Demisability analysis of materials properties for critical optical components in space applications

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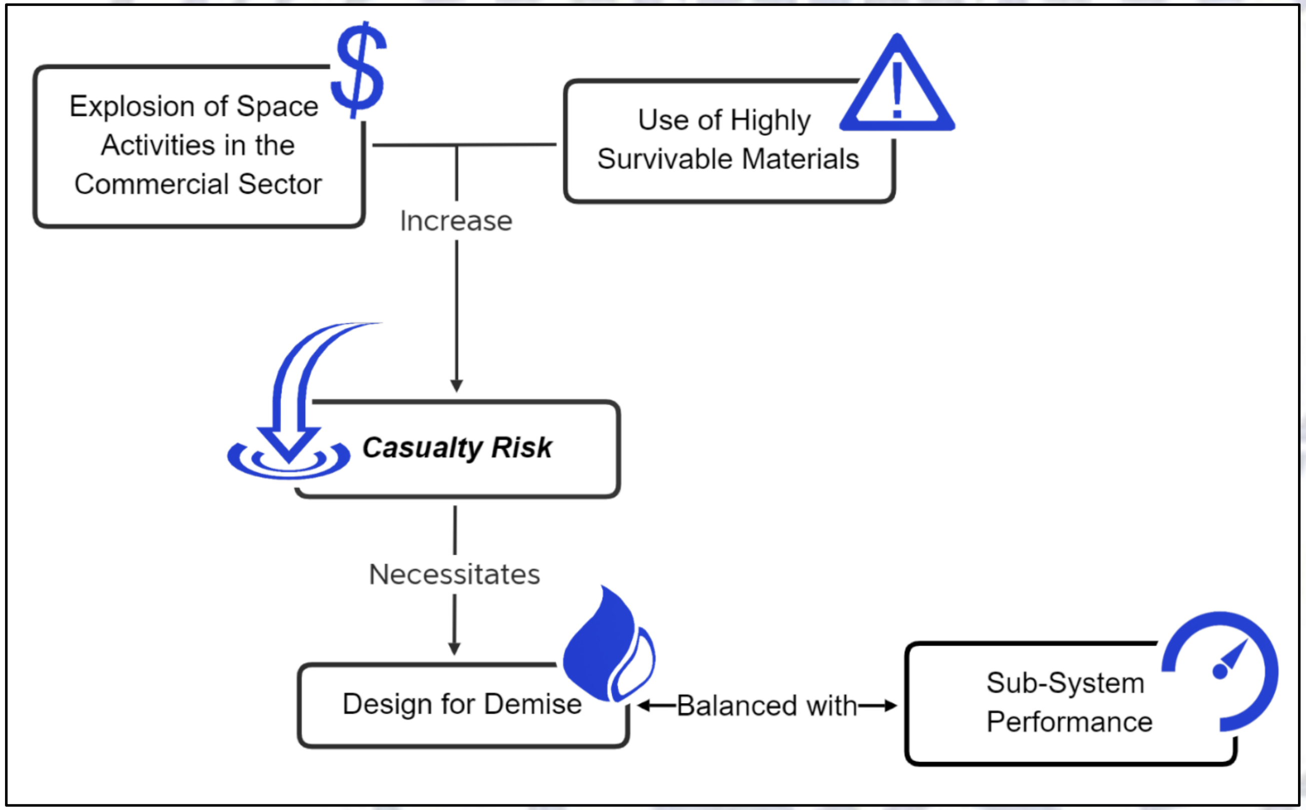
The problem of designing demisable components

The increasing menace of space debris, associated to the current explosion of the small satellite commercial sector, urges the implementation of effective strategies for debris mitigation.

Among these, the substitution of critical materials with more demisable ones represents one of the most effective actions in terms of improved ablation, but often the performance of the components is sacrificed.

How to concurrently evaluate demisability and performance in terms of materials selection?



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Objective functions

One way to address this problem is by defining the metrics we want to maximize/minimize, and expressing them as a function of materials properties.

