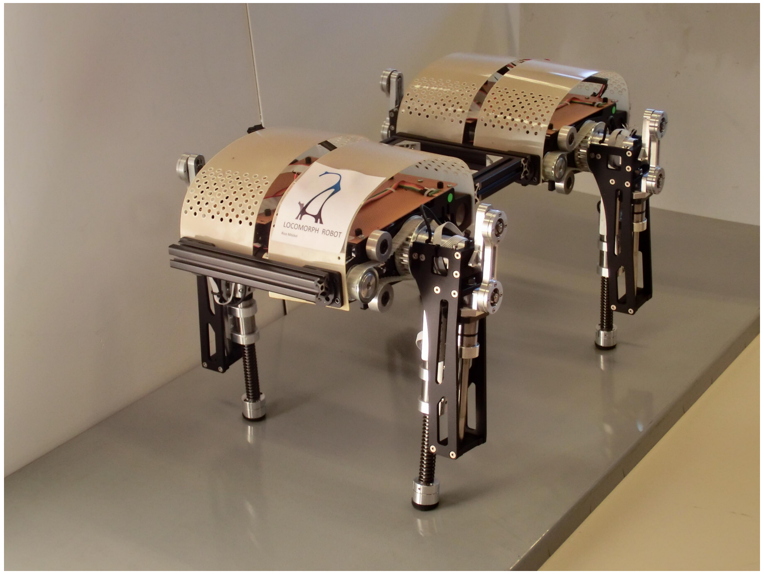
Design of a compliant spine for the Locomorph quadruped robot

Semester Project

Matteo Nessi

Supervisors: Rico Möckel, Peter Eckert
Prof. Auke Jan Ijspeert



Nature analysis

Cheetah spine bending during running
(Cheetahs on the Edge, Director's Cut – NationalGeographic)

Two main reasons:

Spine bending: Increase stride length

Compliance: Flexible system = Shock absorption, Efficient use of energy

Goal

Cheetah bendable and compliant spine

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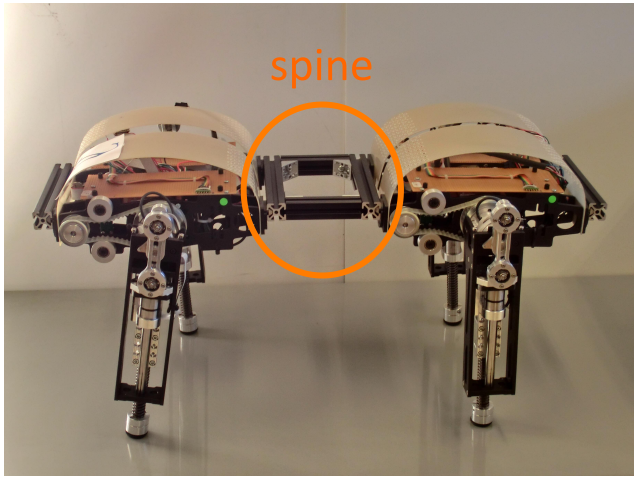


Locomorph robot

- Construction of an actuated and compliant spine for Locomorph robot
- Comparison of results : rigid spine/actuated spine (Speed variation, Energy consumption)

Desired spine properties :

- Torque control
- Spring and actuation in serie
- Lightweight
- Configurable = compliance variation (“Morphosis”)

Robot specifications :

