MSMS Project

Modelling, analysis and optimization of a Formula 1 DRS

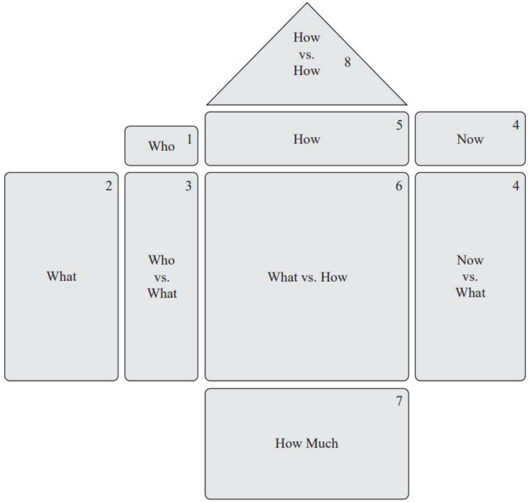
System design

Objective:

1. System description specifications
2. Evaluation criteria
3. Target values

Tools:

- Quality Function Deployment (QFD)
- House of Quality



Customer:

Reality

1. Internal groups
2. FIA
3. Pilot

Our project

- **engine** team
- **aerodynamics** team
- **mechanical** team

Requirements:

- Fixed sum method for relative importance
- Focus on the main ones

How important is it <x> if <y>?	**Importance**
The force of the actuators of the DRS wins the external forces acting on it.	**43**
The DRS quickly switches between open and closed positions.	**42**
The DRS disturbs as little as possible the aerodynamics.	**41**
The change of state of the DRS happens without residual vibrations.	**38**
The DRS uses as little energy as possible.	**34**
The DRS weighs little	**25**
Failures are not allowed.	**24**
The DRS is resistant to the forces and vibrations acting on the vehicle.	**22**
Capable of working with any environment conditions.	**14**
Easy to install and disassemble	**7**
The DRS is made of standard parts.	**6**
Easy to maintain and repair.	**4**

HOQ

Main considerations *a priori*

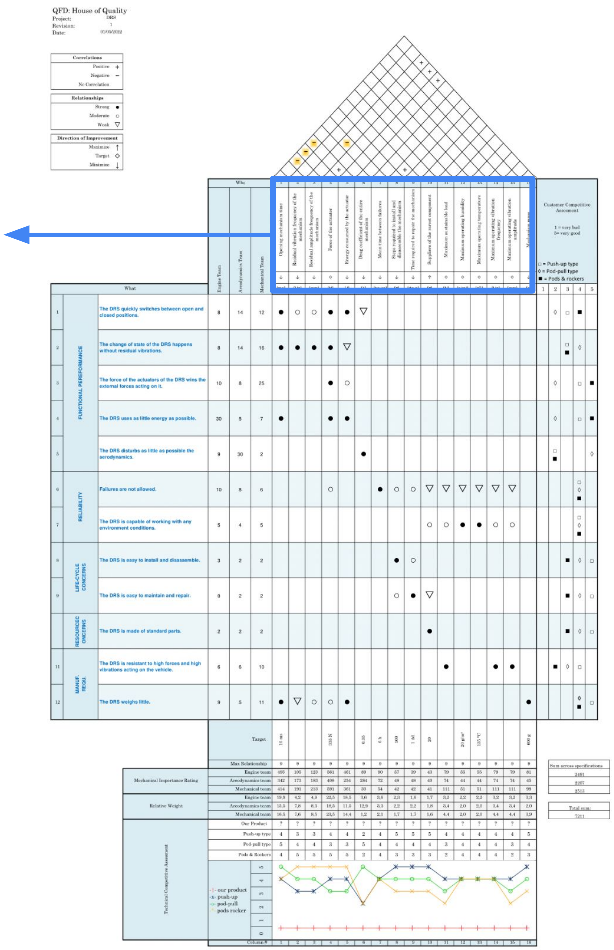
- Different mechanisms as competitors
- High level analysis w.r.t. requirements and engineering specifications

Main considerations *a posteriori*

The final models and simulations mainly focus on:

- the opening times
- the mechanisms velocities
- the actuating forces
- the mechanisms masses

[ms]	←	Opening mechanism time	1
[Hz]	←	Residual vibration frequency of the mechanism	2
[mm]	←	Residual amplitude frequency of the mechanism	3
[N]	◇	Force of the actuator	4
[J]	←	Energy consumed by the actuator	5
[1]	←	Drag coefficient of the entire mechanism	6
[hours]	←	Mean time between failures	7
[#]	←	Steps required to install and disassemble the mechanism	8
[days]	←	Time required to repair the mechanism	9
[#]	→	Suppliers of the rarest component	10
[N]	◇	Maximum sustainable load	11
[g/m³]	◇	Maximum operating humidity	12
[°C]	◇	Maximum operating temperature	13
[Hz]	◇	Maximum operating vibration frequency	14
[mm]	◇	Maximum operating vibration amplitude	15
[g]	←	Mechanism mass	16



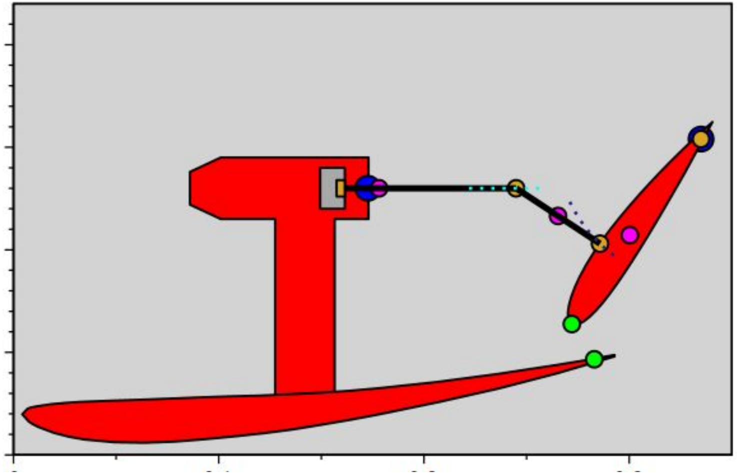
Kinematic analysis

Objective:

1. Visualizing the mechanism
2. Computing the piston stroke
3. Analysis of the mechanism velocity

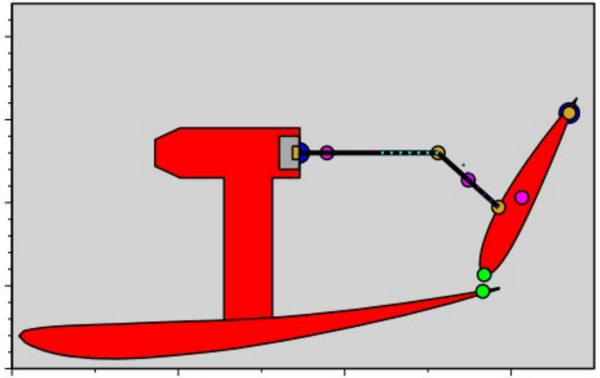
Tools:

- Direct kinematics
  - Position analysis
  - Velocity analysis
  - Acceleration analysis
- Inverse kinematics

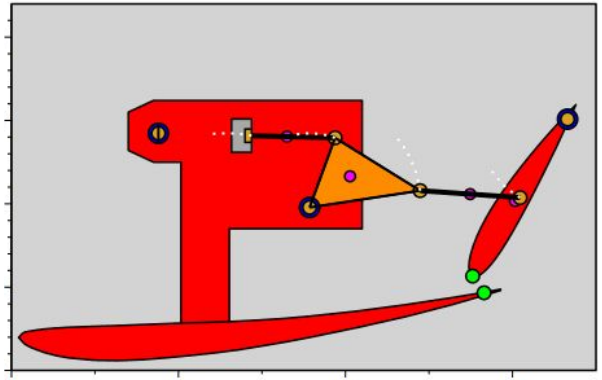


Position analysis

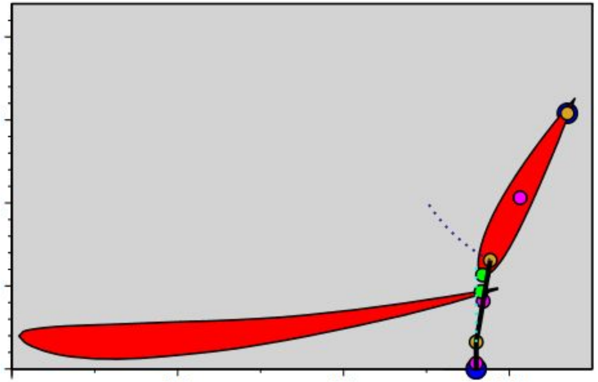
Solution of the kinematic constraints



Pod Pull



Pod Rocker

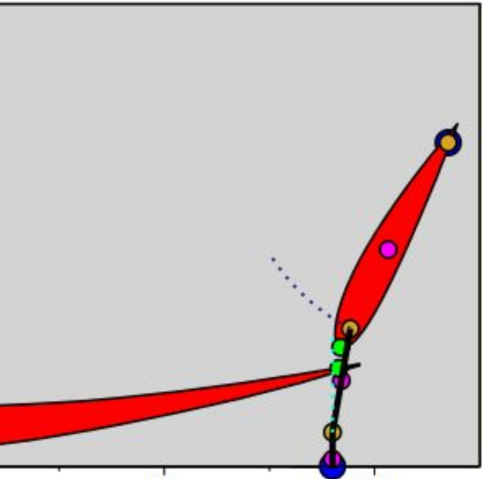


Pod Push

Position analysis

Inverse kinematics

Solved minimizing: $$CostFunction(s(t)) = (Y_{upper\_wing} - Y_{lower\_wing} - imposedDistance)^2$$

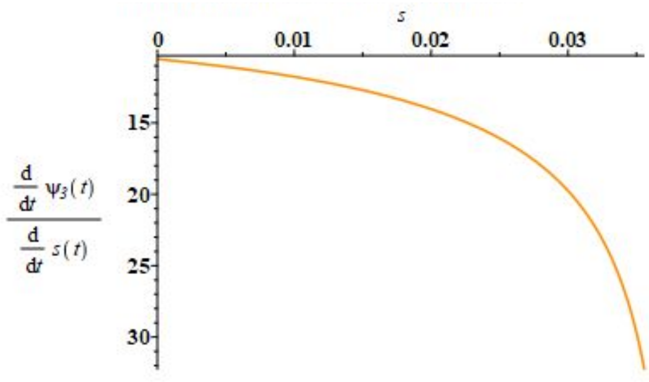


Piston stroke that produces the opened configuration:

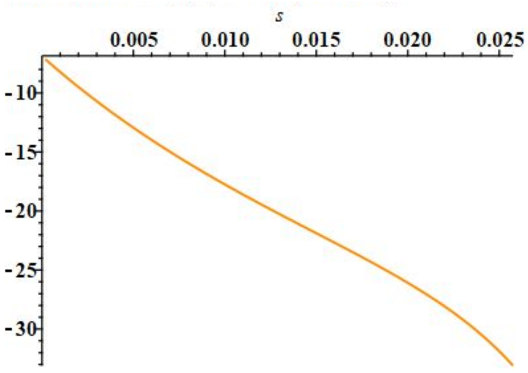
	Pod Pull	Pod Rocker	Pod Push
Piston stroke	35.58 mm	25.55 mm	45.50 mm

Velocity analysis

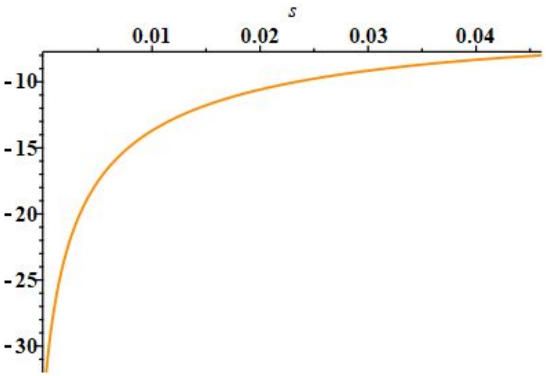
Velocity ratios between piston and wing movement



Pod Pull



Pod Rocker



Pod Push

Aerodynamic data

Source:

- study on airflow characteristics of rear wing of F1 car, link

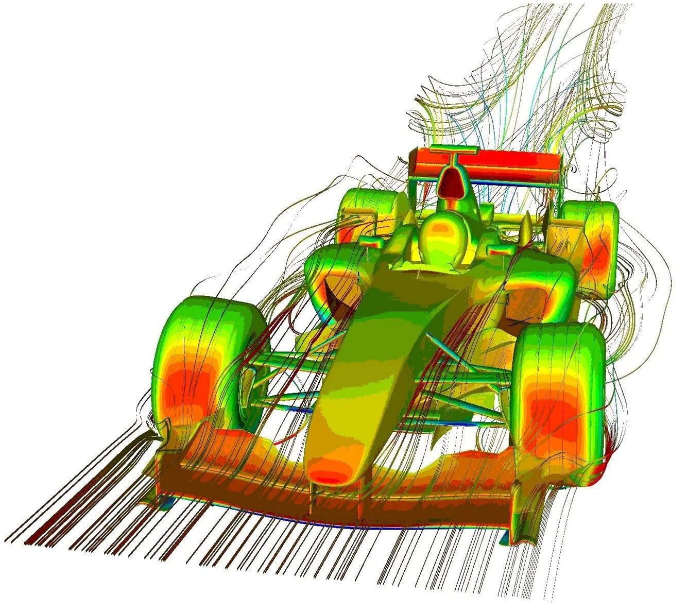
	Wing name	Chord [mm]
Main plane	BE50	290
Flap wing	NACA 2415	120

Status	Drag [N]	Down [N]
closed	145.51	819.12
open	51.32626	745.62

Dynamic Analysis

Objective:

1. Define a desired profile for the opening of the wing
2. Determine the force required to follow the trajectory
3. Analyze the reaction forces
4. Analyze the effect of friction



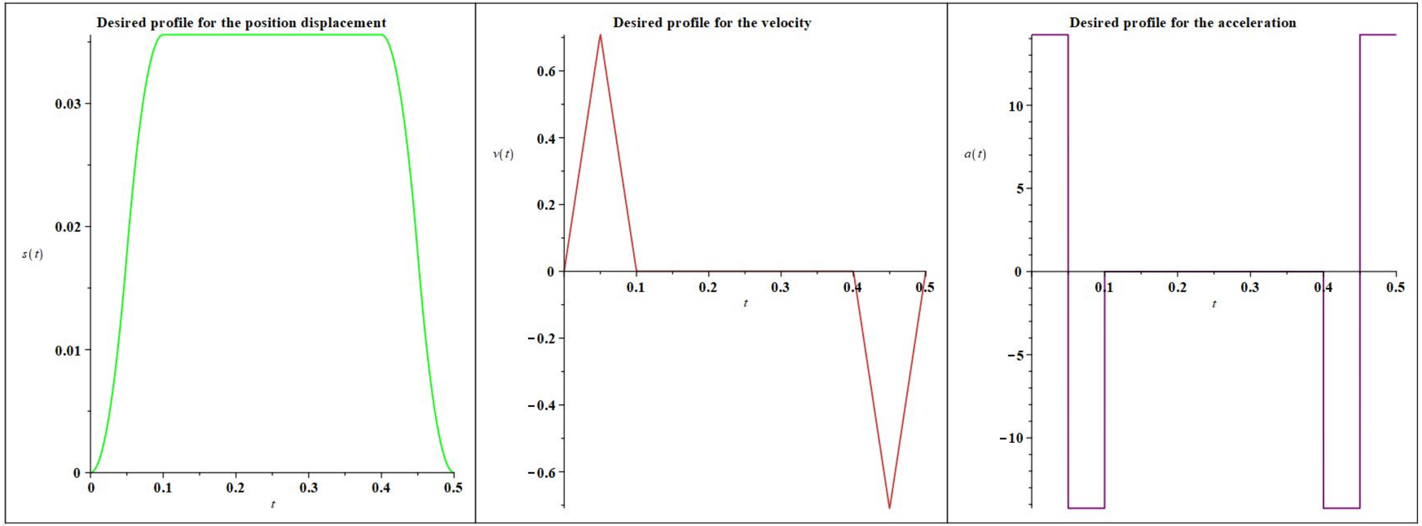
Tools:

- Inverse Dynamics
- Direct Dynamics

Desired profile

Maximum Acceleration (Fixed time period)

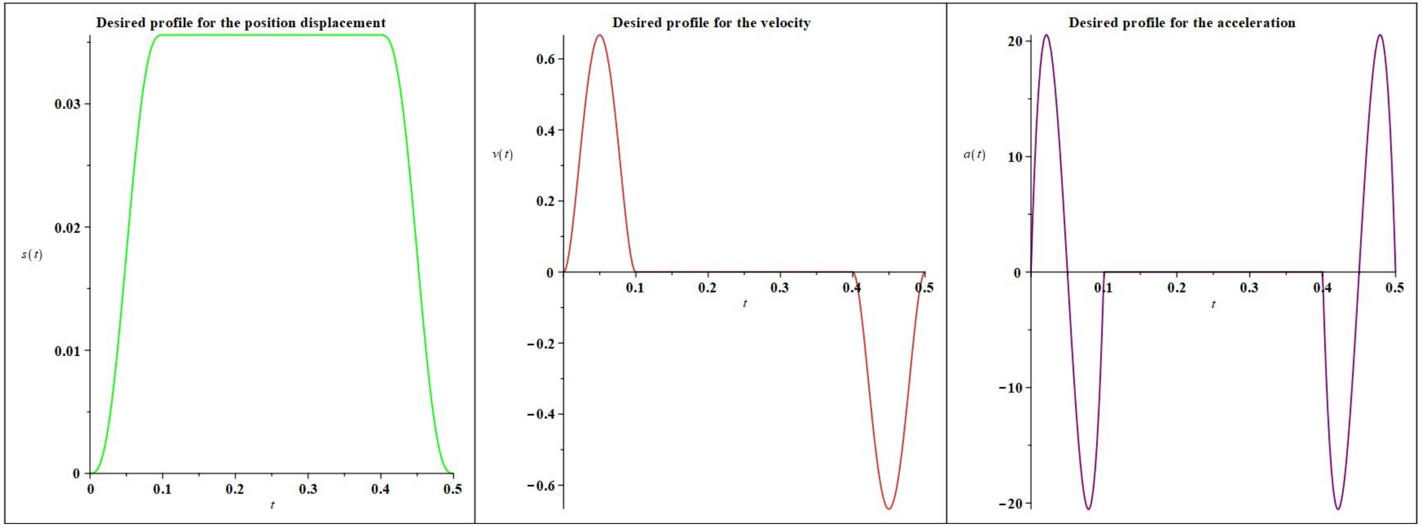
- Most efficient repositioning possible.
- Highly discontinuous force required.



