ONERA-ISAE / Airbus
Presented by: Yann DENIEUL
PhD Student

Integrated Design and Control of a Flying Wing Using Nonsmooth Optimization Techniques

PhD Thesis

Thesis directors: Daniel Alazard & Joël Bordeneuve (ISAE-ONERA)

Supervisors: Clément Toussaint (ONERA) Gilles Taquin (Airbus-EIXOG)

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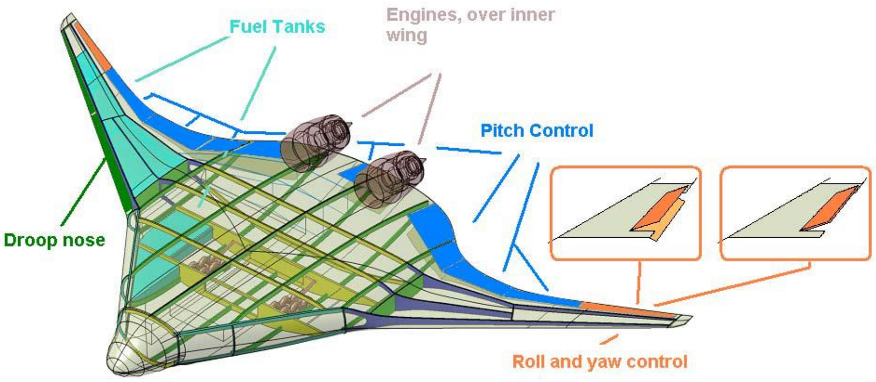
Context and problem

- Previous PhD thesis: “Handling Qualities resolution for Blended-Wing Body” (Saucez, 2013) at the Future Projects Office in Airbus, Toulouse and ISAE-Supaero
  - Flying Wing configuration very promising
  - Handling qualities were a major challenge and not deeply studied yet

- Initial configuration:



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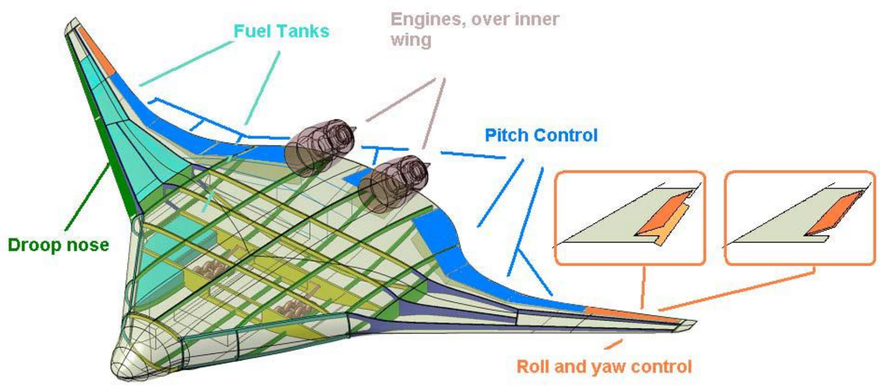
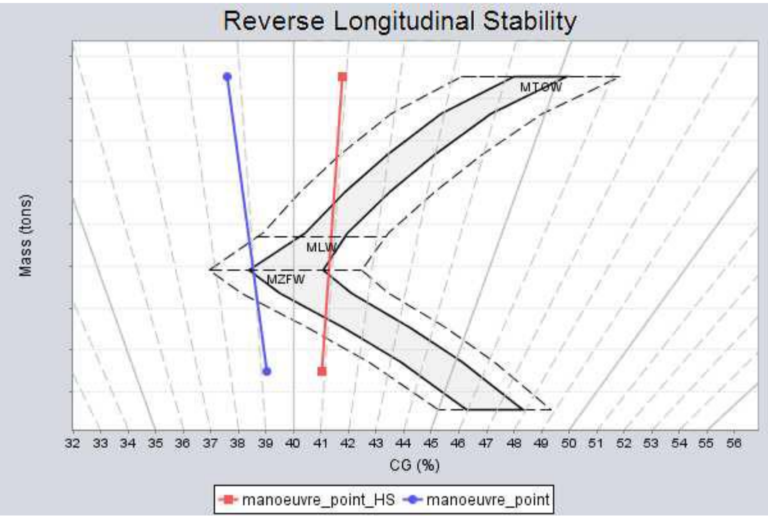


- PhD conclusions:
  - No major showstopper concerning Handling qualities
  - Vertical surfaces needed
  - Multicontrol surfaces necessary
  - Active control mandatory

Context and problem

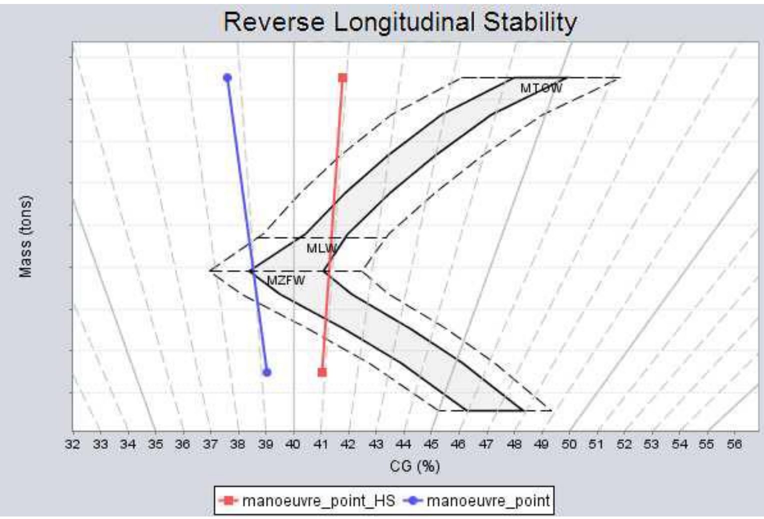
- Focus on the need for active stabilisation



