CONFIDENTIAL

D4D System-Level Techniques
Clean Space Industrial Days

TOGETHER WITH

HTG HYPERSCHALL TECHNOLOGIE GÖTTINGEN GMBH

Fluid Gravity Engineering Ltd

Belstead

Multi-Disciplinary Assessment of Design for Demise Techniques

ESA Contract No. 4000112192/14/NL/GLC

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Critical Elements

Critical element	Risk (Survival) Probability	Risk Severity			Factors			
		Number of debris (typically)	Casualty Area (per debris)	Impact Energy	Materials	Shapes	Mass	Heat Exposure
Propulsion tank	Very High	1	Very High (1.2-1.8 m^2)	>10 kJ	Titanium			Shielding ("demisable" tank)
Battery	Very Low (model granularity)	1	Medium (0.75 m^2)	~100 kJ			Sizing	Shielding (S/C walls)
LCT	Very High	1 (if used)	Very High (1.3 m^2)	~100 kJ	Titanium AlBeMet		Dense	
Magnetorquer	Medium	1 (x3 MTQ)	Medium (0.55 m^2)	Low (<0.5 kJ)	Iron	Rod	Sizing	Shielding (S/C walls)
Reaction Wheels	High (rarely demise)	1 (x4 RW)	Medium (0.5-0.6 m^2)	~10 kJ	Stainless Steel		Sizing	Shielding (S/C walls)
SADM	High	1	Low (<0.5 m^2)	Medium (~10 kJ) to Low (<1 kJ)	Titanium			Layers & Shielding
Optical Payload	Very High	Variable	Medium to Very High	Variable	Ceramics		Medium to Very Large	

Understanding the calculation of the casualty risk

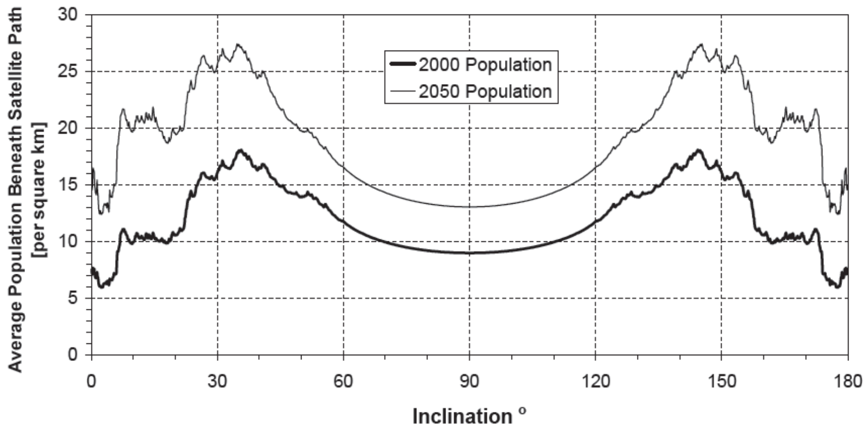
- The casualty risk is the product of the total debris casualty area and the latitude-averaged population density

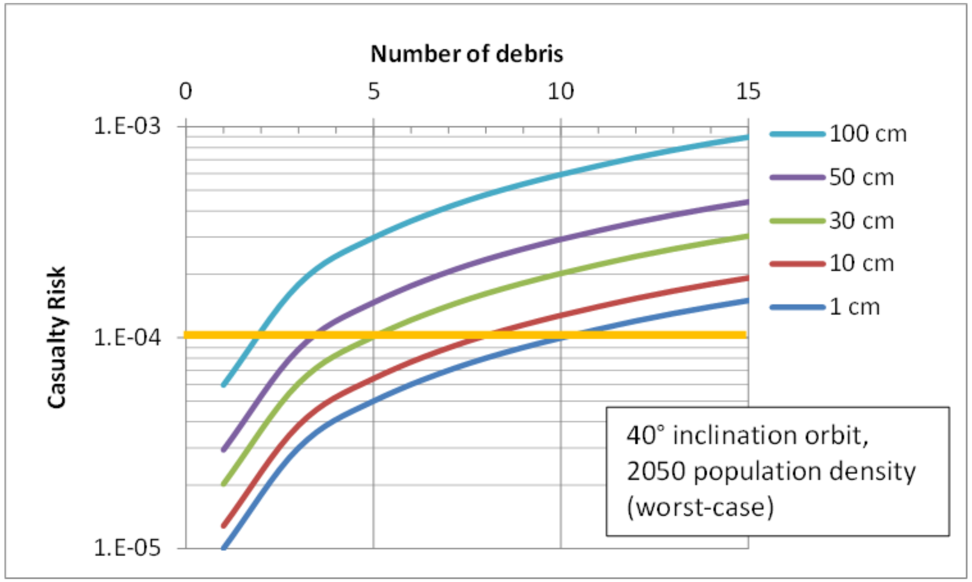
$$E_h = D_A \times P_D$$

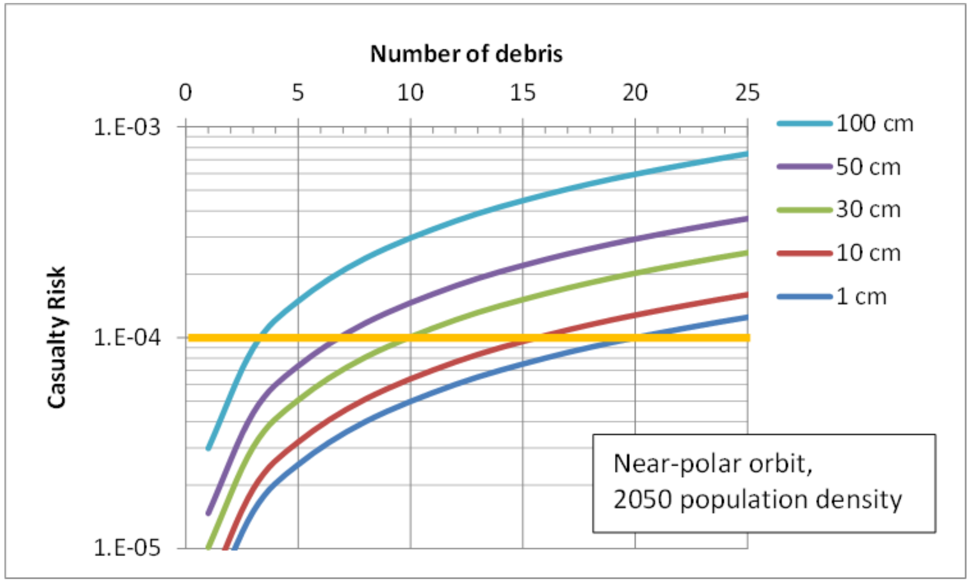
- The casualty area is strongly dependent on the number N of debris

$$D_A = \sum_{i=1}^{N} \left(0.6 + \sqrt{A_i}\right)^2$$

- In an SSO, it takes **10-15 hazardous debris** to fail the casualty risk requirement