Desired profile

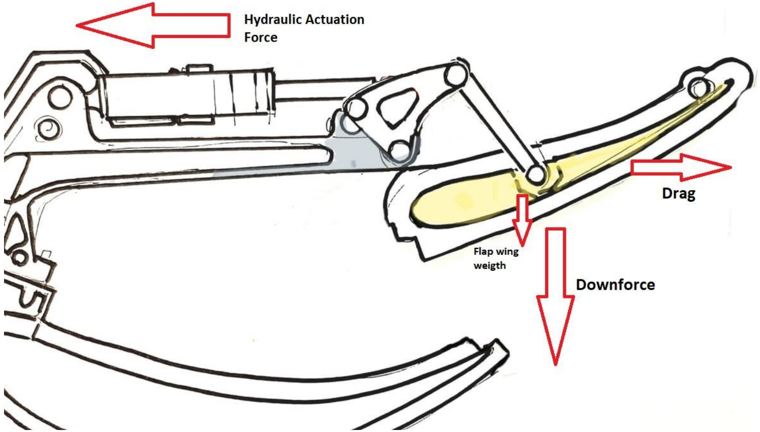
Minimum jerk (Fixed time period)

- Continuous and smooth acceleration.
- Higher maximum force required.

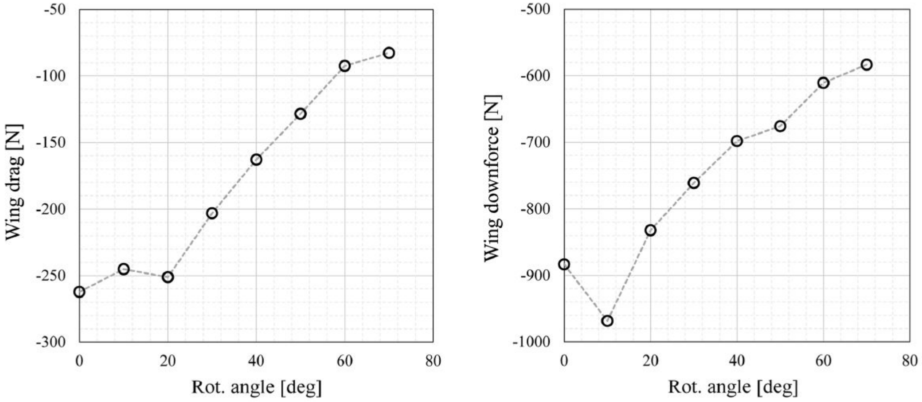


Dynamic scheme

External forces applied



Drag and downforce
estimation:



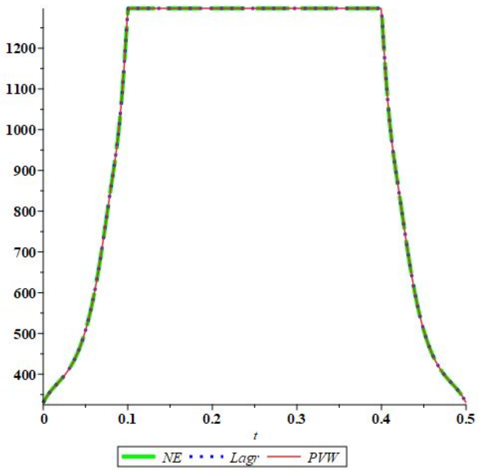
(a) (b)

(Work by Mauro Dimastrogiovanni, Giulio Reina and Andrea Burzoni)

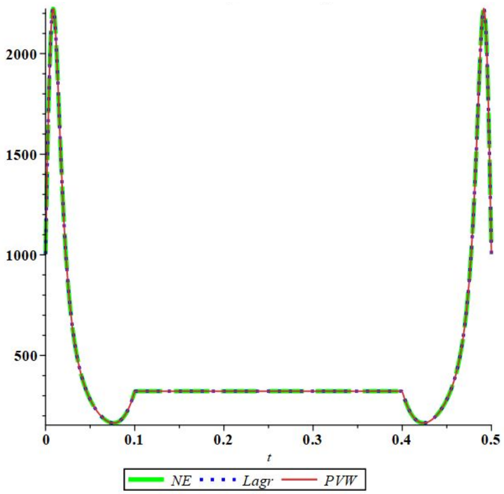
Inverse Dynamics

Solving the inverse dynamics problem we obtain the *required force* to obtain the piston profile:

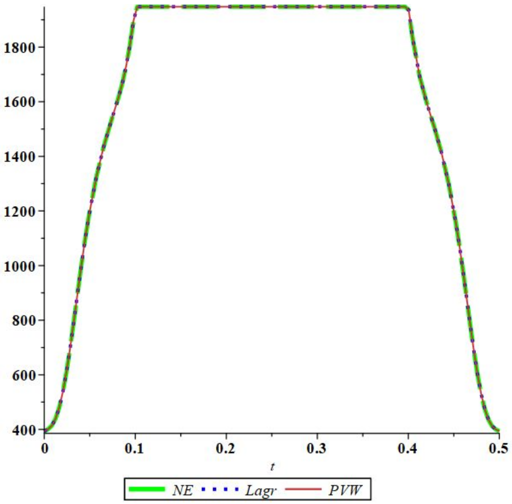
Pod Pull



Pod Push



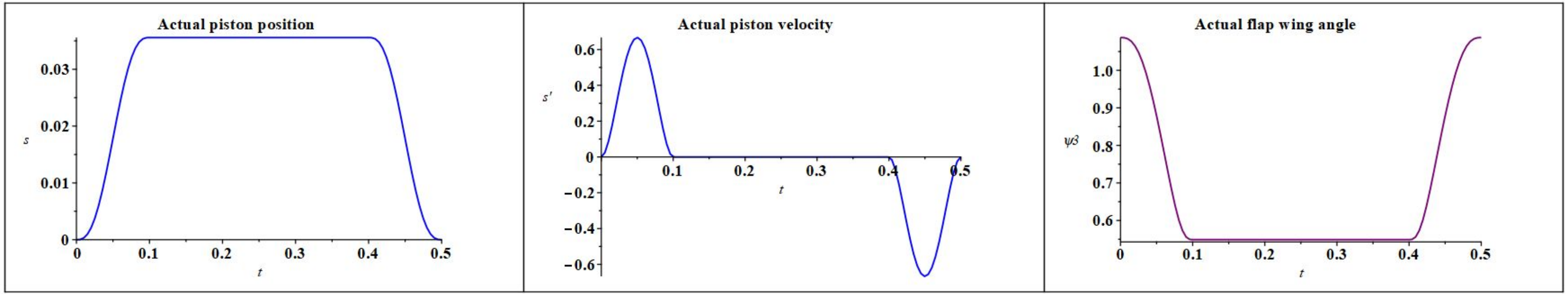
Pod Rocker

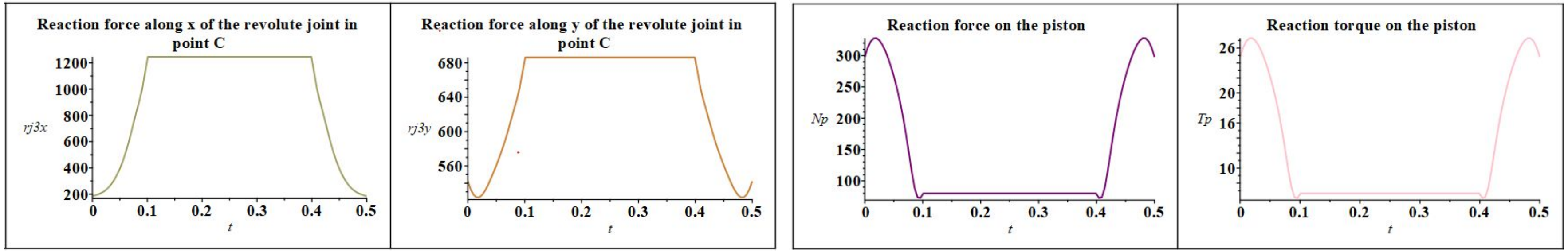


Direct Dynamics

Pod Pull

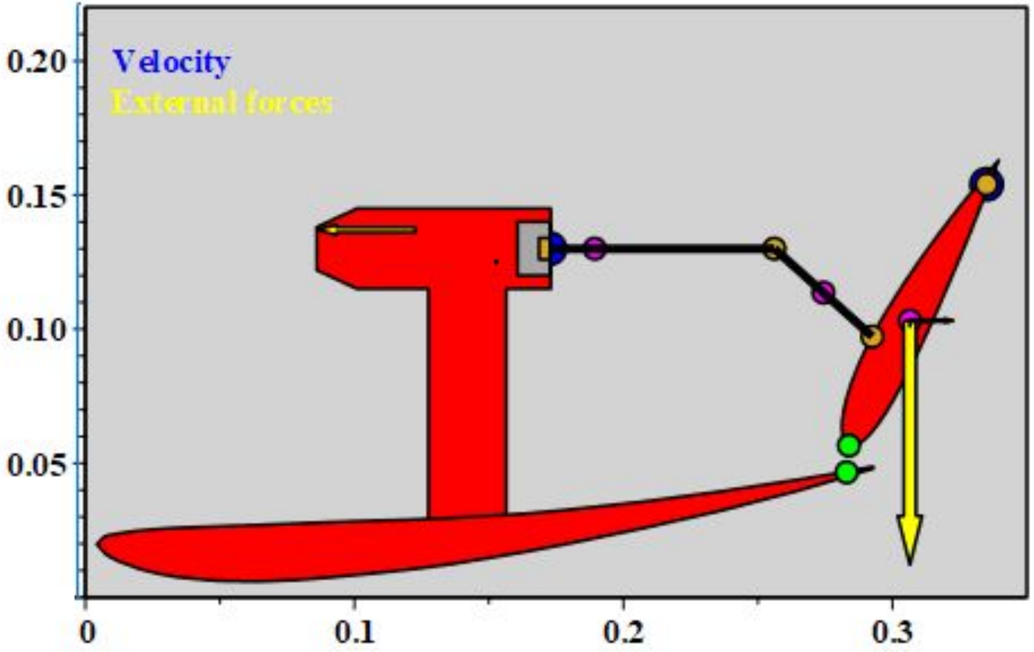
Substituting the obtained force profile and solving the DAE:





Direct Dynamic

Representation of the forces involved



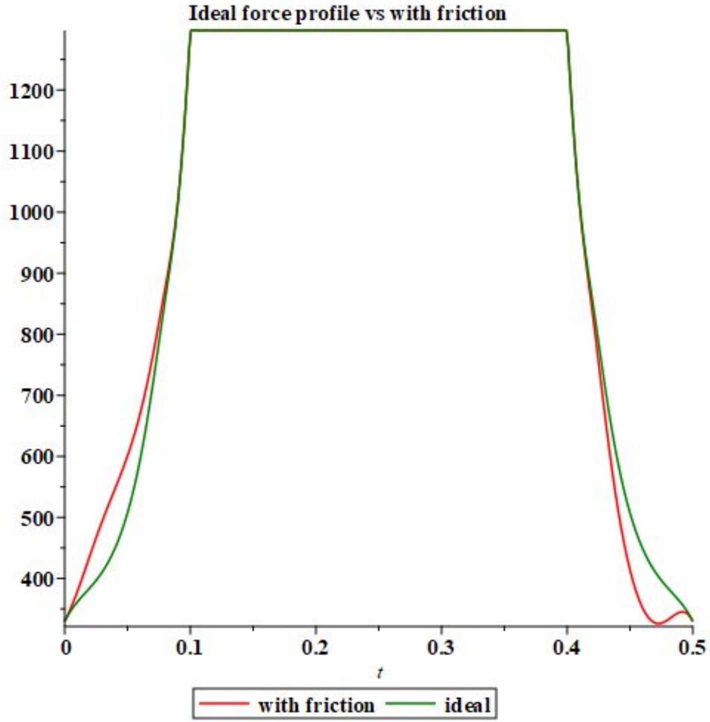
Effect of friction

Pod Pull

- Considered the sliding friction between piston and chamber (Coulomb model):

$$F_A = sign\left(\frac{ds(t)}{dt}\right) \cdot \eta_{fric} \cdot abs\left(N_p(t)\right)$$

- Negative effect in the opening maneuver, positive effect in the closing repositioning.



