EP orbit raising: environmental effects impact on satellites, modelling and challenges

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Abstract: The latest advancements in the EP field let the market to opt for more satellites based on electric propulsion. OHB has developed and is actually developing a satellites family partially equipped with electric propulsion (only for station keeping) or fully equipped for orbit raising phase. Orbit raising lasting longer with an electric propulsion system than the classic orbit raising (with chemical system), the satellite undergoes different environmental zones that test its capacity and resistance to various effects. These environmental effects need to be taken into account during the design phases and accordingly modelled. These effects are quite harsh to the satellite and are: Atomic Oxygen at LEO orbit, debris during the whole process, the venting of the spacecraft from the air trapped inside during the first hours and finally the plume impingement from the spacecraft itself.

Introduction

In the first days of the launch, the satellites will be in an orbit where an atmospheric layer is still existing. In this case, the Atomic Oxygen (AO) can erode materials due to its high energies (4 to 7eV). The AO density is characterized with the spacecraft orbit and speed and the solar activity. The spacecraft is then modelled and a ray-tracing technique is used by taking into account reflections and AO density to assess the fluency on the surfaces, and thus the eroded thickness. This erosion can affect the general performance of the spacecraft such as the thermal behavior, power issues. These effects occur from 200 km attitude up to 800km where an atmosphere is still existing.

Once the AO handled, the spacecraft will be exposed for a non-negligible period to a plasma and radiation environments. In this case, the environmental plasma will have an impact on the thruster plume and on the floating potential of the spacecraft through charging effects. Modelling all of these effects together is a quite complex task and usually, the worst case of each effect is studied independently from the other: radiation analysis is used to calculate the shielding of the units, the plasma plume for the thruster accommodation and the charging effects for shunting some solar cells to avoid power issues. These effects are discarded in the current paper and more focus is given on the venting phenomena.

During the ascent, the launch fairing is subjected to a fast depressurization which causes the venting of the internal volumes of the satellite. In this addition, the outgassing of materials inside the electronic box would start and therefore the gas is trapped inside the box and vented slowly. Incorrect venting of outgassed materials into a high voltage region could also lead to Corona discharge.

Once arrived in-orbit, the spacecraft will have to handle possible impacts from meteoroids and orbital debris. The Probability of No Penetration (PNP) is evaluated on different spacecraft structures and equipment. The impacts are modelled through ballistic equations where the shadowing effects is evaluated through ray-tracing techniques.

The paper will present a summary of the used modelling tools to model all these effects, the impact on the spacecraft design through some examples and how the synergies between all these effects can be taken into account.

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I. Atomic Oxygen impact

As an atmospheric layer still exists at LEO orbits, the density of the atomic oxygen is of a great interest for assessing its impact on the spacecraft. It depends on the altitude and latitude of the spacecraft orbit, the solar activity at that time and its associated magnetic activity and of course the time of the launch. In the AO community, the analysis relies on empirical atmosphere models giving the temperature and the density of the components with data provided by satellites observations and other radars. To assess the impact of AO on a spacecraft, the fluency is calculated by integrating the flux crossing a surface over time. By taking into account the AO velocity, the final fluency is estimated which leads to the assessment of the erosion of component on the spacecraft. The erosion yield is characterized from in-orbit experiments on the ISS and usually this quantity helps to analyze the impact on the spacecraft.

Modelling this effect can be done through two method. The first one is carried out with SPENVIS[1] that gives the total fluency without taking into account the real spacecraft geometry. The second method is based on ray-tracing technique provided by Systema tool[2] and in this case, the spacecraft geometry is taken into account along with velocity models, environment models and the atmosphere. Reflection of AO is also modelled since this could lead to some degradation on unexpected components.