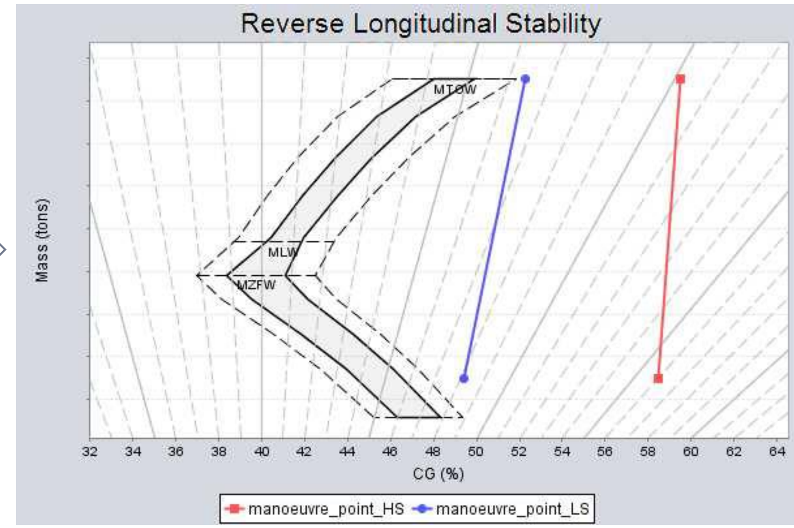
Natural Aircraft

Context and problem

- Focus on the need for active stabilisation



Control laws



Natural Aircraft

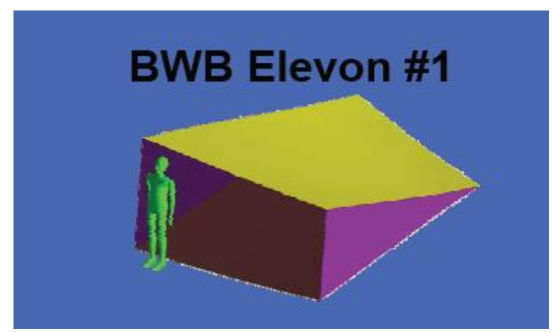
Augmented Aircraft

- Consequences of the active stabilization:

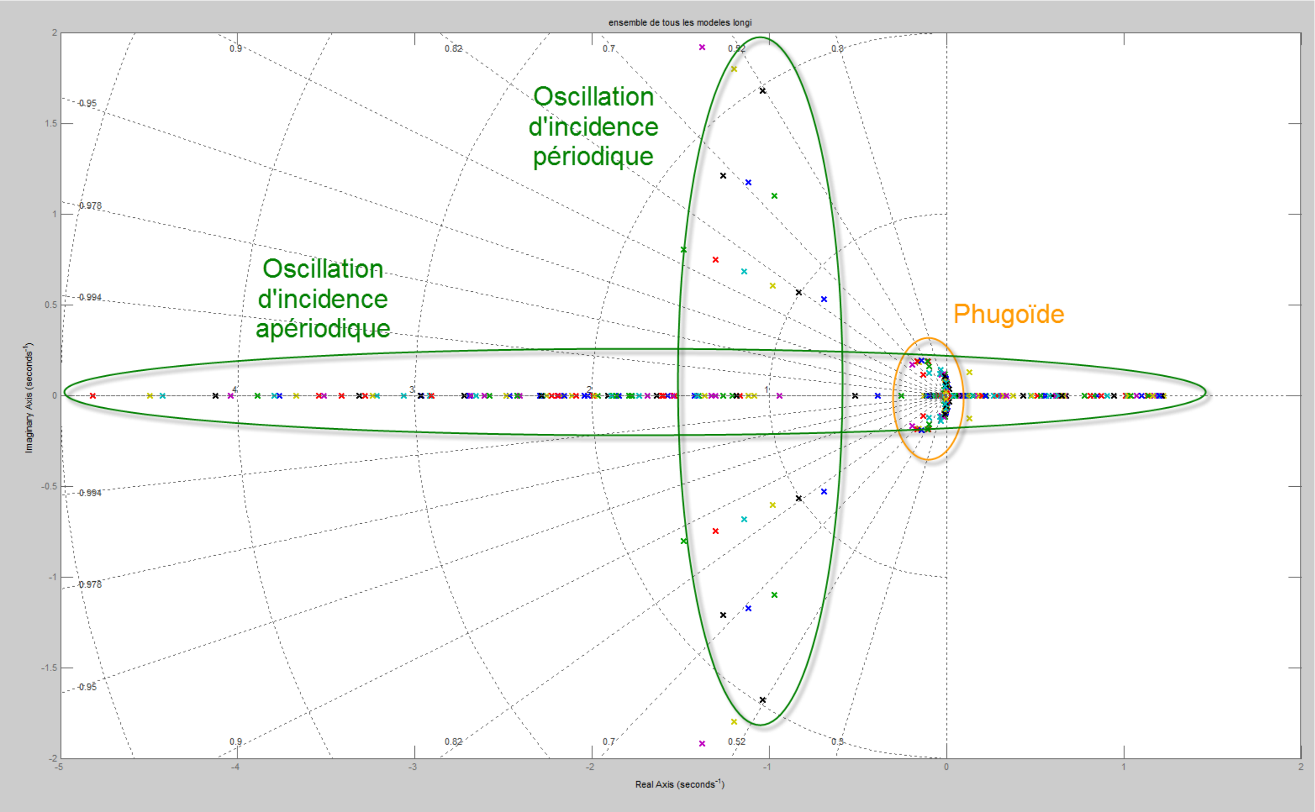
⇒High-rate control surfaces

create large secondary power demand

- Cost of instability on A/C design



How unstable is the flying wing? Longitudinal modes

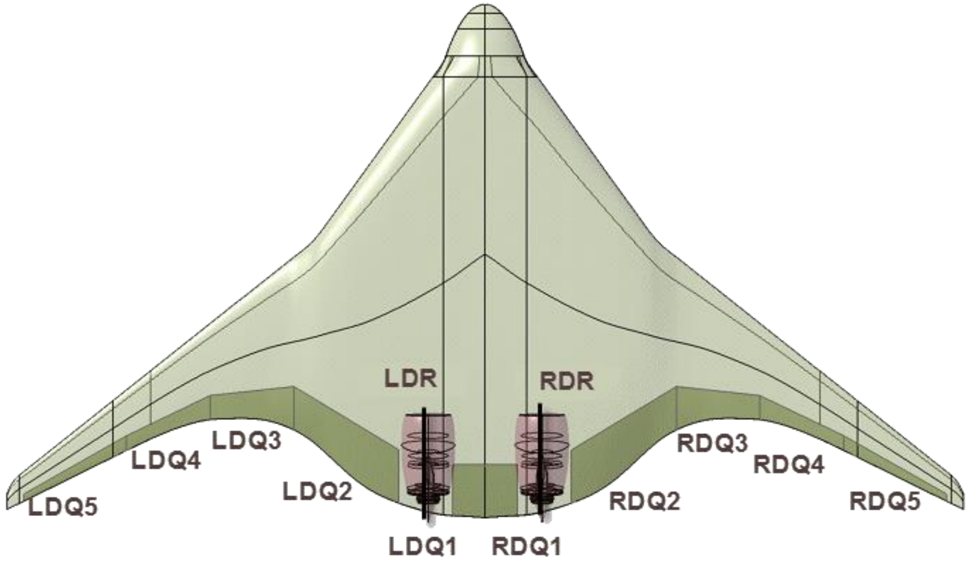


- Max instability: 1,25 rad/s @ Mlight & low Mach
- Impact on actuators Bandwidth? Optimal actuators sizing?

