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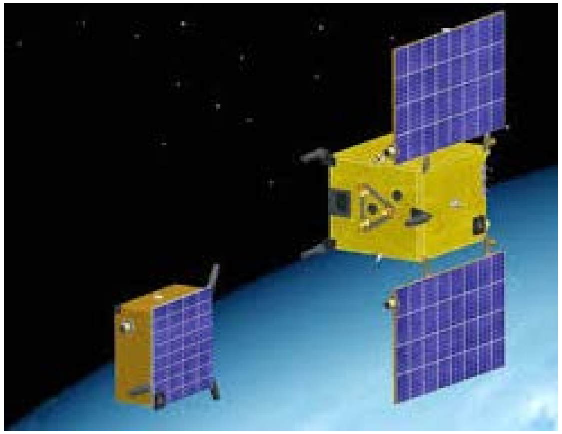
SATELLITE SYSTEMS

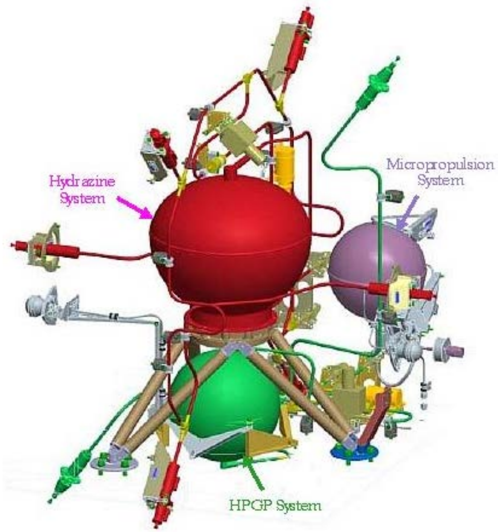
ESA study: System impacts of Propulsion passivation
OHB Sweden - OHB System - FOI - Etamax

27.05.2016

Agenda for the next 25 minutes

1. What is Propulsion Passivation?
2. What are the Space Debris Mitigation requirements for Propulsion Passivation?
3. What does a ”Safe configuration” mean for a Propulsion system at EoL?
4. How do we further reduce the risks in the future?





Prisma mission – Flight configuration and the 3 Propulsion systems passivated in 2015

In-orbit break-up history

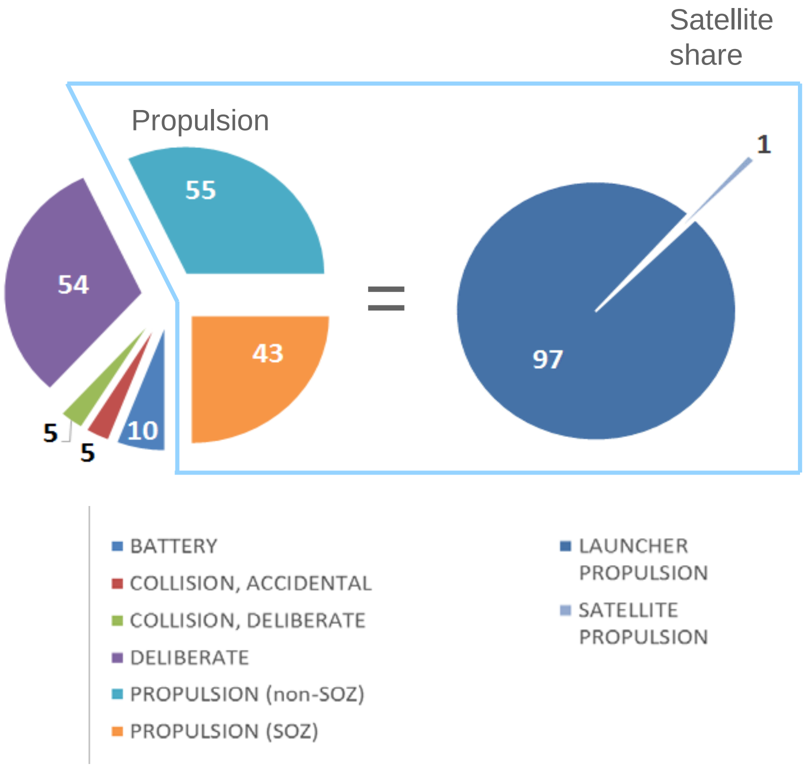
- 233 break-up events in orbit since 1958
(including all known and unknown causes):

