Knowledge-based Flight Control Sysem and Control Surfaces Integration in RAPID

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CONCEPT REALISATION LABORATORY

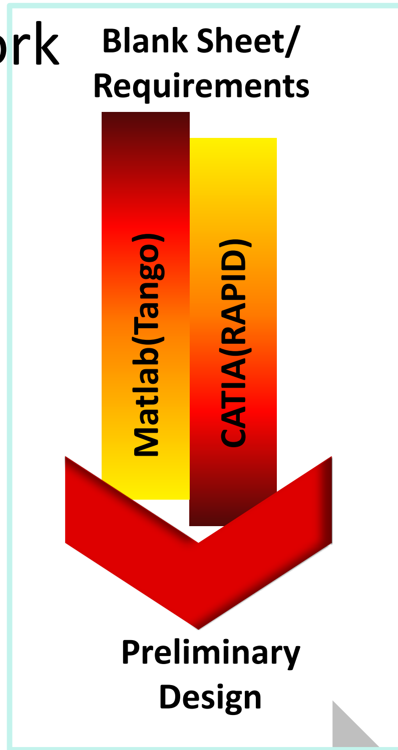
FluMeS

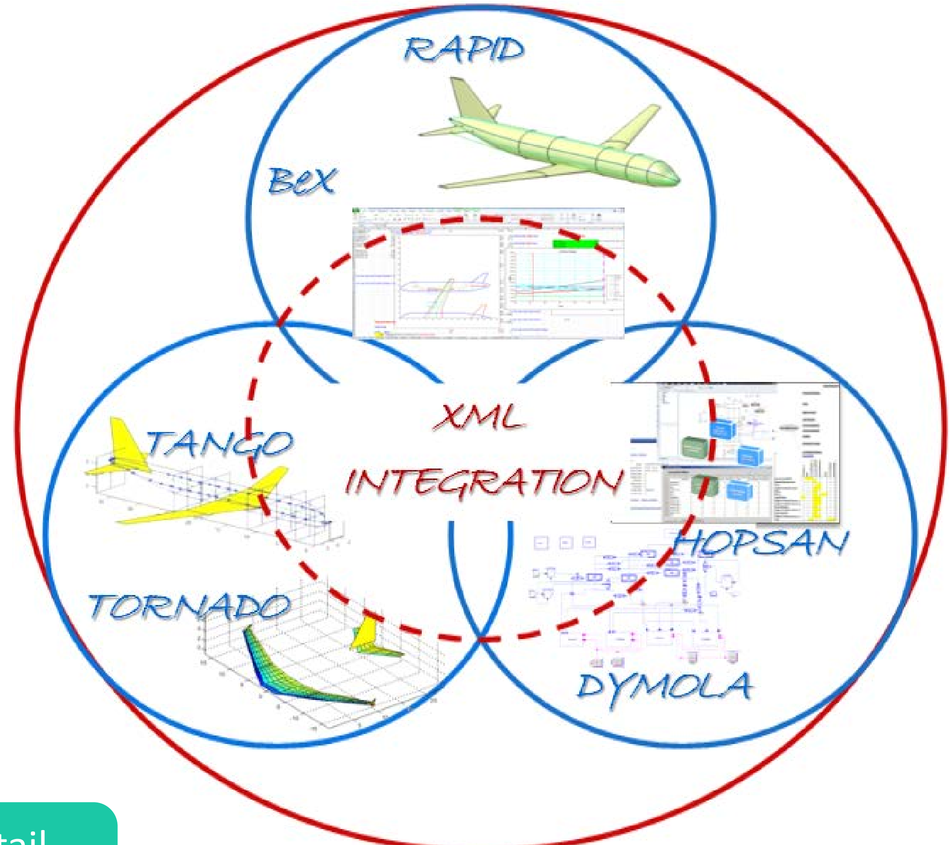
Fluid and Mechatronic Systems

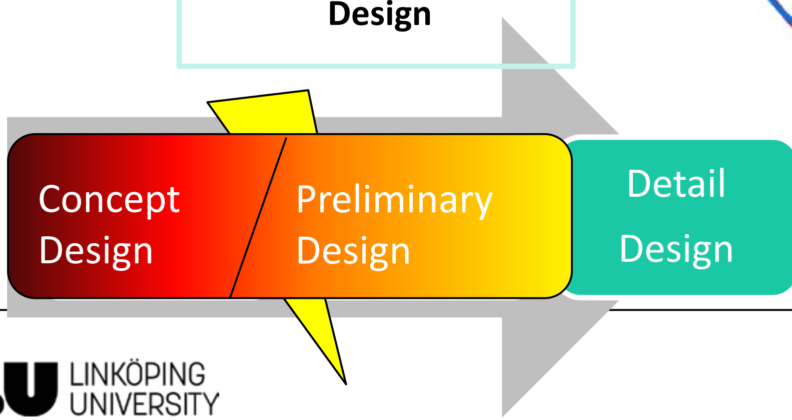
Agenda

- Introduction
  - Framework
- Objective
- Flight Control System Integration
  - Actuator Sizing
- Control Surfacecs Integration
- Conclusions
- Future work

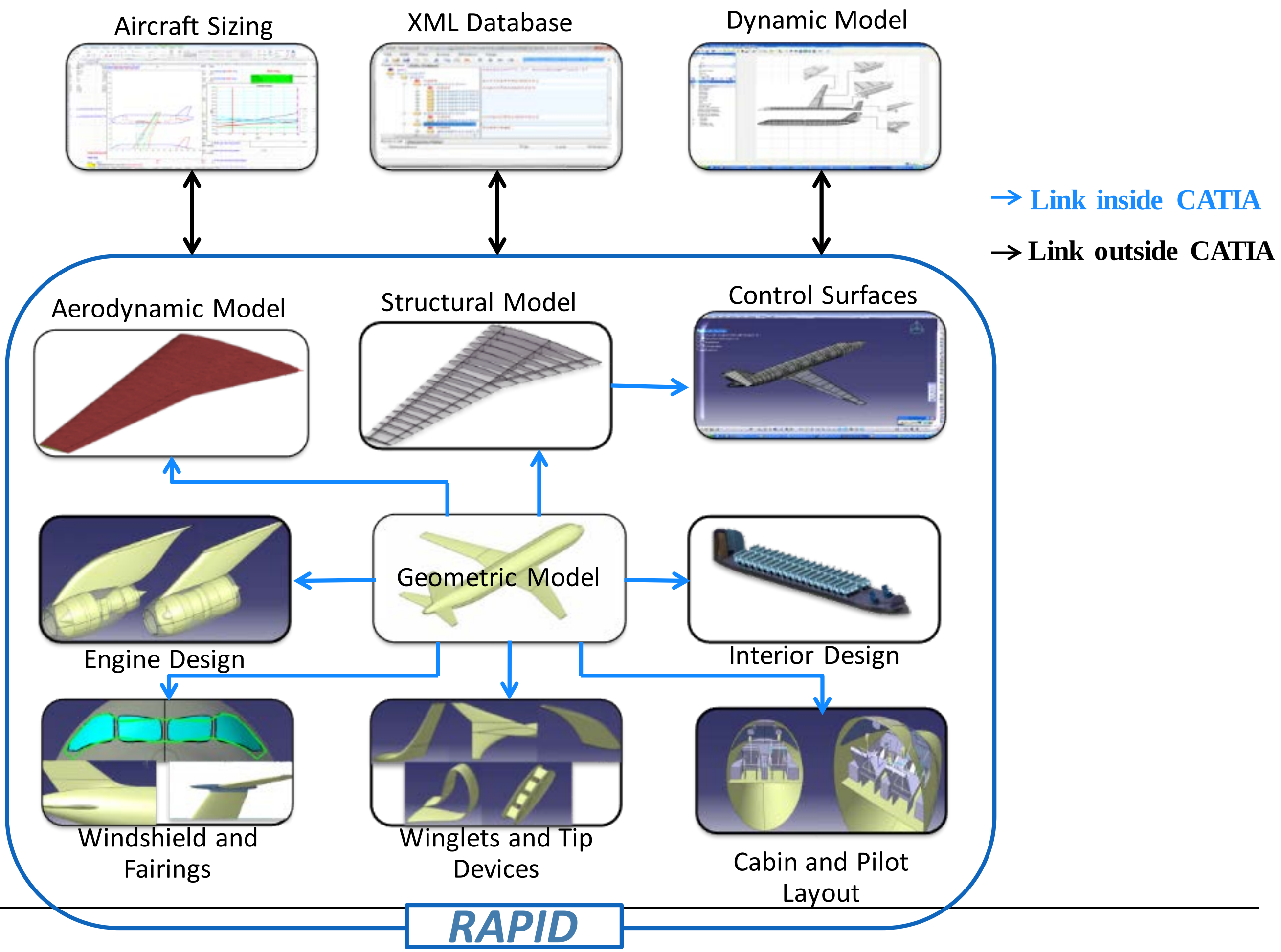
Knowledge-Based Integrated Aircraft Conceptual Design Framework