- Max frequency: 2Hz
- Max amplitude : 30°

Designs introduction

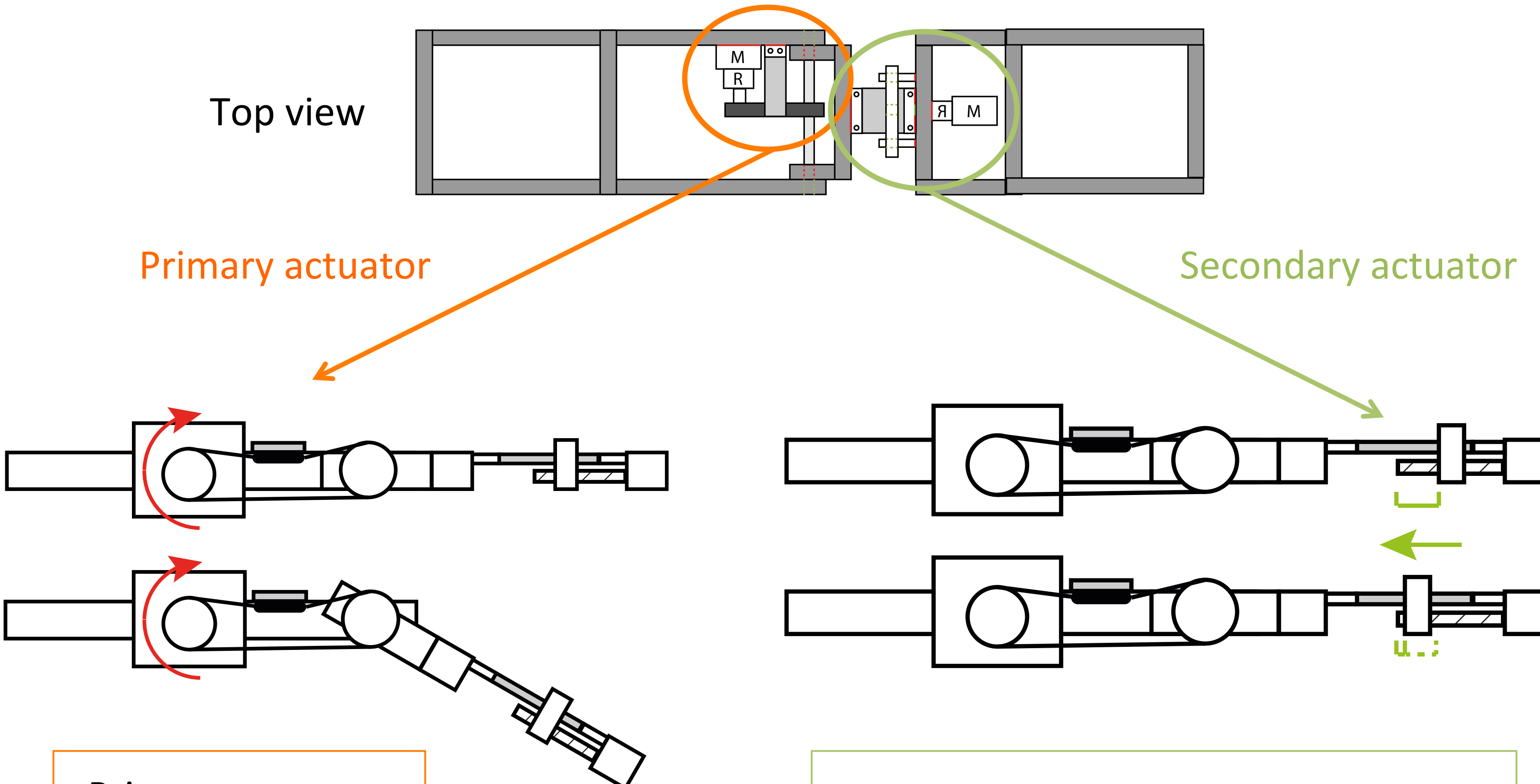
<u>Design 1 :</u>

DC motor, timing belt, leaf-spring

<u>Design 2 :</u>

DC motor, crank-slider, spring

Design 1: Bending mechanism



<u>Primary actuator:</u>

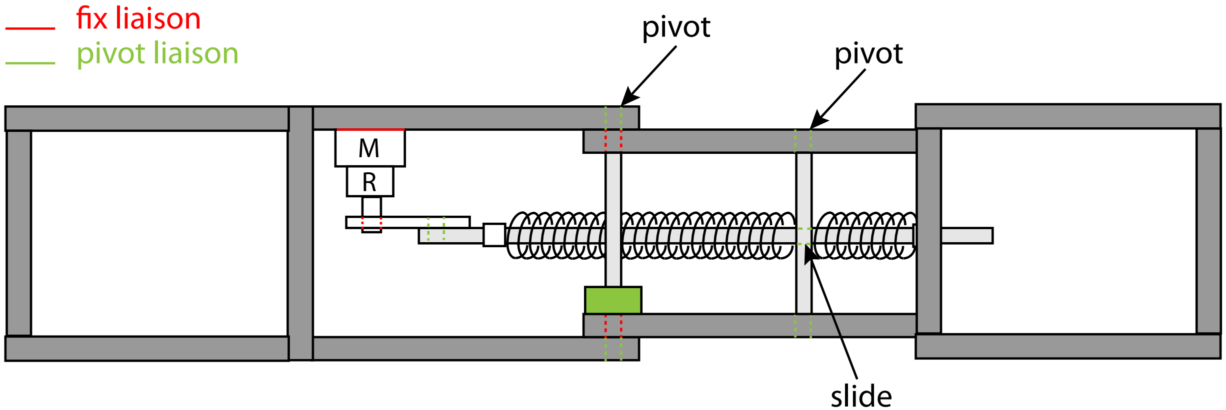
- DC motor
- Timing-belt

<u>Secondary actuator:</u>

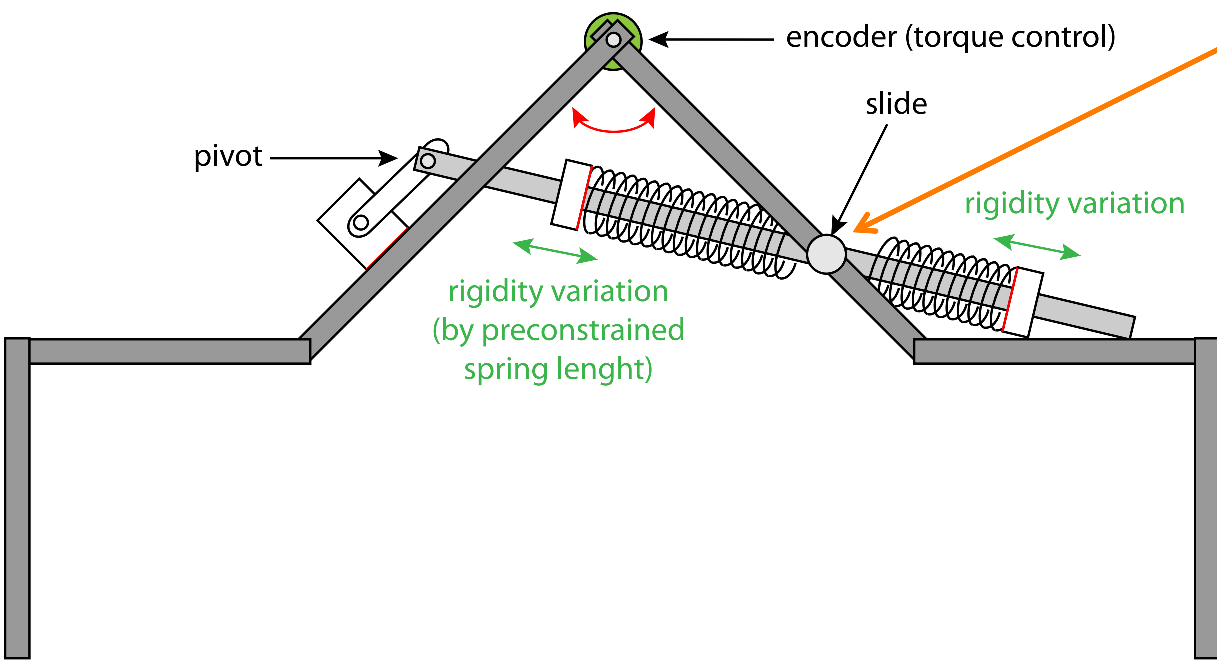
- Leaf-spring (belt tension)

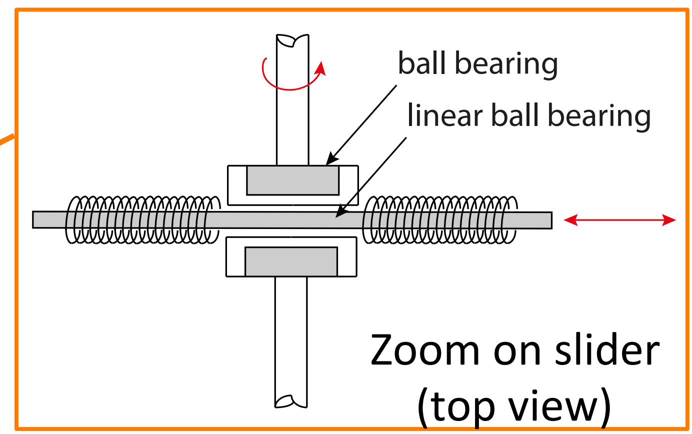
"Morphosis system"= Changing leaf-spring length to change the effective bending for the same force.

