Design considerations when selecting low-particle content solid propellants for de-orbiting applications

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Where there is smoke...

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Where there is smoke...

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... is smoke the same as particles?

- Primary smoke
  - Mixture of liquid and solid particles in the exhaust gas
  - Generated from the combustion of specific ingredients in the propellant
    - Metal based – aluminum, iron, lead, copper, boron
    - Soot (carbon)
- Secondary smoke
  - Condensation of water and gaseous combustion products under specific atmospheric conditions of low temperature and high humidity
    - e.g. hydrochloric acid (HCl) generated from combustion of ammonium perchlorate (AP)
  - Similar to condensation trails from airplanes
- Particles
  - Generated from the ablation and erosion products of the insulation and TVC
  - Ejected objects from ignition system, environmental seal, TVC, etc.

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Few examples of a solid motor being fired in space

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Difference between aluminized and non-aluminized propellant

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"Design considerations when selecting low-particle content solid propellants for de-orbiting applications"

- Depends on more than the propellant alone:
  - Propellant constituents
  - Insulation design and materials
  - Ignition system
  - Environmental seal
  - Thrust Vectoring unit

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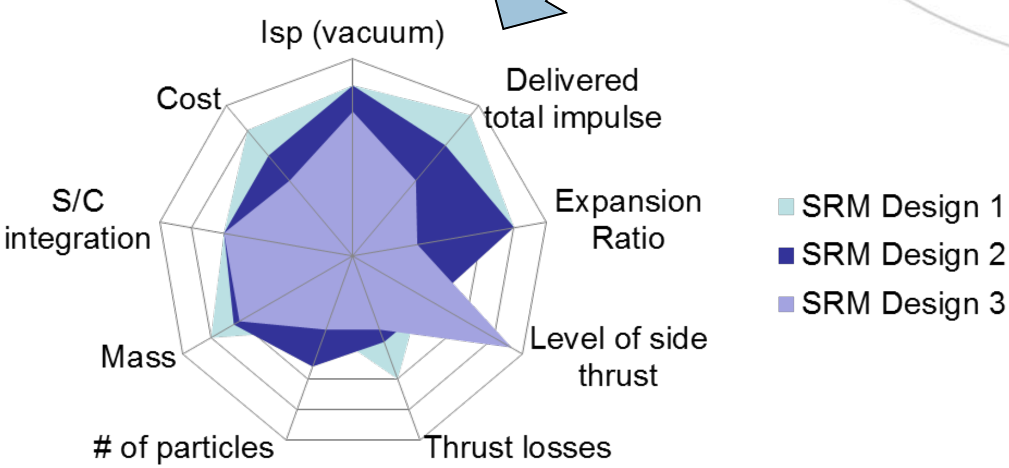
Propellant design considerations

- Aspects of the design of the de-orbiting solid rocket motor influenced by (or influencing the choice of) the propellant
  - Isp (vacuum)
  - Expansion ratio of the nozzle
  - Thrust level
  - Delivered total impulse
  - # of particles
  - TVC design
  - TVC related losses
  - S/C Integration
  - Total mass
  - Cost
  - Etc.

Choice of best compromise is really hard!



