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Minimizing risk of reentry harm from titanium and its ilk

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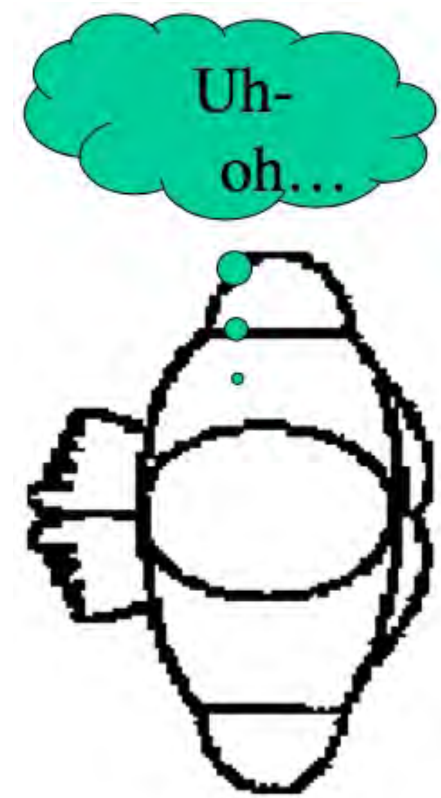
Presentation Outline

- The concern, the requirement
- Reentry scenario
- Achieving compliance: problems and (some) remedies

Public Safety Risk

- De-orbiting from low Earth orbit after end of mission is good;
- Needs to be done while minimizing harm to people.
- **There are rules…**



NASA/ODPO person

UNCOPUOS

United Nations Space Debris Mitigation Guidelines of the Committee On the Peaceful Uses of Outer Space

"…due consideration should be given to ensuring that debris that survives to reach the surface of the Earth does not pose an undue risk to people or property…"

IADC

IADC Space Debris Mitigation Guidelines (2007)

"If a spacecraft or orbital stage is to be disposed of by re-entry into the atmosphere, **debris that survives to reach the surface of the Earth should not pose an undue risk to people or property."**

United States Government

U.S. Government Orbital Debris Mitigation Standard Practices

"If a space structure is to be disposed of by reentry into the Earth's atmosphere, the risk of human casualty will be less than 1 in 10,000."

NASA

Process for Limiting Orbital Debris

(NASA-STD 8719.14Ach1)

"…limit the amount of debris that can survive reentry and pose a threat to people... For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 0.0001 (1:10,000)"

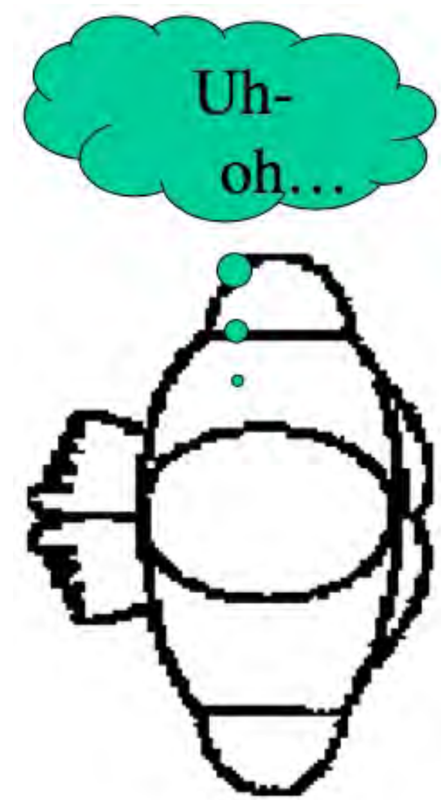
Public Safety Risk

Assessing the Risk

Requires a Debris Casualty Area analysis to determine number and size of reentering objects.

Risk is determined from:

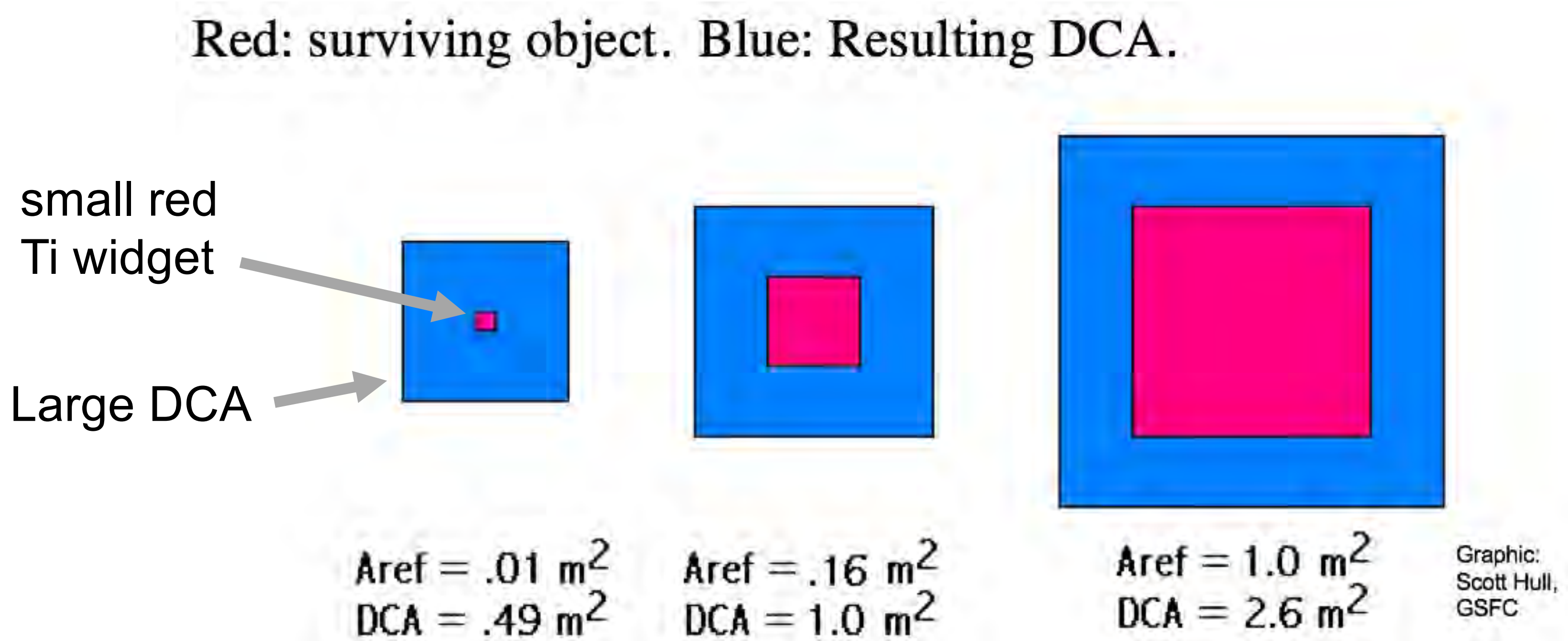
- Debris Casualty Area (DCA),
- Population density along orbit ground track.



