UNIVERSITÀ DEGLI STUDI DI TRENTO

MECHATRONICS ENGINEERING

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Mechanical System Simulation Mod.2 Project

DRS OPTIMIZATION

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Abstract

Assignment 1 | Quality Function Deployment

The *House of Quality* approach expects the designers to plot a chart (the *Quality Function Deployment*) which states all the main parameters concerning the design process. The first QFD is shown in figure 1.0.1 and it's described as follows.

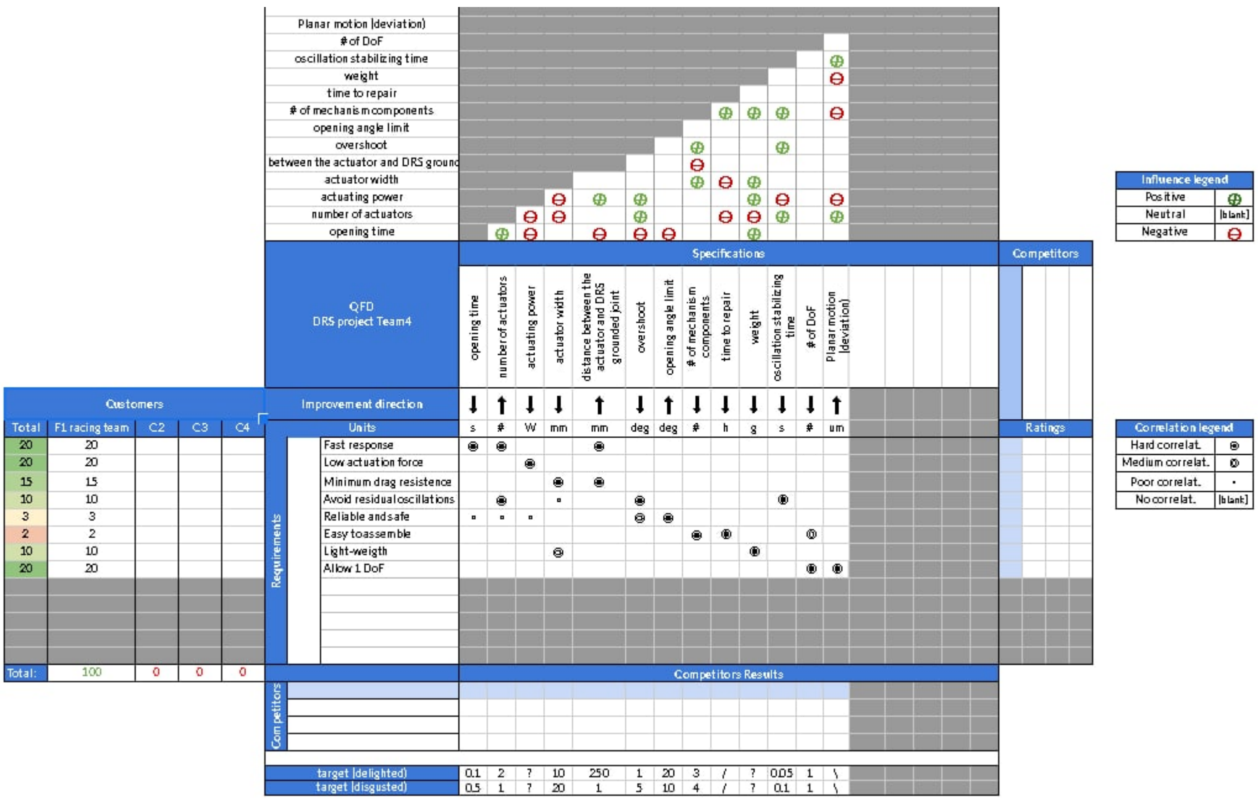


Figure 1.0.1: *Quality Function Deployment chart*

1.1 Customer Requirements

Customers						Improvement direction
Total	F1 racing team	C2	C3	C4		Units
20	20				Requirements	Fast response
20	20					Low actuation force
15	15					Minimum drag resistence
10	10					Avoid residual oscillations
3	3					Reliable and safe
2	2					Easy to assemble
10	10					Light-weigth
20	20					Allow 1 DoF

Figure 1.1.1: QFD details on *Customer Requirements*

The customers (detail in figure 1.1.1) are represented by a F1 racing team which is commissioning the DRS actuating mechanism. Each Requirement has a mark (adding up to 100) representing its importance.

