Development of a passive tuned mass damper for ultra-high vacuum beamline optics

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MEDSI Conference 2021

Diamond Light Source Ltd, Didcot, United Kingdom

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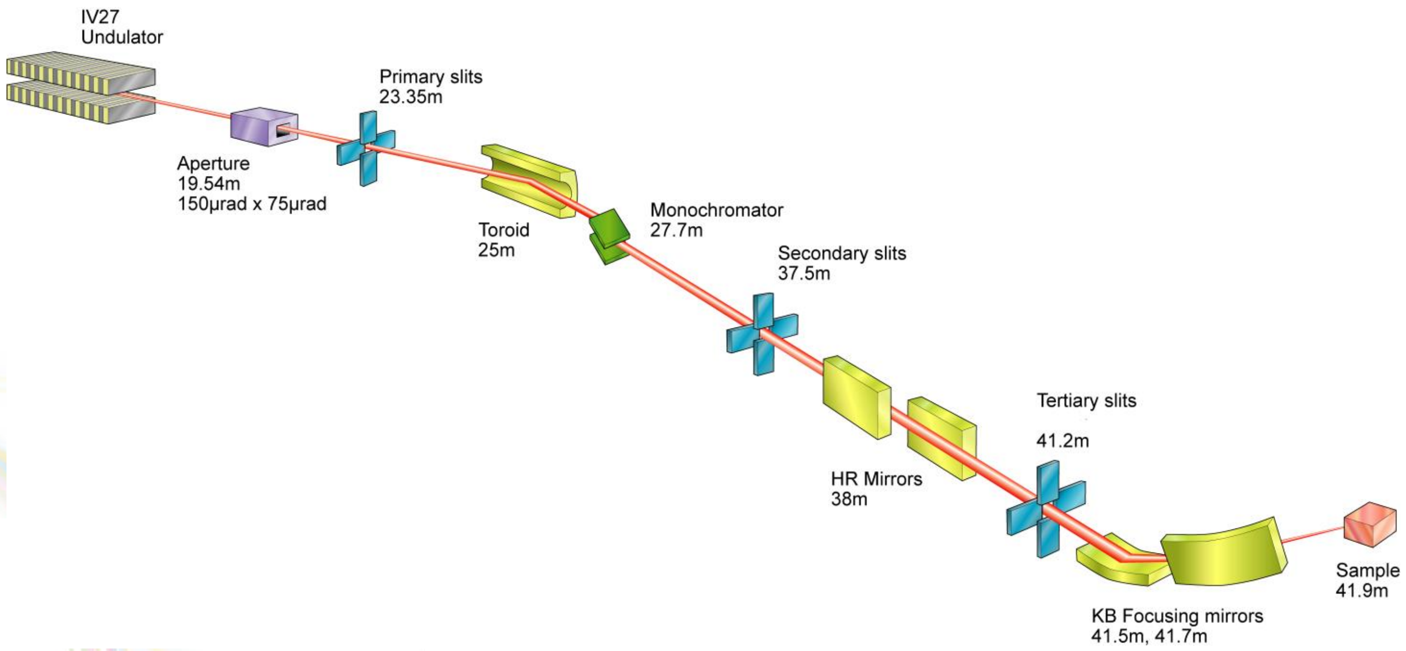
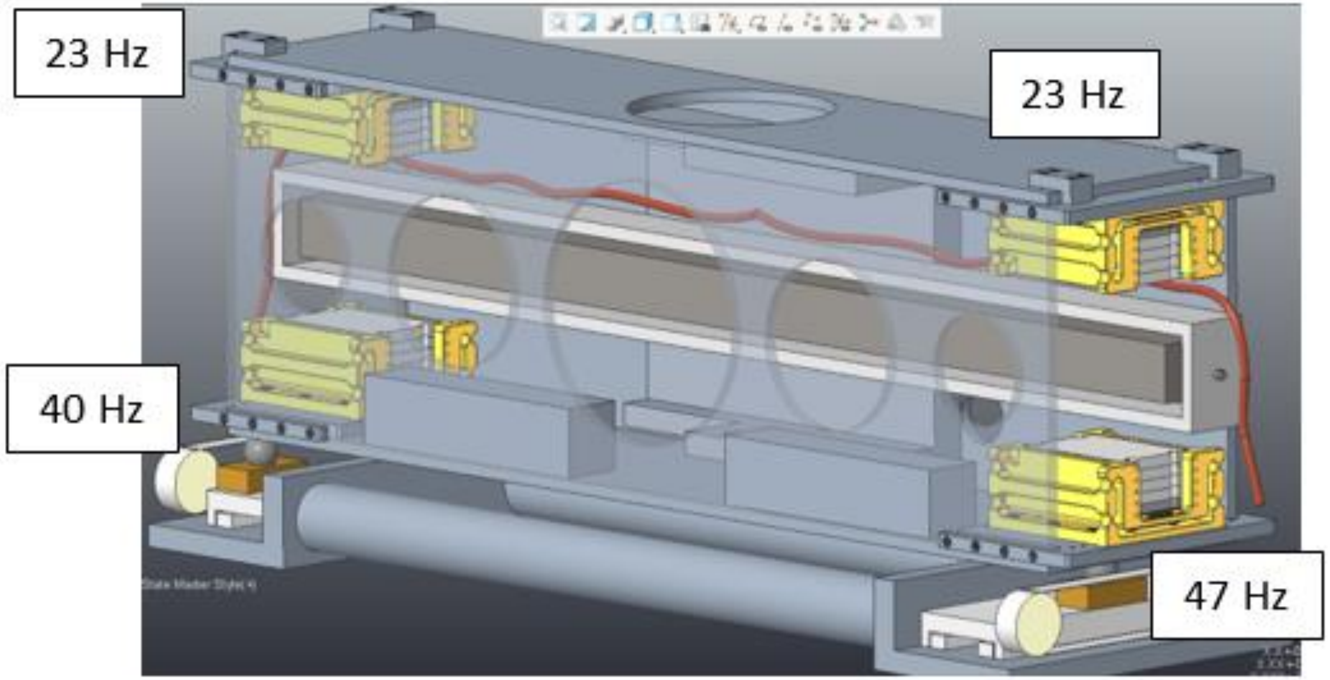
Motivation

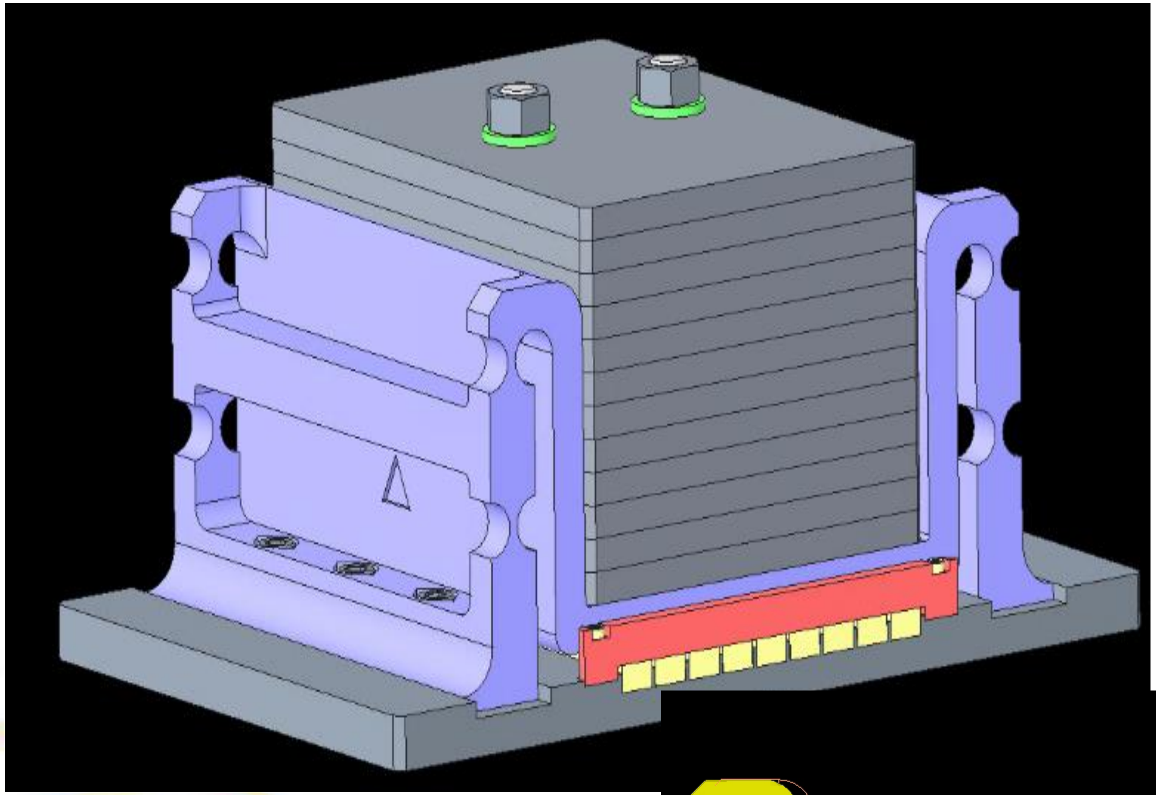
- Diamond-II next generation upgrade
- Precise beam positioning > better imaging at the sample > achieving valuable research!