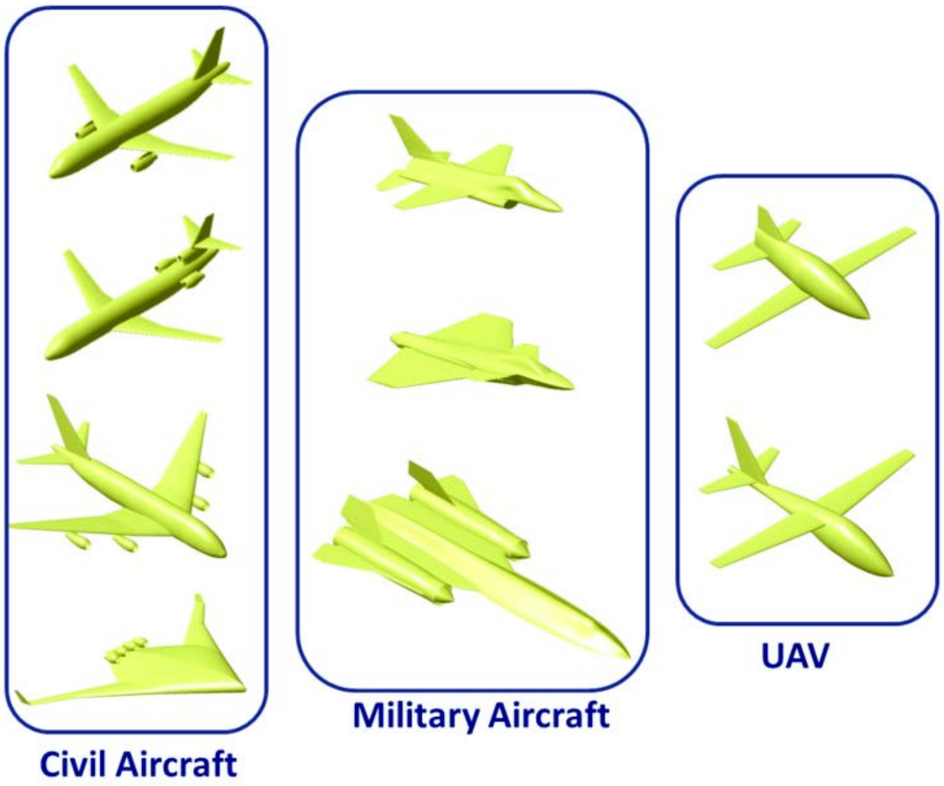




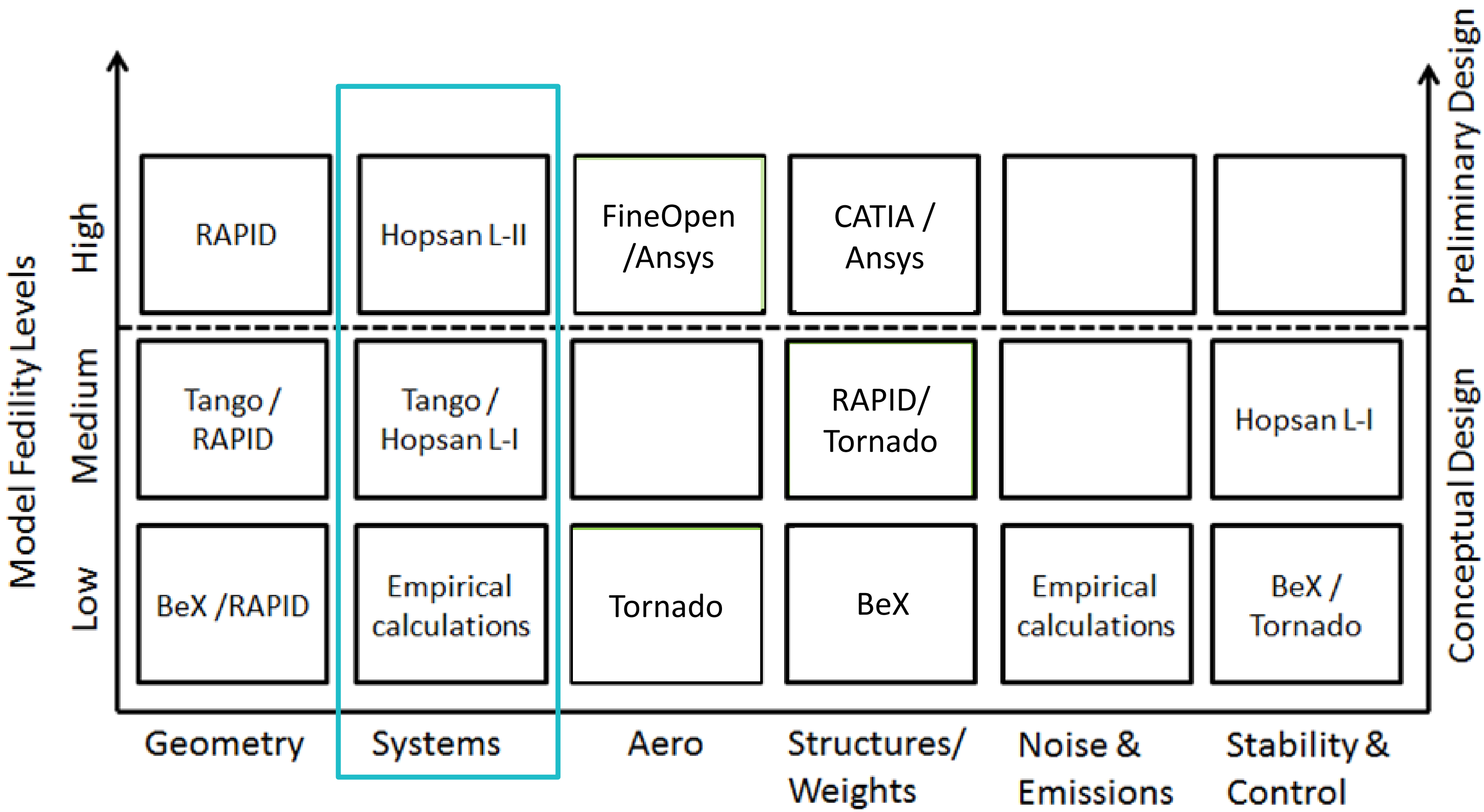
Knowledge-Based Geometry Design



Knowledge-Based Geometry Design



Framework Distribution



Objective

- To investigate the early design stages to define the flight control system integration.
- To develop knowledge-based CAD models of different types of flaps and their integration in RAPID

Flight Control System Integration

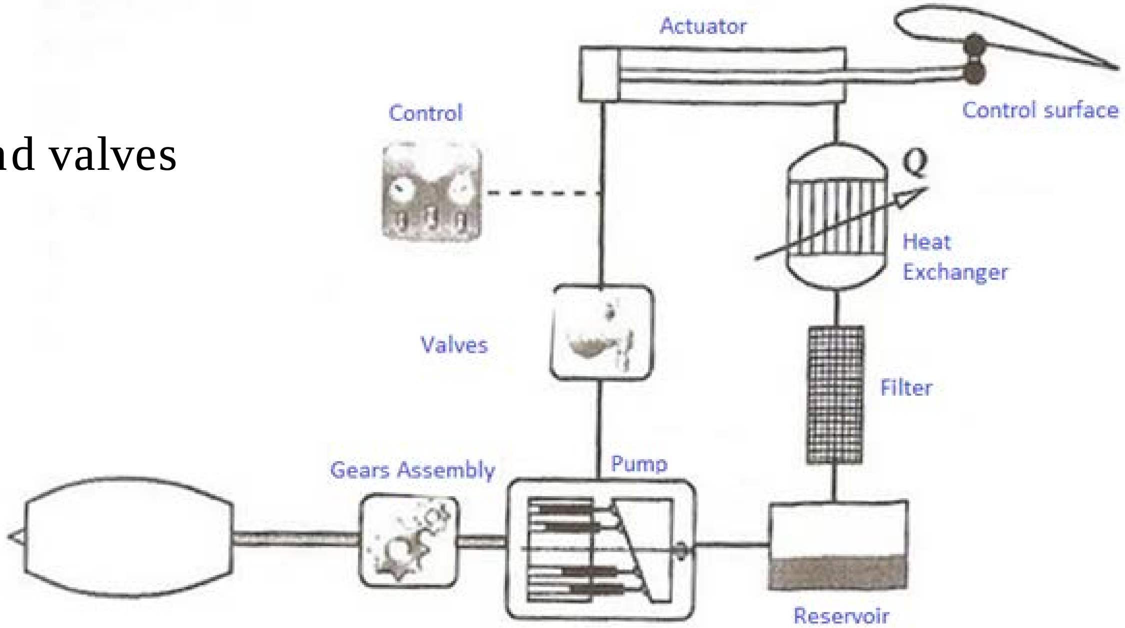
– Closely related to the hydraulic system
– Important dependency on the aircraft definition
– Its definition affects other systems solutions

Flight Control System Integration

- Simplifications and Assumptions
  - Systems symmetry
  - Valves omission
  - Positioning of the flight control system
  - Flight control system
  - Routing
  - Hydraulic Power Assembly
  - Geometry simplicity

Actuation Systems

- Hydraulic System main components
  - Pump
  - Actuators
  - Fluid
  - pipes, filters and valves
  - Tank
- Other Systems
  - Accumulators
  - PTU
  - RAT
  - APU



Flight Control System Integration

Hydraulic Circuit Basic Components		
NAME	**QUANTITY**	**FUNCTION**
Hydraulic Pump	2/system	It generates the hydraulic pressure which will power the actuators in the control surfaces.
Hydraulic Tank (Reservoir)	1/system	It storages the hydraulic fluid which transmits power within the circuit.
Regulating valve of the pump	2/system	It regulates the hydraulic fluid flow.
Hydraulic Accumulator	1/system	It storages hydraulic fluid which will be used in case of emergencies and peak performance.
Hydraulic conductors	N/A	They transfer the hydraulic fluid between the components of the circuit.
APU	1	It generates the hydraulic pressure which will power the actuators in the control surfaces.

Flight Control System Integration

Power and Control Units		
NAME	QUANTITY	FUNCTION
ARTCU	3	Deflection control unit.
Power Unit	1/actuators path	It powers a set of actuators.
Actuator Drive Assembly	1/actuator	It controls a specific actuator.
Electric Drive Unit	1	It powers slats rotary actuator.

Hydraulic Actuators		
NAME	QUANTITY	FUNCTION
Slats	1/surface	Rotary actuator which extends slats in the leading edge.
Ailerons	1/surface	It deflects ailerons' control surface.
Elevators	1/surface	It deflects elevators' control surface.
Rudder	1/surface	It deflects rudder's control surface.
Flaps	1/surface	It deflects flaps' control surface.
Spoilers	1/surface	It deflects spoilers' control surface.

Sizing - EHA

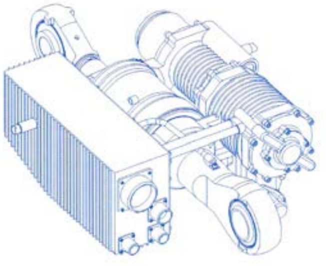


Figure 1. A330/340 Inboard Aileron EHA Solid Model

- Actuators based on an electric motor driven pump connected to a hydro-cylinder
- 5 main components: hydraulic cylinder, pump, motor, accumulator and power electronics
- Power electronics and accumulator size determined by their cooling surface, being considered as a cuboid
- It is assumed that motor and pump are on the same axis parallel to the cylinder

Procedure (Main inputs: F_{act} & $M_{controlsurface}$)

- $Arod = \frac{F}{Pn}$,   Pn: max allowable stress in the material
- $drod^2 = \frac{4}{\pi} Arod$
- $dpiston = \sqrt{drod^2 + \frac{4\,M}{\pi\, m\, pmaxsystem\, r \cos(\frac{\varphi}{2})}}$;
- $Apiston = \frac{\pi}{4}(dpiston^2)$
- $Qnom = Vn\ Apiston$; Q_{nom}: max required flow rate,

  Vn: max loaded velocity)

- $Vg = \frac{Qnom}{n_{nom}}$;   Vg : Volumetric displacement of the pump,

  n_{nom}: nominal speed of the motor

- $\tau = \frac{Pmotor}{n_{nom}}$; τ : Nominal torque of the motor,

  Pmotor: required power

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Frischemeier, S. (1997), 'Electrohydrostatic actuators for aircraft primary flight control-types, modelling and evaluation'.

Sizing - EHA

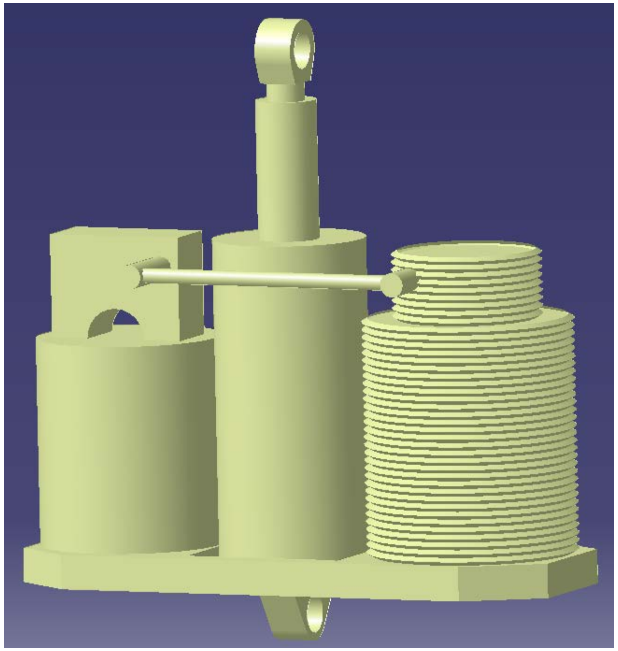
- The previous values and the table below (estimated statistically) allow to have a preliminary sizing of an EHA, depending on the value of the constants. With the dimensions of existing EHAs components it is possible to define those values.

