Comparison of Methods and Devices for High Pressure Vessel Passivation

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Abstract

Recent space passivation requirements implement guidelines for large system integrators to avoid satellite fragmentations due to possible collisions. The propulsion subsystem in particular shall be passivated through venting devices. Numerous options and strategies can be imagined in order to perform such a passivation. In the case of the high pressure section of a pressurised system, the technical challenges could concern the time of the passivation, the physical behaviour of the components and the impact on the spacecraft.

Depending on the spacecraft orbit and the propulsion type (mono-propellant or bi-propellant), the passivation could occur before the operational orbit (Begin Of Life Option) or before the disposal into the graveyard (End Of Life Option). The paper will openly discuss the technical challenges related to the passivation by showing an example of a bi-propellant cold gas passivation where the pressure need to drop from 50 bars to 0.5 bars. When a gas like Helium is passivated at BOL, without proper temperature conditioning, temperature could reached -20˚C in few minutes. However, if the thermal control system is too powerful, the helium temperature is stabilised and some components will overheat and exceed qualification temperatures, which could stop the passivation process.

The gas passivation will also act as a cold gas thruster by impinging the spacecraft surfaces, thus, undesirable effects such as unwanted forces and torques need to be compensated by the Attitude Orbit Control System. Different venting devices were modelled and simulated in a plume analysis. Three Non Propulsive Venting (NPV) devices were considered: with a straight exit (simple tee-fitting), with a conic shaped exit and a narrow exit. The simulation showed that NPV devices induce negligible thrusts but impinge more the surroundings due to the fact that the plume is dispersed. On the other hand, the Propulsive Venting (PV) device (simple cylinder) induces more thrust but, ideally located, the unwanted forces are equivalent to what NPV will induce.

Depending on the geometry surrounding the venting devices, the final choice of the device can be driven by the plume impact (and not only the thrust) and the manufacturing costs. Easy to produce, the straight vent could be used in a specific configuration: its location should be optimized to avoid high impacts on the surroundings.

The paper will provide a comparison of the various options and discuss their implications.

1. Introduction

The passivation process need to be studied at two levels: the subsystem level and the spacecraft level. In the first level, the subsystem layout is designed so it integrates the devices as an additional branch. By setting up this additional branch, the different components need to be studied and their thermal and fluidic behavior analyzed. The second level of analysis deals with the impact of the cold gas passivation on the satellite. The forces and torques are estimated in order to be counter-acted by the AOCS system

2. Passivation methods modelling

- <u>Strategy</u>

Numerous options for passivation can be imagined depending on the spacecraft mission and the propulsion subsystem design. For example, passivation could be performed through the LAE (Liquid Apogee Engine) or through a specific passivation device that need to be integrated into the subsystem assembly.

This dedicated device could be passivated before the operational orbit or before the disposal. Before the operational orbit, the transition to blow down mode need to be confirmed. The advantage of this option is that once the tank passivation is performed, the power is saved. In fact, no more heating is needed for some components like the tanks for example.

Another advantage is that during the satellite LEOP phase, the passivation will happen when the LAE is isolated. The passivation will be then smoothly integrated in the operations process.

The main issue that can appear in this phase are the impingement torques that can have a negative impact on the platform at Begin Of Life. As shown in the next section, these forces and torques need to be studied and analysed thanks to a Plume analysis.

Passivating at End Of Life would occur after reaching the graveyard orbit. The passivation sequence will be isolated from the LAE venting that already happened during the LEOP phase. The issue in this option of passivation is that some of the valves are qualified only to a certain time. EOL for geostationary satellites could count up to several years (10 to 15 years) and in some cases, the spacecraft life elongated. By choosing this option, the tanks would need to be thermally controlled until EOL.

- <u>Modelling analysis</u>

The passivation of a bi-prop subsystem cold gas tank open the question of the duration of this process. To model such a set-up, a 1D fluid simulation tool is needed [1]. This tool help setting up the passivation device and integrate it into the whole propulsion subsystem assembly.

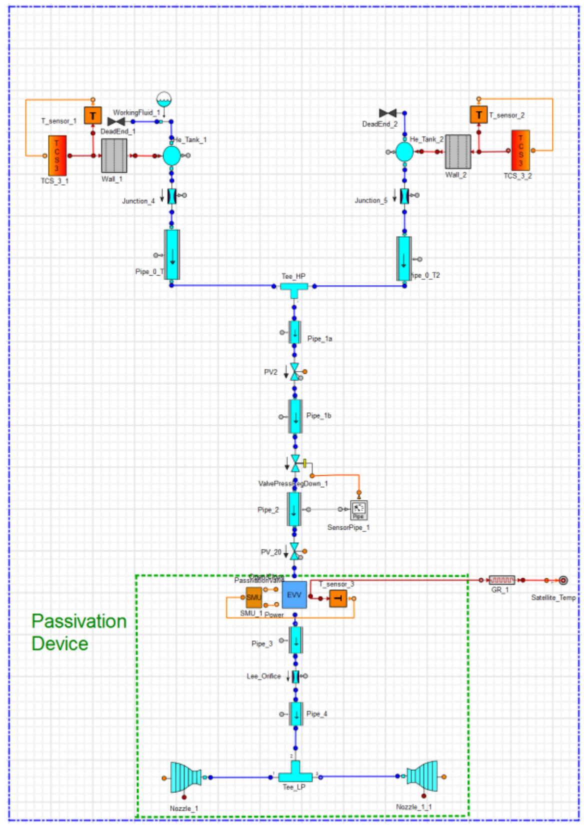

Figure 1: Example of a passivation device

Initially at 50 bars, the pressure need to drop below 0.5 bar to complete the process. The duration could reach 40 hours or some hours by choosing the adequate mass flow.

