Spacecraft Plasma Interaction Analysis and Simulation Toolkit

SPIS

Final Presentation

ESTEC Contract No. 16806/02/NL/JA

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Outline

- SPIS project overview
- Code description
- Code testing
- Applications
  - Microscope: electric propulsion
  - Charging in GEO (multiscale)
  - ESD triggering
- Future
  - Erosion module
  - Time dependent charge and discharge simulator
  - SPIS - GEO
"Historical" Overview

- SPINE community (Spacecraft Plasma Interaction Network in Europe) was set up around year 2000 (SPINE meetings 1-3)
  - An idea was born: gather European efforts for SC-plasma interactions
  - Exchange: knowledge, data, codes, results...
- ESA ITT in 2002 (Spacecraft Plasma Interaction Analysis and Simulation Toolkit - SPIS)
  - Boost the development of a common simulation toolkit
  - ESA/ESTEC Contract No. 16806/02/NL/JA
- Three years, of requirements/development/testing/applications involving contractors and community
- Final Presentation of "SPIS initial development" contract in Dec. 2005 (SPINE workshop 10)
- Final Presentation Days, today
- Future: SPIS and SPINE further development planned

Project Development Logics

- A community tool
  - major: SPIS was developed for (and by) SPINE community
  - Open source, object oriented approach => modularity
  - Community was a central actor of the phase 1 (requirements), and 3 (testing and validation)
  - was not quite as active concerning development (phase 2): only marginal contributions (various debugging, adaptation of vtk library to Mac platform, …).
- SPIS = a one-button-click software?
  - Initially thought as a multi-purpose and multi-physics code rather than as a single effect (e.g., charging level) assessment code
  - Priority to its modularity
  - More packaged, two-button-click versions can perhaps be developed later
  - Yet, following the users’ demands, higher priority was set to operation from Graphical User Interface (GUI) than from script or source modification
SPIS Development Organisation

- Three major entities:
  - The contractor: proposes requirements and design, develops software, supports WGs
  - Software Development Advisory Board (SDAB): supervises and orients development
  - Working Groups (and whole SPINE community): expresses requirements, participates in the development, tests the software

- Three major phases
  - Dec 2002
  - June 2003
  - June 2004 v3.1
  - Dec 2005 v3.2

Modelling perimeter

- Code can cover any spacecraft plasma interaction issue (possibly through enhancement):
  - Plasma dynamics:
    - Any Debye length / orbit
    - Quasi-neutral and space-charge regions
    - Electric or electromagnetic interactions
    - Volume interactions (collisions)
  - Spacecraft/Material interactions
    - All surface interactions
    - Spacecraft equivalent circuit (coatings + extra device)
Major requirements and choices

- SPIS main requirements and choices (URD-SRD):
  - Modularity: easiness to add new modules
  - Second was to answer the modelling needs (previous slide)
  - Major choices:
    - Unstructured mesh (⇒ multi-scale)
    - Java (OOA)
    - Solvers: cf. code description below
  - Framework requirements: support a whole modelling chain:
    - Pre processing: modelling, meshing, properties
    - Post processing
  - Community support:
    - Organise SPINE meetings for SPIS development: SPINE workshops 4 to 10 in years 2003-2005
    - Web-based community tool (see below)

Fulfils initial requirements
- Can model a lot of situations (cf. examples below)
- Validated in some significant situations (cf. below)
- Already used in many places:
  - Known: ESA, CNES, ONERA, CNRS/CETP, QinetiQ, Cril technology, KIT...
  - Downloaded by many more...

Releases
- Last public version: 3.1 December 2004
- Last version delivered to customers (ESA + close collaborators): 3.2 December 2005
- Last version will be publicly released very soon (April)
SPIS project overview

Code description

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Code Structure

The user

SPIS-UI
User (and software) interface

SPIS-Num
Numerical core

Other tools
GMSH, vtk, Cassandra...

Directory architecture

LibreSource-based
SPINE web site
SPINE web site

- This presentation
- Many other SPIS and SPINE documents

http://www.spis.org

LibreSource based (Artenum-INRIA):
- Collaborative development platform (next generation forge)
- Configuration versioning system
- Groupware platform

In practice:
- Work on the same sources
- Exchange sources and documents (common or private spaces)
- Forums, bug trackers...
- ObjectWeb consortium best use case awards

SPIS Framework

- SPIS/UI: a real simulation framework
  - Modelling chain
  - Task dependency handling engine
  - Scenario handling for tailoring
  - Powerful post processing tool
Main solvers characteristics

- Matter: PIC kinetic model, fluid Boltzmann distribution (thermal equilibrium)
- Fields: Poisson equation, possibly non linear (implicit solver => authorises $\lambda_D << cell$)
- Interactions: photo-emission, secondary emission, conductivities, RIC
- Specific sources: thrusters, field emission
- Spacecraft circuit: coatings + discrete components

