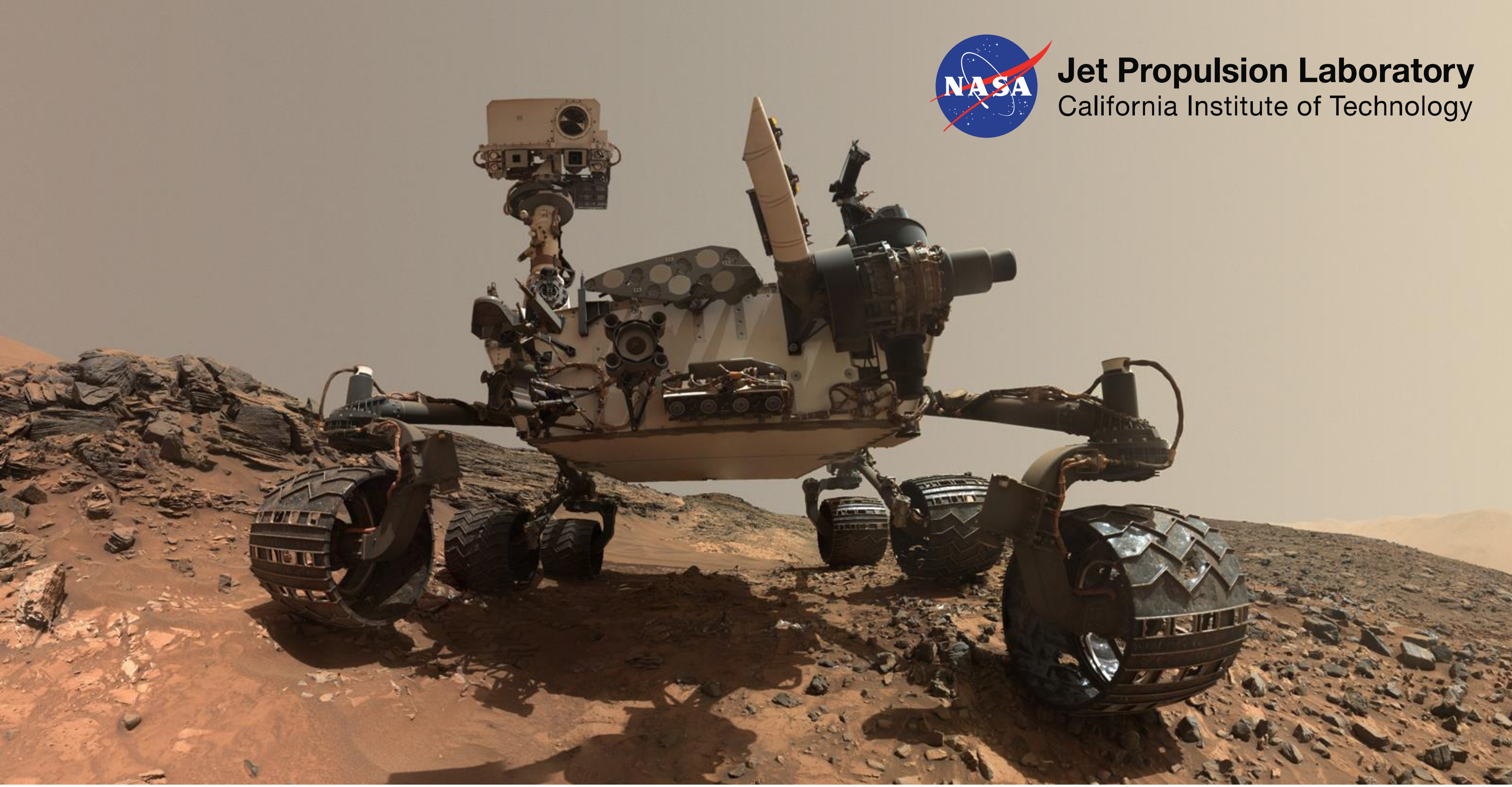

Multiphysics optical instrument design problem

A JPL design challenge

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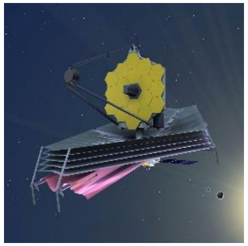
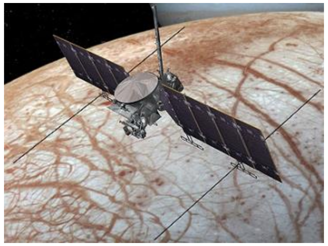
August 10th, 2020