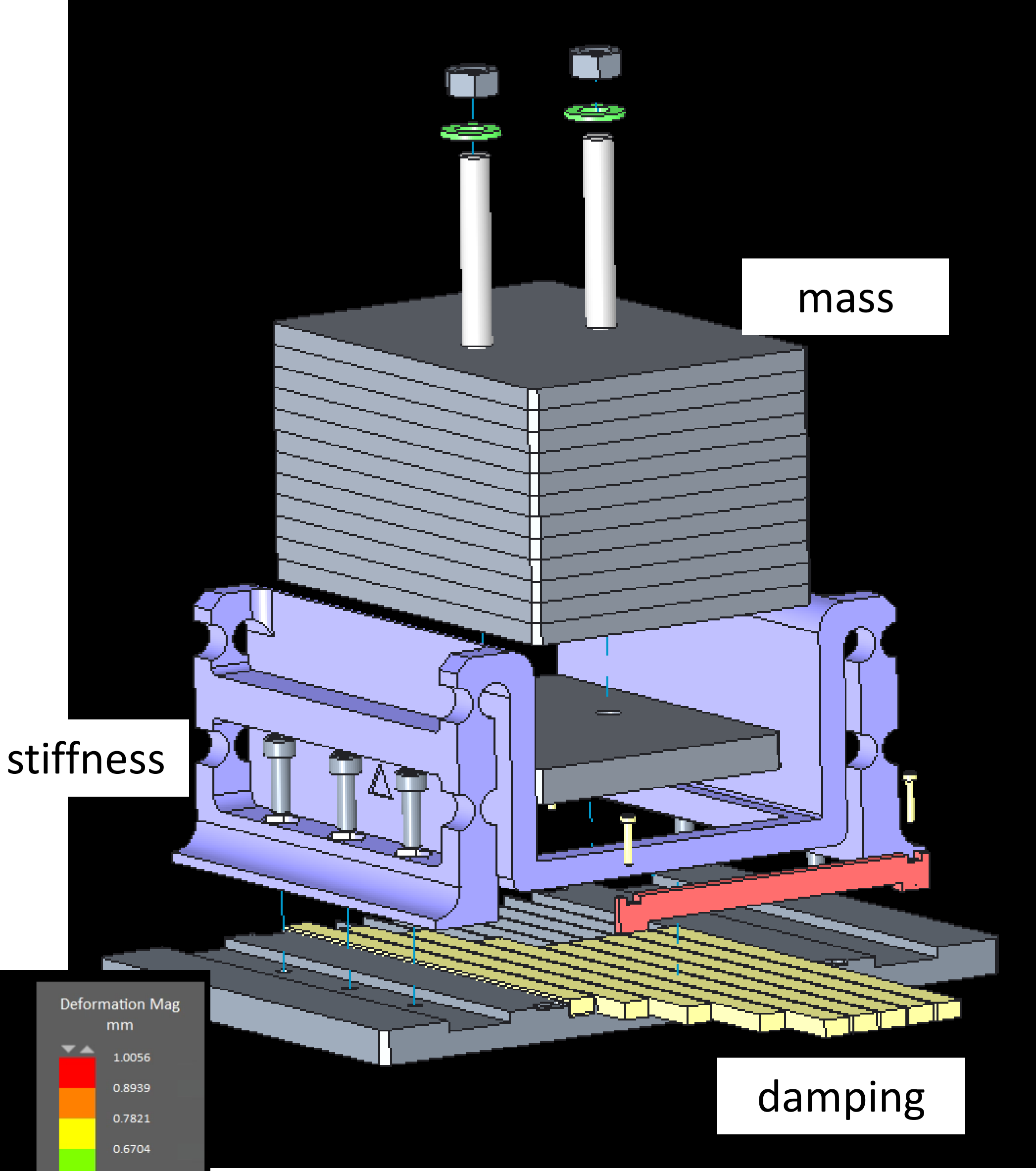


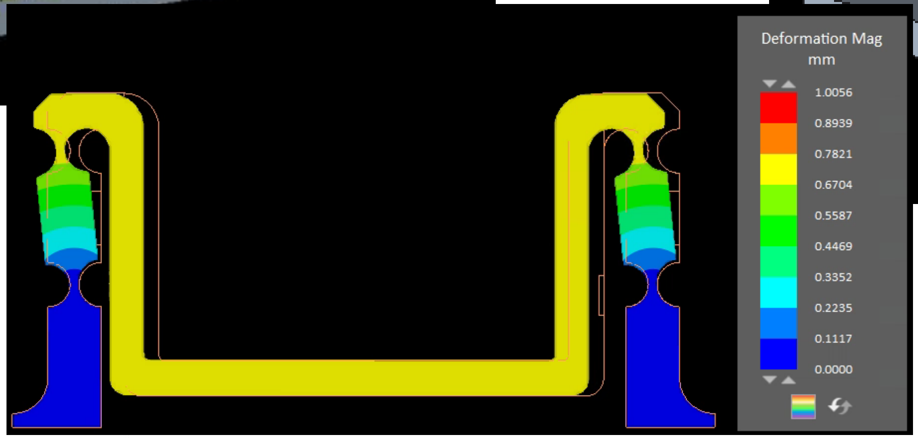
Horizontally Focussing Mirror (HFM)



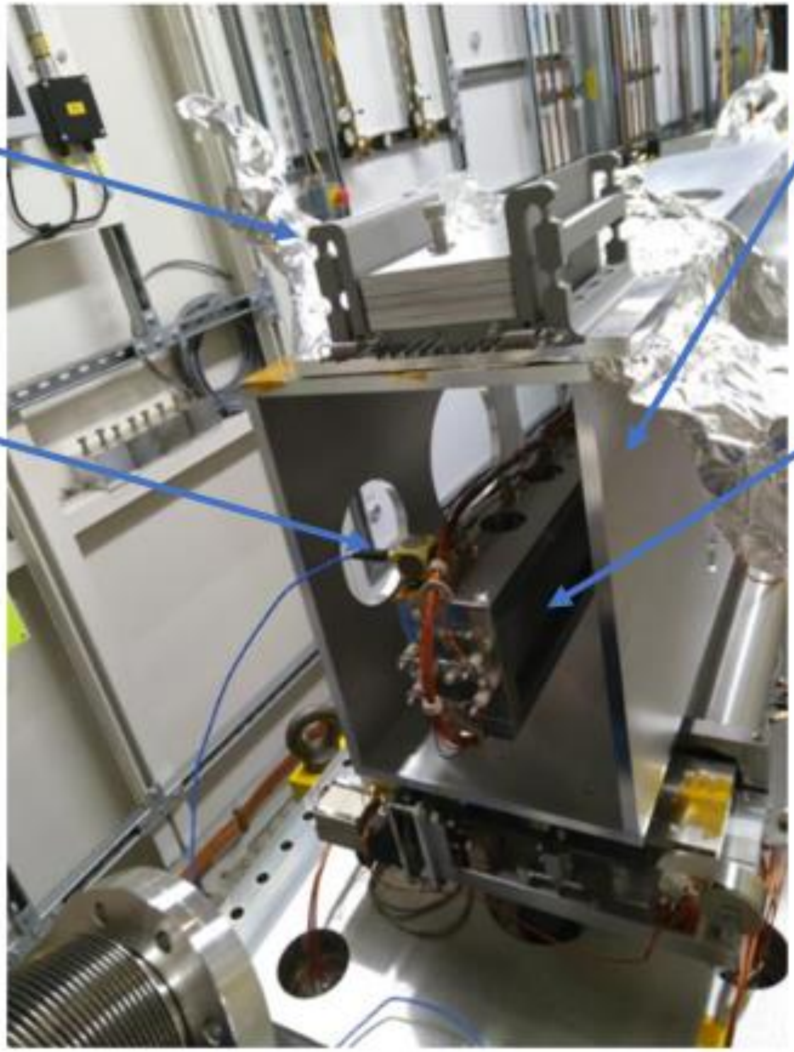
3D Printed TMD







3D Printed TMD



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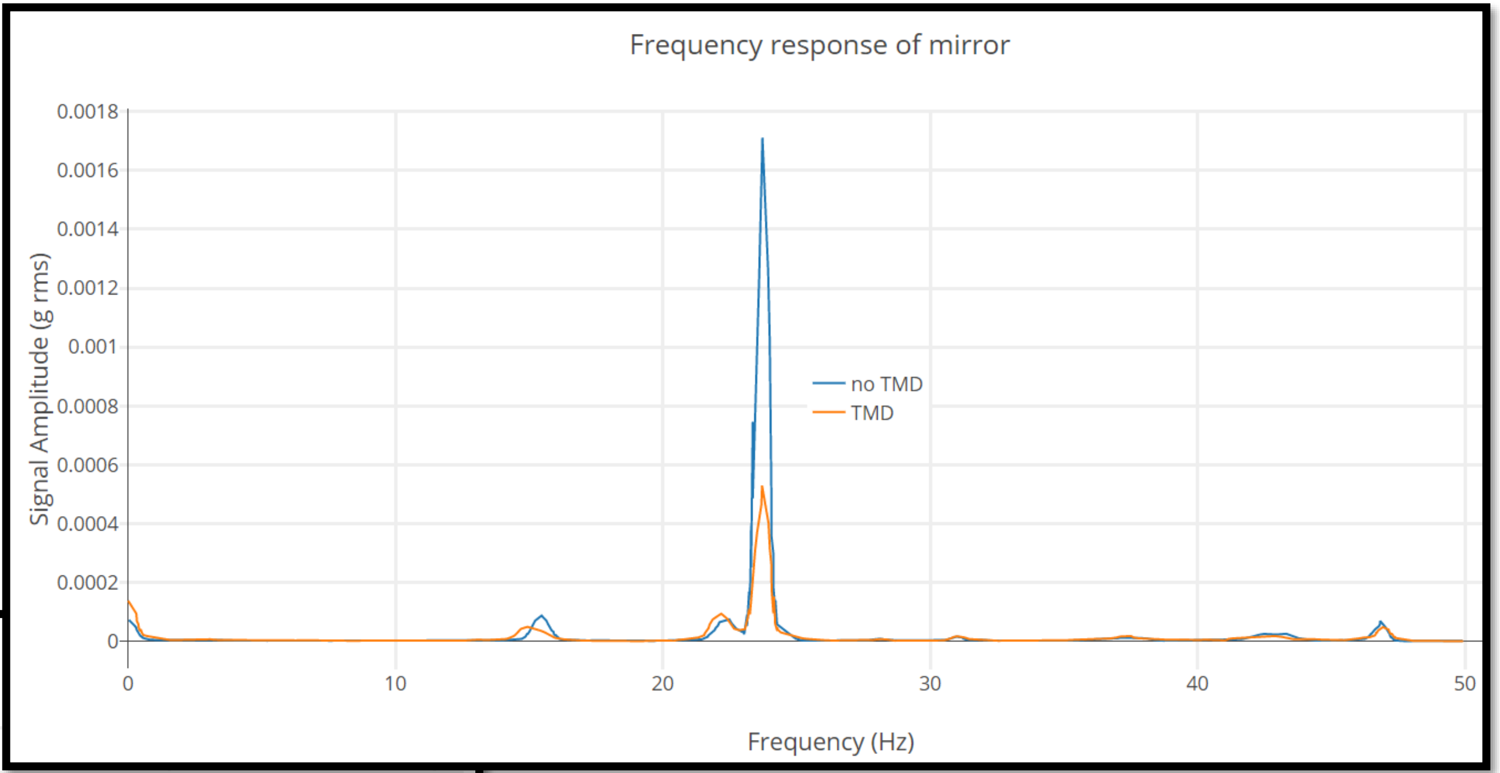
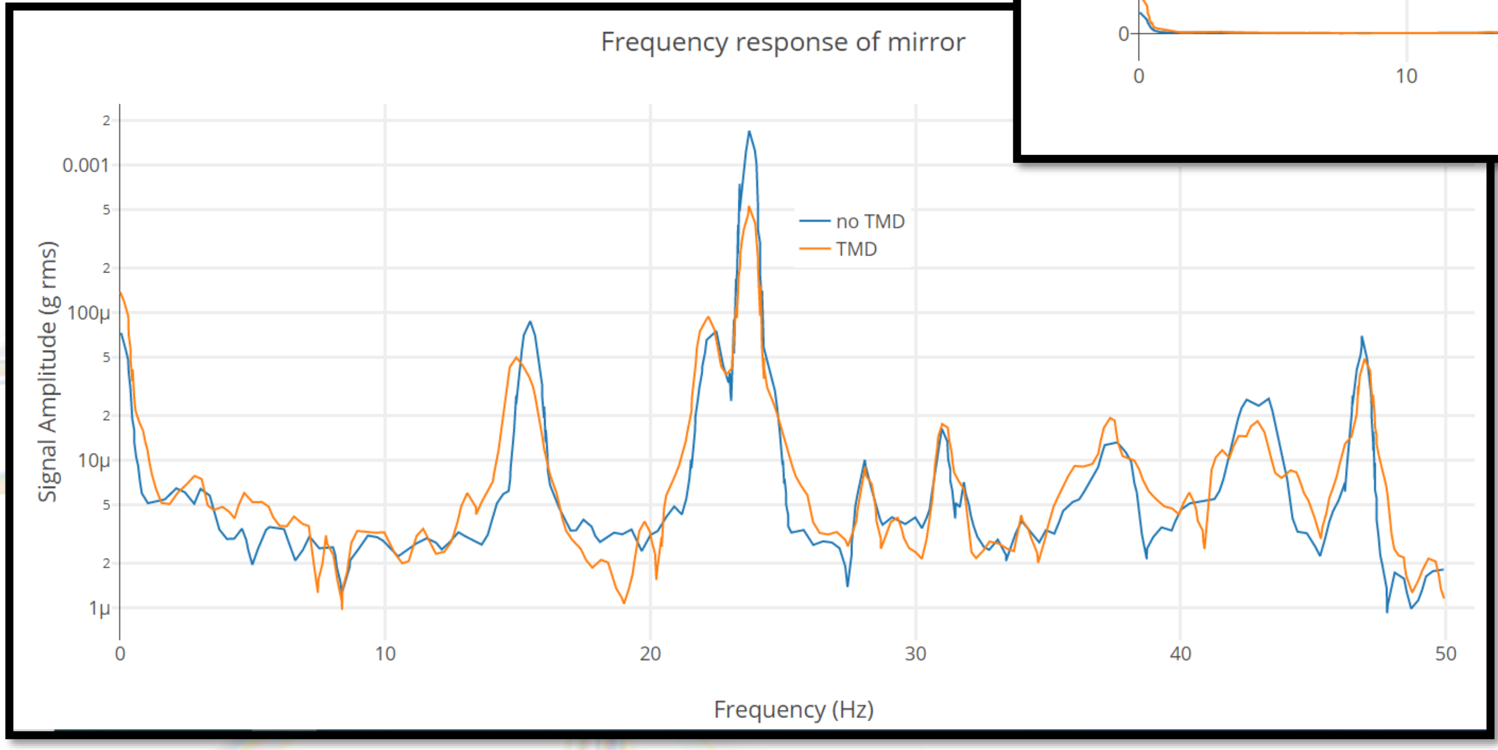
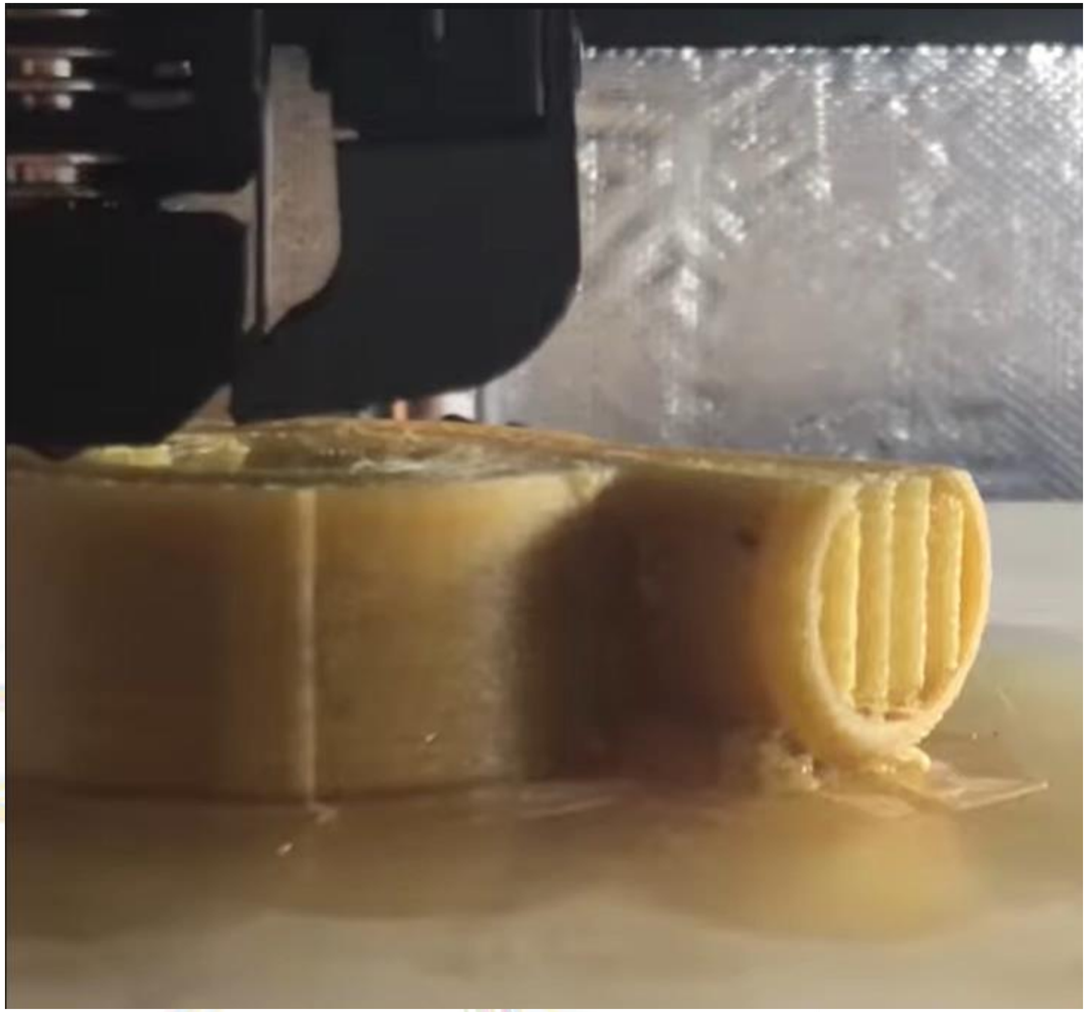




