Model Based Aircraft Control System Design and Simulation

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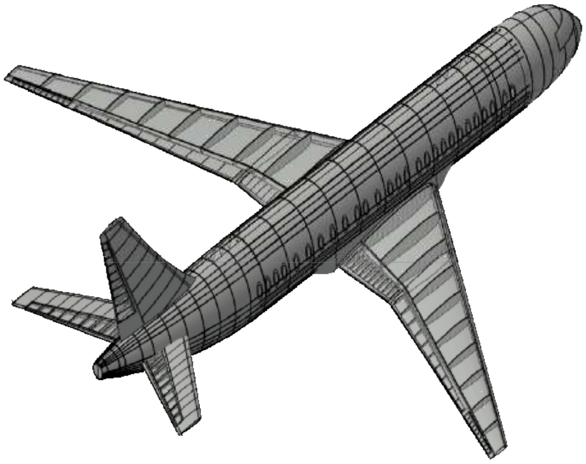
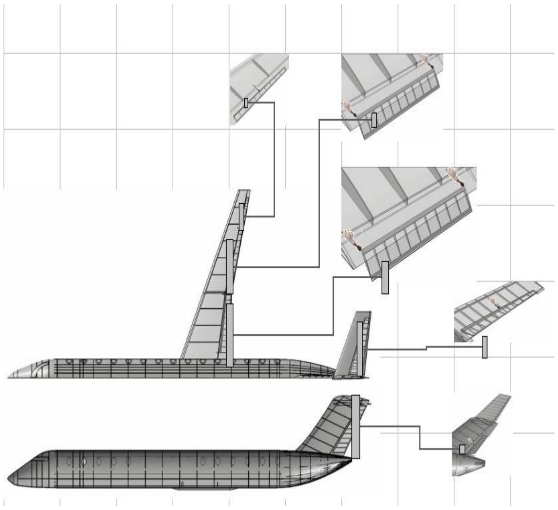
Division of Machine Design





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European Masters in Design and Technology of Advanced Vehicle
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Abstract

Development of modern aircraft has become more and more expensive and time consuming. In order to minimize the development cost, an improvement of the conceptual design phase is needed. The desired goal of the project is to enhance the functionality of an in house produced framework conducted at the department of machine design, consisting of parametric models representing a large variety of aircraft concepts.

The first part of the work consists of the construction of geometric aircraft control surfaces such as flaps, aileron, rudder and elevator parametrically in CATIA V5.

The second part of the work involves designing and simulating an Inverse dynamic model in Dymola software.

An Excel interface has been developed between CATIA and Dymola. Parameters can be varied in the interface as per user specification; these values are sent to CATIA or Dymola and vice versa. The constructed concept model of control surfaces has been tested for different aircraft shapes and layout. The simulation has been done in Dymola for the control surfaces.

Acknowledgement

Master thesis work is carried out in the **Department of Management and Engineering, Division of Machine Design** at *Linköping University (LITH) Linköping, Sweden*. As a part of acknowledgement, I want to express my gratitude towards many people whose insightful suggestions and contributions have enabled me to enhance my work at each stage. In addition to this, I wish to acknowledge the assistance provided by IEI Department of Linköping University.

I am deeply indebted to my supervisor Mehdi Tarkian from Linköping University whose help, suggestions and encouragement during the research process enabled me to successfully complete my master thesis. I specially thank Prof. Patrick Berry and Christopher Jouannet for their guidance.

Especially, I am grateful to my parents and brothers whose love and affection has been a great support for each and every success in my carrier. My friends are always with me encouraging during difficult situations and played a vital role in my work.

Raghu Chaitanya.M.V

CONTENTS

1. INTRODUCTION

1.1 Background

Systems engineering is a technique which is used in many engineering fields such as control engineering, industrial engineering, and interface design etc to deal with the complex projects. Coordination between projects and teams can be handled. The used tools are modeling, simulation, analysis and scheduling. Apart from this overlapping between technical and human disciplines can be managed with system engineering [7, 30].

A design phase consists of many compromises such as technical and economical factors. New methods that allow engineers to achieve a design at low cost and time have to be developed. In the aircraft industry the recent challenge is to improve design, lower production time and cost. Figure 1.1 [15] shows an interdisciplinary for Aircraft Conceptual Design.

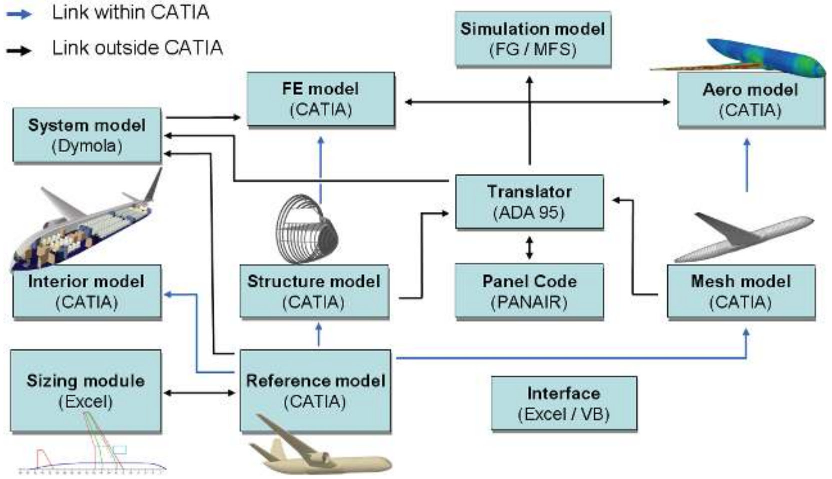


Figure 1.1: Interdisciplinary for Aircraft Conceptual Design

1.2 Objective

The purpose is to increase the functionality of the Conceptual Aircraft Design by the construction of control surfaces on an existing Conceptual Aircraft Design and to integrate two powerful tools that are being used in the design and analysis processes in aircraft Industry. The interdisciplinary covered in this project is as shown in Figure1.2 [15].

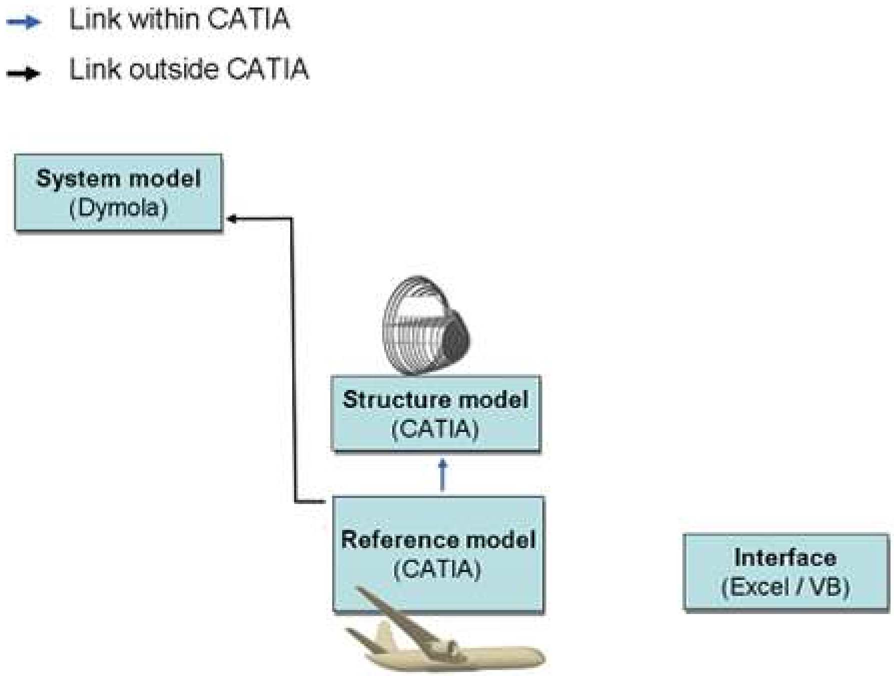


Figure 1.2 : Interdisciplinary in this project

The objectives of the thesis are

1. Construction of structure control surfaces such as flaps, aileron, rudder and elevator using CATIA V5.
2. Simulation of the dynamics of the control surfaces in Dymola.
3. Extend several functionalities in the Excel User-Interface.

1.3 Conceptual Design on Aircraft Control surfaces and Actuators

1.3.1 Control surfaces conceptual design

The primary control surfaces are ailerons, elevator and rudder, while the secondary control surfaces are flaps and slats. The required aileron area can be estimated from Figure 1.3 [6]. The ailerons extend from 50% to 90% of the span and remaining extra 10% provides little control effectiveness due to the vortex flow at the wing tips. In some cases, the ailerons extend until the wing tips.

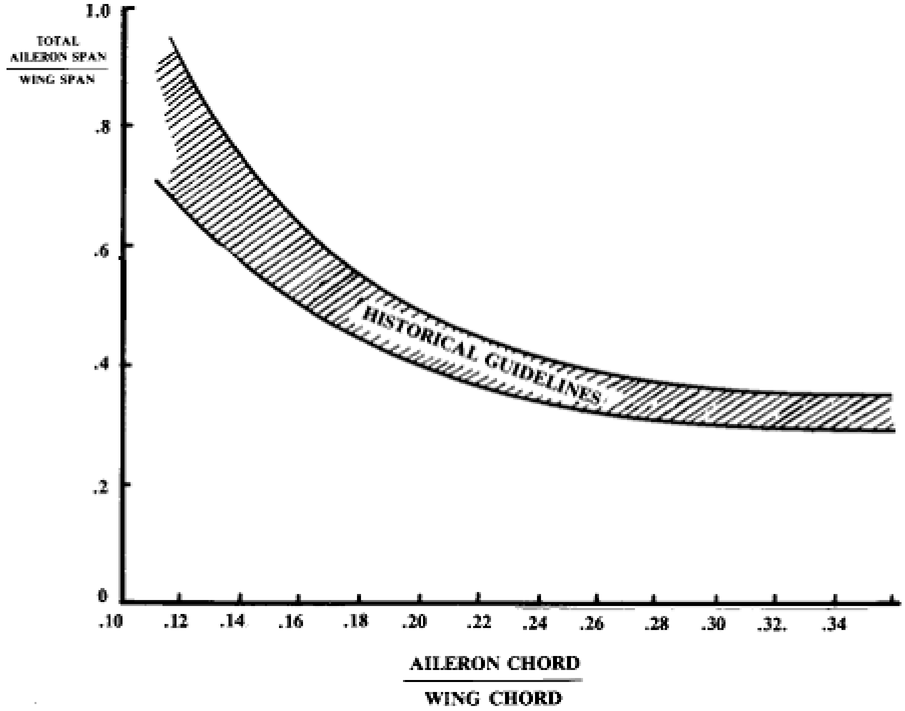


Figure 1.3: Aileron guidelines

Elevators and rudders generally start on the side of the fuselage and extend to the tip of the tail [90% of the tail span].In case of High-speed aircraft; a rudder of large chord extends to about 50% of the span and avoids a “rudder effectiveness” problem which is similar to “aileron reversal”. For maximum lift flaps the span must be as large as possible; they occupy the part of the wing span, inboard of the ailerons.

In order to maintain a constant percent chord, the control surfaces are tapered in chord by the equivalent ratio as wing or tail which is shown in Figure 1.4[6]. In general, flaps and aileron are 15% to 25% of wing chord, while elevator and rudder are of 25% to 50% of the tail chord.

In case of control surfaces, the hinge axis should not be farther aft than 20% of the average chord as shown in Figure 1.5[6]. In a manually-controlled aircraft, the horizontal tail is designed in such a way that it is always normal to the aircraft central line. This helps in connecting right-hand and left-hand elevator surfaces to the torque tube [6, 9, 10, 21]. For the construction of control surfaces in section 5 this knowledge is implemented. The user can take into account the information to design and modify accordingly.

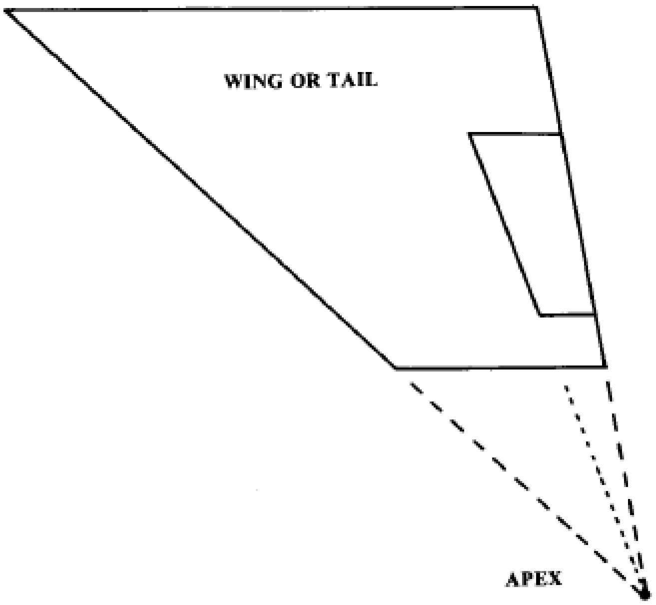


Figure1.4: Chord control surface for constant-percent

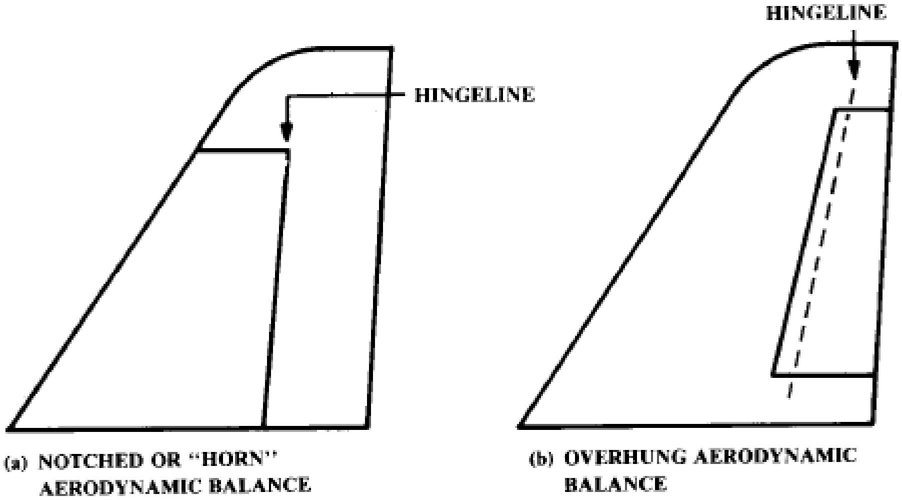


Figure1.5: Aerodynamic balance

1.3.2 Actuator conceptual design

The actuator sizing method depends upon the actual basic design and varies depending on manufacturer. The functionality of the actuator is to sustain the operating thrust, pressure in the process. In engineering applications, the electromechanical or electrohydraulic actuators are sized upon the process as well as frictional forces that appear with added thrust to maintain the safety conditions.

With the high level of engineering required for these actuators, the prevailing thought is that it is better have too much actuator than not enough. The safety factor for sizing varies from 25% to 50% of the actuator available thrust. The cost of the electromechanical and electrohydraulic actuators is considerably high.

In cases of higher performance and speed, electromechanical and electropneumatic actuators are recommended instead of pneumatic or hydraulic actuators. The electromechanical and electrohydraulic actuators are used in special or severe based on flow rate and pressure drop .Only a brief introduction for the actuator design is provided here, for detailed designs of actuators see the references [11, 12, 21, 22].