Optical instruments are one of the most common instruments flown by JPL and NASA



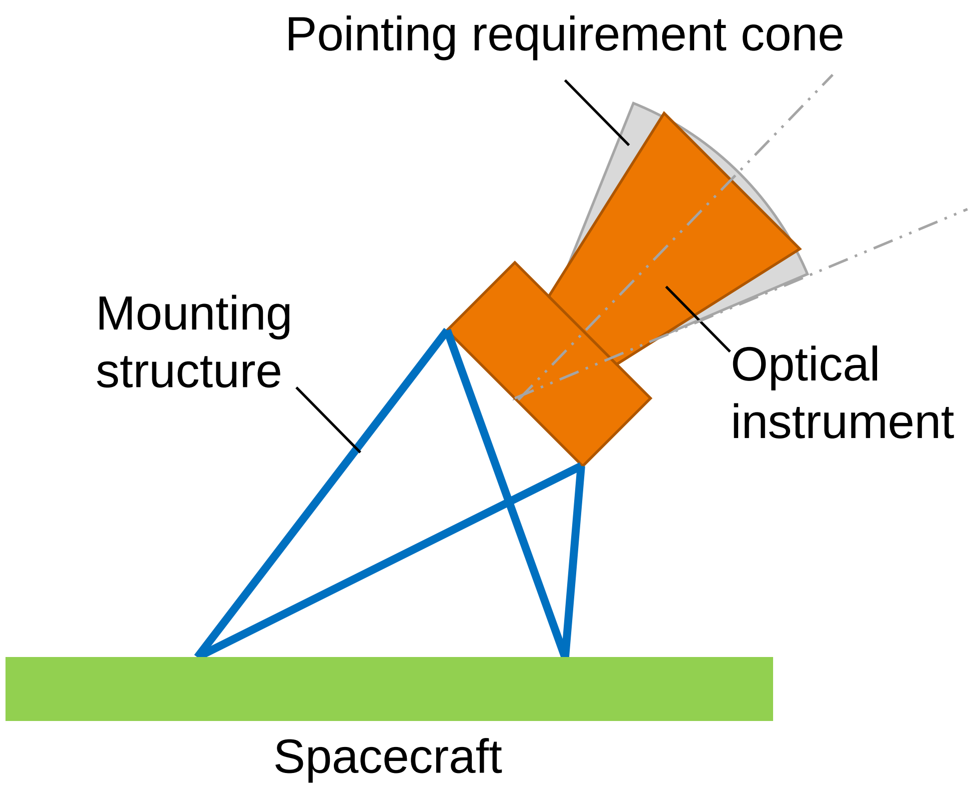

Telescopes
Ex: JWST, Hubble

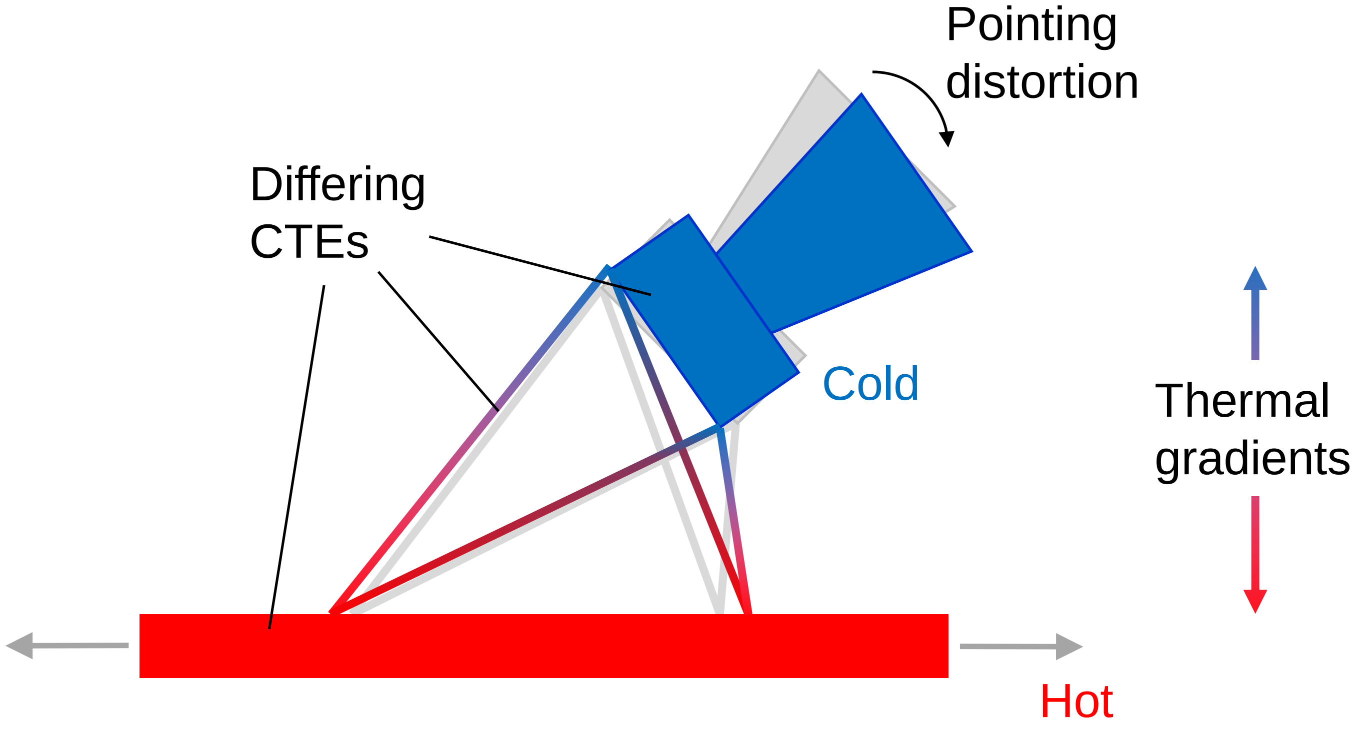
Spectrometers
Ex: Min-TES, MISE


Operational instruments
Ex: star trackers, cameras

To function properly, optical instruments have tight pointing requirements

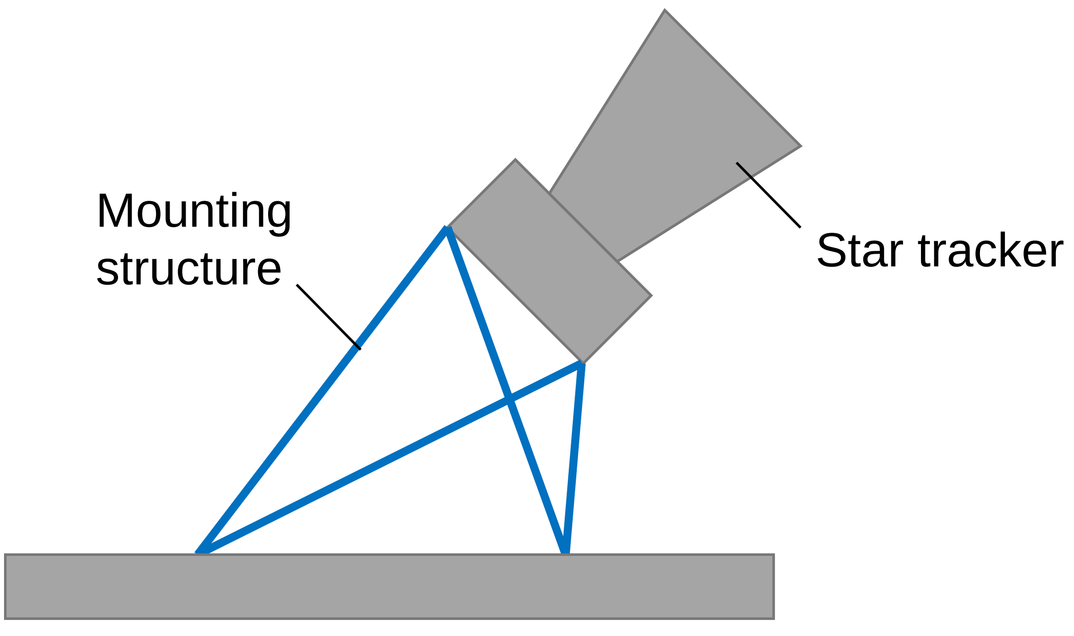


Pointing requirements are difficult to achieve due to extreme temperature conditions in space

