SIZING OF ACTUATORS FOR FLIGHT CONTROL SYSTEMS AND FLAPS INTEGRATION IN RAPID

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Keywords: *EHA, EMA, actuator sizing, flight control surfaces, RAPID, CATIA V5, Knowledge Pattern, Parametrization.*

Abstract

The architecture of the flight control system, essential for all flight operations, has significantly changed throughout the years. The first part of the work consists of a preliminary sizing model of an EHA and an EMA. The second part of the work consists of the development of parametric CAD models of different types of flaps and their integration in RAPID. This thesis addresses the actuation system architecture of what it is named as more electric aircraft with electrically powered actuators. This consists of the development of flexible parametric models of flight control surfaces, being able to adapt to any wing geometry and their automatic integration in RAPID. Furthermore, it represents a first step in the development of an automatic tool that allows the user to choose any possible wing control surface configuration.

Abbreviations

MEA	More Electric Aircraft
FBW	Fly by Wire
PBW	Power by Wire
HA	Hydraulic Actuator
EHA	Electro-Hydrostatic Actuator
$EBHA$	Electrical Back-up Hydraulic Actuator
EMA	Electro-Mechanical Actuator
$CATIA$	Computer Aided Three Dimensional Interactive Design
CAD	Computer Aided Design
VBA	Visual Basic for Applications
EKL	Engineering Knowledge Language
UDF	User Defined Feature
$RAPID$	Robust Aircraft Parametric Interactive Design
LE	Leading Edge
TE	Trailing Edge

List of Symbols

l_{Acc}	Accumulator Length
d_{Acc}	Accumulator Diameter
F	Actuator Force
A_{rod}	Rod Area
K_r	Rod Area Constant
p_m	Maximum Allowable Stress
d_{rod}	Rod Diameter
d_{piston}	Piston Diameter
M	Hingemoment
m	Single/Dual Actuator Parameter
p_{maxsys}	Maximum System Pressure
r	Actuator Hinge Arm
ϕ	Swept Angle
A_{piston}	Piston Area
Q_{nom}	Max Flow Rate
V_g	Volumetric Displacement of the Pump
n_{nom}	Nominal Speed of the Motor
tau	Torque of the Motor
$Pmotor$	Power
x^*	Parameter Scaling Ratio
x_{ref}	Reference Parameter
l^*	Length Scaling Ratio
l_{ref}	Reference Length
$V*$	Volume Scaling Ratio
V_{ref}	Reference Volume

V	Volume
l	Length
ρ	Density
ρ^*	Density Scaling Ratio
M^*	Mass Scaling Ratio
F^*	Force Scaling Ratio
T^*	Torque Scaling Ratio
GSD	Generative Shape Design
D_{cyl}	Cylinder Diameter
L_{cyl}	Cylinder Length
D_{ring}	Ring Diameter

1 Introduction

At the beginning of the aircraft industry, flight control systems were controlled by manpower. As the aerodynamic forces that appeared on those aircraft were not excessive, the systems consisted of pushrods, cables, and pulleys. The increase in the size of the aircraft and therefore in the size of the control surfaces caused the implementation of more complex systems which could apply to the greater forces that were needed.

Hydraulic systems have been an essential part of the flight control system for decades, due to its advantages; as the capacity to apply large loads or the accurate control it permits to be applied. During the last years, there has been a general trend in the aeronautical industry to increase the use of electrically powered equipment. This leads to the concepts of "*More Electric Aircraft*" (MEA) and "*Power by Wire*" (PWB), which have introduced new types of actuators for moving the flight control surfaces of an aircraft: *Electro-Hydrostatic Actuators* (EHA) and *Electro-Mechanical Actuators* (EMA), both are powered by an electric motor. In the EHA, a self-contained hydraulic system moved by the electric motor is used while in the EMA the hydraulics are replaced by a screw mechanism moved by the motor.

These actuators are being implemented to be used in flight control systems moving flight control surfaces. These can be divided into primary (ailerons, rudder and elevator) and secondary flight control surfaces (flaps, spoilers, and slats). The construction and integration in RAPID of CAD models of some of the mentioned control surfaces are also addressed in this work. To understand this concept, it must be explained that RAPID [1] is a knowledge-based conceptual design aircraft developed in CATIA at Linköping University with the objective of creating a robust parametric conceptual designing tool.

