenon as propellant.

The SPT-100 was chosen because it is a well-known thruster with a well-characterized thruster plume and extensive flight heritage.



SPT100, image credit ESA.

Temporal Parameters

For SPIS, the duration and timesteps are very important.

- Duration – account for the super-particle “steady-state”*
  (duration 1s, simulation-dt 0.1s)
  **Note: Characteristics of simulation method, not thruster operation.*
- Particle-dt – account for particle speed
  (ion-dt 10e-6 s, electron-dt 10e-9 s)
- Plasma-dt – account for small-scale plasma behaviour (plasma frequency, Deybe length etc.) (10e-6 s)

For openPlumeEP, only thruster “on-time” is required. To allow comparison of the two software, the “on-time” is set to the same value as SPIS (1 s).

Comparison

Proposed procedure:

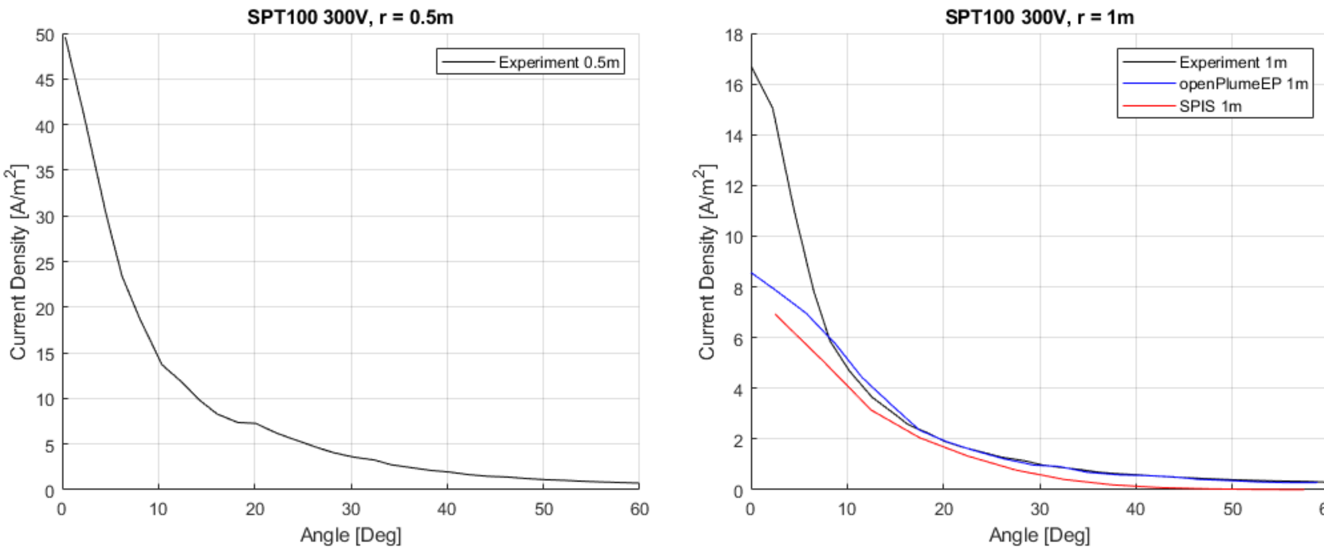
- Input experiment data measured at 0.5 m from SPT100 exit plane.
- Run simulation in both software for 1 second.
- Calculate values at 1.0 m from the exit plane and compare to experimental data.
- The following calculated values are compared;
  I. Ion energies of the expelled particles, as a function of the angel displacement, measured from 0 degrees to 60.
  II. Current densities of the emitted charged particles, as a function of the angel displacement, measured from 0 degrees to 60.
  III. Plume characteristics, meaning the shape and form of the exhaust plume.

Preliminary results

- Current Densities from openPlumeEP and SPIS
- Ion energies from openPlume
- Plume characteristics from openPlumeEP and SPIS

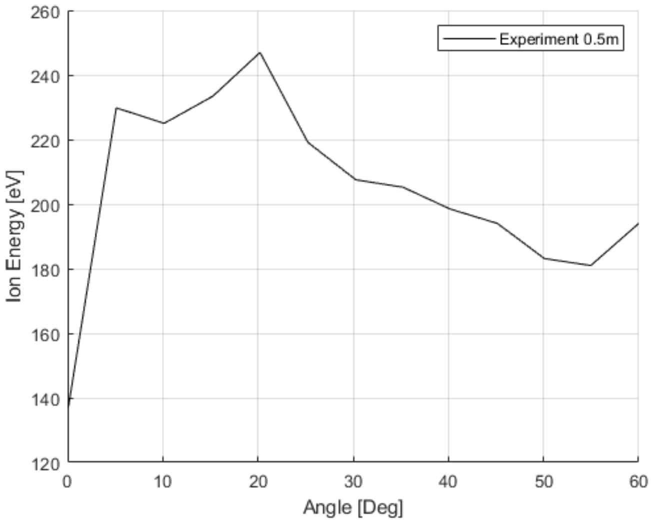
Feedback much appreciated.