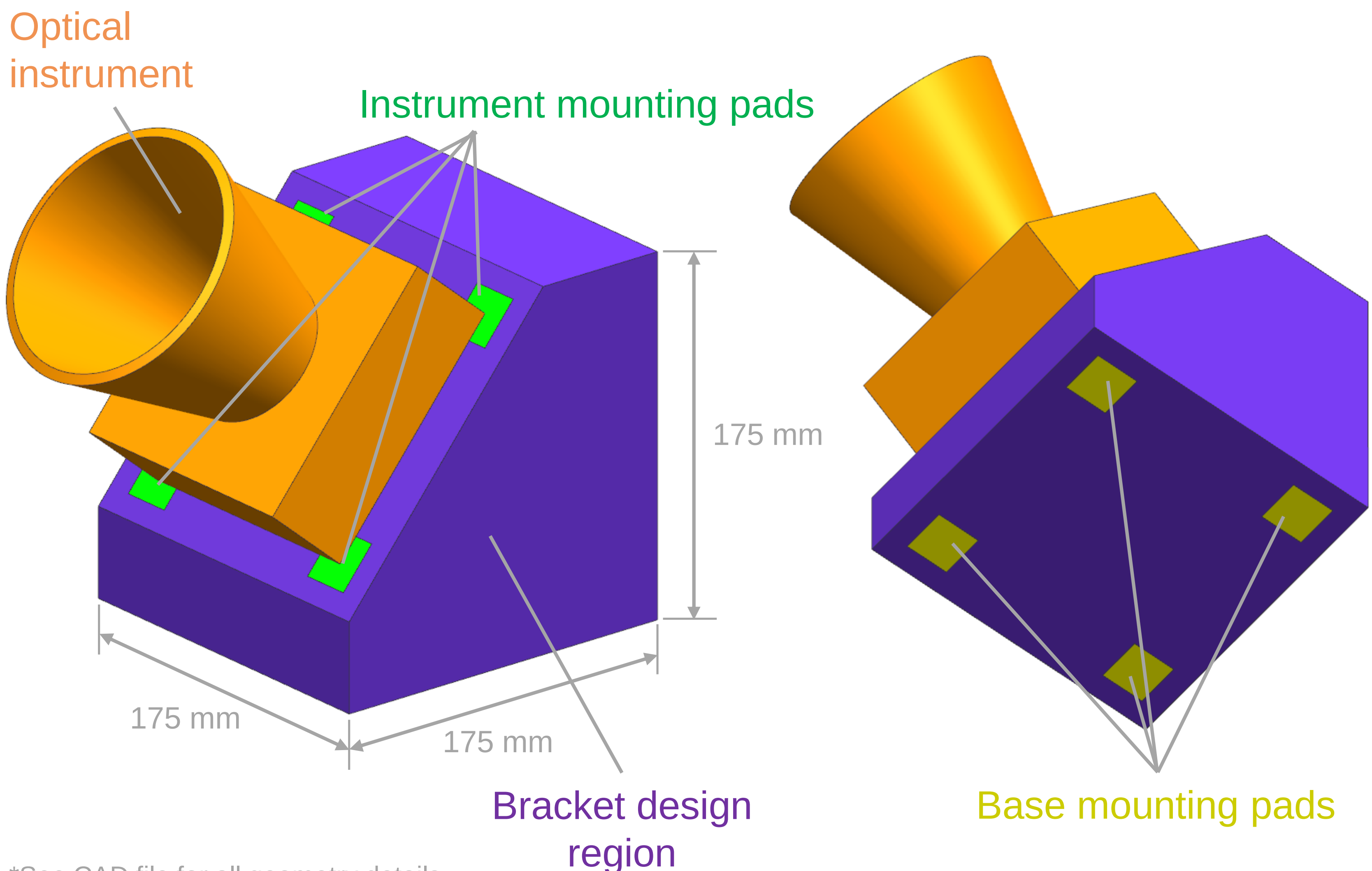


*CTE: Coefficient of Thermal Expansion

Objective is to design the mounting structure for a prototypical star tracker

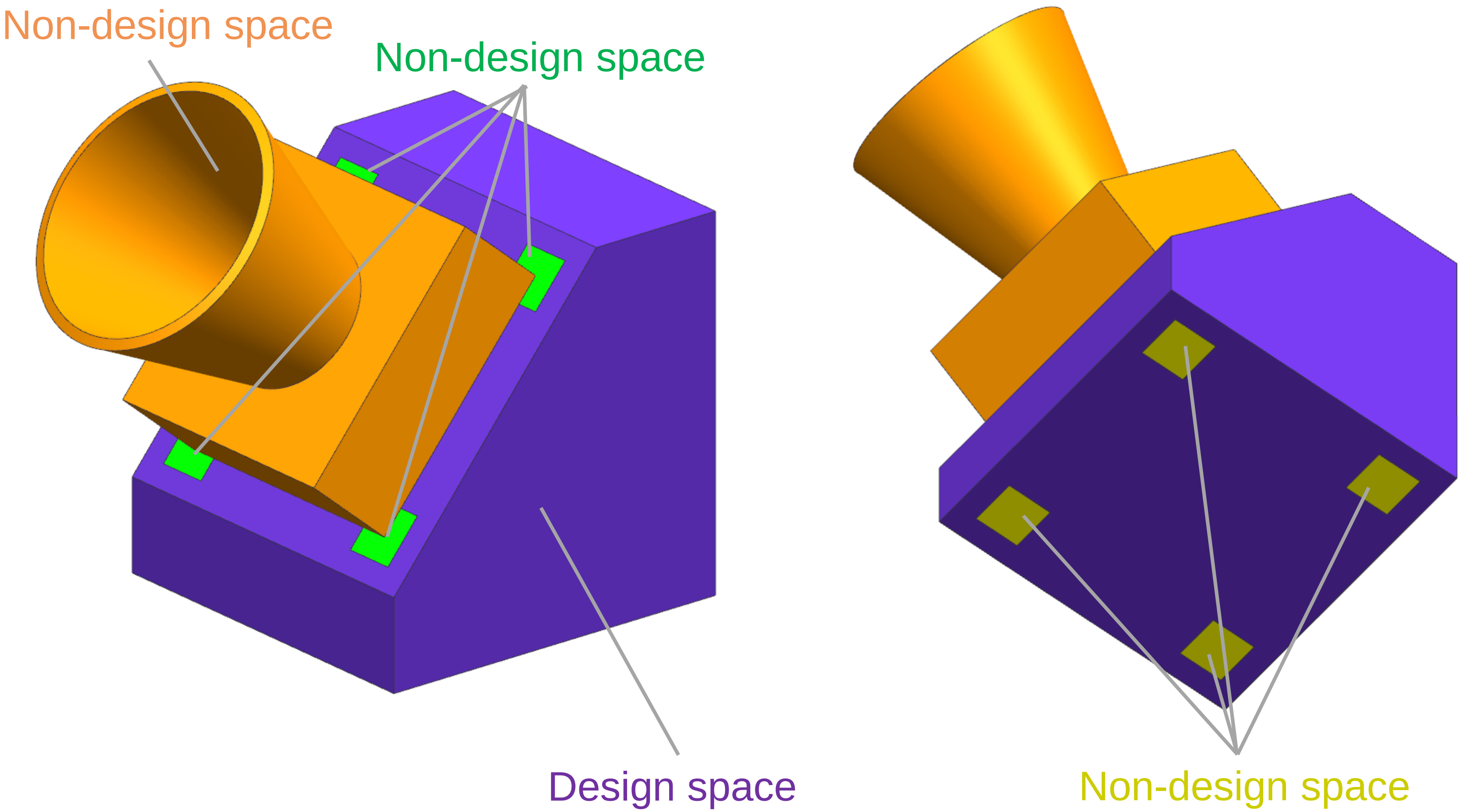


Geometric definition and relevant components

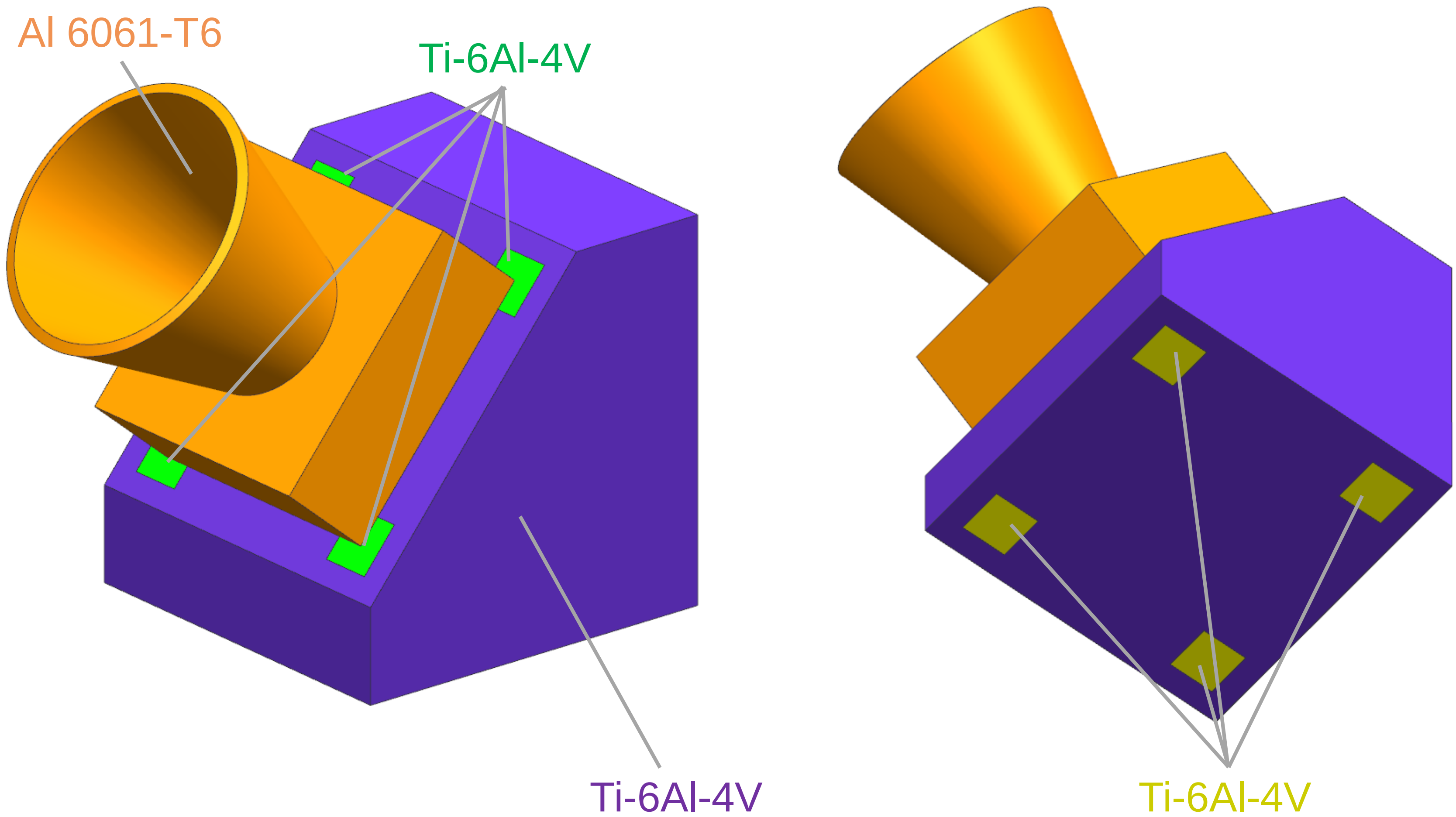


*See CAD file for all geometry details

Design and non-design space



Materials



Material properties

Ti 6Al-4V

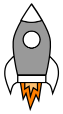
- E = 110 GPa (16 Msi)
- v = 0.31
- ρ = 4430 kg/m^3
- α = 8.8 ppm/°C
- κ = 6.9 W/(m °C)
- σ_y = 827 MPa (120 ksi)
- σ_u = 896 MPa (130 ksi)