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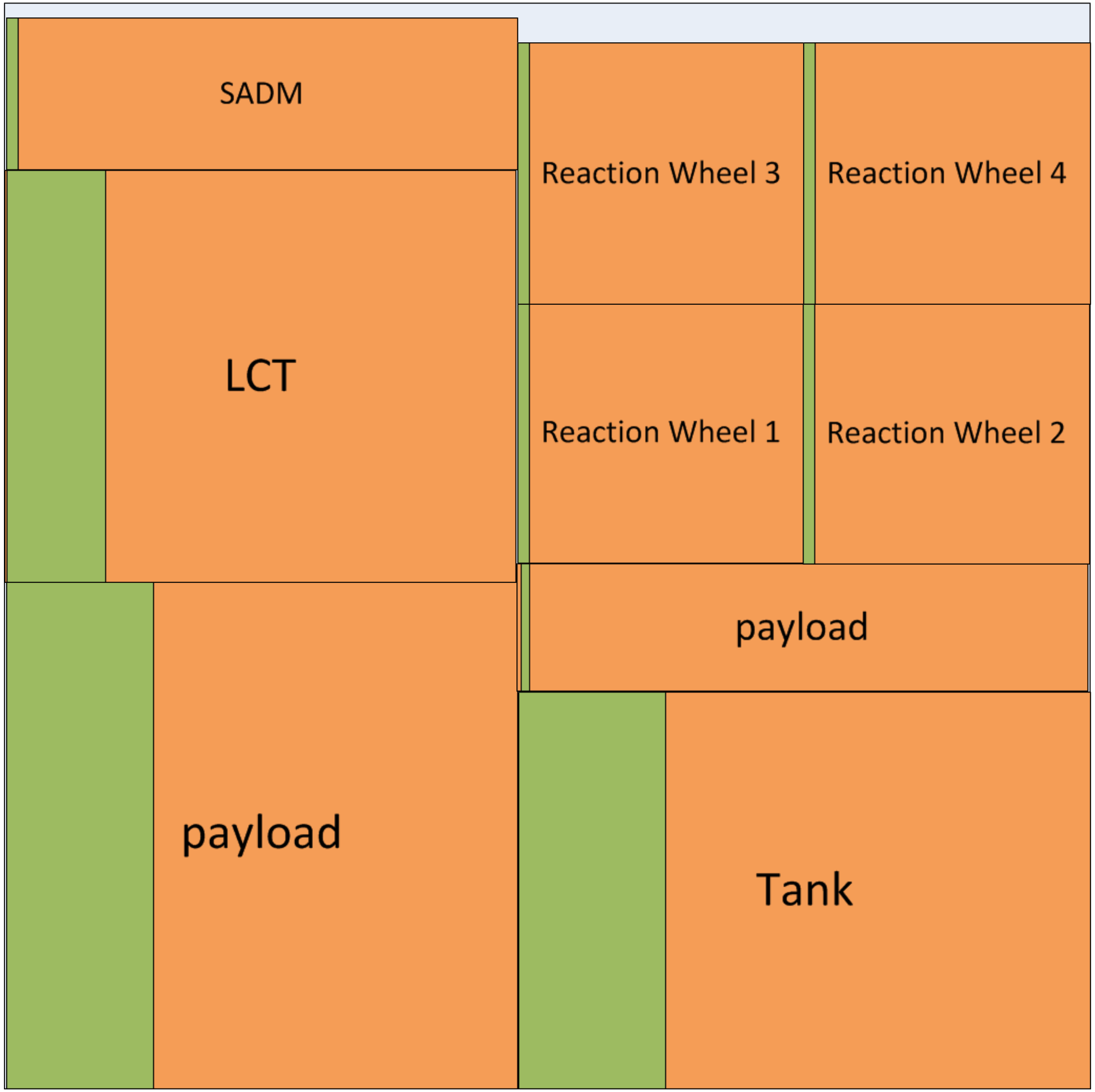
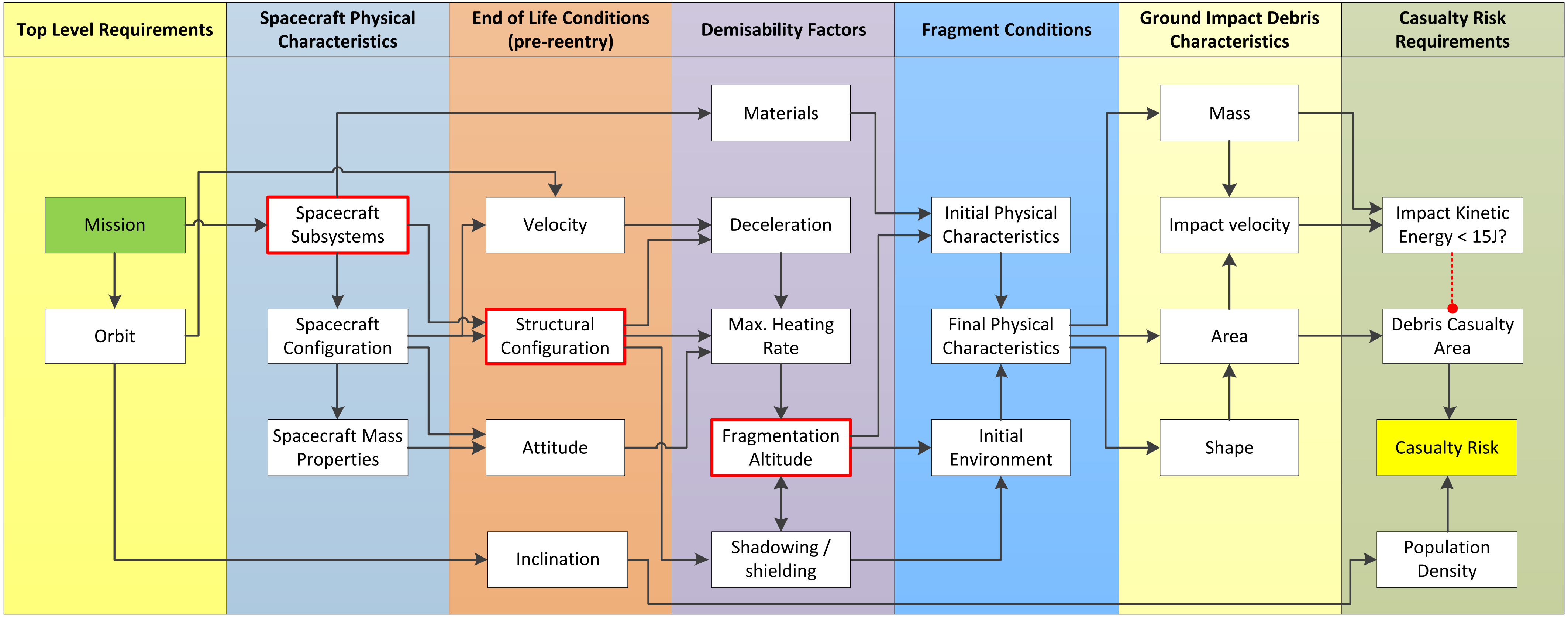

