# MULTISCALE SIMULATION OF ELECTRIC PROPULSION EFFECTS ON ACTIVE SPACECRAFT

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## ABSTRACT

New multiscale numerical methods are needed to accurately simulate the effect of small-scale components, such as the solar arrays interconnects, on the global charging of a spacecraft. Here we present the SPIS implementation of the nonlinear patch method. This numerical scheme allows SPIS to take account of the small-scale effects by introducing local mesh refinements in areas of interest.

Key words: multiscale, plasma simulation, solar arrays, electric propulsion, interconnects, patch method.

## 1. INTRODUCTION

The development of new European satellite platforms involving powerful electric propulsion for EOR is raising several questions about the interaction between the generated plasma plume and active spacecraft components such as solar array generators. New simulations capabilities are needed to accurately predict the currents collected by solar arrays, which have an impact on the satellite charging and available electric power. Such simulation needs can also be found in solar cell and interconnects design, to evaluate the impact of solar cell geometries on erosion and snapover effects.

Modern multiscale numerical methods are required to precisely simulate the coupling between plasmas and small-scale components of a spacecraft. Resolving these finer scales in plasma simulations is necessary to give correct estimates of the impact of smaller exposed components on spacecraft charging, such as solar array interconnects.

We have developed a new numerical method called *iterative nonlinear patch method*, that allows us to solve previously intractable simulation problems. With this modern numerical method, the simulation is resolved on a coarse global mesh, and refined on local *patches*. We show that

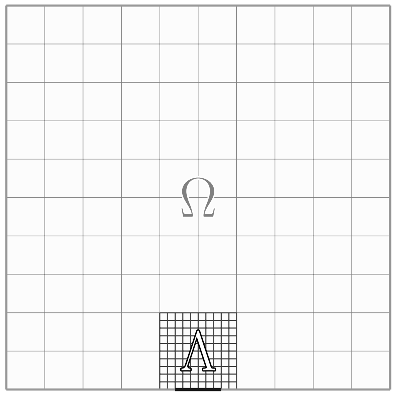


*Figure 1. A localized patch $\Lambda$ on a global mesh $\Omega$. Illustration on a structured 2D mesh.*

this flexible method allows the SPIS plasma simulation code to efficiently solve large multiscale simulations with multiple plasma models.

Here we present the SPIS implementation of the multiscale iterative nonlinear patch method for the simulation of current collections by solar array cells with interconnects. Simulation results are being validated by experimental data from Onera's JONAS facility. We have measured collected currents for different interconnect geometries and varying plasma densities. Comparing simulation results to experimental data allows us to validate the use of these new numerical methods in SPIS.

## 2. NONLINEAR PATCH METHOD

The iterative patch method [10, 6, 5] is a particularly flexible domain decomposition method that aims at solving multiscale elliptic problems using several overlapping grids. An extension of this numerical method to solve nonlinear problems, such as the Poisson-Boltzmann problem raised in space plasma simulation, has been proposed and studied in [2].

The method consist in embedding local refined meshes called patches in a global coarse mesh. Figure 1 shows a typical patch refinement next to a boundary of the computational domain, for instance around a solar array interconnect. Each iteration of the patch method consists in solving the problem on each mesh, introducing volumic source terms representing the coupling between meshes. It has been shown in [5] that the sum of the solutions on the different meshes converges towards the solution of the global problem.

In the nonlinear case, this method can be merged with an iterative Newton method, yielding good overall convergence properties, as discussed in [2]. We propose to use this method to solve for the electrostatic field in SPIS, either with the linear particle-in-cell model, or with the nonlinear Boltzmann model for electrons.

## 3. SPIS IMPLEMENTATION

The SPIS numerical core is composed of a Poisson solver and a particle pusher that are being adaptated to this new numerical method.

Both the coarse mesh and the patch are provided by the user as a nonconnex and overlapping mesh. This mesh is automatically sorted into connex parts by a Cuthill-McKee ordering of the nodes, and the data structures for the operators have been modified to allow for efficient partial application and solving.

A new Poisson solver has been developed and implements the iterative patch method, solving alternatively on each mesh, and introducing coupling terms thanks to a precomputed coupling operator.

To ensure a fine resolution of the electric field for the particle pusher, particles are only inserted in the refined cells. When entering the patch area, a dedicated code search for the proper patch cell to insert the particle in. When computing the electric field in these cells, the effect of the coarse mesh solution is added. These operations can be efficiently done with proper data structures.

Instead of integrating the densities on the final state of the particles after pushing them, as is classicaly done, the charge densities are integrated along the path of the particles during the pushing. This integration scheme allows for the reduction of the numerical noise in relatively small cells.

## 4. NUMERICAL EXAMPLE

Local simulations of solar arrays interconnects have been carried out in the litterature, both for negative [9] and positive [3, 8, 1] interconnects, particularly in the LEO environment. However, these references only simulate infinite solar arrays with homogeneous environments, lacking the coupling with other parts of the spacecraft and between interconnects with different charging.