Design 2 : DC motor, crank-slider, spring



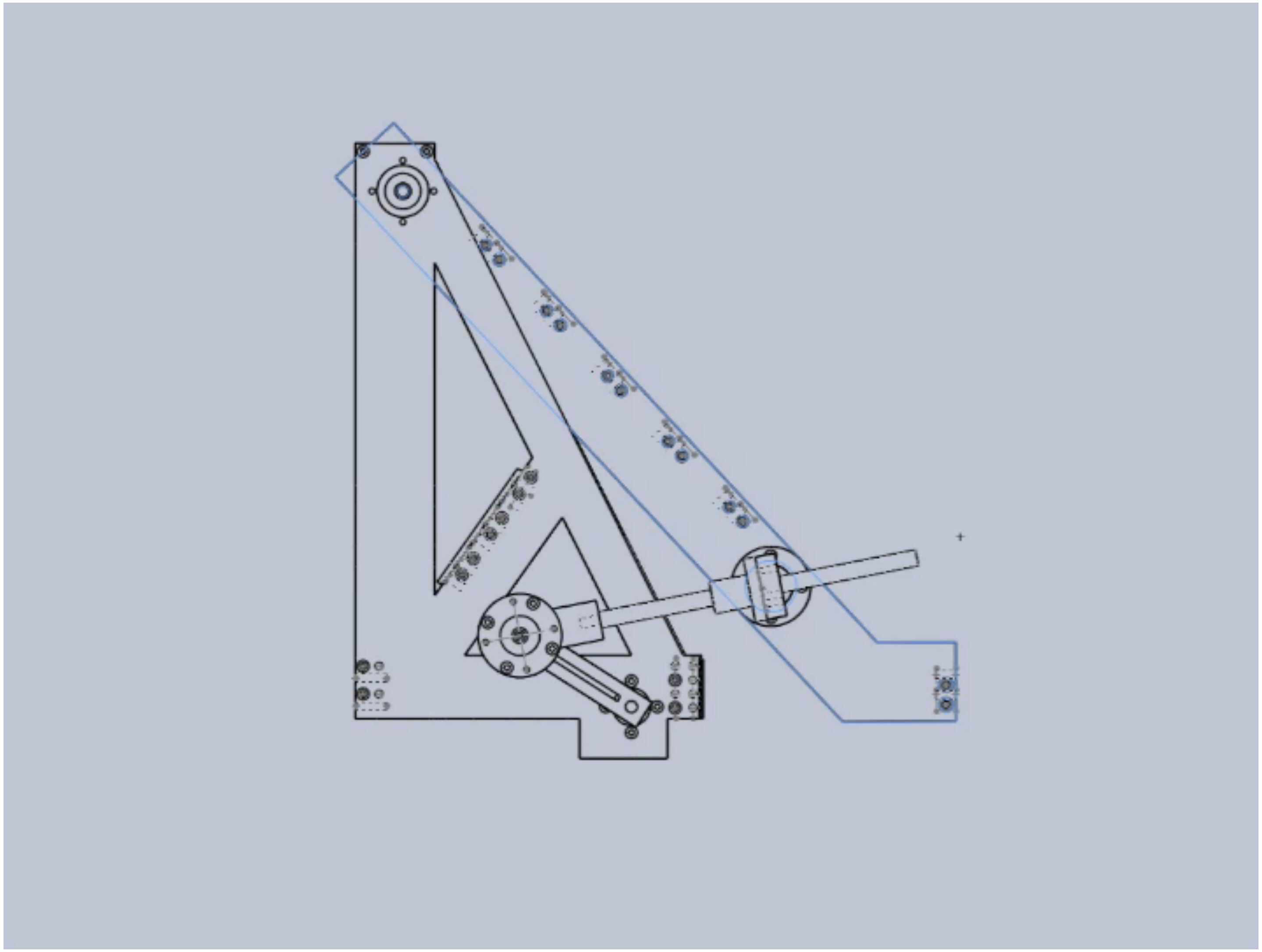
Top view



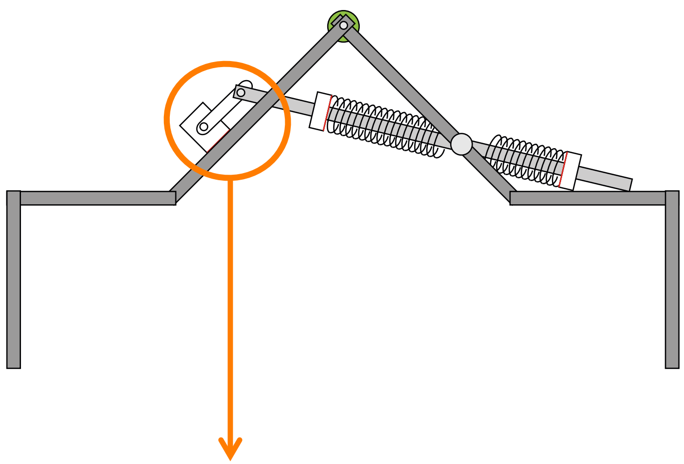


Side view

Design 2: Working principle

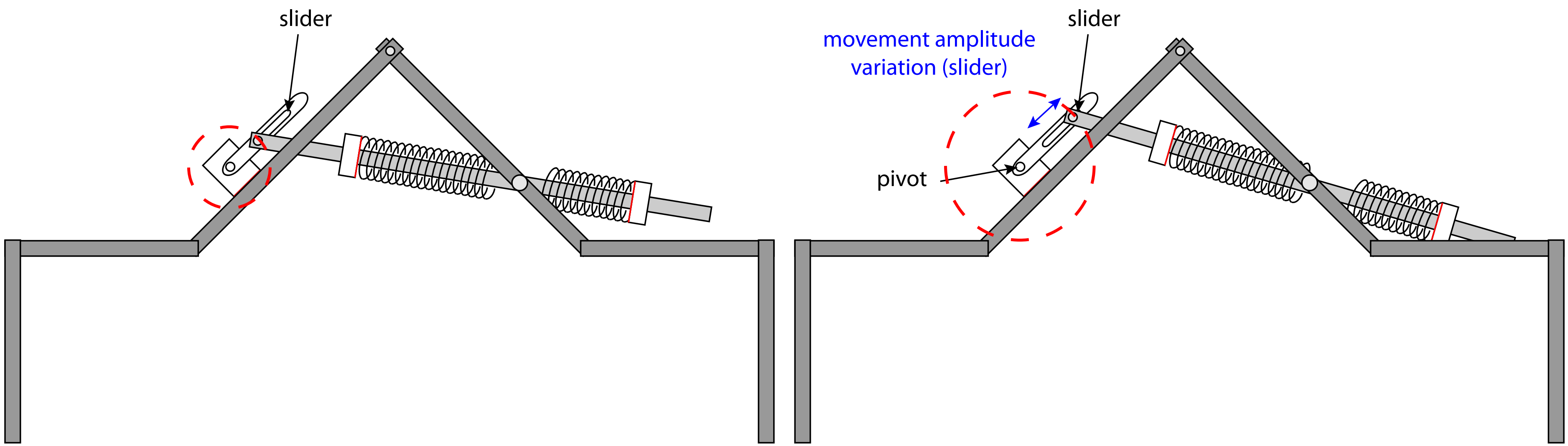


Design 2: Changing movement amplitude



Principle :

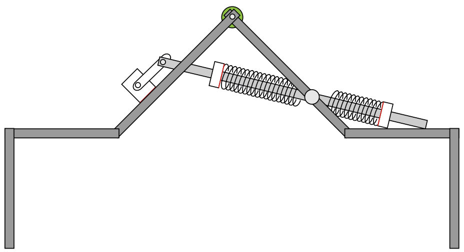
Sliding the attach point on the crank-slider
= changing amplitude of leg movement



Designs comparison

Design 1: Timing belt + Leaf-spring	Design 2: Crank-slider + Linear springs
- Not continuous rotation	+ Continuous rotation
- Open loop	+ Close loop
+ Timing-belt for adapting gear ratio	
- Requires timing belt loading mechanism	
+ More flexible control of amplitude (timing belt)	- Changing amplitude require changing crank-slider geometry
	- Torque of crank-slider changes depending on it's extension

<u>Chosen mechanism:</u> Design 2 (Crank-slider + linear springs)



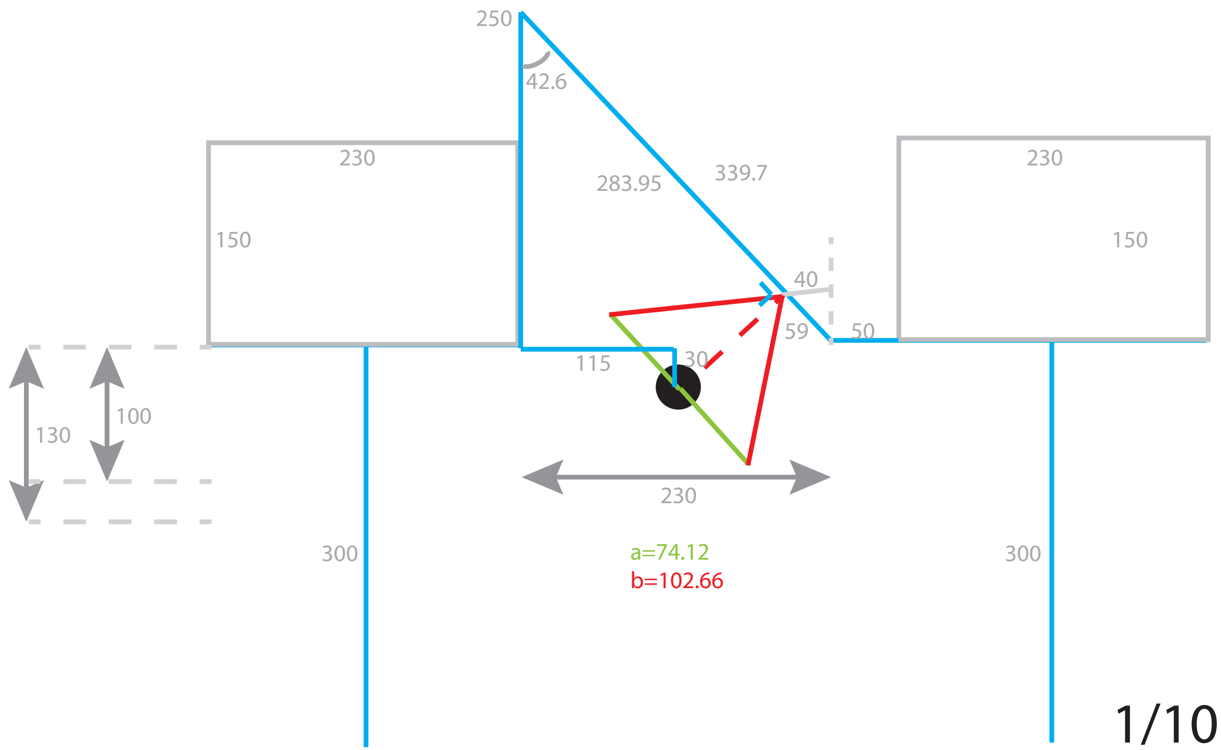
Design 2: Dimensioning

<u>Boundary conditions:</u>

- Spine length: ratio 2/3 (leg length/spine length), as in the cheetah
- Unavailable space next to the floor

<u>Optimal actuator placement:</u>

- Crank-slider attachment point close as possible to the leg structure
- Crank-slider force applied perpendicularly to the structure
- Actuator in the center: optimal weight distribution