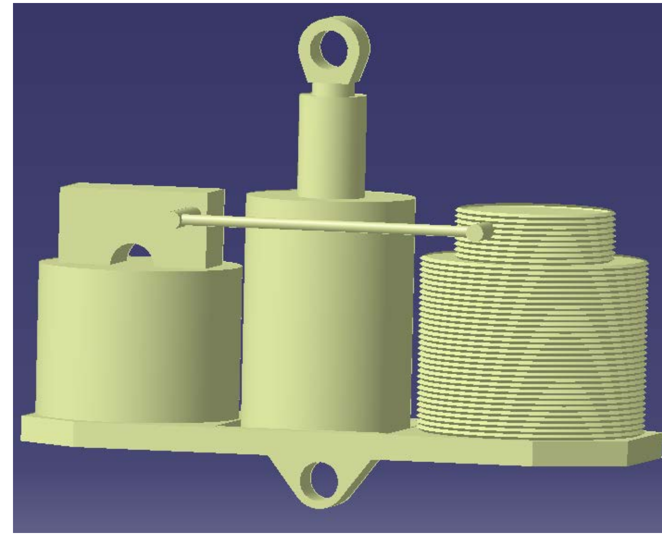
Component	**Parameters**	**Dimension Estimate**
Cylinder	piston diameter d_Z, stop-to-stop stroke $x_{\max} - x_{\min}$	$h_{Zyl} \approx k_0 + k_1\, d_Z$ $b_{Zyl} \approx k_2 + k_3\, \frac{d_Z^2}{h_{Zyl}}$ $l_{Zyl} \approx k_4 + k_5\, (x_{\max} - x_{\min})$
Axial piston pump	geometric displacement $V_{g\max}$, typical $\frac{l_P}{\sqrt{A_P}} =: \lambda_P,\ A_P = b_P \cdot h_P$	$l_P \approx k_0\, \lambda^{\frac{2}{3}}\, \sqrt[3]{1 + k_1\, V_g}$ $d_P \approx 2\sqrt{\frac{A_P}{\pi}} = \frac{2}{\sqrt{\pi}}\, \frac{l_P}{\lambda_P}$
AC induction / brushless DC motor	nominal torque $M_{mot,nom} := \frac{P_{mot,cont}}{n_{mot,\max}}$	$V_{mot} = \frac{\pi}{4} d_{mot}^2\, l_{mot}$ $V_{mot} \approx k_0\, M_{mot,nom}^{k_1}$

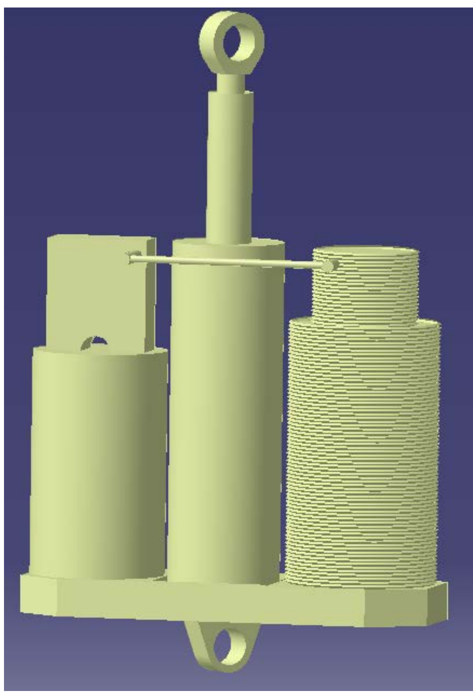
Frischemeier, S. (1997), 'Electrohydrostatic actuators for aircraft primary flight control-types, modelling and evaluation'.

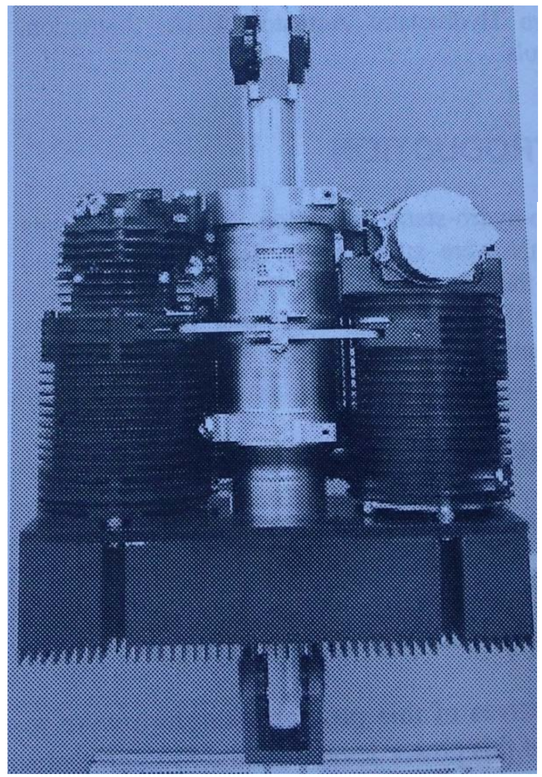
Sizing - EHA

HINGE MOMENT(Nm)		Fmax (kN) (Actuator)		Ashaft (m^2)	Dshaft (m)		Qmax (m^3/s) (Flow Rate)	
15		353		0,002199377	0,052918179		0,000892223	
		Max allowable stress (MPa) (shaft material)						
m FACTOR		160,5						
1				Dpiston (m)	Apiston (m^2)		Vg (m^3/rad) (Pump Displacement)	
				0,111181906	0,009708634		2,84004E-06	
pmax sys (MPa)								
20,68								
r (Actuator hinge arm) (m)								
0,1								
Swept angle (deg)		Stroke (Xmax-Xmin) (m)						
30		0,1						
		k0						
Vmax (m/s) (max loaded velocity)		0,2		Cylinder			Pump	
0,0919		k1		hc (m)	lc (m)		lp (m)	dp (m)
		1,3		0,344536478	0,5		0,108576838	0,306289606
n (rpm) Nominal speed (motor)		k4						
3000		0,3						
		k5						
P max nominal (kW) (motor)		2						
2,23		λ						
		0,4						
M (Nm) (Torque motor)								
7,098310462								









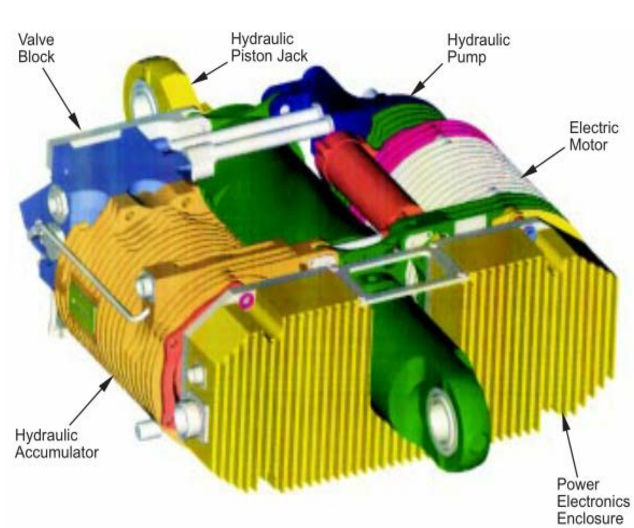


Figure 2. Large EHA

Sizing - EMA

- Actuator where a mechanical gearing is used to couple an electric motor to a flight control surface.
- Aerospace EMA major components: Brushless motor (cylindrical or annular); Gearbox, Spur gear or Cycloidal reducer; ball or roller screw, Spherical, axial or radial load bearing
- Main design model: Scaling laws

Scaling Laws

- Scaling laws evaluates the effect of varying parameters of a component compared to a known reference
- Scaling ratio of a paremeter: $x^* = x/x_{ref}$
- 2 main assumptions:
  - All material properties are identical to those of the reference
  - The ratio of all the lengths of the considered element to all the lengths of the reference component is constant
- Parameters representing geometric quantities can be directly obtained from the assumption of geometric similarity: $V^*=l^{*3}$, $M^*= l^{*3}$

Sizing - EMA

- For mechanical components
  - $F^* = l^{*2}$
  - $T^* = l^{*3}$

Thus the variation of the diameter, length or mas can be expressed as a function of the transmitted force F* or torque T*

Established scaling laws for bearings and ball and roller screws.

Parameter	***Unit***	***Rolling bearings (incl. end-bearings)***	***Spherical bearing***	***Ball and roller screws (nut and screw)***
Definition parameter(s)		Dynamic load capacity C_{nom} (N)	Nominal static load C_0 (N)	Nominal output force F_{nom} (N)
Integration parameters Length, diameter, width and depth	*m*	$l^* = C_{nom}^{*1/2}$	$l^* = C_0^{*1/2}$	$l^* = F_{nom}^{*1/2}$ (diameter)
Inner diameter	*m*	$d_{in} = d_{ext} - (F^*)^{1/2}\Delta d_{ref}$	$d_{in} = d_{ext} - (F^*)^{1/2}\Delta d_{ref}$	-
Mass	*Kg*	$M^* = C_{nom}^{*3/2}$	$M^* = C_0^{*3/2}$	$M^* = F_{nom}^{*3/2}$ (nut)
Mass per unit length	*kg/m*	-	-	$M_l^* = F_{nom}^*$ (screw)

Botten, S. L., Whitley, C. R. & King, A. D. (2000), 'Flight control actuation technology for next generation allelectric aircraft', Technol. Rev. J 23(6), 55–68.

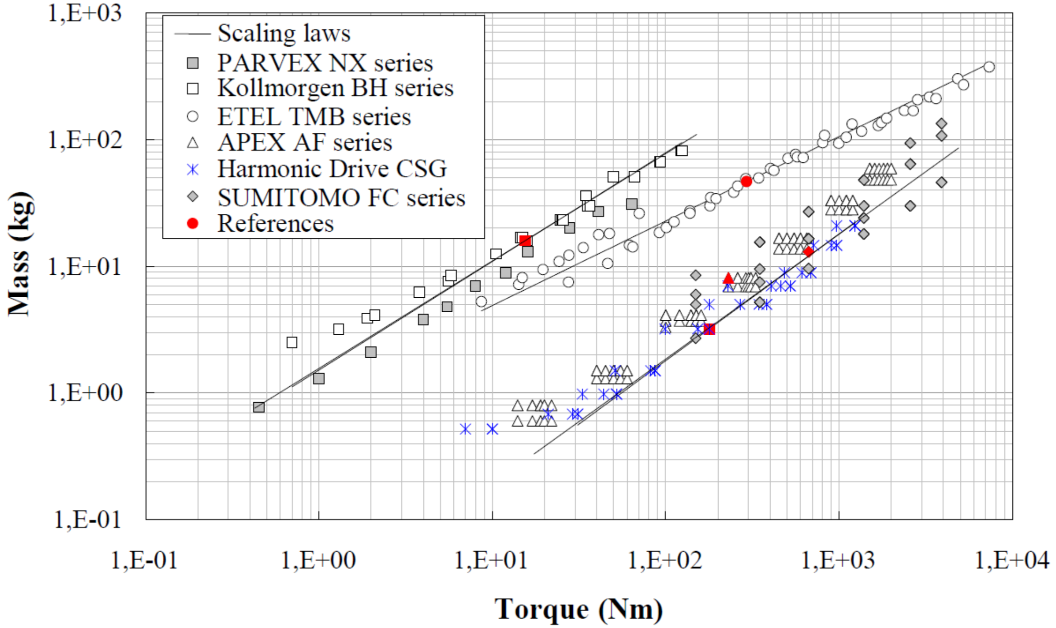
Established scaling laws for the speed reducers.

Parameter	*Units*	*Speed reducer - 1 stage* *Cycloidal, Harmonic Drive*	*Speed reducer -n stages* *Planetary gearboxes*
Definition parameter		Nominal output torque T_{nom} (Nm) Transmission ratio k	Nominal output torque (Nm), stage number i $T^*_{i,nom} = \dfrac{T^*_{n_s,nom}}{k^{\left(1-\frac{1}{p}\right)\left(1-\frac{i}{n_s}\right)} \eta^{n_s-i}}$, $i < n_s$ Total reduction ratio k
Integration parameters Length *(l)* and diameter *(d)* Mass	*M* *Kg*	$d^* = T^{*1/3}_{nom}$ $l^* = T^{*1/3}_{nom}$ $M^* = T^*_{nom}$	$d_i^* = T^{*1/3}_{i,nom}$ $l_i^* = T^{*1/3}_{i,nom}$, $l_i \geq l_{i,\min}$ $M_i^* = T^*_{i,nom}$ or $M_i^* = T^{*2/3}_{n_s,nom} . l_i^*$

Established scaling laws for brushless motors

Parameter	*Units*	**Cylindrical motor**	**Annular motor**
Definition parameter			
Nominal continuous torque	*Nm*	$T^*_{em,nom} = l^{*3.5}$	$T^*_{em,nom} = l^{*3}$
Operating voltage	*V*	$U^* = n^* l^*$	$U^* = n^* l^{*3} \omega^*_{elec,\max}$
Integration parameters			
Length and diameter	*m*	$l^* = T^{*1/3.5}_{em,nom}$	$l^* = T^{*1/3}_{em,nom}$
Mass	*kg*	$M^* = T^{*3/3.5}_{em,nom}$	$M^* = T^{*2/3}_{em,nom}$

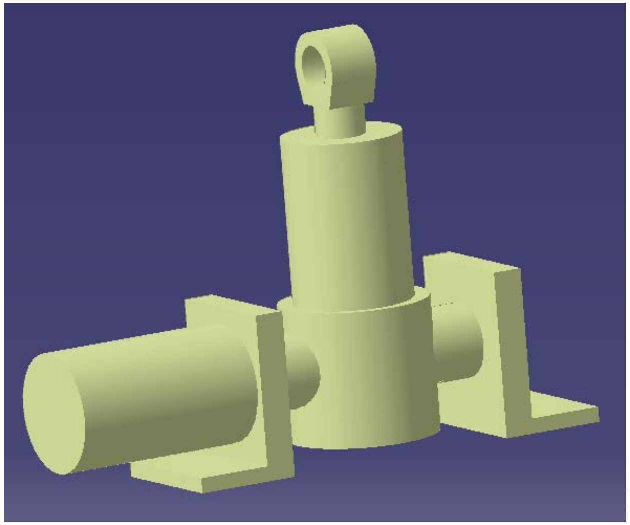
Botten, S. L., Whitley, C. R. & King, A. D. (2000), ‘Flight control actuation technology for next generation allelectric aircraft’, Technol. Rev. J 23(6), 55–68.