Optimization

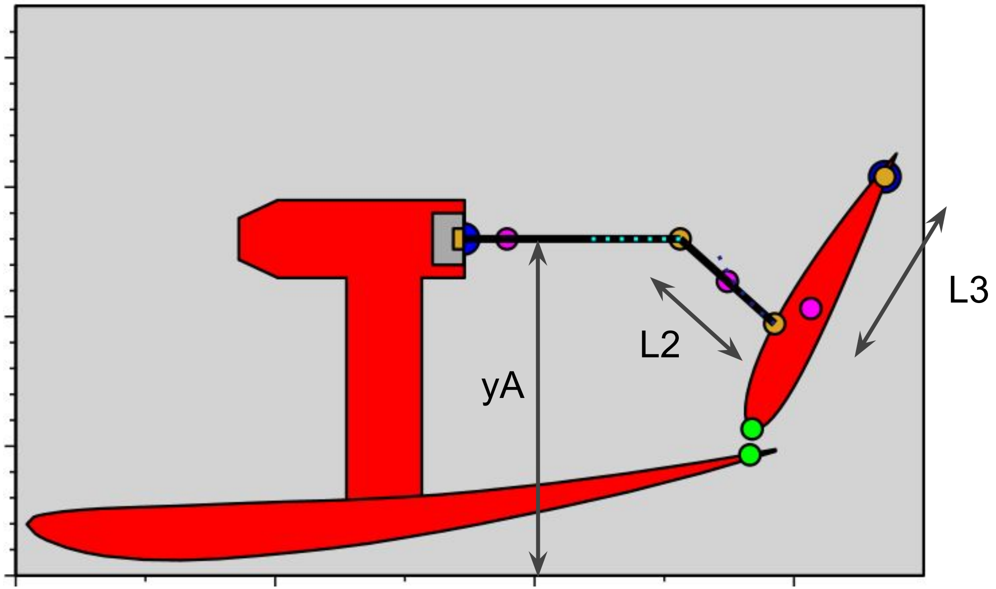
Objective:

Manipulation of L2, L3 and yA in order to:

1. Minimize piston stroke
2. Minimize overall weight
3. Maximize wing opening velocity
4. Reduce force required by the actuator

Tools:

- Functions sampling
- Cost functions minimization



Optimization

Definition of the cost function

$$\textbf{Cost} =$$

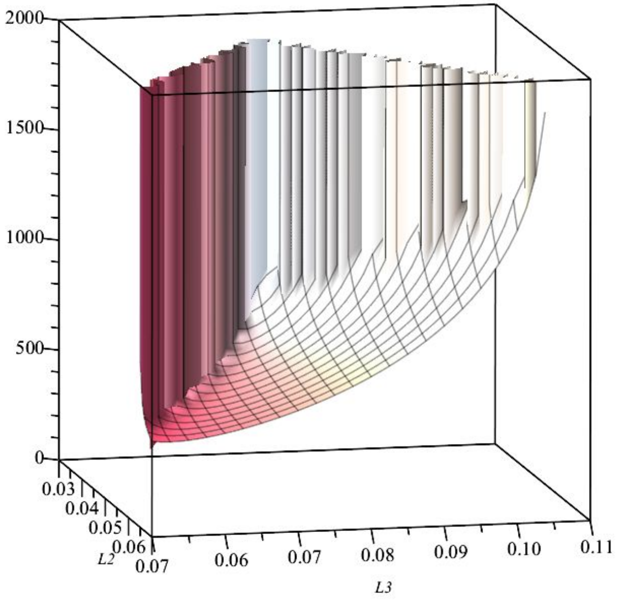
$$\left(\frac{1}{2}\Phi \cdot \Phi^T\right) +$$ *(kinematic constraints)*

$$(s_{max} - s_{min}) +$$ *(piston stroke)*

$$\left(-\sum_{\psi_3 \in range} \tau^{-1}\right) +$$ *(velocity ratio)*

$$\left(\sum_{t=0}^{T_{tot}} F_{piston}\right) +$$ *(required force)*

$$(\rho \cdot (L_1 + L_2))$$ *(mechanism mass)*

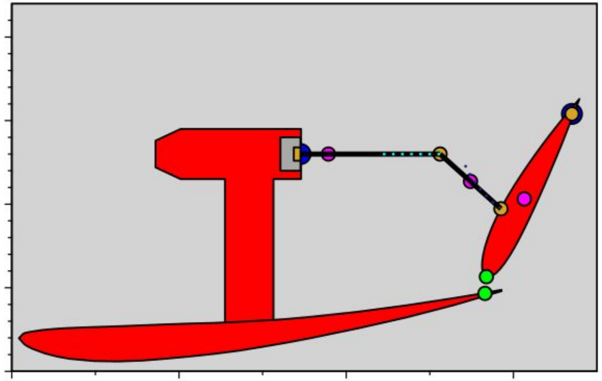


(Each factor of the cost function has been normalized)