SADM
Reaction Wheel 3
Reaction Wheel 4
LCT
Reaction Wheel 1
Reaction Wheel 2
payload
payload
Tank

Demisability / Survivability Factors



Key drivers for debris surviving the re-entry

- Spacecraft subsystems and equipment onboard (including the materials they are made of)
- Satellite/structural configuration:
  - Drives the satellite fragmentation altitude(s) – the higher the better
  - Also drives the shielding of onboard equipment

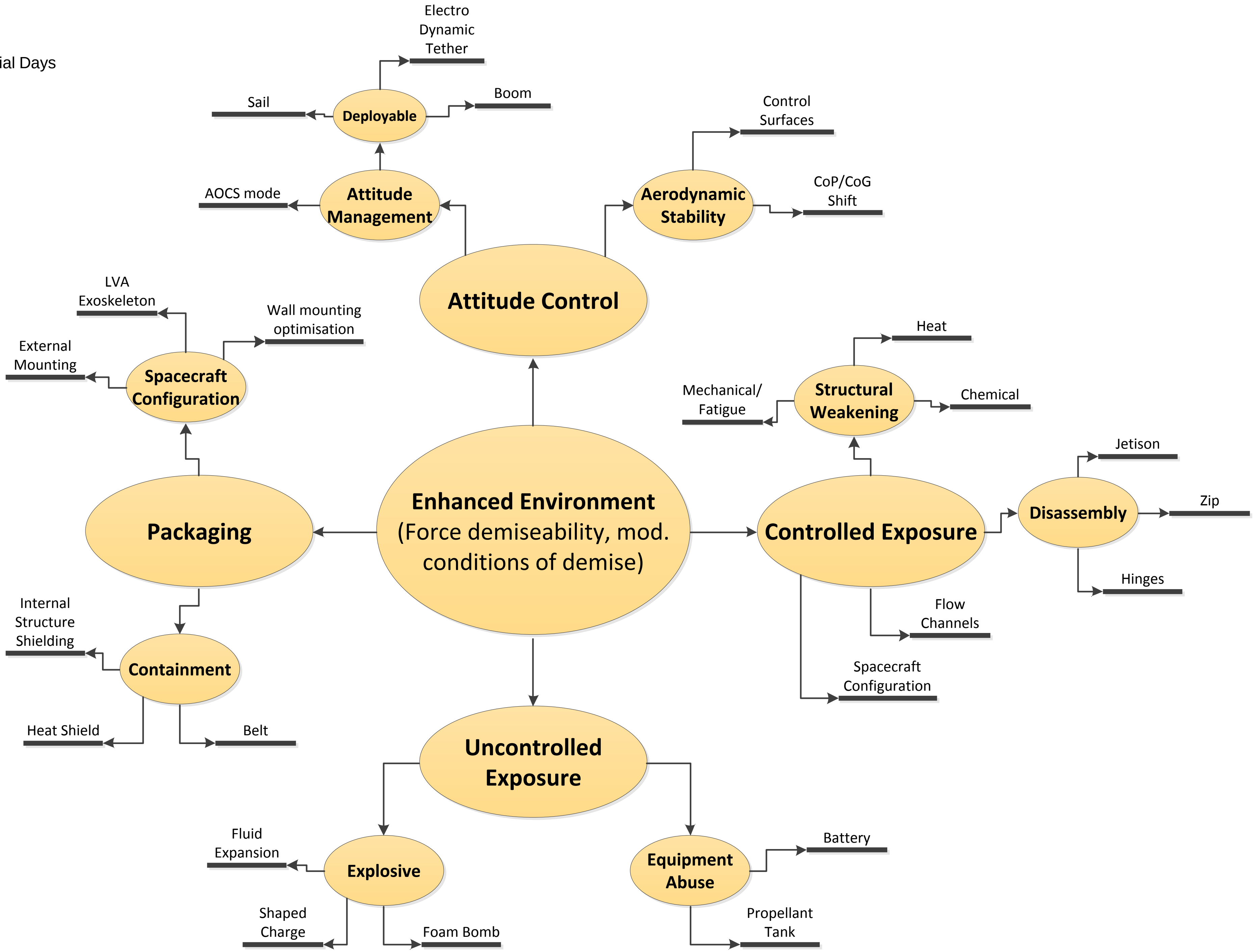
How to demise…

$$Q_{received} > Q_{demise} + Q_{radiated}$$

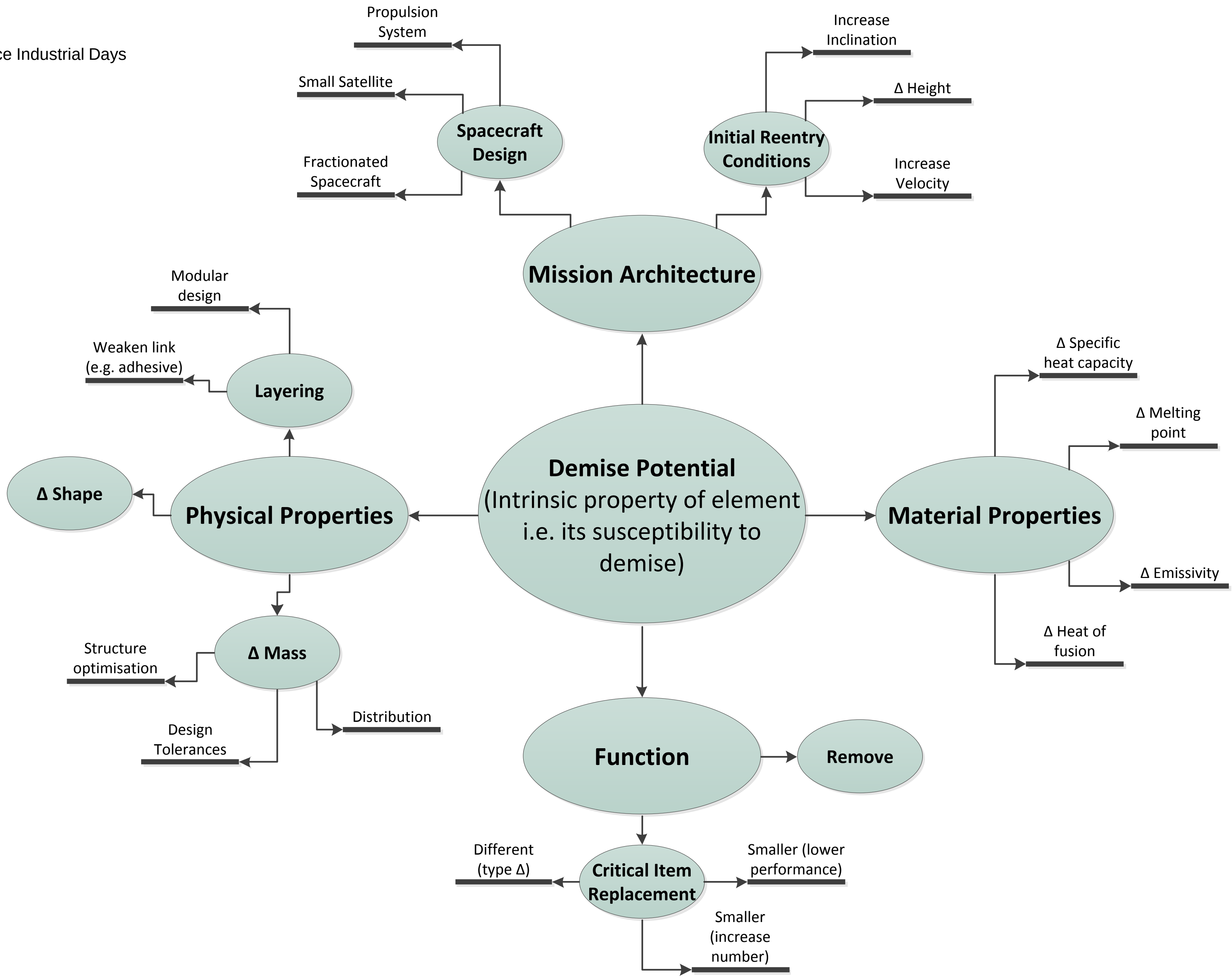
Exposure
- Fragmentation altitude
- External accommodation

Material properties
- Latent heat of fusion
- Specific heat capacity
- Melting temperature
- Density (mass)

Material properties
- IR emissivity


Enhanced Environment
(Force demiseability, mod. conditions of demise)
Attitude Control
Attitude Management
Aerodynamic Stability
Deployable
Electro Dynamic Tether
Sail
Boom
AOCS mode
Control Surfaces
CoP/CoG Shift
Packaging
Spacecraft Configuration
LVA Exoskeleton
Wall mounting optimisation
External Mounting
Containment
Internal Structure Shielding
Heat Shield
Belt
Controlled Exposure
Structural Weakening
Heat
Mechanical/ Fatigue
Chemical
Disassembly
Jetison
Zip
Hinges
Flow Channels
Spacecraft Configuration
Uncontrolled Exposure
Explosive
Fluid Expansion
Shaped Charge
Foam Bomb
Equipment Abuse
Battery