- Fast Response (mark 20):
  The speed at which the DRS responds to the pilot command is a priority requirement to take advantage of all the DRS zone in order to maximize the effectiveness of overtake while ensuring the driver's safety.

- Low actuation force (mark 20):
  Another key requirement is the magnitude of the actuation force which should be as little as possible in order to minimize the power consumption of the car.

- Allow only 1 DoF (mark 15):
  Since the actuator controls only one degree of freedom, the mechanism should comply with this requirement as well; therefore any deviation from the ideal movement should be minimal.

- Minimum drag resistance (mark 10):
  The air flow around the DRS and the rear main wing are important to maximize performance and reduce non-ideal disturbing flows.

- Avoid residual oscillations (mark 3):
  The DRS should ideally stop exactly in the final position without oscillating about it; this means that spurious displacements need to be kept as little as possible and the time taken by the system to stabilize in the final position should be minimal.

- Reliable and safe (mark 2):This requirement states a boundary (from regulations) on movement range, speed and accelerations ment to limit the risk of injury of the pilots.

- Easy to assemble (mark 10):
  It might be needed a fast replacement of parts during races.

- Lightweight (mark 20):
  A light system is easier to actuate and is less burdensome on the car.

1.2 Existing Solutions

In order to better understand the problem, existing mechanisms need to be analyzed beforehand. This task is quite difficult since the racing teams do not disclose their products so only a qualitative description

can be performed.
In the course of the years 2 types of actuators have been used (hydraulic and electric) and 4 types of mechanisms (*push-up*, *pod-rocker*, *pod-pull*, *cables*).
The hydraulic actuating system is by far the best one since it's lighter, slender and reliable; moreover it can maintain a static position without additional power consumption [1].
The push-up mechanism 1.2.1 (a) is light, reliable and economic due to it's simplicity but it generates a lot of air flow disturbances. The pod-rocker mechanism's 1.2.1 (b) main advantage it's the mechanical advantage that the actuator has due to the lever; this allows to remove the support pillar and generates very little disturbance. The pod-pull mechanism 1.2.1 (c)is a simpler version of the latter but it requires higher pressure (which is generally not a problem). *Mercedes* used a cable system nested inside the side plates which is aerodynamically perfect but generates a lot of friction during opening and closing phases [1].

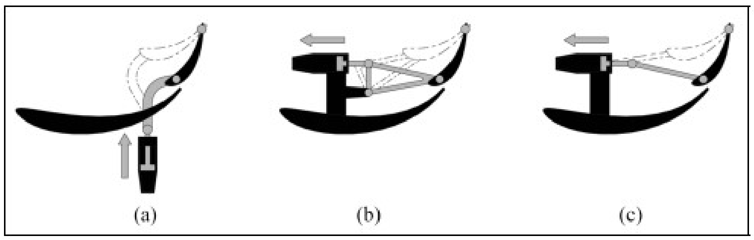


Figure 1.2.1: Existing DRS solutions: (a) push-up type, (b) pod-rocker type and (c) pod-pull type (adapted from Scarborough). Closed configuration is shown in filled greyscale view, whereas open configuration is contoured by a dashed line. DRS: drag reduction system.[1]

Nowadays all F1 teams adopt either the pod-rocker mechanism or the pod-pull one which seem to be the go-to choices.