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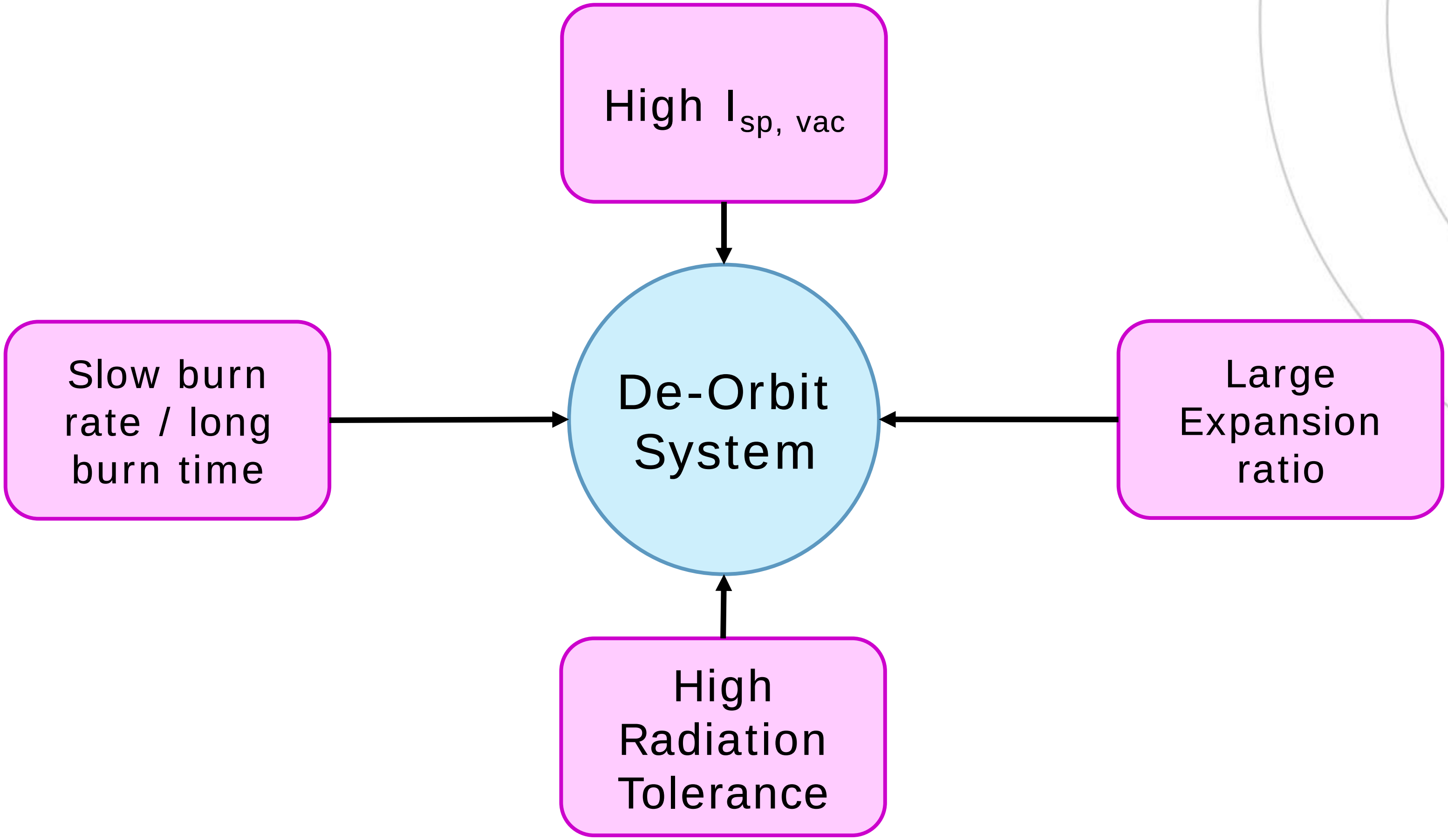
Considerations WRT de-orbiting application