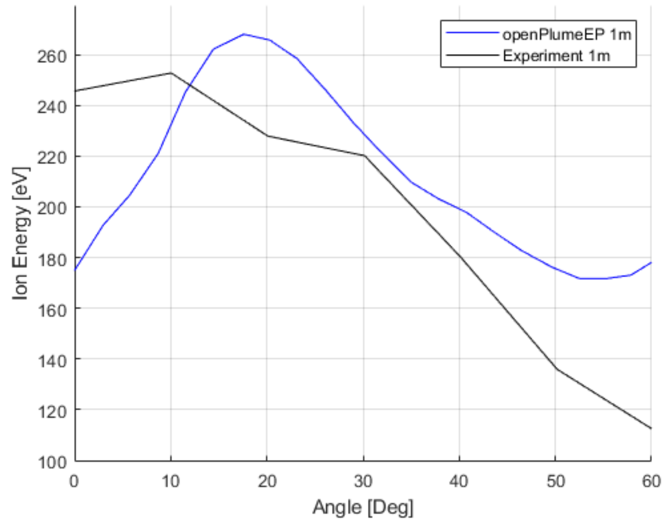
Results – Current Density



Experiment data from research paper ”Particle Simulations of the SPT-100 Plume”, by Douglas B. VanGilder and Iain D. Boyd, Cornell University, Ithaca, NY 14853, U.S.A.

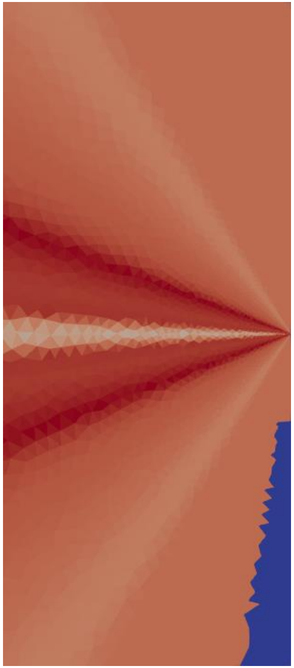
Results – Ion Energy





Experiment data from research paper ”Particle Simulations of the SPT-100 Plume”, by Douglas B. VanGilder and Iain D. Boyd, Cornell University, Ithaca, NY 14853, U.S.A.

Results – Plume characteristics

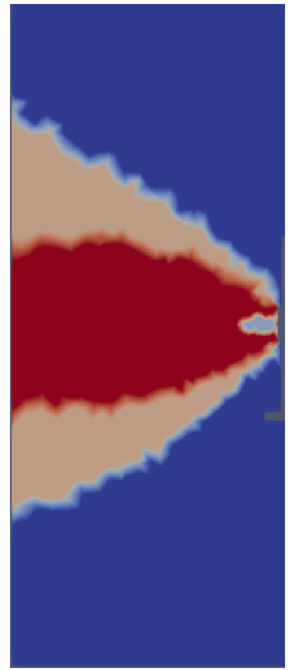


Ion Energy Xe+
openPlumeEP

Ion Energy Xe+
SPIS

Results – Plume characteristics

Charge Density Xe+
openPlumeEP



Charge Density Xe+
SPIS

Summary of results

- **Both software**: Calculated current densities in the near field SPT-100 plume compare well with experimental measurements, calculations are lower to the experiment data at low angular displacement.
- **SPIS:** In the far field (high angular displacement), calculations are lower compared to experiment data.
- **openPlumeEP:** Calculated ion energy as a function of angle differs in shape from experimental measurements at 1 m.
- Would like to calculate ion energy in SPIS and charge density in openPlumeEP. This would allow comparison of the calculated values.

Discussion & Conclusion

Possible explanations for the different results:

- openPlumeEP creates rays in all directions given a pre-determined angular distribution of current density and ion energy.
- openPlumeEP does not modelling electric/magnetic fields but SPIS does.
- Neither SPIS nor openPlumeEP models CEX collisons, but SPIS implements Monte-Carlo collisions.
- Parameters could be tweeked better to improve the results for SPIS. (Sensitivity analysis, eg. avg. number of particle per cell).
- For this work, in openPlumeEP only the ”curve-fitting” thruster model was used. If relevant experiment data becomes available, the PIC thruster model could also be used.

Thank you for listening!