1.3 Engineering Specifications

Specifications												
opening time	number of actuators	actuating power	actuator width	distance between the actuator and DRS grounded joint	overshoot	opening angle limit	# of mechanism components	time to repair	weight	oscillation stabilizing time	# of DoF	Planar motion (deviation)
⬇	⬆	⬇	⬇	⬆	⬇	⬆	⬇	⬇	⬇	⬇	⬇	⬆
s	#	W	mm	mm	deg	deg	#	h	g	s	#	um

Figure 1.3.1: QFD detail on *Engineering Specifications*

Engineering specifications are measurable parameters which are needed to express the customer requirements (at least one per c.r.). Each of them has a reference unit and a *development direction* (represented by the upwards and downwards arrows) which states wether the parameter ideally needs to be increased or decreased.

- Opening time [s] ↓:
  it determines the time that the mechanism uses to get from the closed configuration to the open one, therefore it's one of the most fundamental paramenters.

- Number of actuators [#] ↑:
  it determines the number of mechanisms used to actuate the DRS which can be nested in more aerodynamic efficient positions, e.g. behind the main-wing supports.

- Actuating power [W] ↓:
  it's the power subtracted from the vehicle during the actuation of the DRS, resulting in less racing performance, then it should be minimal.

- Actuator width [mm] ↓:
  it determines the encumbrance of the mechanism and hence the aerodynamic impact on the flap; a narrow mechanism would disturb less the air flow.

- Distance between the actuator and DRS grounded joint [mm] ↑:
  it affects the opening time and the aerodynamic disturbance.

- Overshoot [deg] ↓:
  it's the amount of extra degrees that the flap does above the final angular position due to dynamical effects; the lower the better.

- Opening angle limit [deg] ↑:
  since regulations only limit the range of the closed position and gives quite a lot of freedom for the open configuration (it only needs to close by itself under the action of air pressure) maximizing the open-configuration-angle means that the DRS can exploit more drag/downforce ratios for different circuits.

- Number of mechanical components [#] ↓:
  : it affects the leverage that can be exploited, the opening time and the encumbrance of the mechanism; simpler mechanisms are easier to maintain, easier to optimize and are more reliable. Keeping this number reasonably low should be prefearable.

- Time needed to repair [s] ↓:
  durign races it may happen that the DRS needs to be changed or adjusted (e.g. after a crash) therefore if it takes less time to prepare it's better.

- Weight [g] ↓:
  a lightweight mechanism is easier to actuate and is less burdensome on the power consumption, though it might imply more critical dynamic effects and/or resistance conditions.

- Oscillations stabilizing time [s] ↓:
  it's the time needed for the mechanism to settle to a steady configuration (e.g. open one); the less time it takes to recover from overshoots, the better it is.

- Number of DoF [#] ↓:
  the number of degrees of freedom is set to be 1.

- Deviation from planar motion [um] ↓:
  if the mechanism does not move only on the "actuation plane" it leads to spurious effects which may hinder the performance of the DRS, therefore this deviation from the ideal configuration should be minimal.

Note that some of the E.S. stated above either are difficult to evaluate without producing experiments or do not really concern the kinematic and dynamic optimization of the mechanism (rather than the mechanical design). Hence only the most important ones will be taken in consideration for the optimization process

Specification	Target delighted	Target disgusted
Opening time	0.1	0.5
Number of actuator	2	1
Actuating power	/	/
Distance	10	20
Overshoot	250	1
Opening angle limit	/	/
N. of mechanism components	3	6
Time of repair	/	/
Weight	/	/
Oscillation stabilizing time		
N. of DoF	1	1
Planar motion (deviation)	/	/

Table 1.1: Table of delighted and disgusted values for each specification.

1.4 Target Values

In order to guide and compare the optimization, a set of target values are stated taking into consideration the already-existing solutions to the problem. For each engineering specification a *delighted* and *disgusted* target value are given and shown in Table 1.1.

As can be seen in the table many values couldn't be found. This values will be updated during the project with the increasing knowledge on the subject.