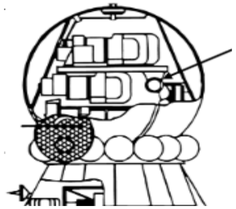
Source: NASA Orbital Debris Program Office (ODPO). The "History of On-Orbit Satellite Fragmentations" and "Orbital Debris Quarterly News" (ODQN)

- The Two Main Sources for Propulsion:

54 Deliberate Satellite Break-ups
→ **52 x COSMOS APO System**

98 Propulsion Break-ups
→ **97 Rocket Upper Stage**





COSMOS APO System

Upper Stage Break-up

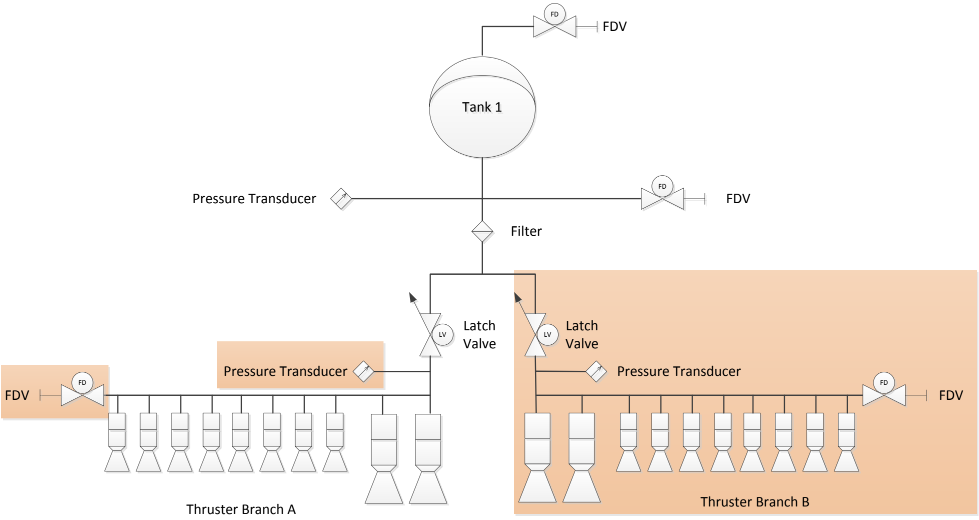
→Only one case of propulsion induced SAT break-up known (**USA-68**: **Solid Rocket Motor**)

→**USA-73** break-up in 2004:
Propulsion S/S is most likely not the break-up cause (Battery failure instead, as for USA-109)

Passivation operations – Residual energy in current missions

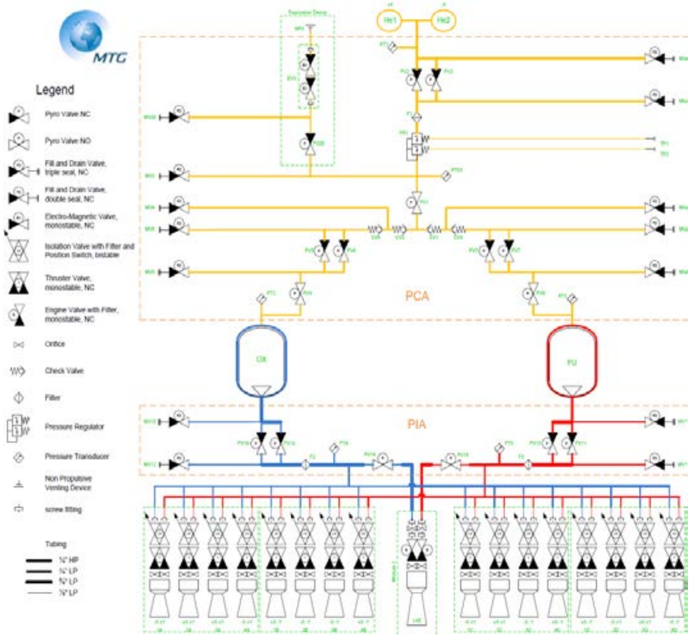
LEO reference case

- Passivation limited by diaphragm tank
  N2 : ~5.5bar at EoL
  N2H4: ~5.5bar, 2% residuals
- Depletion down to the min qualified thruster feed pressure.