2 Objectives

The aim is to offer a general view to self-contained electric actuators sizing and supplement control surfaces implementation in the existing applications of RAPID. Therefore, to achieve these purposes, the main objectives are:

- Development of a preliminary sizing model for EHAs and EMAs offering a general view of the actuator sizing.
- Design of parametric CAD models of different flight control surfaces.
- Automatic integration of the previously mentioned CAD models in RAPID.
- Allow parametric modifications of the instantiated models by the user to achieve multiple wing control surfaces configurations.
- Guarantee the models flexibility through parameters as well as by automatic adjustment to the wing geometry.

3 SIZING OF ACTUATORS

The current aviation tendency is the development of MEA concept, this section presents, a general overview of the sizing of EHA and EMA actuator.

3.1 EHA Sizing

This section is based on a general analysis of the sizing of an EHA. EHA is an actuator based on an electric motor and driven pump connected to a hydraulic cylinder. In order to be able to size an EHA, it's main components must be identified:

- Hydraulic cylinder

- Fixed-displacement pump
- Electric Motor
- Accumulator
- Power electronics

First of all, it is assumed that the motor and the pump are positioned on the same axis, parallel to the hydraulic cylinder. This criterion is usually used in large aircraft or high power requirements, as shown in Figure. 1.

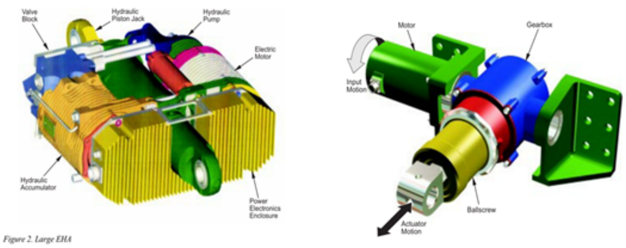

Fig. 1 EHA (left) and EMA (Right) [2]

The accumulator is considered as a cylinder and its size is determined by volume within some limits of l_{Acc}/d_{Acc} ratio, l_{Acc} and d_{Acc} are the length and diameter of the accumulator respectively. Power electronics size is usually determined by its cooling surface, thus the same considerations apply as with the accumulator, but for a cuboid [3]. As the design is focused on control surface actuators, a sizing method is obtained depending on the main inputs that appear on the control surface. In other words, the desired objective is to obtain a connection between the control surface and the actuator. Hence, in this sizing procedure the actuator force and the control surface hinge moment are used as main inputs. Therefore,

$$A_{rod} = k_r \frac{F}{p_m} \tag{1}$$

Where F is the actuator force, p_m is the maximum allowable stress in the material and k_r is a constant related to the rod diameter, including a safety factor in order to achieve the structural requirements.

The diameter of the rod is given by the following formula:

$$ {d_{rod}}^2 = \frac{4}{\pi} A_{rod} \tag{2}$$

d_{rod} the required rod diameter, With the rod diameter as a known parameter and the hinge moment applied to the control surfaces as an input, the diameter of the piston can be calculated through the next equation:

$$d_{pistion} = \sqrt{{d_{rod}}^2 + \frac{4M}{\pi m p_{maxsys} r \cos\frac{\phi}{2}}} [4] \tag{3}$$

$d_{pistion}$ is the diameter of the actuator piston, M is the hinge moment for a flight control surface, p_{maxsys} is the maximum system pressure, r is the actuator hinge arm and ϕ is the swept angle. The parameter m is a factor describing the type of actuator used: if the actuator is a single actuator m=1 and if it is a tandem actuator m=2 [4].

The piston area can be finally obtained through the next equation:

$$A_{pistion} = \frac{\pi}{4} {d_{rod}}^2 \tag{4}$$

Once the piston parameters have been obtained, the next step is to calculate the flow parameters: the maximum required flow rate and the volumetric displacement of the pump. To obtain the first parameter:

$$Q_{nom} = V_n A_{pistion} \tag{5}$$

Where Q_{nom} is the maximum required flow rate and V_n is the maximum loaded velocity of the actuator (the required velocity for the correct flight control actuation). With the max flow rate it is possible to obtain the volumetric displacement of the pump with the following formula:

$$V_g = \frac{Q_{nom}}{n_{nom}} \tag{6}$$

Where V_g is the volumetric displacement of the pump and n_{nom} is the nominal speed of the motor. Finally, the motor size can be varied as a function of its nominal torque within some l/d

limits. Thus, the torque of the motor must be obtained:

$$\tau = \frac{P_{motor}}{n_{nom}} \tag{7}$$

τ is the nominal torque of the motor and P_motor the required motor power. Now all the main variables of the main components, piston dimensions, pump volumetric displacement and torque motor are used in a design model of the EHA.