1.5 Specifications relationships: "Hows vs Hows"

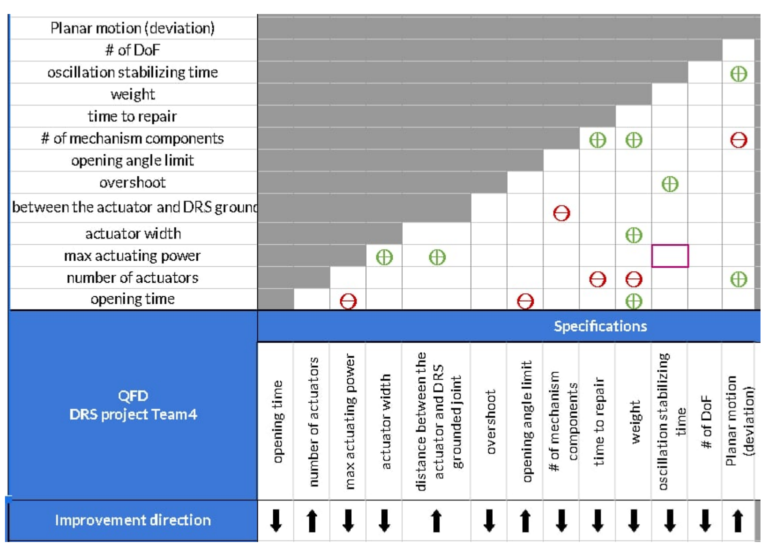


Figure 1.5.1: QFD detail on *HOWS*

In order to improve different engineering specifications we need to highlight the trade-offs. In figure 1.5.1 a detail of the chart is shown.

Since there are way too many relationships between the various E.S., we stated only the most important ones.

- Opening time vs actuating power: (**trade off**) we want to have lightweight and small actuator but also have enough power to open the mobile wing in the smallest time possible.
- Number of actuator vs planar motion deviation: (**positive interaction**) increasing the number of actuators there is a more uniform distribution of forces, so each mechanism divert less from ideality.
- Maximum actuating power vs actuating width: (**positive interaction**) We want to decrease the maximum power needed and doing so we also decrease the size of the actuator.
- Maximum actuating power vs distance between the actuator and DRS grounded joint : (**positive interaction**) placing the actuator further, the actuation power needed is lower.
- Distance between the actuator and DRS grounded joint vs number of components: (**trade off**) a longer mechanism is needed if the actuator is placed further.
- Overshoot vs oscillation stabilizing time: (**positive interaction**) decreasing the magnitude of the overshoot when the mechanism is opened helps also to have smaller oscillation.

Assignment 2 | Kinematic analysis

Task:

- Derive the 2D kinematic model
- Address the initial position problem, position analysis and velocity analysis
- Compute the purely kinematic engineering specifications and performance indices
- (Optional) produce dimensional optimization

Firstly we decided a set of reasonable parameters to share between mechanisms:

Parameter	Value	Unit
flap length	300	mm
opened angle*	5	deg
closed angle*	70	deg

,

* with respect to the horizontal ground

2.1 Position analysis

Then we performed Even though for the different mechanisms there might be some differences, the same analysis have been carried out as follows.

Firstly we have defined all the reference frames and points using the **recursive approach**.
Then all the **constraint equations** have been derived from the joint equations and finally they have been solved.

2.2 Initial position problem

In order to find the initial length of the piston at a given angle of the flap we used the initial configuration problem. This problem could be solved in several ways, we decided to use the Newton-Raphson method. It is based on a linearization of the system, the constrain equation are substituted with the first two terms of the Taylor expansion in the point q_i resulting in

$$\Phi(q,t) \cong \Phi(q_i) + \Phi_q(q_i)(q - q_i) = 0$$

The point q_i will have one exact coordinate, in our case the angle of the wing, and the other will be a guess. Taking the results from the previous example and using it as next starting point will bring to a better results. Iterating this process the solution converges at the point that we were searching. Operationally this is done in maple through a for cycle with 20 iteration.

2.3 Velocity analysis

For the velocity analysis two different approaches could be used:

- derive the constraint equation and solve them
- find the velocity ratios

The first method is quite trivial, so only a description on how the velocity ratios are founded is provided.

2.3.1 Velocity ratios

Given the constraint equation

$$\Phi(q,t) = 0$$

by differentiating with respect to time we obtain the velocity ratios as

$$\tau = -\Phi_{q_D}^{-1}(q,t)\Phi_{q_I}$$

where Φ_{q_D} and Φ_{q_D} are respectively the Jacobian of $\Phi(q,t)$ in respect of the dependent and independent variables.