Contents

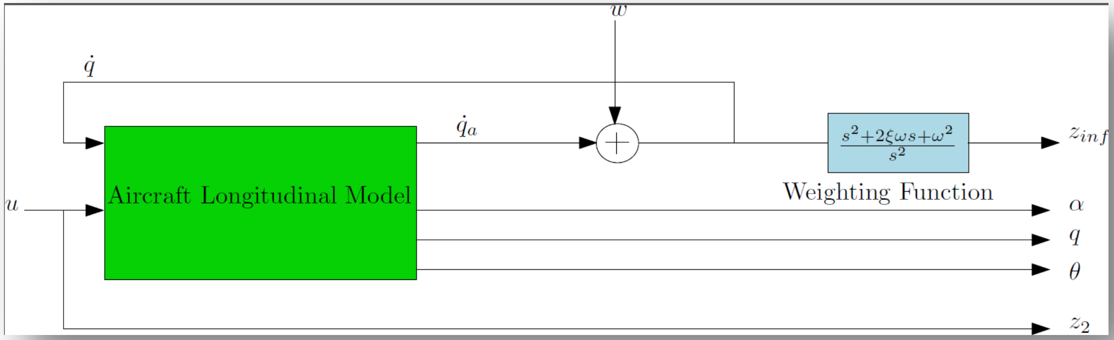
Control Problem Setup

- Aircraft Model:
  - Longitudinal Model, 4 states $X = \begin{bmatrix} \delta V \\ \delta\ \alpha \\ \delta q \\ \delta\theta \end{bmatrix}$
  - 11 Controls
  - Measures for control: $\mathrm{Y} = \begin{bmatrix} \delta\ \alpha \\ \delta q \\ \delta\theta \end{bmatrix}$



Standard form for H2/H∞ control

- Standard form:



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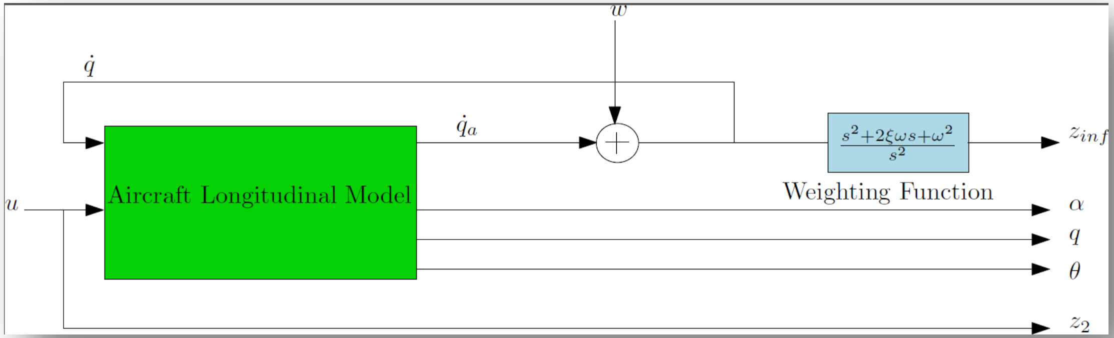

- H2/H∞ control problem:

$$\min_{K} \quad \|T_{w\rightarrow u}\|_2$$

$$\text{subject to:} \quad \|T_{w\rightarrow z_{inf}}\|_\infty \leq \gamma$$

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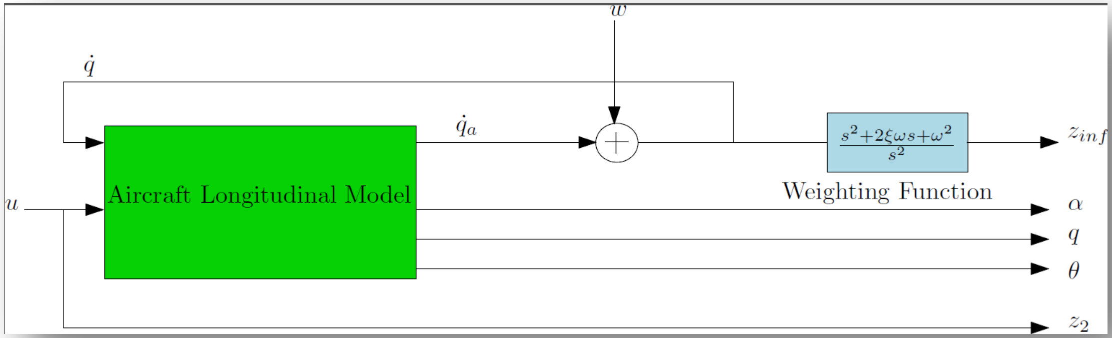

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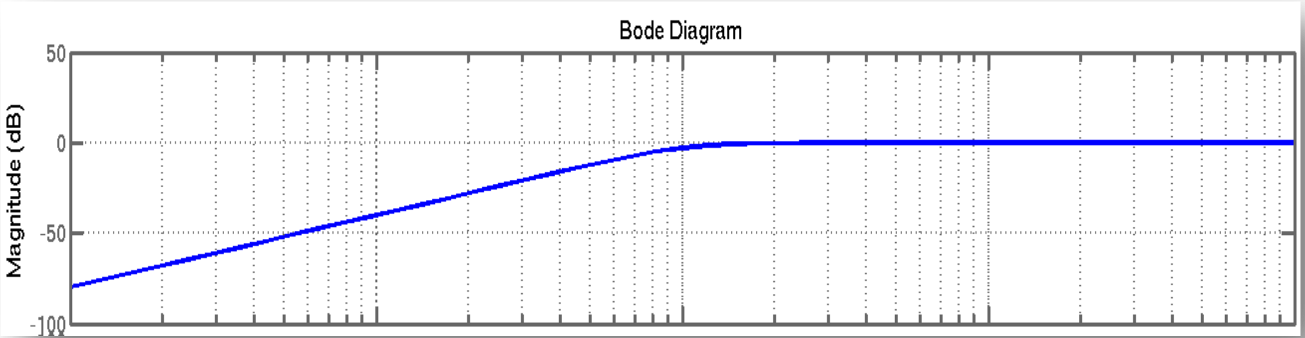
- Weighting function on pitch acceleration:



Controller structure

- Static 11x3 State-feedback

- Linear Control Allocation is performed by the compensator
  - Allocation strategy is given by the optimisation
  - How to mix Nonlinear Control Allocation (ie including saturations) with structured controller is an open question for us

Co-design approach

- Co-design:
  - Meaningful physical parameters are considered as controller parameters
  - Physical parameters are optimised in the controller synthesis
  - Example: in (Alazard et al., 2013), a delay accounting for sensor quality is optimised conjointly with an attitude controller

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- Co-design:
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  - Example: in (Alazard et al., 2013), a delay accounting for sensor quality is optimised conjointly with an attitude controller
  - In litterature:
    - Integrated design and control (also known as plant-controller optimization) was performed using LMI framework (Niewhoener et al., 1995)
    - Full-order controllers
    - Handling Qualities requirements hardly translated into H_∞ constraints
  - Adress this problem using nonsmooth optimization tools for structured controllers

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Co-design approach

- Parametrized first-order bandwidth: $$\frac{y_{act}}{u_{act}}(s) = \frac{\omega_i}{\omega_i + s},\ i = 1\ldots 11$$

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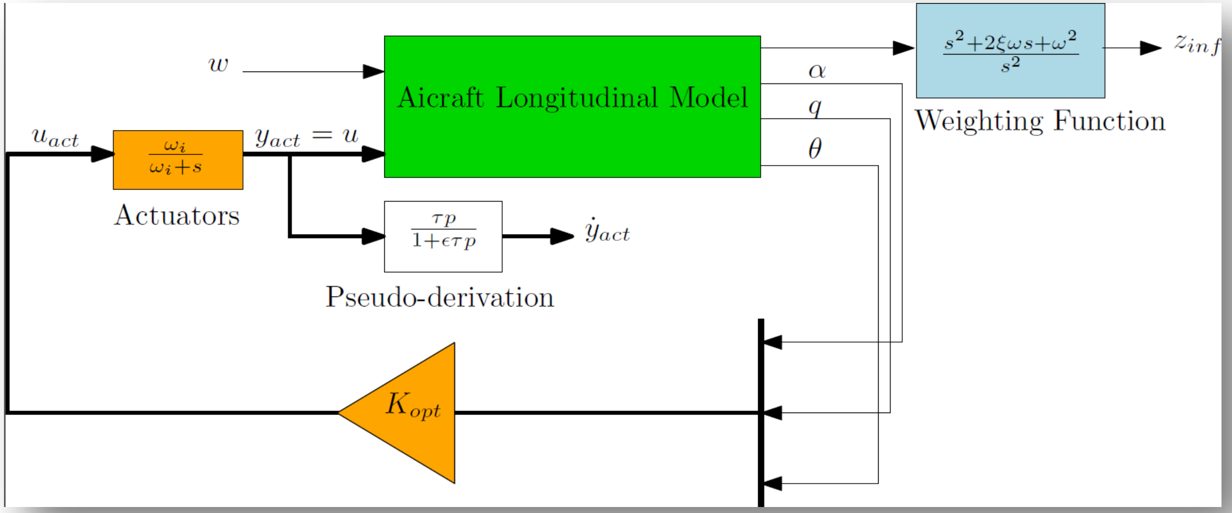

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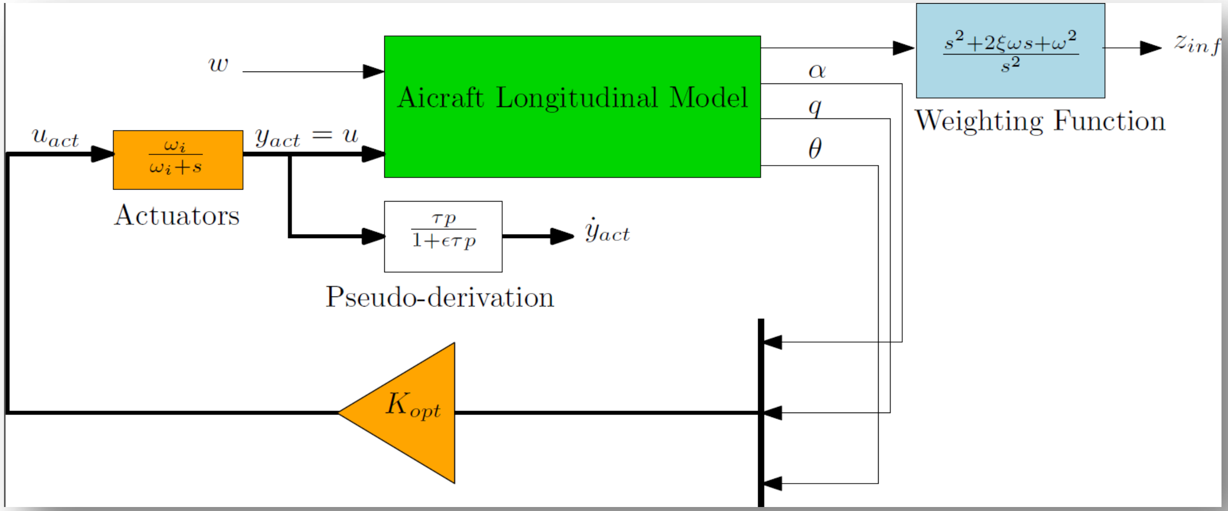

- New optimization problem:

$$\min_{K,\Omega} \max \; \{W_2 \|T_{w\to u}\|_2, W_3 \|T_{u_{act}\to \dot{y}_{act}}\|_2\}$$
$$\text{subject to: } \; \|T_{w\to z_{inf}}\|_\infty \leq \gamma, \; 0 \leq \Omega \leq \Omega_{max}$$

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Systune

- Why using Systune?

  - Allows for mixed H2/H∞ synthesis and multiobjective optimization.