In this study:

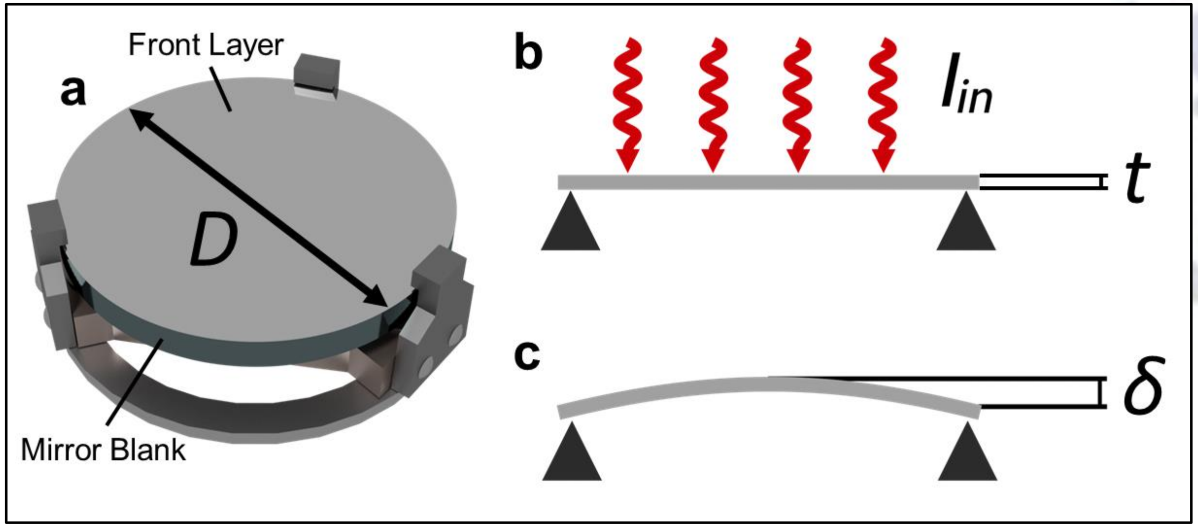
- Performance - Mass $m = \rho V$ → Dependant on geometry
- Demisability - Heat for ablation $\dot{q} = mc_p\dot{T} - \dot{m}h_m + \varepsilon\sigma A T^4$

The two are strictly interconnected!

Basic system and requirements

To identify the best materials, we need to apply a set of constraints related to the function of the component.

For example, in this analysis we consider a basic mirror blank and we impose mechanical and thermal stability.



ID	Description
C_{m1}	Maximum allowable deflection upon bending
C_{m2}	Maximum allowable deflection due to thermal expansion

From Constraints to Materials Indices

$$\delta_{mec} = \frac{3(1-\nu^2)g\rho D^4}{16Et^2} < \delta^*_{mec} \longrightarrow M_{m1} = \left(\frac{1-\nu^2}{E}\right)^{\frac{1}{2}} \rho^{\frac{3}{2}} \qquad M_{a1} = \left(\frac{1-\nu^2}{E}\right)^{\frac{1}{2}} \rho^{\frac{3}{2}}(c_p T_m + h_m)$$

$$\delta_{th} = \sqrt{\frac{\alpha_{th}}{2\pi c_p \rho t}} < \delta^*_{th} \longrightarrow M_{m2} = \frac{\alpha_{th}}{c_p} \qquad M_{a2} = \frac{\alpha_{th}}{c_p}(c_p T_m + h_m)$$

These are defined by mission requirements. We don't need to specify them now as we are performing a general analysis.

Materials indices related to performance

Materials indices related to demisability

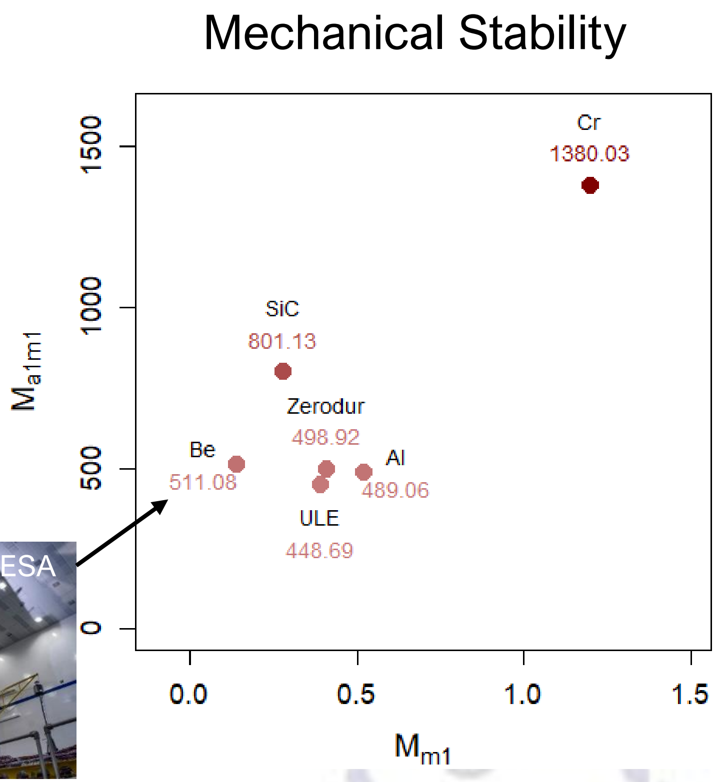
Each constraint determines the minimum thickness, *t*, that the component should have to comply with the requirement.