From this equation it can also be noticed that if the determinant of Φ_{q_D} is equal to zero the velocity ratios could not be found; this points are called **singular configurations**.

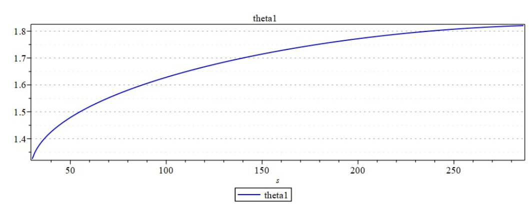
2.4 Purely kinematic engineering specifications and performance indeces

In order to compare PISTON STROKE DISTANZA TRA LA COPPIA DEL FLAP E LA POSIZIONE PIU' VICINA DELL'ATTUATORE

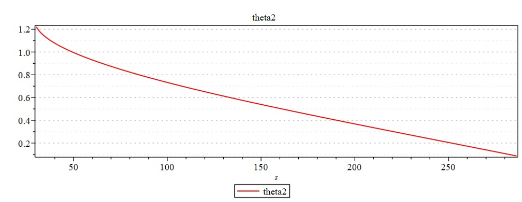
2.5 Results

Here we plot the results of each analysis for every mechanism.

2.5.1 Push-up

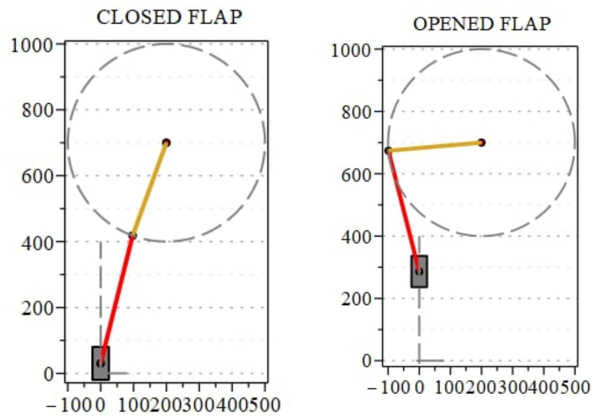


(a) *Linkage angle:* θ_1



(b) *Flap angle:* θ_2

Figure 2.5.1: Dependant variables (a)(b) as function of the driver (piston stroke)



(a) *Initial configuration* (b) *Final configuration*

Figure 2.5.2: Initial (a) and final (b) configurations

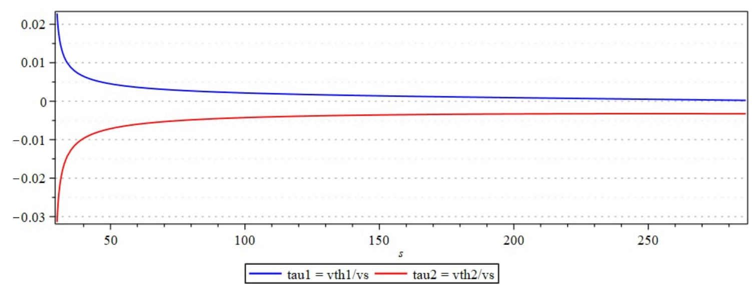
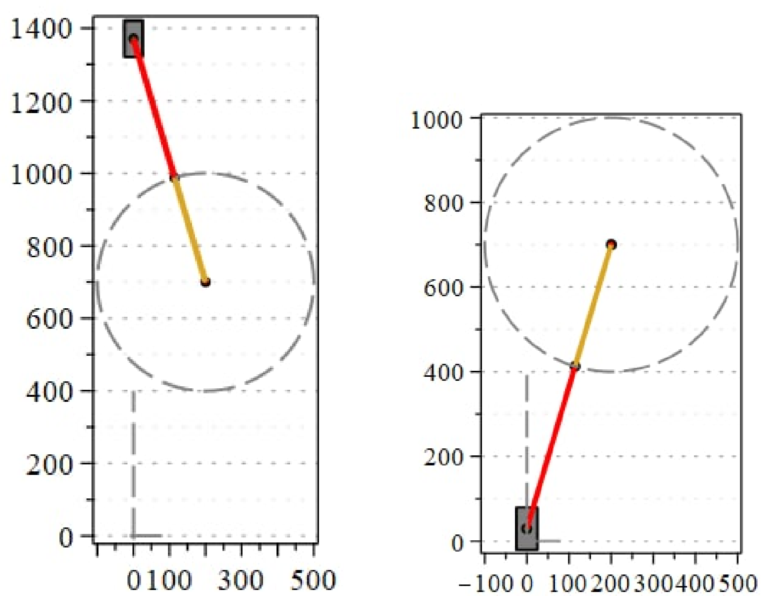