When the fast option is chosen, the Helium could generate thrust up to 50mN and when the slow option is chosen, less than 3mN. More details about the generated forces are shown in section 3.

In addition to the operations constraints (40 hours could block the LEOP phase), the passivation of the Helium influences the thermal behaviour of the whole assembly. Tanks are thermally controlled through a "Thermal Control System" that starts to be active when the temperature is under a certain level.

In fact, as shown in Figure 2, without proper temperature conditioning, temperature could reached -20˚C in few minutes.

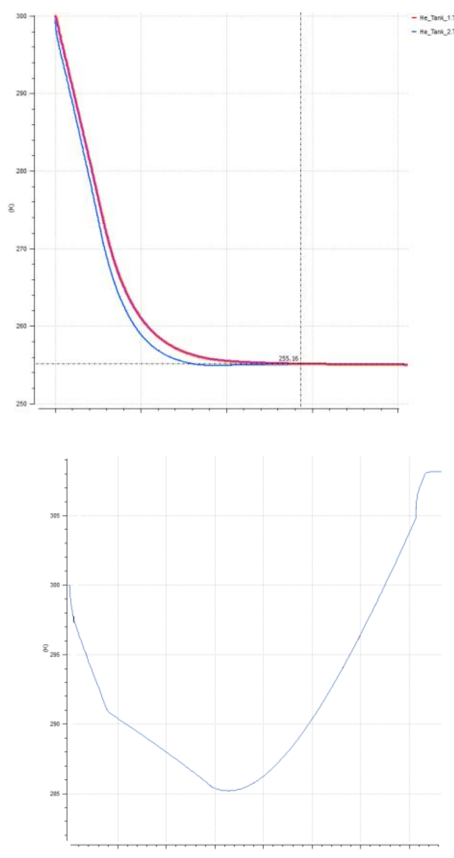

Figure 2: Helium temperature drop without (up) and with thermal conditioning (down)

In a case of a separated passivation device, the thermal behaviour of the "passivation valve" is a key driver for the passivation process. Each time this valve is used, a power is generated due to its own performance characteristics.

The "passivation valve" is connected to the spacecraft thermal environment taking into account the component emissivity and dimensions.

Similar to the TCS tanks, the SMU control unit closes the "passivation valve" when the maximum qualification temperature is reach.

The results showed that, if the thermal control system is too powerful, the helium temperature is stabilised and the "passivation valve" will overheat and exceed qualification temperatures, which could stop the passivation process.

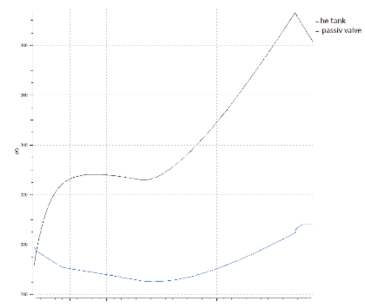

Figure 3: Passivation valve temperature increase

Slowing up the process lead to no heating of the "passivation valve".

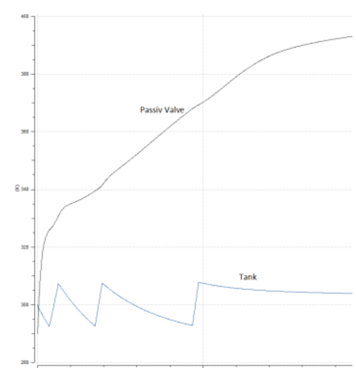

Figure 4: Less increase when the mass flow is small

Depending on the mission profile and the components behaviour, the passivation process is sensitive to different parameters and need to be designed so that all the process is not stopped to the overheating or due to under-heating.

3. Passivation devices modelling

- Passivation devices

Two types of passivation devices are possible: propulsive (PV) or non-propulsive vents (NPV). In order to study their impact, OHB simulated the two types by modelling the cold gas venting through the devices.

The propulsive venting device is a simple vent consisting of a cylinder. Three possible configurations of the non-propulsive venting device were studied: the straight exit, the conic exit and the narrow exit, as shown in Figure 5.

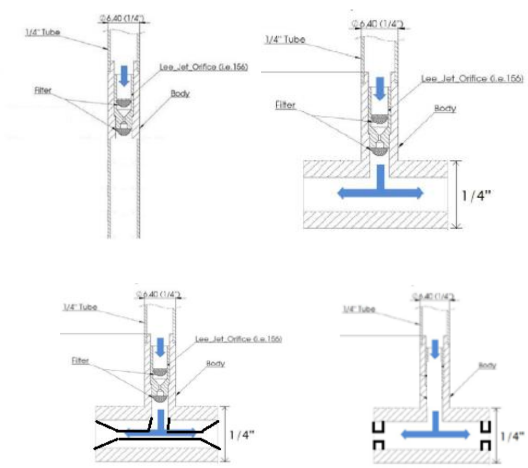

Figure 5: PV (up left), straight exit NPV (up right), conic exit NPV (down left), narrow exit NPV (down right)

As its name indicates, the NPV is supposed to not generate any thrust thanks to the T-fitting. The PV will generate thrust. Then, two effects need to be studied: the self-induced thrust and the forces generated by the Helium impinging the surroundings.

- Cold gas modelling

In order to model the Helium passivation impingement, OHB developed a method based on two parts: a CFD solver for the continuum part and the source-flow method [2] for the far field as seen in Figure 6.