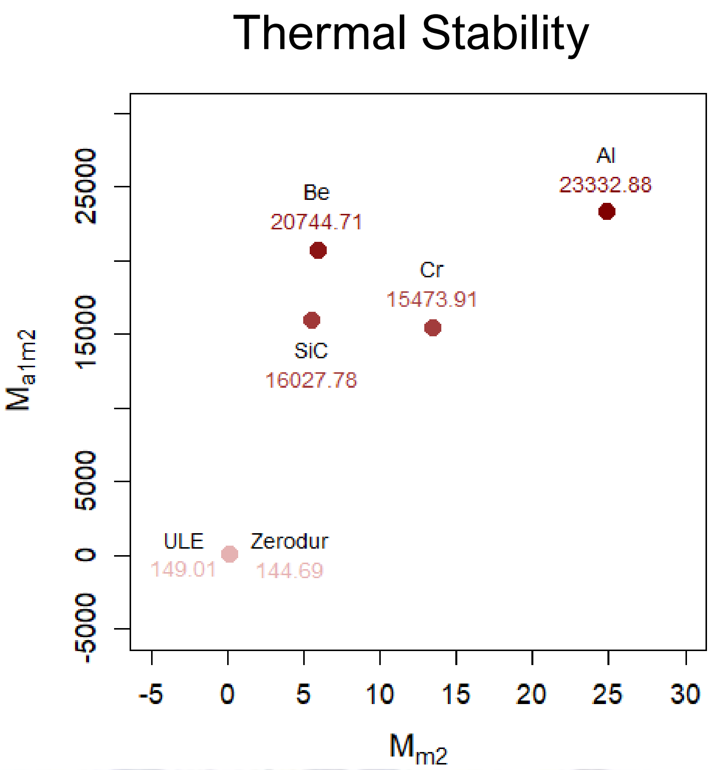
The thickness is substituted inside the objective functions (see slide 3) and, from them, materials properties are isolated (Materials Indices).

Materials Indices represent criteria of excellence, i.e. they allow us to identify the best materials that minimize the mass and the required heat for ablation of the component.