Do we need 3D Printing for this application?



Advantages	Disadvantages
ULTEM is vacuum compatible	Expensive material
Monolithic design	Difficult to print
In-house fabrication	Repeatability and tolerance limitations
	Further investigation into performance (printed part may not fulfil spec)

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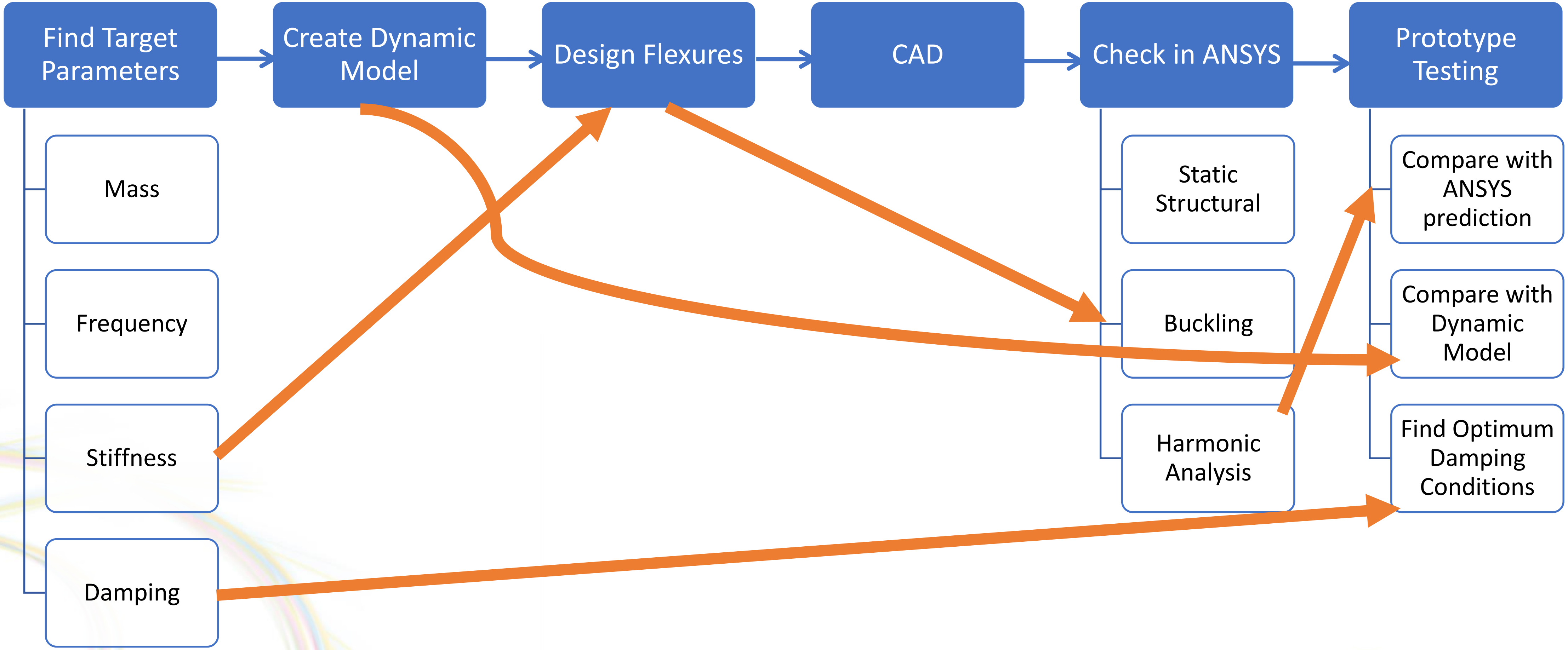
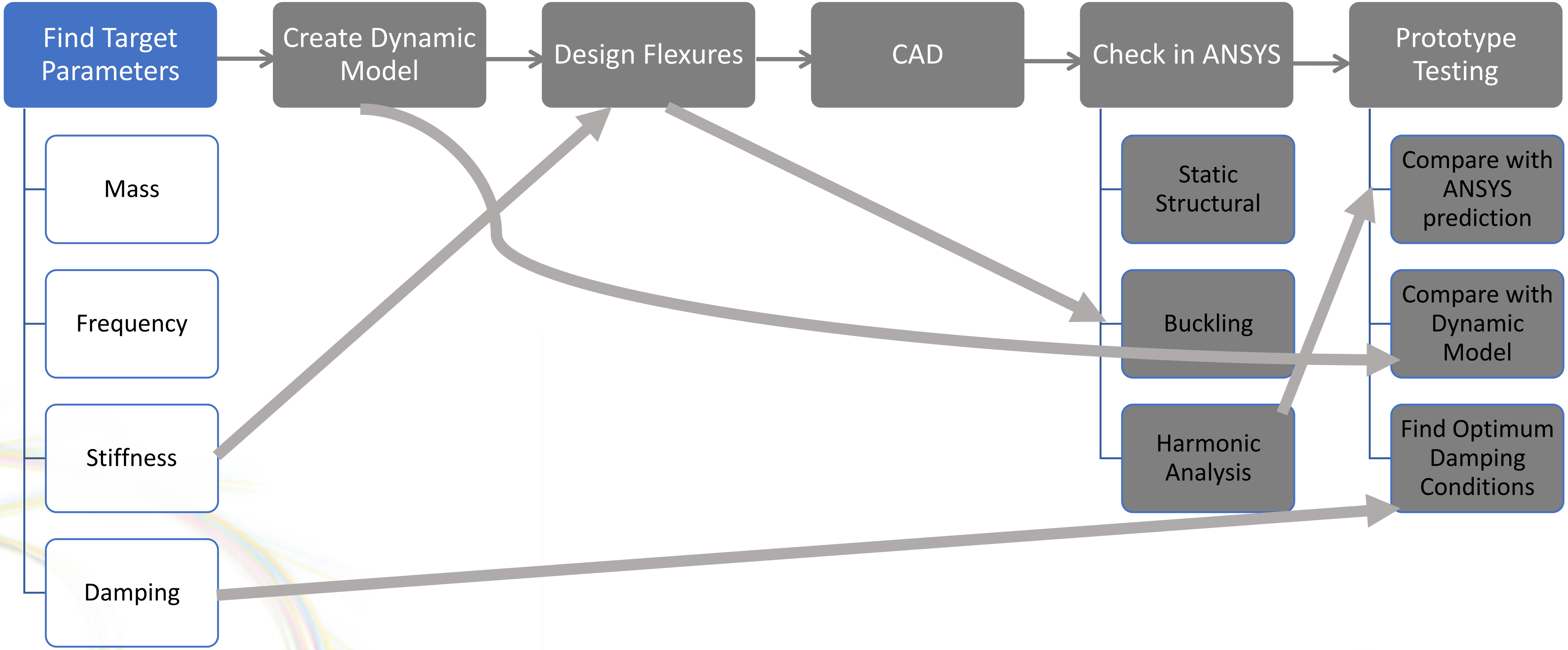
Design Process