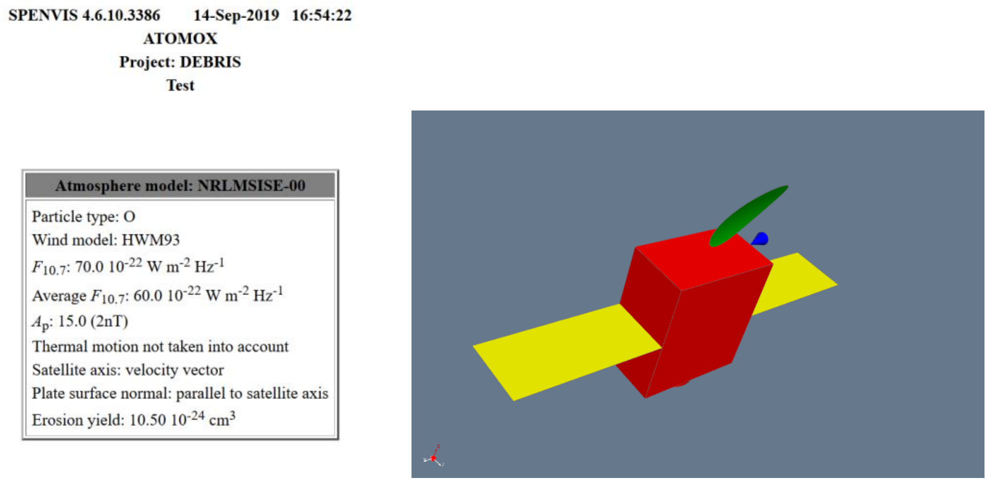

Figure 1. Modelling of atomic oxygen: SPENVIS (left), Systema (right)

The effects on the spacecraft can be summarized as follow:

- Star trackers or any optical element could suffer from a transmission loss
- OSR radiators could have their absorptivity degraded due to AO impingement.
- Solar array could suffer from power loss

In this case then, when OR occurs thanks to electric thrusters, some subsystem could be impacted during the transfer between the LEO and MEO orbit: the thermal deign is impacted and the thermal budget could be updated to see if the used MLI is sufficient. A special design can be used to protect optic elements or the solar panels (additional coating on the interconnectors for example).

However, due to the small time spent on the orbit of interest, AO is found out to be negligible on the kind of mission: some external components such as the thrusters booms must be designed to take into account these effects.

II. Venting

The air trapped inside the spacecraft need to be vented during the ascent phase. This occurs within the spacecraft internal cavities and also, within electronic boxes confined inside. The depressurization can have a non-negligible impact if the spacecraft is not well designed or even on electronic boxes through the Corona effects.

Corona discharge is a complex phenomenon that could happen for various reasons[3]. Physically, at atomic level, free electrons existing in a gas can be accelerated if an electric field is present. By getting accelerated, an “avalanche effect" could be triggered and collisions between electrons and atoms occurs. Atoms'electrons are then excited and jump to higher states. When these electrons return to their former state, light is emitted and visible corona (arcing happen).

To model these effects, two main regimes of the flow are identified: the continuum regime and the transition/free molecular one. The first phase is scheduled to happen the first hundred second of the launch. During this phase, the pressure decay is usually known thanks to the launcher as seen in Figure 2. The spacecraft is then modelled such as cavities and continuum equations are used to check the correct venting of the air into space.

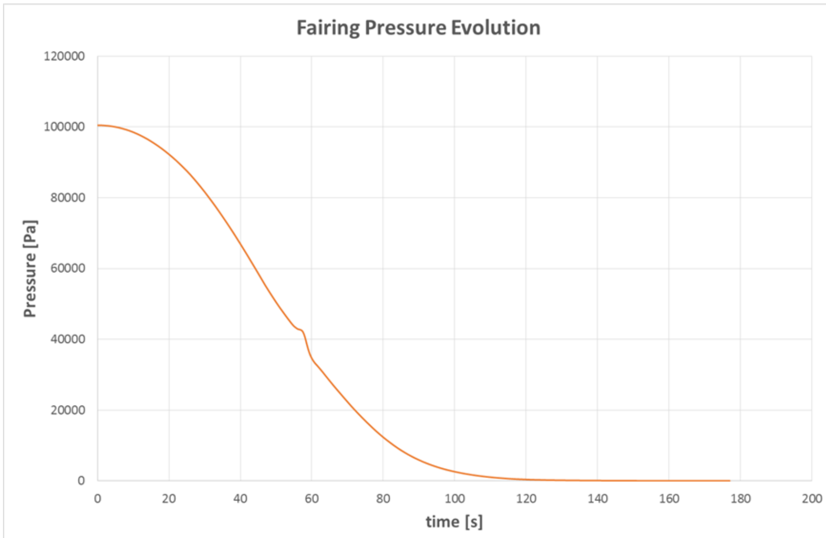

Figure 2. Pressure decay within a launcher

After this phase, the outgassing process inside the electronic boxes starts including in important boxes for the functioning of the electric thrusters. In fact during the transfer phase, if an electronic box is turned on too quickly, Corona effects could occur. If the outgassing process is too long then, it is possible that the mission cannot start and the spacecraft could drift.