With the above calculated values, the Table 1 can now be used:

Table 1 Dimensions of an EHA [3]

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 $M_{mot,nom} := \frac{P_{mot,cont}}{n_{mot,\max}}$	$V_{mot} = \frac{\pi}{4} d_{mot}^2\, l_{mot}$ $V_{mot} \approx k_0\, M_{mot,nom}^{k_1}$

The obtained parameters and Table 1 makes it possible to have sizing of an EHA, depending on the value of several constants $(k_0, k_1, k_2, k_3, k_4 and k_5)$. The values of these constants can be obtained with the dimensions of existing EHAs. It is possible to use the dimensions of those EHAs components and extrapolate them to obtain the constant values. A Microsoft Excel table can be used in order to apply the equations and see how the parameters affect to the global dimensions of the actuator. An example is shown in Table 2.

3.2 EMA Sizing

An EMA is an actuator driven by an electric motor connected to the control surface by a mechanical linkage. The major components are a brushless DC motor (either cylindrical or annular), a mechanical gear reducer, a ball screw and a power off brake [5]. The aim of a preliminary sizing is the development of simple yet quite predictive models, with lower levels of detail than the required for specific designs. For this purpose, a good approach is a use of scaling laws. The scaling laws, also known as similarity laws, allow to study the effect of varying representative parameters of a given system [6].

Table 2 Dimensions of an EHA [3]

Table 1: Screenshot of a possible Microsoft Excel Table

HINGE MOMENT(kNm)	Fmax (kN) (Actuator)
15	353
	Max allowable stress (MPa) (rod material)
m FACTOR	160,5
1	
	kr
pmax sys (MPa)	2
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)	0,1
0,0919	k1
	0,8
n (rpm) Nominal speed (motor)	k4
3000	0,3
	k5
P max nominal (kW) (motor)	2
2,23	λ
	0,1
M (Nm) (Torque motor)	
7,098310462	

Ashaft (m^2)	Dshaft (m)		Qmax (m^3/s) (Flow Rate)
0,004398754	0,074837607		0,001094346
Dpiston (m)	Apiston (m^2)		Vg (m^3/rad) (Pump Displacement)
0,123133058	0,011908011		3,48341E-06

Cylinder			Pump	
hc (m)	lc (m)		lp (m)	dp (m)
0,198506446	0,5		0,021544367	0,2431021

Scaling laws make it possible to have a complete estimation of a product range with just one reference component. Their main principle is to establish a valid relation between a component and its parameters, such as dimensions or physical properties, so it is possible to calculate the new values when varying one of the parameters. One of the advantages of the scaling laws, in comparison with other models, is the relatively low complexity of the problem of obtaining the dimensions and physical properties of a component from its primary characteristics, mainly due to two assumptions[7]:

- All the material properties are assumed to be identical to those of the component used for reference. All corresponding ratios are thus equal to 1. This means that physical properties such as the density of the material or the Young's modulus will remain constant.
- The ratio of all the lengths of the considered component to all the lengths of the

reference component is constant. Therefore, all the dimension variation ratios will be equal to a global dimension variation.

Consequently, using scaling laws reduces significantly the number of inputs and simplifies the model to obtain all the main parameters as a function of one specific parameter, called as the Definition Parameter [7]. The first step is to define the scaling ratio of a given parameter, being used the notation proposed [8] for scaling laws calculation:

$$x^* = \frac{x}{x_{ref}} \quad (8)$$

x is the studied parameter, x_{ref} is the parameter of the component taken as reference and x^* is the scaling ratio of x. Geometric proportions are kept when using scaling laws, being able to link geometric dimensions through a geometric similarity. All the dimensions variations will be equal to a generic length variation l^*. The variation of a cylinder radius r or volume V can be thus expressed as:

$$r^* = l^* \quad (9)$$

$$V^* = \frac{V}{V_{ref}} = \frac{\pi r^2 l}{\pi r_{ref}^2 l_{ref}} \quad (10)$$

This last result remains valid for any other geometry. Using the same procedure it is possible to obtain the variation of other parameters, as mass M as function of l^*:

$$M = \int \rho \partial V \Rightarrow M^* = V^* = l^{*3} (\rho^* = 1) \quad (11)$$