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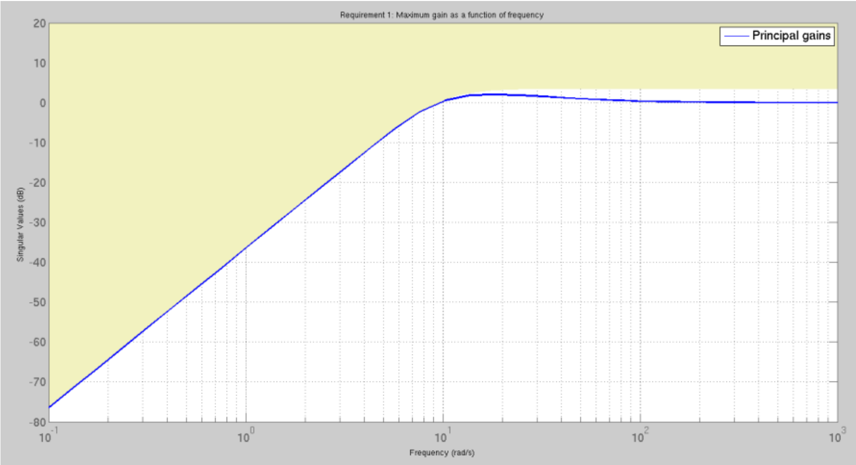
  - Directly specifying closed-loop structure and tunable blocks. Single Simulink model for linear synthesis and nonlinear simulation.

  - Variety of constraints: H∞ but also pole placement constraints: more applicable for Handling Qualities purpose

First results

- Frequency-domain response of $T_{w \to zinf}$ (blue) and W^{-1} (yellow)



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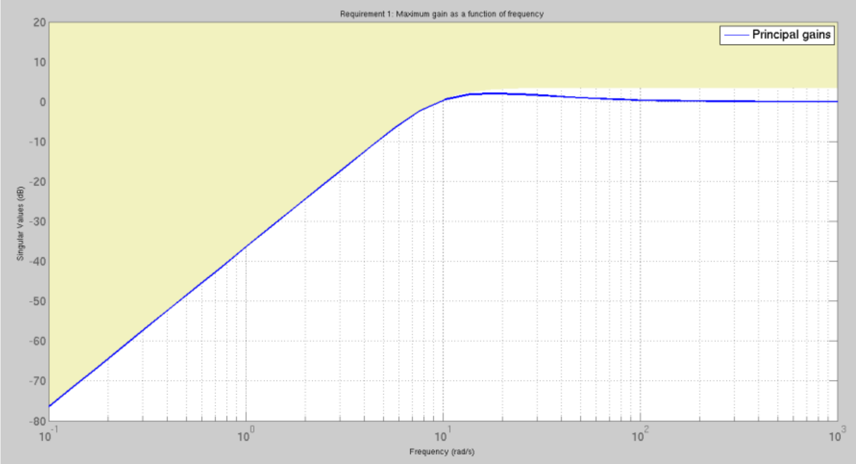

$$\|T_{w \to u}\|_2 = 1.38$$

- Comparison: $\|T_{w \to u}\|_2 = 0.6$ for LQ minimal energy control
- $\|T_{w \to u}\|_2 = 1.26$ for mixed H2/H∞ control with infinite bandwidth

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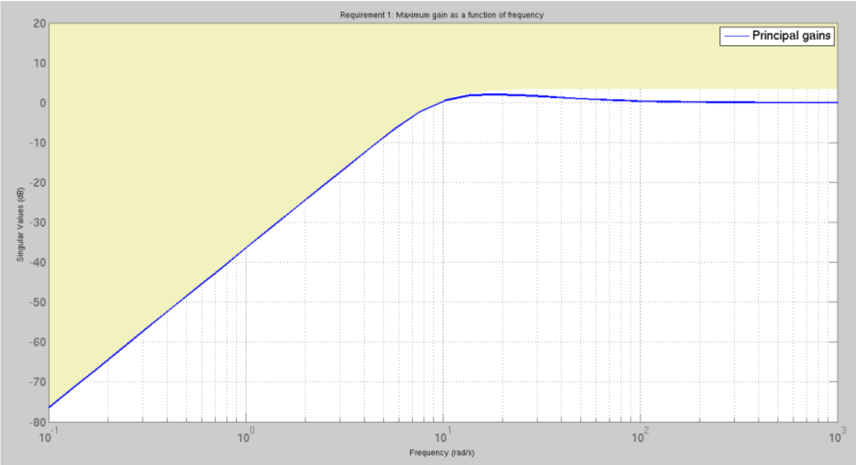

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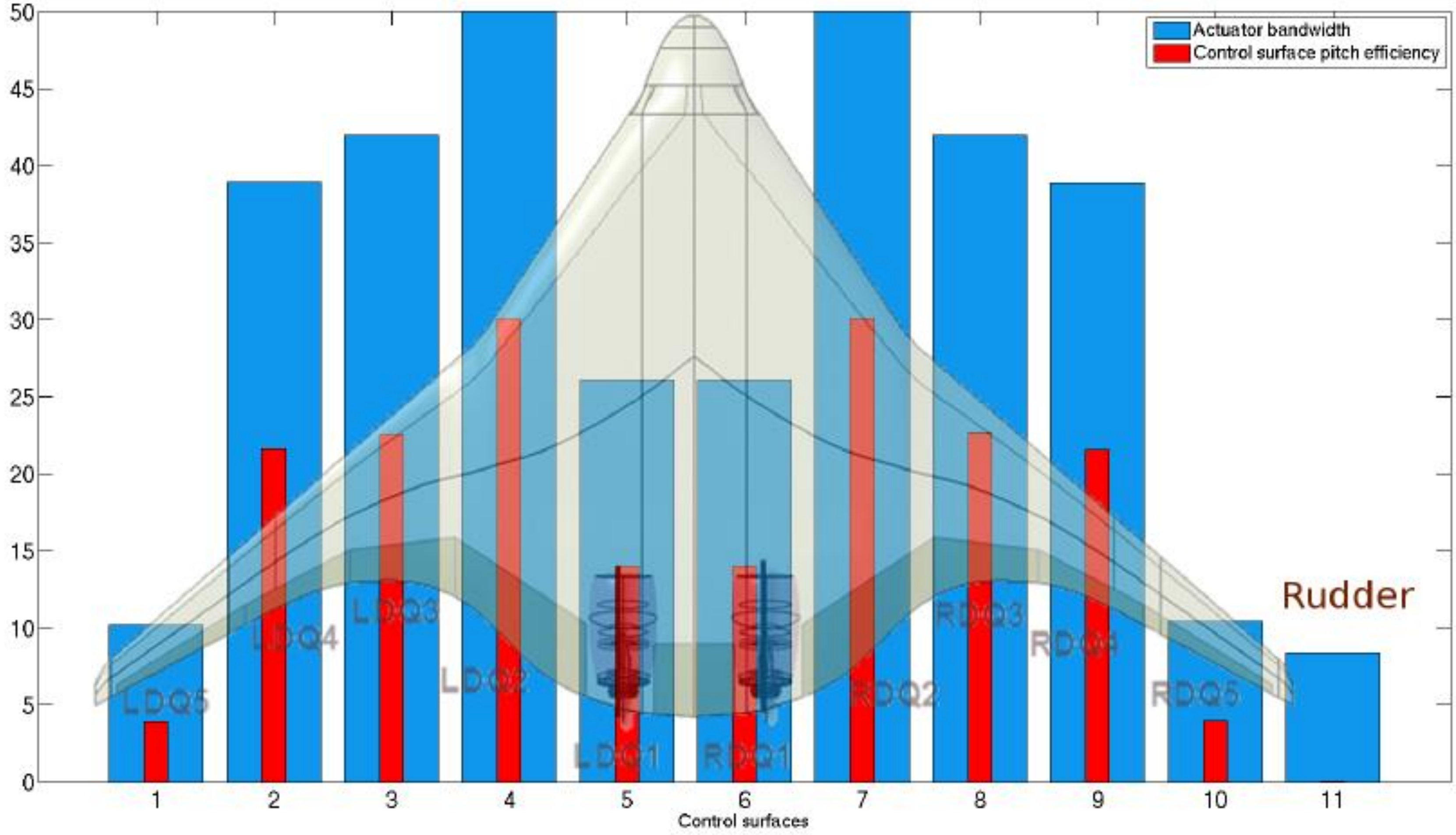
Controller:

$$K_{opt} = \begin{array}{ccc|l}
0.5816 & 1.1211 & 6.0981 & LDQ1 \\
1.3919 & 2.2578 & 14.5759 & LDQ2 \\
1.0279 & 1.7584 & 10.5422 & LDQ3 \\
0.9229 & 1.6367 & 10.0334 & LDQ4 \\
0.2329 & 0.3630 & 1.5500 & LDQ5 \\
0.5824 & 1.1203 & 6.0976 & RDQ1 \\
1.3904 & 2.2612 & 14.5797 & RDQ2 \\
1.0262 & 1.7594 & 10.5529 & RDQ3 \\
0.9235 & 1.6349 & 10.0309 & RDQ4 \\
0.2287 & 0.3664 & 1.5525 & RDQ5 \\
-0.0017 & 0.0028 & 0.0021 & DR \\
\hline
\alpha & q & \theta &
\end{array}$$

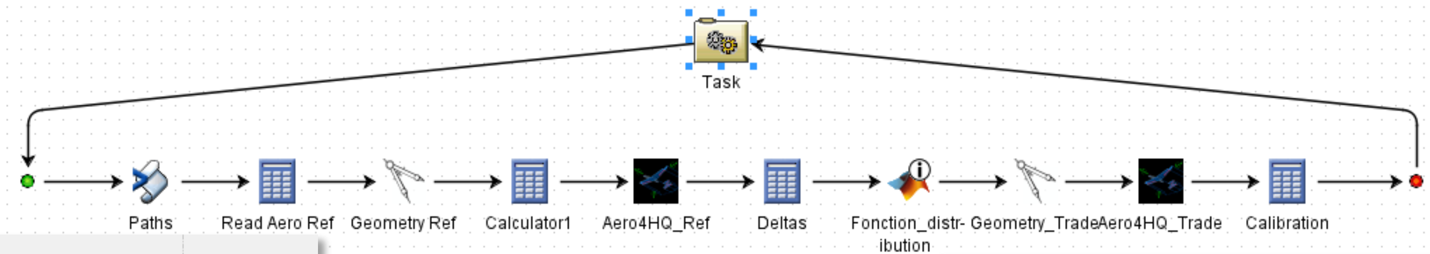
Co-design first results

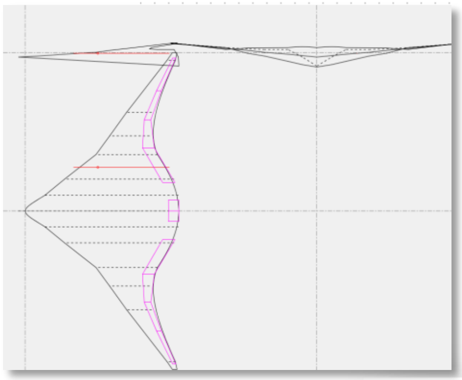


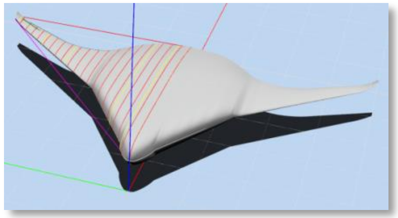
Contents

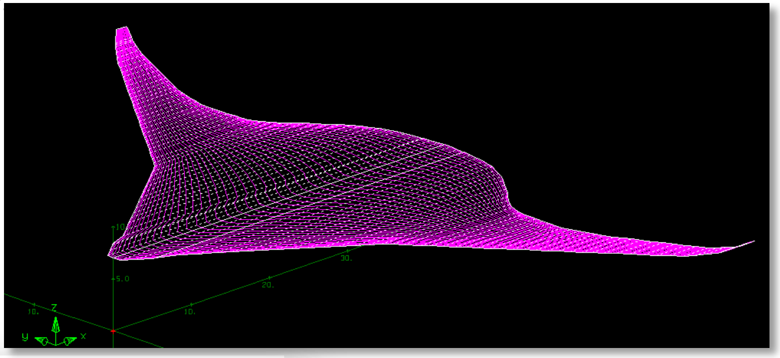
Way forward

- Control surfaces size parametrization and aero model calculation



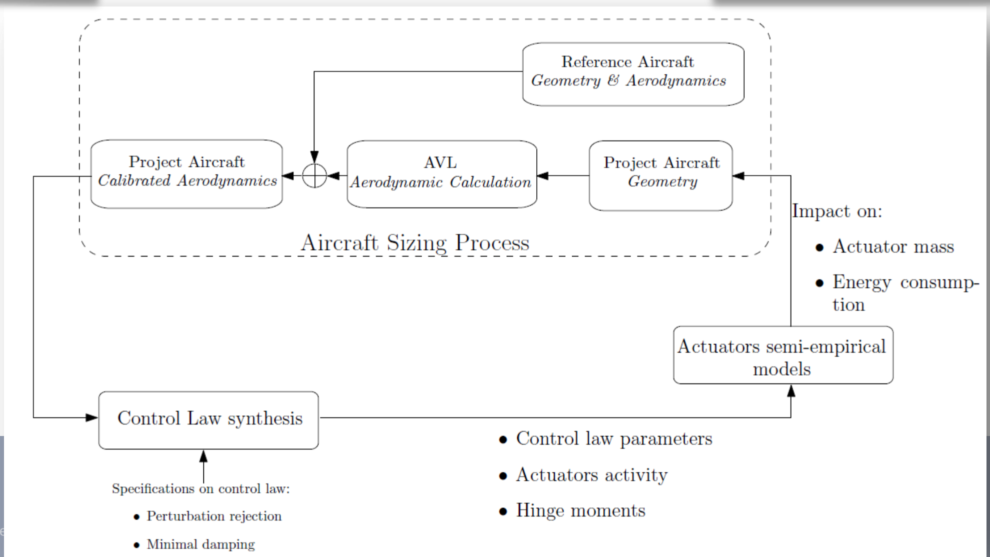






2D Sketcher

AVL Mesh



Way forward

- LFT form of the parametrized aerodynamic model
- Co-design on the LFT form for control surfaces sizing