NASA/ODPO person

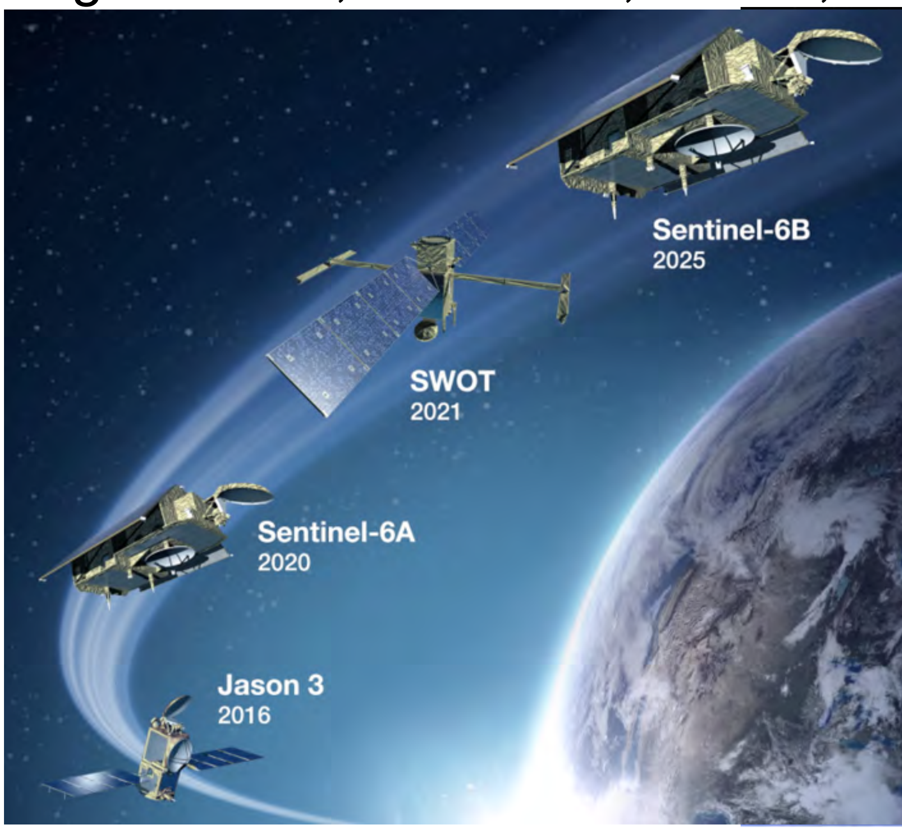
Public Safety Risk

DCA is the footprint of the surviving debris, with the dimensions of a person added to the dimensions of the object; so even a very small object will have a 0.5 m² DCA.



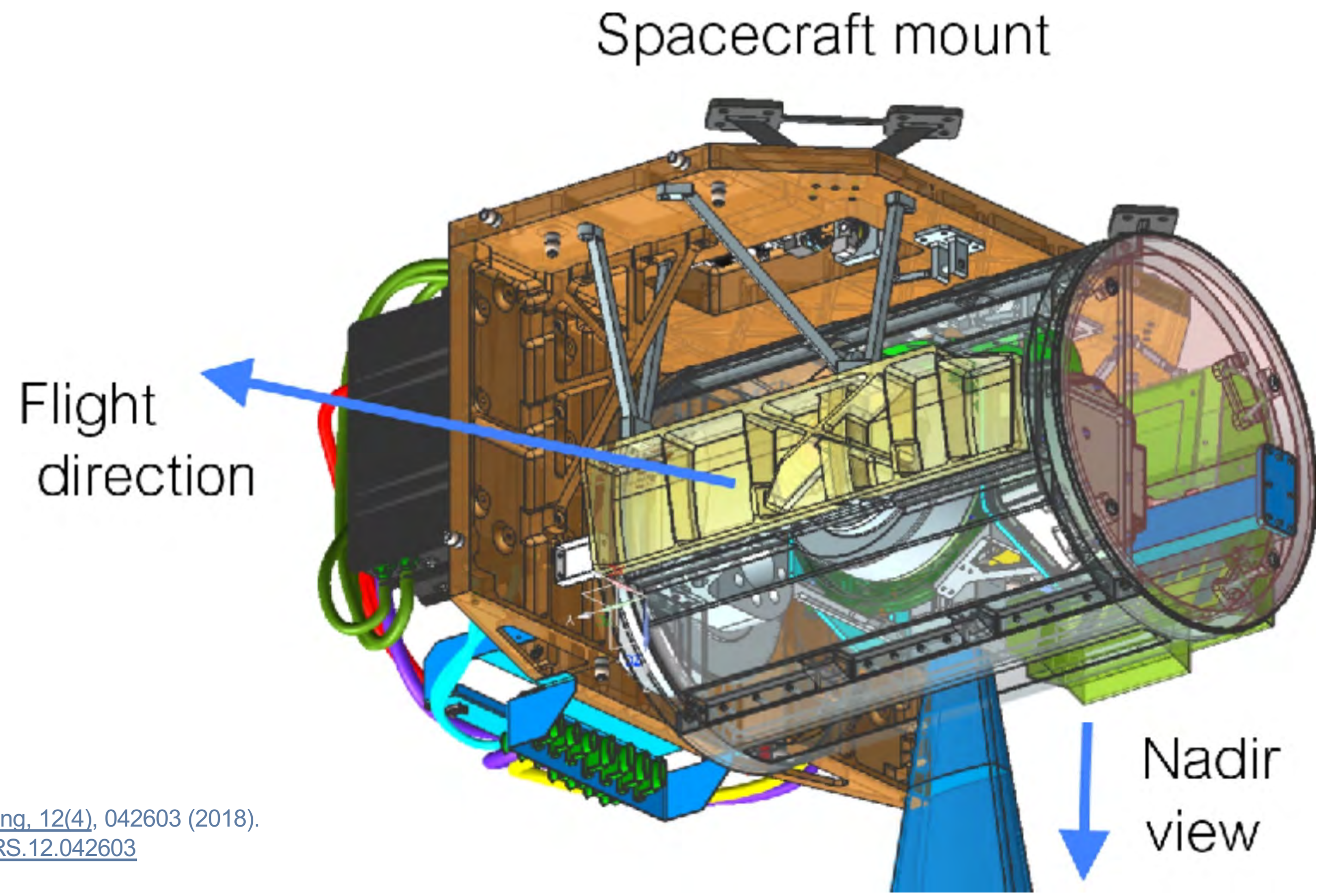
JPL and partners design and build science instruments

e.g. Jason 3, Sentinel-6, SWOT, NISAR, etc.