For mechanical components, basing the design on a fixed constraint σ_{max} allows to link the variation of efforts to the variation of length l^* [6]:

$$F^* = l^{*3} \quad (12)$$

Where F^* is the transmitted force scaling ratio. Therefore, the nominal torque ratio T^* of a mechanical component can be estimated as:

$$T^* = l^2 \quad (13)$$

Estimations models can now be applied individually to each of the components of an EMA. The aim of the models is to minimize the entry parameters required to have a complete definition of the component. For mechanical components, particularly bearings and ball and roller screws (See Figure. 2.), a model as the one showed in Table 3 is applied:

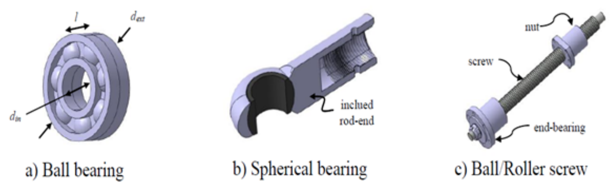

Fig. 2 General Program Diagram

Table 3 Dimensions of an EHA [7]

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)

For the others mechanical and electro-mechanical components, speed reducers and brush-less motors, similar models are used, as shown in the Table 4 and Table 5

Table 4 Dimensions of an EHA [7]

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 $T_{i,nom}^* = \frac{T_{n_s,nom}^*}{k^{\left(1-\frac{1}{p}\right)\left(1-\frac{i}{n_s}\right)} \eta^{n_s-i}}, i < n_s$ Total reduction ratio k
Integration parameters			
Length *(l)* and diameter *(d)*	*M*	$d^* = T_{nom}^{*1/3}$ $l^* = T_{nom}^{*1/3}$	$d_i^* = T_{i,nom}^{*1/3}$ $l_i^* = T_{i,nom}^{*1/3}, l_i \geq l_{i,min}$
Mass	*Kg*	$M^* = T_{nom}^*$	$M_i^* = T_{i,nom}^*$ or $M_i^* = T_{n_s,nom}^{*2/3} . l_i^*$

The typical operational area of the motor will depend on its type. With all the relations it is possible to use the estimation models to create a preliminary sizing of an EMA using existing actuator components as references. The validity of the equations is applied to a single component performance. Nevertheless, before applying those

Table 5 Dimensions of an EHA [7]

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*	$l^{*} = T_{em,nom}^{*1/3.5}$	$l^{*} = T_{em,nom}^{*1/3}$
Mass	*kg*	$M^{*} = T_{em,nom}^{*3/3.5}$	$M^{*} = T_{em,nom}^{*2/3}$

formulas the scaling laws used must be validated by comparison with manufacturer data.

4 CAD Implimentation

The CAD modelling has been carried out in CATIA ® [9]. CATIA is a one of the widely used CAD commercial software in the engineering industry as a design tool. Three are the workbenches used in the utilization of CATIA in this thesis: Generative Shape Design (GSD) workbench, Knowledge Advisor workbench and for the use of Knowledge Pattern the Product Knowledge Template workbench is used. Each of them is used in different levels and applications of the modelling work and has different characteristics that are going to be briefly explained in this chapter.

4.1 Parametric Actuator Models

A parametric CAD model of both types of actuators (EHA and EMA) were developed. The aim was to have a basic 3D model through parametric design so it was possible to change its dimensions and position it in a quick and simple way.

4.1.1 EHA Model

The model had to be flexible and cover a wide range of different measures of the components. The result is shown in Figure. 3, with all the components specified. It has been tried to achieve a similar model to the ones shown in Figure. 1, that were EHAs for flight control surfaces for large aircraft and the one developed by TRW respectively.Through the parametric design it is possible to vary its dimensions by changing the values of the corresponding parameters.