Propellant Tank


D4D
Design for Demise


Demise Potential
(Intrinsic property of element i.e. its susceptibility to demise)
Mission Architecture
Spacecraft Design
Propulsion System
Small Satellite
Fractionated Spacecraft
Initial Reentry Conditions
Increase Inclination
Δ Height
Increase Velocity
Material Properties
Δ Specific heat capacity
Δ Melting point
Δ Emissivity
Δ Heat of fusion
Physical Properties
Layering
Modular design
Weaken link (e.g. adhesive)
Δ Shape
Δ Mass
Structure optimisation
Design Tolerances
Distribution
Function
Remove
Critical Item Replacement
Different (type Δ)
Smaller (lower performance)
Smaller (increase number)


D4D
Design for Demise

Summary of techniques

- A large range of D4D techniques (>40) have been proposed
  - From the simple ones to the “blue-sky-thinking” ones
- A first qualitative assessment was performed, to eliminate techniques of little interest and/or feasibility
- A selected dozen were evaluated through re-entry simulations (SAM tool)
  - To evaluate the sensitivity of each technique
  - These confirm (or correct) the anticipated worth, in terms of demisability, of each technique
- Key message on the promising techniques
  - Panels/walls/plates separating early during re-entry is a very worthy technique, especially if critical elements are mounted on them
    - Whatever mean is used to achieve it.
    - The earlier the separation, the better.