And titanium is used for flexures, thermal isolation, etc…

e.g. MAIA



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https://doi.org/10.1117/1.JRS.12.042603

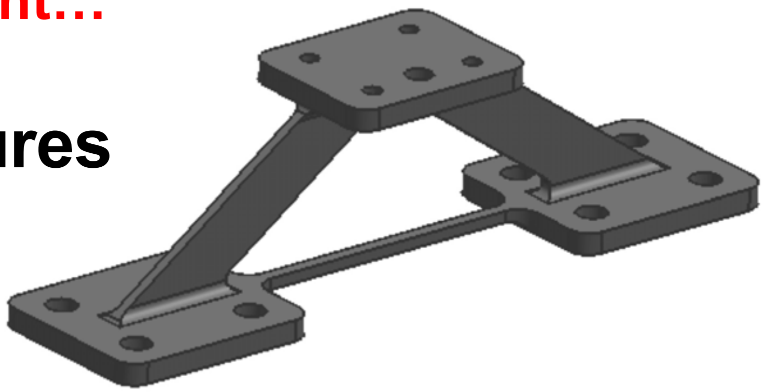
Design Challenges

Common Requirements in Instrument Design:

- High strength-to-mass ratio (*Y/m*)
- Control and compatibility of thermal expansion
  - Matching materials' Coefficient of Thermal Expansion (*CTE*)
  - Flex rather than break when CTE doesn't match
- Thermal isolation
  - Low thermal conductivity (κ)

Performance Requirements for Instruments

When aluminum and steel are not sufficient…

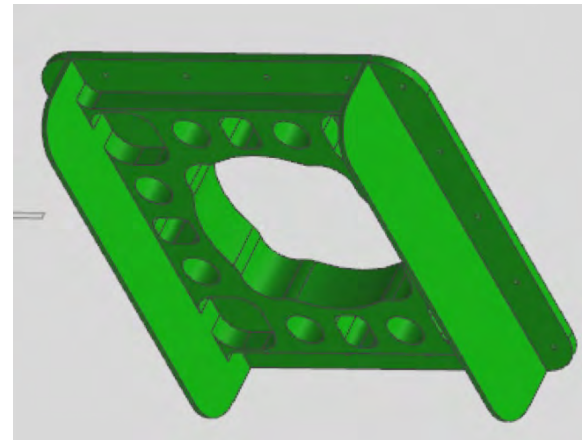


- **Mounting hardware such as flexures**
  - Strength and yield properties
    - Allows for flexing
    - Withstands launch vibrations
  - Thermal isolation (low thermal conductivity κ) for temperature control

Titanium meets these needs.

Performance Requirements for Instruments

When aluminum and steel are not sufficient…



- **Mounting hardware such as brackets**
    - Thermal isolation
    - Coefficient of Thermal Expansion (CTE) compatible with bonding to carbon-composite structure
    - Strength not critical

Titanium meets these needs.

Performance Requirements for Instruments

When aluminum and steel are not sufficient…

- **Very-Low-mass solution for low CTE**
  - Also high thermal conductivity
  - Also high strength and stiffness

Beryllium alloys meet this need.

Requirements for Controlling Hardware Center of Mass

When you WANT to add mass…

- **Ballast (or Balance Mass) material**
  - provide most mass in least volume

Tungsten alloys meet this need.

…but brass might suffice
(at double the volume).

The Down Side: enhanced tendency to survive reentry

Titanium and Tungsten:

- HIGH melting-point temperature.