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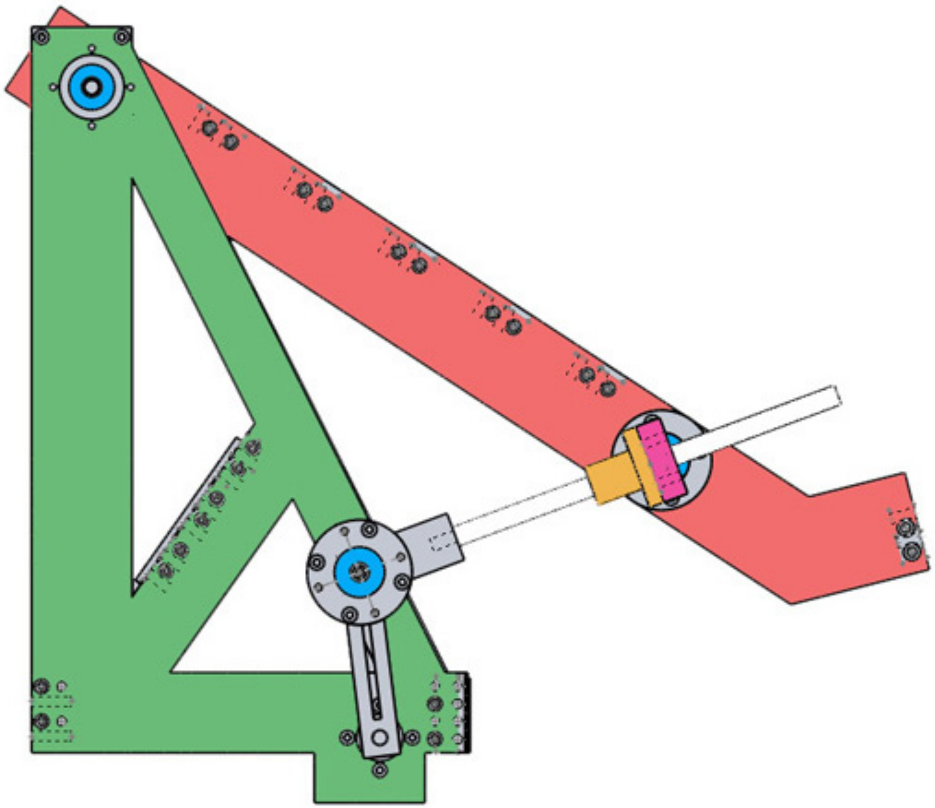
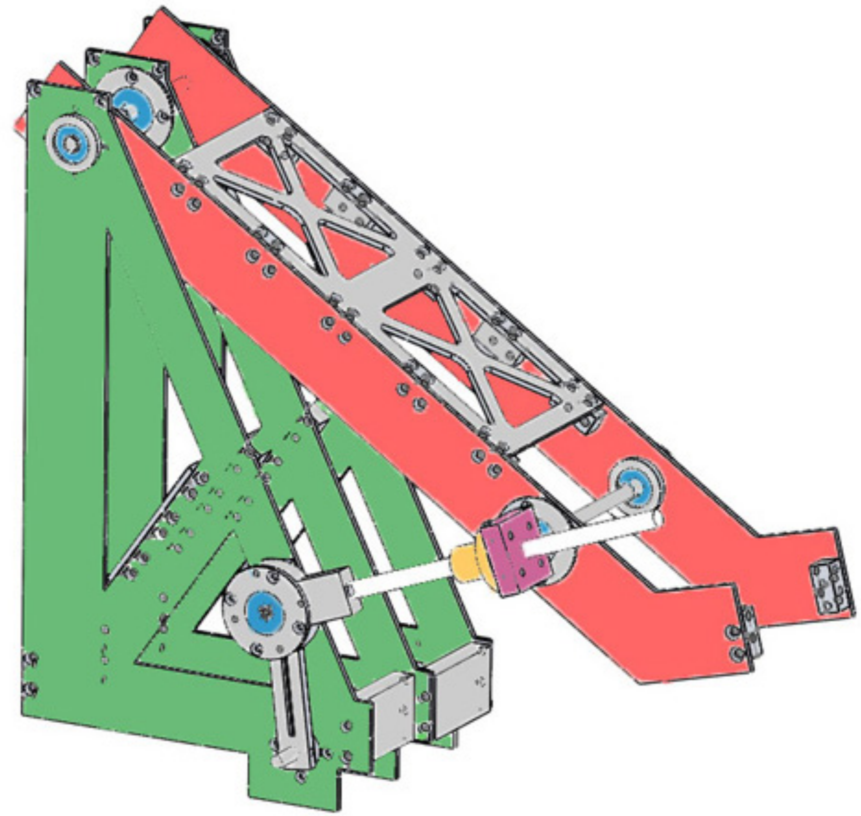
Design 2: Structure details

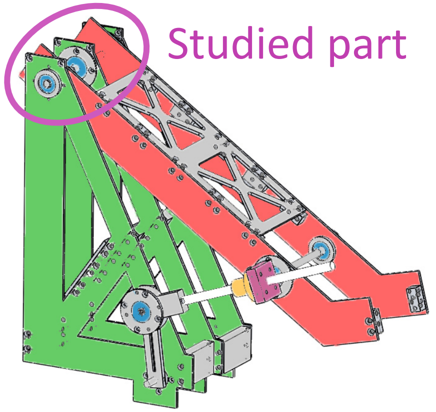




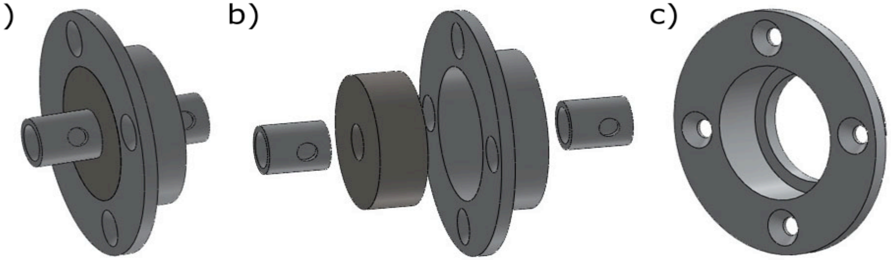
<u>Main components:</u>

- Bending axis / ball-bearing
- Crank-slider mechanism
- Motor/ gearbox

Bending axis / ball bearing



Ball bearing:



Bending axis:

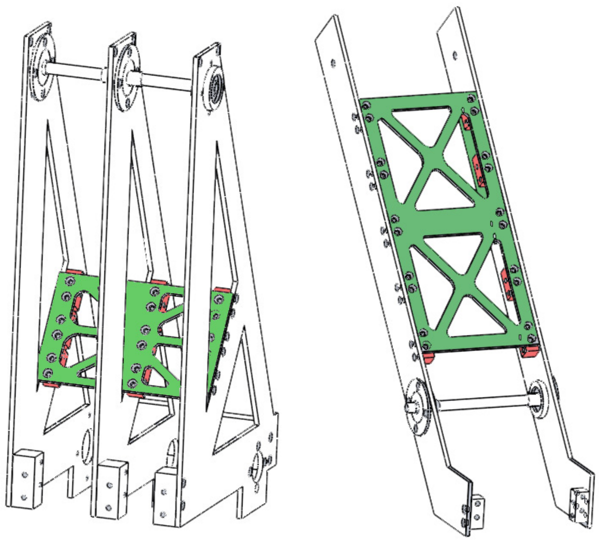
- Steel ⦰6mm

Flexion calculus: P= 36N (mass of front legs)

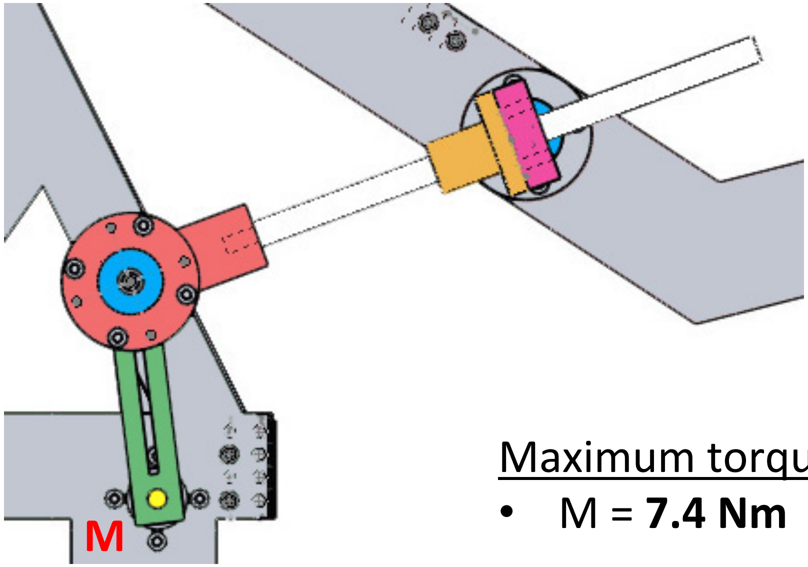
$$f = \frac{Pl^3}{3EI} = 2.8mm$$ with $$I_X = \frac{Pi \cdot d^4}{64}$$