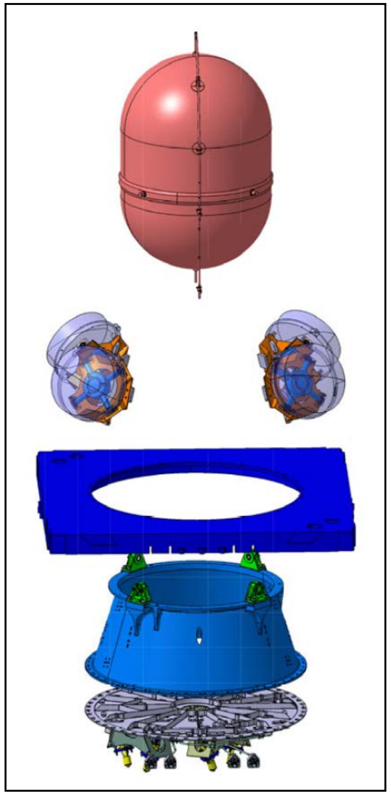
"Technique 0"
Demisable tank

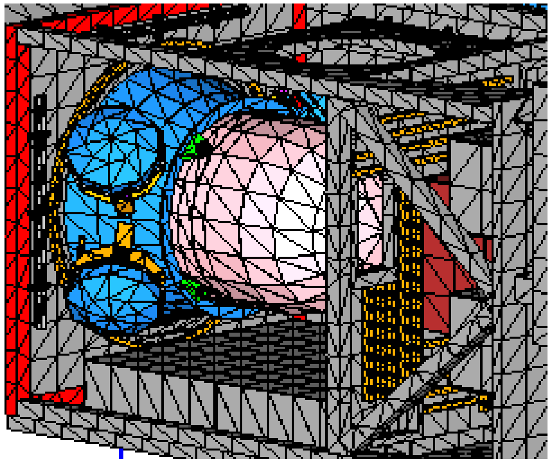
- Al-Li tank
  - Thickness doubled w.r.t. Titanium tanks
  - Mass increased by ~10%.

- Sentinel 2 test case: Al-Li tank demises completely
  - But not necessarily true for other missions

- Generally, Al-Li tanks demise from an early exposure (before 80-83 km).

-22%





D4D Design for Demise

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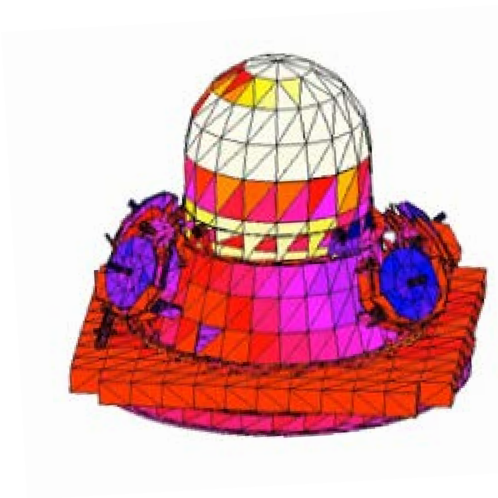
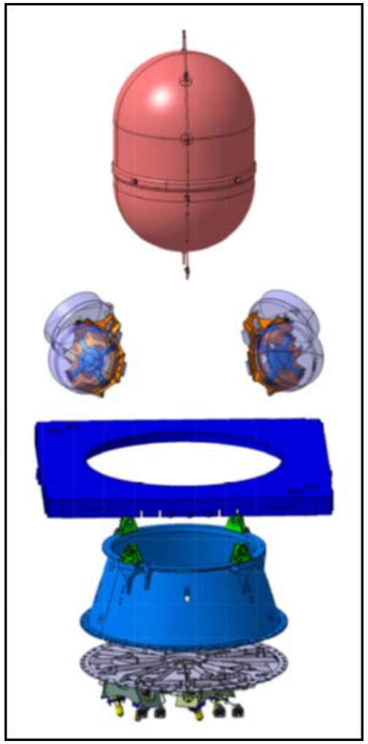
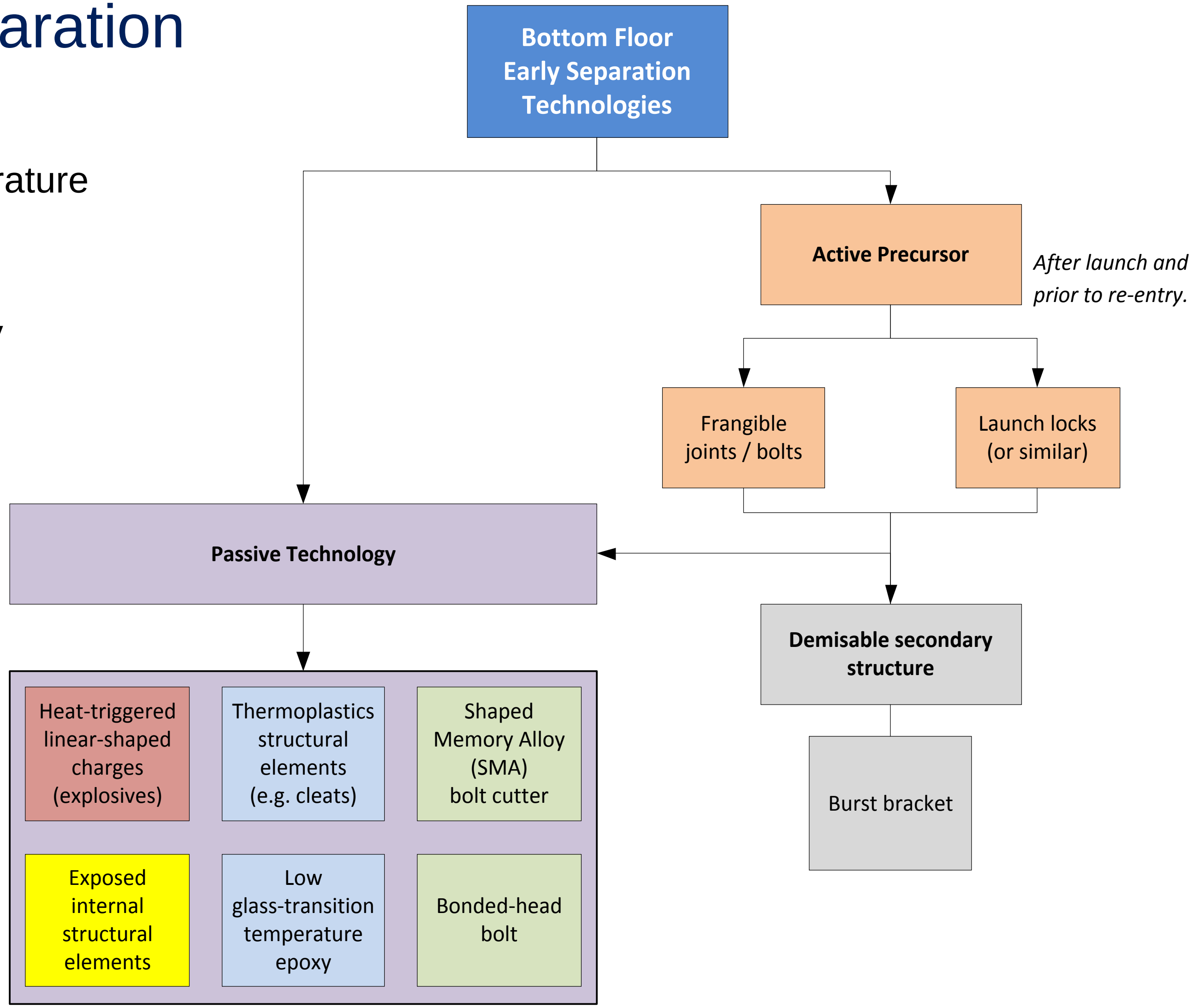
Technique #1
Bottom Floor Jettisoning/Separation