Beryllium:

- HIGH heat capacity
- HIGH heat of fusion

  (heat needed to go from solid to liquid at the melting-point temperature)

Heating/Cooling Mechanisms

Reentry heating of object is determined by:

Heat absorbed by object

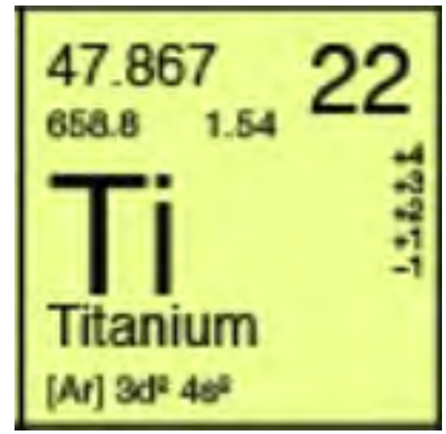
- Aerodynamic (frictional) heating
- Heating due to oxidation of surface

Heat radiated from object

- More pronounced at high temperature T:

$$\text{Radiated Energy} \sim T^4$$

Is it possible to avoid the use of titanium? Yes… in some cases.



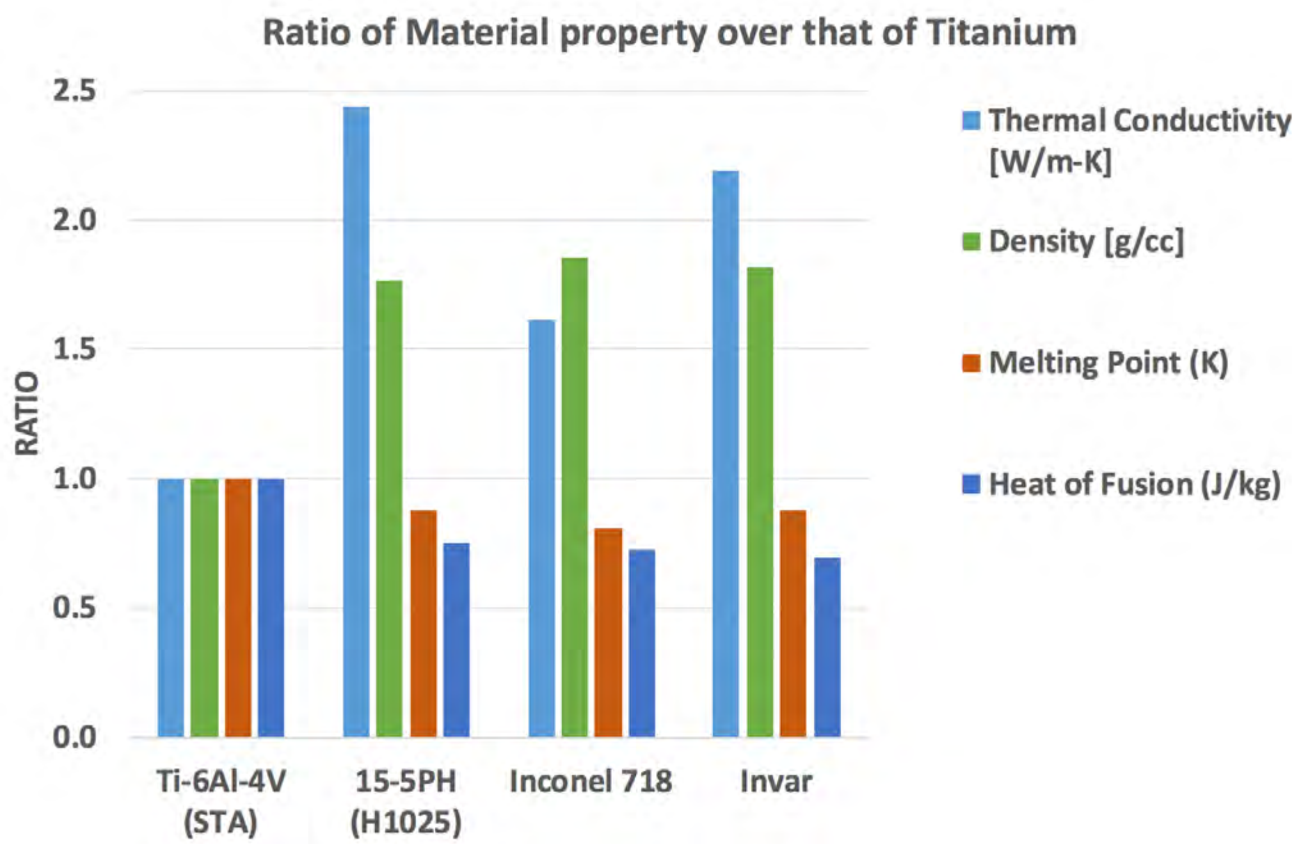
The important material parameters need to be identified, e.g.