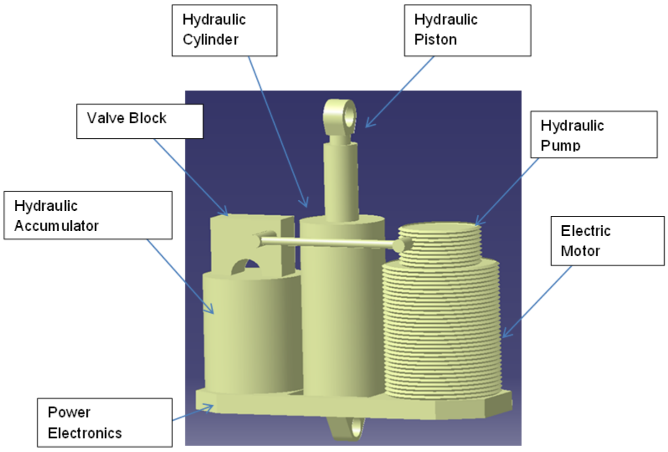

Fig. 3 EHA and its components

Figure. 4 show possible configurations of the EHA through the variation of the parameters

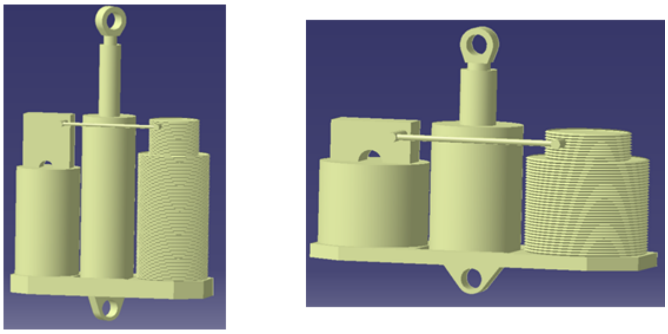

Fig. 4 Different configurations of the EHA parametric 3D model

4.1.2 EMA Model

As in the case of the EHA, the EMA model must be simple and contain the main components of an electro-mechanical actuator:

- Electric motor
- Gearbox reducer
- Ball screw

The most sought in the model is the flexibility to cover a wide range of measures. The result of the EMA model is shown in Figure. 5, where it can be appreciated that for the electric motor it has been chosen a cylindrical one. Figure. 6 shows possible combinations using different components.

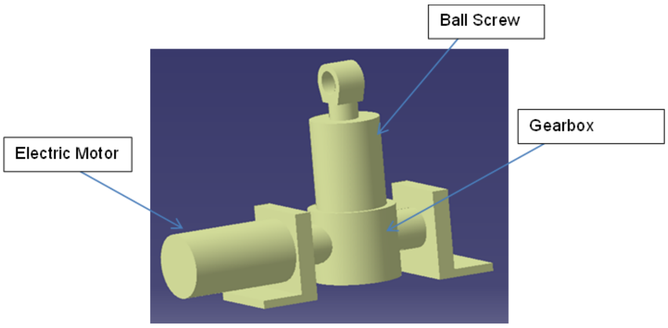

Fig. 5 EMA Model and its components

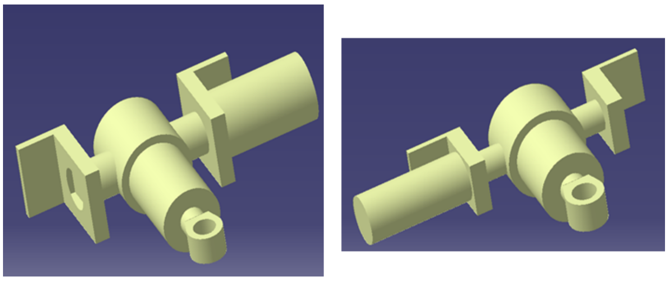

Fig. 6 Different configurations of the EMA parametric 3D model

5 Flaps Integration in RAPID

One of the objectives as mentioned before is the development of different types of CAD models for control surfaces through automatic parametric design in CATIA V5 and its integration in RAPID. The majority of those control surfaces are different types of flaps.

RAPID [1] (Robust Aircraft Parametric Interactive Design) is a knowledge based aircraft conceptual design tool developed in CATIA. For the control surfaces integration references have been taken from it, as it will be further explained in this section.The following control surfaces have been developed:

- Aileron
- Plain Flap
- Double Slotted Flap
- Triple Slotted Flap
- Fowler Flap
- Split Flap
- Zap Flap
- Slat

Each of the models allows the user to choose the corresponding angle deflection and extended length of the control surface, as well as positioning and sizing it along the wing, among other parameters. It is also possible to combine each of the control surfaces along with slats.

5.1 Positioning and Sizing

As all the models can be positioned and their span can be chosen, in the same way, this section also provides information of the positioning and span sizing implementation. The control surface span starts on what it is going to be named Left Airfoil and finishes in the Right Airfoil. These airfoils are going to be considered the first and the last control surfaces airfoils, respectively. Figure. 7 shows all the elements involved to help the following procedure description.