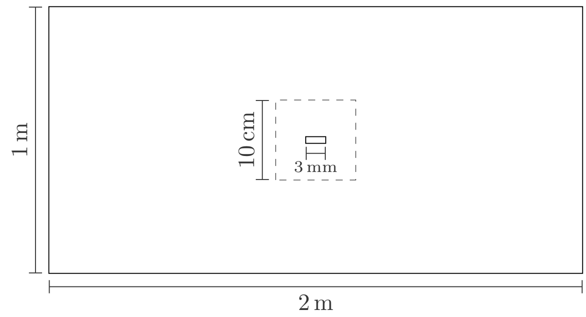


*Figure 2. Spacecraft geometry (not to scale). The considered computational domain is a* $50\,\mathrm{cm}$ *thick box based on this geometry. The dashed squared is the patch location, the inner rectangle is the interconnect geometry.*

On the other hand, global electrostatic interactions between solar arrays and other elements of a spacecraft have been of growing interest, especially for All-Electric GEO missions [7, 4, 11]. In these global simulations, small-scale components are simplified with analytical models to resolve for instance the current collection or erosion effects, and thus the impact of these components on the global electrostatic state of the satellite is often not fully resolved. We propose to use multiscale numerical simulation methods to accurately simulate the coupling between local small-scale effects and the global charging of a spacecraft.

We here showcase the simulation of a negatively biased solar array interconnect in a relatively large SPIS computational domain. As presented on figure 2, the domain is defined as a $2\,\mathrm{m} \times 1\,\mathrm{m} \times 0.5\,\mathrm{m}$ box. A spacecraft dielectric boundary coundition is applied on one side of the box, and a small $1\,\mathrm{mm} \times 3\,\mathrm{mm}$ conductor is embedded in the center of this surface to model the interconnect.

The patch is automatically generated by subdivision of a selection of coarse cells, yielding around 125 refined cells per coarse cell. The obtained patch is covering a box of $10\,\mathrm{cm} \times 10\,\mathrm{cm} \times 5\,\mathrm{cm}$ around the interconnect. The typical size of the coarse cells range from $10\,\mathrm{cm}$ to $1\,\mathrm{cm}$, and the size of the patch cells range from $5\,\mathrm{mm}$ down to $0.5\,\mathrm{mm}$. Electrons in the plasma are modelled by a Boltzmann statistic, and ion densities are computed by a particle-in-cell numerical model.

Figure 3 shows the computed electrostatic potential for an interconnect biased at $-100\,\mathrm{V}$. It is readily seen that the small-scale features of the potential around the interconnect are well resolved by the simulation code.

## 5. CONCLUSION

A new multiscale numerical method has been proposed for the simulation of spacecraft charging. The iterative

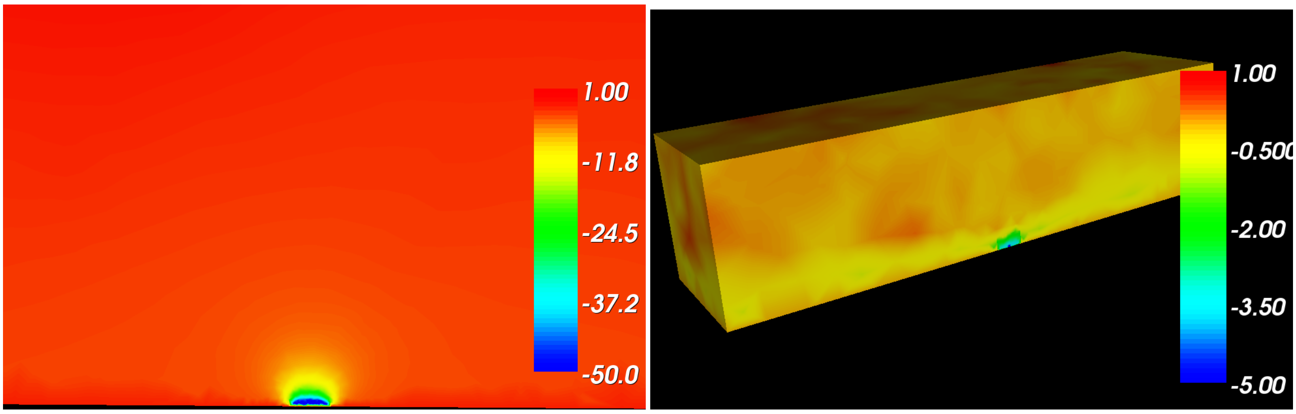


*Figure 3. Resulting electrostatic potential around a* $-100\,\mathrm{V}$ *interconnect – Closeup on the interconnect and global solution*

patch method currently being implemented in SPIS is showing promising preliminary results for the simulation of complete plasma-satellite interactions down to the sub-millimetric scales.

In particular, the integration in the SPIS simulation software of this flexible numerical scheme, coupled with analytical models and interpolation schemes, will allow the simulation of the impact of solar array interconnects in the plasma collection and the electrostatic state of a spacecraft.

## ACKNOWLEDGEMENTS

This work is supported by the French national space agency (CNES) and the French aerospace laboratory (ONERA). The authors would like to thank Artenum for their help and ideas.

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