Optimization results

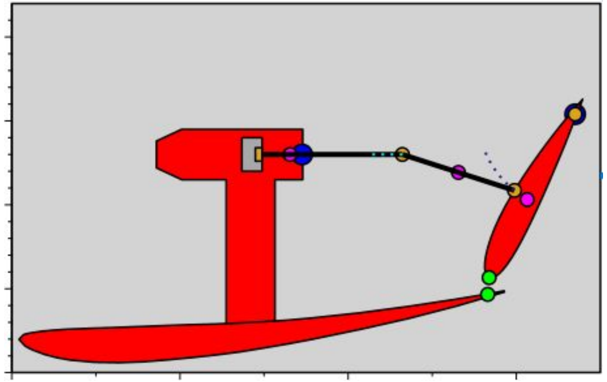
Pod Pull

Starting mechanism



L2 = 0.049 m
L3 = 0.070 m
yA = 0.130 m

Optimized mechanism

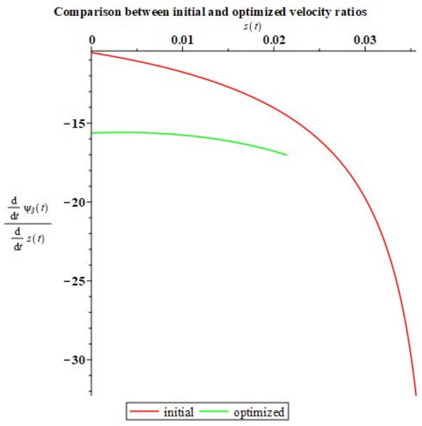


L2 = 0.070 m
L3 = 0.057 m
yA = 0.130 m

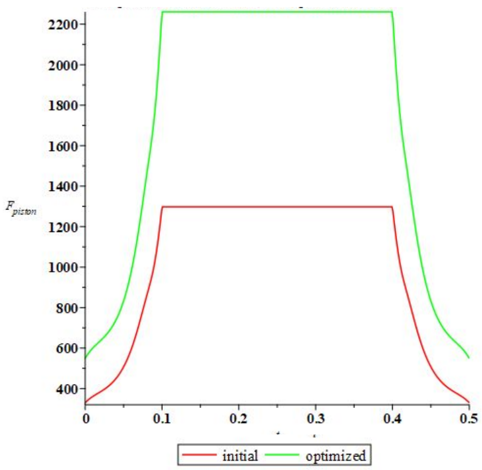
Optimization results

Pod Pull

- Piston stroke:
  0.0356 m *pre-optimization*
  0.0215 m *post-optimization*
- Weight:
  323.4 g *pre-optimization*
  377.5 g *post-optimization*
- Velocity ratio (wing/piston stroke):



- Required piston force:



Control

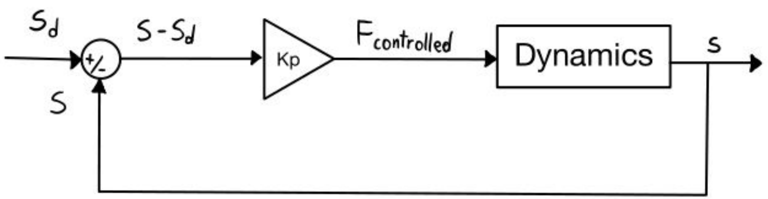
Objective:

1. More realistic simulation
2. Estimate the value of the gain of proportional controllers

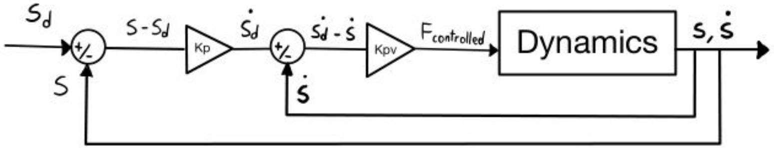
Tools:

- Position loop
- Position-velocity loop

Position Loop

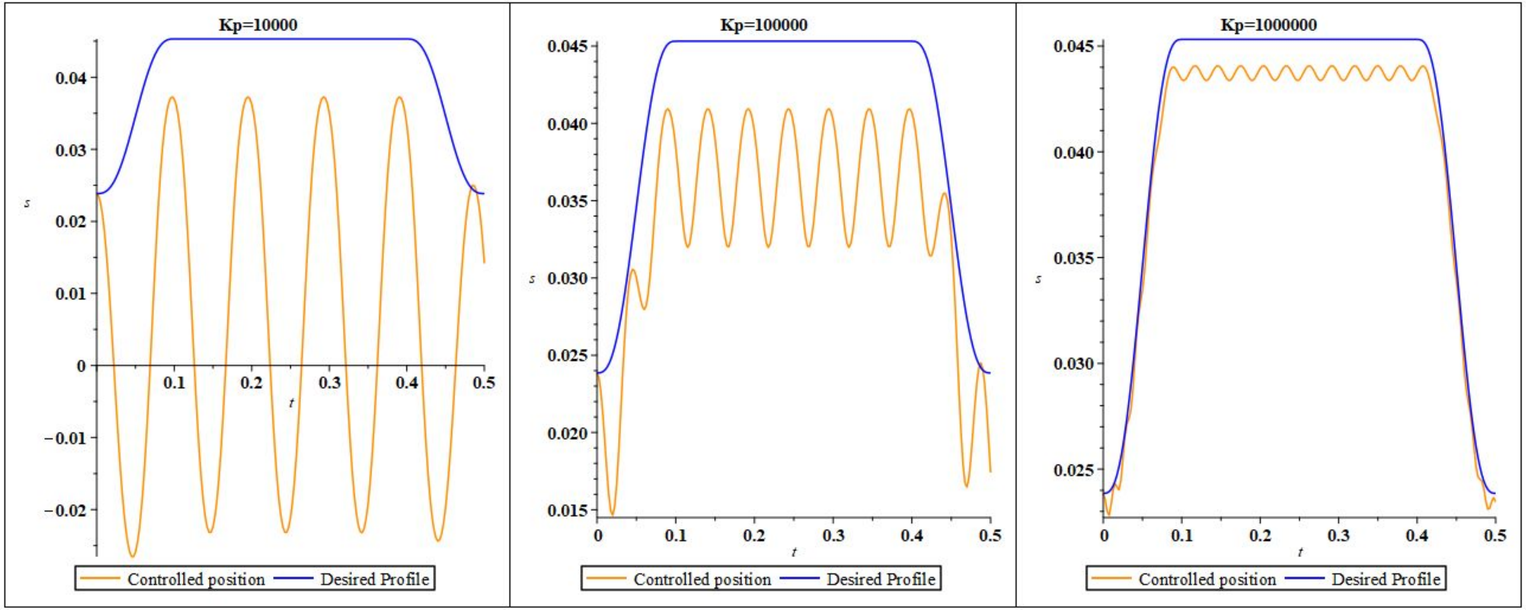


Position-Velocity Loop



Position loop

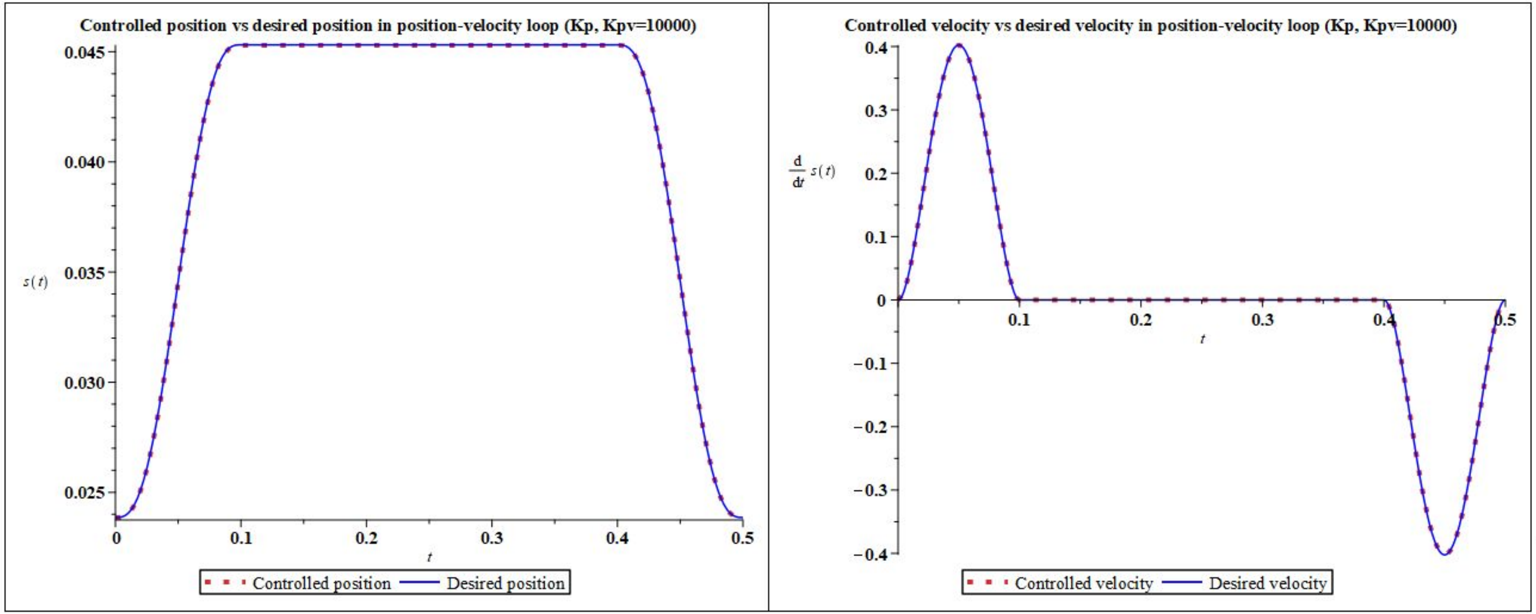
Proportional controller on the position of the pod-pull mechanism



Note: increasing the gain up to 10^6 is not enough to avoid errors and considerable vibrations.

Position-velocity loop

Proportional controller on the position of the pod-pull mechanism



Note: setting the gain of the two loops to 10^4 gives very accurate results.

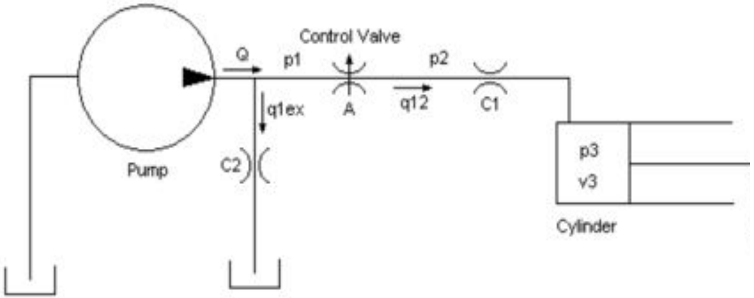
Hydraulic system

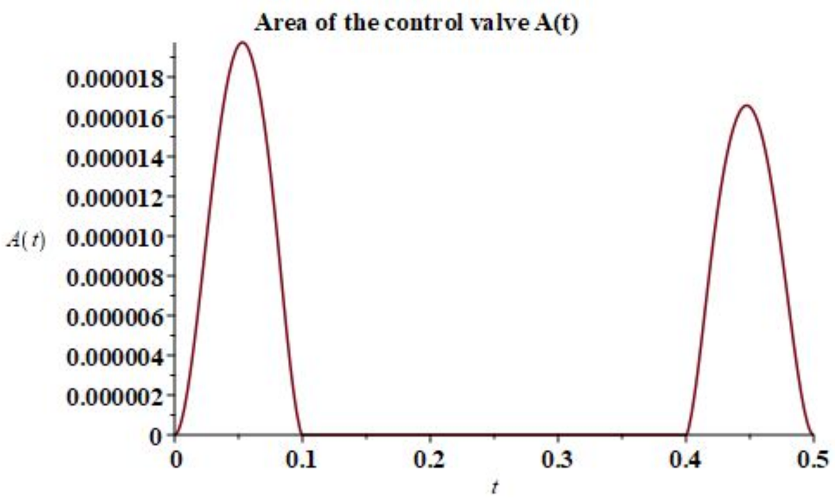
Objective:

1. Simulate a real hydraulic activation
2. Calculate the valve aperture to get the a desired piston force profile

Tools:

- Equations from MapleSim and lecture





(Fixed pump flow)

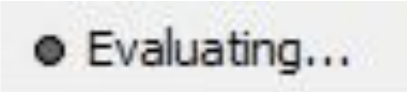
Numerical integration

Objective:

Integrate the Maple equations with different methods of the Prof. Bertolazzi's library.

Steps:

- reduce the DAE (obtained with Lagrange) to first order
- reduce the DAE to an ODE
- apply Baumgarte stabilization
- export the code to Matlab
- integrate using the differents methods and with different steps



Problem:

Even inserting the data and simplifying the forces the library call never print the code to export.