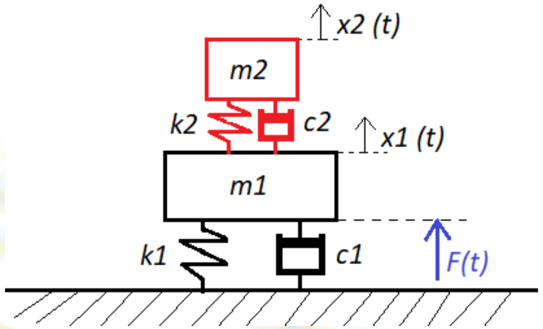


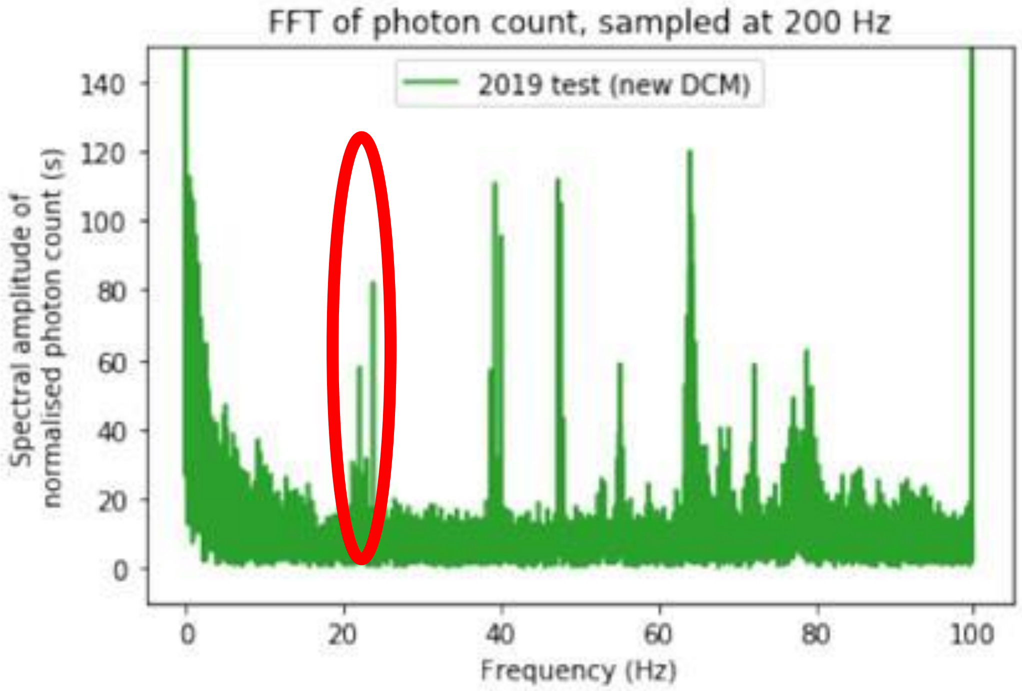
Design Process



Finding Target Parameters (w/ Case Study)*

1. Choose the mass
2. Find the frequency
3. Calculate the stiffness
4. Choose the required damping





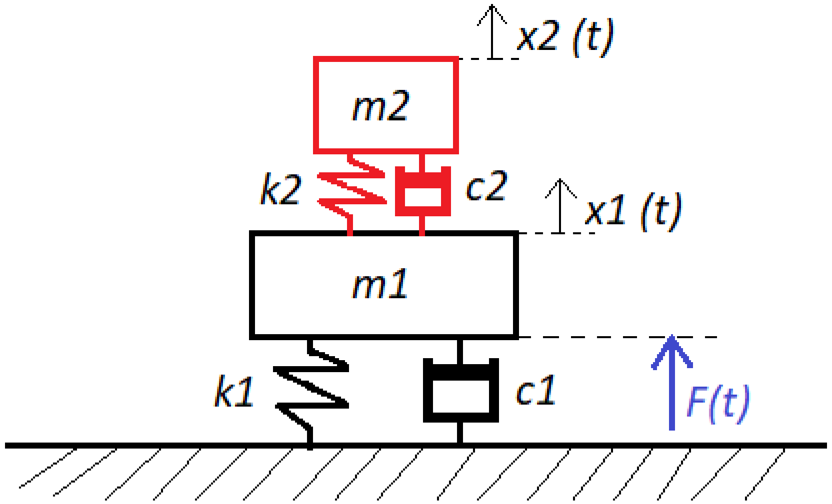
*same process used for 40 Hz and 47 Hz TMDs

mass — frequency — stiffness — damping

Finding Target Parameters

1. Choose the mass of the TMD

Limit m2 = 4kg per TMD



As a guideline: model the system and have a target reduction factor

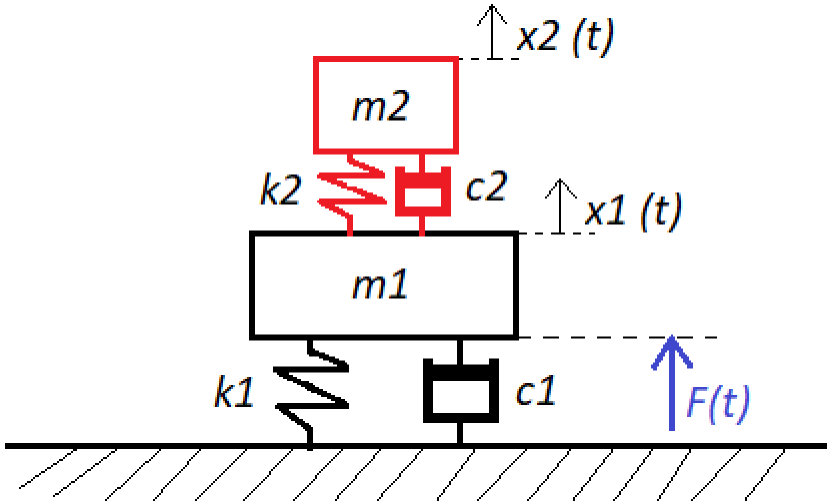
Mass ratio

$$\mu = \frac{m_2}{m_1} = 0.44$$

mass frequency stiffness damping

Finding Target Parameters

2. Find the frequency



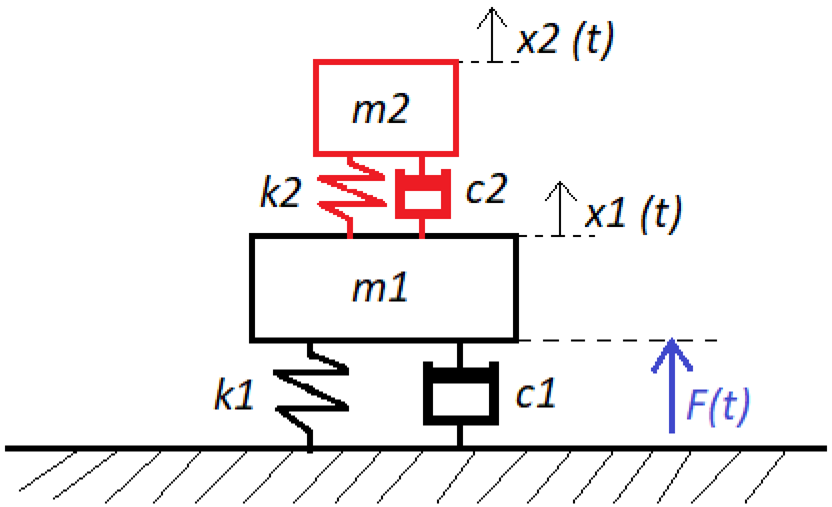
Slightly under the system frequency (remember we're adding mass)

Frequency ratio

$$\frac{f_2}{f_1} = \frac{1}{1+\mu} = 0.69$$

mass frequency stiffness damping

Finding Target Parameters



2. Find the frequency

Slightly under the system frequency (remember we're adding mass)

<u>Frequency ratio</u>

$$\frac{f_2}{f_1} = \frac{1}{1+\mu} = 0.69$$

3. Calculate the stiffness

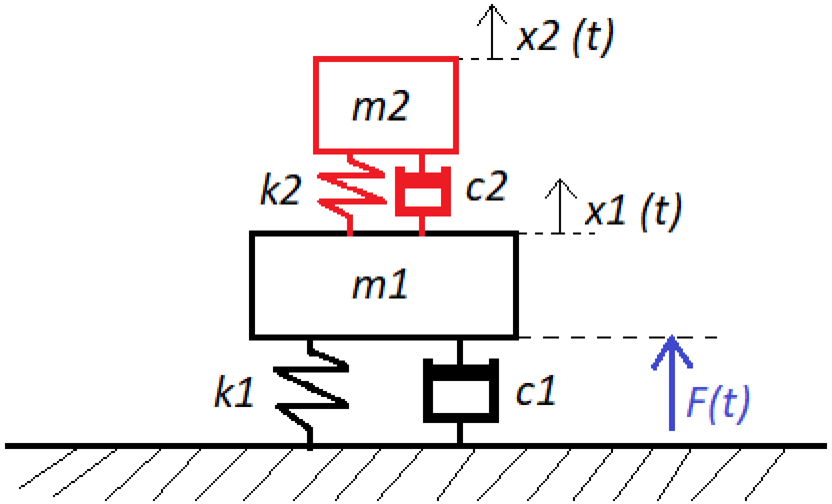
We already have both mass and frequency:

<u>Stiffness</u>

$$k_2 = (2\pi f_2)^2 m_2 = 80403\ N/m$$

(40202 N/m per TMD)

Finding Target Parameters



4. Choose the required damping

Optimal (relative) damping:

$$\xi_2 = \sqrt{\frac{3\,\mu}{8\,(1+\mu)}} = 0.34$$

Absolute damping:

$$d_2 = 2\xi_2\sqrt{k_2 m_2} = 543.6 \text{ Ns/m}$$

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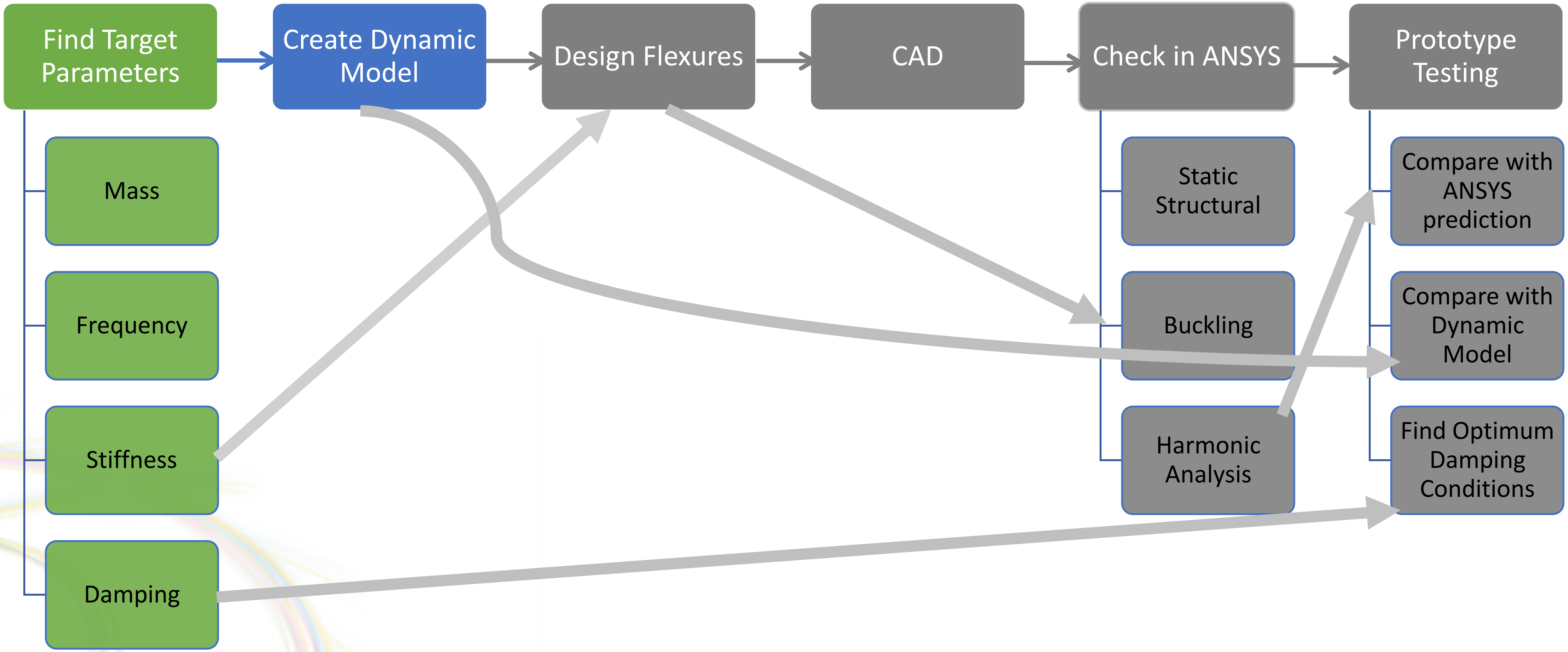
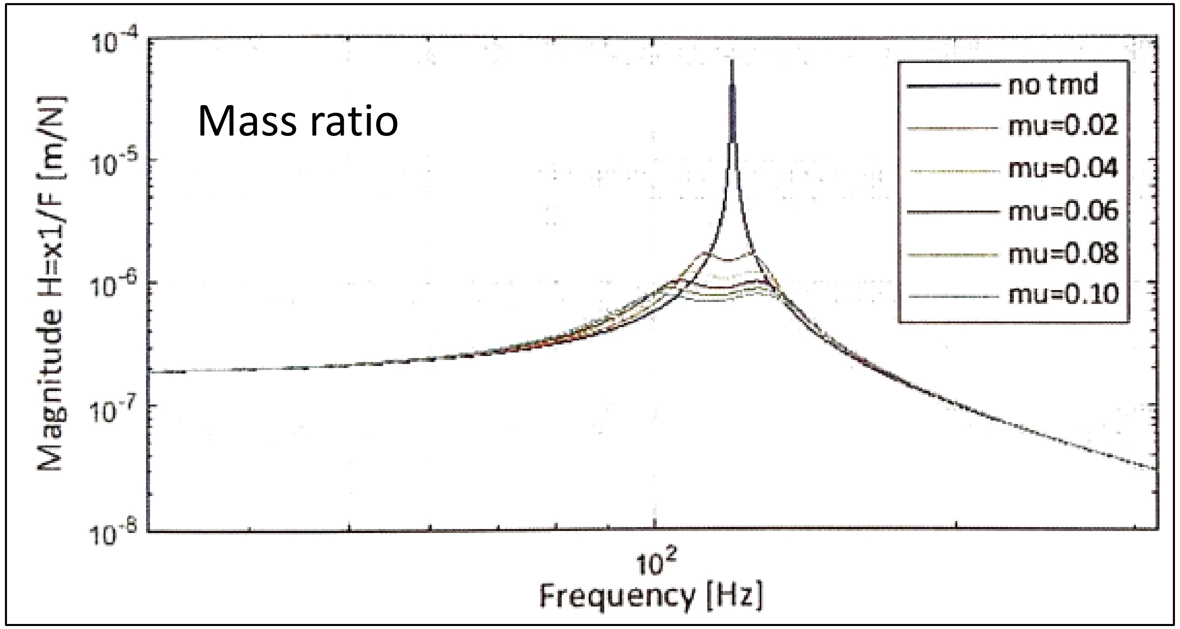
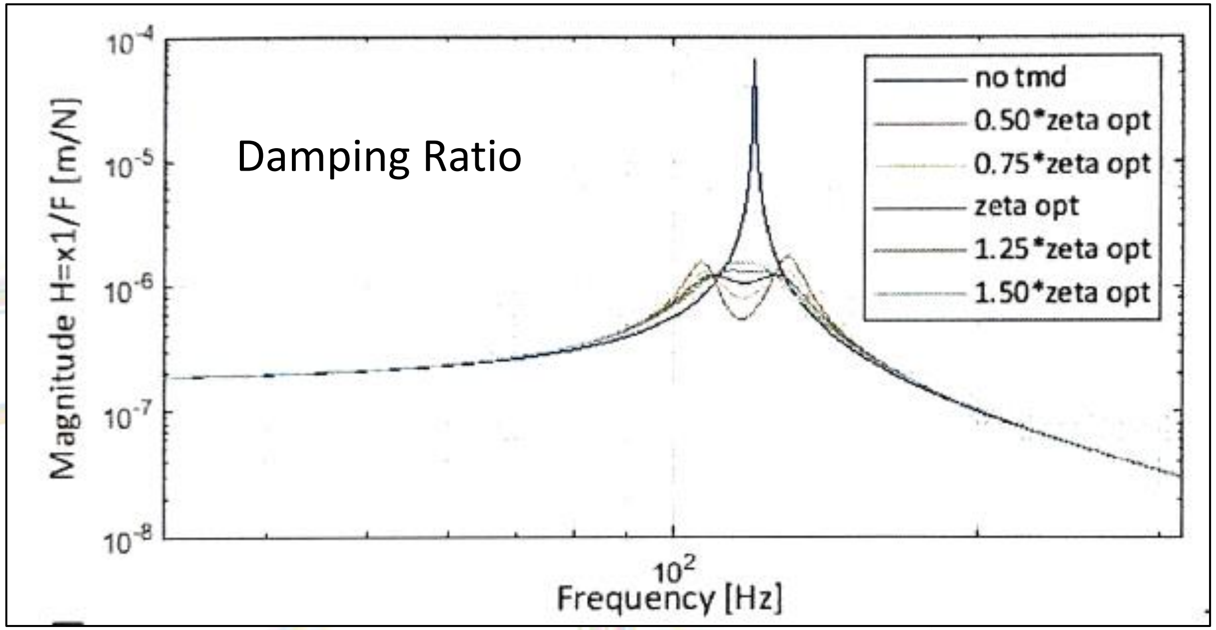
Design Process

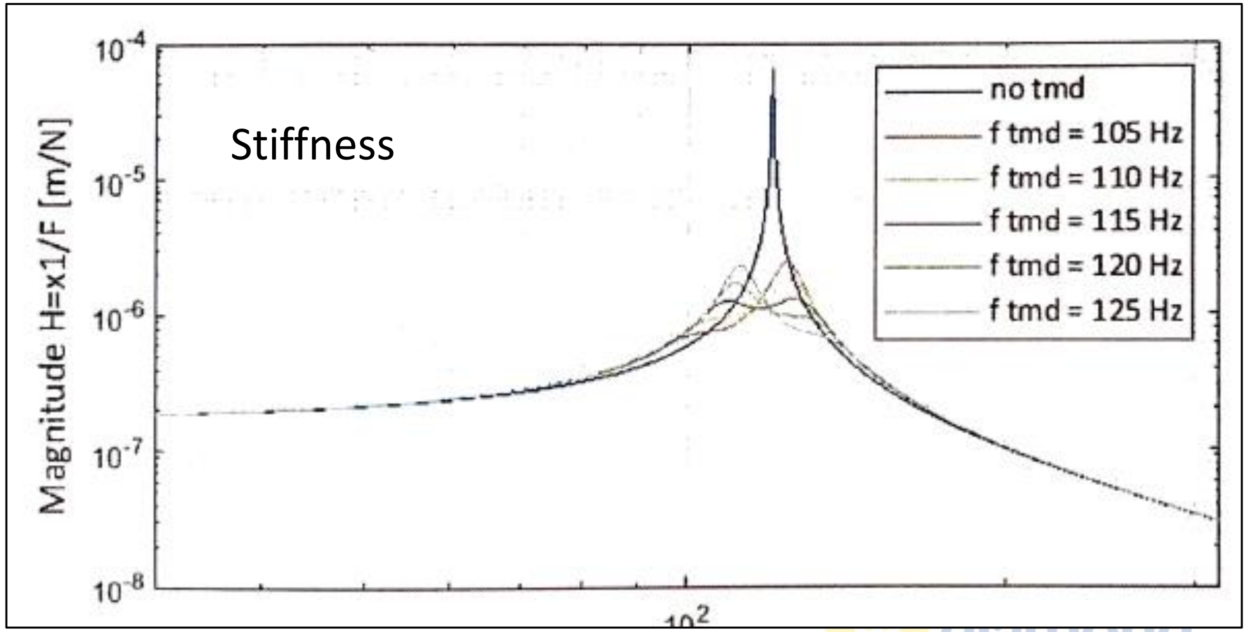


Dynamic Modelling

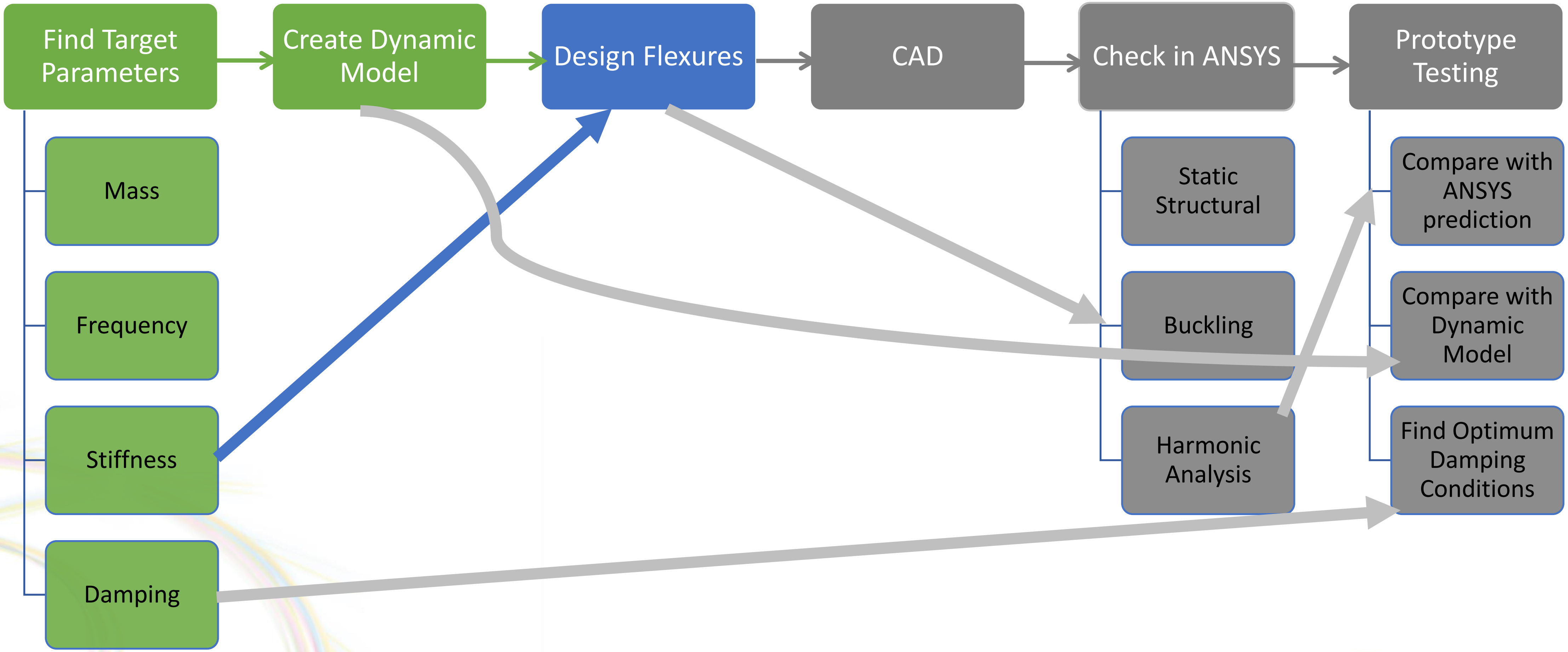
- Creating double-mass-spring-damper systems in MATLAB / Simscape