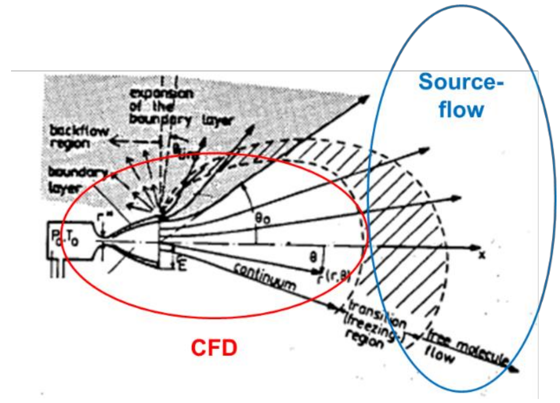

Figure 6: Method: CFD + source flow method

The set of Navier-Stokes equations used in fluid mechanics to model continuum flows is based on three principles: conservation of mass (1), conservation of momentum (2) and conservation of energy (3).

$$\frac{\partial \rho}{\partial t} + \boldsymbol{\nabla} \cdot [\boldsymbol{u}\rho] = 0$$

$$\frac{\partial (\rho \boldsymbol{u})}{\partial t} + \boldsymbol{\nabla} \cdot [\boldsymbol{u}(\rho \boldsymbol{u})] + \nabla p - \boldsymbol{\nabla} \cdot \boldsymbol{T} + \boldsymbol{f} = \boldsymbol{0}$$

$$\frac{\partial (\rho E)}{\partial t} + \boldsymbol{\nabla} \cdot [\boldsymbol{u}(\rho E)] + \boldsymbol{\nabla} \cdot [\boldsymbol{u}p] + \boldsymbol{\nabla} \cdot (\boldsymbol{T} \cdot \boldsymbol{u}) + \boldsymbol{\nabla} \cdot \boldsymbol{j} = 0$$

The density in the free molecular regime varies with the square of the distance to the source point:

$$\rho \sim \frac{1}{r^2}$$

This method have been validated numerically by comparison to another CFD tool and physically with regard to available on-ground experiments performed in DLR [3] with Nitrogen.

Figure 7 shows the spatial distribution of the number of density variating with the angle. The differences between the experiment and the simulations are shown in Table 1.

The method shows good agreement especially when the transition domain from the continuum to the free molecular is well chosen.

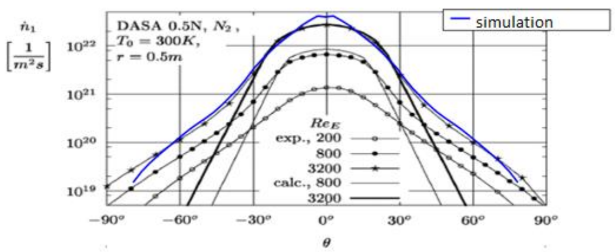

Figure 7: Density distribution

Angle	Simulation deviation w.r.t experiment
0	35%
10	13%
20	-17%
30	29%
40	38%
50	28%
60	25%
70	-4%

Table 1 – Simulation deviation with regard to the experiment

- <u>Plume impingement analysis</u>

The narrow exit was modeled as 2D axisymmetric geometry. The conic and straight exits were 3D modeled due to the T-junction.

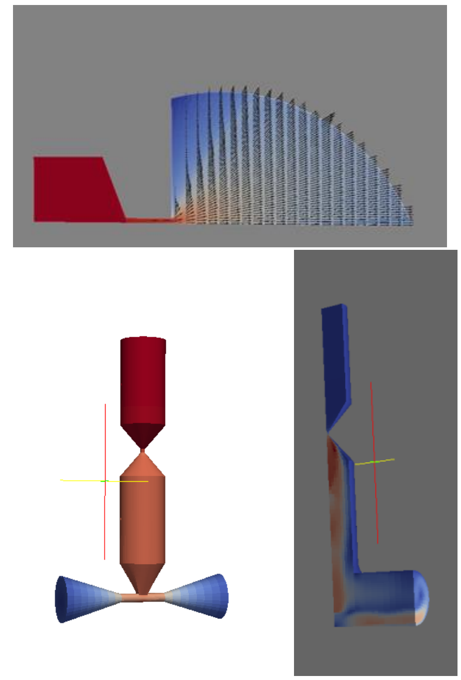

Figure 8: Gas densities for NPV Narrow exit (up), conic exit (down left) and straight exit (down right)

The obtained plume for the narrow exit is not centered but rather dispersed on all angles. No self-induced thrust is generated, as expected. The conic plume is centered and drops around angles superior to 50 degrees. The straight exit plume is dispersed in all directions and a net force about 10mN appeared.

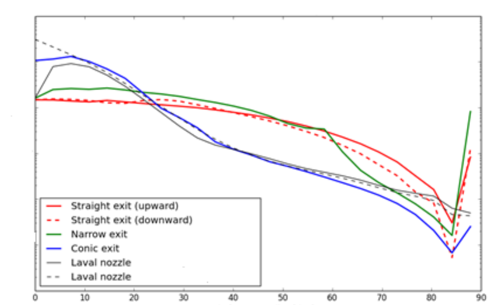

Figure 9: NPV densities

The propulsive vent has a self-induced force of about 50mN and the plume is not spread everywhere.