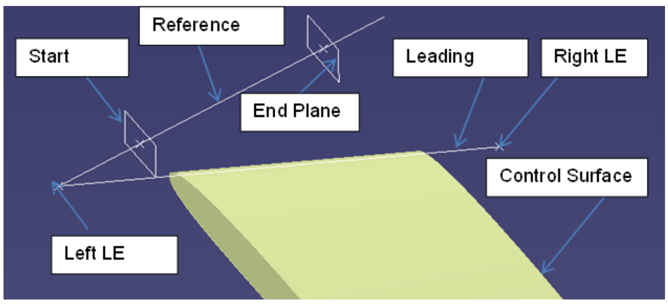

Fig. 7 Positioning and Span Sizing of the Control Surface

The Leading Edge Points are the most forward points of the airfoils, and all of them set up the Leading Edge (LE). The Leading Edge starts on the Left Airfoil and ends in the Right Airfoil. A Reference Line is then created with the wing span (transverse axis) direction. Reference line goes from Left Airfoil to the plane that contains Right Airfoil. In that line, two planes are created: Start Plane and End Plane. These planes define where between the Left Airfoil and the Right Airfoil the control surface starts and ends. Two parameters control the position of both planes.

5.2 Control Surfaces CAD Models

This section presents the control surfaced created in CAD and the instantiation of the same.

5.2.1 Aileron and Plain Flap

The similarities between these control surfaces make possible to integrate both surfaces in the same model. Actually, even the single slotted flap can be included, just adding a slot to the control surface as it is going to be later explained. The CAD model is as shown in Figure. 8:

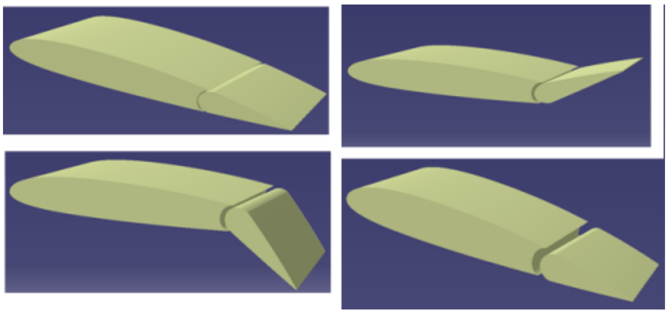

Fig. 8 Aileron or Plain Flap and different configurations

5.2.2 Double Slotted Flap

This model is similar to the plain flap, a second slot has been added to represent double slotted flap as shown in Figure. 9.

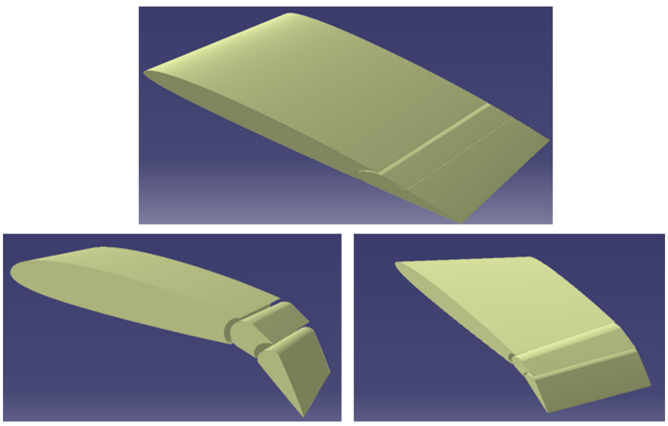

Fig. 9 Double Slotted Flap and different Configurations

5.2.3 Triple Slotted Flap

The triple slotted flap has an added slot to the double slotted flap is as shown in Figure. 10

