Charging simulations in the LEO auroral plasma

Recent results and feedback on environment definition

DEFENCE AND SPACE

Dr.-Ing. Christian Imhof

AIRBUS

Outline

- Introduction
  - – Environment definition evolution
- Simulation Results for MetOp-SG
  - – Eclipse
  - – Sun
- Discussion
  - – Comparison to literature
  - – Feedback on the environment definition
- Plasma Instruments on operational ESA satellites
- Summary and Conclusions

Environment definition evolution – The problem

- LEO polar auroral environment is specified in ECSS-E-ST-10-04C clause 8.2.3
  - Definition is based mostly on data and measurements gathered by the US DMSP satellite-fleet
  - Several worst cases are mixed together in the definition
    - Strongest measured electron spectrum
    - Very low density of cold background plasma (ion density)
    - Maximum time span for an auroral crossing is defined

➢ strict application of these parameters will lead to a huge overestimation of the charging on the satellite

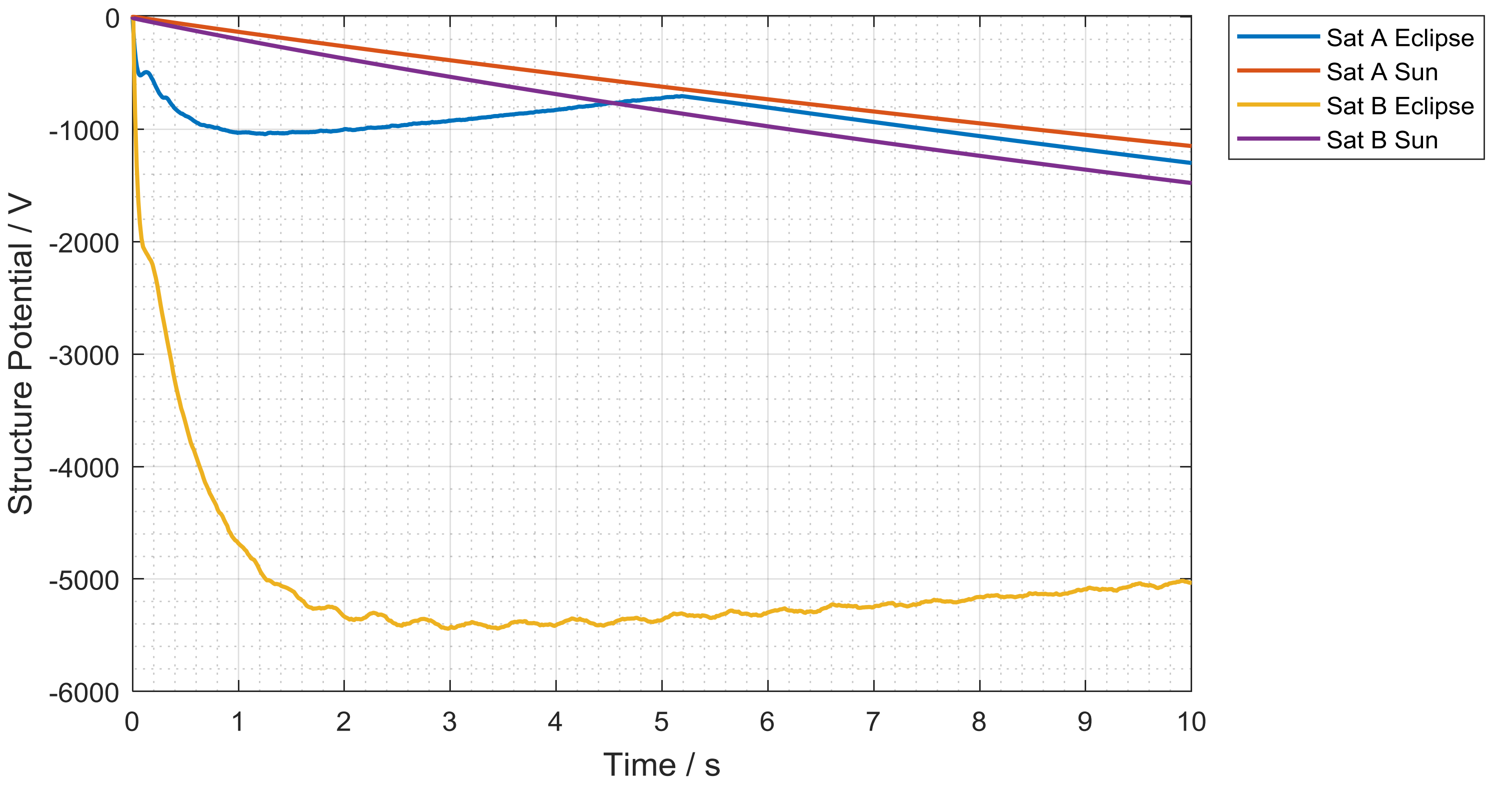
- This “drawback” of the environment definition has been identified
- Working group for the ECSS-E-ST-20-06 standard and ECSS-E-HB-20-06 handbook took over the task to propose a revision to be put into the 10-04 standard
  - Intense discussions and quite thorough literature research have led to a conclusion