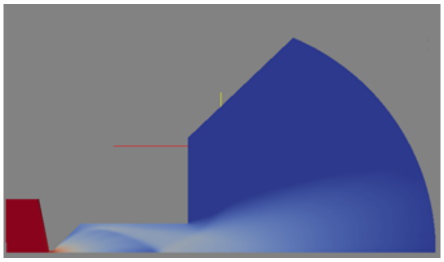

Figure 10: Gas density for PV

These different models were integrated within Systema to model the impingement on the spacecraft surroundings. The PV and NPV positions were optimized so no significant impingement is expected.

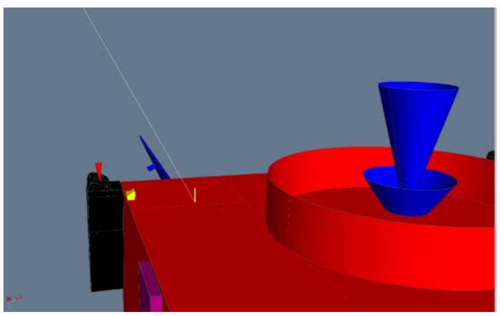

Figure 10: Passivation device integrated into a satellite model

Table 2 summarize the impacts. It has to be noticed that the PV induce less plume impact than the NPV but more self-induced force.

Force (mN)	Thrust	Plume	Total
NPV Conic	< 1	< 15	< 15
NPV Straight	< 10	<40	<50
NPV Narrow	< 1	<40	<50
PV	<50	<10	<50

Table 2 – induced forces

The total induced forces are comparable for all the devices. Therefore, a choice is left to the system engineering team to choose the best solution for its satellite. The passivation devices could also be tilted through the Center Of Gravity to cancel the torques.

4. Conclusion

This paper summarized some of the technical challenges that need to be analyzed and modeled. The propulsion subsystem behavior was studied in order to prevent overheating of some components and to have a smooth passivation process. The impact on the spacecraft has no significant disturbance forces and torques if the position of the devices is optimized.

5. Acknowledgments

The authors would like to thank their OHB colleagues for their help and support: Robert Simonovic, Birk Wollenhaupt and Stefano Naclerio.

6. References

[1] EcosimPro/ESPSS: software user manual

[2] G. Dettleff (1991): Plume Flow And Plume Impingement in Space Technology. *Prog. Aerospace Sci. Vol. 28, pp. 1-71*

[3] K. Plahn and G. Dettleff (2000): Modelling of N2-thruster plumes based on experiments in STG. *AIP Conf. Proc. 585, 848 (2001); 9-14 July 2000, Sydney (Australia).*

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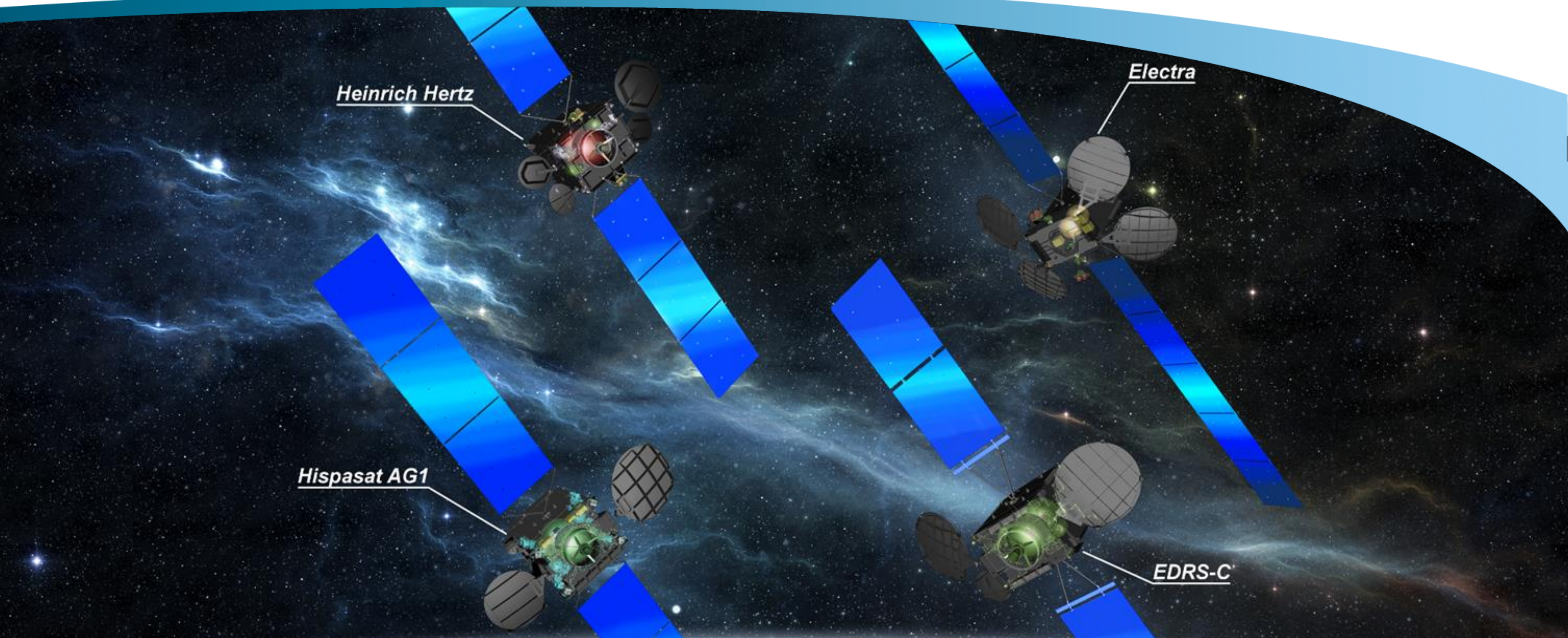