2. FLIGHT CONTROL SYSTEM

2.1 Principle of Flight Control

The four basic forces acting upon an aircraft during flight are lift, weight, drag and thrust as shown in Figure 2.1.

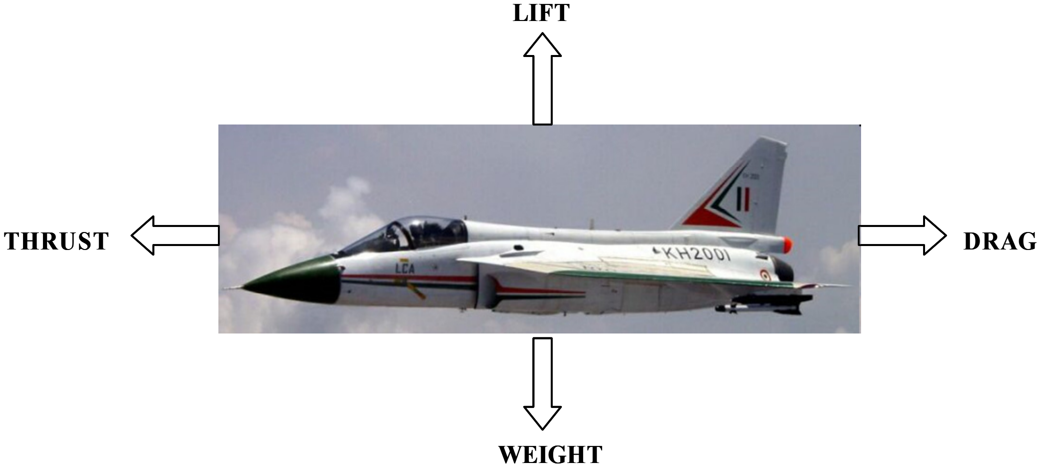


Figure 2.1: Forces acting on an aircraft

2.1.1 Lift

Lift is caused by the flow around the aircraft. Lift is the upward force created by the wings, which sustains the airplane in flight. The force required to lift the plane through a stream of air depends upon the wing profile. When the lift is greater than the weight then the plane raises.

2.1.2 Weight

Weight is the downward force created by the weight of the airplane and its load; it is directly proportional to lift. If the weight is greater than lift then the plane descends.

2.1.3 Drag

"The resistance of the airplane to forward motion directly opposed to thrust". The drag of the air makes it hard for the plane to move quickly. Another name for drag is air resistance. It is created or caused by all the parts.

2.1.4 Thrust

The force exerted by the engine which pushes air backward with the object of causing a reaction, or thrust, of the airplane in the forward direction.

2.2 Flight Control Surfaces

An aircraft requires control surfaces to fly and move in different directions. They make it possible for the aircraft to roll, pitch and yaw. Figure 2.2 [8] shows the three sets of control surfaces and the axes along which they tilt.

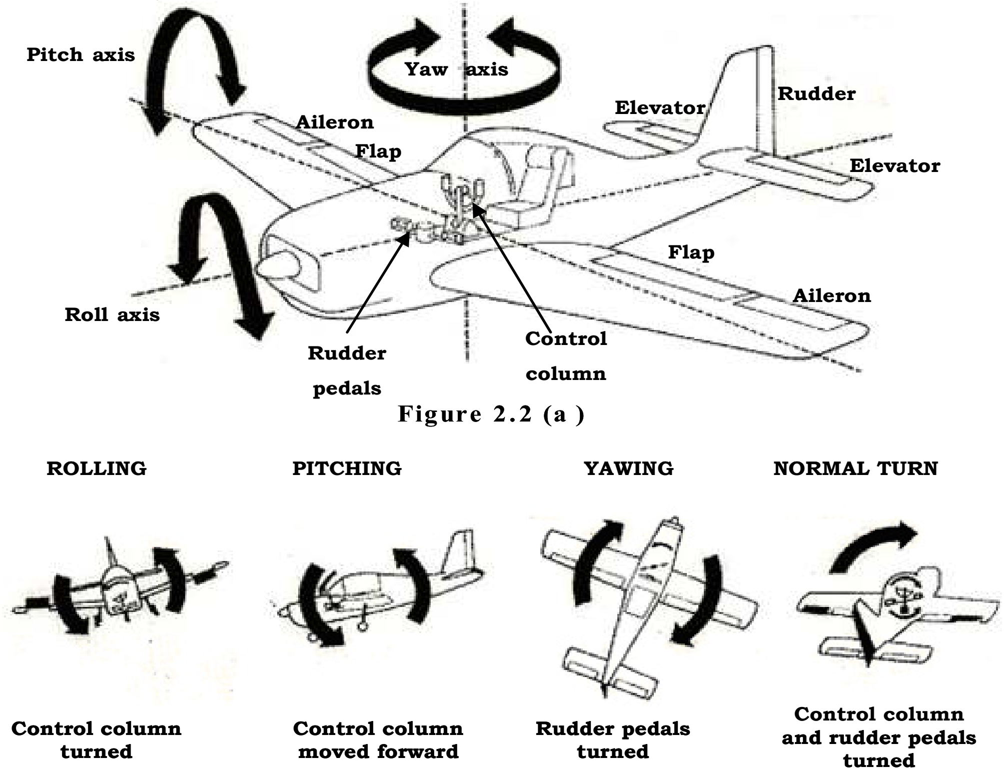


Figure 2.2 (a)

Figure 2.2 (b) Figure 2.2 (c) Figure 2.2 (d) Figure 2.2 (e)

Figure 2.2: Control Surfaces and Axes

There are three sets of control surfaces that tilt the plane along three axes. The ailerons, operated by turning the control column [Figure 2.2(a)], cause it to roll. The elevators are operated by moving the control column [Figure 2.2(a)] forward or back causes the aircraft to pitch. The rudder is operated by rudder pedals that make the aircraft yaw.

Depending on the kind of aircraft, the requirements for flight control surfaces vary greatly, as specific roles, ranges and needed agilities. Primary control surfaces are incorporated into the wings and empennage for almost every kind of aircraft as shown in the Figure 2.3 [1]. Those surfaces are typically: the elevators included on the horizontal tail to control pitch; the rudder on the vertical tail for yaw control; and the ailerons outboard on the wings to control roll. These surfaces are continuously checked to maintain safe vehicle control and they are normally trailing edge types.

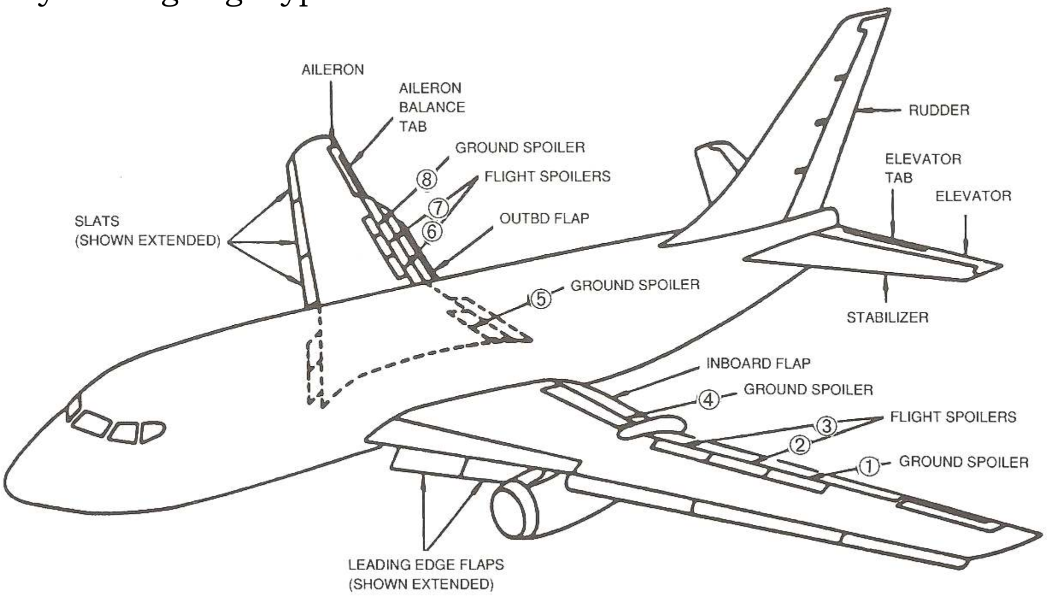


Figure 2.3: Flight Control Surfaces of Jet Passenger Carrier

2.3 Primary Control Surfaces

The primary flight controls surfaces are ailerons, elevator and rudder.

2.3.1 Ailerons

Movement about the longitudinal axis is controlled by the two ailerons, which are movable surfaces at the outer trailing edge of each wing. The movement is roll. If the aileron on one wing is lowered, the aileron on the other will be raised. The wing with the raised aileron goes down because of its decreased lift and the wing with the lowered aileron goes up because of its increased lift. Thus, the effect of moving one of the ailerons is complemented by the simultaneous and opposite movement of the aileron on the other wing.

The ailerons are connected to each other and to the control wheel (or stick) in the cockpit by rods or cables. While applying pressure to the right on the control wheel, the right aileron goes up and the left aileron goes down. Thus, the airplane is rolled to the right as the down movement of the left aileron increases the wing camber (curvature) and the angle of attack. The right aileron moves upward and decreases the camber, what results in a decreased angle of attack. Thus, an increased lift on the left wing and decreased lift on the right wing cause a roll and bank to the right.

2.3.2 Elevators

The movement of the airplane about its lateral axis is controlled by the elevators. This motion is called pitch. The elevators are free to swing up and down and form the rear part of the horizontal tail assembly. They are hinged to a fixed surface; the horizontal stabilizer. A single airfoil is formed by the horizontal stabilizer and the elevators. The chamber of the airfoil can be modified by changing the position of the elevators, which increases or decreases the lift.

Control cables are used to connect the elevators to the control wheel (or stick) as it happens with the ailerons. The elevators move downward when forward pressure is applied on the wheel. Thus, the lift produced by the horizontal tail surfaces is increased, what forces the tail upward, causing the nose to drop. Conversely, the elevators move upward, when back pressure is applied on the wheel, decreasing the lift produced by the horizontal tail surfaces, or maybe even producing a downward force. The nose is forced upward and the tail is forced down.

The angle of attack of the wings is controlled by the elevators. When back pressure is applied on the control wheel, the angle of attack increases as the tail lowers and the nose rises. Conversely, the tail raises and the nose lowers when forward pressure is applied, decreasing the angle of attack.

2.3.3 Rudder

The movement of the airplane about its vertical axis is controlled by the rudder. This motion is called yaw. The rudder is a movable surface hinged to a fixed surface which is the vertical stabilizer, or fin. Its action is similar to the one of the elevators, except that it swings in a different plane; from side to side instead of up and down. The rudder is connected to the rudder pedals by controlled cables.

2.4 Secondary Control Surfaces

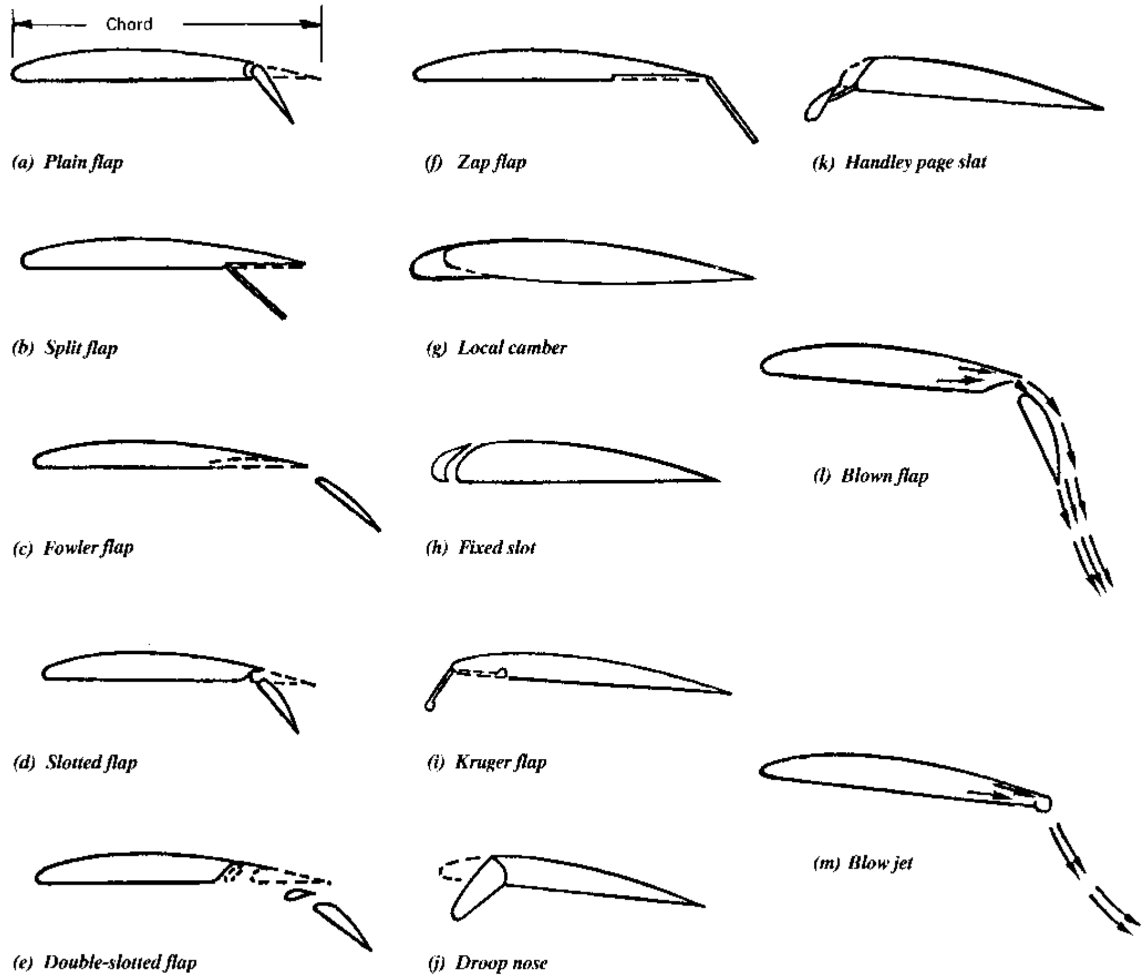
Wing Leading and Trailing edges are used to increase the aerodynamic performance of the aircraft by reducing stall speed mainly during take-off and landing speed. High lift control is provided by a combination of flaps and leading edge slats. The flap control is affected by several flap sections located on the inboard two-thirds of the wing trailing edges. The flaps are deployed during take-off or the landing approach to increase the wing camber and improve the aerodynamic characteristics of the wing.

2.4.1 Flaps

Flaps are mounted on the trailing edge but can also be mounted on the leading edge. They extend the edge by increasing the chord of the wing. They pivot only (simple and split flaps), extend and come down (complex and slotted flaps) or extend and camber (Krueger flaps). There are other types as well.

2.4.2 Slats

Slats are usually mounted on the leading edge. Slats extend the edge and they sit like a glove on the edge. "Slats" is an abbreviation for "slotted flaps", which means they have a nozzle like slot between the high-lift device and the wing; on the contrary, flaps do not have this slot. Figure 2.4 [4] shows the wing leading and trailing edge configurations commonly used.