Arbitrary grouping for illustration purposes



Considerations WRT de-orbiting application

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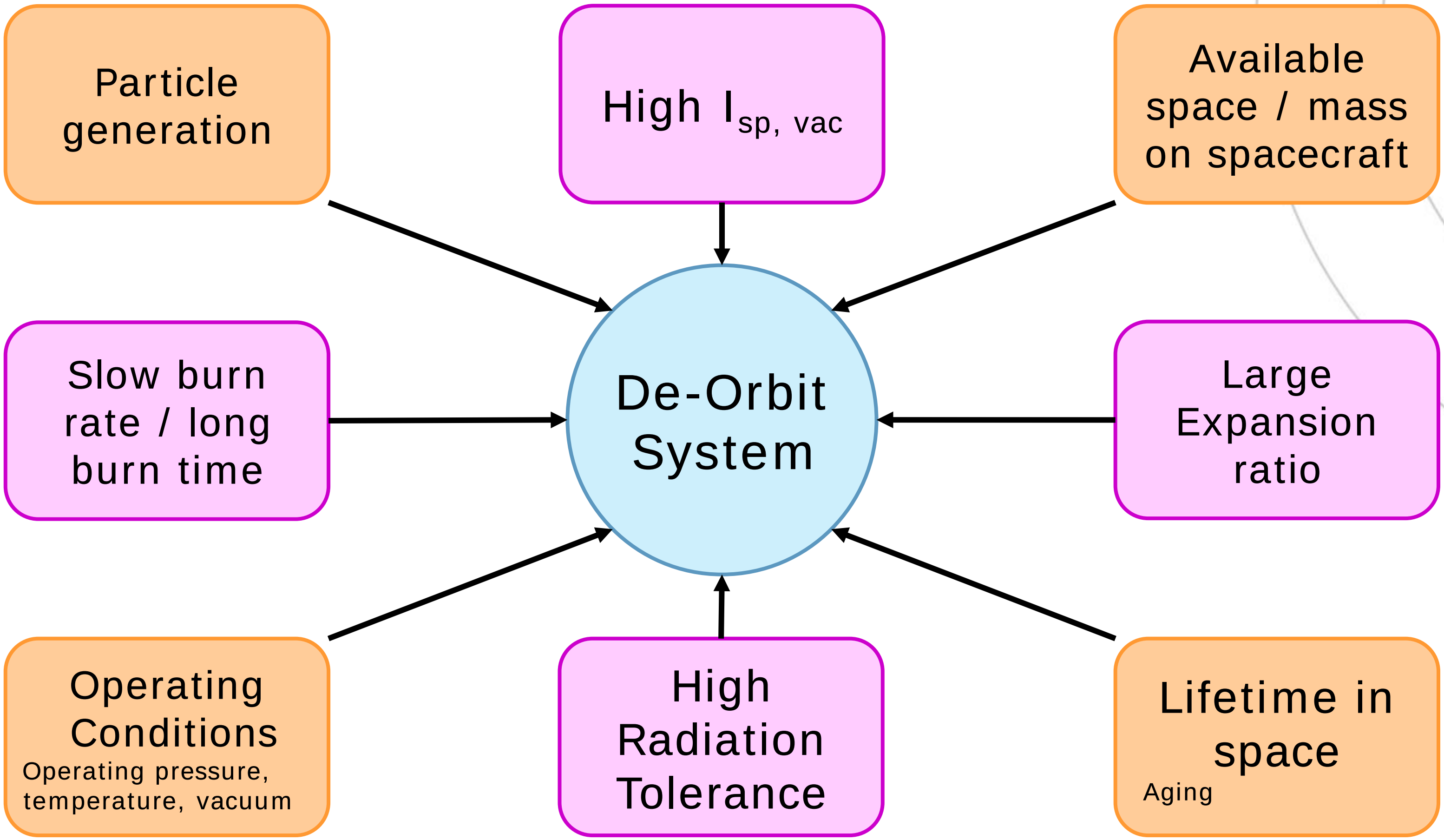
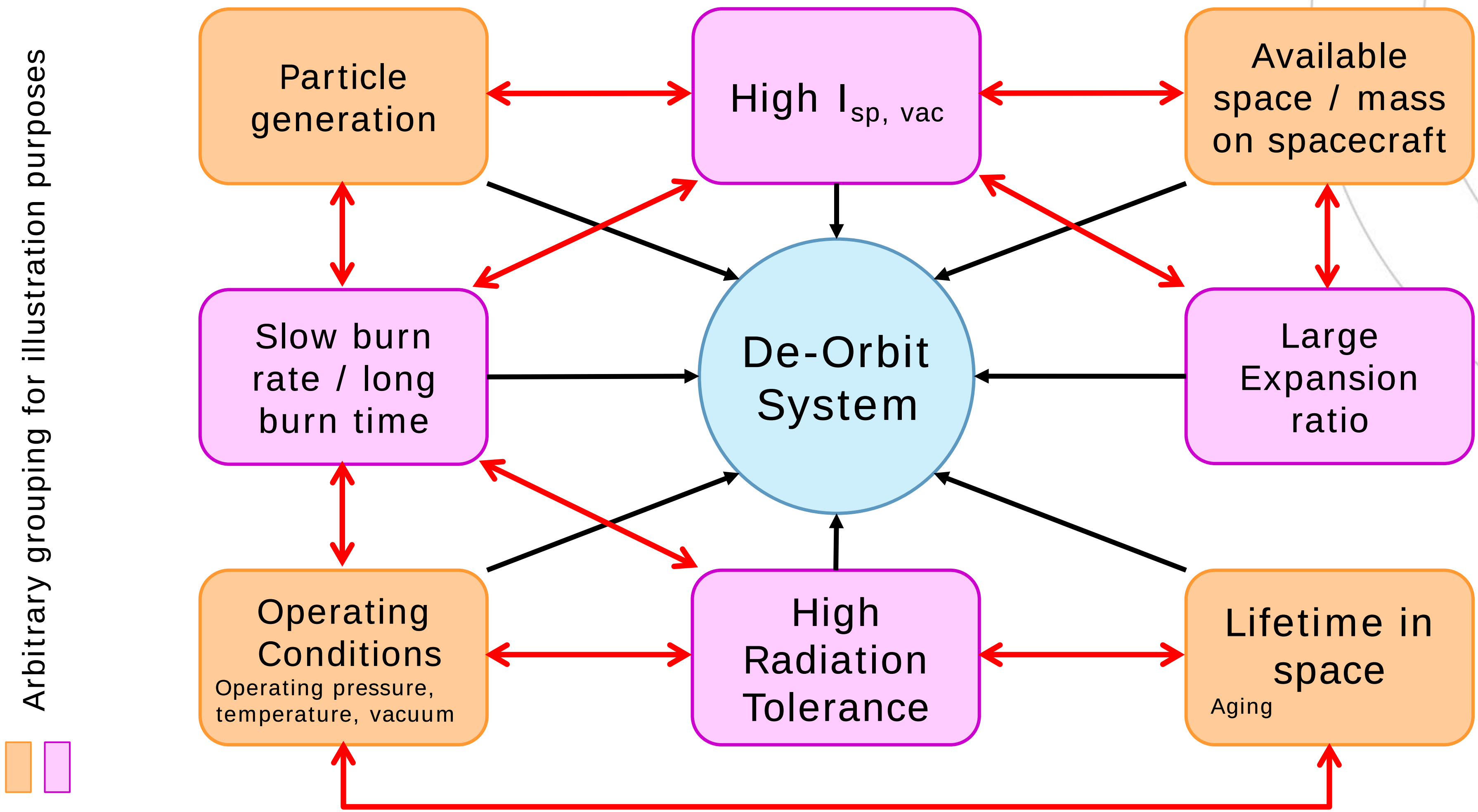
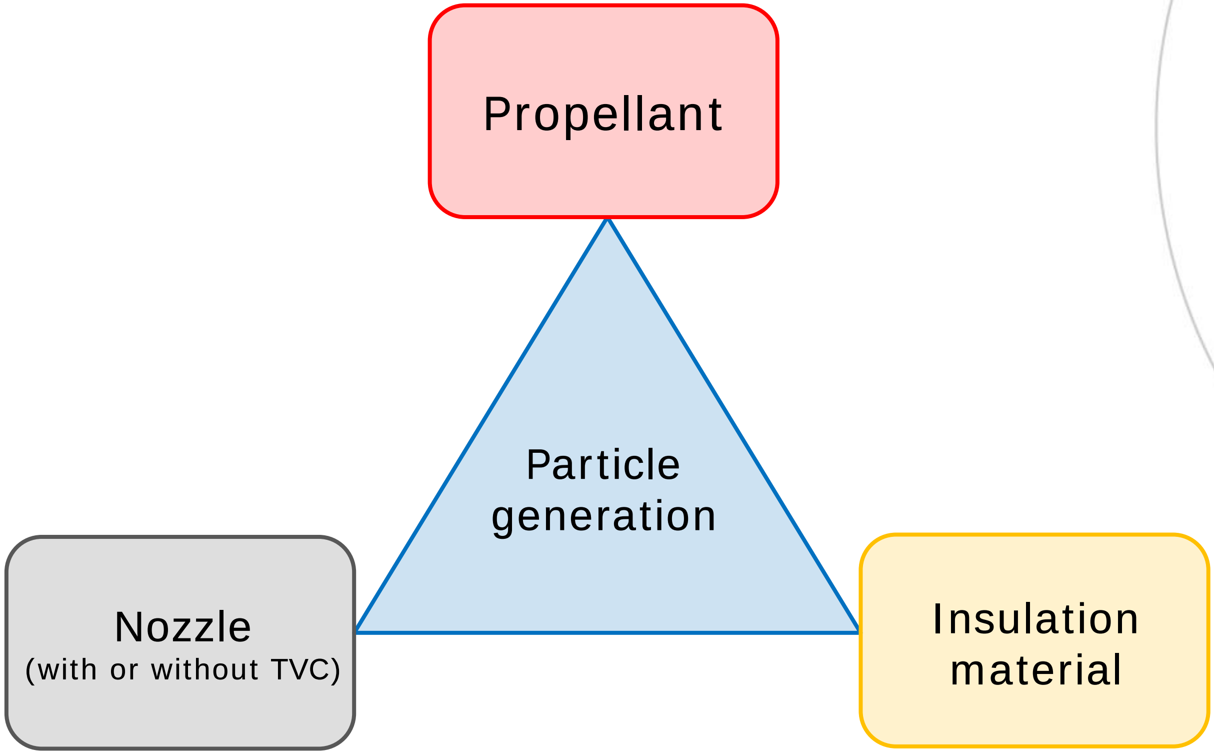