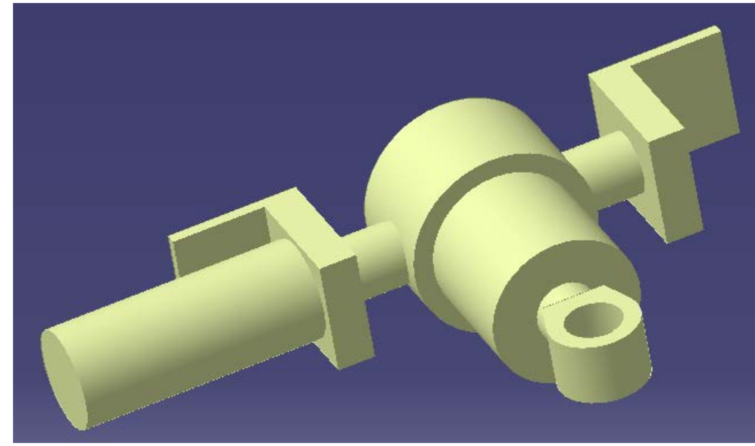
(a) Brushless motor and speed reducer masses as a function of the nominal torque.

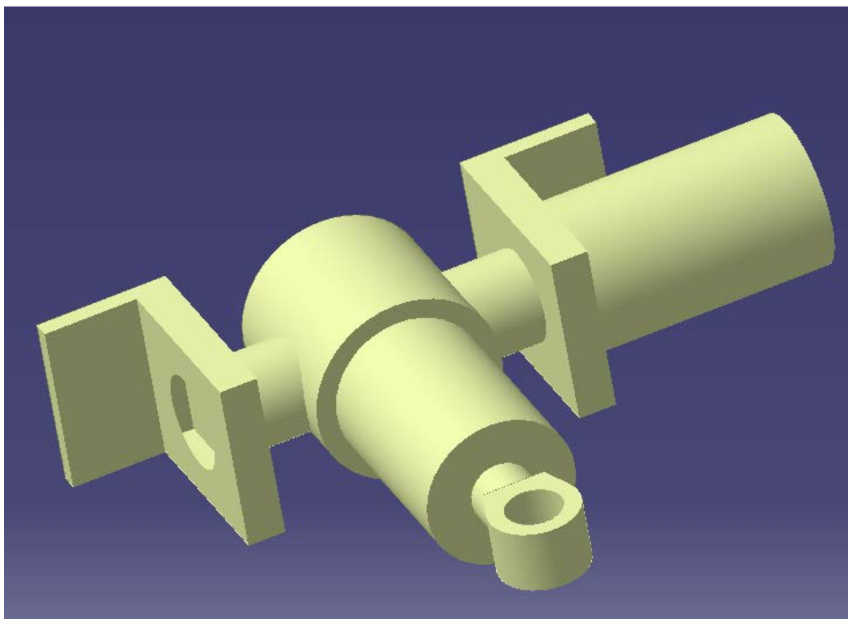
$$y^* = x^{*b} \Rightarrow y = \frac{y_{ref}}{x_{ref}^b} x^b \Rightarrow \log(y) = \log\left(\frac{y_{ref}}{x_{ref}^b}\right) + b.\log(x)$$

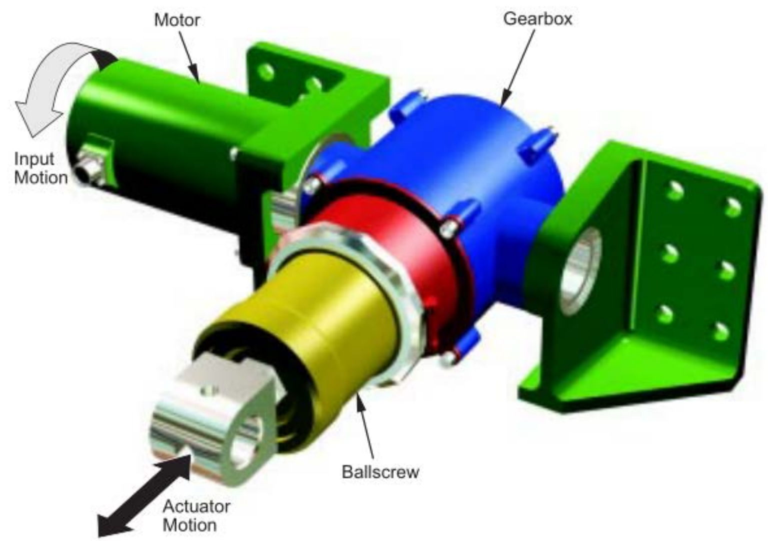
Botten, S. L., Whitley, C. R. & King, A. D. (2000), ‘Flight control actuation technology for next generation allelectric aircraft’, Technol. Rev. J 23(6), 55–68.




Parameters
Dcyl=100mm
Lcyl=200mm
Dring=25mm
Angle_Ring=90deg
Cylinder_Orientation=X_Direction
Rotate_Cyl_Axis=0deg





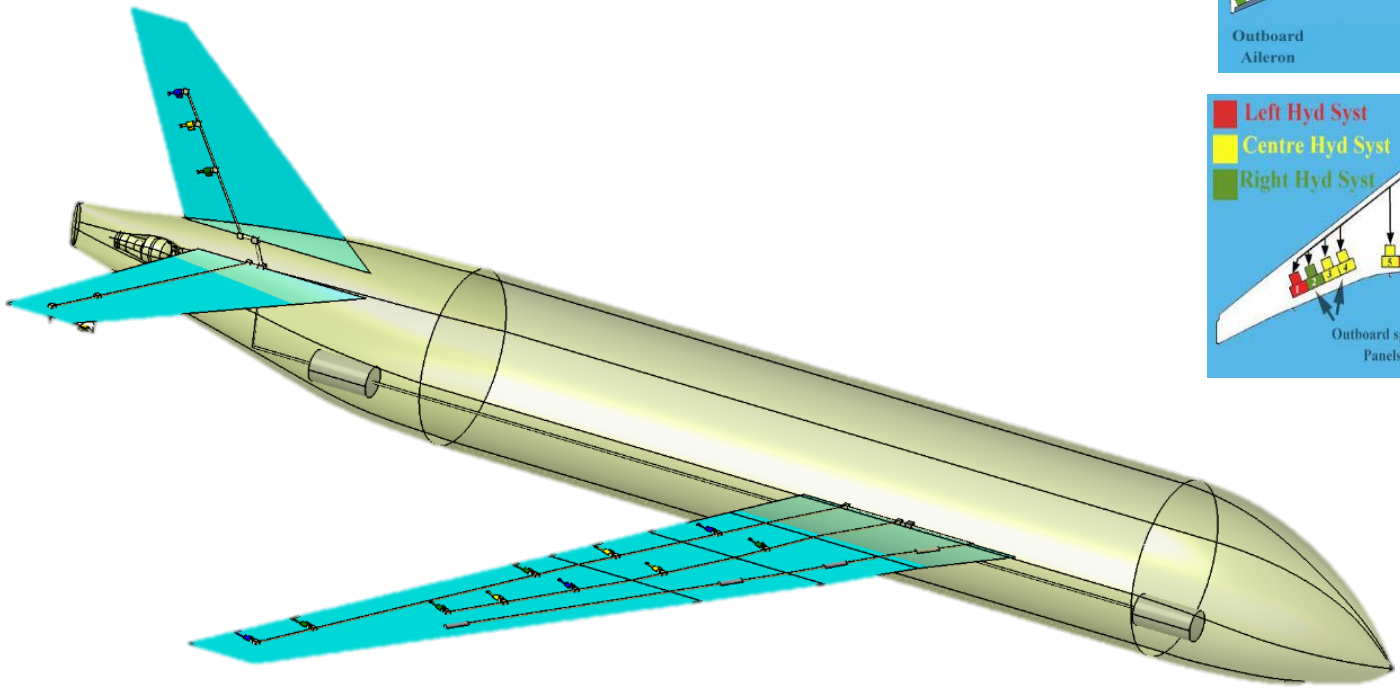

Motor
Gearbox
Input
Motion
Ballscrew
Actuator
Motion

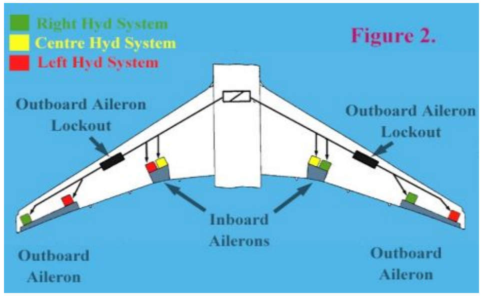
Actuator Data

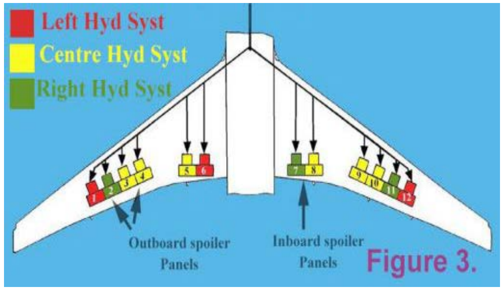
EHA		STROKE (m)	WEIGHT (kg)	OUTPUT POWER (kW)	Max Rate (m/s)	LOADED VELOCITY	STALL/OUTPUT FORCE (kN)
F-35 (Tandem)	RUDDER	0,0337	41,282	4,82	0,14	0,0919m/s at 62,285kN	56,49
A319/320/321	ELEVATOR	0,0609			0,0609		
	RUDDER	0,109			0,109		
	AILERON	0,043			0,088		
	SPOILER	0,083			0,099		
A330/340	ELEVATOR	0,099			0,119		101,86
	RUDDER	0,157			0,134		93,85
	AILERON	0,083			0,109		165,03
	SPOILER	0,071			0,0609		111,21
F-18	FLAPERON	0,1143	18,8		0,195		59,16
EMA							
F-18	FLAPERON	0,1048	11,8		0,1702		58,72
TRANSPORT	SPOILER	0,152	17,7		0,118		222,4
C-141	AILERON	0,137	15,9		0,118		84,74
Medium Size	Ametek-117PE101	0,1	6,4		0,133		40