GEO reference case

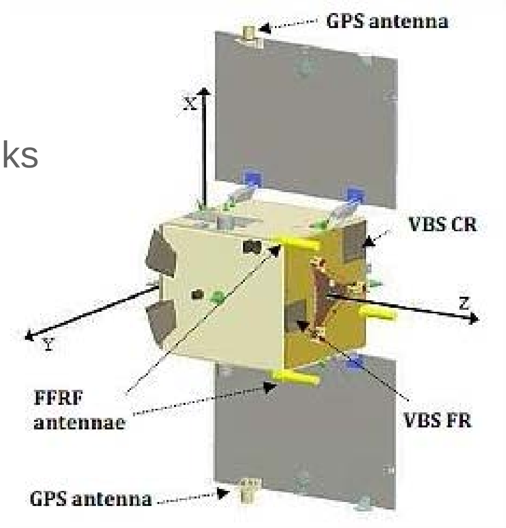
- Passivation limited by isolation of Gas side after LEOP:
  Helium: ~50bar after LEOP
  MON-MMH: ~9bar, 1.8 to 2.6% residuals
- Depletion down to the min qualified thruster feed pressure
- MTG: Additional passivation line downstream MPR

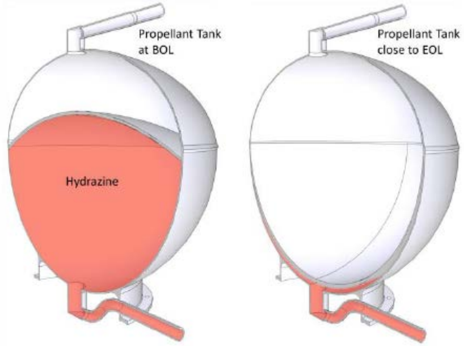


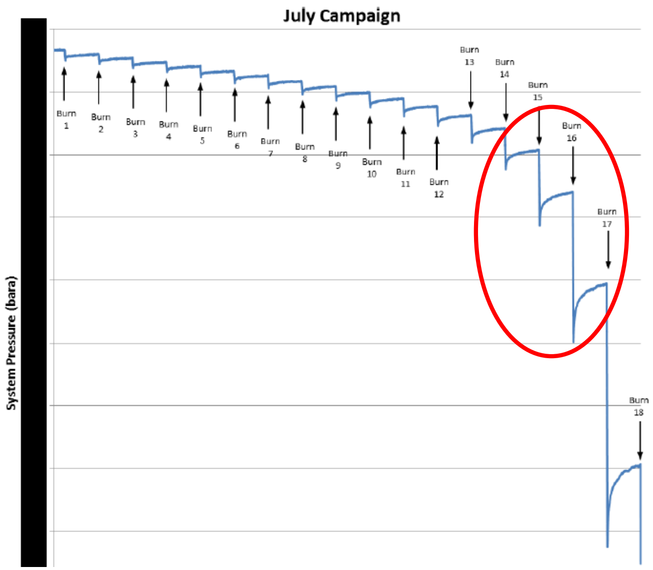
Passivation operations – PRISMA Hydrazine system

Attitude control

- AOCS mode: **Normal Mode** to reduce operational risks
- Last operations in visibility of ground only
- Last burn with SA to the sun and Antenna to Earth
  → Safest configuration (NLLP mode)







Propulsion monitoring and controls

- P_drop during burns increases quickly at EoL (Bladder reaches tank wall)
- Critical pressure predicted with a ±**0.1 bar** accuracy
- Thrusters temperatures (Catbed, FCV) monitored at 1Hz, although no attitude divergence due to bubbles is expected
- Duty cycles with reduced ON time are used

Results:

- Passivation down to ~5 bar. Is this safe? Which risks remain?

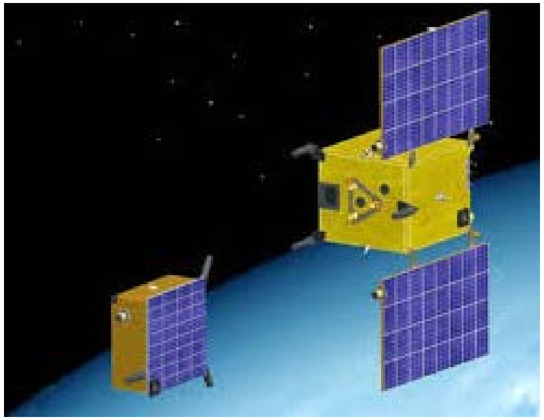
Passivation operations – Recommendations for LEO missions

Propulsion:

- **Detect bubbles**: PT noise + FCV/Cat bed temperatures monitoring
- **Predict Critical pressure** by analysis (±0.1bar accuracy)
- **Safe duty cycles**: Reduced T_ON
- **Maintain RCT feed pressure**: Increase tank temperature
- **Maintain Hydrazine liquid**: Decrease tank temperature
- **Stop passivation** when/if attitude is no longer controlable

Attitude and orbit:

- **Ensure telemetry access**:
  Attitude and operation time selection
- **Limit aerodynamic perturbations**
  Adapt attitude at low altitudes (SPOT-1)



TM/TC:

- **Detect bubbles**: Monitor angular velocities (risk of attitude divergence)
- **Detect bubbles:** PT and TT acquisition rate: >1Hz to detect bubbles

→Propulsion passivation **should not put at risk the other Passivation operations** (E.g. Battery)

→**No generic passivation sequence** or strategy since it depends on S/C design, Telemetry access...