(a) Plain flap
(b) Split flap
(c) Fowler flap
(d) Slotted flap
(e) Double-slotted flap
(f) Zap flap
(g) Local camber
(h) Fixed slot
(i) Kruger flap
(j) Droop nose
(k) Handley page slat
(l) Blown flap
(m) Blow jet

Figure 2.4: Wing Leading and Trailing edge Configurations

3. ACTUATOR THEORY

3.1 Introduction

Actuators are the devices that convert energy into motion; the motion can be either linear or rotary motion. Actuators act as the final elements in a control system. An energy input and a low power command signal are sent to the actuators to be amplified as appropriate to produce the required output. There is a wide range of applications that vary from simple low power switches to high power hydraulic devices operating flaps and control surfaces.

3.2 Classification of Actuators

Actuators are broadly classified into two kinds, one is fluid mechanical and another one is electric.

3.2.1 Fluid mechanical

Fluid mechanical actuator drives are in the form of hydrostatic energy converters. In most of the applications their operation is based on the displacement principle, so they convert the pressure energy of the fluid into mechanical work and vice-versa. Fluid mechanical actuator mainly consists of piston, cylinder and springs. Piston is operated inside the cylinder filled with fluids and works against spring force. The rectilinear motion is transmitted from the piston to other actuating elements for the desired motion. Automotive brakes are an important example.

The two types of fluid mechanical actuators are Pneumatic and Hydraulic Actuators, the common device is a pneumatic cylinder and hydraulic cylinder respectively. The hydrodynamic transformer converts flow energy (kinetic energy of the moving fluid) into mechanical work. The hydrodynamic torque converter used in most automatic transmission systems is an important automotive application. Figure 3.1(a) [26] shows hydraulic actuator and Figure 3.1(b) [26] shows pneumatic actuator that is used in aircrafts.

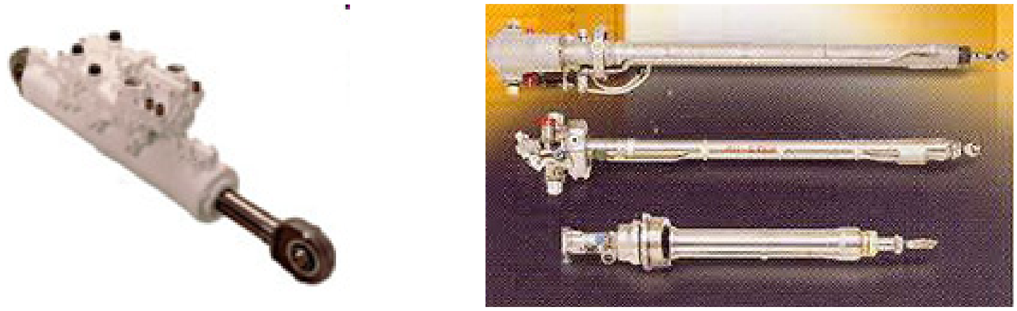


Figure 3.1 (a) Hydraulic Actuator

Figure 3.1 (b) Pneumatic Actuator

Figure 3.1 (c) Electromagnetic Actuator

Figure 3.1 (d) Electrohydraulic (EH) Actuator

Figure 3.1 (e) Electrohydrostatic (EHA) Actuator

Figure 3.1 (f) Electromechanical (EM) Actuator

Figure 3.1: Different types of Actuators used in Aircrafts

3.2.2 Electric Actuators

Electric actuators are operated by motor drive which provides input to valves. The most common types of valves used in electric actuators are gate valves. Some of the types of electric actuators are electromagnetic, electrodynamic and electromechanical.

3.2.3 Electromagnetic actuator

They use the mutual attraction of soft ferrous materials in a magnetic field. One coil has the function of providing the field energy to be transformed. A return device, as a spring, is needed because the attractive force is unidirectional. The fans, head lights, horn and wipers in cars, are switched on with a current demand that is supplied by relays or solenoids based on this principle. Figure 3.1 (c) [26] shows an electromagnetic actuator.

3.2.3.1 Electrodynamic actuator

It is based on the (Lorenz) force generated when a current carrying conductor is placed in a magnetic field. DC motors are frequently used as part of an actuator system. Actuating elements are activated by very strong magnetic field and it is possible to operate mechanisms such as circuit breaker, hammer etc. As per the mechanism, current induces transient magnetic field in the conductor which produces repulsive forces between the coil and the conductor and enables to activate the actuator. In order to minimize the wear and tear of repulsive elements, the system is connected to coolants. For an effective work of the system, recoil forces are damped properly. Figure 3.1(e) [27] shows an electrodynamic actuator.

3.2.3.2 Electromechanical

The two renowned concepts such as Electro-Hydrostatic Actuators (EHA) and Electro-Mechanical Actuators (EMA) come under the broader domain of more electric aircraft (MEA).The electrical-power have been used more frequently and successfully with the concept More Electric Aircraft (MEA). The need of MEA concept is to run not only the high power electric actuation systems but also the flight control surfaces such as rudders, ailerons and spoilers. Figure 3.1(f) [27] shows an electromechanical actuator.

Hydraulic systems are being replaced with electrical devices. This trend is due to the desire of having cleaner systems (no hydraulic fluid) and making the integration with other (normally electrical) control systems easier to achieve. Hydraulic system was the only system available until recently but new cars are often fitted with electric power assisted steering now. Braking systems development is also progressing in the field of electrical assistance. In the aviation industry, it is also possible to observe these trends of electrical systems, but there are some difficulties due to the very high power densities and forces required from some actuators.

In this concept, the basic idea is to replace hydraulics with the electrical systems which not only increases the efficiency but also provides less maintenance cost [14]. The major objective is to provide detailed information regarding suitability and safety with respect to actuators that are in turn operated by electrical motors and power converters. Broadly actuators are classified into two groups: Electro Hydrostatic

Actuator (EHA) and Electro-Mechanical Actuator (EMA). EHA concept have been used in aircraft such as Airbus A380 and Boeing 787 because of its level of safety, low production cost and emission standards. Apart from these characteristics, it is jamming free under working environment. Even though EHA technology has been successfully used in new aircrafts such as A380 and Boeing 787, its initial and maintenance cost is much higher when compared to EMA [14], it makes EMA concept advantageous.

EMA is a concept of loading an actuator on demand but in case of EHA, the hydraulic actuators needed to be loaded continuously independently of the operation. The basic components used in EMA concept electrical machine are a gear box and screw mechanism. Even though there are numerous advantages, safety and reliable factors such as jamming free are needed in EMA. The additional use of equipments can improve the safety and reliability raising the cost and complexity. EMA has been used successfully in the secondary flight controls and military aircrafts.

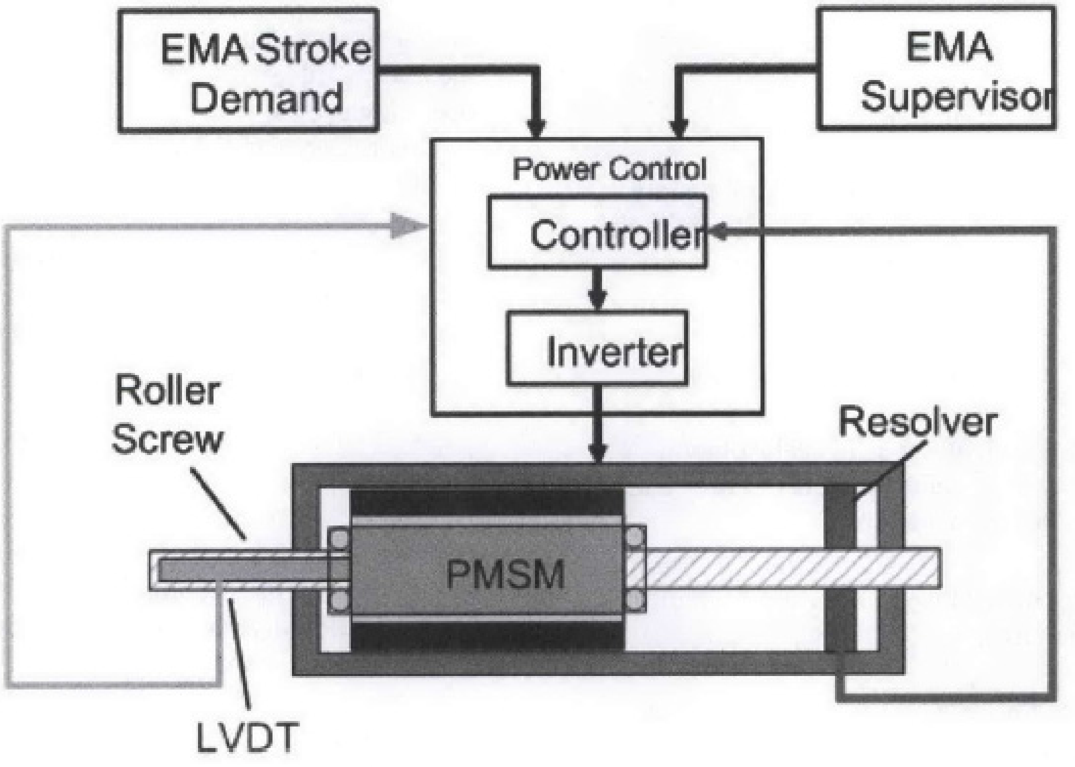


Figure 3.2: Direct Drive architecture for EMA

Direct Drive architecture for EMAs has also been used successfully in train and launcher applications by overall dimensions and weight optimization. This technology has merits in compactness and weight optimization. The direct drive electrical system is described on basis of Figure 3.2 [14]. It is built by a power convertor and an electrical motor.

The electrical motor is connected to a roller screw and the screw is connected to the actuator.

Linear Variable differential Transducer (LVDT) converts the rectilinear motion of an actuator to electrical signal for the purpose of control. The power converter is used to regulate the angular velocity of the electric motor and torque output with respect to voltages applied in stator windings. The sub components in power converters are a rectifier, filter, dc link capacitor and inverter. The inverter is recommended to be connected with dc link by means of a capacitor for constant voltage. High frequency power transistors are needed for the conversion of D.C voltage into A.C voltage.

The safety and reliability are the key objectives in aircraft industry which is based on motor and electronics. The motor and electronics are internally dependent on inverter characteristics, such as:

- High efficiency in the full operating range
- High torque per ampere design which leads to reduction of losses and height

In this work a simple EMA is considered. Due to its simplicity and construction as shown in section 5, having a model of this nature is more beneficial. The transmission of motion in this designed EMA is linear.

4. MULTIDISCIPLINARY DESIGN

4.1 Model definition for re-usability

CAD tools are used for design and found application in conceptual design generating output such as weight, mass inertia and centre of gravity etc. For analysis, traditional tools were ineffective and giving poor results. By innovative ways of CAD modeling, an effective geometrical model that includes several concepts is developed. Geometrical modeling is categorized into two; one that explained morphological levels of geometry and another that explains the effectiveness, reusability of various geometrical objects.

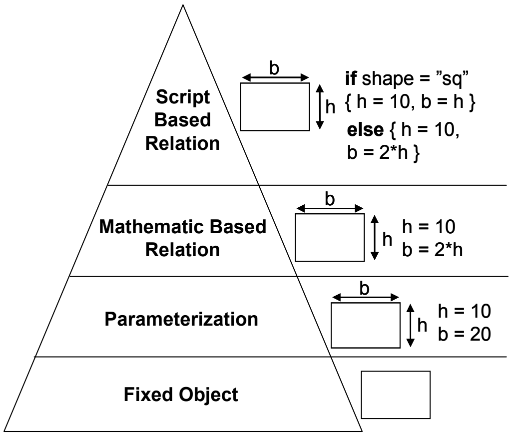


Figure4.1 the morphological pyramid visualizing the stages of geometric modeling

Morphologic geometric objects are categorized into four stages:

- Fixed Objects (FO) are geometrical objects with fixed shape. These objects are either intentionally or non-intentionally, static and have fixed output.

- Parameterization is the model in which geometric object values and their outputs are varied. There exists no relation between geometric object and are unrealistic.

- To minimize the input parameters, a relation between objects of the model is needed and can be done by Mathematic based relation (MBR) in Figure 4.1.

- Script Based Relations (SBR) models were generated by the relations using script based programming which was described in Figure 4.1. The main advantage SBR over MBR is the existence of non numerical parameters.

The relations in stage 3 & 4, are explained not only by direct script in CAD software, but also connected externally via the CAD API (application programming interface).The demerits of morphological based models in the automatic design application process are that the numerous objects are fixed during the simulation. More over, a method to make the models efficient, reusable and/or replaceable is still yet to be developed.

In order to explain the topological process two terms namely template and constraint are used. “A template refers to an initial model to be re-initiated and constraints are conditions which have to be satisfied by the initiated instances”. The various levels of initiating geometric instances are visualized in the topological pyramid in Figure 4.2.

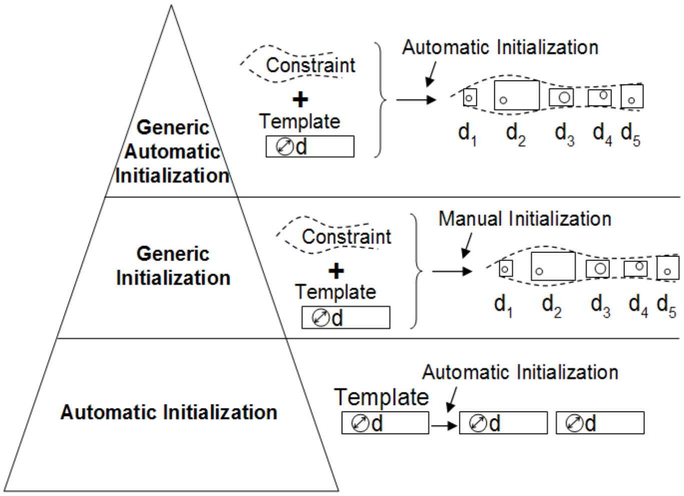


Figure 4.2 topological pyramid visualizing the stages of geometric initialization

The topological pyramid consists of the following stages:

- Automatic Initialization (AI): Template is defined and the constraint is undefined in the first stage of the designing process. Models are generated and degenerated by CAD tools such as pattern. Some cases models a lack unique parameters and it cannot be context dependent due unconstraint model definition.

- Context dependency for initiated instances is obtained by template and constraint production. The template initiation in stage 1 leads to reusability in stage 2 (Generic Initialization (GI)).

- Generic Automatic Initialization (GAI) is used when there is a need of pre-defined functions which generate or delete instances depending upon user input.

4.2 Defining Reusable model in CATIA

The programming languages such as Visual Basic for Applications (VBA), and the Engineering Knowledge Language (EKL) are supported by CATIAV5. A compilation is done before execution improving the performance of the system. Figure 4.3 shows the programming language with respect to execution speed, accessibility and control. The portion which was completed is plotted on y-axis and fastness of code on X-axis. In the engineering Knowledge Language (EKL) name, their names and addresses are explicitly written while in VBA the name is variable.