Considerations WRT de-orbiting application



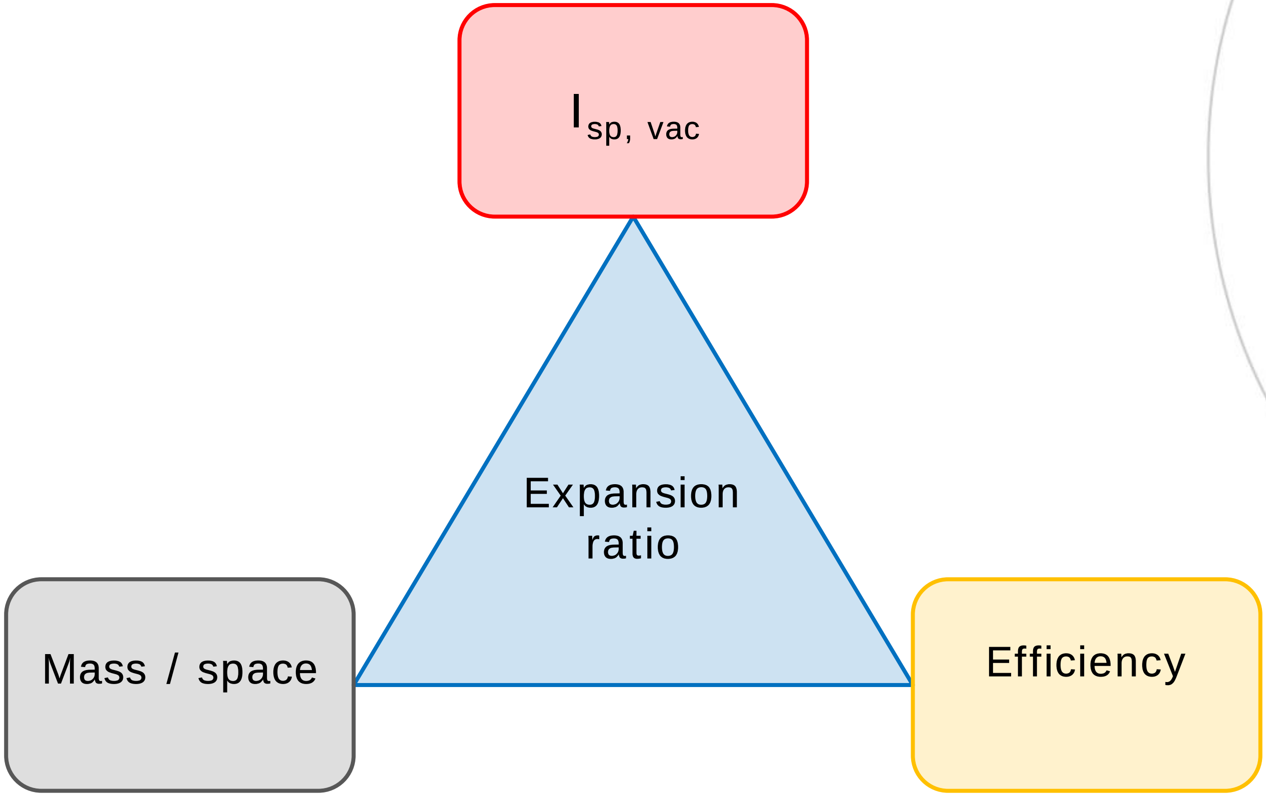
Particle generation



Even if a low particle content solid propellant already is chosen:

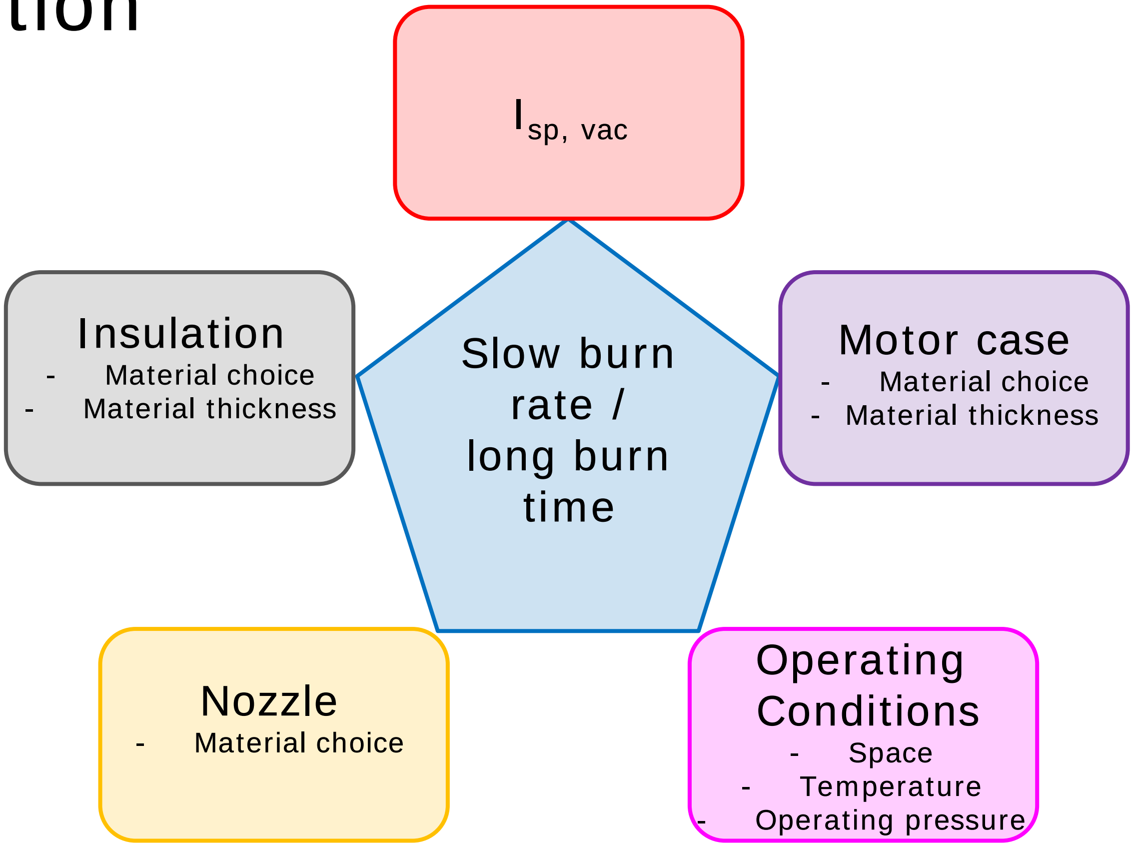
- Low erosion nozzle (with or without TVC) & burst disc not ejecting fragments
- Insulation material with combustible fibres and low solid content
- Maintain stable combustion