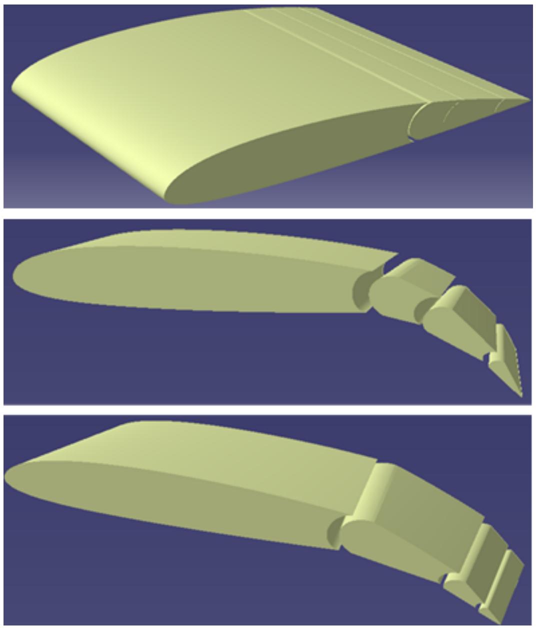

Fig. 10 Triple Slotted Flap and different Configurations

5.2.4 Fowler Flap

The Fowler Flap model is shown in the figure below Figure. 11

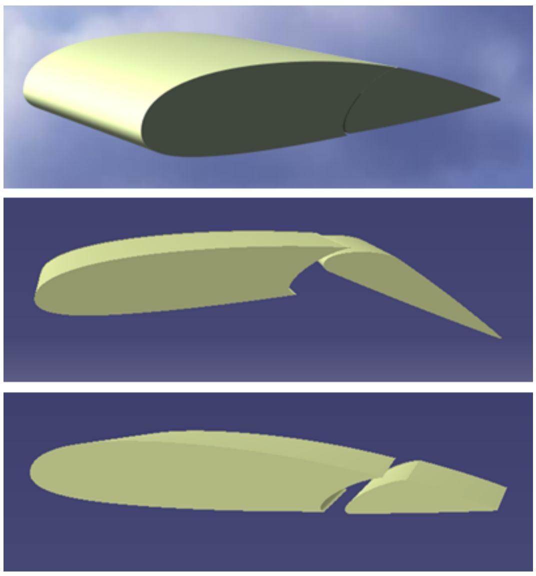

Fig. 11 Fowler Flap and different configurations

5.2.5 Split and Zap Flap

The similarities between these control surfaces make possible to integrate both surfaces in the same model. The Zap Flap is like the split flap with the added feature of the translation of the control surface. Figure. 12 shows a screenshot of this CAD model.

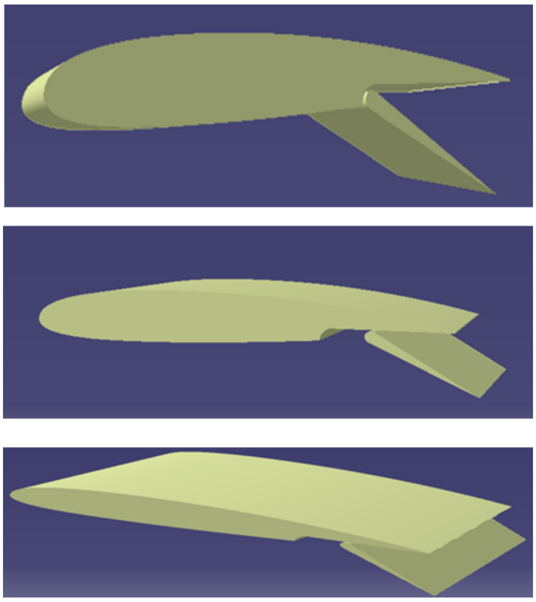

Fig. 12 Split & Zap Flap and different configurations

5.2.6 Slat

A slat model has also been developed to make possible a closer configuration of a real wing. This CAD model is shown in Figure. 13.

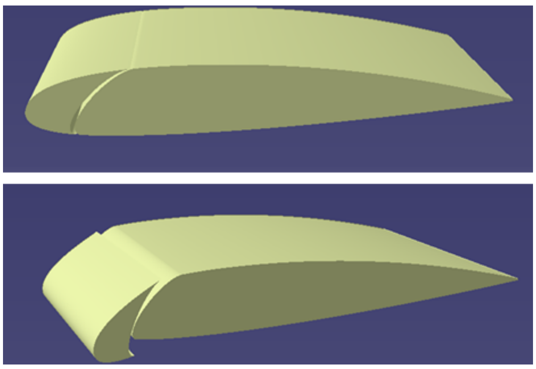

Fig. 13 Slat and its deflected configurations

5.3 Results and Flexibility of the Model

One of the main objectives of the work based on this chapter was not only to achieve the flap integration in RAPID but also to guarantee the flexibility of the instantiated models. Through the parametric design the user is able to modify each of the control surface parameters as well as the wing parameters- and observe how each of them affects the whole model and the different configurations that can be achieved. The possibility of choosing the position and the span length of the control surfaces through the two positioning parameters makes the model quite flexible and allows the user to define precisely the placement of the control surface, adapting the model to the needed requirements. Moreover, the possibility of changing the root and the tip chord length of the control surfaces provides the models with multiple configurations.