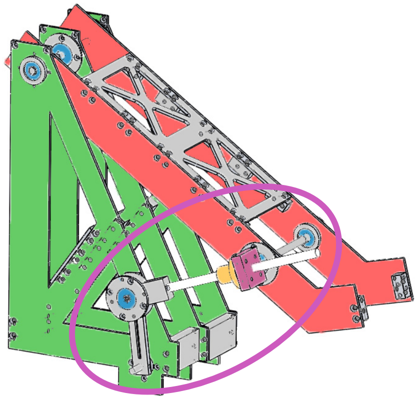
⇒ Maximum flexion: **2.8mm**

⇒ **Need of stiffening structure**



Crank-slider mechanism

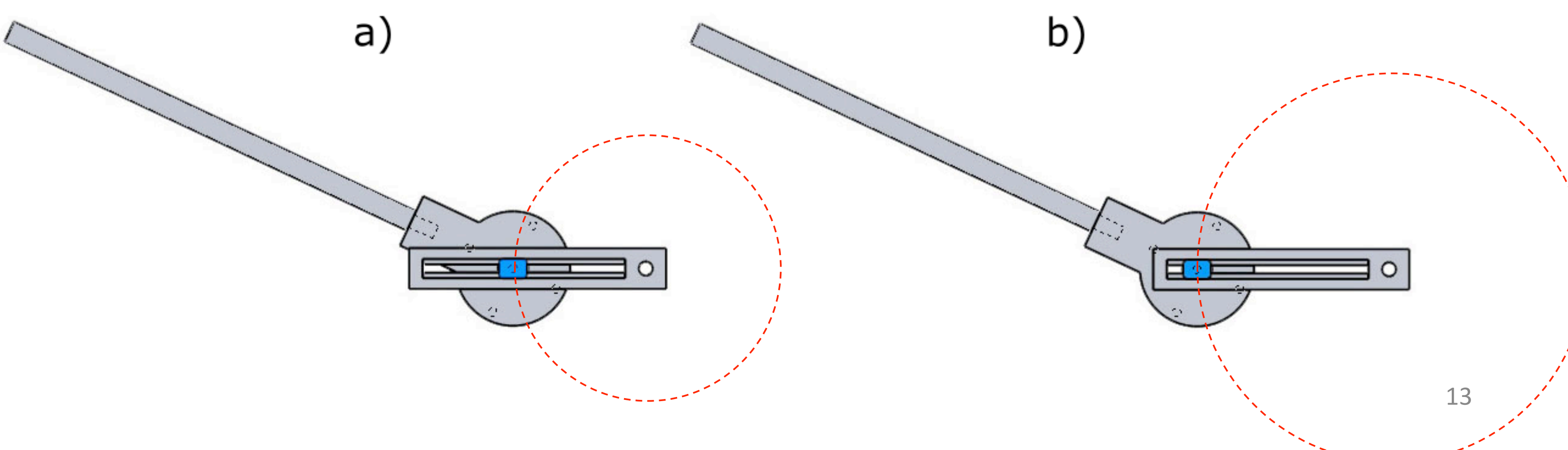




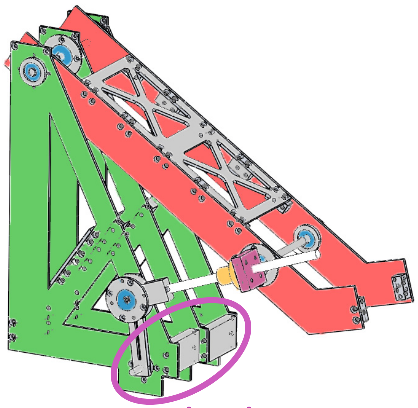
Maximum torque on rotation axis:

- M = **7.4 Nm**

Changing amplitude: changing first segment length **=> slider**



Motor / gearbox



Motor: Maxon EC-4pole 22

- Nominal torque: 64.9mNm
- Nominal speed: 15'600rpm

Our case

Planet. Gearbox: Maxon GP 32 C, 1-6 Nm, 111:1

- Reduction factor: $I_{reduction} = 111$
- Max bending freq.: $\frac{15'600}{111} = 140rpm = 2.33Hz$

$$M_{motor} = \frac{M_{crankslider}}{I_{reducction}} = \frac{7.4}{111} = 66mNm$$

Ideal case

Planet. Gearbox: Maxon GP 32 C, 1-6 Nm, 132:1

- Desired bending frequency: $2Hz = 120rpm$
- Needed reduction factor: $I_{reduction} = \frac{15'600}{120} = 130$

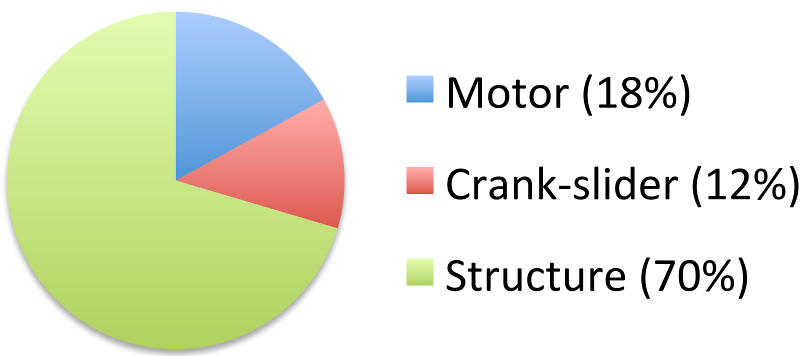
$$M_{motor} = \frac{M_{crankslider}}{I_{reducction}} = \frac{7.4}{130} = 57mNm$$

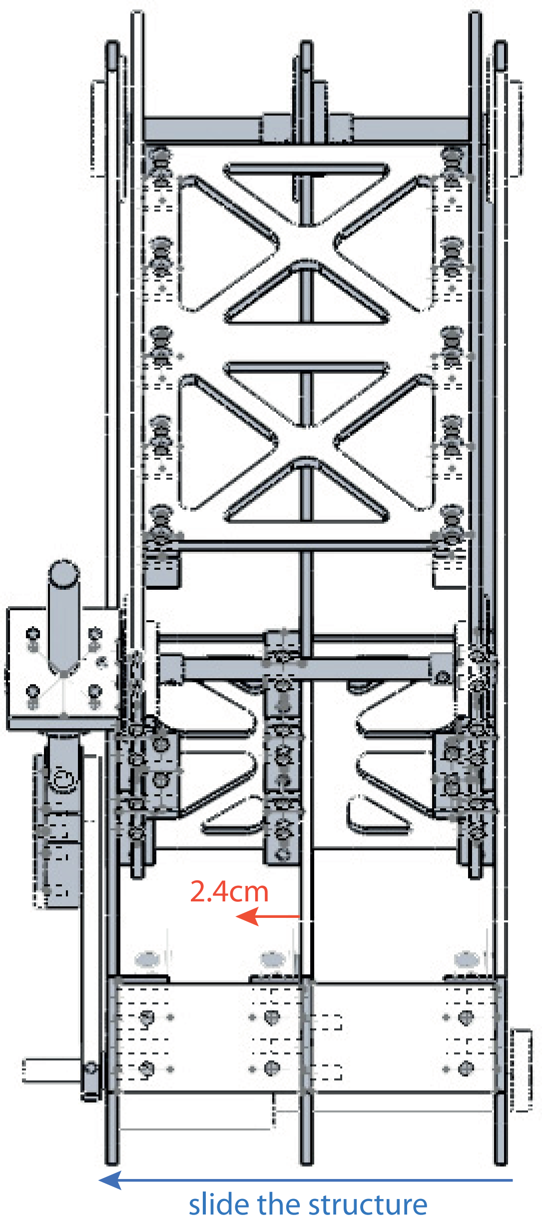
Weight analysis

<u>Weight:</u> **1.24kg**

- Motorization: 223g
- Crank-slider: 149g (possible weight improvement)
- Structure: 868g (possible weight improvement)

=> Weight improvement: **60-120g** (5-10%)