→A full list of recommendations has been issued in the Study

Passivation operations – Recommendations for GEO missions

Propulsion:

- **Detect bubbles**: PT noise + FCV/Cat bed temperatures monitoring
- **Safe duty cycles**: Reduced T_ON
- **Maintain RCT feed pressure**: Increase tank temperature
- **Maintain MON/MMH liquid**: Decrease tank temperature
- **Stop passivation** when/if attitude is no longer controlable
- **Avoid freezing of lines:** Monitor shadowed RCT flow valves
- **Avoid bubble contamination**: Optimize thruster selection, Use bubble migration models

Attitude and orbit:

- **Earth Pointing Mode**:

\+ Good telemetry access
\+ Predictable Forces
\- Usually less robust than Sun Pointing

- **Sun Pointing mode**:

\- Usually poor telemetry access
\+ Preferred mode directly after 1st bubble appears

TM/TC:

- **Detect bubbles**: Monitor angular velocities if assymetrical Thrust is expected
- **Detect bubbles**: Use high PT / TT acquisition rate

→Propulsion passivation **should not put at risk the other Passivation operations** (E.g. Power S/S passivation)

→**No generic passivation sequence** or strategy since it depends on S/C design, Telemetry access...

→A full list of recommendations has been issued in the Study

SDM Requirement and compliance assessment

ECSS-U-AS-10C
10 February 2012

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Space sustainability

Adoption Notice of ISO 24113:
Space systems - Space debris
mitigation requirements

ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
Noordwijk, The Netherlands

ISO 24113: Adopted in ECSS-U-AS-10C

- ”What to do?” - International high-level debris mitigation requirements

*”...permanently **deplete or make safe** all remaining on-board sources of stored energy…”*

ESSB-HB-U-002 SDM Compliance Verification Guidelines - ESA handbook

- ”How to do it?” - Aims of providing compliance verification methods
- Problem: It remains at the same level of ISO 24113

→ Risk of contradicting requirements (E.g. Risk of HyperVelocity Impact excluded from ISO 24113)

Compliance status:

- LEO ref: Residuals in the Diaphragm tank, by design
- GEO ref: Residuals in the Pressurant side + Propellant PMD tank, by design

→ Full depletion not achievable, not required, and not needed if S/C is already safe.

→ In any case, we need to fill the knowledge gaps to define what a ”Safe state” is.

Risk assessment - 1/ Tank burst due to thermal drift

Thermal analysis - Worst case assumptions in LEO:

- Single side radiator pointing to the Sun
- Equilibrium condition (t=∞)
- No cooling by structure
- No tumbling motion
- EOL material properties
- Conservative also for albedo/IR flux

→ Propellant Tank Temperature **< 90°C** at EOL

Risk of burst (Assuming 200°C!)

- **LEO**: Tank ~ 10bar << Burst (~50bar)