Al 6061-T6

- E = 68 GPa (9.9 MSi)
- v = 0.33
- ρ = **9555*** kg/m^3
- α = 22.2 ppm/°C
- κ = 152.3 W/(m °C)

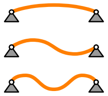
* This is not the true density of Al (which is 2700 kg/m^3). To achieve the appropriate instrument mass of 3 kg (without including concentrated masses), the material density has been scaled up.

Relevant load cases



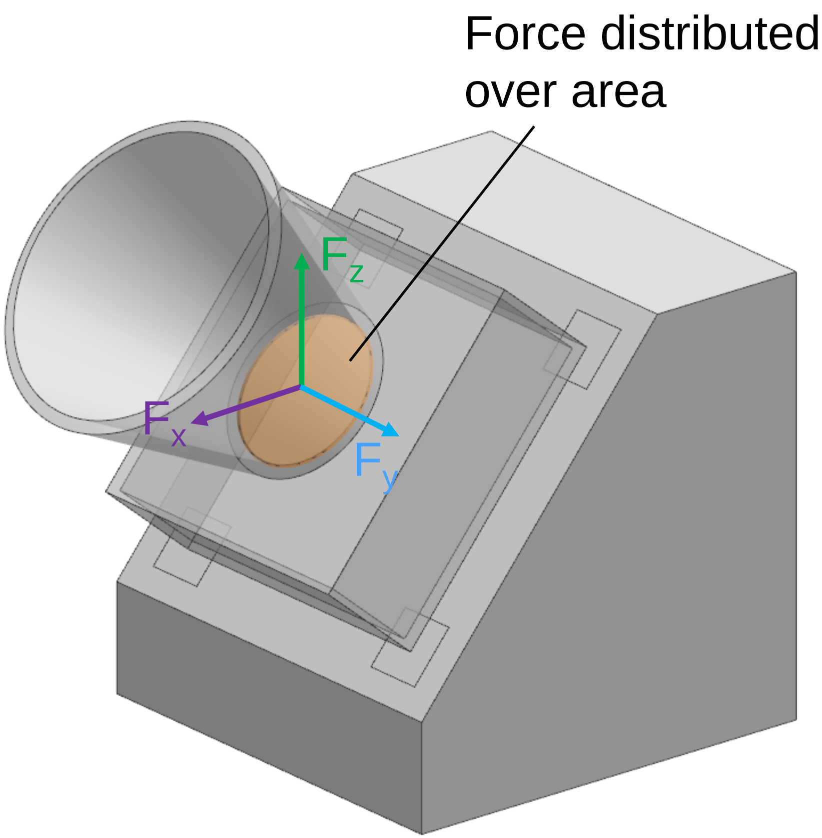
1. Launch: 3 sub cases
   - Boundary conditions: fixed base
   1. 2,000 N load in the x direction
   2. 2,000 N load in the y direction
   3. 2,000 N load in the z direction

2. Thermal: 3 sub cases
   - Boundary conditions: fixed base
   - Initial condition: uniform temperature of 20°C
   1. Thermoelastic bulk soak at 85°C
   2. Steady state (SS) heat conduction
   3. Thermoelastic deformation from SS heat conduction temperature field