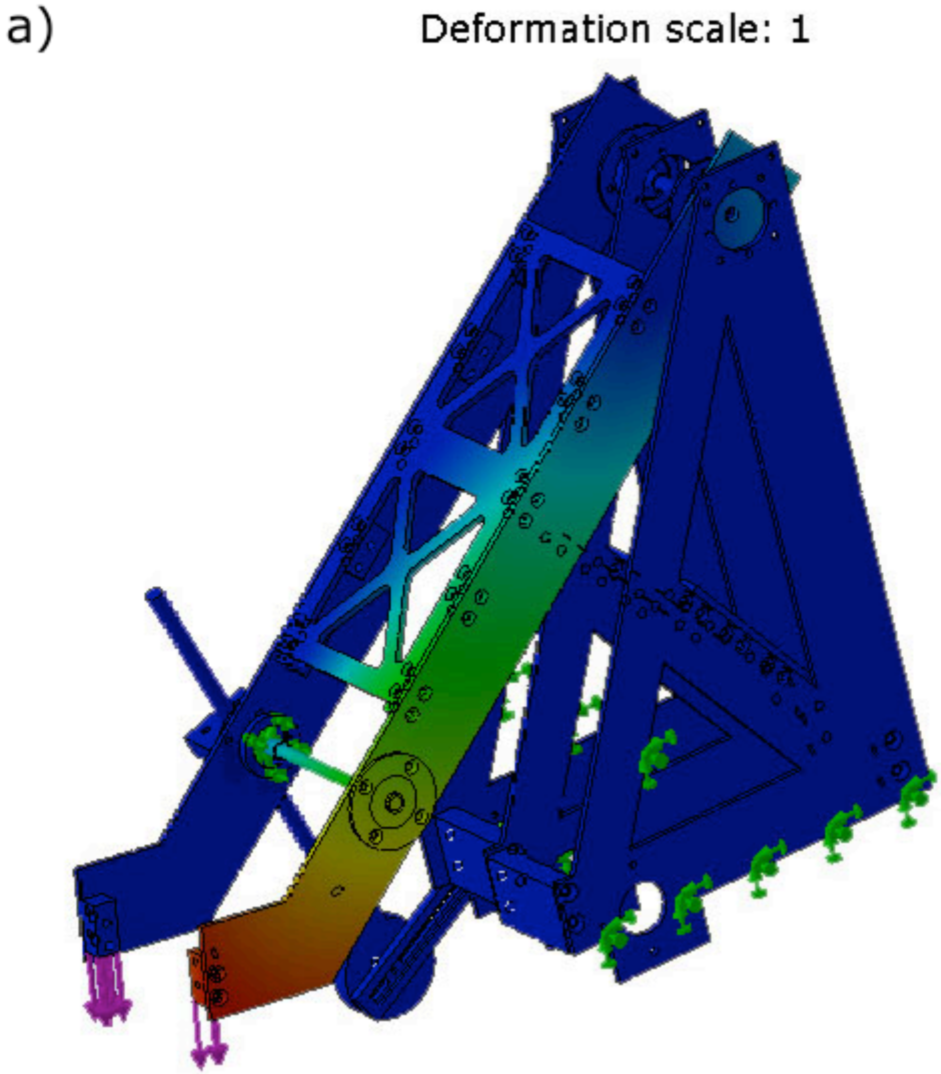


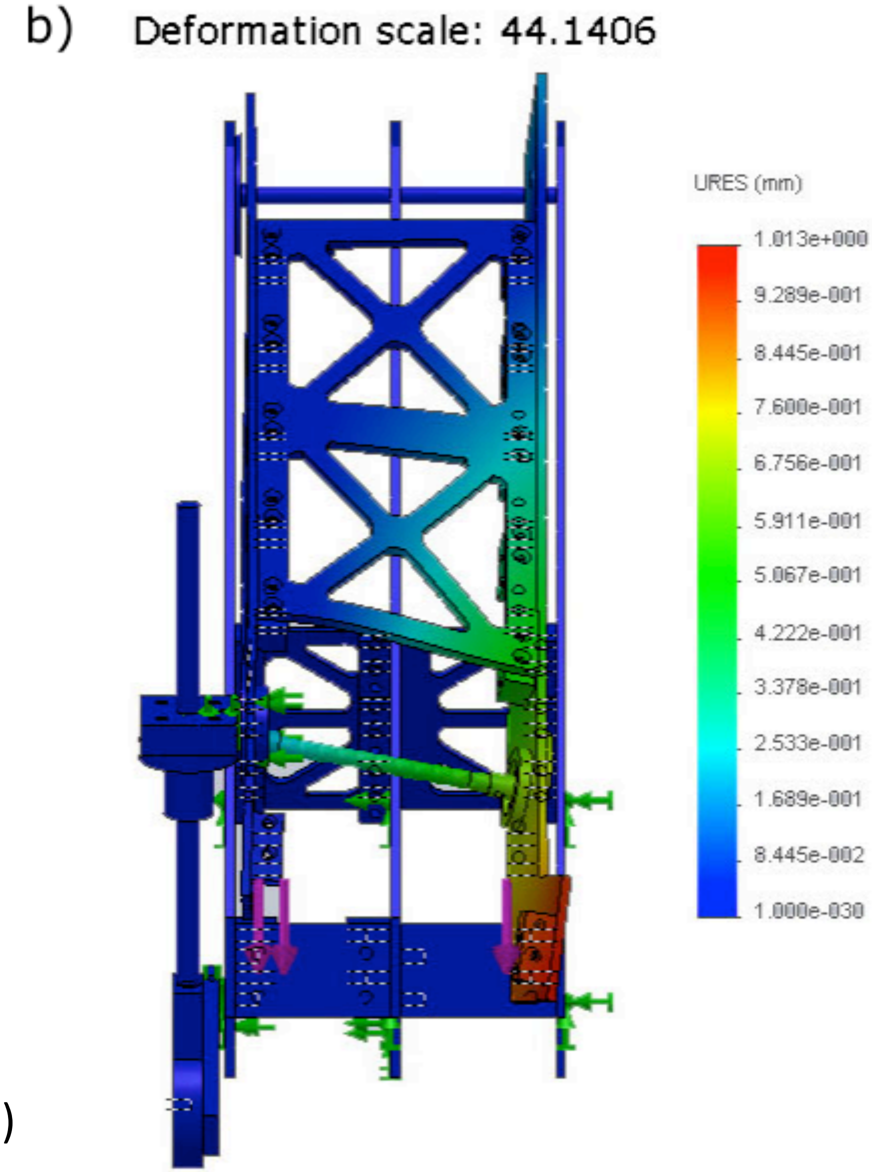
<u>Center of gravity:</u> **2.4cm** (from center)

- Solution: slide the structure

Help of Massimo

Deformation analysis





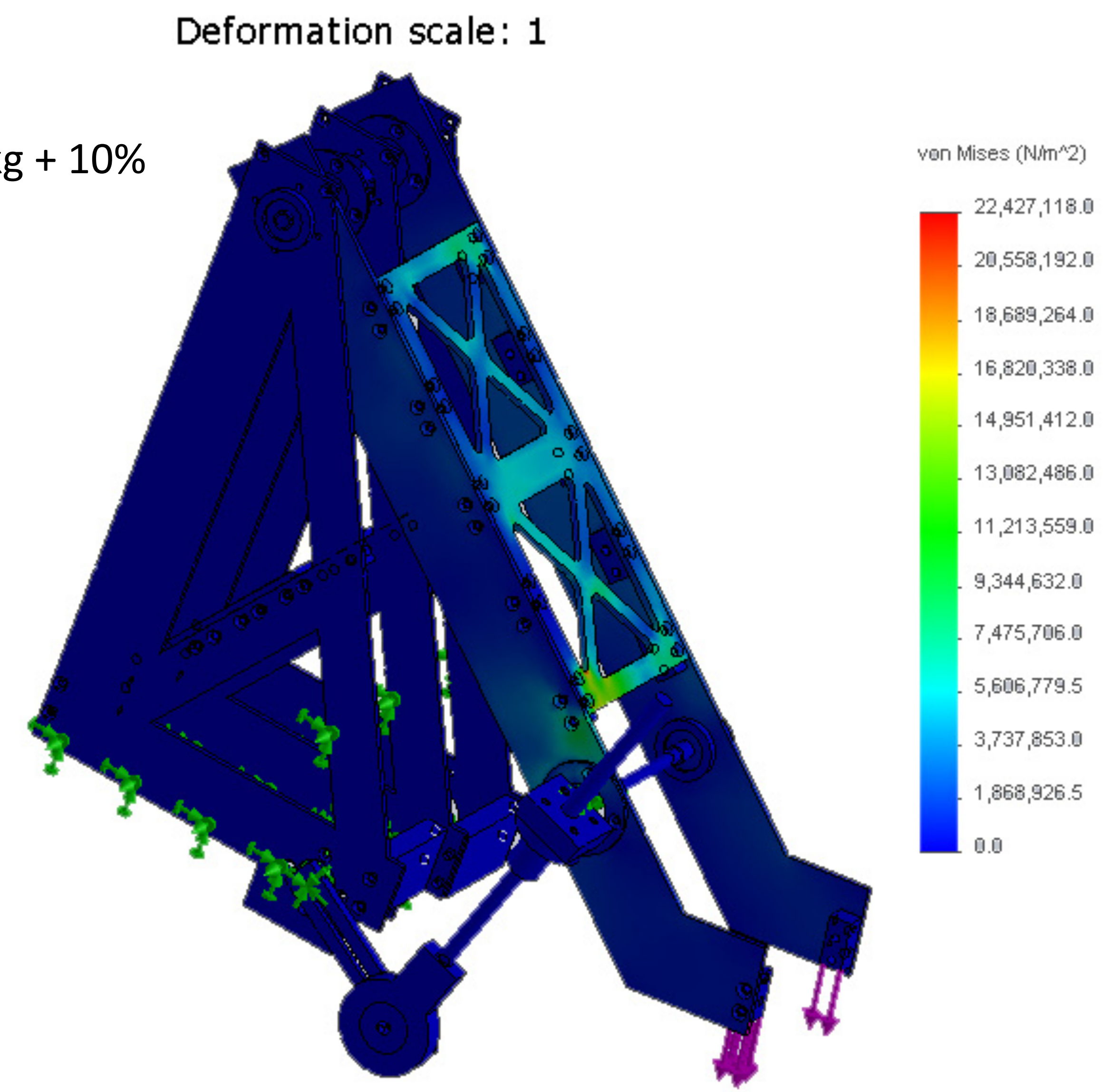
<u>Applied force:</u> **40N** (leg weight 3.6kg + 10% margin)

=> Maximum deformation = **1.01mm**

Stress analysis

Applied force: **40N** (leg weight 3.6kg + 10% margin)

=> Maximum stress location= **stiffening plate**



Goals summary

Goals	Status	Solution / Results
Actuated bendable spine	✓	DC motor + crank-slider
Possibility to change movement amplitude	✓	Slider
Possibility to change elastic behavior of the spine	✓	Clamping rings
Bending frequency	✓	1.85Hz
Bending amplitude	✓	30°
Possibly of torque controlled mechanism	✓	1 encoder on axis motor + 1 encoder on bending axis
Lightweight	✓	1.2kg, max improvement 5-10%
Build the mechanism	✓	
Test and compare performances	X	