Expansion ratio



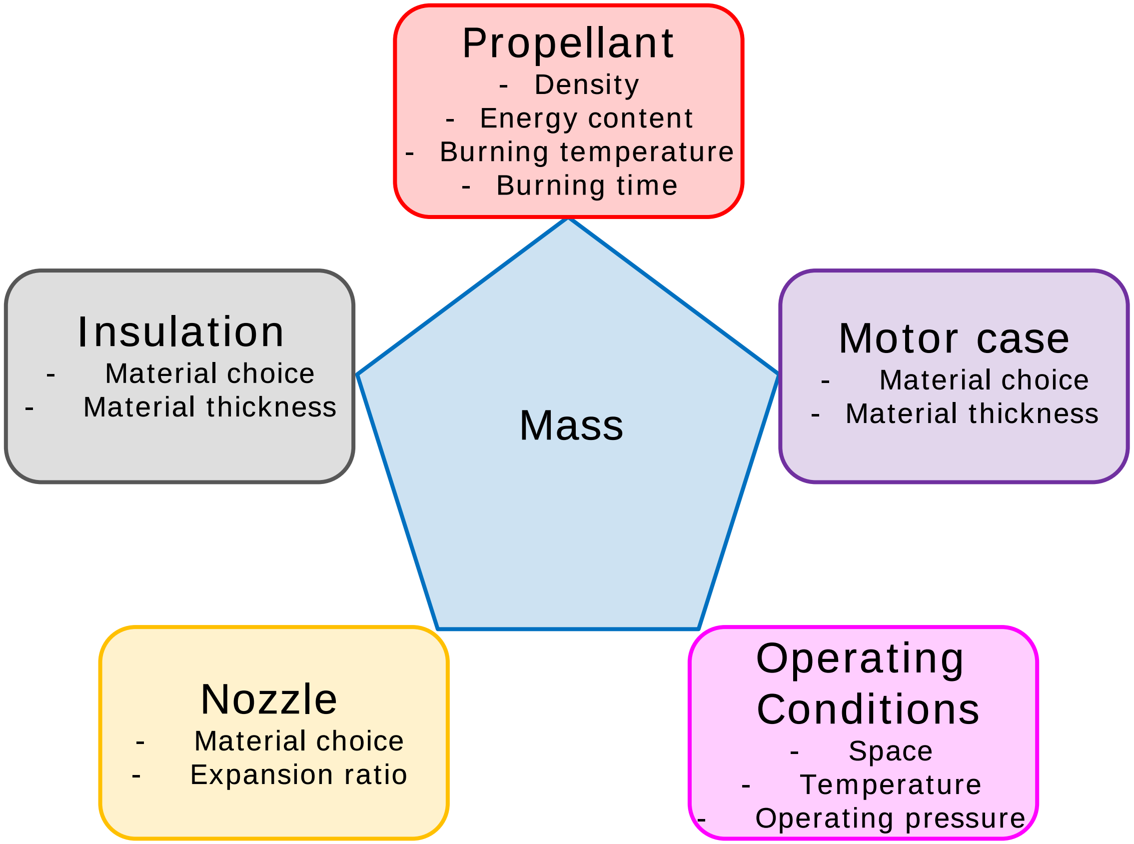
Competition between $I_{sp,\ vac}$, available mass/space and optimum efficiency. Higher pressure and temperature increases $I_{sp,\ vac}$, but requires a larger nozzle contour demanding more space and increasing mass, while at the same time the efficiency of an end mounted TVC solution will be reduced

Combustion



Competition between $I_{sp,\ vac}$ and slow burn rate. High $I_{sp,\ vac}$ leads to a high burning rate. Burn rate also depends in a high degree on the operating conditions. Long burn times require the right choice of insulation, nozzle and motor case materials (erosion & thermal stress).

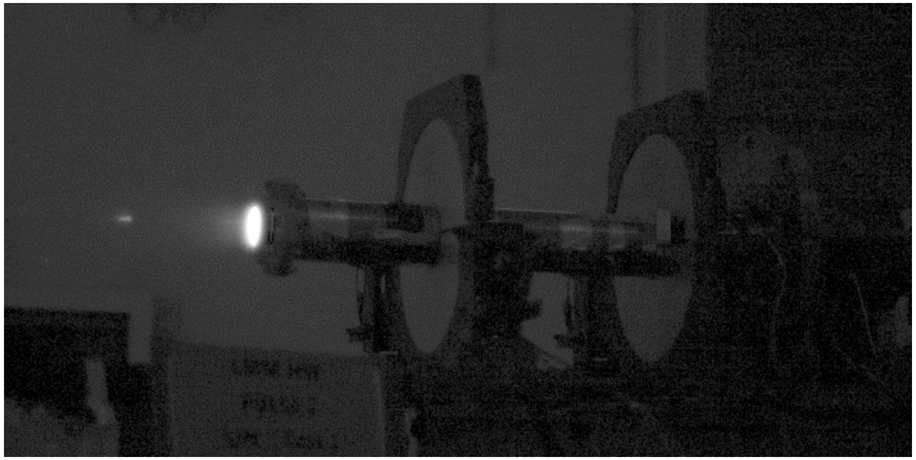
Mass



Mass could increase caused by the long burn times and the low density propellant (no metals) → increased thermal stress influence motor case wall thickness and insulation design as well as requiring a heat and erosion resistant nozzle.