Figure 2.5.3: Velocity rations between dependent variables and driver

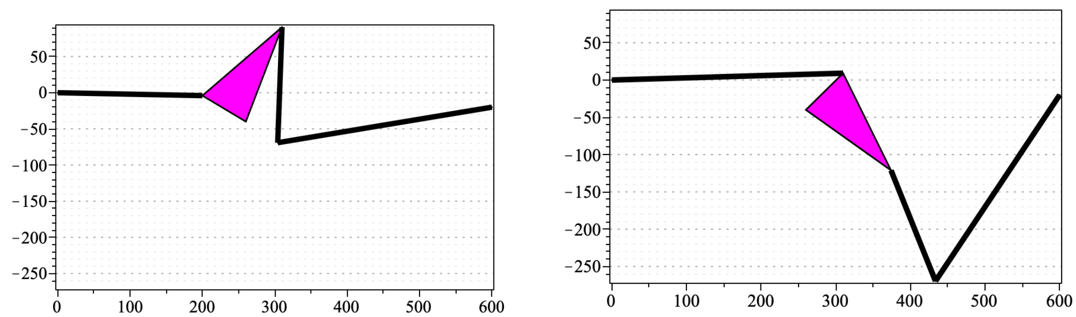


(a) (b)

Figure 2.5.4: Singular configurations

2.5.2 Rocker-Pod

From the initial position problem we derive the minimum length of the piston, 42.36 to have a final angle of the flap of $10deg$, and the maximum length, 155.56 to have initial angle of $58deg$.



(a) *Cosed flap* (b) *Open flap*

Figure 2.5.5: Plot of the configuration with the closed wing and the open wing.

Then the constraint equation are solved keeping the piston as the independent variables. In Figure 2.5.9 the plot of the angle.

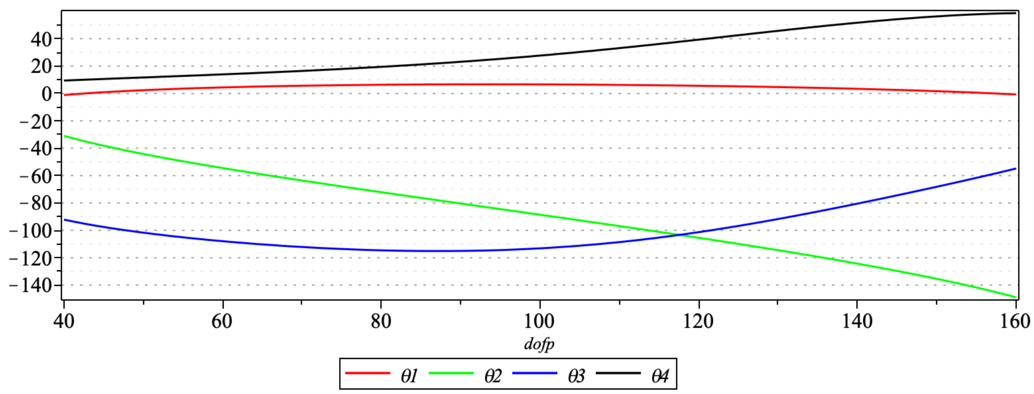


Figure 2.5.6: Angles of the mechanism components in function of the piston length.