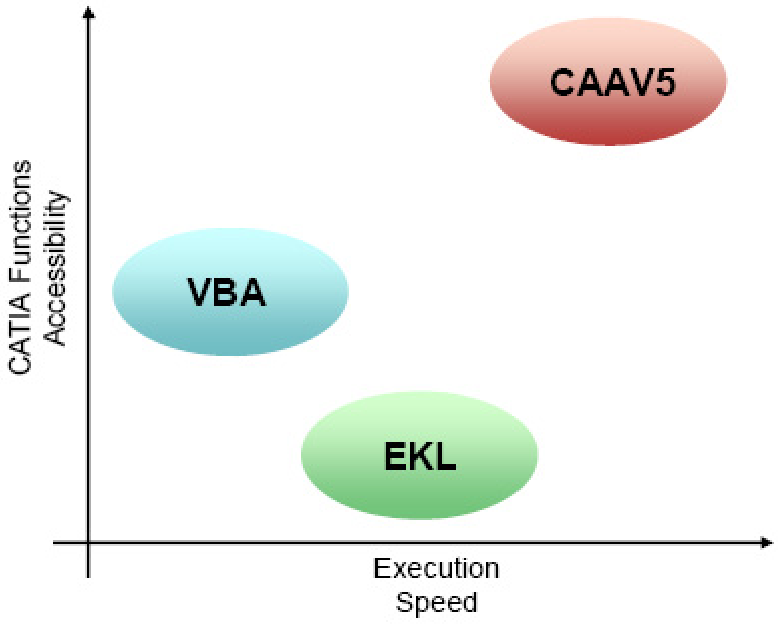


Figure 4.3: Performance difference between EKL, VBA and CAAV5

4.3 Knowledge advisor

The workbench of the Knowledge Advisor is visualized in Figure 9.4 in Appendix. The following section explains the important functions and tree important objects that have been used during the work.

4.3.1 Formula Function

This function is used to create and modify the parameters as shown Figure 4.4(a) in Appendix. To create a new parameter, the type of parameter is selected first and then a value or a formula is added to it. Newly created parameter can be seen in the Parameter tree; the object Parameters such as Curve, Circle, Point and Line which are featured under a Geometric Set as Object Parameter. If a relation or rule is not specified all the newly parameters in the formula function are called a parameter. A Relation based Parameter is called a Derived Variable, and Parameter is called Derived Object Variable.

4.3.2 Rule Function

Rule was formed with the help of Engineering Knowledge Language which was shown in Figure 4.4 (b). The script was written in the editor window and software was provided by basic scripts to help the user. Parameters were created as per requirement in the tress and were controlled by the rules.

4.3.3 Reaction Function

Here a Reaction is created using the Engineering Knowledge Language or Visual Basic Language of CATIA. The Reaction created is visualized under a Relation Set in the models tree. The reaction is a feature that reacts to events on its sources by triggering an action. It is designed to cope with the rules and the behaviors limitations and to create more associative and reactive design.

The script is written in the editor window. A Dictionary is incorporated to assist the user with basic scripts just as the Rule function. However if the VB action is chosen then another editor environment will be shown and the script is written following the VB syntax instead of EKL.

4.3.4 Check Function

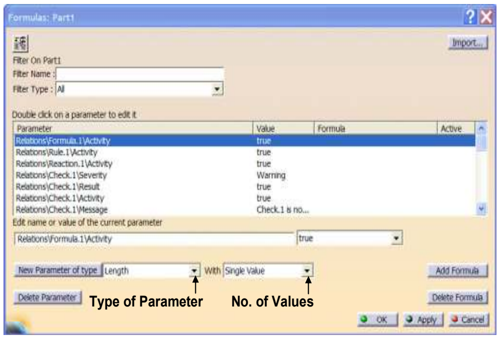
Check is created using the Engineering Knowledge Language of CATIA. The Check created is visualized under a Relation Set in the models tree. A Dictionary is incorporated to assist the user with basic scripts just as the Rule function.

4.3.5 Parameter Set Function

By clicking on the Parameter Set Function a Parameter Set is created in which a set of Parameters can be stored in the model tree. An example of how such a division might look like is visualized in Figure 4.8.

4.3.6 Relation Set Function

By clicking on the Relation Set Function a Relation Set is created in which a set of Relations can be stored in the model tree.



Filter On Part1
Filter Name :
Filter Type : All

Double click on a parameter to edit it

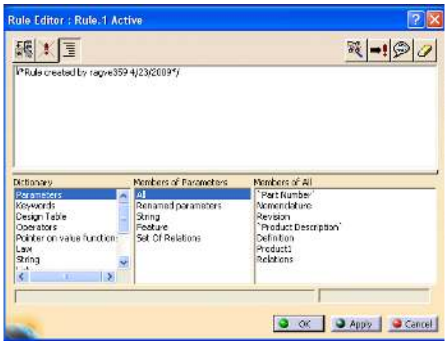
Parameter	Value	Formula	Active
Relations\Formula.1\Activity	true		
Relations\Rule.1\Activity	true		
Relations\Reaction.1\Activity	true		
Relations\Check.1\Severity	Warning		
Relations\Check.1\Result	true		
Relations\Check.1\Activity	true		
Relations\Check.1\Message	Check.1 is no...		

Edit name or value of the current parameter
Relations\Formula.1\Activity true
New Parameter of type Length With Single Value

Type of Parameter

No. of Values

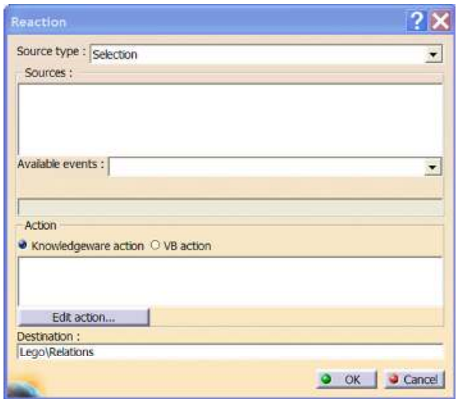
Figure 4.4 (a) Formula function



```
/*Rule created by ragve359 4/23/2009*/
```

Dictionary	Members of Parameters	Members of All
Parameters	All	\`Part Number\`
Keywords	Renamed parameters	Nomenclature
Design Table	String	Revision
Operators	Feature	\`Product Description\`
Pointer on value function	Set Of Relations	Definition
Law		Product1
String		Relations

Figure 4.4 (b) Rule function script editor



Source type : Selection
Sources :
Available events :
Action
● Knowledgeware action ○ VB action
Destination :
Lego\Relations

Figure 4.4 (c) Reaction function script editor

External Parameters
Wing_skin_Thickness=0.0
t1=0.12
t2=0.12
Length_of_Flap=0.9
Dist_from_Root_Chord=0.
Leading_Edge_Angle (..!..
Parameters [...] (4)
Leading_Edge_Angle=5de
Chord_of_Flap_Left_Edge=
Chord_of_Flap_Right_Edge
Flap_Angle=0.184deg=an

Figure 4.4 (d) Parameters ordered in a hierarchal fashion using Parameter Sets

Figure 4.4: Knowledge advisor functions

4.3.7 Power Copy Instances

By means of Power Copy function a template is produced which is initiated either manually or automatically and reused in the topological pyramid.

4.3.7.1 Manually Initiated Power Copies

The Generic Initialization level of the topological pyramid is generated manually with the help of power copy function in CATIA. The two scenarios to reach this level for the created templates are:

- A need of context reliant while defining restrictive boundary conditions.

- In the context the geometric objects of the initiated instances should be modified parametrically. Every geometric objects defined in the model have unique parametric values.

In order to achieve the GI method in CATIA, the power copy function is helpful, where the Template model, visualized under Selected Components, consists of a point, a sketch, a relation and a parameter. In Inputs Components the required Constraint is shown and the sketch is constructed on the plane. In order to have boundary conditions two spline curves are constructed in the sketch.

4.3.7.2 Automatic Initiated Power Copies in a Part

In this section an example is shown in how the ribs of the flap of Aircraft model are generated. The model tree of the ribs part can be seen in Figure 5.15. Here a power copy is initiated automatically, but also the reduction process of the instances is performed by introducing a new reaction, in this case called Initiate_delete_Sets. Refer Appendix for the code used to create the ribs.

5. GEOMETRIC MODEL

5.1 Aircraft Parametric Model

5.1.1 Use of CATIA in the Thesis

The existing parametric aircraft model has been designed in CATIA and this work involves designing the control surfaces for it.

The basic workbenches used in CATIA are:

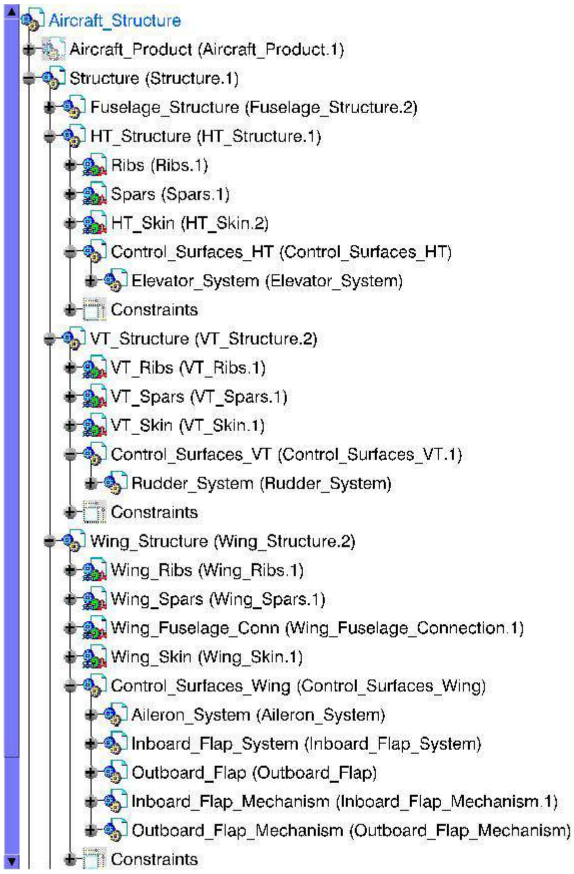
1. Knowledge Advisor
2. Generative Shape Design
3. Part Design
4. Assembly Design

All the control surfaces; elevator, aileron, rudder and flaps, have been designed parametrically using CATIA. The way of designing the control surfaces is explained in detail in 5.2

5.2 Structure Buildup

The Parametric Model of the control surfaces has been built to export the geometry to CATIA by means of Excel user interface. The model has been built and re-built several times to accomplish the goals. It has been a challenge to find the simplest functioning model.

Every part has a set of parameters that are controlled by Rules and Reactions. The user needs to change the parameters in the model to get the desired result. The structure hierarchy is as shown in Figure 5.1. The Control surfaces designed are as shown in Figure 5.2



- Aircraft_Structure
  - Aircraft_Product (Aircraft_Product.1)
  - Structure (Structure.1)
    - Fuselage_Structure (Fuselage_Structure.2)
    - HT_Structure (HT_Structure.1)
      - Ribs (Ribs.1)
      - Spars (Spars.1)
      - HT_Skin (HT_Skin.2)
      - Control_Surfaces_HT (Control_Surfaces_HT)
        - Elevator_System (Elevator_System)
      - Constraints
    - VT_Structure (VT_Structure.2)
      - VT_Ribs (VT_Ribs.1)
      - VT_Spars (VT_Spars.1)
      - VT_Skin (VT_Skin.1)
      - Control_Surfaces_VT (Control_Surfaces_VT.1)
        - Rudder_System (Rudder_System)
      - Constraints
    - Wing_Structure (Wing_Structure.2)
      - Wing_Ribs (Wing_Ribs.1)
      - Wing_Spars (Wing_Spars.1)
      - Wing_Fuselage_Conn (Wing_Fuselage_Connection.1)
      - Wing_Skin (Wing_Skin.1)
      - Control_Surfaces_Wing (Control_Surfaces_Wing)
        - Aileron_System (Aileron_System)
        - Inboard_Flap_System (Inboard_Flap_System)
        - Outboard_Flap (Outboard_Flap)
        - Inboard_Flap_Mechanism (Inboard_Flap_Mechanism.1)
        - Outboard_Flap_Mechanism (Outboard_Flap_Mechanism)
      - Constraints

Figure 5.1: Aircraft Structure Build Up

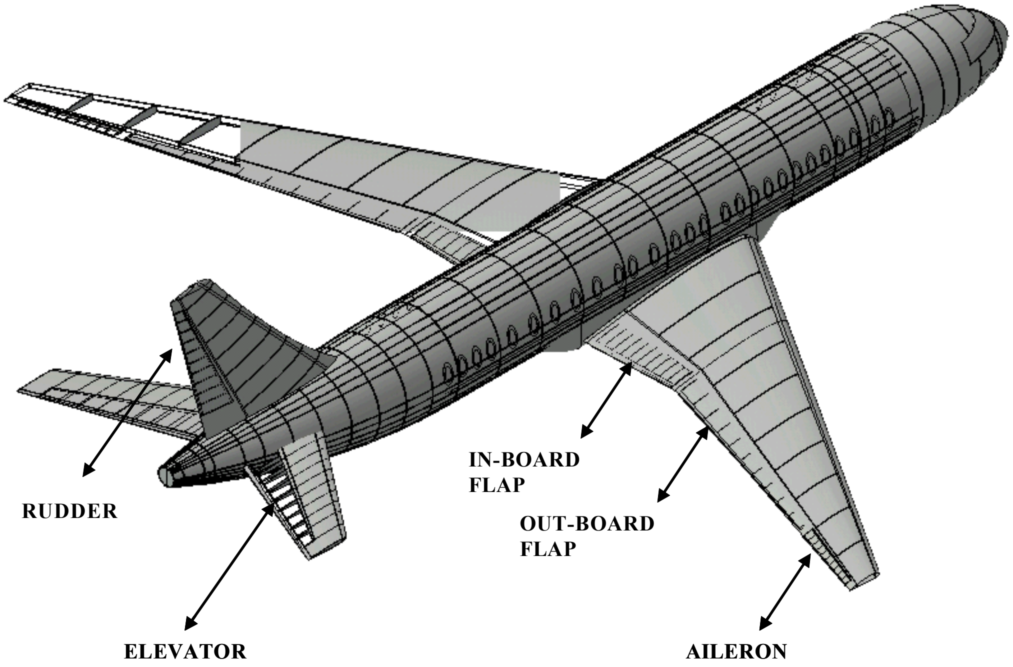
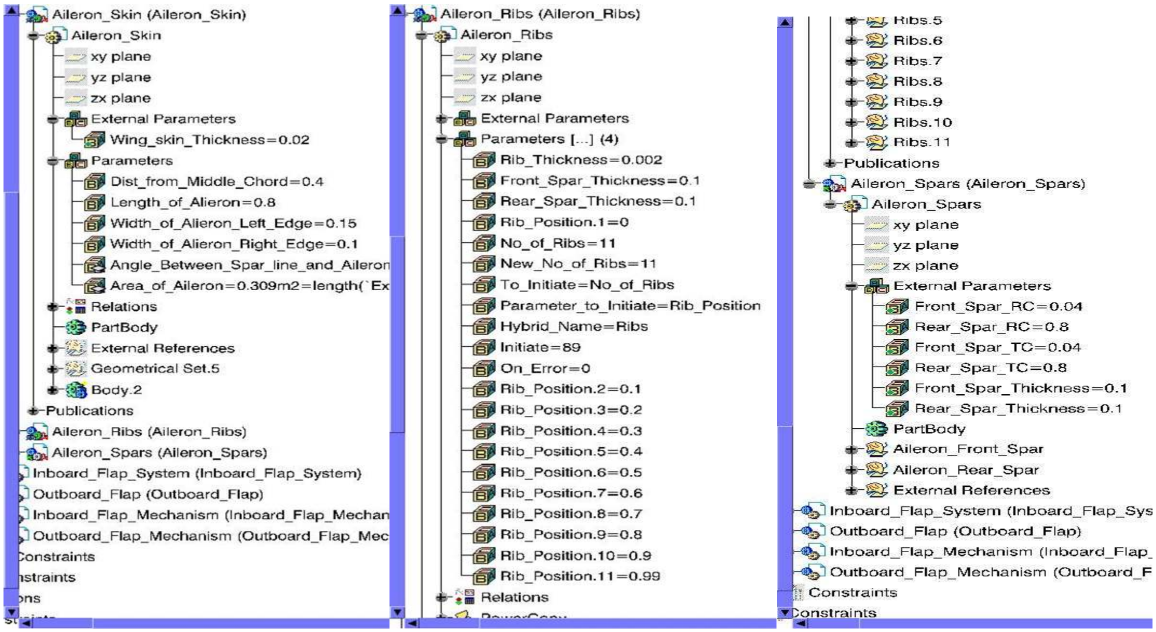