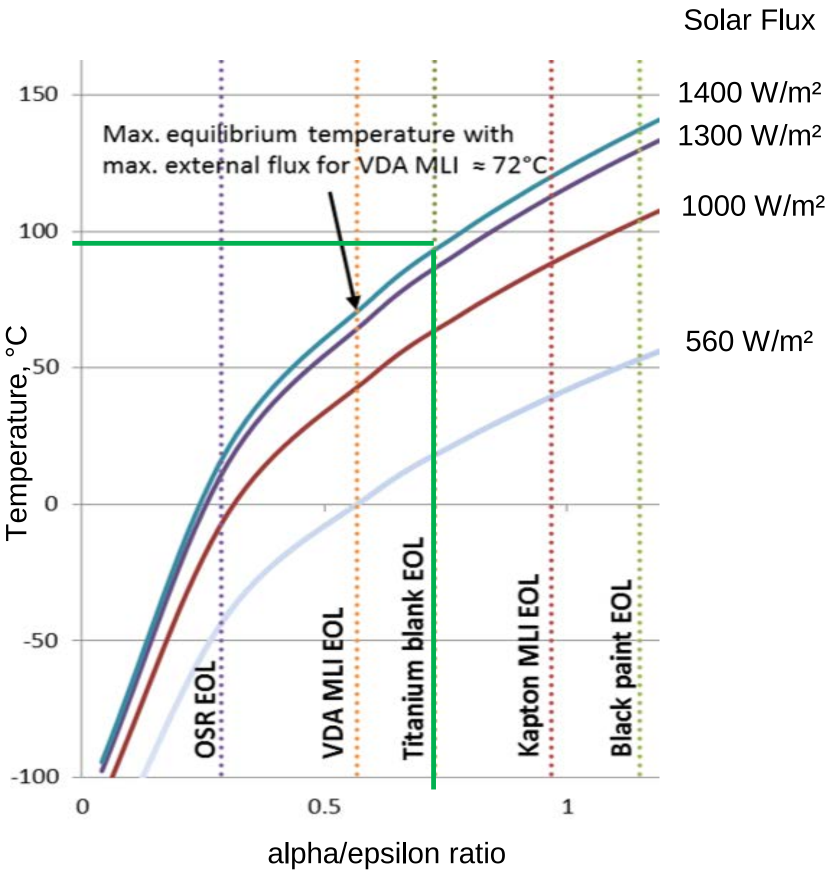
→Low risk TBC (Hydrazine decomposition to be assessed)

- **GEO**:

MON/MMH Tanks ~ 15bar << Burst (~30bar)

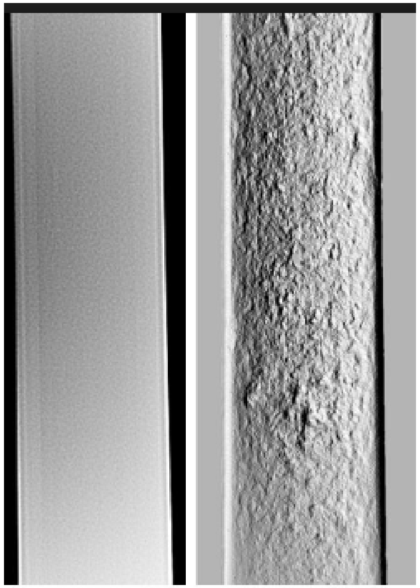
He Tank ~ 96bar << Burst (~620 bar)

→Low risk



Note: VDA MLI and Titanium are typical materials

Risk assessment - 2/ Long term chemical effects



LEO - MEO: Hydrazine tanks

- Hydrazine dissociation → Exothermic reaction + Corrosion
- Long term compatibility test (US Air Force):

→ < 5% N_2H_4 decomposed after 25 years (at 43°C)

→ **N_2H_4 decomposition and metal dissolution minimized with SS and Ti**

☐ Effects of N_2H_4 decomposition on Tank Pressure to be assessed.

☐ Risk of Tank thermal fatigue to be assessed

GEO: MMH - MON tanks

- **Low risk of corrosion** with MON (NTO+NO). NO inhibits stress-corrosion cracking

☐ MON - MMH known for their good storability but accelerated ageing tests are needed to justify their "safe state".

Risk assessment – 3/ Fragmentation due to Hypervelocity Impacts

- **Study case**

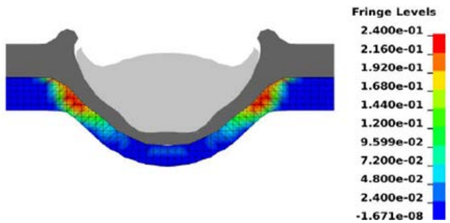
Target: 50cm Titanium hydrazine tank - Externally mounted - 5bar residual Hydrazine

Orbit: 800km, 98.6degrees inclination

Debris: 3.5 mm and 13mm Ø Al spheres. (Probability of impacting the target over 25 yrs is 10^{-2} and 10^{-3} resp.)