-17 to -25%

- Separation assumed to be triggered by temperature
  - 200°C
  - 400°C
  - Separated from the beginning of the re-entry
  - (Al melt ~600-650°C)



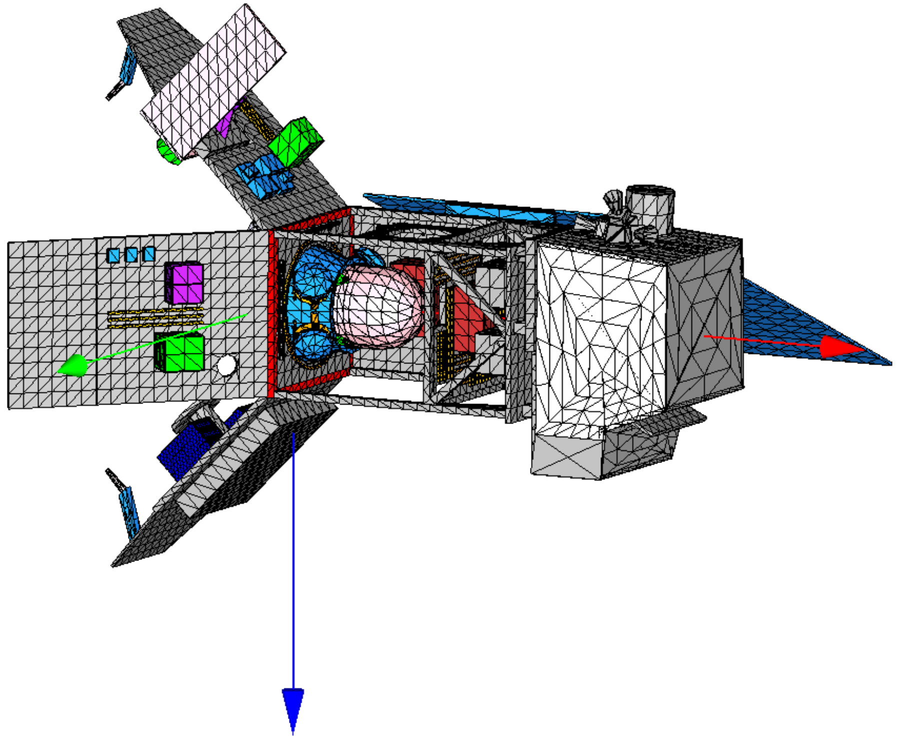




Technique #2
Side Panel Opening

-27 to -33%

- A variation of technique #1, the aim is to expose the insides of the platform to the re-entry heat flux from the beginning.
- However, this implies the controlled opening of the side panel(s) before the satellite is passivated.
- Structures are primarily designed to survive the launch
  - To simplify the end-of-life opening system, it is proposed to first weaken the structure during LEOP (e.g. standard pyro devices)
- The more panels are opened, the better