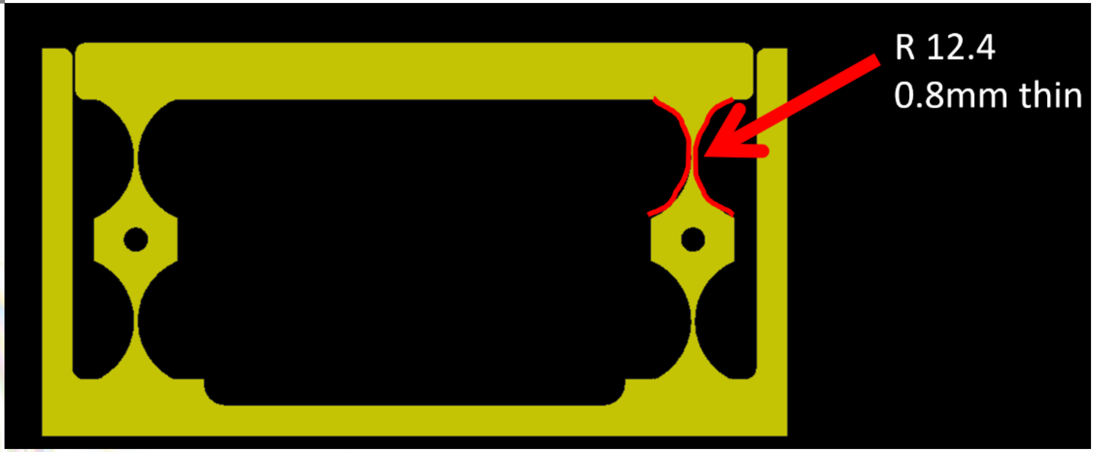
Design Process

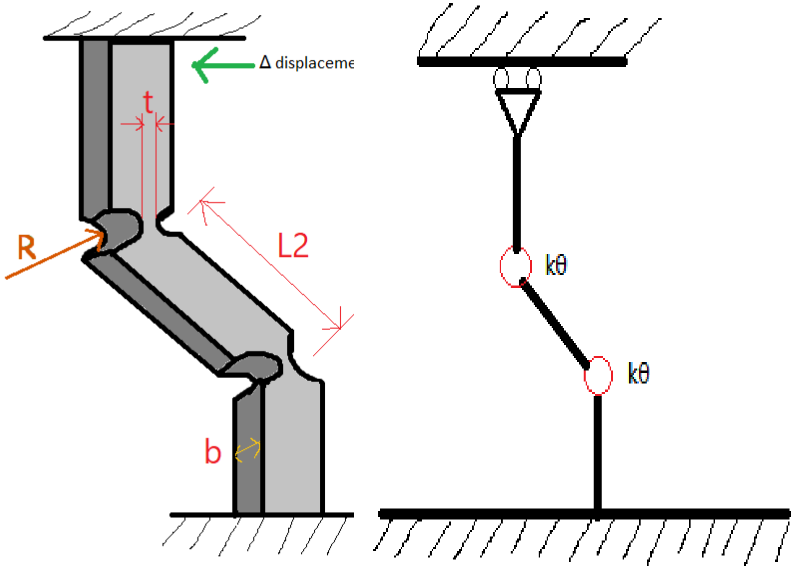


$$k_f = \frac{4Ebt^{5/2}}{9\pi L2^2 R^{1/2}}$$

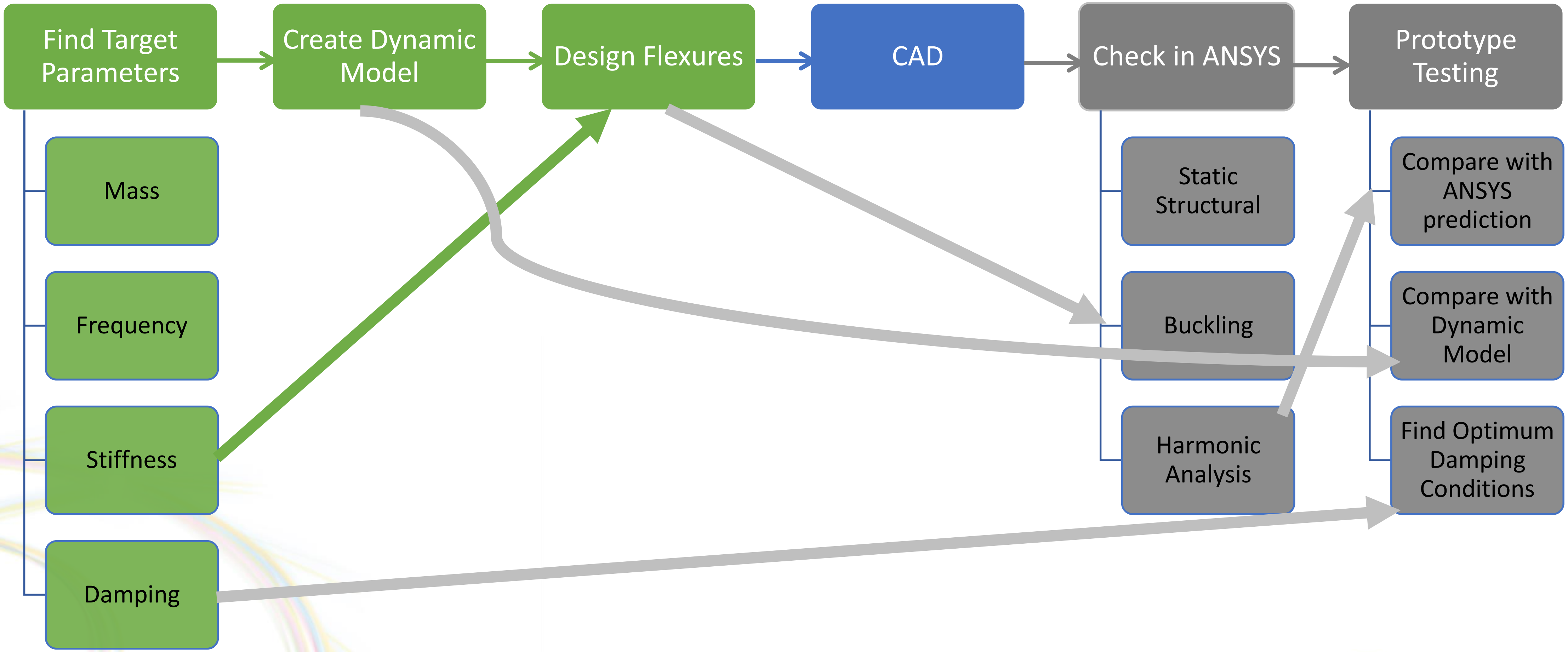
Flexures

- Derived from first principles
- Relate one double-hinge flexure column to torsional springs