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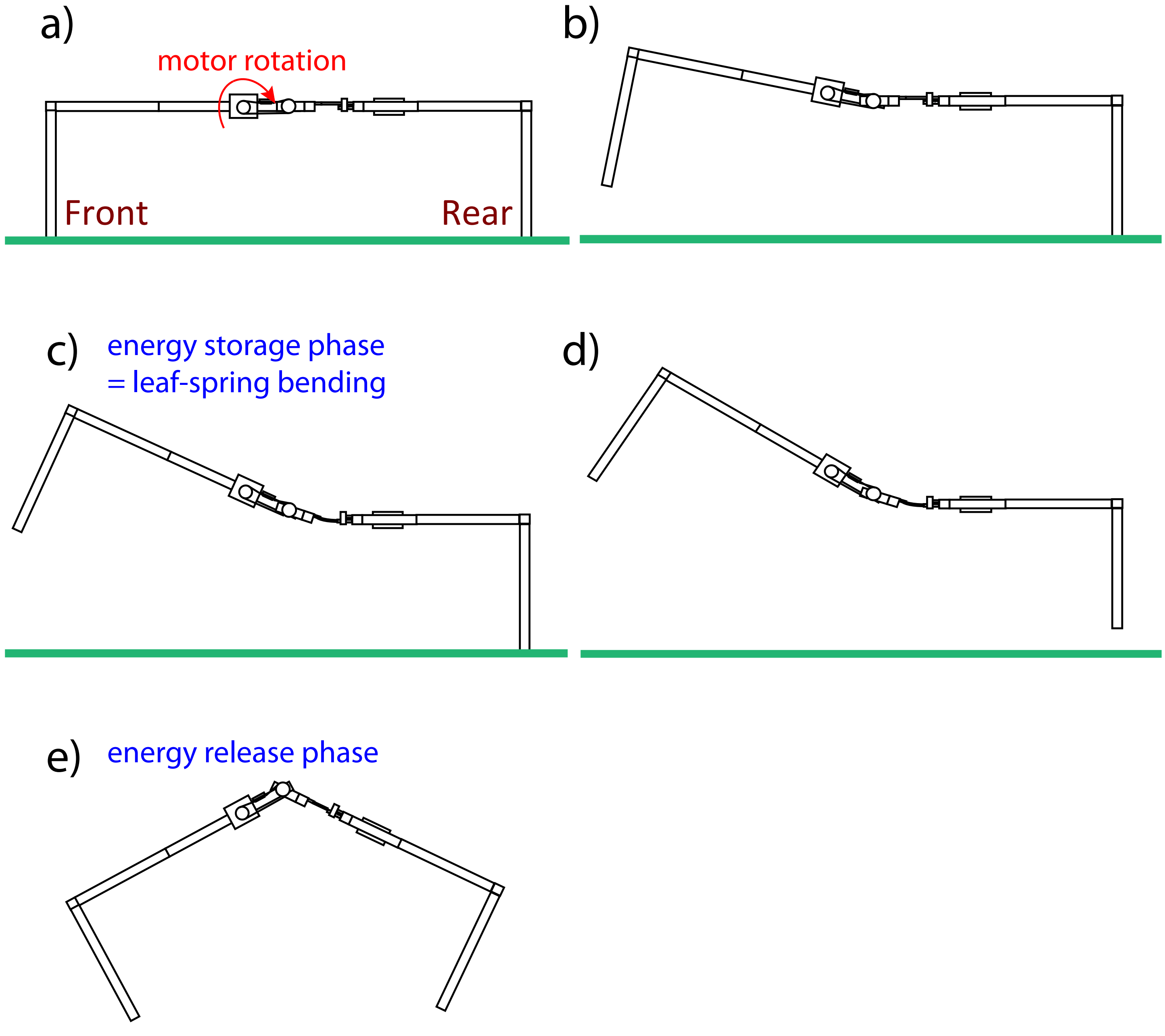
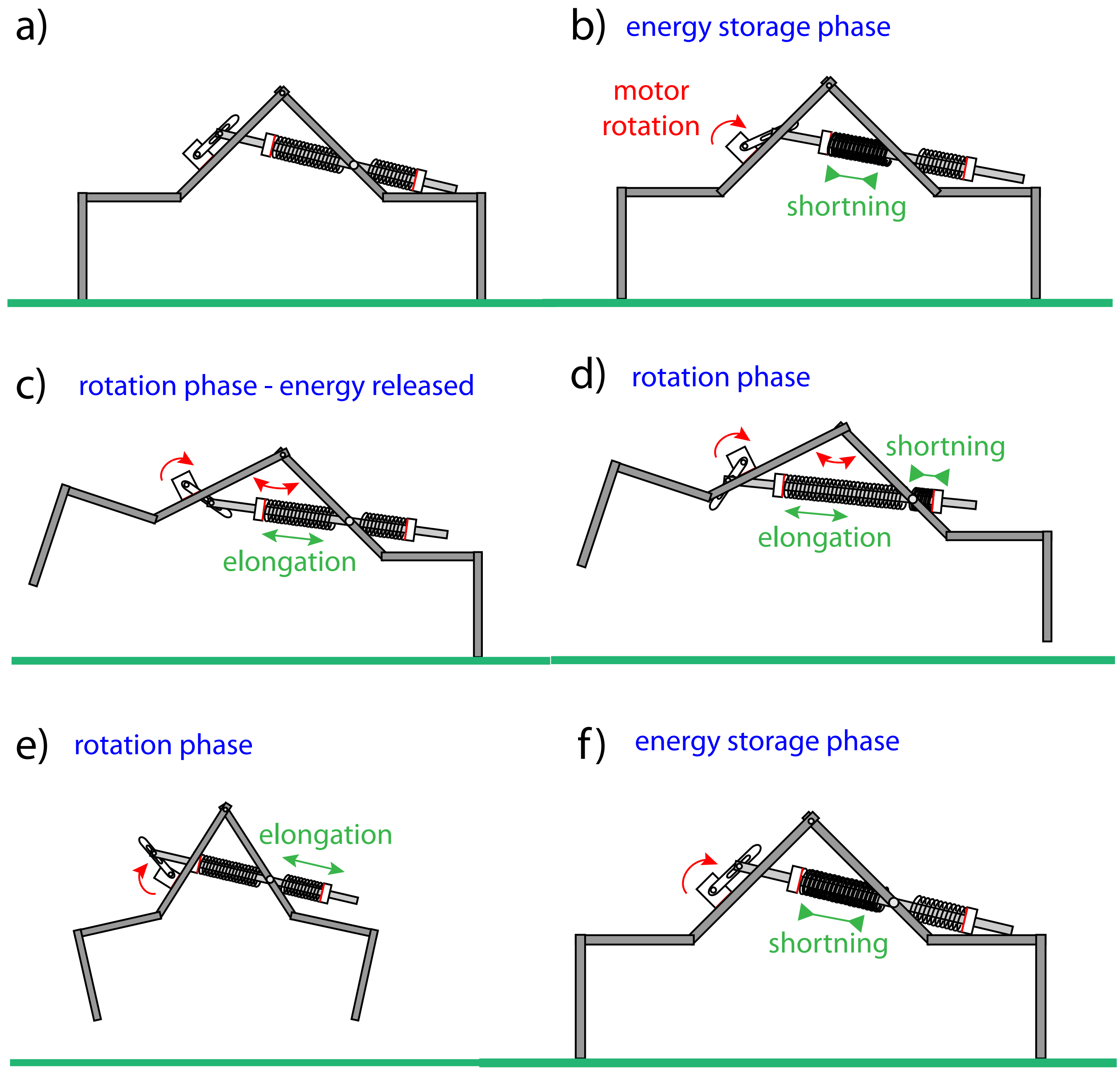
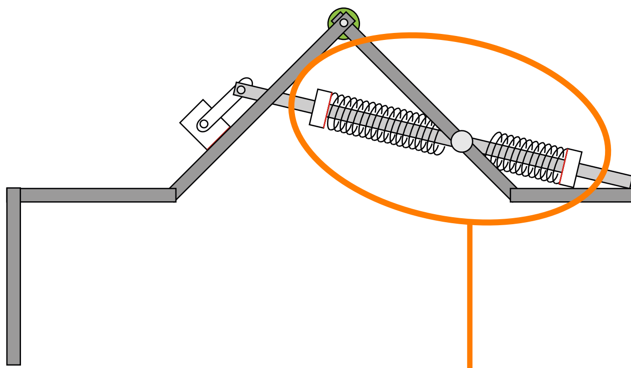
Appendix 1 - Design 1: Working principle