Diameter (m)	Length Retracted (m)	Length Extended (m)
0,1235	0,3835	0,4835

Flight Control Systems Integration







Flight Control Systems Integration

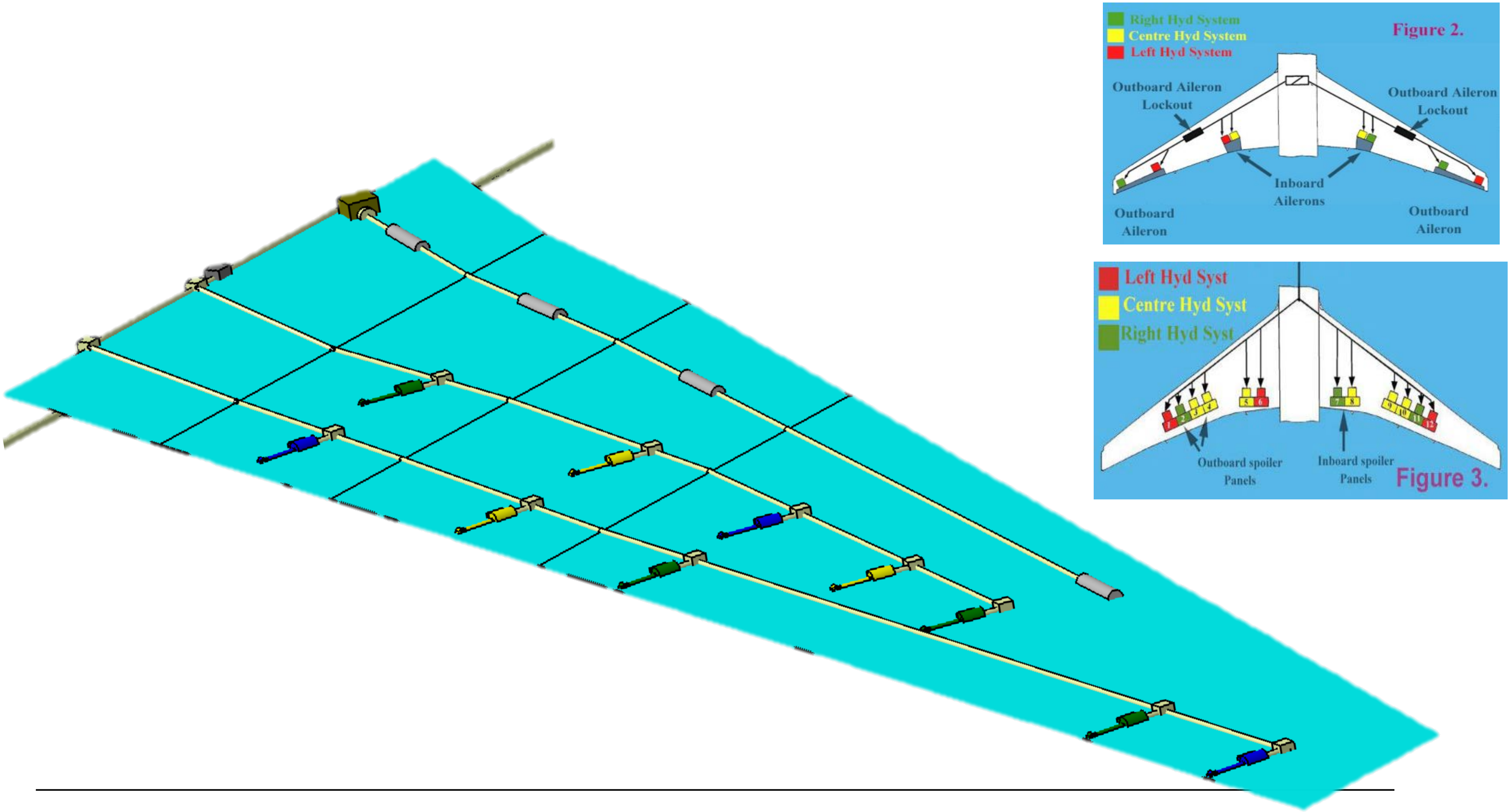
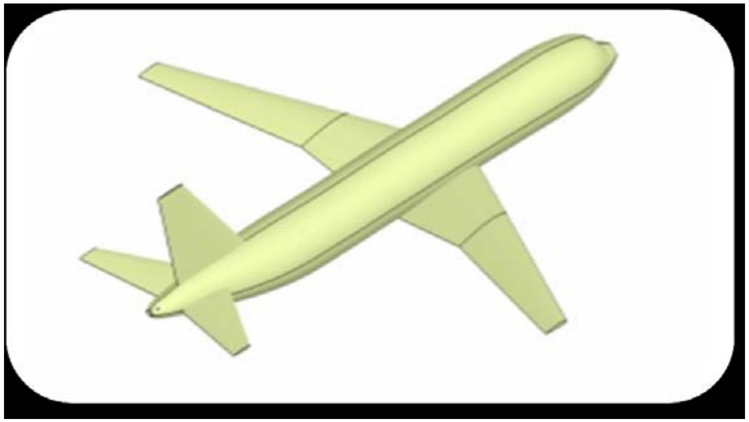
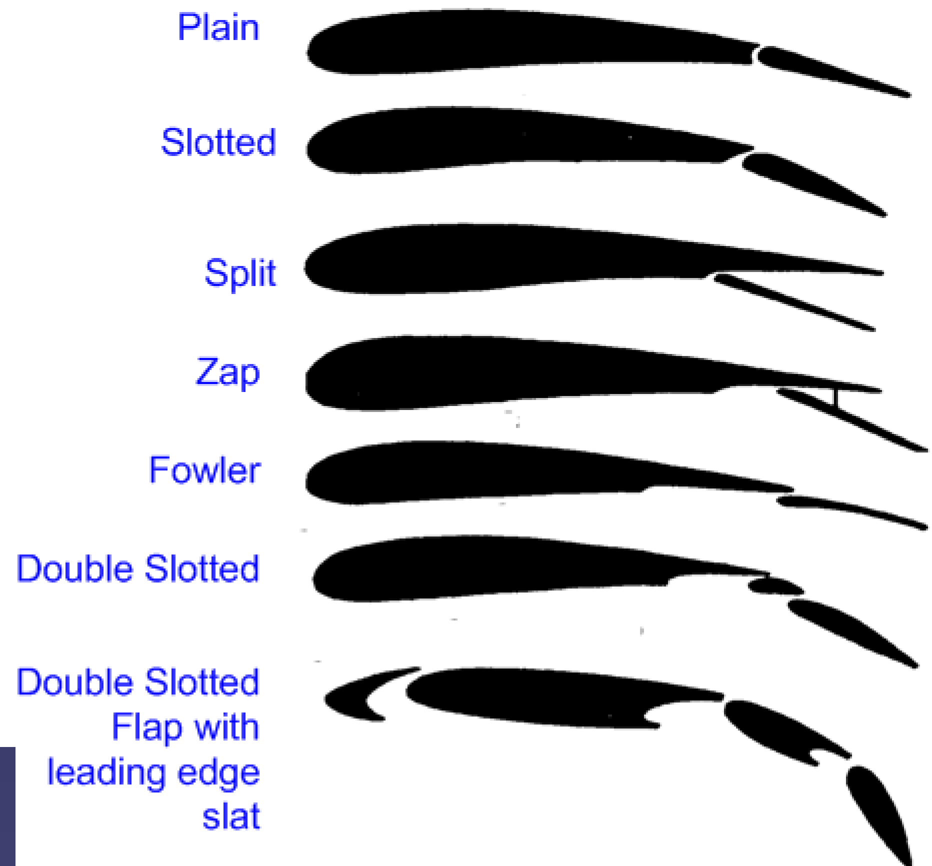


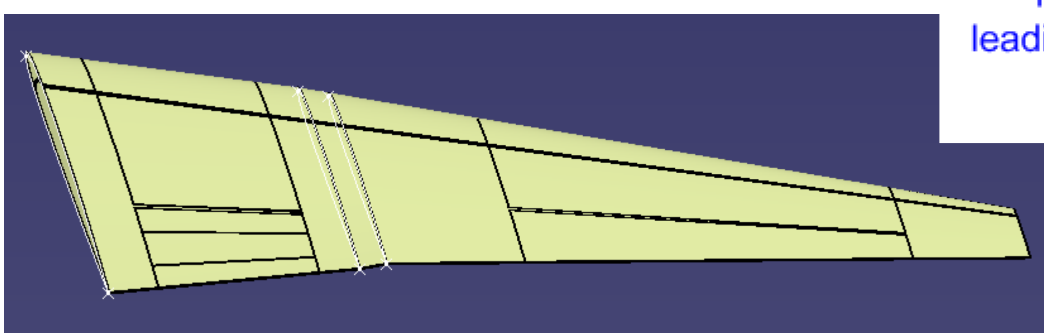
Figure 2.

Figure 3.