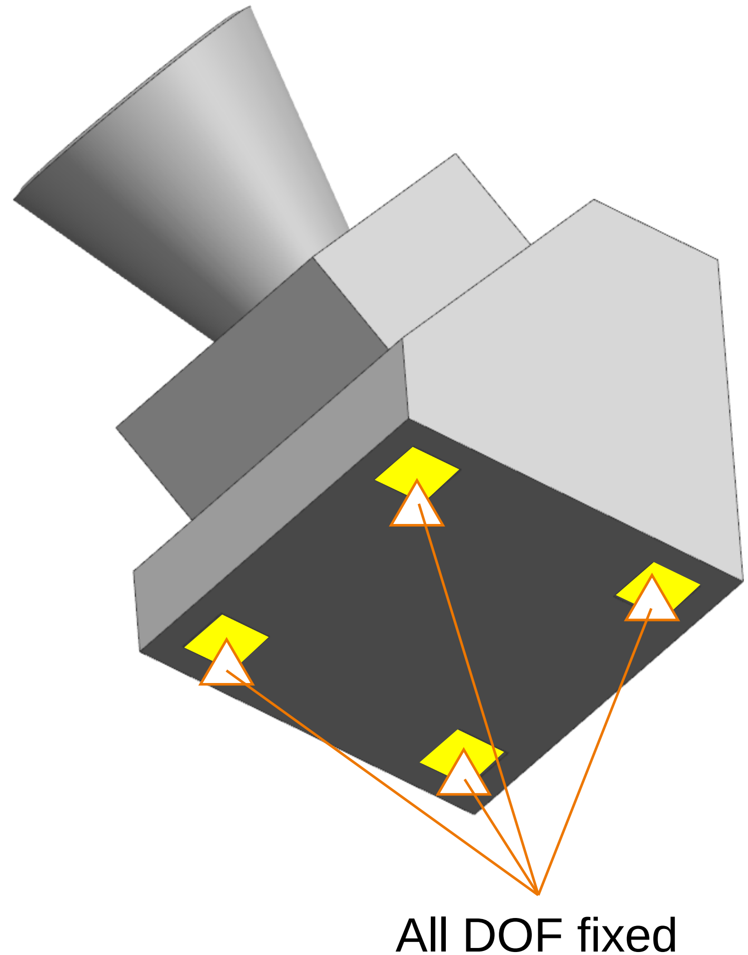


3. Normal modes
   - Boundary conditions: fixed base

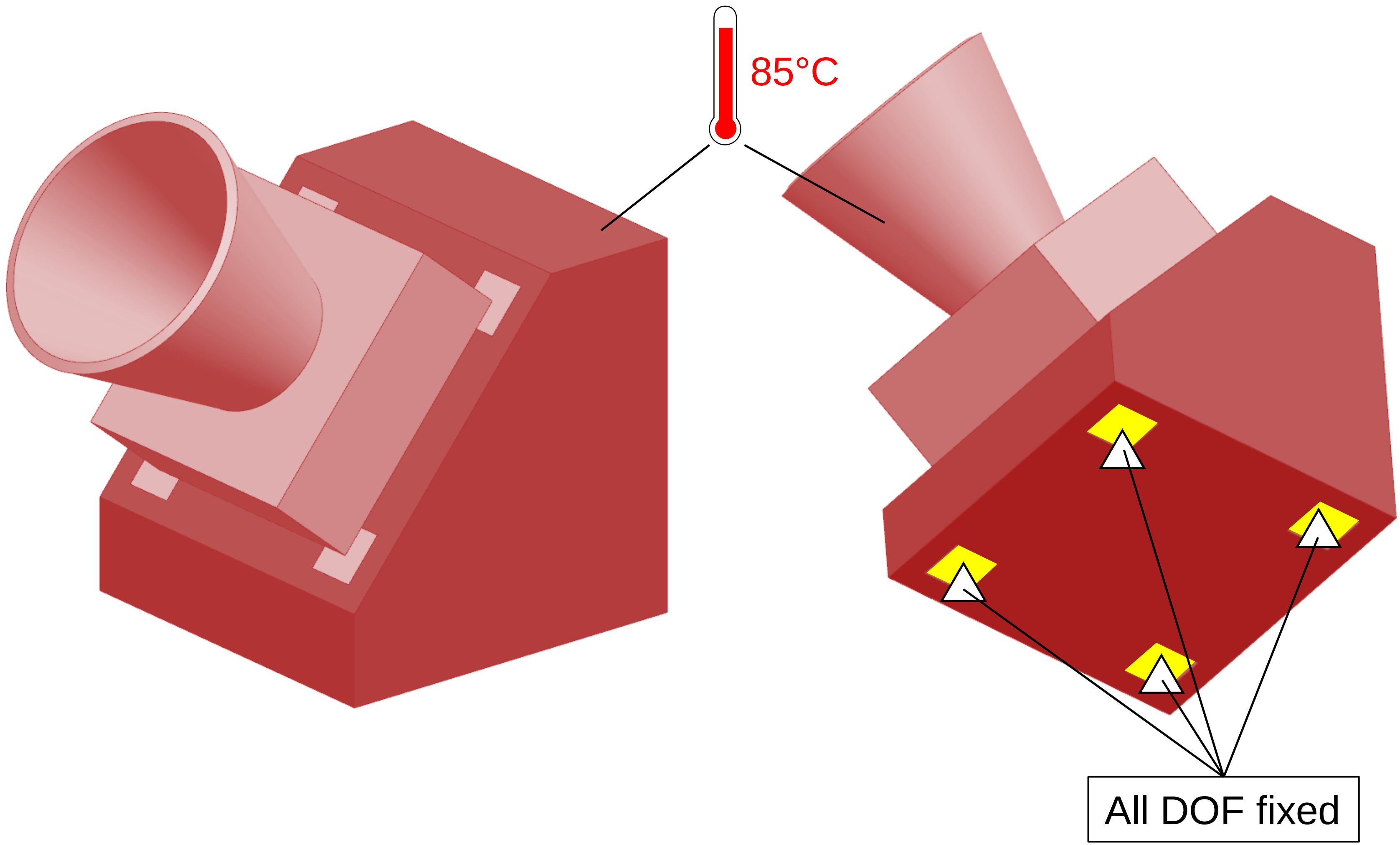