For the velocity analysis the velocity ratios are found. The results are shown in Figure 2.5.10.

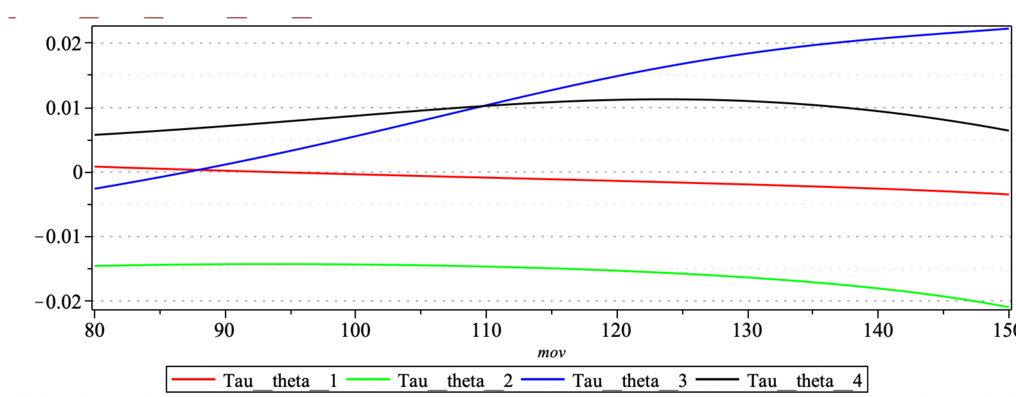


Figure 2.5.7: Velocity ratios in function of piston position.

2.5.3 Pull-Pod

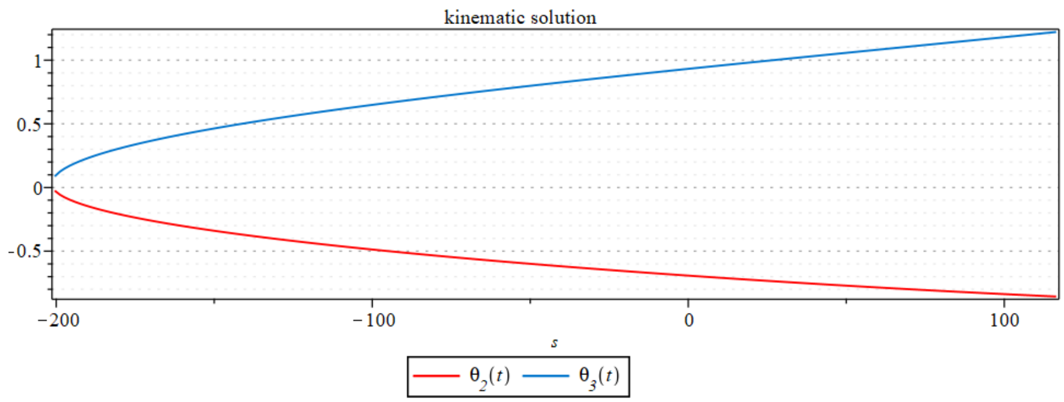
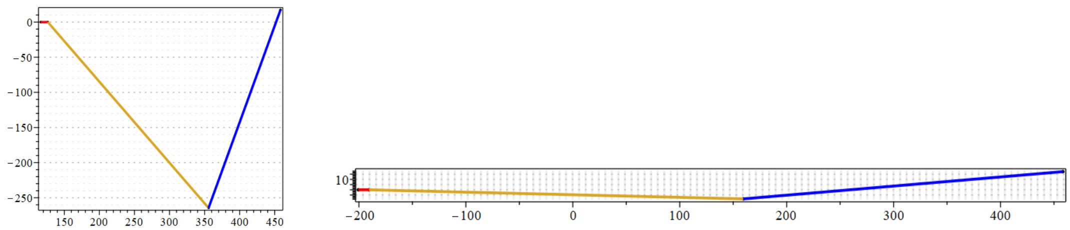


Figure 2.5.8: Dependent variables in function of actuator position.