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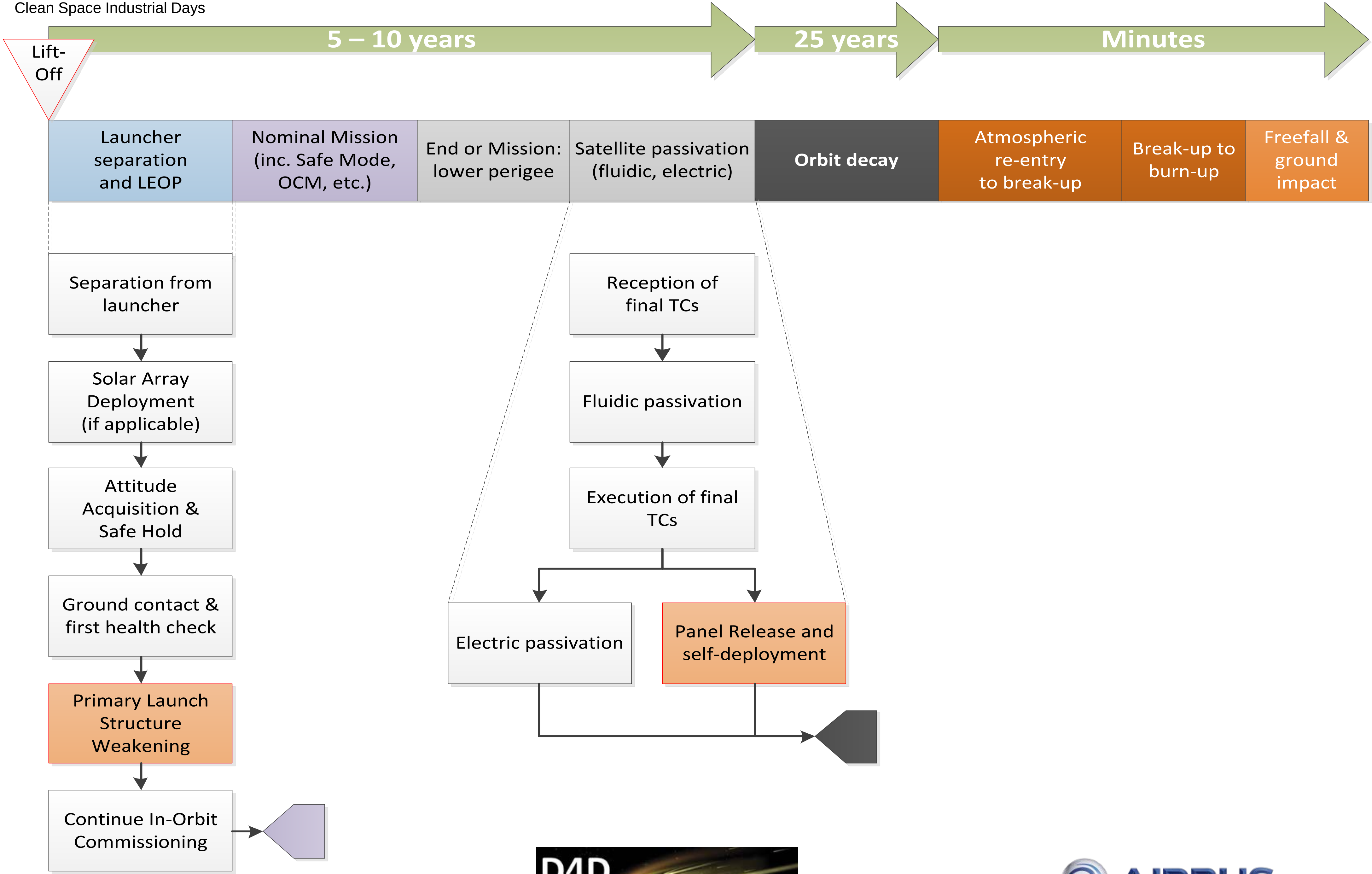
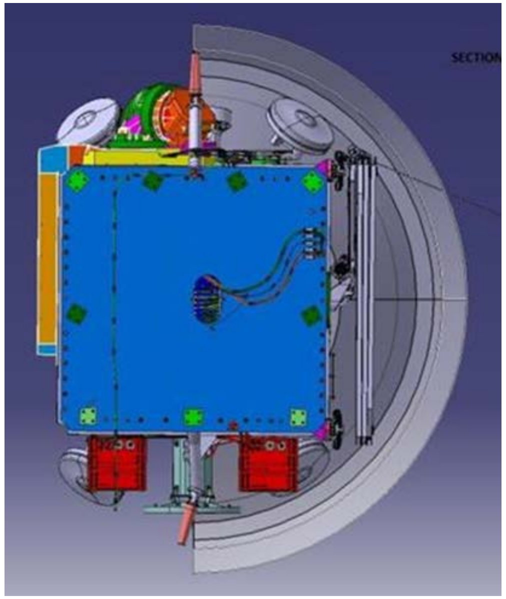
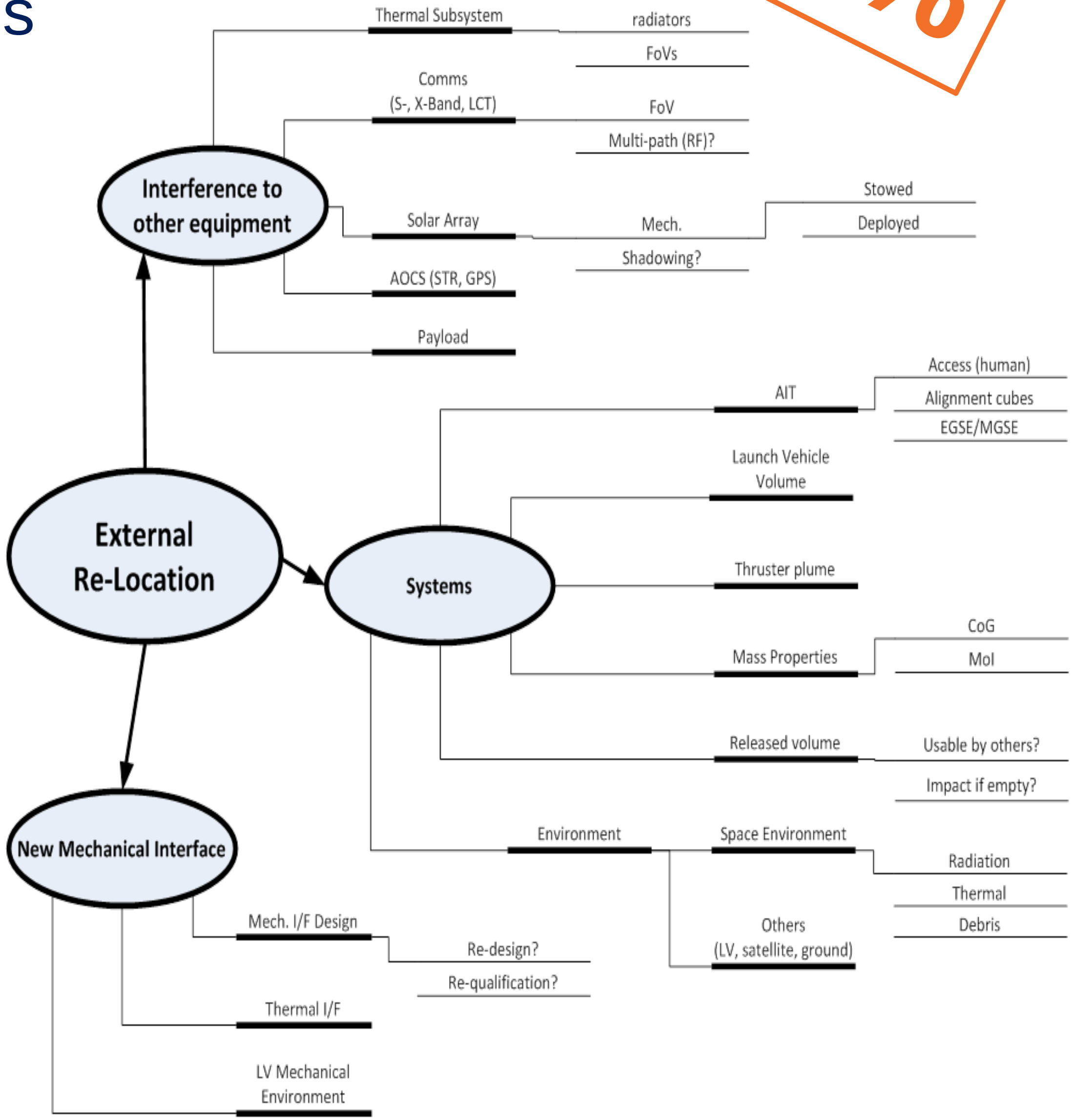