Figure 5.2: Aircraft structure

5.2.1 Aileron Buildup



```
Aileron_Skin (Aileron_Skin)
  Aileron_Skin
    xy plane
    yz plane
    zx plane
    External Parameters
      Wing_skin_Thickness=0.02
    Parameters
      Dist_from_Middle_Chord=0.4
      Length_of_Alieron=0.8
      Width_of_Alieron_Left_Edge=0.15
      Width_of_Alieron_Right_Edge=0.1
      Angle_Between_Spar_line_and_Aileron
      Area_of_Aileron=0.309m2=length(`Ex
    Relations
    PartBody
    External References
    Geometrical Set.5
    Body.2
  Publications
Aileron_Ribs (Aileron_Ribs)
Aileron_Spars (Aileron_Spars)
Inboard_Flap_System (Inboard_Flap_System)
Outboard_Flap (Outboard_Flap)
Inboard_Flap_Mechanism (Inboard_Flap_Mechan
Outboard_Flap_Mechanism (Outboard_Flap_Mec
Constraints
nstraints
ons
```

```
Aileron_Ribs (Aileron_Ribs)
  Aileron_Ribs
    xy plane
    yz plane
    zx plane
    External Parameters
    Parameters [...] (4)
      Rib_Thickness=0.002
      Front_Spar_Thickness=0.1
      Rear_Spar_Thickness=0.1
      Rib_Position.1=0
      No_of_Ribs=11
      New_No_of_Ribs=11
      To_Initiate=No_of_Ribs
      Parameter_to_Initiate=Rib_Position
      Hybrid_Name=Ribs
      Initiate=89
      On_Error=0
      Rib_Position.2=0.1
      Rib_Position.3=0.2
      Rib_Position.4=0.3
      Rib_Position.5=0.4
      Rib_Position.6=0.5
      Rib_Position.7=0.6
      Rib_Position.8=0.7
      Rib_Position.9=0.8
      Rib_Position.10=0.9
      Rib_Position.11=0.99
    Relations
```

```
      Ribs.5
      Ribs.6
      Ribs.7
      Ribs.8
      Ribs.9
      Ribs.10
      Ribs.11
    Publications
  Aileron_Spars (Aileron_Spars)
    Aileron_Spars
      xy plane
      yz plane
      zx plane
      External Parameters
        Front_Spar_RC=0.04
        Rear_Spar_RC=0.8
        Front_Spar_TC=0.04
        Rear_Spar_TC=0.8
        Front_Spar_Thickness=0.1
        Rear_Spar_Thickness=0.1
      PartBody
      Aileron_Front_Spar
      Aileron_Rear_Spar
      External References
Inboard_Flap_System (Inboard_Flap_Sys
Outboard_Flap (Outboard_Flap)
Inboard_Flap_Mechanism (Inboard_Flap_
Outboard_Flap_Mechanism (Outboard_F
Constraints
Constraints
```

Figure 5.3: Parts in aileron assembly

Figure 5.3 shows the parts that are present in the aileron assembly; they are Aileron_Ribs, Aileron_Skin and Aileron_Spars. Figure 5.4 also shows the corresponding parameters that are available in each part.

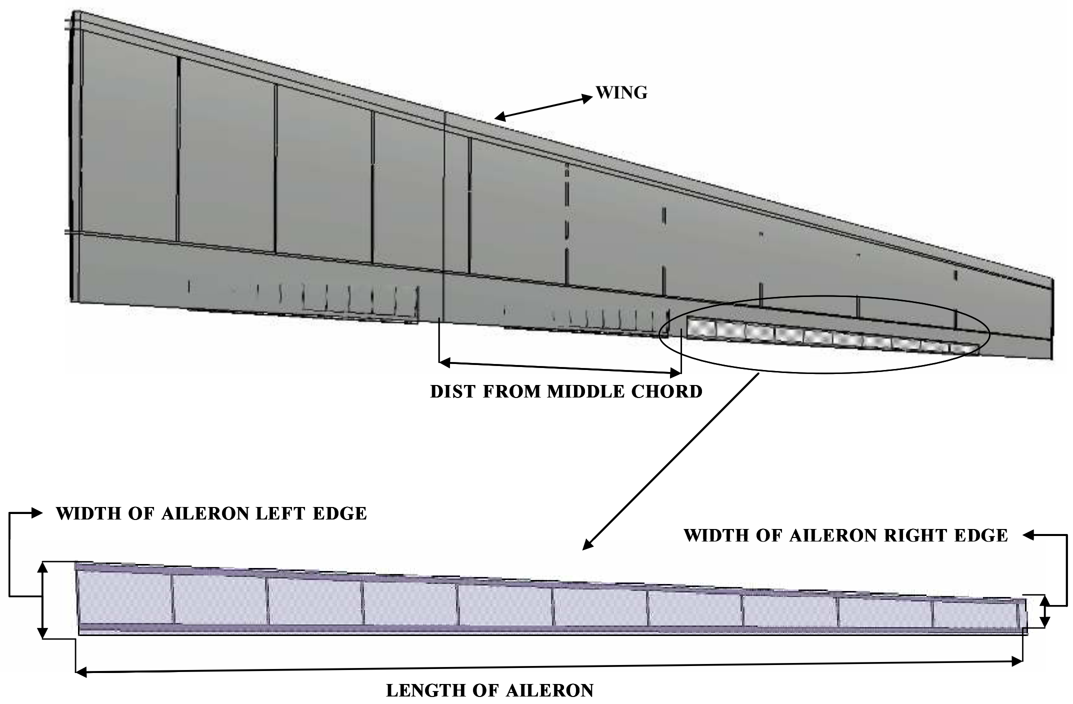


Figure 5.4: Aileron Structure

As the wing is divided into two segments, for simplicity the reference for the aileron is taken from middle chord. The distance from the middle chord is the ratio measured along the trailing edge. The leading edge is created from the width of the left and right edges measured from the trailing edge along the Middle and Tip chords respectively. The number of ribs used in the aileron can be varied using the Excel user interface. The Front and Rear spars thickness can also be varied as per the requirements.

5.2.2 Elevator Buildup

The hierarchy in the elevator assembly is analogous to as shown in Figure 5.3. The Root chord is taken as the reference to place the elevator. The widths of the left and right edges are the ratios measured on the Root and Tip chords respectively. The construction of the elevator is as shown in Figure 5.5. The pictures of different aircraft configurations are shown in Appendix.

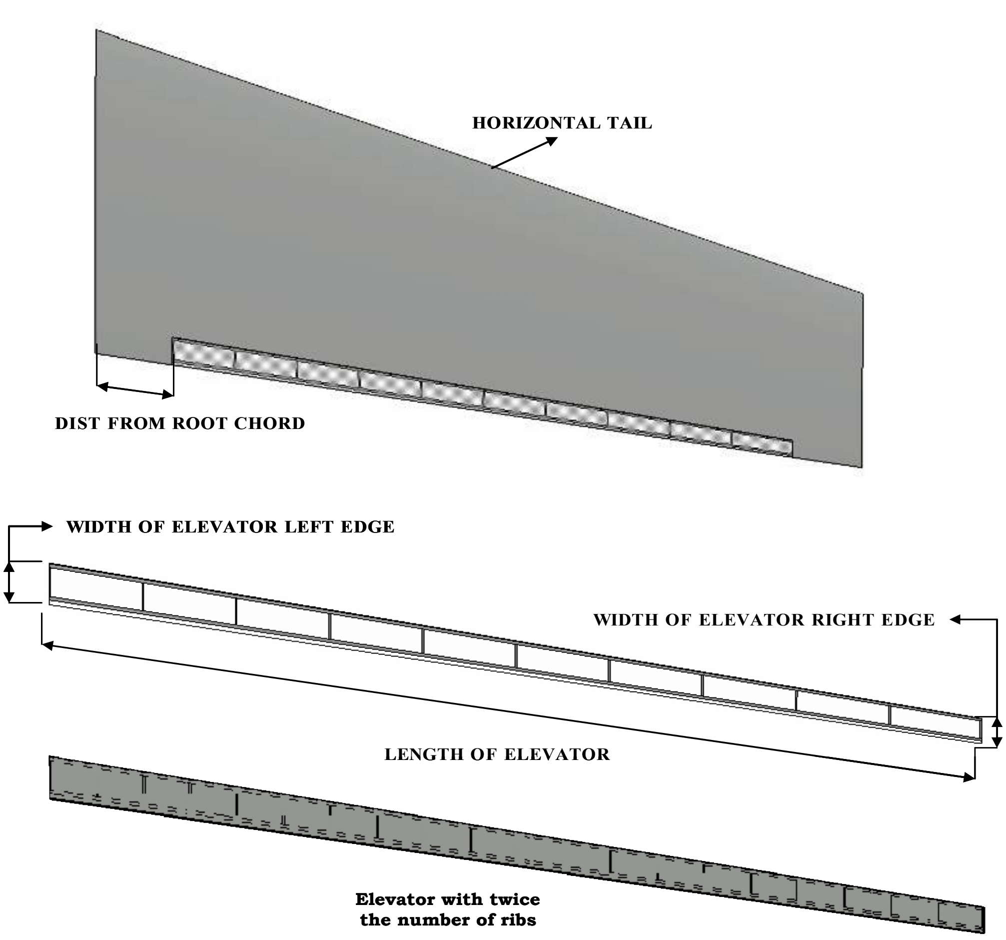


Figure 5.5: Elevator Structure

5.2.3 Rudder Buildup

The order of the rudder assembly is as that of the aileron assembly. The Root chord is taken as the reference to place the rudder. The rudder can only move between rear spar of the vertical tail and the trailing edge. The construction of elevator is as shown in Figure 5.6. The pictures of different configurations are shown in the appendix.

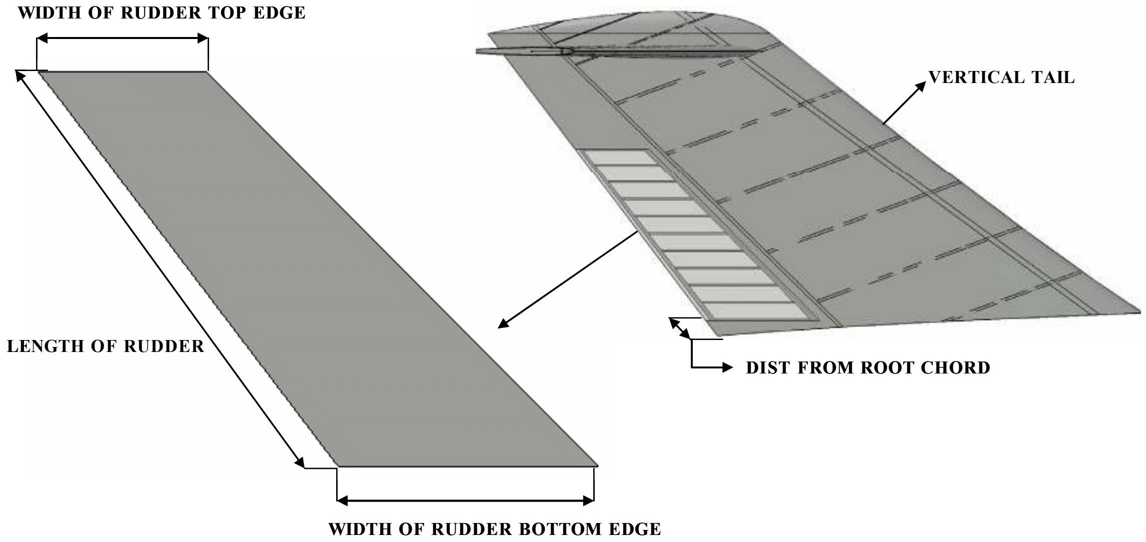


Figure 5.6: Rudder Structure

5.2.4 In-board and Out-board Flaps Buildup

The construction of both In-board and Out-board flaps is comparable. The difference between them is only the reference taken for the placement of the flaps. The Root chord is taken as the reference for inboard flap and Middle chord is taken as the reference for the outboard flap as shown in Figure 5.7.

The angle between the Rear spar of the wing and the leading edge of the flap is given as Leading edge angle for the flap. The angle can be varied to obtain the desired position of the flap. Root and tip chords can be changed using the user interface.

The mechanism is also designed for the flap to extend and retract by changing the stroke of the actuator. Many experiments are done to design the simplest mechanism parametrically. Some examples are shown in appendix. The actuator can also be designed using the user interface.

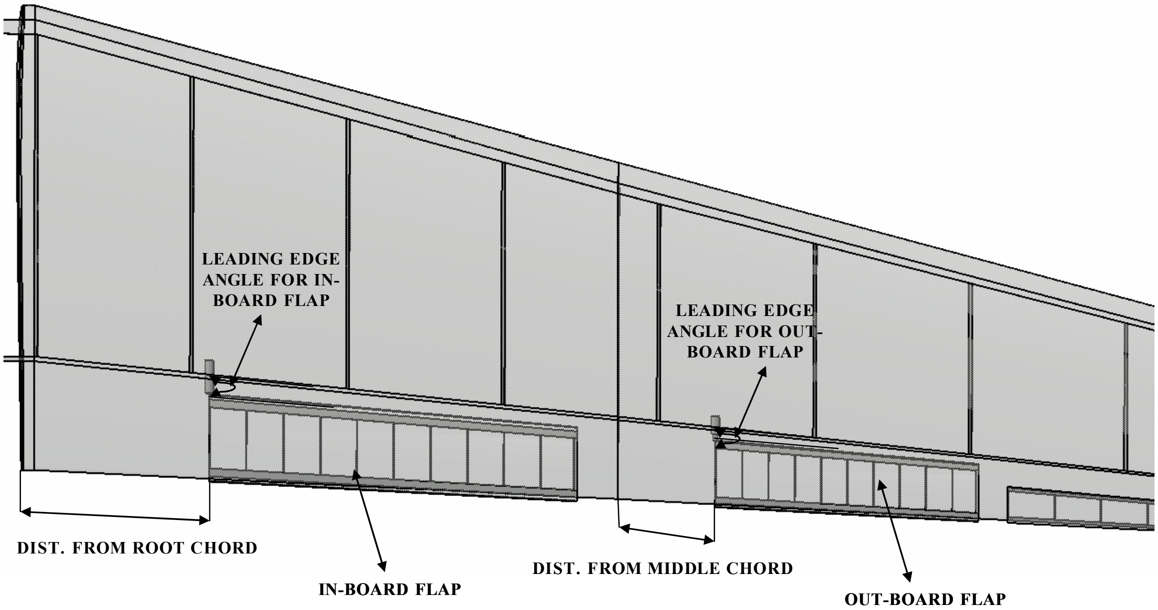


Figure 5.7: In-board and Out-board flaps Structure

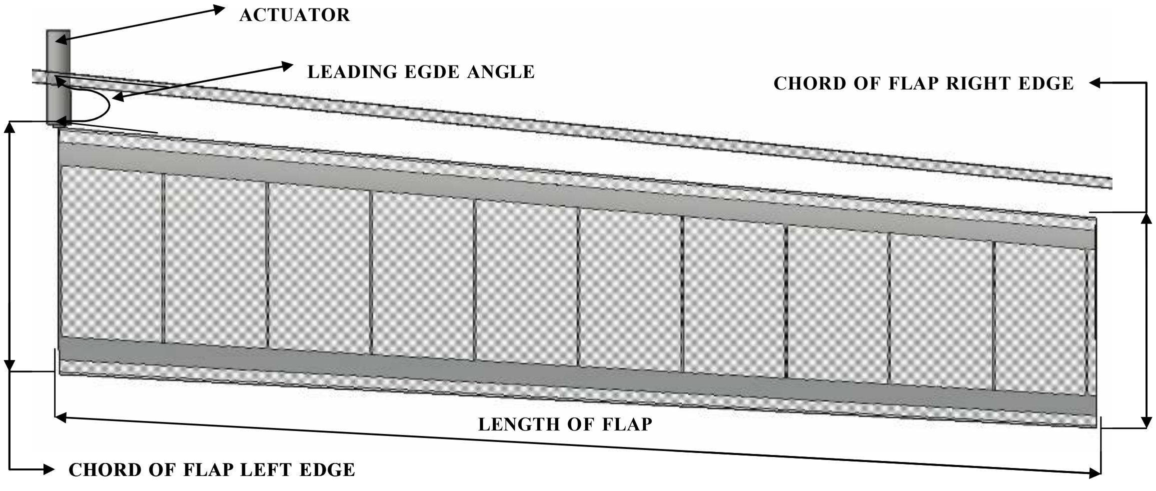


Figure 5.8: Flap Structure

5.3 Construction of Control surface

In this section a brief description is provided on the construction of the aileron. The construction of other control surfaces is similar, except the fact that only the references change. The adaptation of the aileron is shown in Appendix.