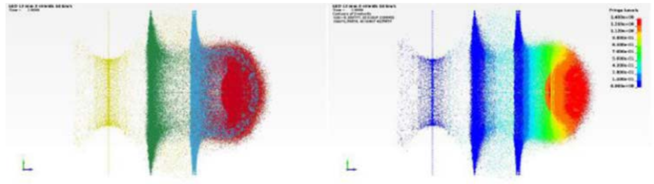
- **Hyper-velocity impact modelling**

1. Debris penetration simulation (FEM-Exp)



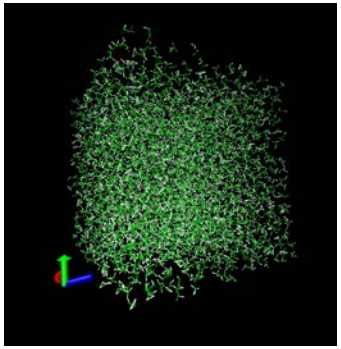
2. Propagation of the debris plume (FEM-SPH)

3. Impact of a Shielding structure (FEM-SPH)

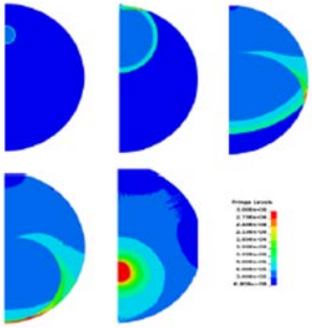


Simulation of a 13mm debris at 14km/s (relative velocity) hitting the S/C structure before impacting the tank wall (blue)

4. Detonation in the liquid phase? (RMD)



5. Detonation in the vapour phase? (Cheetah)



Conclusion – HyperVelocity Impact risk assessment

14 km/s impact with a non-shielded tank

13 mm particle, T>90 ºC
EXP: rupture
SPH: Violent interaction at rear wall
RMD: Liquid detonation not ruled out
FEM: Vapour det.: clear frag.
Rupture

13 mm particle, T<90 ºC
EXP: rupture
SPH: Violent interaction at rear wall
RMD: Liquid detonation not ruled out
FEM: vapour det: small contribution
Rupture

3.5 mm particle, T>150 ºC
EXP: f/b performation, no rupture
SPH: very dispersed plume
RMD: liquid detonation unlikely
FEM: vapour det.: clear frag.
Rupture

3.5 mm particle, 90ºC<T<150 ºC
EXP: f/b performation, no rupture
SPH: very dispersed plume
RMD: liquid detonation unlikely
FEM: vapour det.: significant contrib.
Transition zone

3.5 mm particle, T<90 ºC
EXP: f/b performation, no rupture
SPH: very dispersed plume
RMD: liquid detonation unlikely
FEM: vapour det.: small contrib.
No rupture
(Safe state)

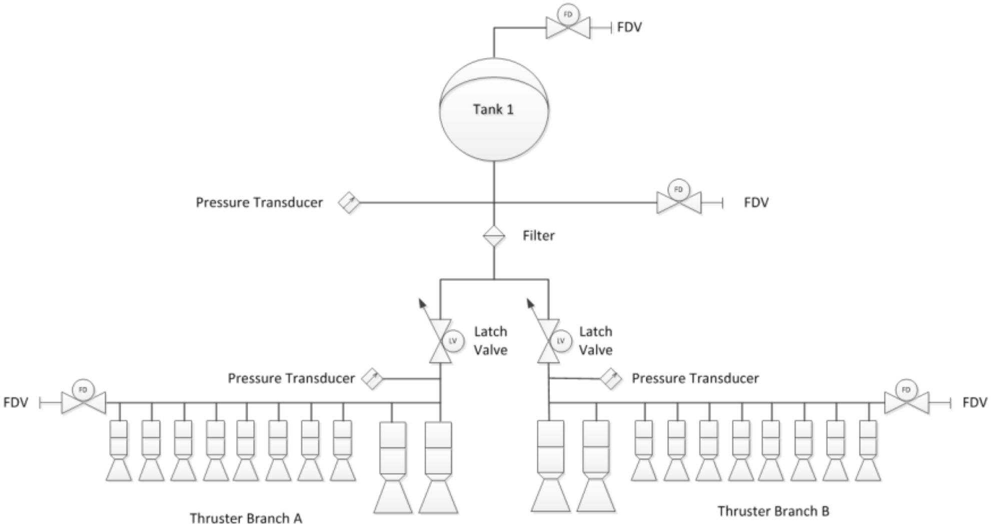
Activities to improve passivation levels for LEO missions