5 – 10 years
25 years
Minutes
Lift-Off
Launcher separation and LEOP
Nominal Mission (inc. Safe Mode, OCM, etc.)
End or Mission: lower perigee
Satellite passivation (fluidic, electric)
Orbit decay
Atmospheric re-entry to break-up
Break-up to burn-up
Freefall & ground impact
Separation from launcher
Solar Array Deployment (if applicable)
Attitude Acquisition & Safe Hold
Ground contact & first health check
Primary Launch Structure Weakening
Continue In-Orbit Commissioning
Reception of final TCs
Fluidic passivation
Execution of final TCs
Electric passivation
Panel Release and self-deployment

Technique #3
Externally-Mounted Reaction Wheels

-20%

- Stainless steel RW can demise, provided they are exposed early on.
- The alternative to the first two techniques, specifically for the RWs, is to mount them externally.
- However,
  - It is not enough for the RWs to be outside.
  - They need to separate early too





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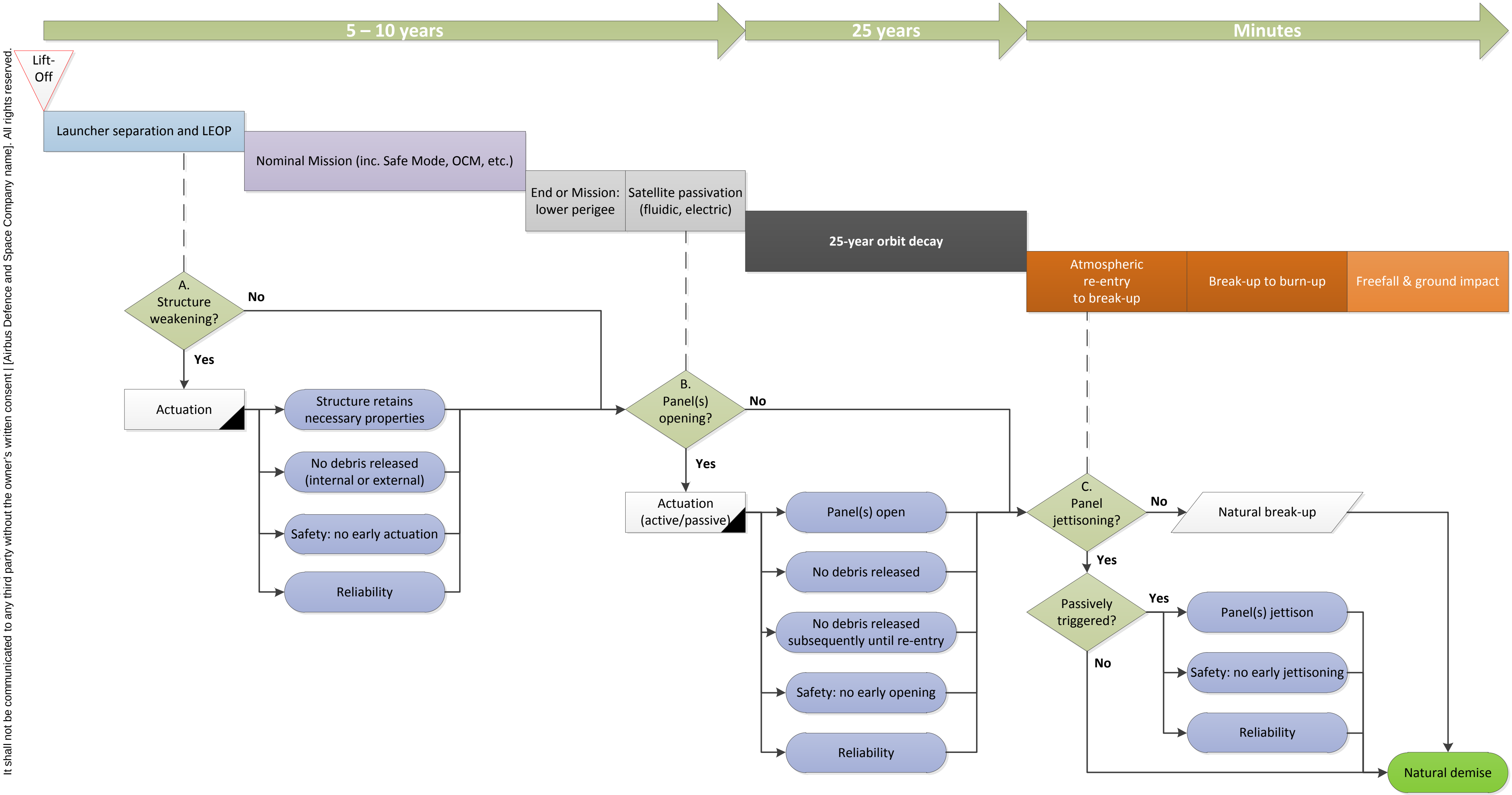
Technique #4
Payload Early Jettisoning

- Optical payload are a big issue

- Key question:
  - What happens if we separate the payload early? — Not much
  - Does it improve the casualty risk? — Slightly (not in the way we aimed for)

- Ceramics are ceramics
  - To the best of our current knowledge, they won't demise

"Mission Timeline" of D4D techniques – Re-cap



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Recommendations

To minimise the casualty risk:

- Materials, materials, materials
- Early exposure and release

$$Q_{received} > Q_{demise} + Q_{radiated}$$

In practising the dark magic:

- Mind the gap…
  - Between simulation tools and reality
    - Call in the experts
- At system level, create a casualty risk budget

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