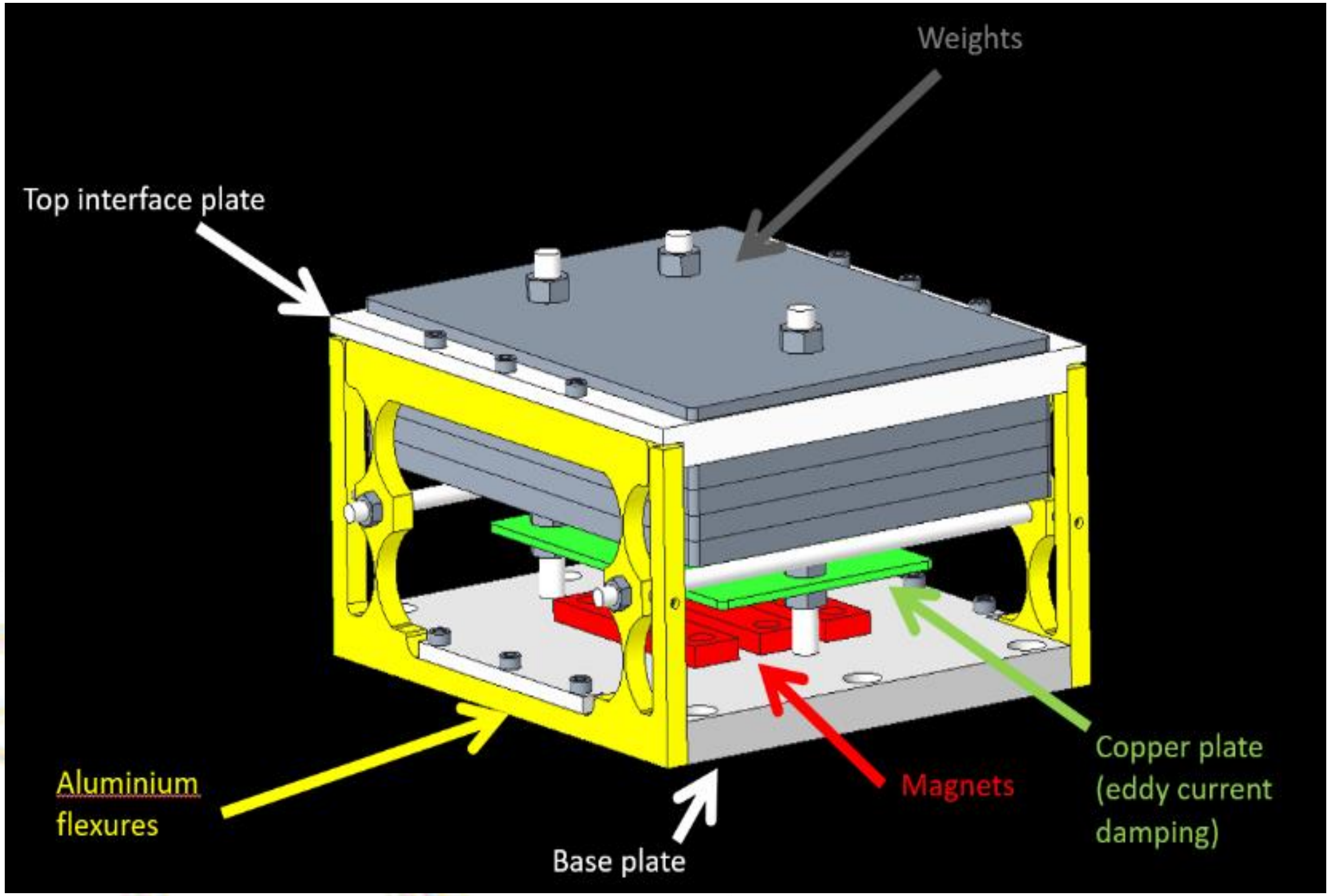


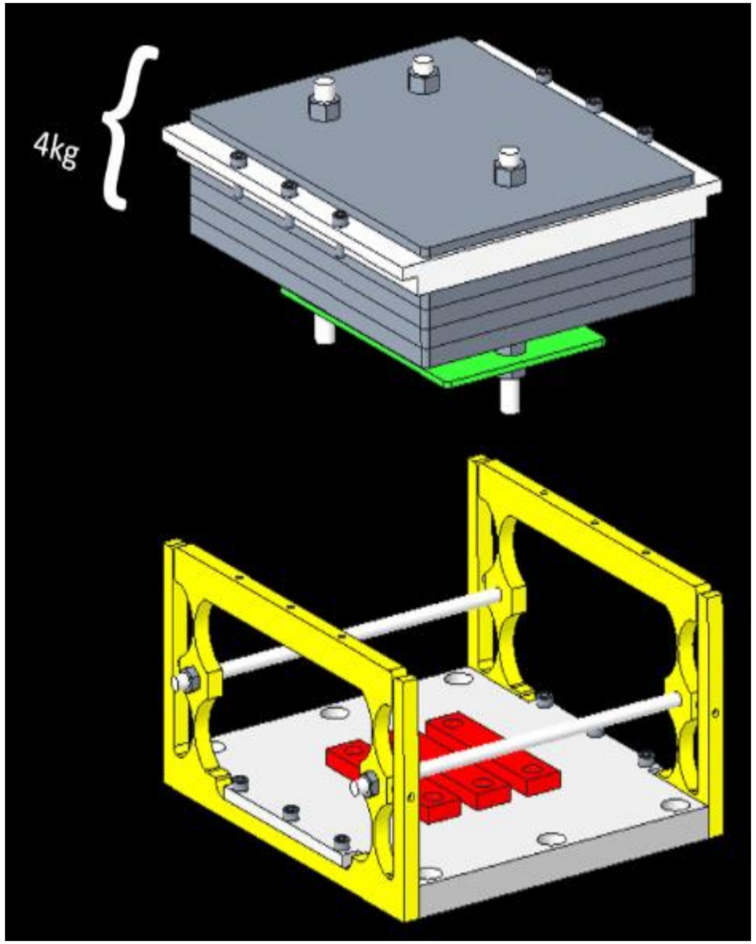


Design Process

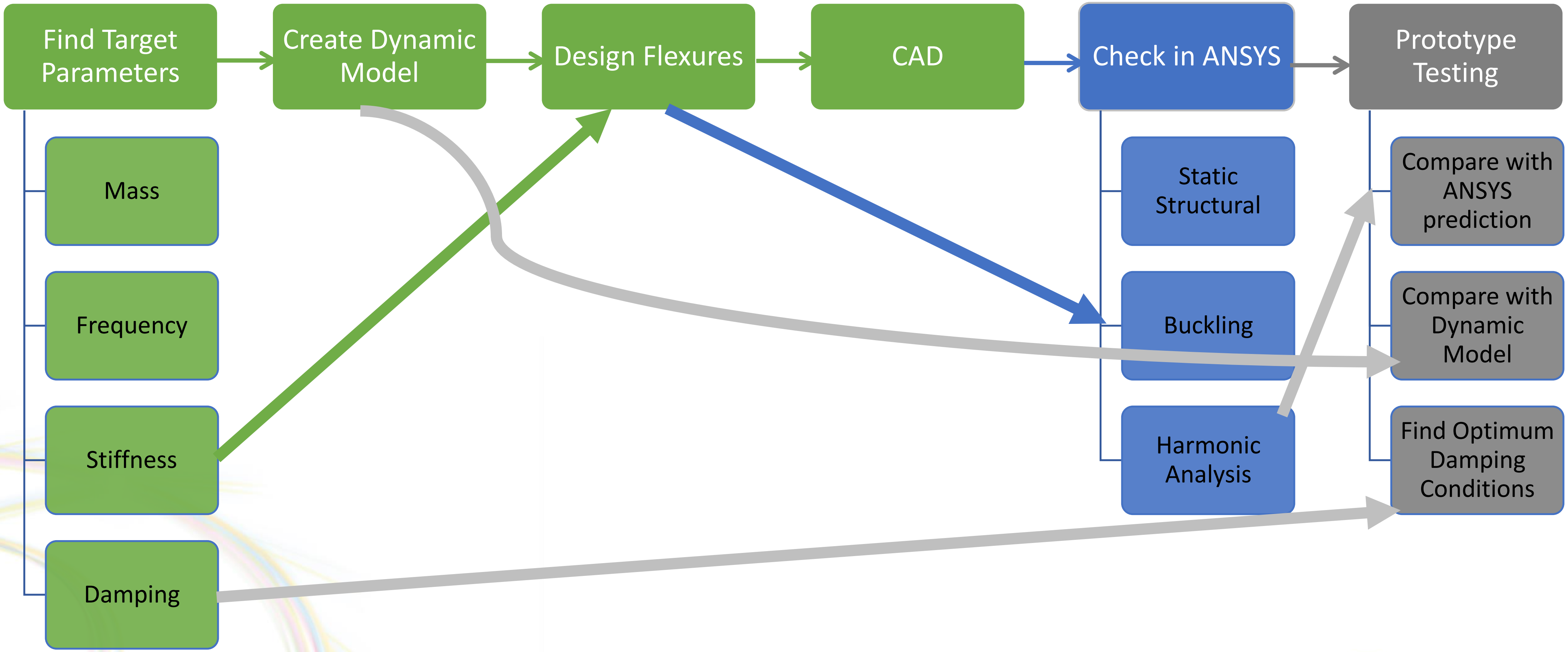


Design TMD in CAD



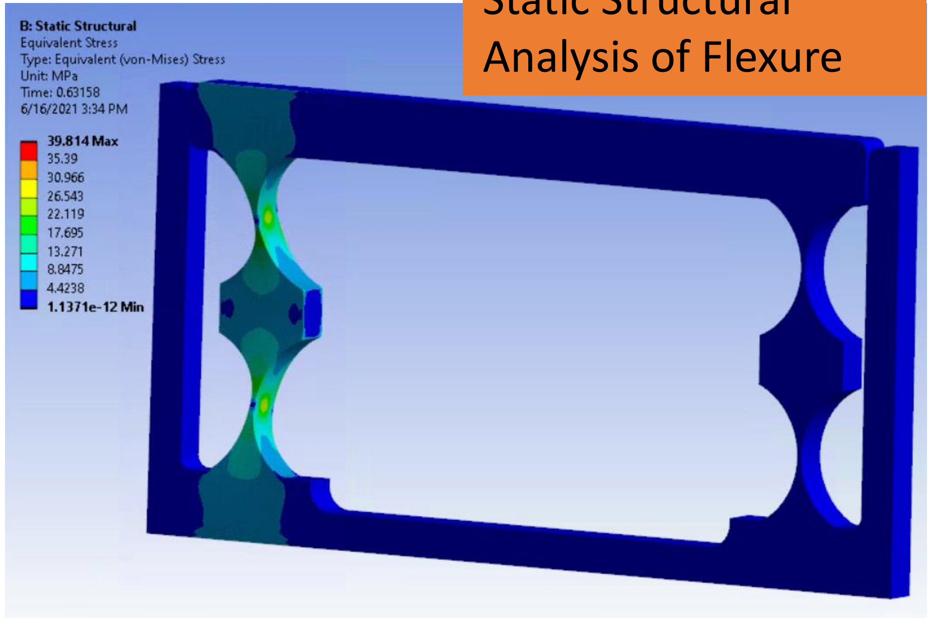


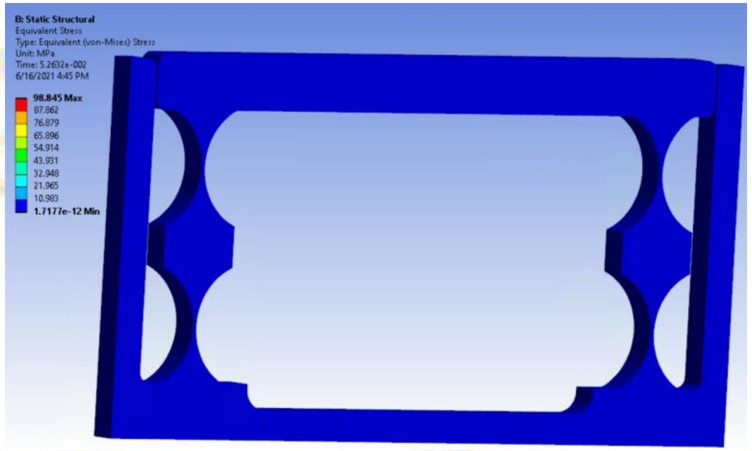
Design Process



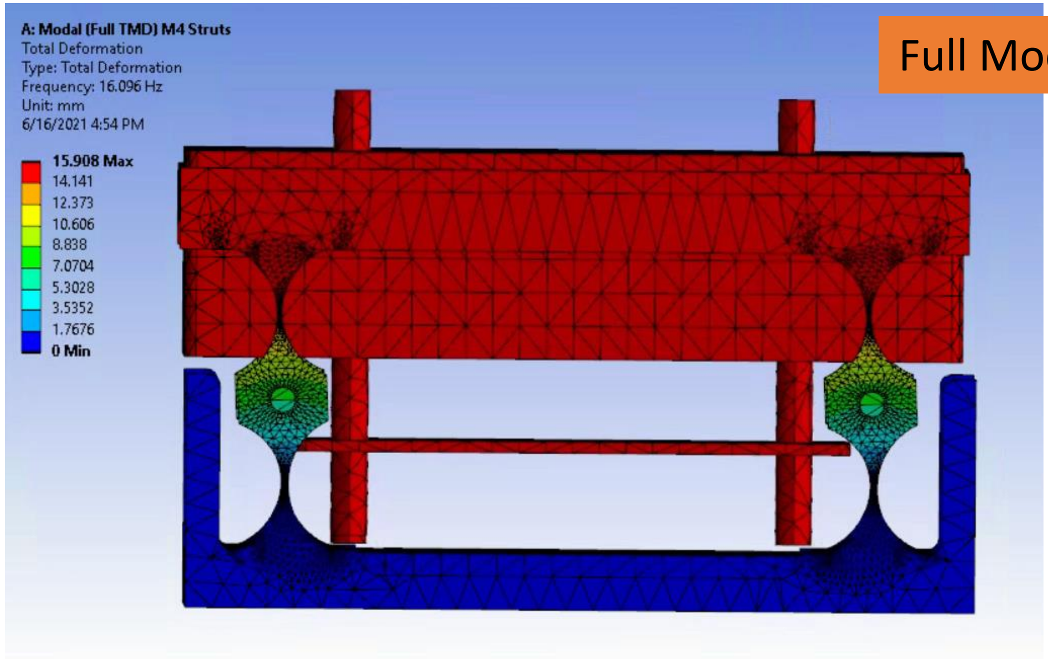
ANSYS Simulation

Static Structural Analysis of Flexure

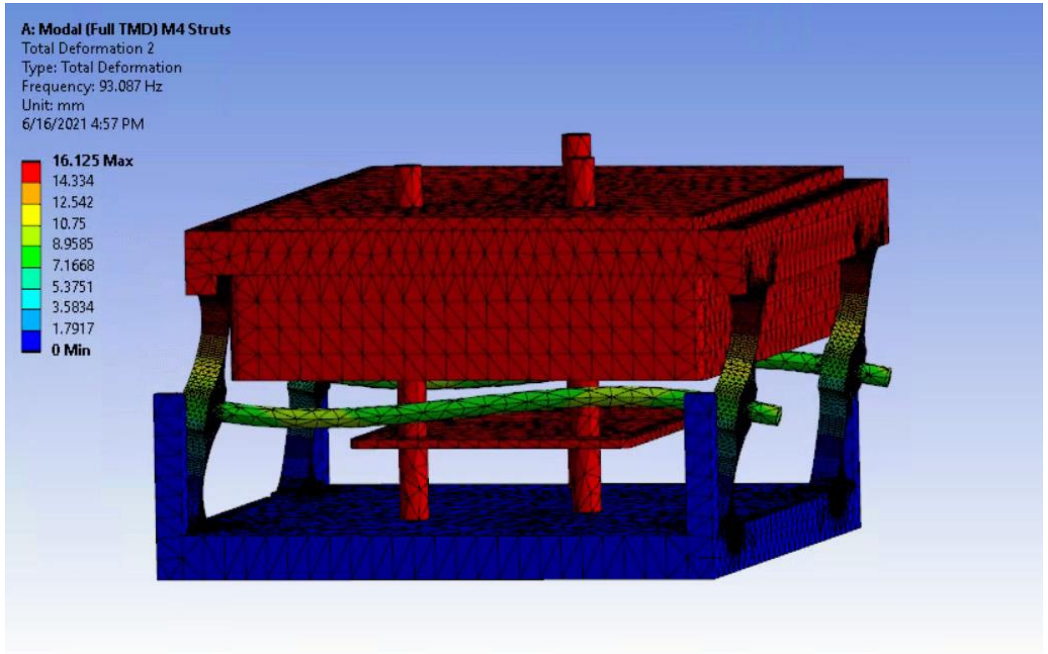




Full Modal Analysis



16 Hz Mode



80-90 Hz Mode

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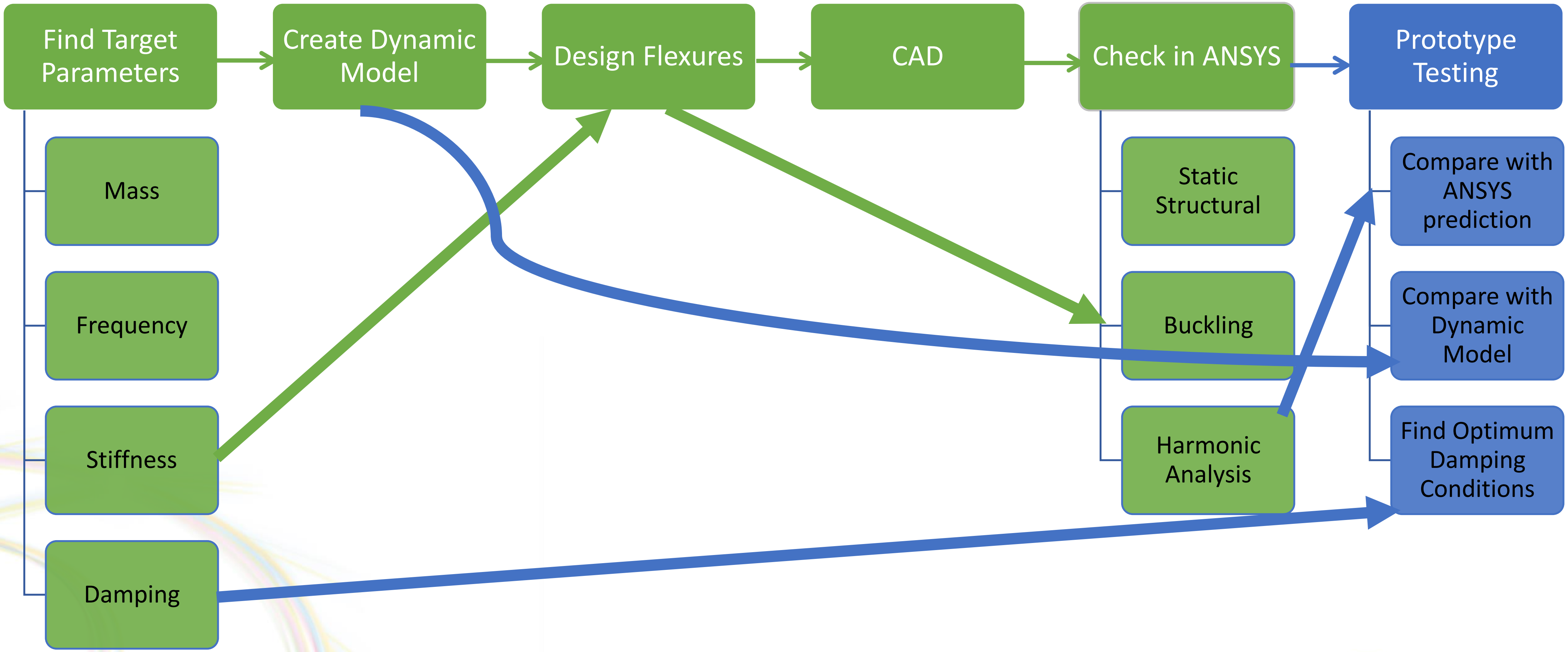