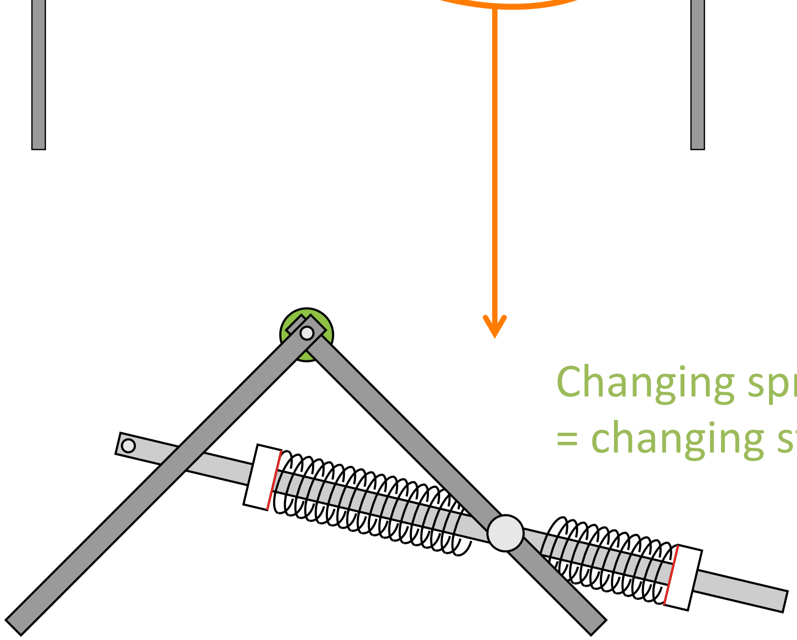
Appendix 2 - Design 2 : Working principle



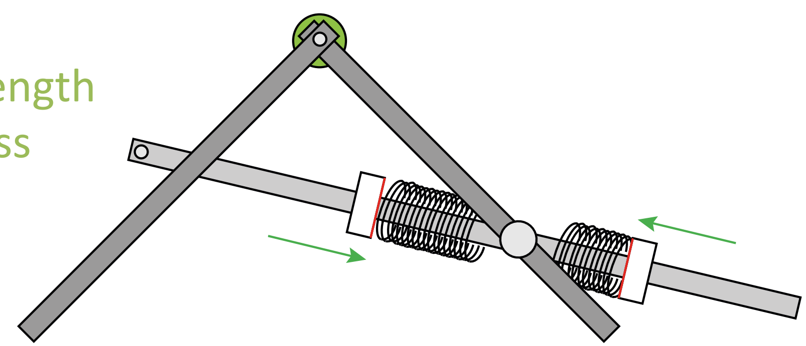
Appendix 3 - Design 2: Changing stiffness mechanism



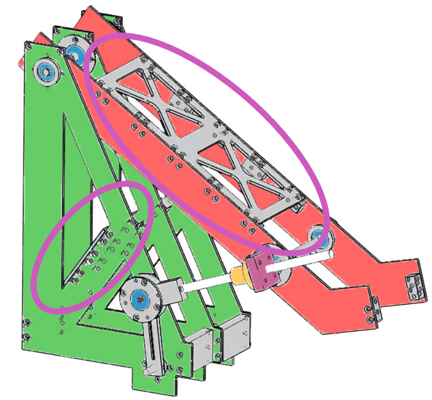
Options:
- 2 motors + worm-slider
- Clamping ring



Changing spring length
= changing stiffness

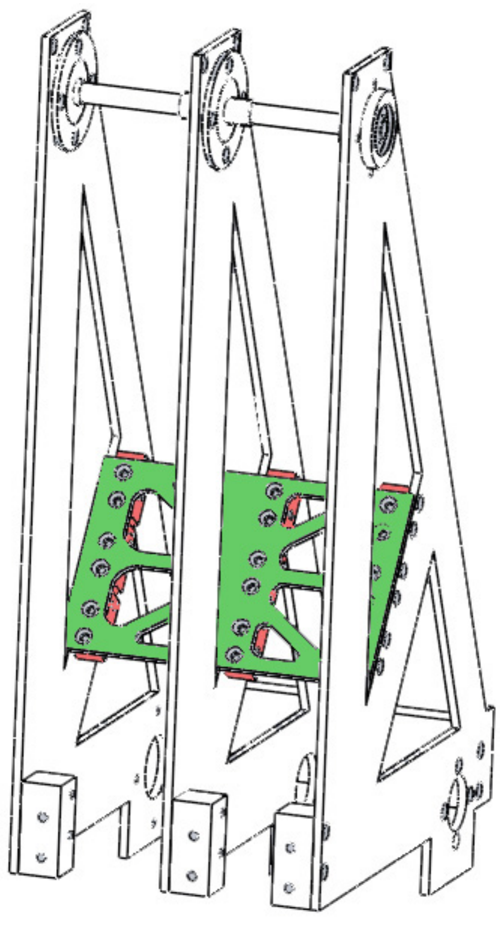


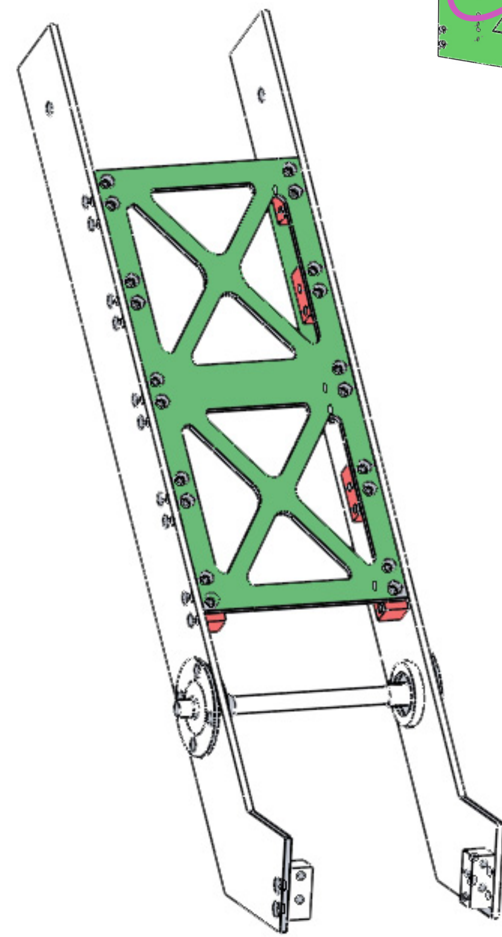
Structure stiffening



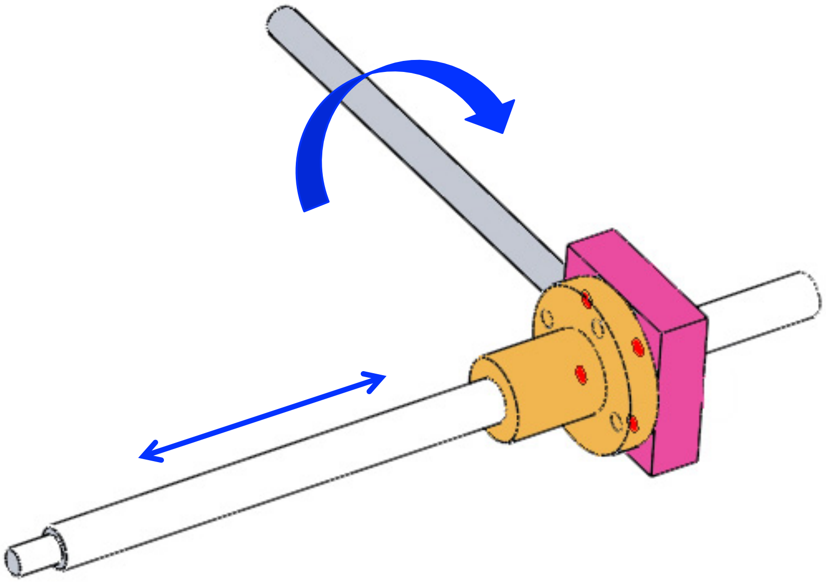
<u>Stiffening:</u>

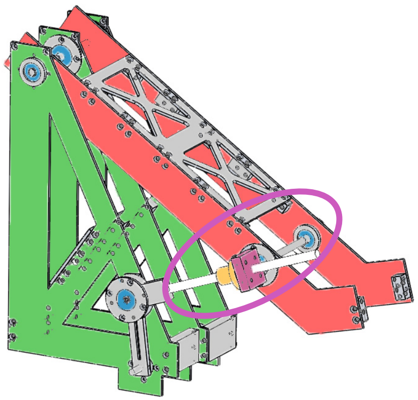
- Goal: Create a volume structure
- Carbon fiber plates (grid pattern=less weight)
- Fixation: POM parts screwed





Ball spline / linear springs





Studied part

Ball-spline:

- Pink: fixation to the axis
- Steel axis: ⦰8mm

Linear spring:

- DIMENTIONNING
- DRAWING OF SPRING MOVEMENT