Techniques to optimize propellant formulation for de-orbiting applications

- Remove metal based fuel constituents
- Remove metal based additives
- Use high energy, energetic ingredients with only gaseous combustions products
- Use ablative materials with combustible fibers
- Use ceramic based insulation materials



Nammo excellent positioned to provide Solid Propellant solution to the de-orbiting system

- One of the world's largest databases on composite propellant formulations for a multitude of applications
- Many years of research and development on Clean and Minimum Smoke propellants
- In-house design and manufacturing of ceramic composite insulation components
- Recent investment in the expansion of the propellant plant for Clean Propellants (e.g. Nitramines based)

Advanced high temperature furnaces for pyrolysis and siliconization

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Unique wide-ranging experience in solving the challenge of “finding” the right compromise

- Aluminized and non-aluminized
- High burn-rate and low burn-rate
- Short burn time and long burn-times
- Propellant masses from 3kg-120kg

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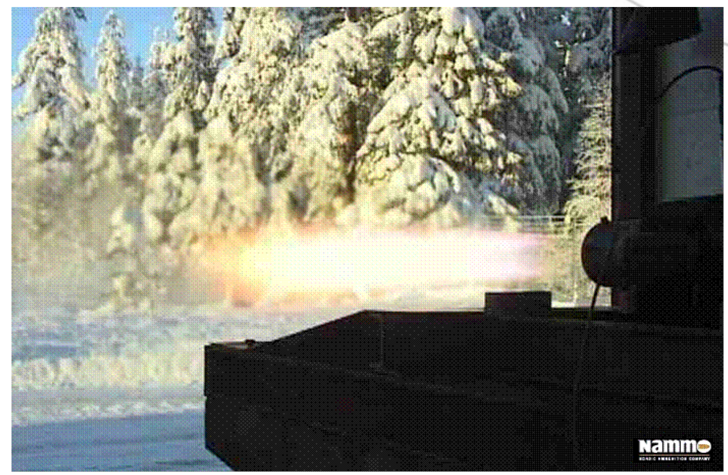
New developments in Clean Propellants
at Nammo

- Investments in new production plant for Energetic Propellants
- State of the Art Glycidyl Azide Polymer (GAP, Energetic Polymer) with HMX (RDX) Solids and selected additives industrialized in 2014
  - Minimum smoke class AA
  - Excellent structural and ballistic properties
  - Excellent ageing characteristics (18 years predicted)
  - Low sensitivity, passed all UN tests
- Technology based on 20 years experience with energetic polymers and novel oxidizers
  - GSTP 1, WEAG and Euclid
- Recent Improvements obtained based on energetic plasticizers, neutral bonding agents and readily available oxidizers
  - HMX and RDX instead of HNF, ADN and CL20

GAP/HNF

GAP/CL-20



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New Generation Minimum Smoke (no particles) Solid Rocket Propellant industrialized by Nammo

New 300 gallon Nato Class 1.1 mixer

GAP
(energetic binder)

RS-RDX or RS-HMX
(energetic filler)

BuNENA
(low sensitivity energetic plasticizer)

Additives

- Neutral Polymeric Bonding Agent → Improve structural properties
- Lead-free Burn Rate Modifier → Improve ballistic properties

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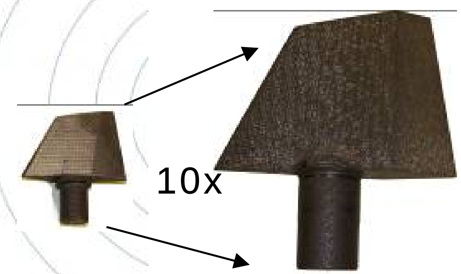
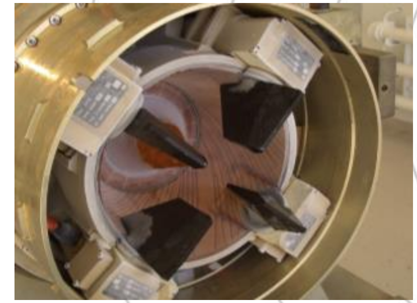
C-C/SiC Manufacturing Line

In-house manufacturing of critical components

- Ceramic Composites for rocket motors
  - Series production of Jet Vanes (>4000)
  - Development of new TVC concepts
  - Development of new nozzles concepts and low erosion nozzle inserts





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Conclusion

- Selecting low-particle content solid propellants for de-orbiting applications cannot be isolated from the motor design
- Sub-optimization can cost significant performance at system level
- Achieving low-particle emissions while maintaining performance depends on more parameters than the propellant alone:
  - Propellant constituents
  - Insulation design and materials
  - Ignition system
  - Environmental seal
  - Thrust Vectoring unit
- New propellants (and insulation materials) are ready to be introduced but need flight opportunities to demonstrate long term properties

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