1. Define what a safe state is

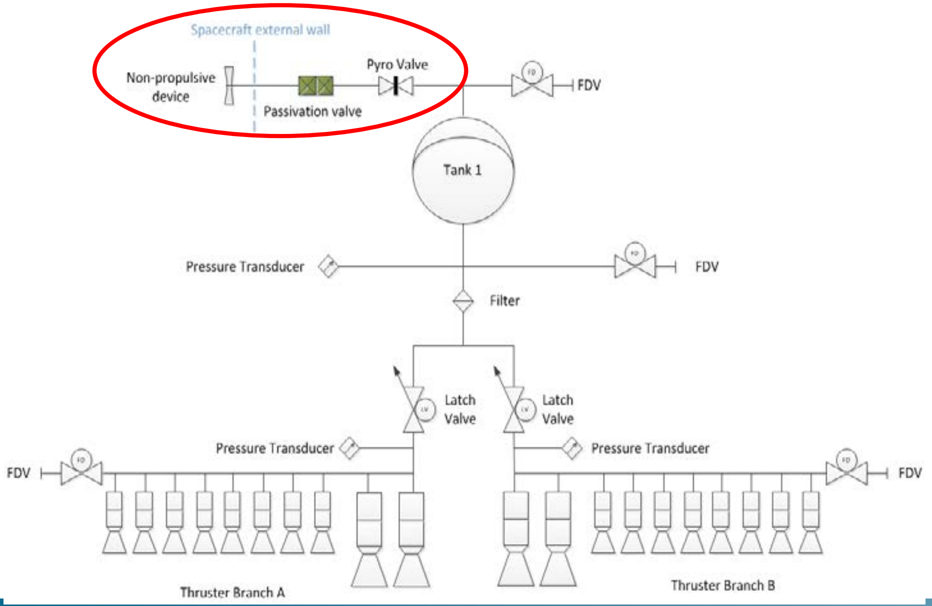
- Define a Safe Pressure at EoL (HVI models to be validated by tests, as done for Upper stages)
- Investigate EoL thermal configuration (200ºC)
- Assess risks of pressure build-up in tanks

2. Future architectures minimizing System impacts - Trade-off conclusions

- **Delta-qualification of RCTs** to low inlet pressures is the preferred option



- **Develop a passivation valve** (TBC if needed)



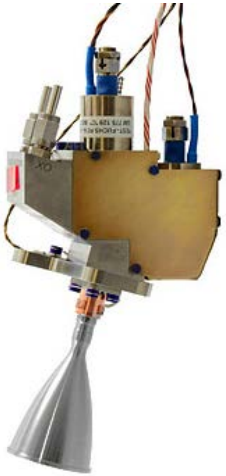
Activities to improve passivation levels for GEO missions

1. Define what a safe state is

- Define a safe pressure threshold at EoL (HVI models to be validated by tests, as done for Upper stages)
- Investigate EoL thermal configuration
- Assess risks of pressure build-up in tanks

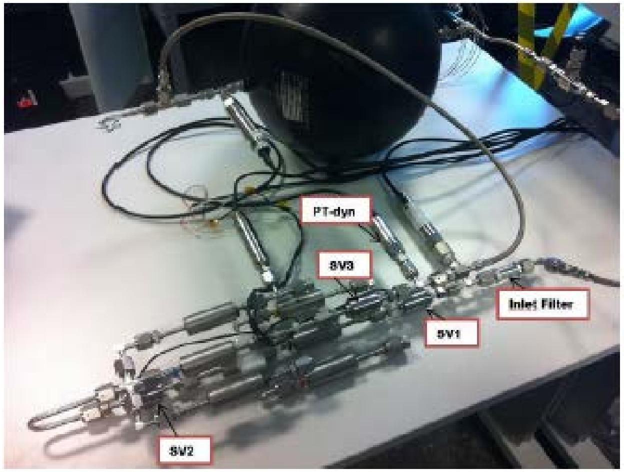
2. Future architectures minimizing System impacts - Trade-off conclusions

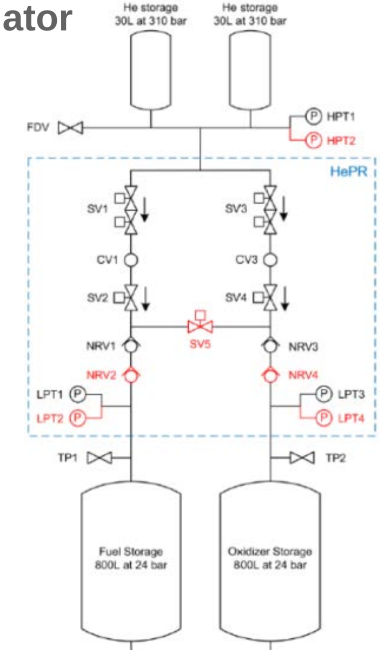
- **Delta-qualification of bi-prop RCTs** to low inlet pressures



- **Develop a He Electronic Pressure Regulator**

→ Increases system performances while permitting gas depletion !