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- Pole placement constraints

Way forward

- LFT form of the parametrized aerodynamic model
- Co-design on the LFT form for control surfaces sizing
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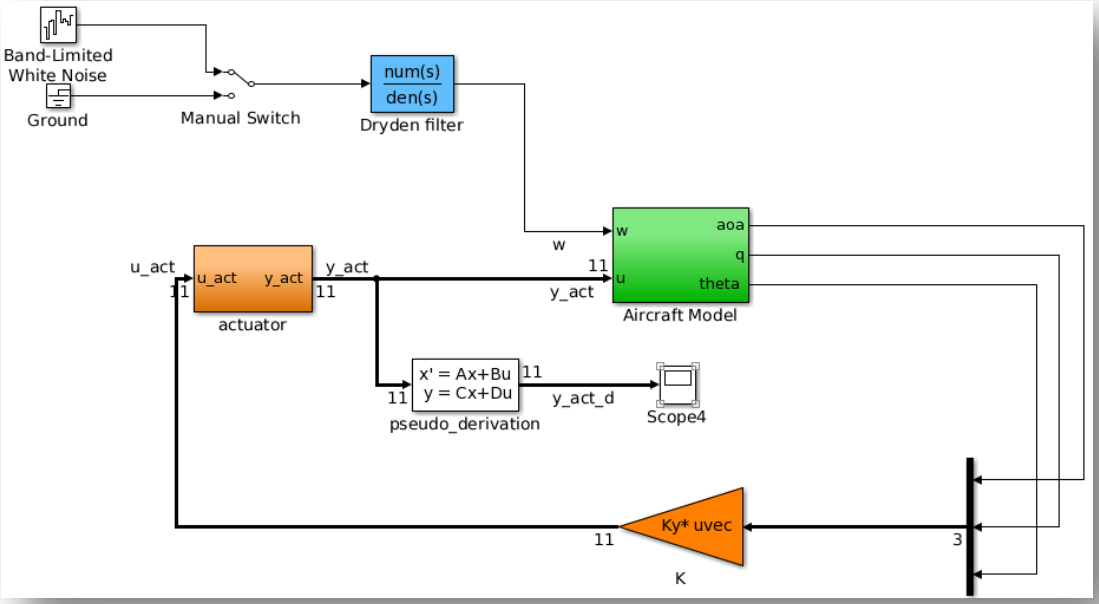
- More physical criterion: mass / energy minimization through actuators mass models

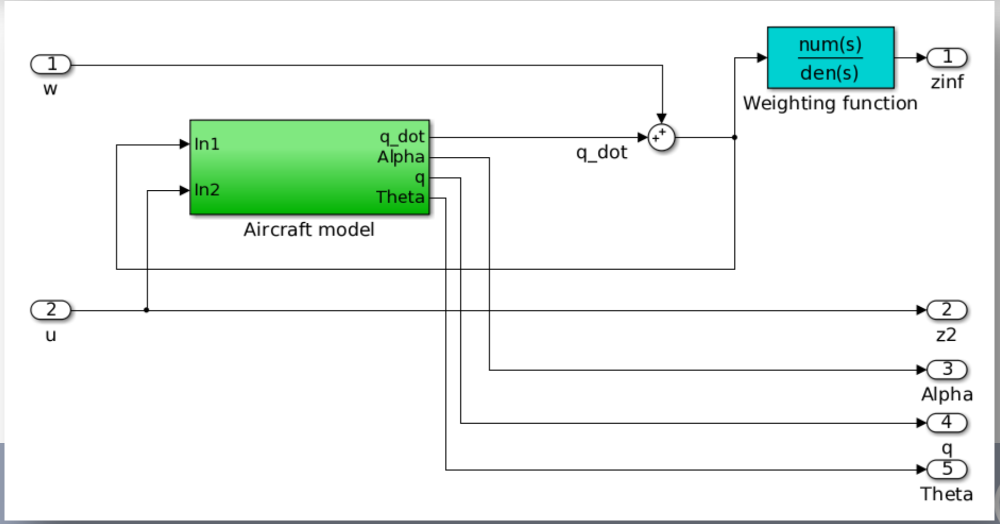
Thank you for your attention

Questions?