Load case 1.1-1.3: launch



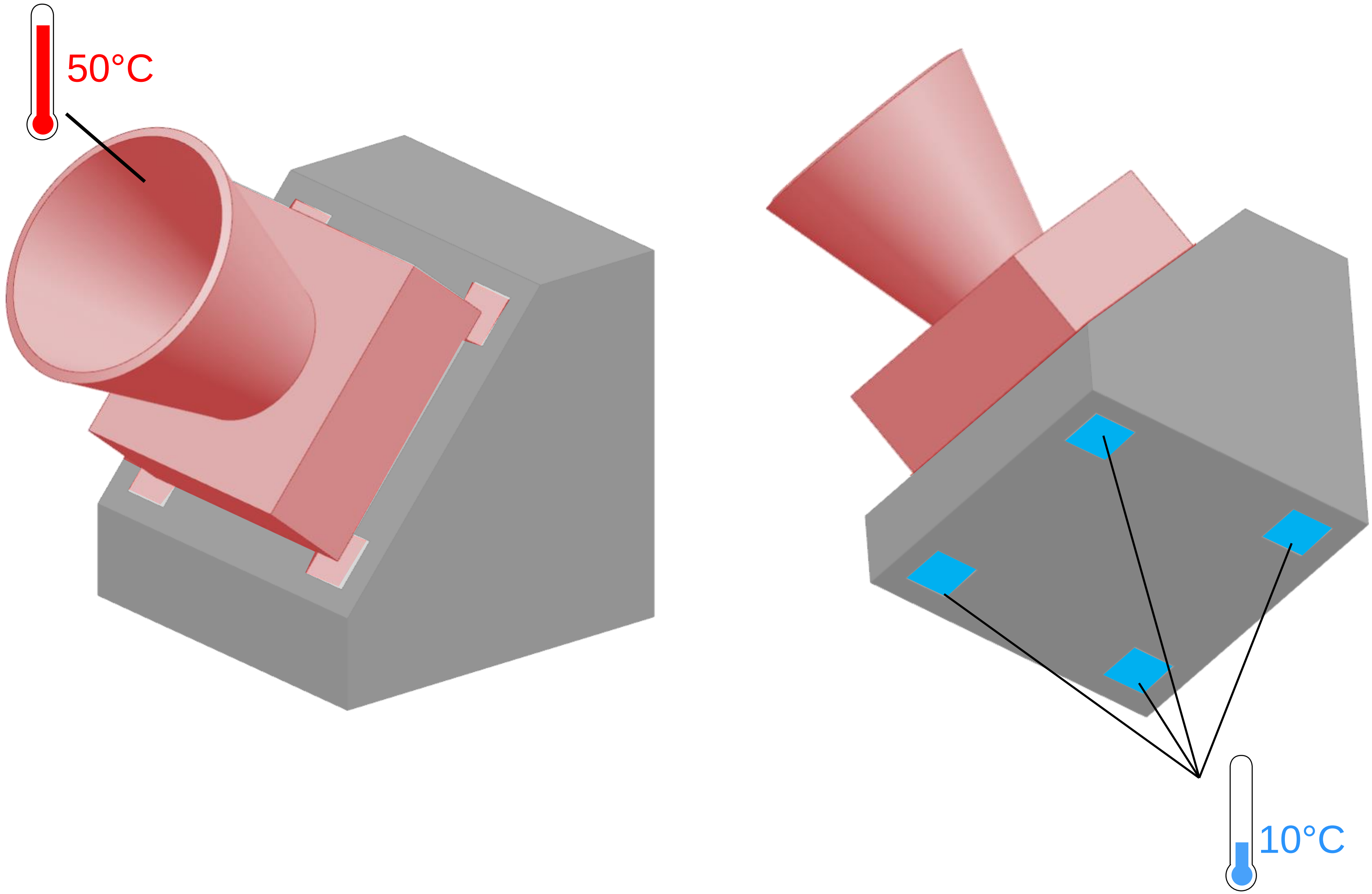
Subcase 1: F_x = 2,000 N
Subcase 2: F_y = 2,000 N
Subcase 3: F_z = 2,000 N