Results - Mirror

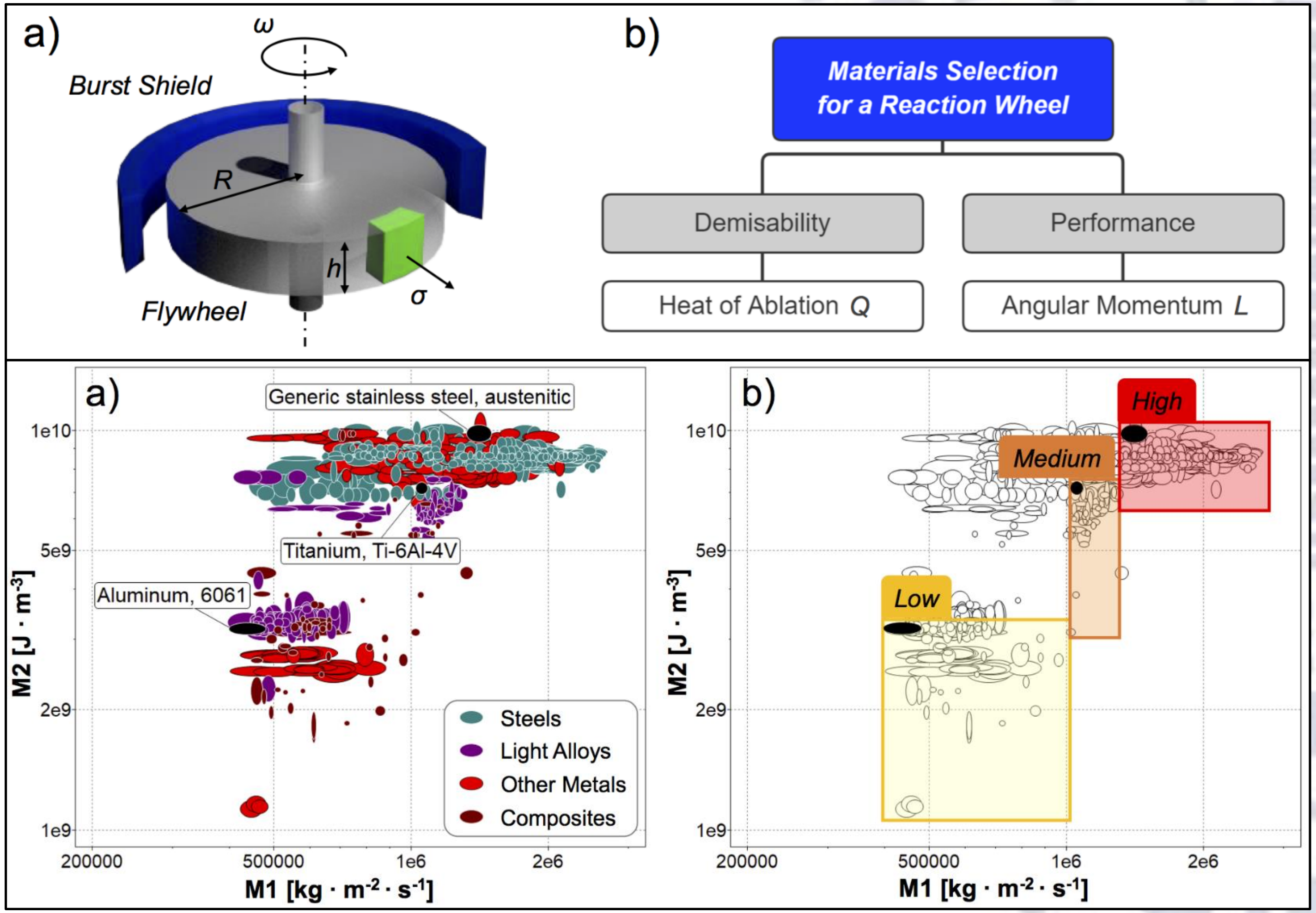
Material	Mm1	Mm2	Ma1m1	Ma1m2
ULE	0.39	0.13	4.49E+02	1.49E+02
Zerodur	0.41	0.12	4.99E+02	1.45E+02
Aluminium	0.52	24.87	4.89E+02	2.33E+04
Beryllium	0.14	5.88	5.11E+02	2.07E+04
SiC	0.28	5.56	8.01E+02	1.60E+04
Silver	3.61	83.76	1.19E+03	2.76E+04
Chromium	1.20	13.45	1.38E+03	1.55E+04
Gold	8.77	112.50	1.77E+03	2.28E+04
Generic Steel	1.48	38.10	1.17E+03	3.02E+04





Low thermal expansion and stiff materials guarantee high dimensional stability and, therefore, are the best candidates of the selection.

Examples – reaction wheels



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Pros and Cons

Advantages:

- General approach - can be applied to every component/element
- Extremely flexible and scalable method (multitude of objective functions and constraints)
- Can be used in combination with computational tools (like DRAMA, for example) to refine the design of demisable components

Drawbacks:

- Reliability of materials data (importance of experimental characterisation)
- Definition of demisability (alternative expressions of the heat for ablation, emissivity)

Conclusions

- It is possible to define and optimize, under a materials selection point of view, performance and demisability (concurrently).
- The methodology provides consistent results with the state-of-the-art solutions.
- Each selection has to be performed by a case-by-case analysis (high-value missions by space agencies and private commercial satellites may require different solutions).
- The analysis is highly data-sensitive.
- Valuable asset for the quantification of the potential impact (in terms of performance loss) and for supporting the effective implementation of D4D solutions.

Thank you

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