Annexes

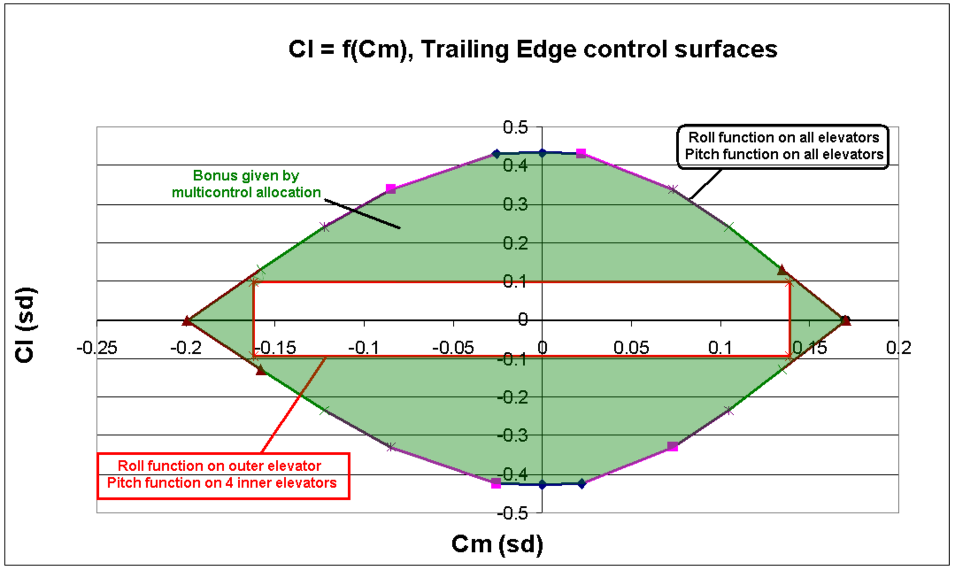
Simulink

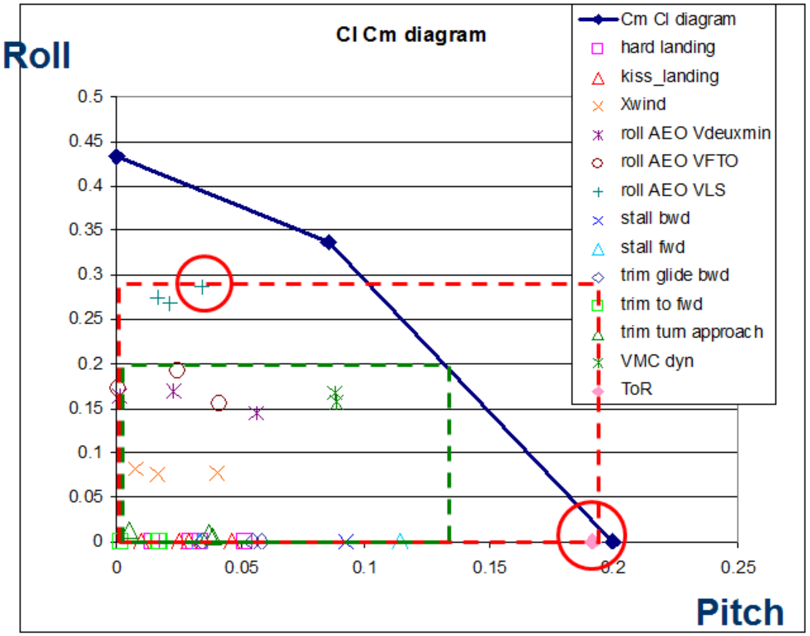

Band-Limited
White Noise
Ground
Manual Switch
num(s)
den(s)
Dryden filter
w
aoa
q
u
theta
Aircraft Model
u_act
y_act
actuator
11
y_act
x' = Ax+Bu
y = Cx+Du
pseudo_derivation
y_act_d
Scope4
Ky* uvec
K
3


1
w
In1
In2
q_dot
Alpha
q
Theta
Aircraft model
q_dot
num(s)
den(s)
Weighting function
1
zinf
2
u
2
z2
3
Alpha
4
q
5
Theta

Context and problem

- Focus on the need for multicontrol

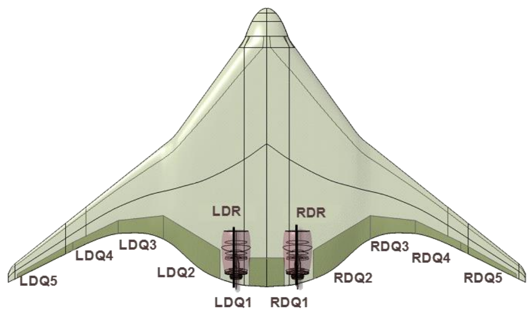


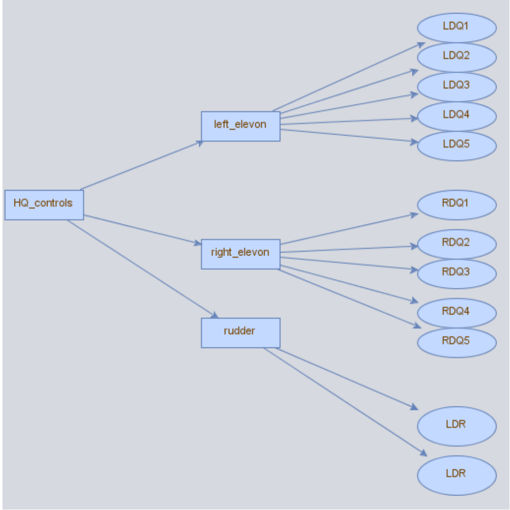


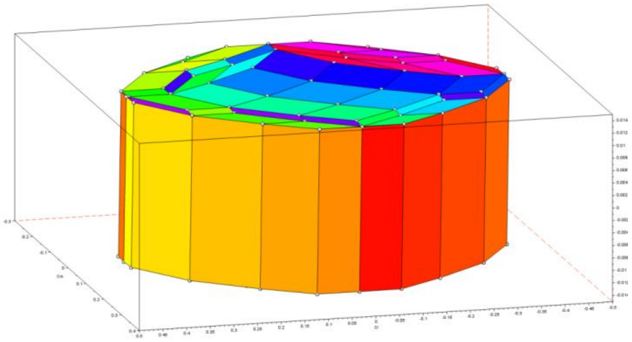
Multicontrol mandatory or not.

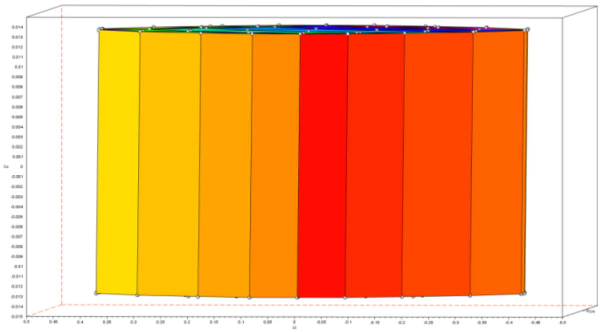
⇒ Internship on multicontrol allocation
⇒ Developement of a control allocation module

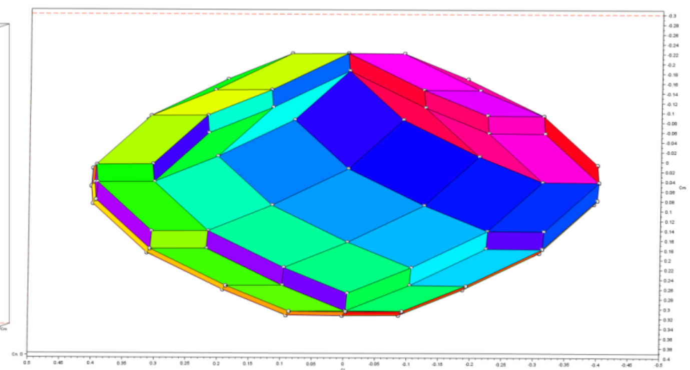
Control allocation: Attainable Moments Subset











Direct control allocation

- Calculation of the intersection facet