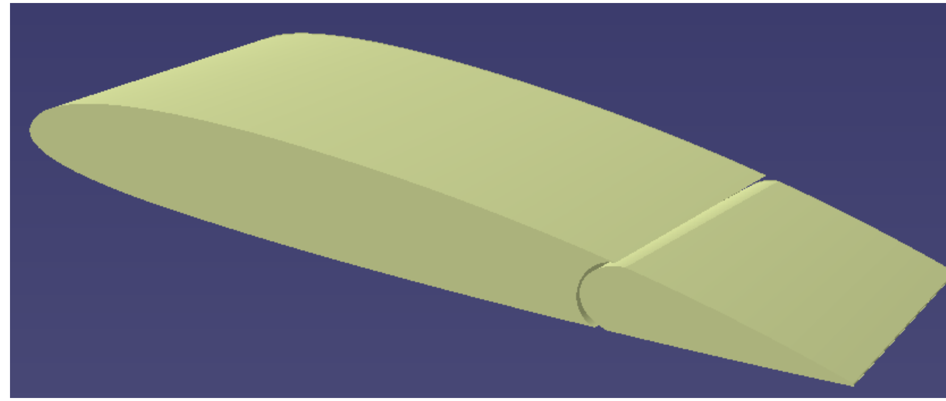
Control Surfacecs Integration

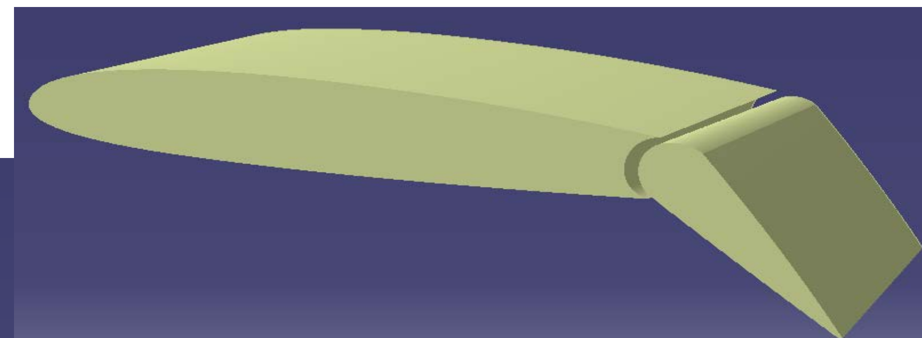


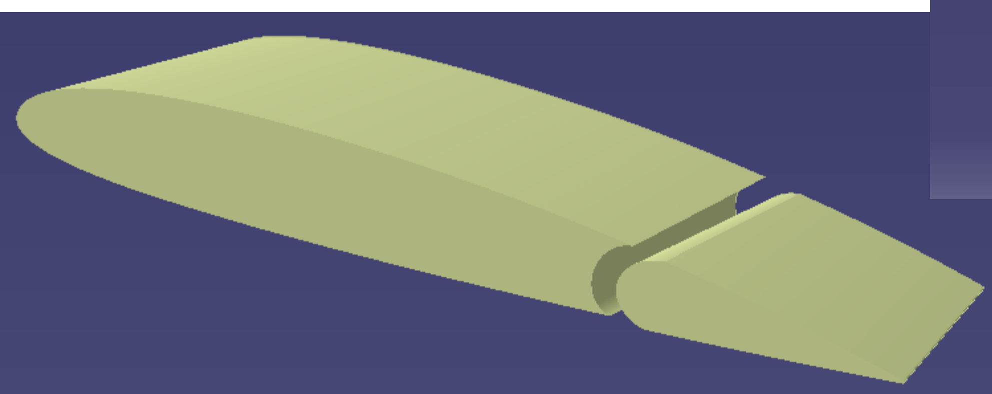


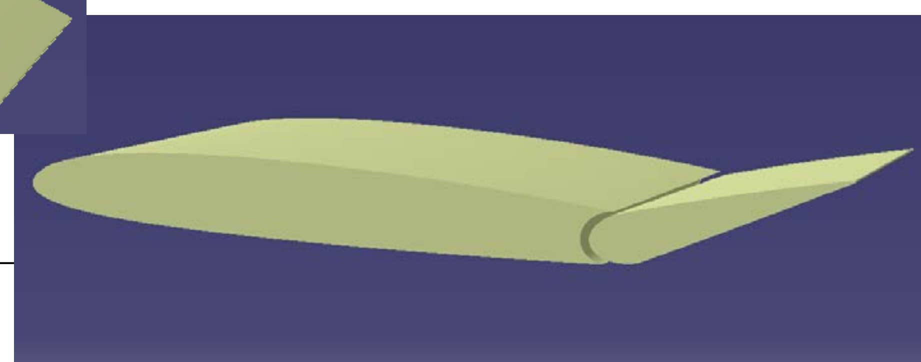


Plain flap/Aileron









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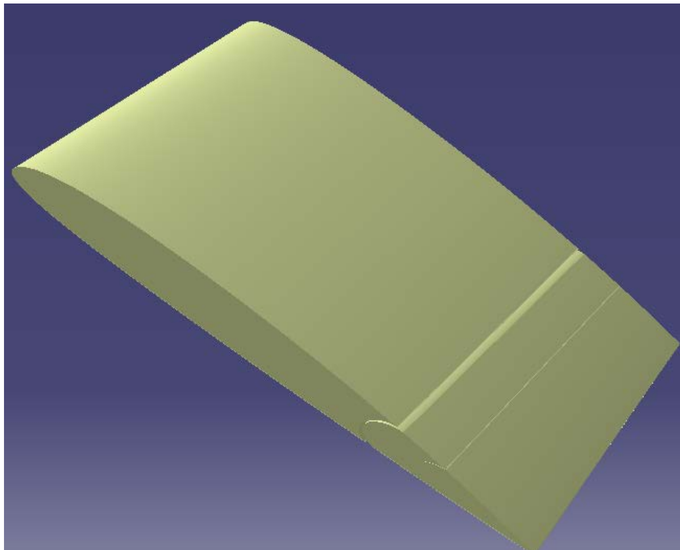
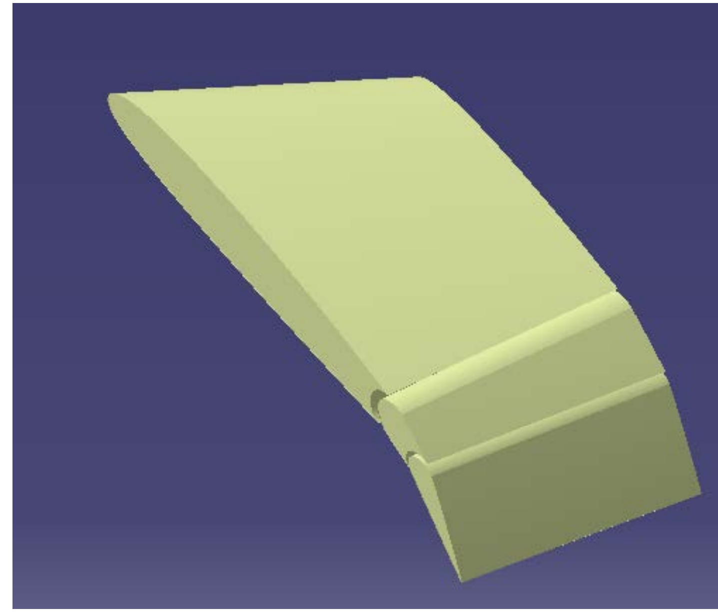
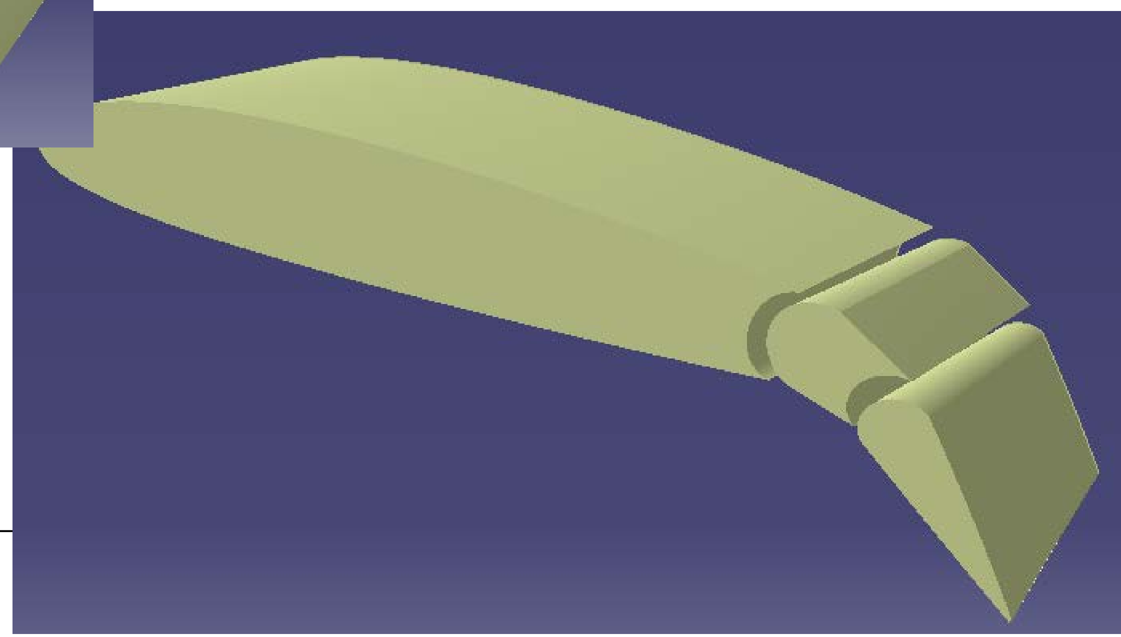
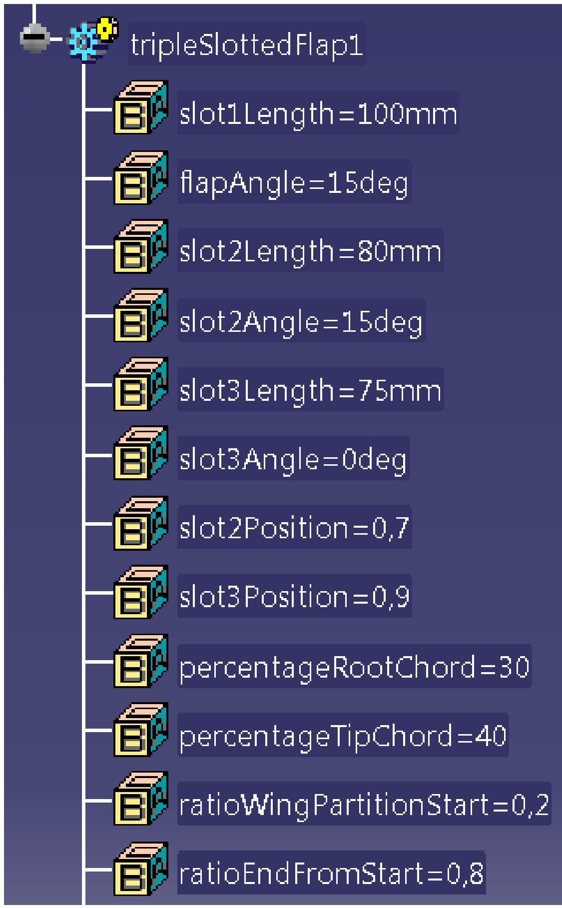
Double Slotted Flap