Field singularities handling

- $E$ field singularities
  - Around small structures, not easy to mesh
  - Thin 1D wire: $V(r) \sim \ln(r)$
  - Thin 2D plate: $V(\theta) \sim \theta$
- Solution
  - Substract analytical singularity
  - Accuracy improved w.r.t. a simple mesh of the small structures
  - Test example
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Validation tests

- Detailed validation provided by modelling of geometry with known alternative solving methods (cf Hilgers et al., SCTC-2005, Tsukuba, Japan, April 2005).
- Detailed validation by comparison of potential profiles:

Collecting spherical probe: $V(r)$
Validation tests (cont'd)

Spherical probe with uniform electron emission, build up of a potential barrier: $V(r)$

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ex 1: Microscope Electric Propulsion System

- Study funded by CNES, performed by ONERA
- Drag compensation by Field Effect Electric Propulsion (FEEP)
- Emissions: Cs+ ions at several keV, neutral Cs
- Risk of contamination by Cs deposit: direct or through charge exchange (CEX)
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Ex 2: Charging in GEO (multiscale)

- Study funded by CNES, performed by ONERA
- Typical situation in GEO: inverted gradient, potential barrier
- This study: charge at small scale, close to an intercellular gap

Inverted Voltage Gradient situation (sun on top) Potential barrier blocking photoelectron escape
Ex 2: Charging in GEO (multiscale)

- Charge at small scale, close to an intercellular gap:
  - Photoemission blocked by the influence of the more negative potential in the gap (left)
  - \[\Rightarrow\] smaller potential difference close to the gap (right)
  - Explains experimental observation: ESD thresholds are larger in GEO electron conditions than in LEO plasma (macroscopic potential measurements)

Potential on top of a gap assuming a uniform potential on cover glass
(older non-SPIS non-self-consistent computation)

Potential on top of a gap
(SPIS self-consistent computation)

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Starting a 3D ESD modelling with SPIS

- Study funded by CNES, performed by Cril Technology and CNES post-doctoral student
- Some code improvements: field effect emission, hoping...
- In future: improved multiscale time handling, backtracking...

Field intensification close to a small needle tip (equipotential lines)

Potential around a triple point

Electronic density (once ESD is triggered)

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Philosophy

Future requirements, developments, testing and validation:
- Must answer users needs
- Resource must be available

Possible ways to achieve these goals:
- Setting up a consortium (formal or informal) with members and votes for orientation, the successor of the SDAB
  => planned
- A series of development opportunities enhancing the code (manpower, funding...)
  => less structured, starts this way anyway

Code recognition and maturation:
- Have users
- Make publications: last SCTC 4 papers (3 oral), journal article planned
- Benchmark with US and Japanese codes should start soon (NASCAP, MUSCAT)
- Validation: some done, experimental GEO failed (ARTES)

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Erosion module

- Modelling of impingement by fast ions of Electric Propulsion (Microscope example: plume model only, incl. CEX)
  - Erosion yield (versus energy and angle)
  - Distribution of erosion products (2 angles) + transport + deposition rate
  - From literature data (and our results)
  - Possibly from microscopic model later (TRIM-like)

- CNES funding (granted), following SPIS open source policy

- Development by ONERA

- Schedule: 2006

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Modelling dynamical phenomena:
- Realistic time-dependent charging, even in presence of very variable time scales
- Discharges
- Plasma expansion
- => need improved solvers (S/C circuit, plasma model...)

ESA/ARTES funding (facultative program)

ONERA made a bid (France supported)
=> ONERA or other contractor

Schedule: hopefully starting in 2006

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Derive a version of SPIS for GEO charging:

- Charging of telecom spacecraft in GEO
- Oriented by industry S/C charging needs (their requirements)
- Dedicated packaging: closer to one-button click
- Good robustness
- Some solver improvement, and important interface improvement

Prime companies express the need of a European tool for detailed modelling of GEO charging

CNES looks to be coming closer and closer to finance it

Requirements, development and testing: contractors TBD

Schedule: maybe 2007?

Conclusions

SPIS has been developed in less than 3 years based on:

- S/C charging community requirements
- ESA support
- Community contribution

SPIS has already proven its correctness and usefulness for S/C plasma interaction effects assessment (charging, EP plume contamination,…).

SPIS seems to meet the requirements to become a reference tool (in replacement of the old US tools) for assessment of spacecraft charging and most common spacecraft plasma interactions effects addressed by space industry.

Support from SPINE, ESA, and CNES has been critical for the success of this project.

Such a support is still needed for future evolution.