5.3.1 Construction of aileron skin

- Middle chord, tip chord and the trailing edge of the wing are taken as references to construct the aileron. Two points Pt1 and Pt2 are then created on both tips of the trailing edge as shown in Figure 5.9

- Taking these points as the references, points Pt3 and Pt4 are created on middle chord and tip chord with ratios equal to 'Width_of_Alieron_Left_Edge' and 'Width_of_Alieron_Right_Edge' using the ratio on curve. Line (L1) is then created by joining points Pt3 and Pt4; it is used as the leading edge reference for the aileron.

- Taking Pt1 as reference Pt5 is created on the trailing edge with the ratio equal to 'Dist_from_Middle_Chord'. Point Pt6 is then created using the reference Pt5 with ratio equal to 'Length_of_Alieron'.

- Two lines L2 and L3 are drawn using these points (Pt5 and Pt6) and parallel to the chord line. Points Pt7 and Pt8 are created by the intersection of lines L1, L2 and L1, L3. By joining the points Pt5, Pt6, Pt7 and Pt8 the area of the aileron is obtained.

- Lines connecting the above mentioned points are joined to make an extrusion. This extrusion is then split with respect to the skin of the wing to obtain the profile for the aileron. It is then extruded inwards to obtain the thickness for the skin as shown in Figure 5.10.

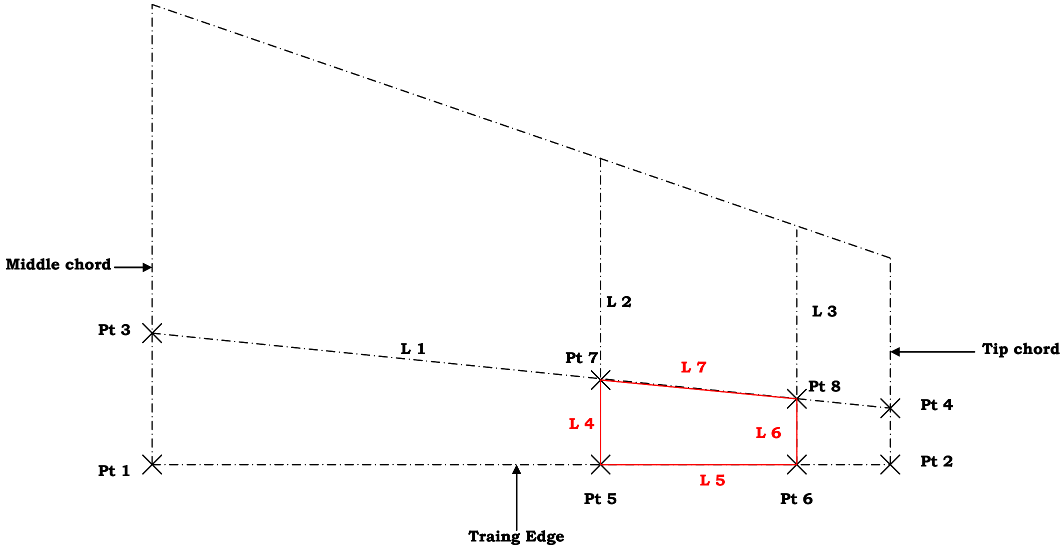
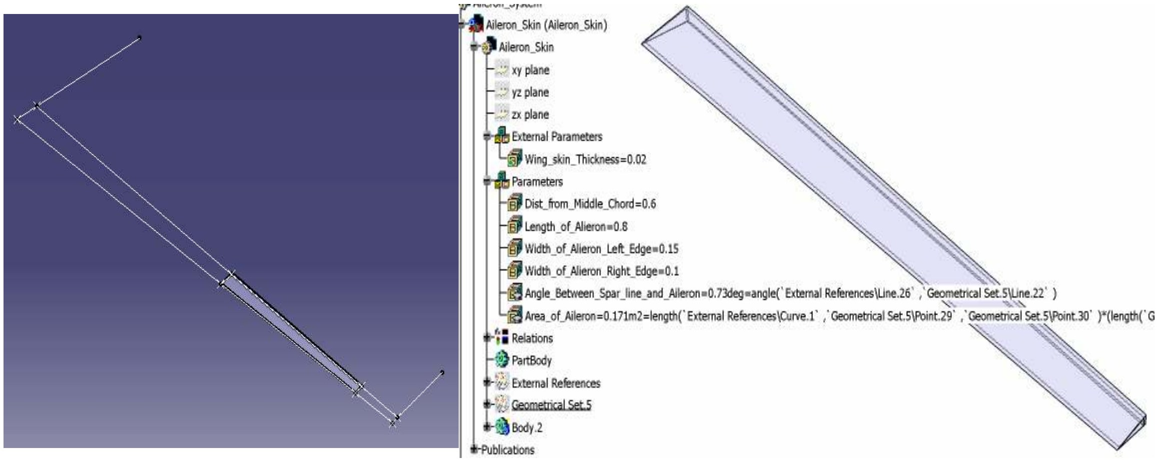


Figure 5.9: Aileron Construction



Wing_skin_Thickness=0.02
Dist_from_Middle_Chord=0.6
Length_of_Aileron=0.8
Width_of_Aileron_Left_Edge=0.15
Width_of_Aileron_Right_Edge=0.1
Angle_Between_Spar_line_and_Aileron=0.73deg=angle(`External References\Line.26` ,`Geometrical Set.5\Line.22`)
Area_of_Aileron=0.171m2=length(`External References\Curve.1` ,`Geometrical Set.5\Point.29` ,`Geometrical Set.5\Point.30`)*(length(`G

Figure 5.10: Aileron Skin

5.3.2 Construction of aileron spars

Front and rear spars are constructed by using the points created in the aileron skin as references.

- To build the front spar; points Pt9 and Pt10 are created from points Pt7 and Pt8 respectively using the ratio equal to the skin thickness. Line L8 is created by joining the points previously created. This line is then extruded to intersect the aileron inner skin.

- Points Pt11 and Pt12 are created by using the reference points Pt9 and Pt10 and ratio of thickness of the spar. The newly created points are joined by line L9 and extruded to meet the inner skin. The extrapolated surfaces are trimmed and then 'Close surface' option is used to obtain the solid as shown in Figure 5.12.

- Steps 1 and 2 are repeated by taking points Pt5 and Pt6 as reference to obtain the rear spar as shown in Figure 5.11

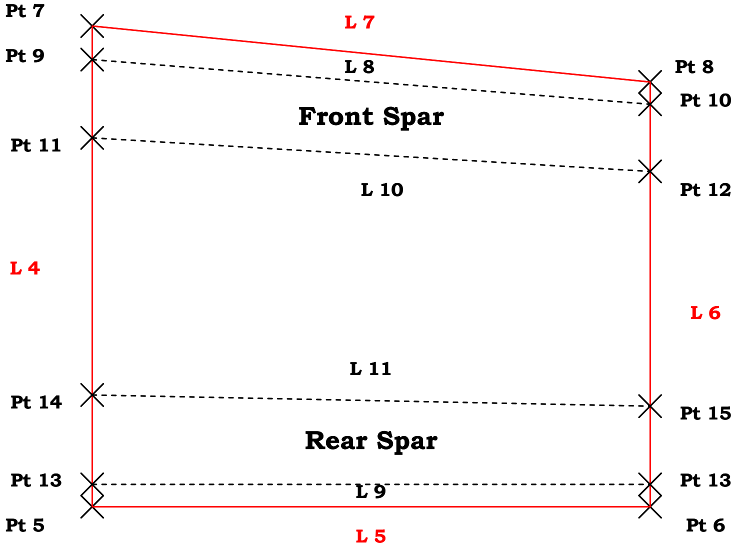
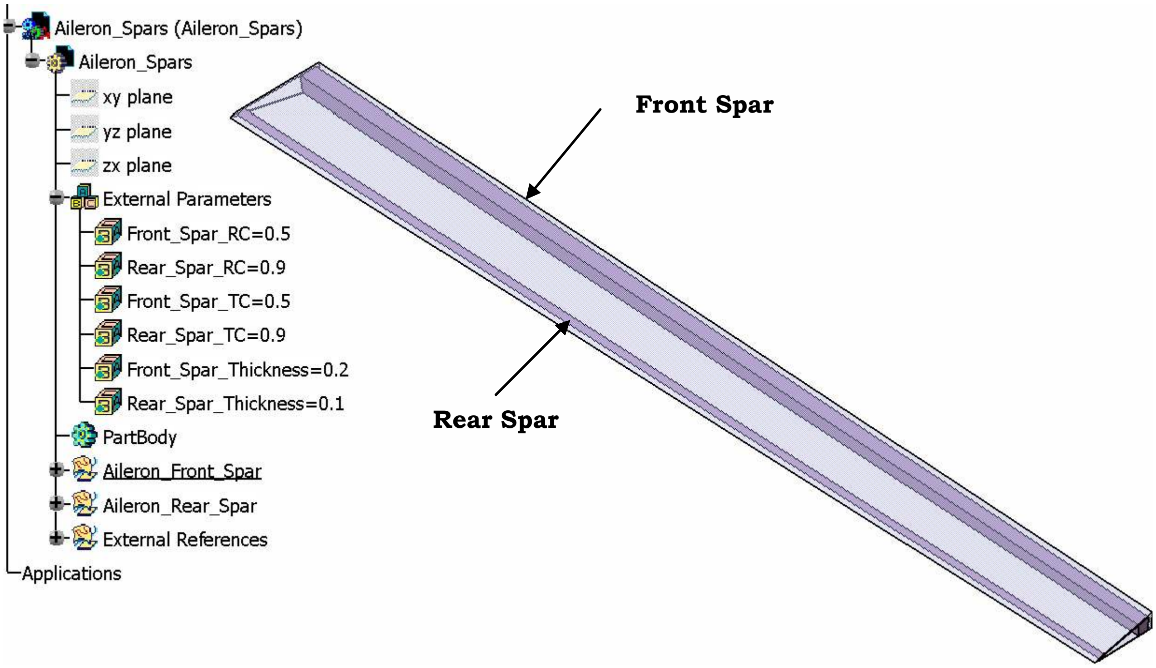


Figure 5.11: Ribs Construction



Aileron_Spars (Aileron_Spars)
  Aileron_Spars
    xy plane
    yz plane
    zx plane
    External Parameters
      Front_Spar_RC=0.5
      Rear_Spar_RC=0.9
      Front_Spar_TC=0.5
      Rear_Spar_TC=0.9
      Front_Spar_Thickness=0.2
      Rear_Spar_Thickness=0.1
    PartBody
    Aileron_Front_Spar
    Aileron_Rear_Spar
    External References
Applications

Figure 5.12: Aileron spars

5.3.3 Construction of aileron ribs

The first rib is constructed and then a ‘Power copy’ (Refer section 4) is used to instantiate the rib.

- For the construction of the ribs the reference points Pt11 and Pt14 are taken as reference. Points Pt15 and Pt16 are created with the ratio equal to the rib thickness on the lines L10 and L11. Line L12 is obtained by joining the newly created points as shown in Figure 5.13.

- The lines L4 and L12 are extruded to intersect the inner skin surface. Later they are split with respect to the inner skin and ‘Close surface’ is used to obtain a solid.

- All the elements used to create the rib and the rib is then used to ‘Power copy’. This is as seen in stage 3 as Generic Automatic Initiation (Figure 4.2). Refer section 9.5 in Appendix for the code used to instantiate the rib. The parameters used to create are as shown in Figure 5.14, and an example is shown in Figure 5.14