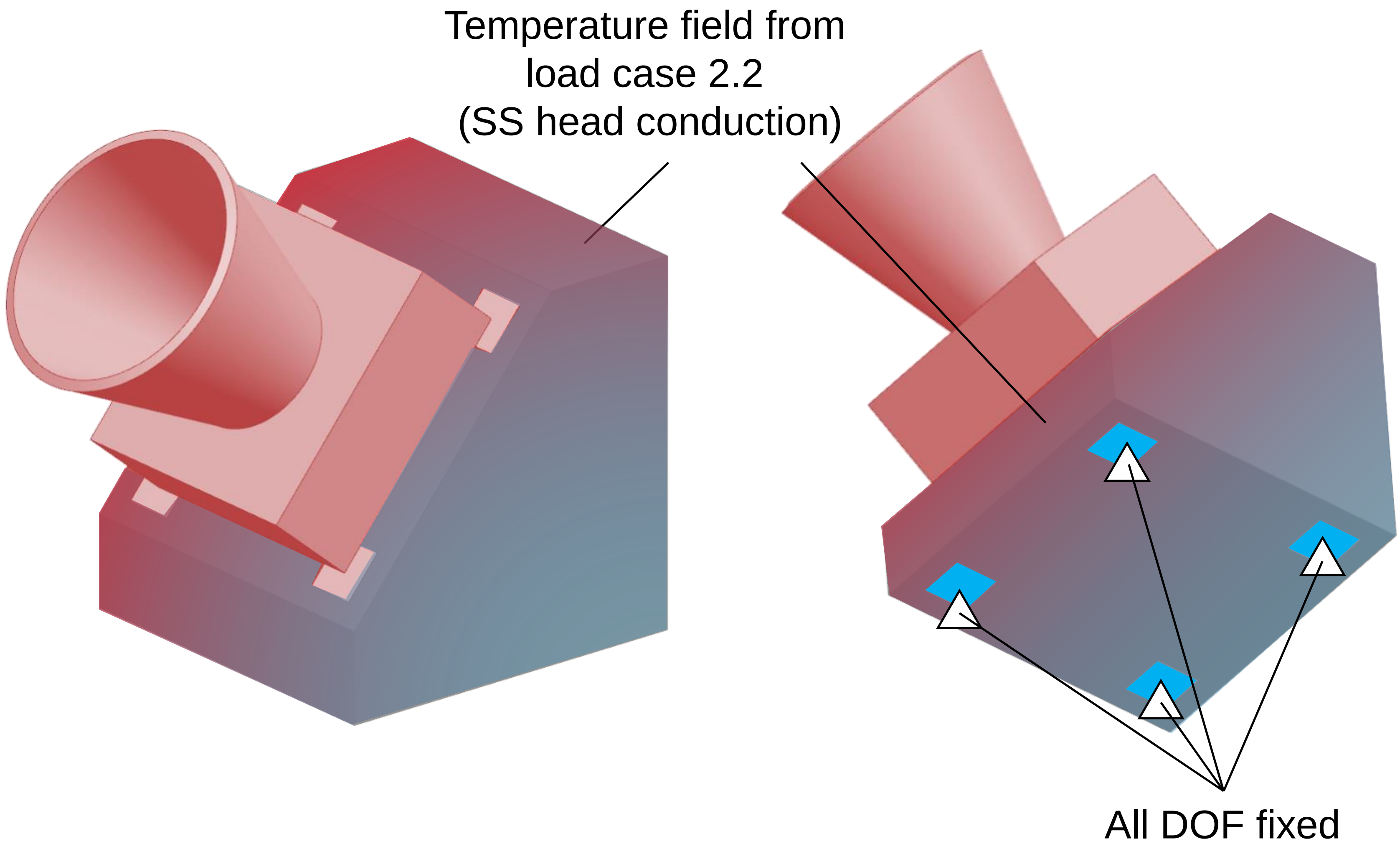
Load case 2.1: bulk temperature soak



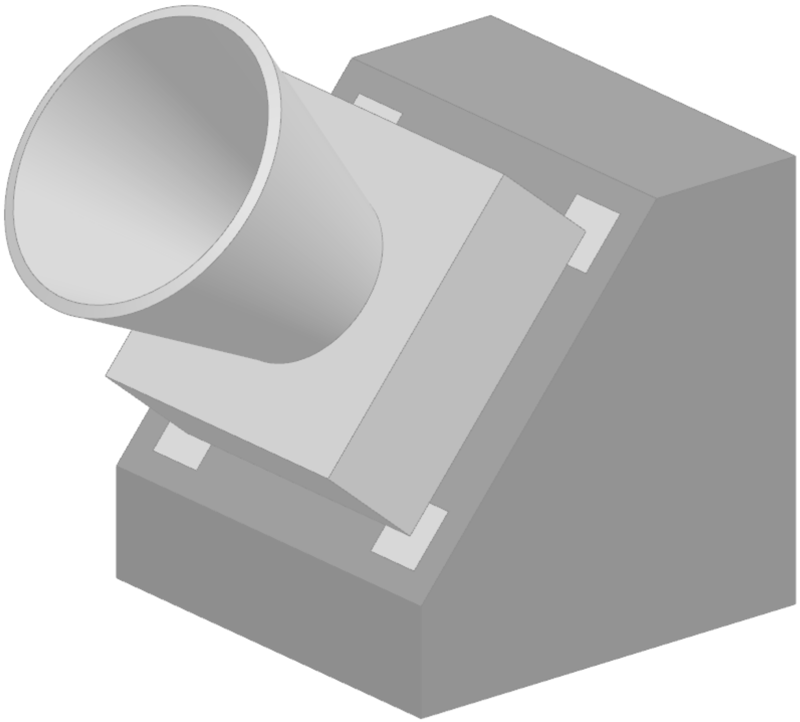
Load case 2.2: steady state heat conduction

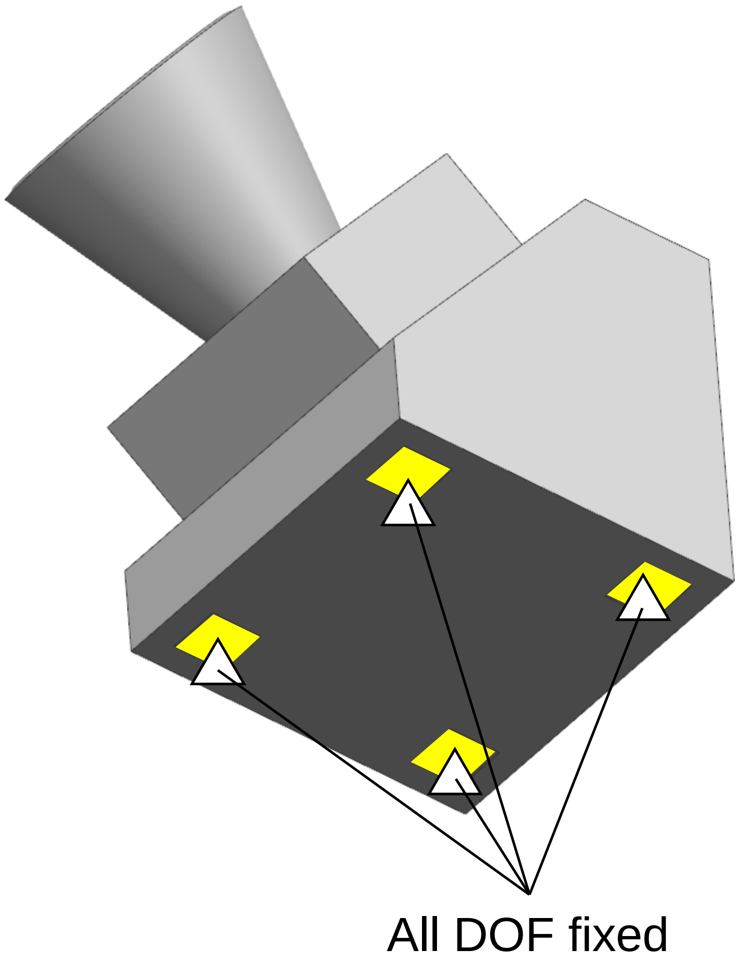


Load case 2.3: thermoelastic deformation from SS heat conduction temperature field



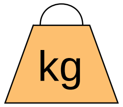
Load case 3: normal modes





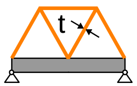
Design problem goal and requirements

Priority
- Must have
- Nice to have
- Extra credit



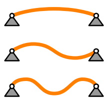
Goal: Minimize mass

Requirements



Minimum member size

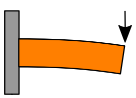
t > 1mm



Fundamental frequency

$\lambda > 200$ Hz

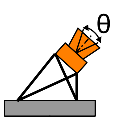
Load case: 3



Structure shall not yield

$1.25\ \sigma_{von\ mises} < \sigma_y$

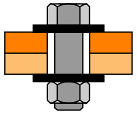
Load cases: 1.1-1.3, 2.1, 2.3



Minimal pointing deviation

$|\theta| < 0.001°$ (cone central axis best fit)

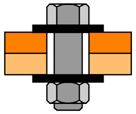
Load case: 2.3



Base interface shall not slip

$F_{shear} < 1{,}500$ N (each mounting pad)

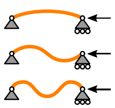
Load cases: 1.1-1.3, 2.1, 2.3



Instrument interface shall not slip

$F_{shear} < 1000$ N (each mounting pad)

Load cases: 1.1-1.3, 2.1, 2.3



Structure shall not buckle

$2\ p < p_{crit}$

Load cases: 1.1-1.3, 2.1, 2.3

Minimal heat loss through base interface

$\oiint_A q\ dA < 4$ W (over all base mounting pads)

Load case: 2.2

Communication of results

1. Bracket mass (excluding mounting pads)
2. Requirements compliance
3. Geometry file of design (CAD, STL, etc)
4. Basic manufacturing plan
5. List of relevant modeling assumption

Final notes

There are no stipulations on design methodology

Ex: Topology optimization can be used but isn't required

Design should be manufacturable

Manufacturing method is up to the designer

Cite problem definition as follows

Author: Ryan Watkins
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Institution: Jet Propulsion Laboratory

Date: August 2020