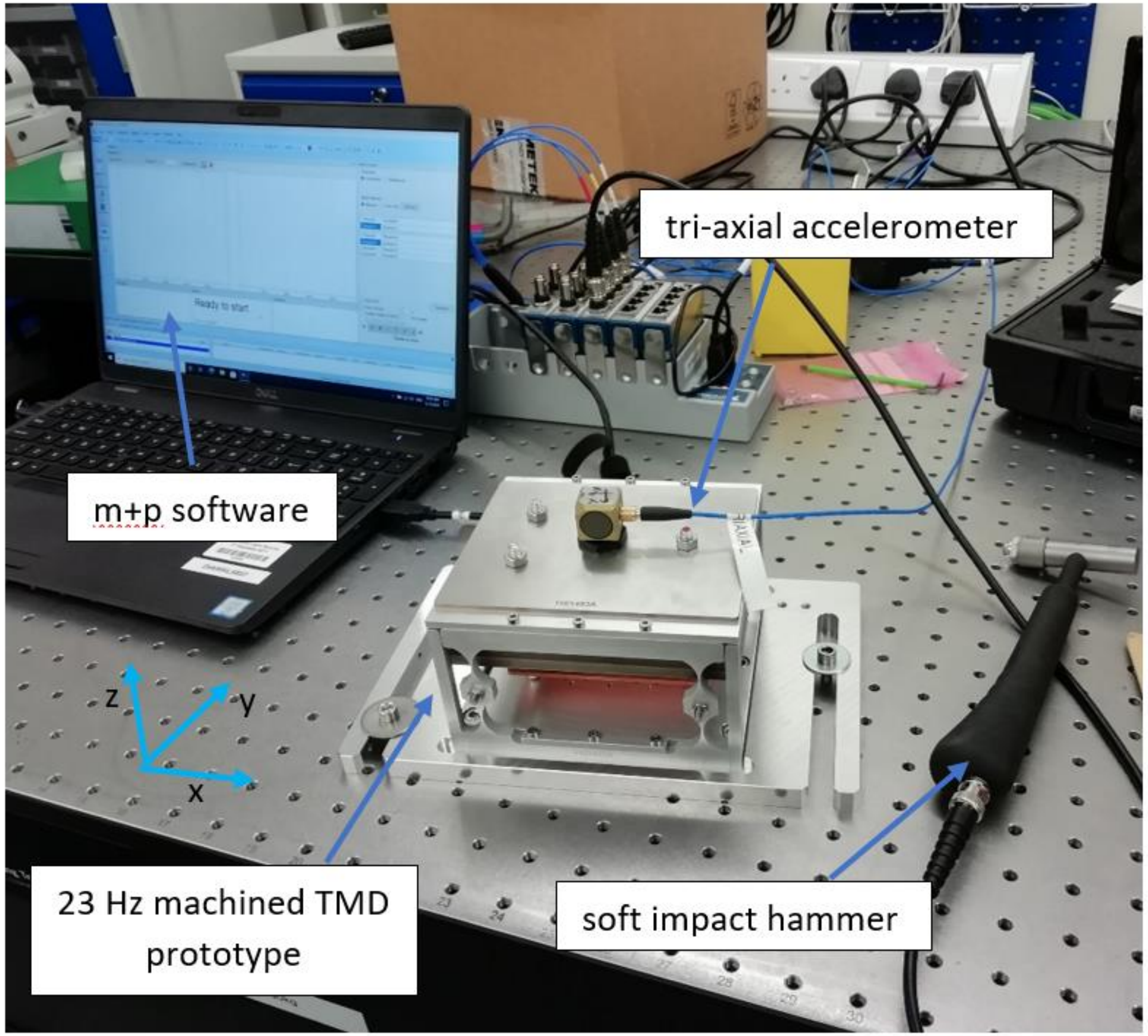
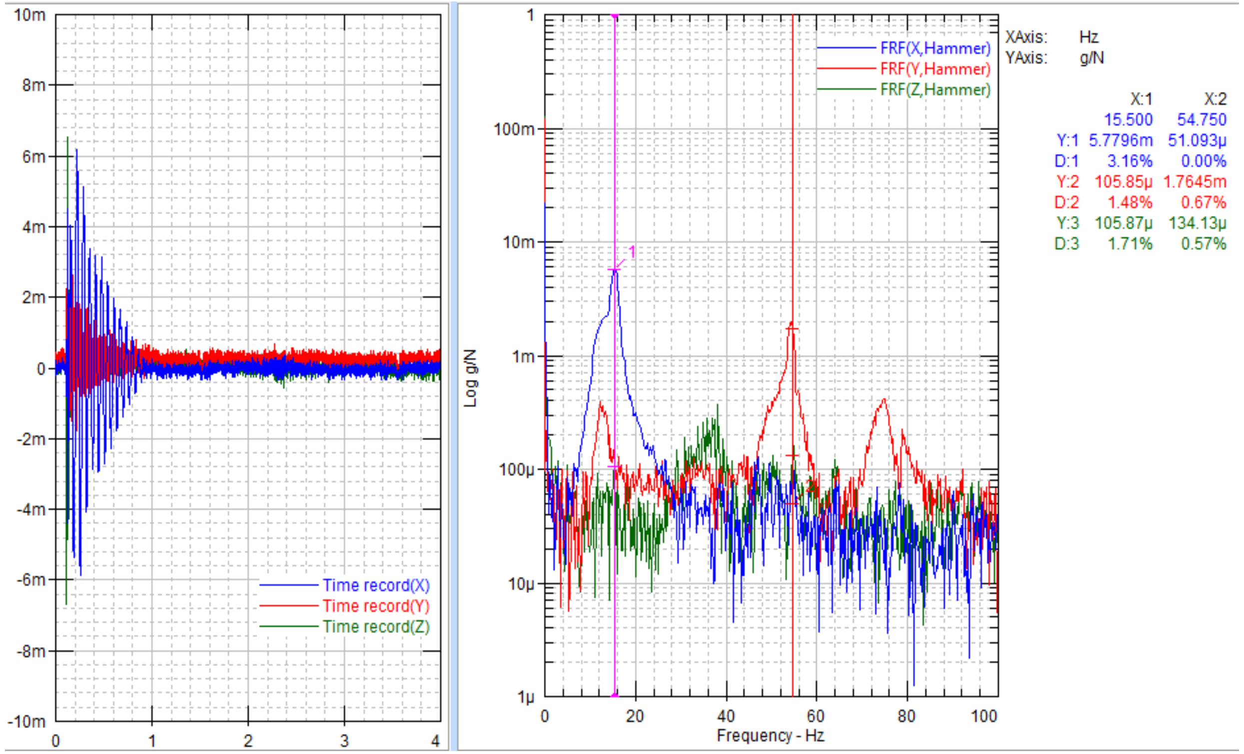
Design Process



Prototype Testing





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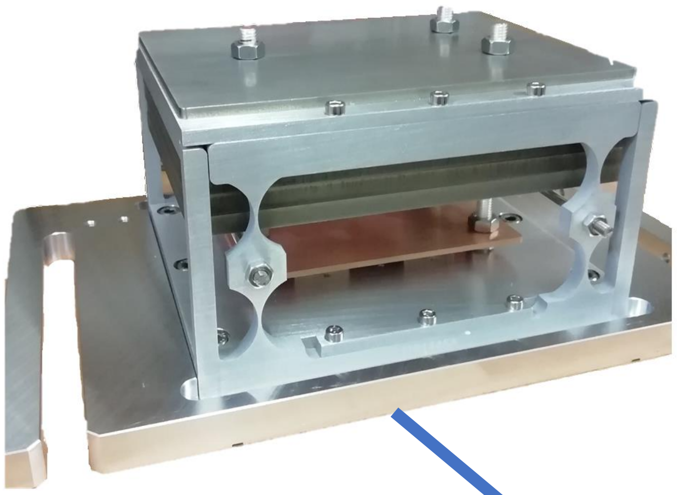
Final Comparison + Conclusion



	TARGET	Theory	ANSYS	Prototype
f_2 [Hz]	15.95	16.16	16.268	15.5
k_2 [N/m]	40201.534	40203.8485	41754.94169	36715.2343
m_2 [kg]	4	3.9413	3.9965	3.871
ξ	0.339	-	-	~0.0316

- ✓ Modelling
- ✓ Reducing risk on the beamline
- ✓ Extending life of older equipment