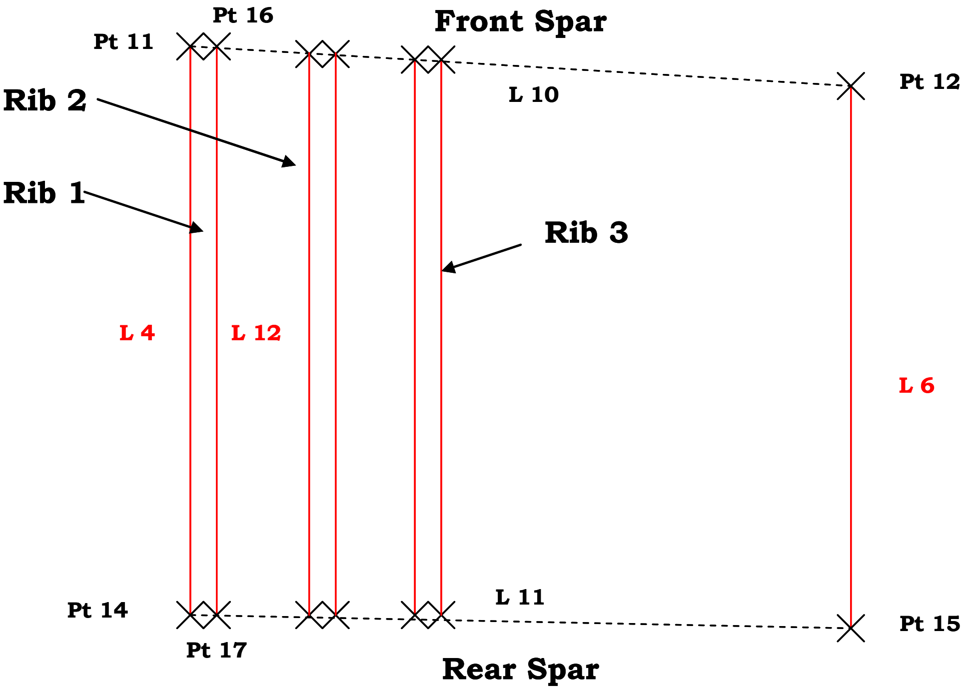
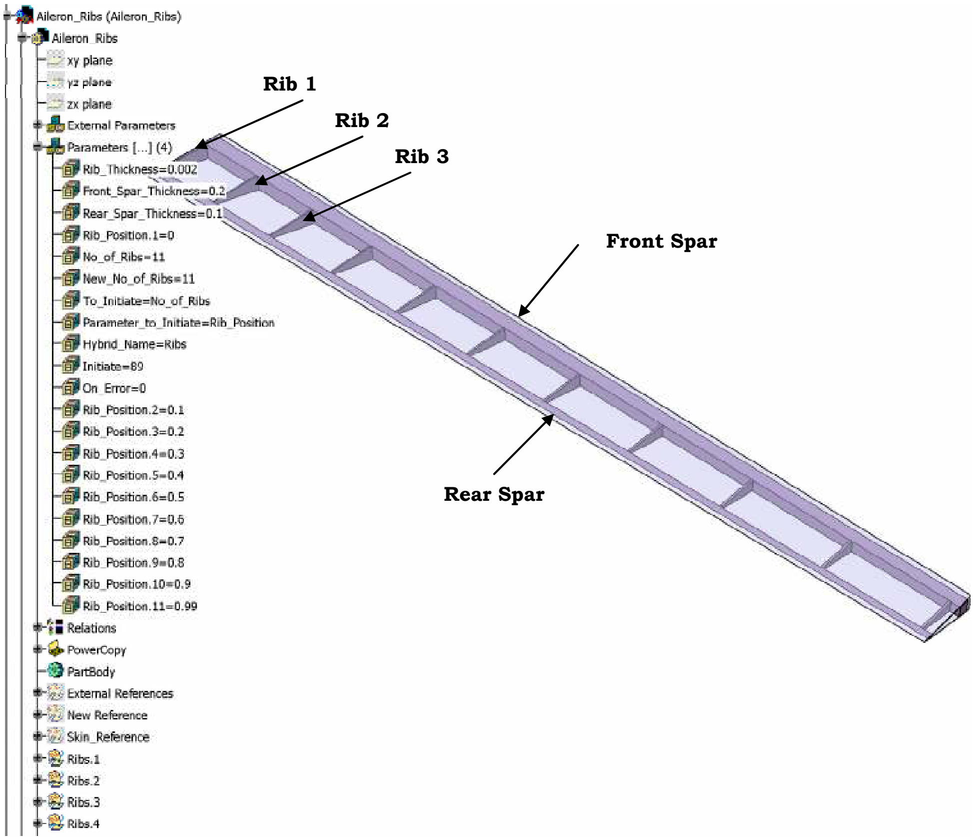
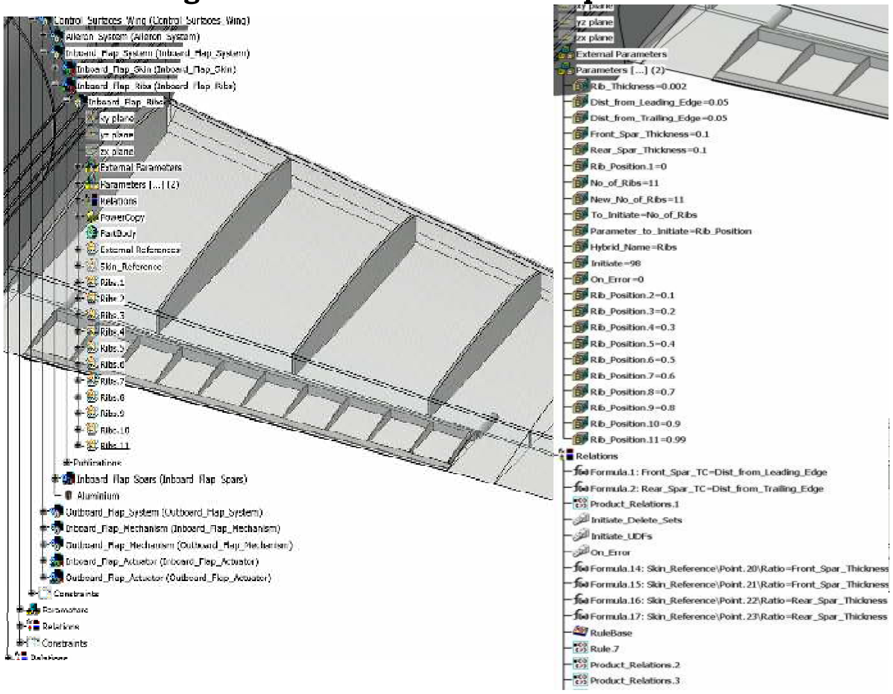


Figure 5.13: Aileron Ribs



Aileron_Ribs (Aileron_Ribs)
- Aileron_Ribs
  - xy plane
  - yz plane
  - zx plane
  - External Parameters
  - Parameters [...] (4)
    - Rib_Thickness=0.002
    - Front_Spar_Thickness=0.2
    - Rear_Spar_Thickness=0.1
    - Rib_Position.1=0
    - No_of_Ribs=11
    - New_No_of_Ribs=11
    - To_Initiate=No_of_Ribs
    - Parameter_to_Initiate=Rib_Position
    - Hybrid_Name=Ribs
    - Initiate=89
    - On_Error=0
    - Rib_Position.2=0.1
    - Rib_Position.3=0.2
    - Rib_Position.4=0.3
    - Rib_Position.5=0.4
    - Rib_Position.6=0.5
    - Rib_Position.7=0.6
    - Rib_Position.8=0.7
    - Rib_Position.9=0.8
    - Rib_Position.10=0.9
    - Rib_Position.11=0.99
  - Relations
  - PowerCopy
  - PartBody
  - External References
  - New Reference
  - Skin_Reference
  - Ribs.1
  - Ribs.2
  - Ribs.3
  - Ribs.4

Figure 5.14: Aileron Ribs with parameters



Control_Surfaces_Wing (Control_Surfaces_Wing)
- Aileron_System (Aileron_System)
- Inboard_Flap_System (Inboard_Flap_System)
  - Inboard_Flap_Skin (Inboard_Flap_Skin)
  - Inboard_Flap_Ribs (Inboard_Flap_Ribs)
    - Inboard_Flap_Ribs
      - xy plane
      - yz plane
      - zx plane
      - External Parameters
      - Parameters [...] (2)
      - Relations
      - PowerCopy
      - PartBody
      - External References
      - Skin_Reference
      - Ribs.1
      - Ribs.2
      - Ribs.3
      - Ribs.4
      - Ribs.5
      - Ribs.6
      - Ribs.7
      - Ribs.8
      - Ribs.9
      - Ribs.10
      - Ribs.11
    - Publications
  - Inboard_Flap_Spars (Inboard_Flap_Spars)
  - Aluminium
- Outboard_Flap_System (Outboard_Flap_System)
- Inboard_Flap_Mechanism (Inboard_Flap_Mechanism)
- Outboard_Flap_Mechanism (Outboard_Flap_Mechanism)
- Inboard_Flap_Actuator (Inboard_Flap_Actuator)
- Outboard_Flap_Actuator (Outboard_Flap_Actuator)
- Constraints
- Parameters
- Relations
- Constraints
- Relations

- xy plane
- yz plane
- zx plane
- External Parameters
- Parameters [...] (2)
  - Rib_Thickness=0.002
  - Dist_from_Leading_Edge=0.05
  - Dist_from_Trailing_Edge=0.05
  - Front_Spar_Thickness=0.1
  - Rear_Spar_Thickness=0.1
  - Rib_Position.1=0
  - No_of_Ribs=11
  - New_No_of_Ribs=11
  - To_Initiate=No_of_Ribs
  - Parameter_to_Initiate=Rib_Position
  - Hybrid_Name=Ribs
  - Initiate=98
  - On_Error=0
  - Rib_Position.2=0.1
  - Rib_Position.3=0.2
  - Rib_Position.4=0.3
  - Rib_Position.5=0.4
  - Rib_Position.6=0.5
  - Rib_Position.7=0.6
  - Rib_Position.8=0.7
  - Rib_Position.9=0.8
  - Rib_Position.10=0.9
  - Rib_Position.11=0.99
- Relations
  - Formula.1: Front_Spar_TC=Dist_from_Leading_Edge
  - Formula.2: Rear_Spar_TC=Dist_from_Trailing_Edge
  - Product_Relations.1
  - Initiate_Delete_Sets
  - Initiate_UDFs
  - On_Error
  - Formula.14: Skin_Reference\Point.20\Ratio=Front_Spar_Thickness
  - Formula.15: Skin_Reference\Point.21\Ratio=Front_Spar_Thickness
  - Formula.16: Skin_Reference\Point.22\Ratio=Rear_Spar_Thickness
  - Formula.17: Skin_Reference\Point.23\Ratio=Rear_Spar_Thickness
  - RuleBase
  - Rule.7
  - Product_Relations.2
  - Product_Relations.3

Figure 5.15: Model tree of rib for the flap

5.4 Flap Mechanism

'Single slotted fowler flap' [Figure 2.4(c)] mechanism is built both for In-board and Out-board flaps (Refer section 2 for types of flaps). The flap extends and retracts when the stroke of the piston is changed. Wing area and chord increases as the flap extends [Figure 5.16] and decreases as the flap retracts. Figure 5.15 shows the extended and retracted flaps.

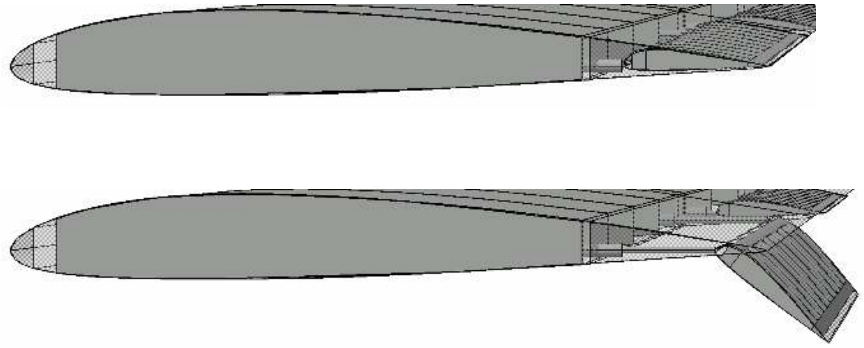


Figure 5.16: Retracted and extended flaps

The flap mechanism constructed is as shown in figure 5.16. The actuator is fixed to the rear spar of the wing. Flap is connected to the piston and as the piston extends, the flap moves to the rear. The link connecting guide and flap helps the later to rotate. The mechanism can be modified to suit with the different aircraft models given in Appendix.

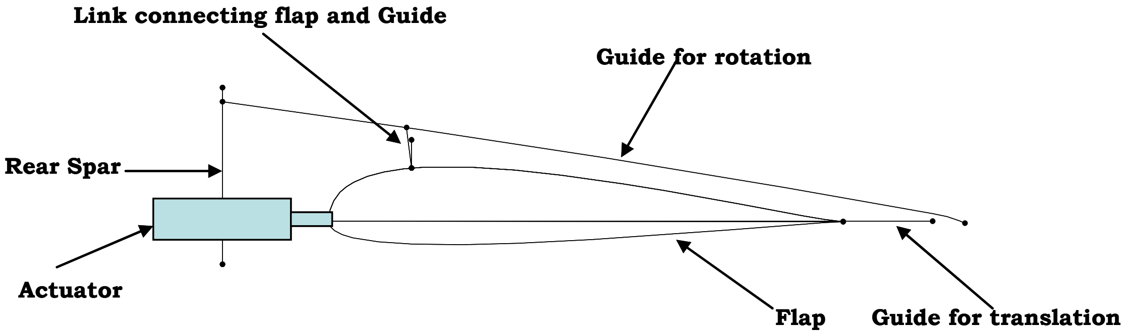


Figure 5.17: Flap mechanism construction

6. DYNAMIC MODEL

In this chapter the main point is the understanding of how the dynamic model is built in Dymola and how the model is analyzed. The parameters and results that have been regarded as the more relevant are the ones that are going to be explained through this chapter.

6.1 Dymola

Dymola [25] (an abbreviation for "Dynamic Modeling Laboratory") is a software suitable for modeling of several kinds of physical systems. It supports hierarchical model composition, libraries of truly reusable components, connectors and composition of casual connections. Model libraries are available in many engineering domains. Dymola uses a new modeling methodology based on object orientation and equations. The usual need for manual conversion of equations to a block diagram is removed by the use of automatic formula manipulation [3].

6.2 Modelica

The programming language Modelica [25] is a modeling software which is used for dynamic mathematical models. Model integration, model evolution and reusability are the major features of Modelica [3]. Modelica is developed by the Modelica Association and is used in both industry and academia. The modeling and simulation supported by object oriented structure are used in several engineering domains. Model integration and model evolution can be managed throughout the design process by the object oriented code. Modelica is primary based on equations while traditional languages such as FORTRAN, C and MATLAB were based on allocation of variables.

In order to manage complexity and integration of components and sub-models connectors are used to define the interfaces between the components. The secondary feature hierarchical modeling deals with complexity of the model in which the complex model is subdivided into few components and can be used simultaneously by many people. The inheritance feature in Modelica is used in model evolution. Inheritance is extremely useful from initial development and later it is used and extended in various models for more functions. The reusability of models is supported by classes and instances which are reused in several models. By the application of the object oriented program it is not possible to model them but simulate the models. [19].

6.3 Dynamic Model

The inverse dynamic model of the aircraft is developed in Dymola using Modelica language. The model includes aircraft control surfaces that are discussed in section 5. The dynamic model is based on the Modelica multi-body library [20]. The connection diagram in Figure 6.1 shows an example of an aircraft dynamic model, including the control surfaces.

An Excel interface is used for transferring parameters from the geometrical model to the dynamic model. This provides the dynamic model with a variable geometry with parameters such as weight, inertia, center of gravity, etc. shown in Figure 6.1.

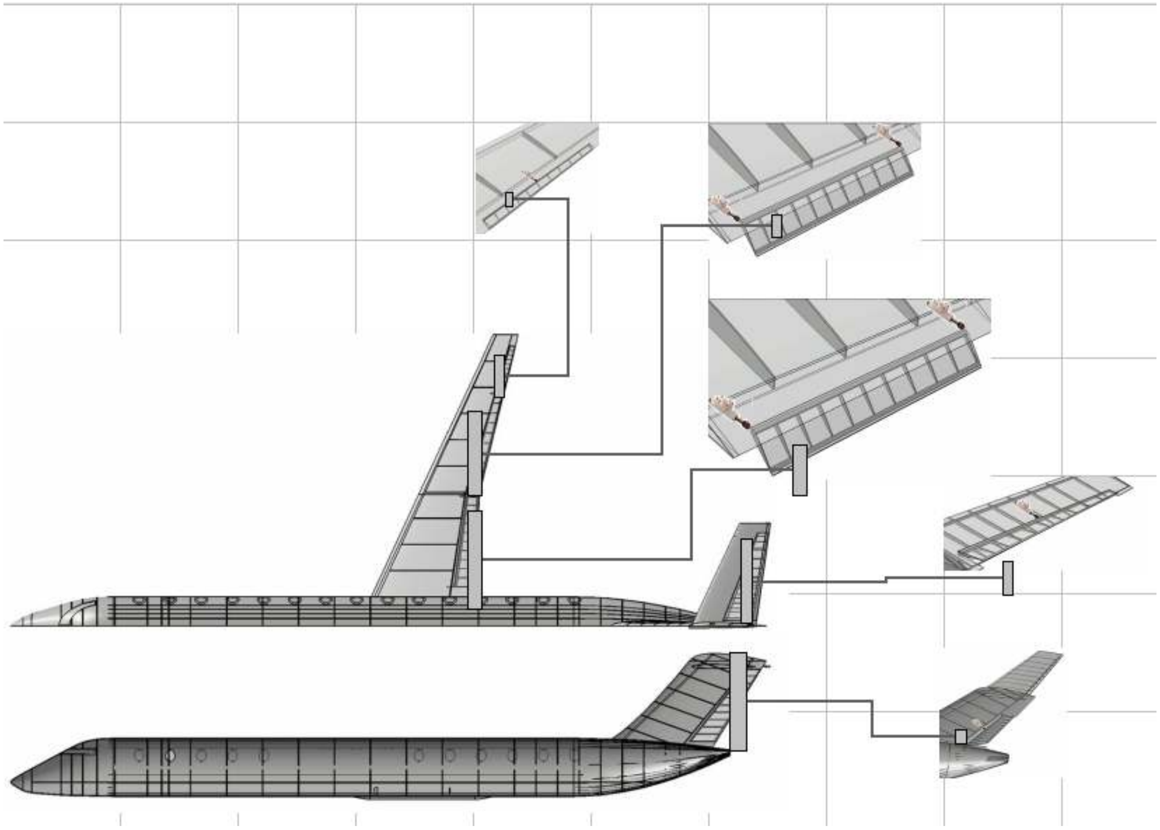


Figure 6.1: Parametric connection between aircraft of the geometric and dynamic models.