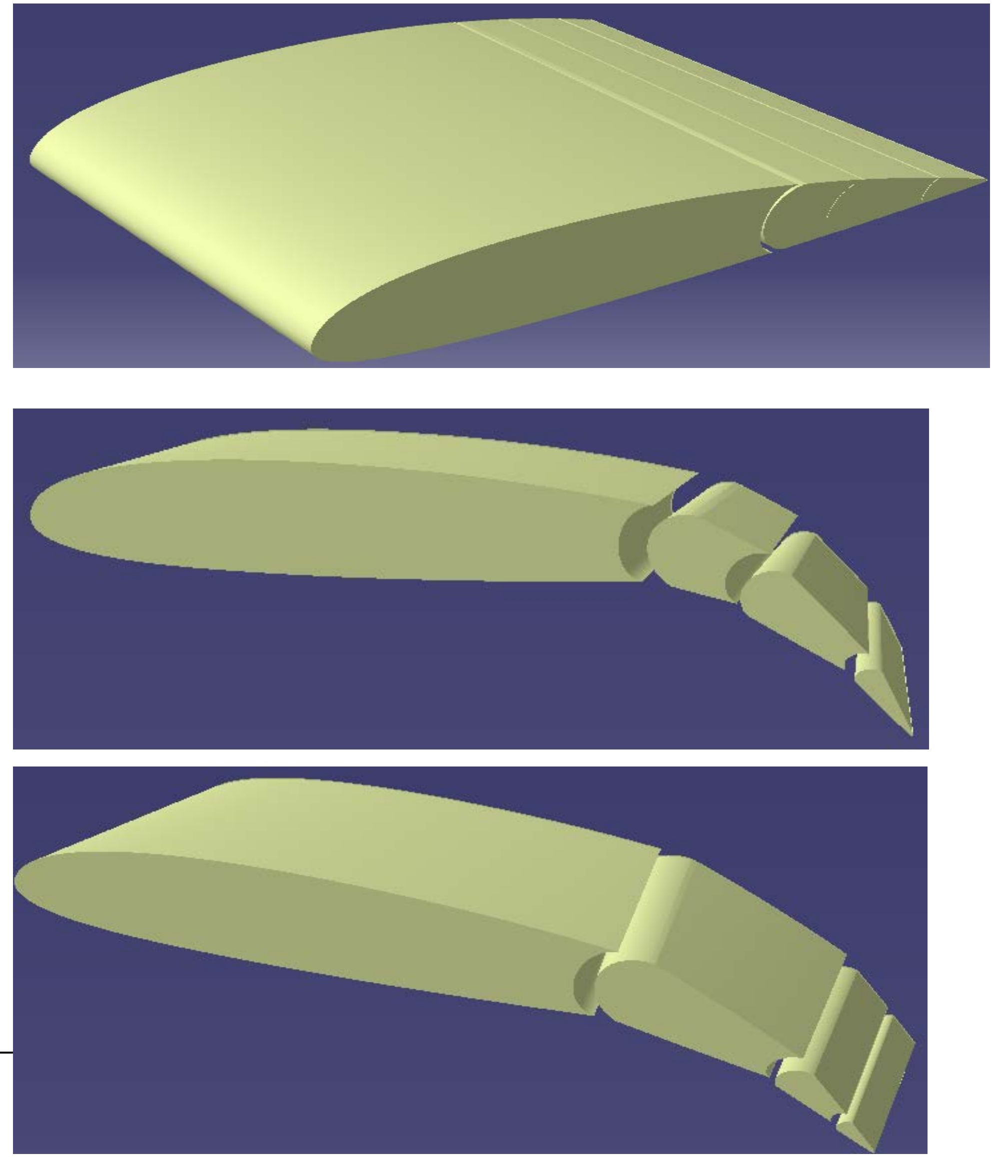




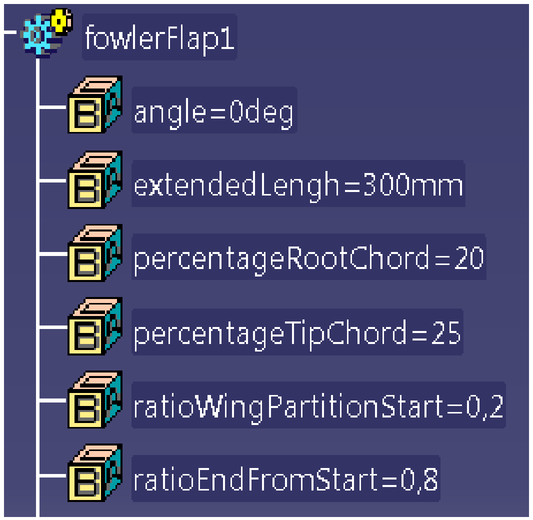


Triple Slotted Flap





Fowler Flap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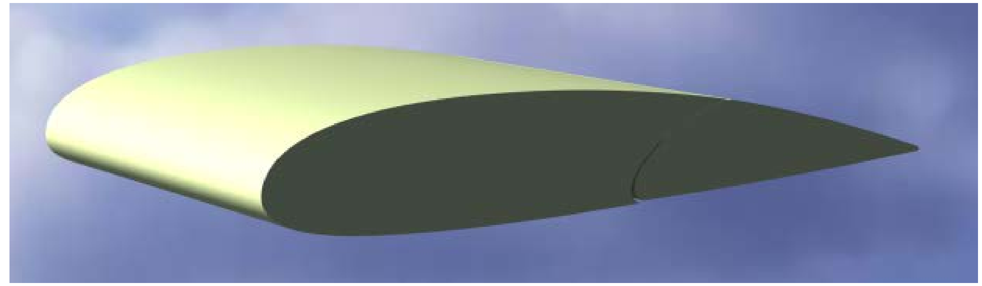
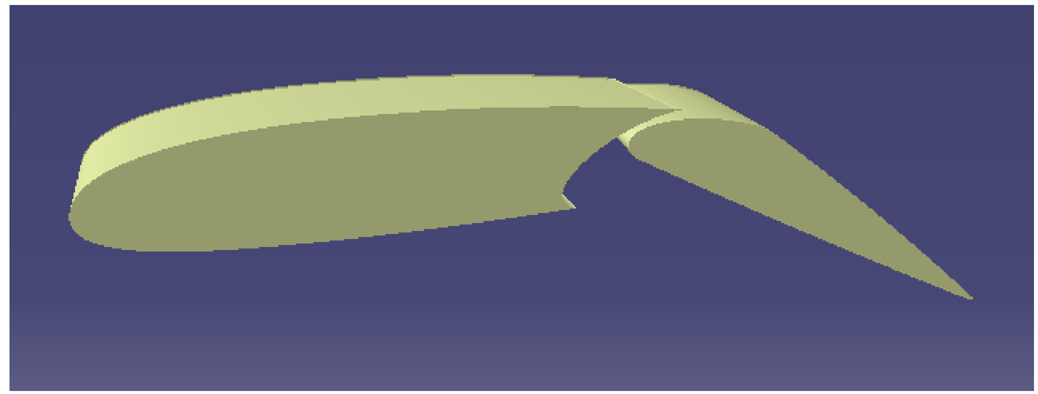
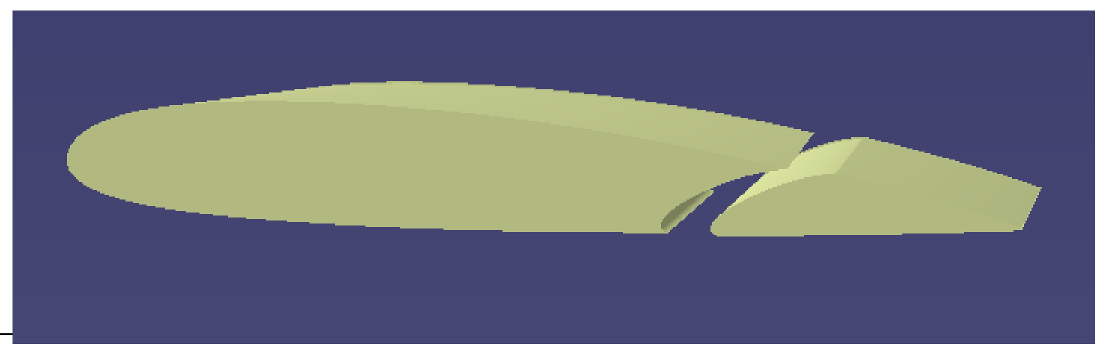
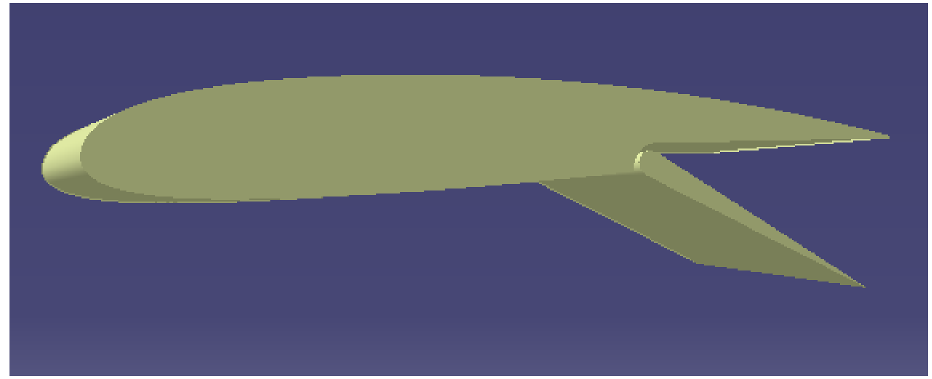
extendedLengh=300mm
percentageRootChord=20
percentageTipChord=25
ratioWingPartitionStart=0,2
ratioEndFromStart=0,8