- **Density**
- **Yield Strength**
- **Young’s Modulus**
- **CTE (coefficient of thermal expansion)**
- **Thermal conductivity**

Comparison of Material Properties

<u>Steel has Lower</u>
- Melt temp
- Heat of Fusion.

Are higher κ and ρ acceptable?

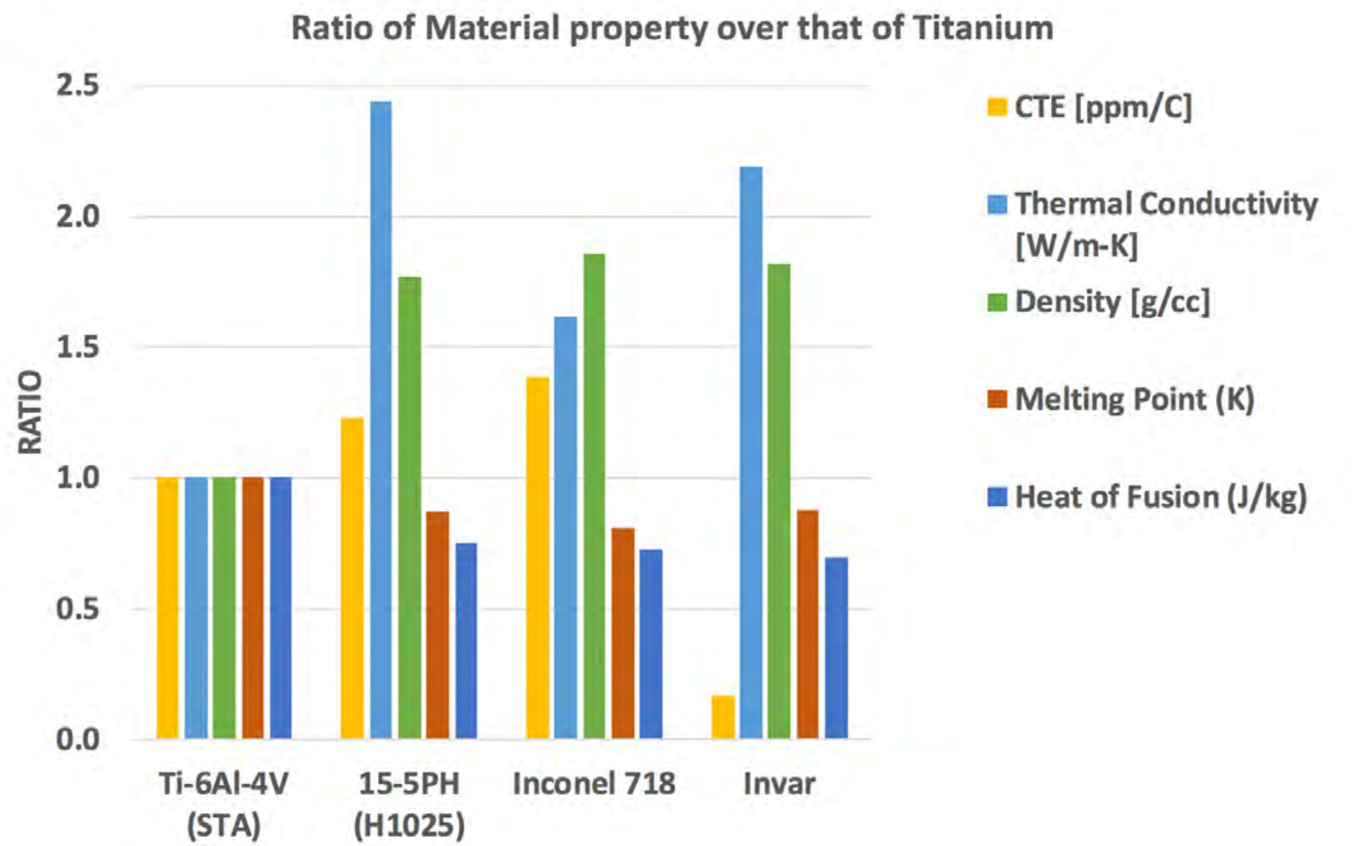


κ

ρ

Comparison of Material Properties

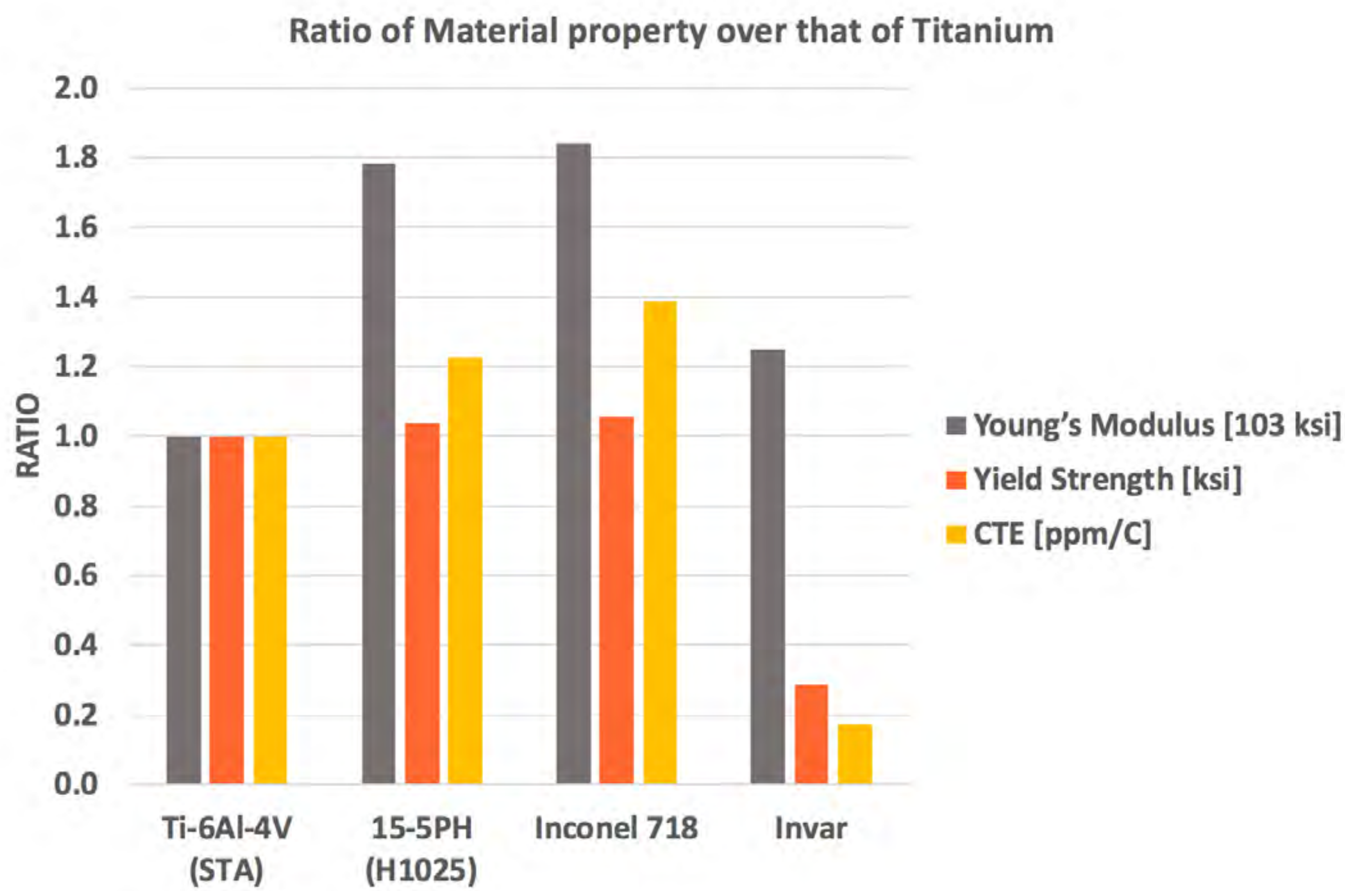
Steel CTE is larger than Ti (except for Invar)



Comparison of Material Properties

Invar strength is low;

Steels are stiffer than Ti (higher Young's Modulus)



Work-arounds

For Ti assemblies, use these tricks:

- For assemblies of Ti parts, bolt Ti parts together with Ti fasteners (and recess the fastener heads).

- Use Ti washers for thermal isolation

  (they will survive, but < 20g will impact with < 15 J)

Closing Remarks

Design Requirements can clash with Reentry Safety Requirements

- Optimal performance may not always be optimally safe
- Improved safety is traded against mass cost (replacing titanium and beryllium)
- Improved safety is traded against volume cost (replacing tungsten)
- Non-Ti solutions are sometimes possible.

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