Environment definition evolution – The adaption

- Electron spectrum is maintained -> this is a very clear measurement
- Background plasma density is also maintained
  - mainly due to the lack of exact measurements since this is very challenging for a satellite which is charging strongly negative
- Maximum time span for the application of this worst case environment has been adapted to max 10 s
  - Main rationale is that although the passage of the auroral region can last much longer the environment is highly dynamic and the observed worst case is not applicable over such a long time period
- Additionally a Maxwellian fit to the theoretical equation given in the standard is added to ease the use of SPIS for LEO auroral charging

Simulation Results for MetOp-SG

- Second generation of European low earth orbit meteorological satellites operated by Eumetsat
- Focus in this talk is on the structure potential calculated using SPIS
  - This is the value which is best recorded during charging events observed in orbit
  - For more detailed results and risk assessment please refer to presentation from last SPINE meeting or paper published in the CEAS Space Journal (CEAS Space J (2020) 12:137-147; DOI 10.1007/s12567-019-00279-3)



Comparison to literature

- Strong charging in both Eclipse and Sun conditions with structure potentials of up to several kV in eclipse and > 1000 V in sunlight
- Eclipse charging is in reasonable agreement with literature reports for DMSP
  – potentials exceeding 2000 V are not reported for LEO satellites
  – There also the satellite geometry can play a big role -> see differences between the two MetOp-SG satellites
- Strong simulated charging in sunlit conditions is not reported in literature
  – Even more eclipse/shadow is one of the mentioned pre-requisites for strong charging in LEO polar orbits
  – Seems to be a “weak spot” in the current environmental definition

Feedback on the environment definition

- Despite the observed differences the recent change of the auroral plasma definition with the reduction of time for the worst case is considered as a valuable update
  - First of all since a clear definition is now given in an official standard
  - Worst case eclipse simulations are in reasonable agreement with literature values and of course we want to design against a worst case
  - Although the charging is rather strong the implications on the satellite design are not huge

Feedback on the environment definition

- Improvement of the plasma definition needed?
  - No immediate action is required…but:
    Improvement and refinement is always good and could be beneficial especially regarding two points

➢ Background plasma density and the combination of the worst case background with the worst case electron flux
  - Here literature has clearly revealed that these two mechanisms are not correlated
    - T. Hamanaga, "Statistical data analysis of the auroral electrons and thermal ions for spacecraft charging analysis", JAXA-SP-07-030
    - P.C. Anderson, "Characteristics of spacecraft charging in low Earth orbit", Journal of Geophysical Research, Vol. 17, A07308, 2012
  - Strongest electron fluxes are typically around solar maximum but then due to the stronger UV activity of the sun the background plasma is typically more dense
  - Lowest cold plasma densities are typically encountered around solar minimum but there the high energy electrons are typically more benign

➢ Differentiation of the definition between sunlit and eclipse conditions
  - Again the density of the cold background plasma might be the point here
  - In sunlight the density might be larger due to the direct UV illumination by the sun

Plasma instruments on operational ESA satellites

- Any changes to the environmental definition should be driven and supported by new measurements and simulations
  - No longer exclusively relying on data recorded 10 – 20 years ago
  - Try to tackle the background density problem with supporting simulations of the charging; approach similar to the one presented by V. Davies (MODELING OF DMSP SURFACE CHARGING EVENTS) at SCTC in 2016 could be possible
    - Use the measured electron spectrum as input into simulations and then tune the background plasma density so that the recorded structure potential is resembled

➢ Plasma monitoring instruments as “additional small payloads” would be very beneficial
  - Very often radiation monitoring units are installed on satellites
  - Why not fly some low energy plasma sensors instead, especially since there are sensors readily available e.g. AMBER

Plasma instruments on operational ESA satellites

- Brief history from MetOp-SG
  - On the MetOp-SG satellites a classical radiation monitoring unit is hosted for measuring high energy particles
  - In the beginning of the project there has been an attempt to "upgrade" the unit by adding another channel for lower energies
  - This initiative unfortunately failed which leads to the question: WHY?
- Enhancement of the unit has been accompanied with clear performance requirements for the instrument
  - For the high energy particles this is no big deal since the particle flux is not strongly altered by the satellite potential and sheath etc.
  - Compliance to the requirements also for the low energy channels would have been a design driver for the complete satellite (implementation of boom for the instrument or implementation of very stringent charging control program)

➢ This approach was very unfortunate with mistakes/misunderstandings made on both sides

➢ For possible future plasma monitoring it would be beneficial to specify differently

➢ With a certain existing instrument in mind:
  - ➢ Ask for a certain mass, power budget, allocated volume
  - ➢ Clarify the needed interfaces, e.g. thermal, electrical
  - ➢ Specify some reasonable accommodation constraints (e.g. field of view, NADIR or ZENITH side, ram/wake)

Summary and Conclusion

- Simulation results from MetOp-SG satellites in the LEO auroral plasma using the environment definition from the latest revision of ECSS-E-ST-10-04 are compared to literature reports on in orbit charging in LEO auroral conditions
  - Some deviations are identified especially for the cases in sunlight
- Feedback on the environment definition is given
  - Mostly the new definition is considered an improvement but there is always room for further improvement
- Implementation of plasma sensors on operational ESA satellites are discussed
  - If improvements and/or changes to the environment definition are to be made these additional measurements are mandatory to support any decisions regarding the standard
- Some feedback from the failed attempt to place a low energy particle detector on MetOp-SG is given
  - Some thoughts on the set up of requirements are given which hopefully will ease the implementation of plasma sensors in the future

Thank you