(a) *Cosed flap*

(b) *Open flap*

Figure 2.5.9: Plot of the configuration with the closed wing and the open wing.

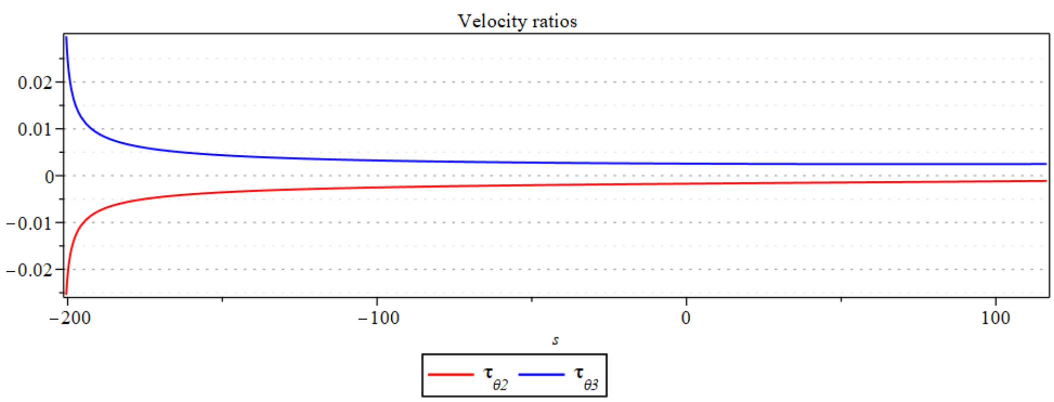
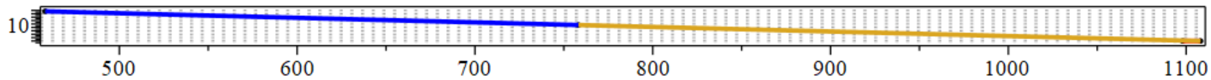
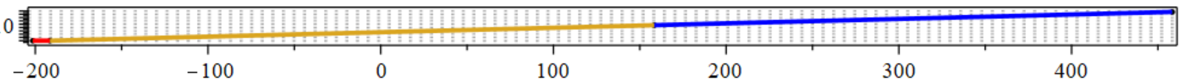


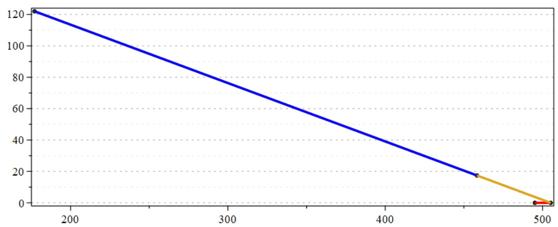
Figure 2.5.10: Velocity ratios in function of actuator position.



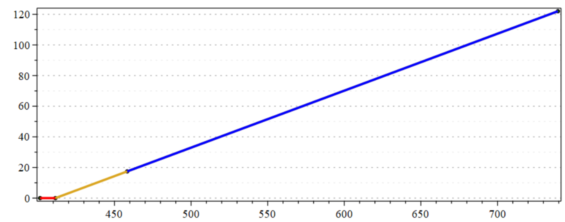
(a) *Singular configuration 1*



(b) *Singular configuration 2*



(c) *Singular configuration 3*



(d) *Singular configuration 4*

Figure 2.5.11: Singular configurations of Pod-Pull mechanism.

2.5.4 Comparison

Mech Type	Engineering Specs	Value
Push-Up	piston stroke	256 [mm]
Push-Up	encumbrance	460 [mm]
Rocker-Pod	piston stroke	
Rocker-Pod	encumbrance	
Pod-Pull	piston stroke	316 [mm]
Pod-Pull	encumbrance	342 [mm]

Assignment 3 | Asd

Assignment 4 | Asd

Bibliography

[1] Mauro Dimastrogiovanni, Giulio Reina, and Andrea Burzoni. "An improved active drag reduction system for formula race cars". In: *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering* 234.5 (2020), pp. 1460–1471.