SPACE SYSTEMS

Methods and devices for passivation

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Overview

I. Introduction

II. **Passation methods**
1. Strategy
2. Modelling analysis

III. **Passivation devices**
1. Description
2. Cold gas modelling
3. Plume impingement analysis

IV. **Conclusion**

Passivation context

- **Recent space passivation requirements set guidelines to be respected by LSI**
- **Propulsion subsystem need to passivated through venting devices**
- **In case of a high pressure vessel passivation:**
  - **Different strategies can be imagined:**
    - before the operational orbit
    - before the disposal
  - **Different venting devices can be tested:**
    - the venting occurs through the LAE
    - Or through a dedicated passivation branch
- **Passivation needs to be studied at two levels**
  - **Subsystem level:**
    - to calculate the passivation time
    - to check gas tanks temperatures
    - to check if the components are suited for the passivation
  - **Satellite level:**
    - to assess the cold gas plume induced forces & torques

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Passivation methods: strategy

- **When passivation occur before the operational orbit**
  - **Advantages:**
    - When the tank is passivated, power is saved (no more heat needed)
    - LAE is already isolated, passivation integrated in the operations
  - **Possible issues:**
    - Impingement forces and torques on the platform

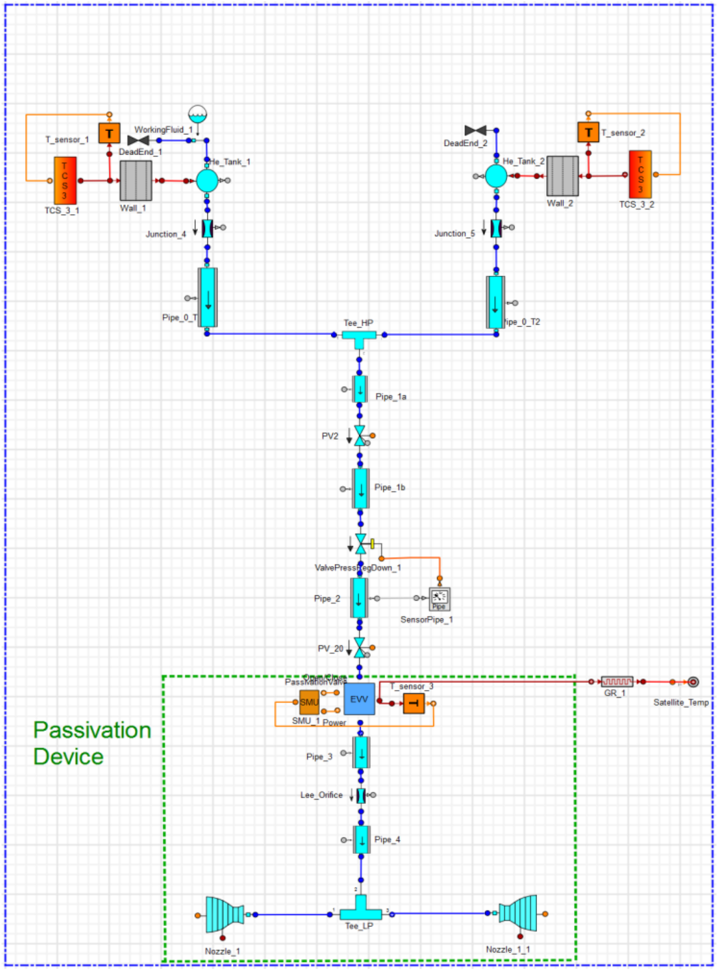
- **When passivation occur after reaching the graveyard:**
  - **Possible issues:**
    - Some components are qualified for a certain period of time
    - What about prolongation of spacecraft lifetime?
    - The tanks need to be thermally controlled until EOL.

Passivation methods: analysis

- **Passivation of bi-prop subsystem is analyzed**
- **Goal: passivate from 50 bar to 0.5 bar**
- **Open questions:**
  - Time of passivation
  - The cold gas thermal behavior
  - Components behavior

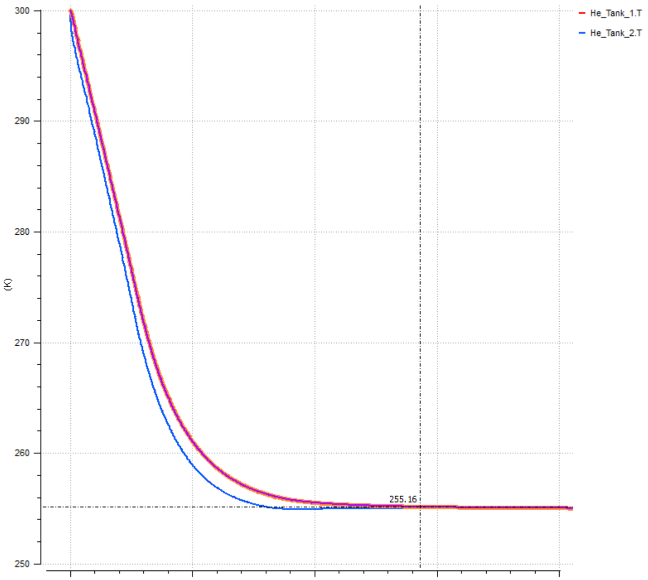
- **Simulation is performed :**
  - thanks to 1D Fluid simulation tool (EcosimPro)
  - by designing the subsystem layout