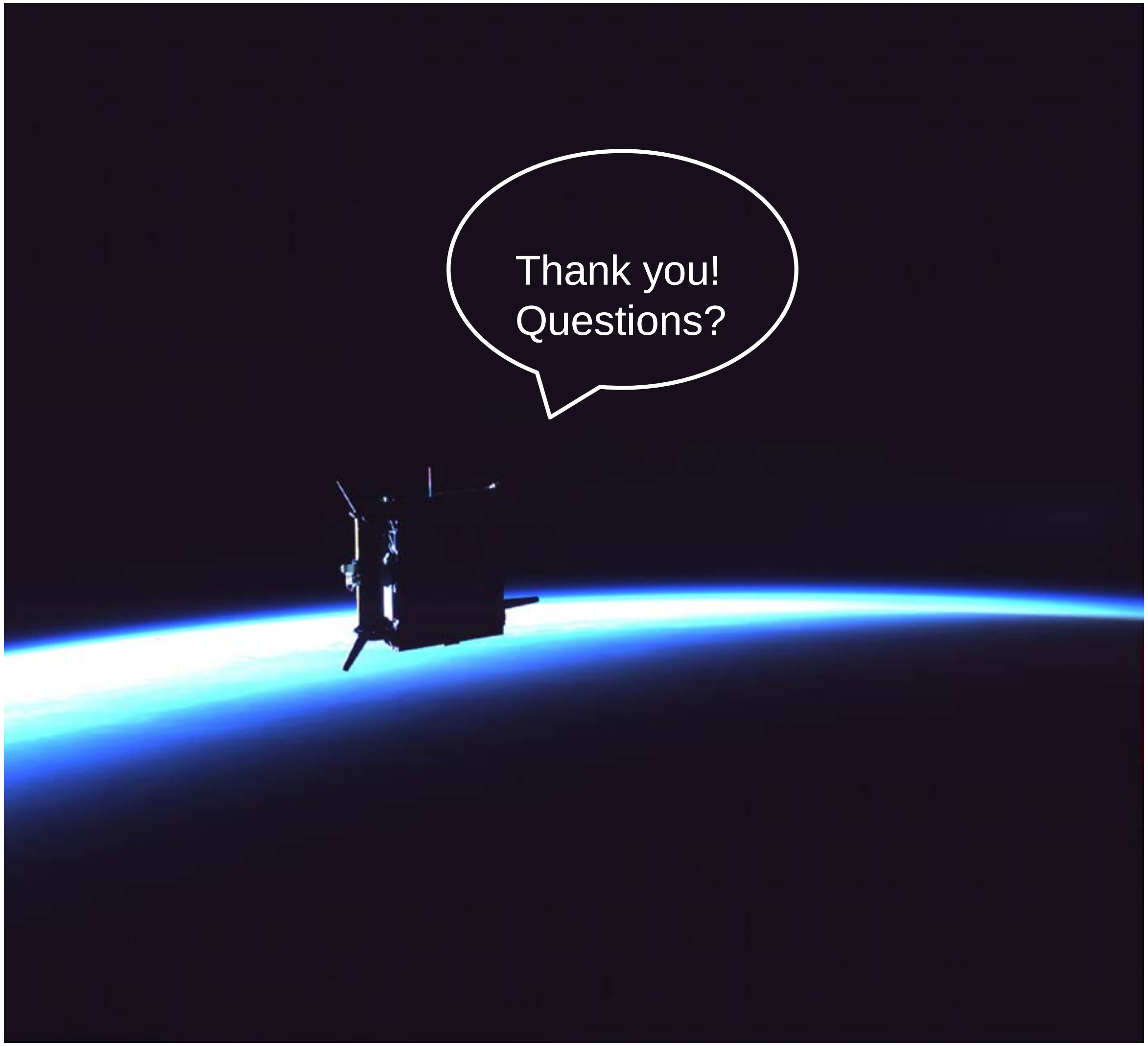


Conclusions

- Propulsion systems need to be made safe at EoL
- Definition of a S/C Safe state is missing → **Engineering activities are identified**
- The risk reduction gained fron passivating a propulsion S/S is unclear
- Operational risks are - on the other hand - clearly identified

New passivation systems should:

- Be useful to the nominal mission phase when possible → **E.g. He EPR, Low Power HET**
- Limit System impact (Reliability, AIT, Cost) → **Delta-qual of RCTs at low Pressures**



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