The flow within the boxes is trickier to model since it is composed of two sources:

- the air that flows through the communication areas and venting holes
- the outgassing due to different materials within the box. Usually, these are PCB, glues, paint…

$$\frac{V}{R \cdot T} \cdot \frac{dP}{dt} = D_{Communication\ Area} + D_{outgas}$$

In the case of a whole spacecraft study, (including boxes of interest), the Knudsen number is calculated at the communication areas to identify the flow nature (Free, transition or continuum). For this phase, OHB developed its own library called FREEMOLVENT that is interfaced with Ecosimpro that allows calculations in the continuum regime. By identifying the pumping rate that is depending on the hole' geometry, the analysis could perform the assessment of a certain box venting process.
The final numerical set-up is shown in Figure 3:

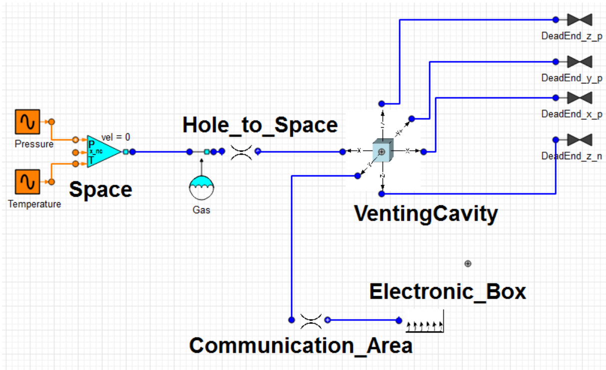

Figure 3. Venting model implementation

The method allows then the system engineers to counter check the suppliers' statement about the correct venting of their units. The validation was carried out by comparing the simulation to a test of one of these units performed by a thruster provider. These showed that to reach a certain pressure within the electronic box 3 hours are needed whereas the test showed 2 hours and 30 minutes.

III. Debris

The final type of effects studied in this paper is the Meteoroids and orbital debris assessment (M/OD) which constitutes a risk during the different phases of the transfer. To assess this impact, a probability of no penetration is evaluated on the external structure and internal equipment of the EOR spacecraft. The equipment vulnerability is calculated taking into account Ballistic Limit Equation (BLE) and different models for the materials.

These can be considered as simple walls, double walls or a unit to be studied. The yield stress and the thickness of the surface can then give an idea about the probability of penetration of an equipment that can be sensitive to the mission such as the thrusters' booms, the Xenon tanks or electronic boxes.

For that, a ray tracing analysis is performed with connecting the MASTER2009 models that can be loaded into the tool. The flux is computed by projecting the environment on a sphere that will surround the spacecraft. The environment depends on the conditions on the orbit such as the LEO, GTO and GEO ones.

All sensitive items of the spacecraft are studied then and the Probability of No Penetration are used for a risk assessment calculation:

	GTO		GEO	
Component x	PNP	PP	PNP	PP
Component 1	0.999	1.0E-04	…	…
Component 2	0.991	1.0E-03	…	…

IV. Conclusion

Taking into account different effect is not new to spacecraft design. What is new is that the orbit raising leads to fields that were not studied for these types of spacecraft that relies solely on EP. The atomic oxygen is not as challenging than for a LEO satellite but needs to be however studied. The venting is a subject of interest especially for electronic boxes that are crucial for the EP thrusters' behavior. Debris is also not a new field but is more often used now due to crowded orbits on LEO. EP thrusters will continue to be used in the future but a special care need to be given to these kind of environmental effects that can jeopardize a whole mission.

V. Acknowledgments

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References

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