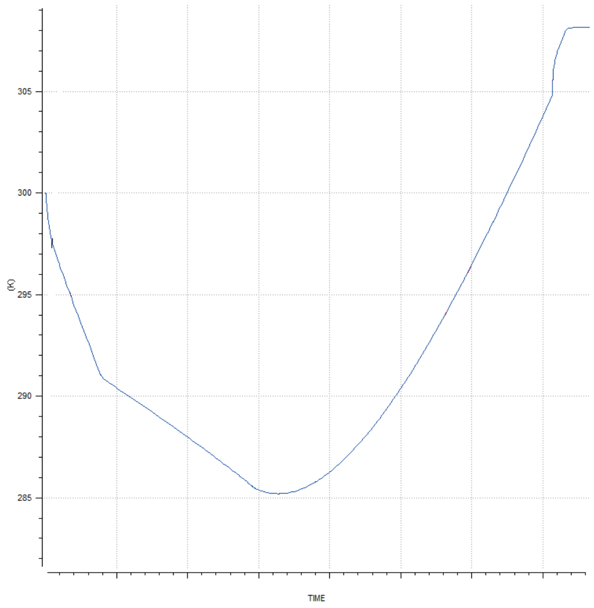
- **Thermal modelling:**
  - Tanks are thermally controlled through TCS
  - Passivation valve is controlled by the SMU

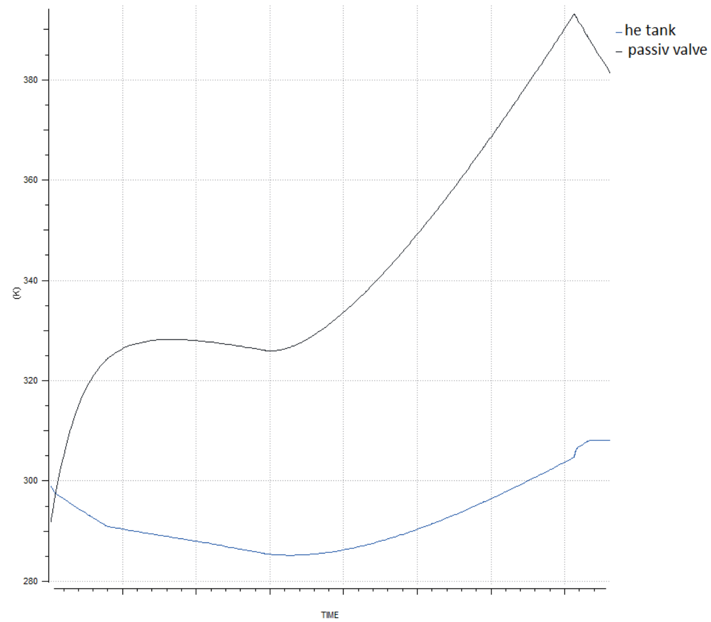


Passivation methods: analysis

- **Thermal analysis:**
  - Cold gas temperature could reach -20 degrees
  - With proper heating, the temperature raises after some minutes
  - This induce heating of the passivation valve
  - Passivation valve induces heating due to its own performance







Passivation methods: analysis

- **Fluidic behavior:**
  - Slow passivation up to some days
  - Fast passivation up to some hours
  - Each option is calibrated with the passivation orifice
  - Possibility of stopping the process due to overheating of components
  - Necessity of developing components suited for passivation?

- **Generated thrust ?**
  - Theoretically, up to 50 mN for the studied bi-prop
  - Is there a necessity to split the flow? So no torque is generated?

- **=> Necessity of a plume analysis**

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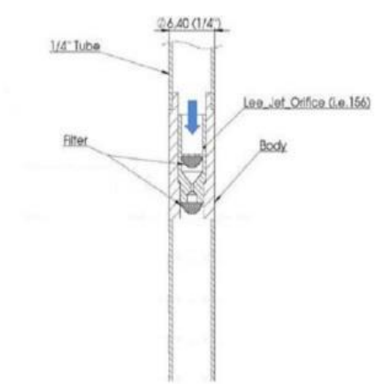
Passivation devices: description

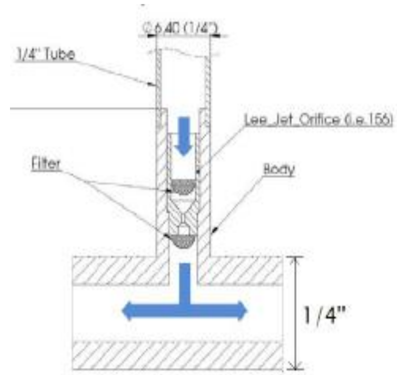
- **Two effects need to be studied:**
  - self-induced thrust
  - plume impingement on the spacecraft
- **Two types of passivation devices:**
  - Propulsive Vent (PV): important self-induced thrust
  - Non Propulsive Vent (NPV): theoretically no self induced thrust