Nevertheless, although the individual parameters of the models already make them quite flexible, that is not all the flexibility the model can achieve. A great part of the flexibility resides in the automatic adaptation to the wing geometry modifications. The main possible modifications that the wing can present are:

- Wing Span
- Airfoils Chord
- Dihedral Angle
- Twist Angle

If any of the above parameters is modified, the model will automatically adapt to the changes. Furthermore, special mention should be made of the two last elements of the above list: the dihedral and twist angle, due to the difficulties had to make possible the model adaptation to these two parameters.

Figure. 14 shows different wing control surfaces configurations through the variation of both individual and wing parameters. It is obviously impossible to observe some of the configurations in real airplanes, with different values of twist and dihedral angles in each of the four input airfoils, but it has just been shown to prove the flexibility of the model.

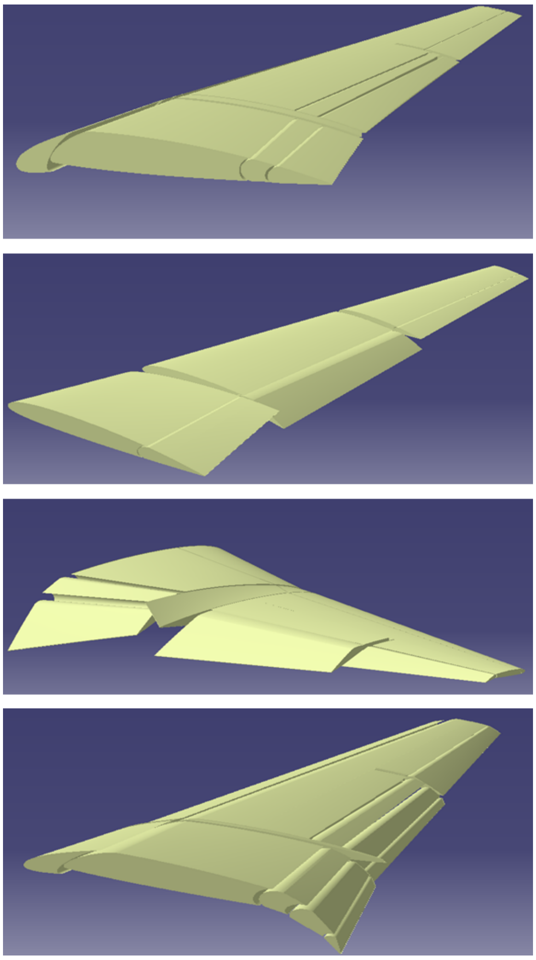

Fig. 14 Different Wing Control Surfaces Configurations

6 Discussion and Conclusion

The main aim of the work carried out in the actuator sizing was to provide a general overview of the new actuators that are currently being implemented. These actuators are powered by an electric motor, due to the present tendency of the development of MEA concept.

It can be considered a first step into a preliminary sizing model of EHAs and EMAs, although at this point more research is needed. It is necessary for the utilization of the model or of any other model based on scaling laws- to have an updated and detailed actuator data table with dimensions and parameter values of existing flight control surface actuators. It would be also necessary a more detailed model of the sizing of both types of actuators in order to achieve a closest solution to real values beyond preliminary design models.

Furthermore, throughout the development of this thesis it has been noticed the endless possibilities and applications that parametric CAD design can have in the field of engineering. The parametric design has been the key point of the flaps integration in RAPID to allow the user to choose any control surface configuration with almost no effort or previous CAD design knowledge.

Moreover, the implementation of automatic instantiations and procedures has also been an essential condition to achieve the objectives sought. Thanks to the automation the users are not only capable to instantiate one model, but to create a whole wing configuration and implement instantly any possible change.

The use of Knowledge Pattern and UDFs in the instantiation process involves a considerable decrease in the complexity of the user interface, as by this instantiation procedure the user interface is only composed by the parameters needed to define the model.

To conclude, flexible flight control surface integration in RAPID has been developed, proving the potential of CATIA GSD and Knowledge Pattern workbenches as engineering design tools.

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