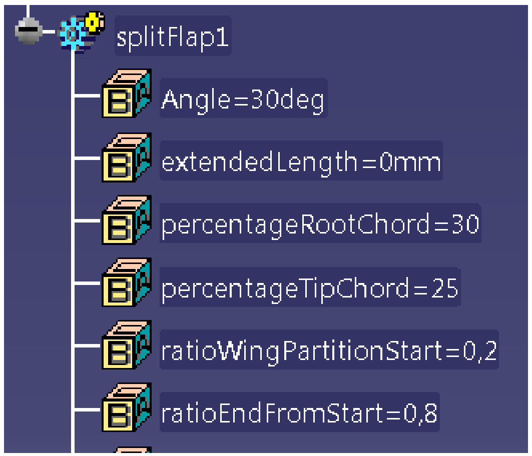


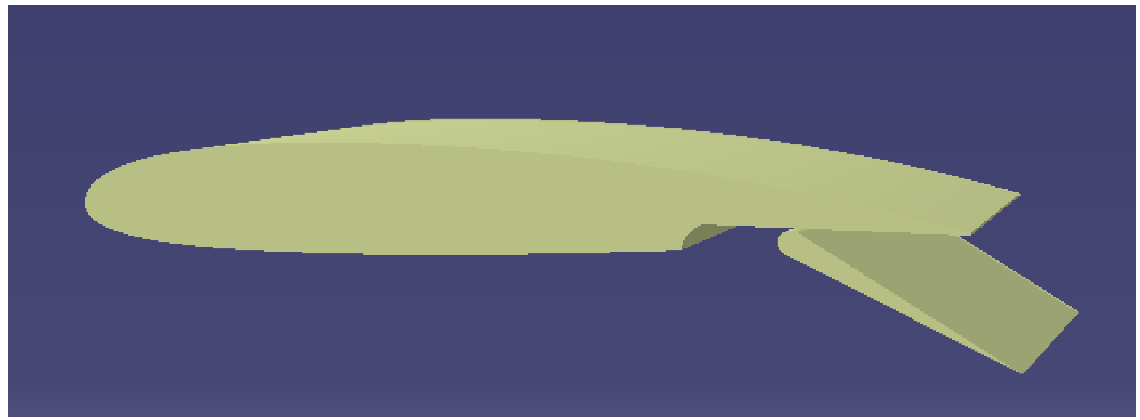


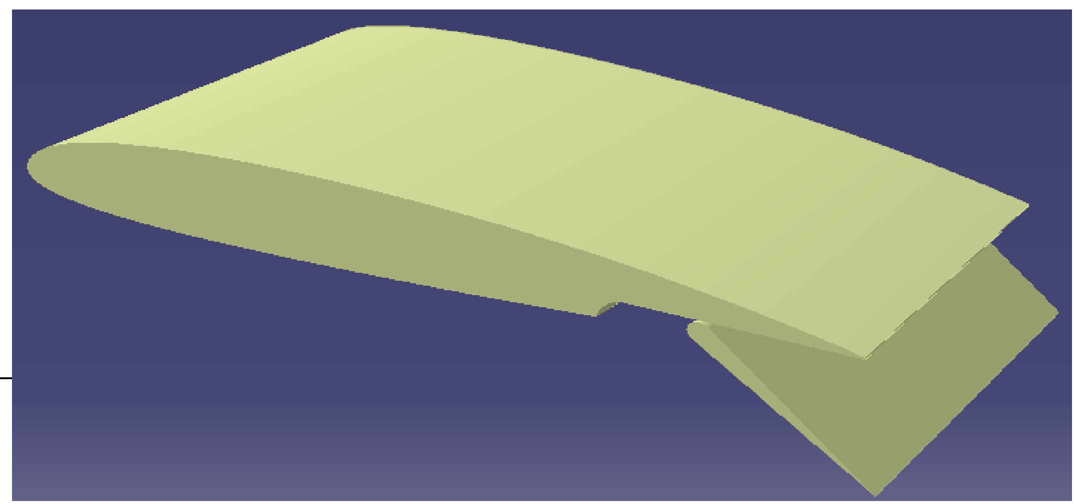


Split/Zap Flap

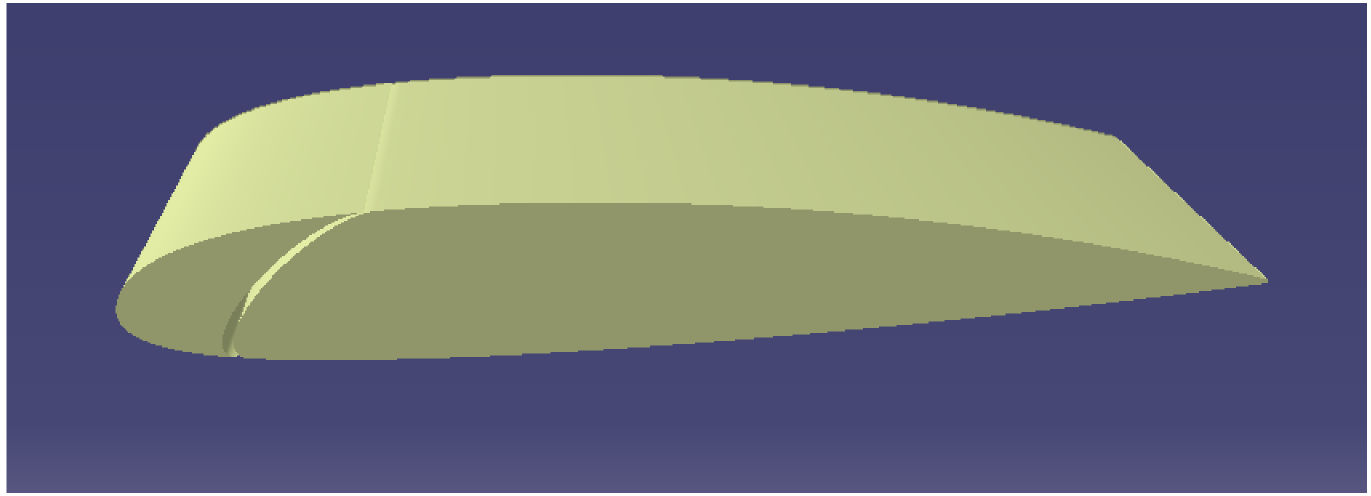








Slat

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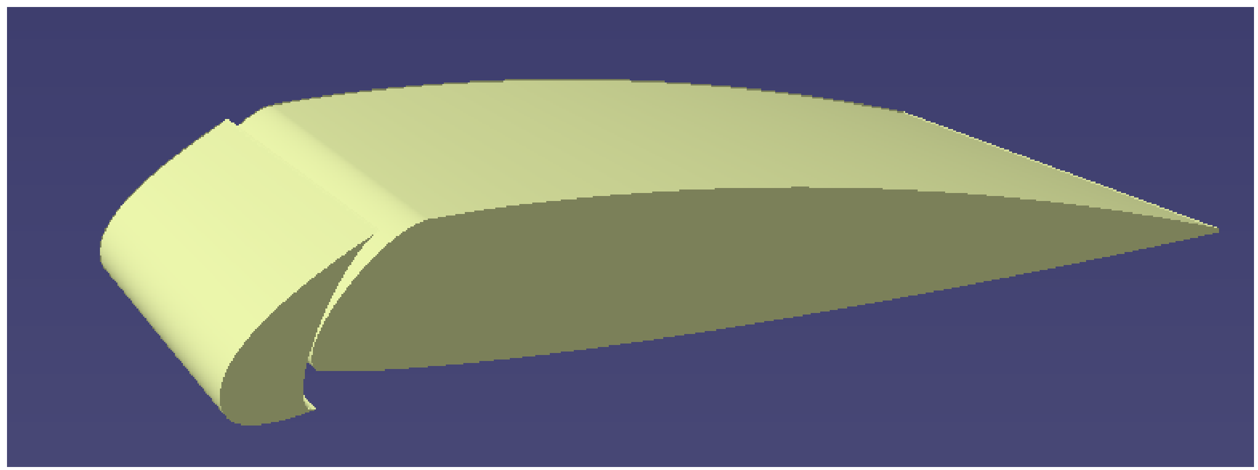
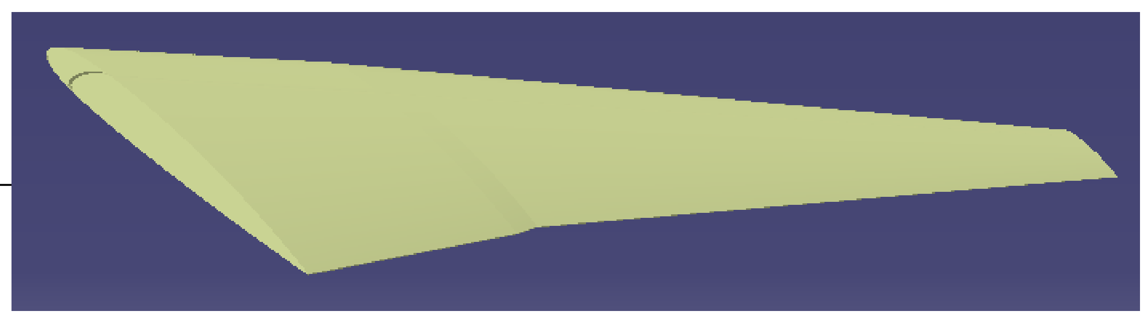
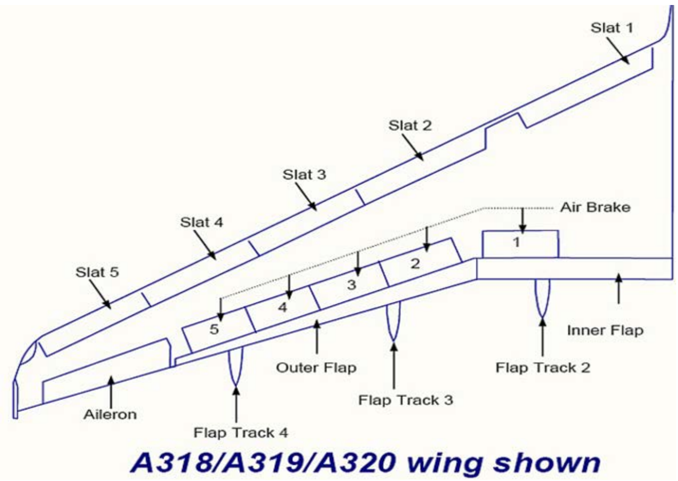
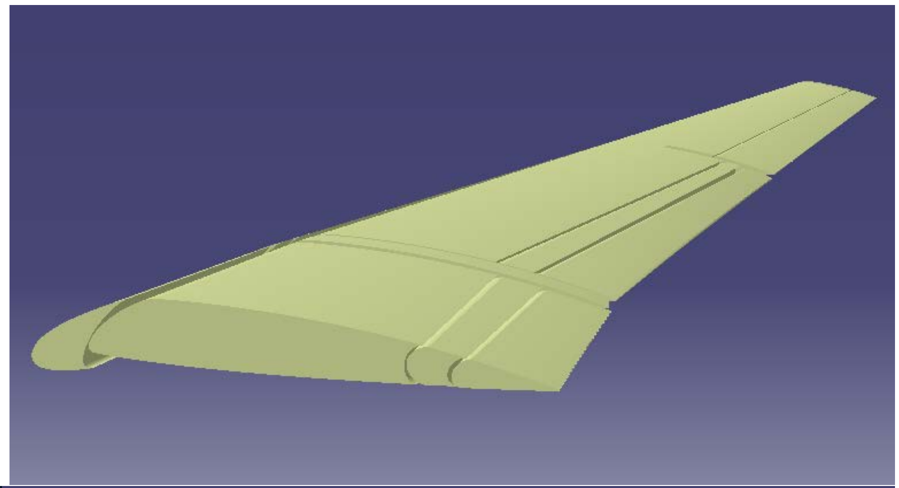
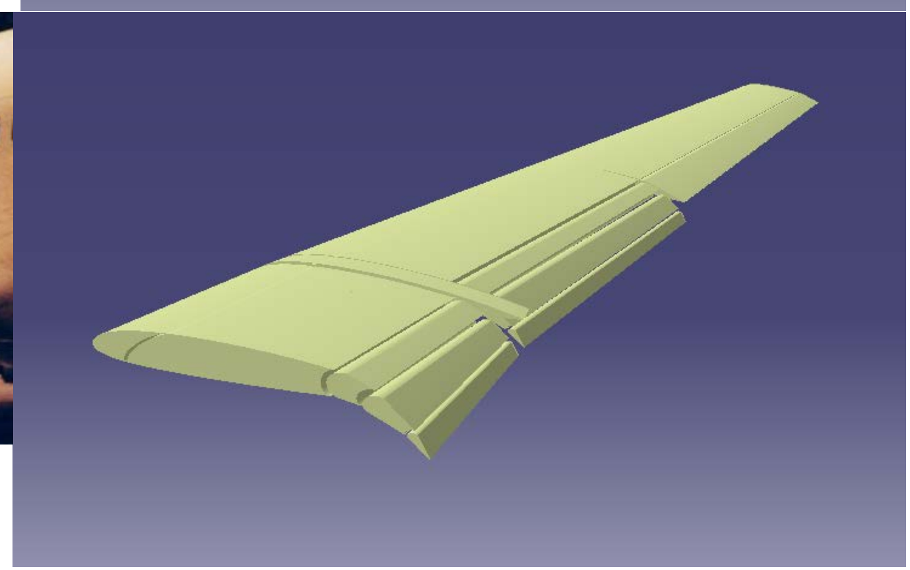




Control surfaces Integration

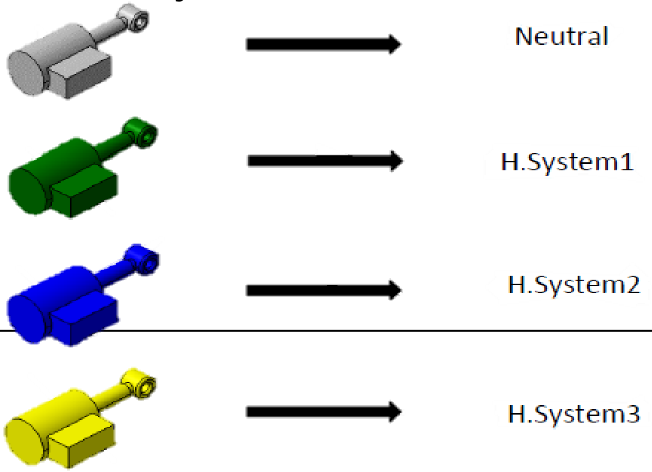




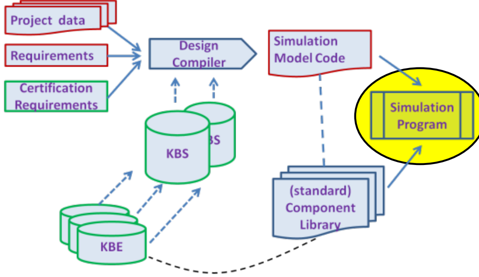


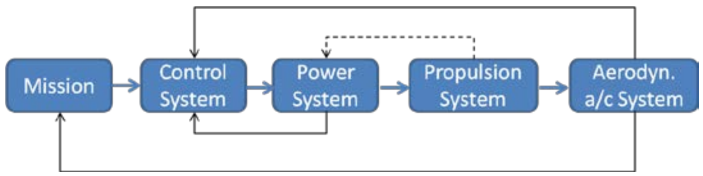
Conclusion

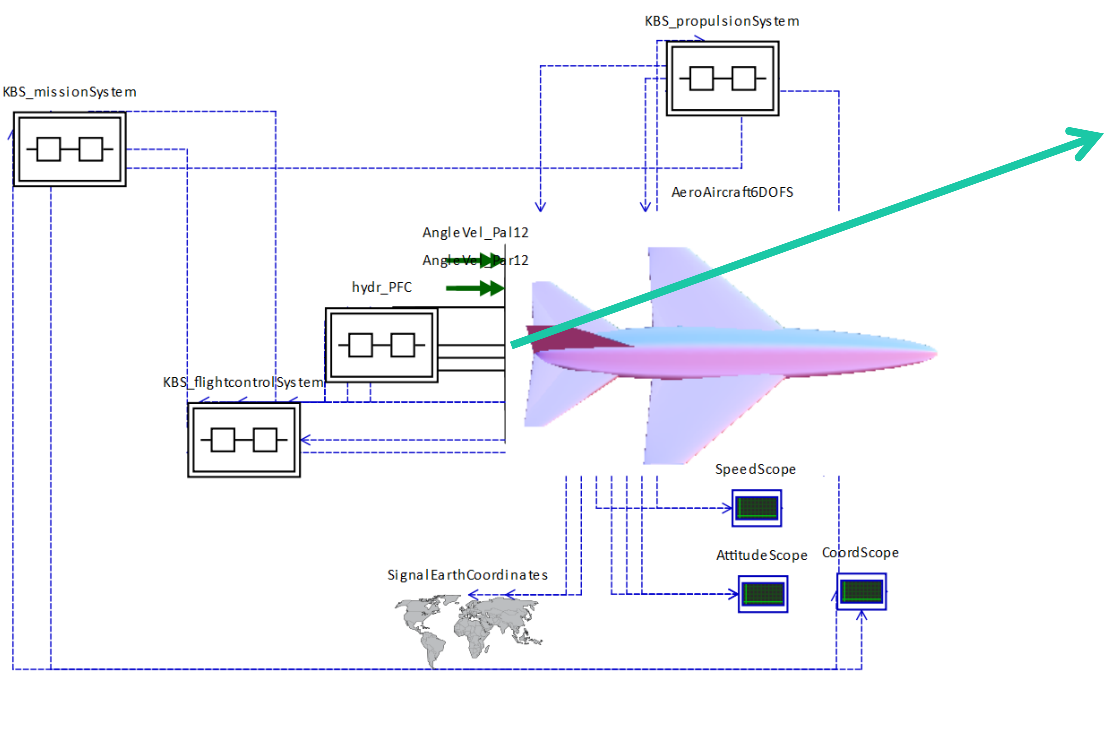
- *Fast realisation of the concept*
- *To support* ***Conceptual*** *to* ***Preliminary*** *Aircraft Design*
- Specialized tool for specialized needs (full CAD env.)
- Coupling to for CFD analysis for all lifting surfaces
- Flexibility level
  - Characteristic parameter
  - It allows to tailor connections between hydraulics systems and flight control surfaces
  - Representation widely used in the industry
-

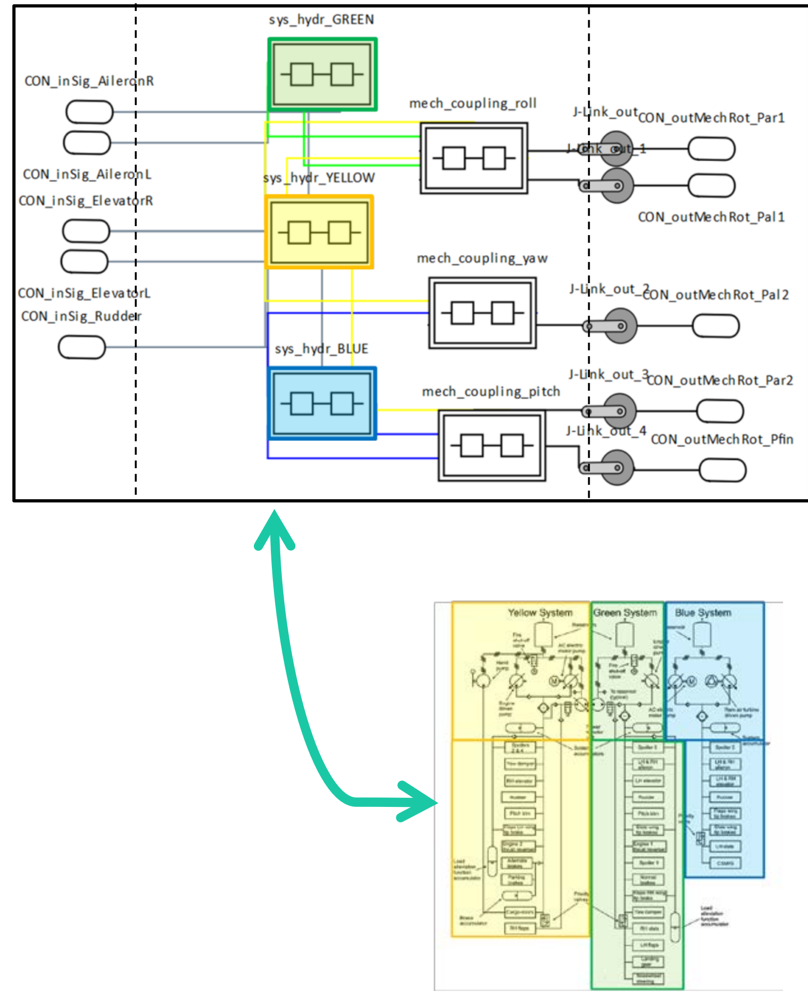


Future Work: Simulation Model









Thank You

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