- **Four geometries have been modeled**

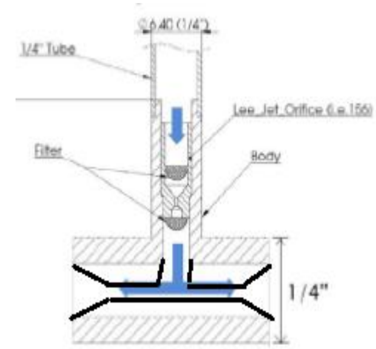
PV straight vent



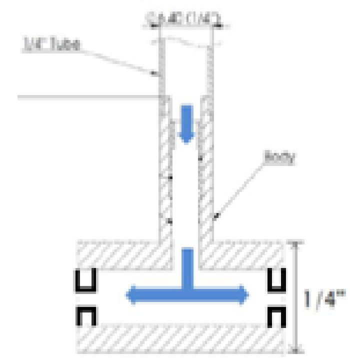
NPV straight exit



NPV conic exit

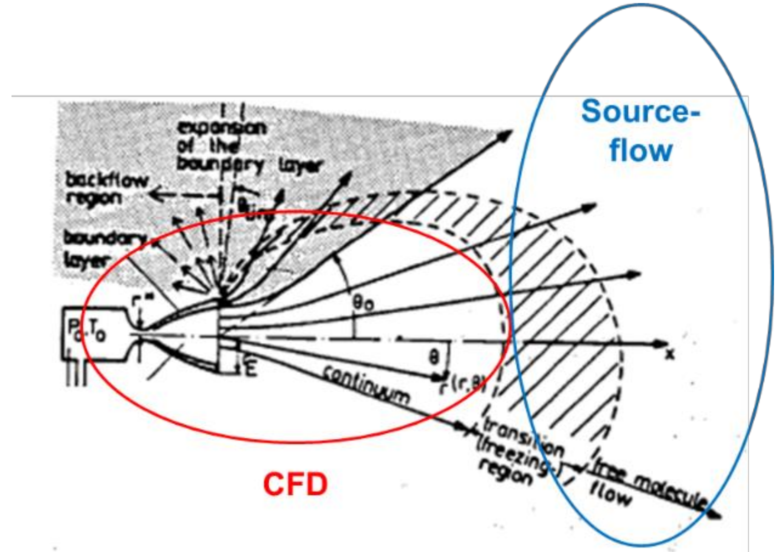


NPV narrow exit



Passivation devices: cold gas modelling

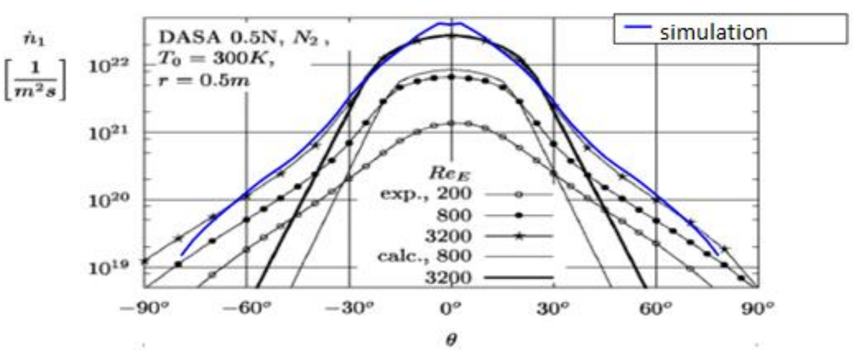
- **Method used in OHB:**
  - CFD solver for the continuum part
  - Source-flow method for the far field



- Navier-Stokes equations to resolve in the near field:
  - conservation of mass
  - conservation of momentum
  - conservation of energy

- Source-flow: $\rho \sim \frac{1}{r^2}$

- Validation with existing experiment carried in DLR facility



Angle	Simulation deviation w.r.t experiment
0	35%
10	13%
20	-17%
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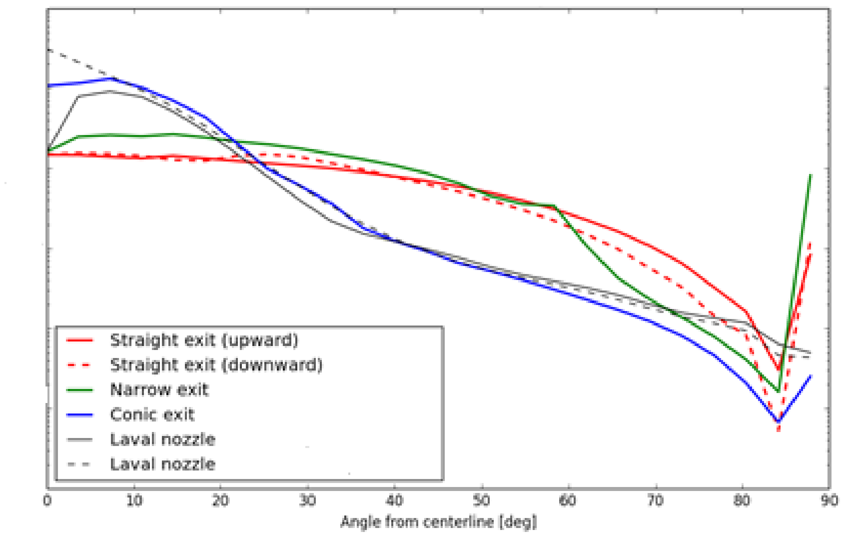
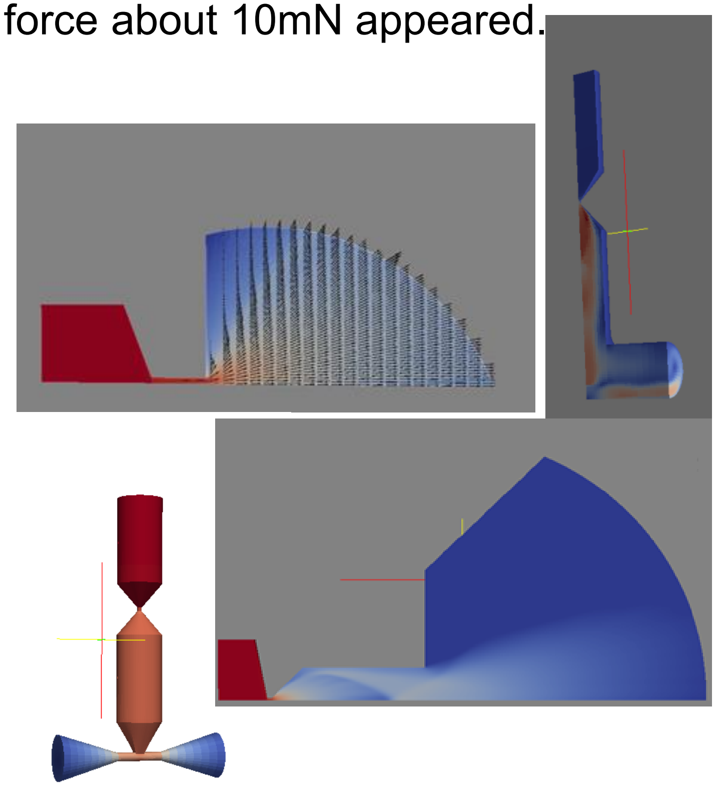
40	38%
50	28%
60	25%
70	-4%

Passivation devices: Plume impingement analysis

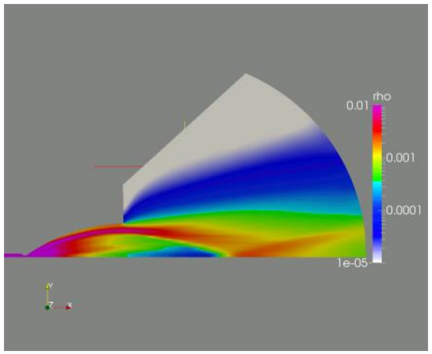
- **Obtained gas densities:**
  - NPV narrow exit plume: not centered, dispersed on all angles, no self-induced
  - NPV conic exit plume: centered
  - NPV straight exit plume: dispersed in all directions, net force about 10mN appeared.
  - PV: centered, 40mN self induced force

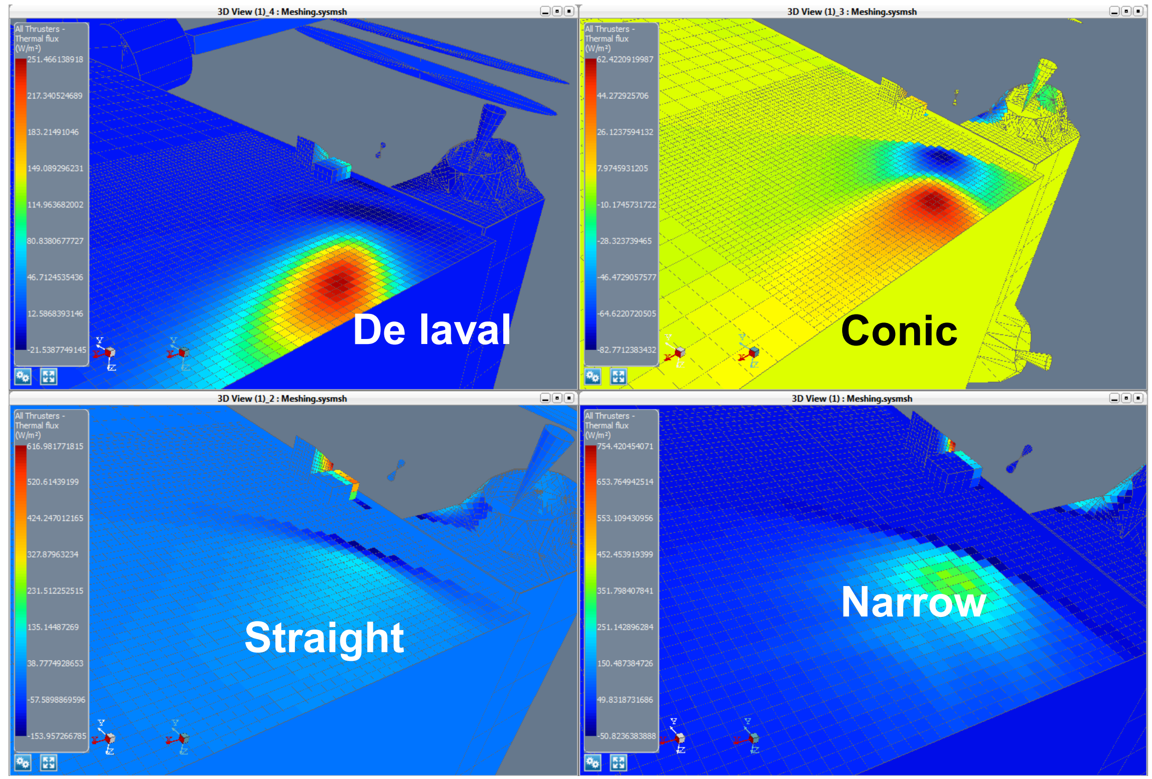




Passivation devices: Plume impingement analysis

- **Injected into Systema tool**





- **Generated forces and torques:**

Force (mN)	Thrust	Plume	Total
NPV Conic	< 1	< 15	< 15
NPV Straight	< 10	<40	<50
NPV Narrow	< 1	<40	<50
PV	<50	<10	<50

Conclusion

- **Propulsion subsystem behavior showed that:**
  - some components could heat if gas heating is too efficient
- **Generated forces and torques:**
  - similar results for all devices
  - if position is well optimized, no issue is foreseen

Acknowledgements

- **Co-authors: L. Denies and M. Peukert**
- **OHB colleagues**

Questions ?