The components used in the aircraft are as shown in Figure 6.2. The dynamic model consists of World, representing a global coordinate system fixed in ground. Rigid bodies with mass and inertia tensor and two frame connectors are used to connect together. The Rigid bodies represent individual sections as in the aircraft. The Dymola model produces a 3D visualization of the geometric object trajectories of the control surfaces. The components used in the control surfaces are as shown in Figure 6.3. The simulated model is as shown in Figure 9.13.

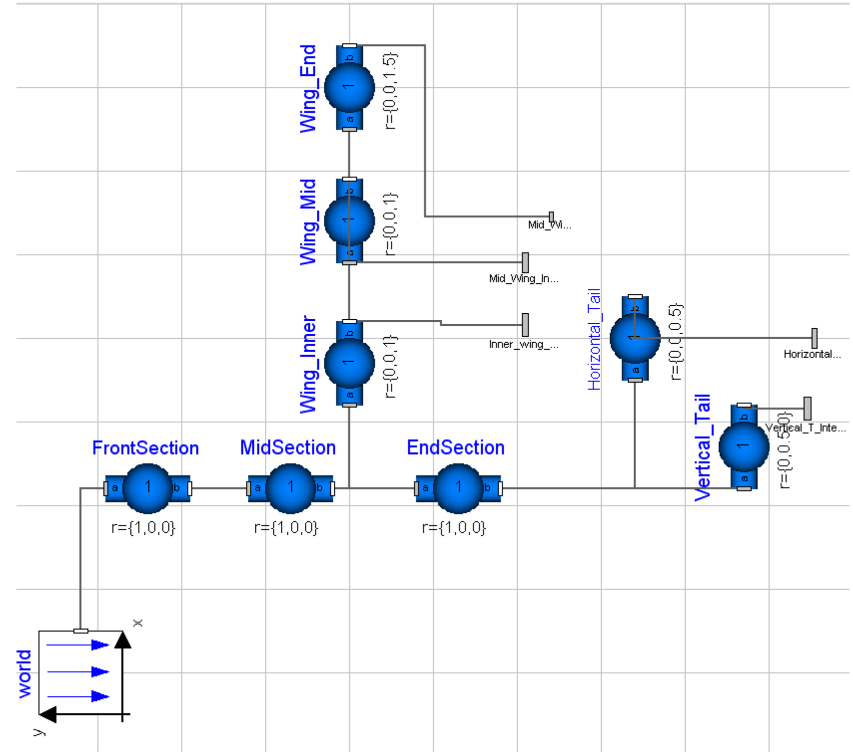


Figure 6.2: Components of dynamic model

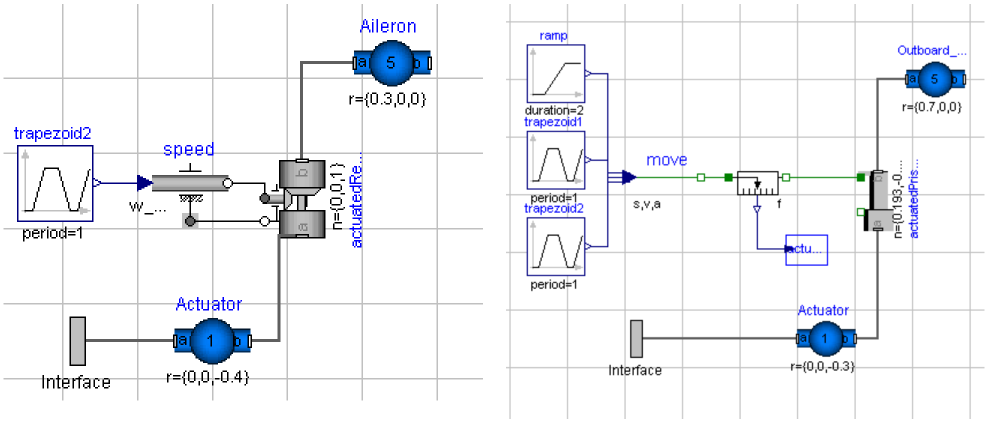


Figure 6.3(a) Componets used in Aileron, Elevator and Rudder

Figure 6.3(a) Componets used in In-board and Out-board Flaps

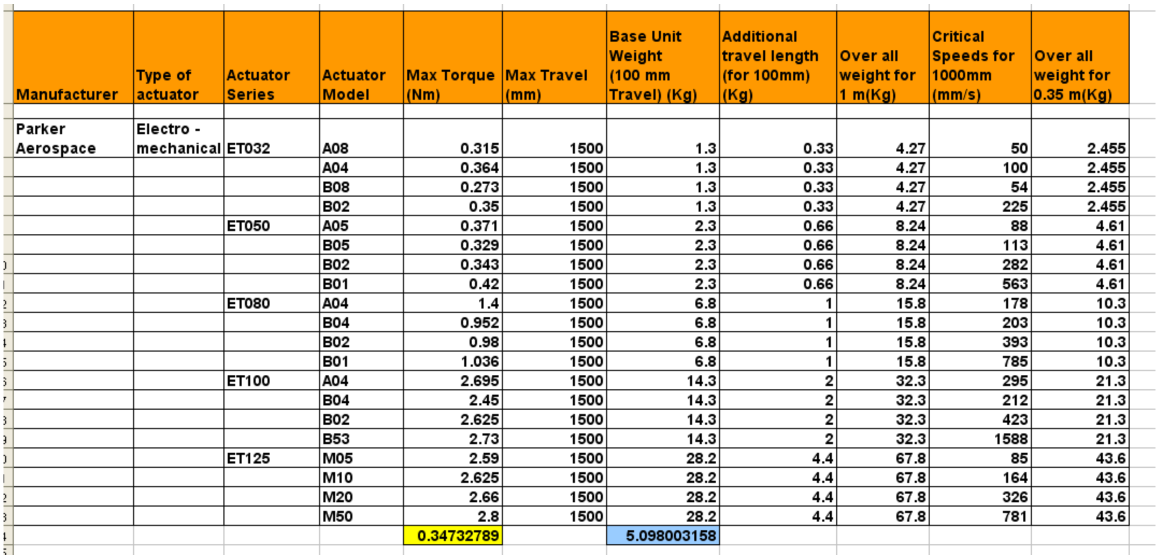
Figure 6.3: components used in control surfaces

6.4 Actuator Calculation

The following section shows the actuator weight estimation and calculations to find the torque required to deflect the control surface.

6.4.1 Actuator weight estimation

To estimate the weight of actuator a reverse engineering is performed from existing electromechanical actuator of Parker Aerospace [27]. The values such as actuator series, maximum torque, maximum travel length, basic weight and weight for additional length etc. are tabularized to find the weight of the actuator for a specific stroke. This weight is used to get the required torque. Figure 6.4 shows the weight estimation for 0.35m stroke.



Manufacturer	Type of actuator	Actuator Series	Actuator Model	Max Torque (Nm)	Max Travel (mm)	Base Unit Weight (100 mm Travel) (Kg)	Additional travel length (for 100mm) (Kg)	Over all weight for 1 m(Kg)	Critical Speeds for 1000mm (mm/s)	Over all weight for 0.35 m(Kg)
Parker Aerospace	Electro - mechanical	ET032	A08	0.315	1500	1.3	0.33	4.27	50	2.455
			A04	0.364	1500	1.3	0.33	4.27	100	2.455
			B08	0.273	1500	1.3	0.33	4.27	54	2.455
			B02	0.35	1500	1.3	0.33	4.27	225	2.455
		ET050	A05	0.371	1500	2.3	0.66	8.24	88	4.61
			B05	0.329	1500	2.3	0.66	8.24	113	4.61
			B02	0.343	1500	2.3	0.66	8.24	282	4.61
			B01	0.42	1500	2.3	0.66	8.24	563	4.61
		ET080	A04	1.4	1500	6.8	1	15.8	178	10.3
			B04	0.952	1500	6.8	1	15.8	203	10.3
			B02	0.98	1500	6.8	1	15.8	393	10.3
			B01	1.036	1500	6.8	1	15.8	785	10.3
		ET100	A04	2.695	1500	14.3	2	32.3	295	21.3
			B04	2.45	1500	14.3	2	32.3	212	21.3
			B02	2.625	1500	14.3	2	32.3	423	21.3
			B53	2.73	1500	14.3	2	32.3	1588	21.3
		ET125	M05	2.59	1500	28.2	4.4	67.8	85	43.6
			M10	2.625	1500	28.2	4.4	67.8	164	43.6
			M20	2.66	1500	28.2	4.4	67.8	326	43.6
			M50	2.8	1500	28.2	4.4	67.8	781	43.6
				0.34732789		5.098003158				

Figure 6.4: Actuator weight estimation

6.4.2 Torque calculations

The torque values are calculated from the equations [13] in Dymola. The equations used are as shown in section 9.7. A conceptual EMA is as shown in Figure 6.5(a) [23] and the forces in contact between thread and nut are as shown in Figure 6.5(b) [13].

The dynamic model is first simulated with the default parameters available in the respective components. The Mass data from the geometric model is obtained in CATIA. These values are then sent to the dynamic model via user interface. In the dynamic model; the force required to extend the flap is obtained and this value is used to find the torque and power required.

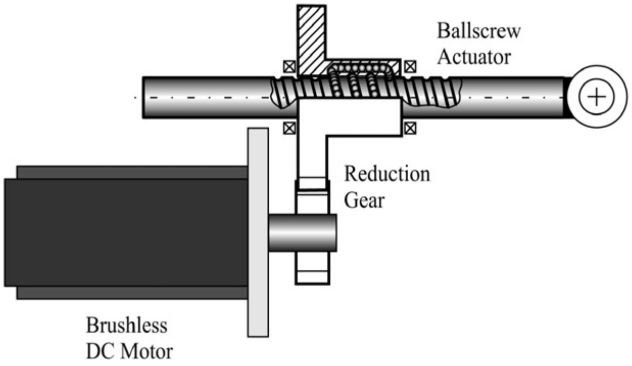


Figure 6.5 (a) Conceptual EMA

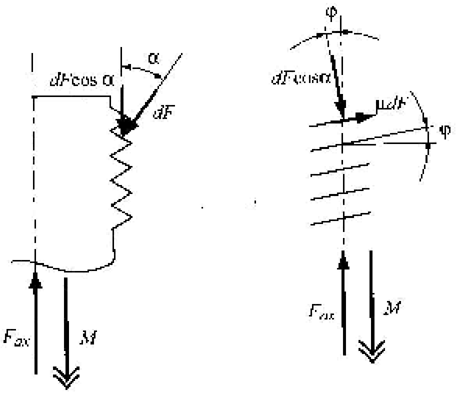


Figure 6.5 (b) Forces in contact in the thread between the screw and nut

Where
M= Mass [Kg]
F = Force [N]
α = Half Outer Angle [deg]
β = Inner Thread angle [deg]
φ = Elevation angle [deg]
ρ = Friction angle [deg]
μ = Friction Coefficient
N = frequency [Rpm]
P = Pitch [mm]

7. USER INTERFACE

Integration has been made between CATIA and Dymola by customized frame work developed in Excel. Many people have the knowledge of Excel, thus this user interface is powerful and the design parameters can be managed easily. As all the required parameters can be modified at one place, this can save time during the design process. The workbook is connected to CATIA and Dymola via VB script. The source code is written entirely in Visual Basic.

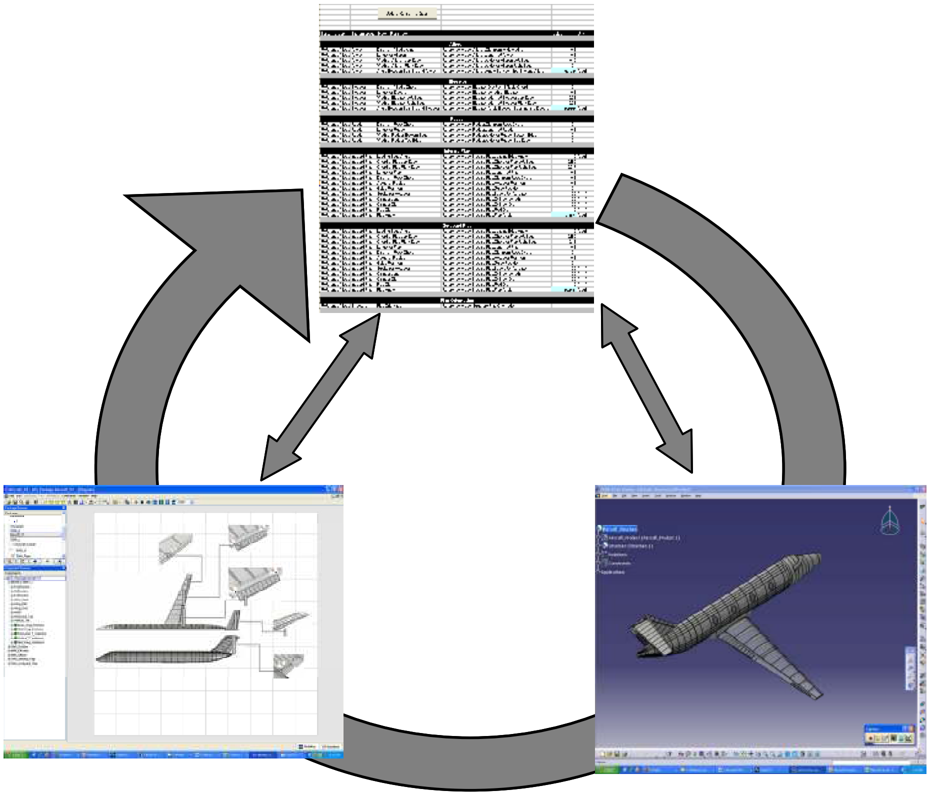


Figure7.1: Tool integration framework for control surface design

7.1 CATIA User Interface

In this user interface all the values for the control surfaces can be modified as per the user specification. Figure 7.2 shows the CATIA user interface. Aileron, elevator, rudder and flaps can be designed by using this interface. The wing is divided into two sections [15], in-board flap is designed by taking the references from the first section, aileron and out-board flap are designed by taking the references from second section. Elevator and rudder are created by taking the reference from their respective sections.

System group	System group	System Parameter		Value	Unit
Aileron					
Reference Mode	Aileron	Dist from Middle Wing	Reference Model.Aileron.Dist from Middle Wing	0.4	
Reference Mode	Aileron	Length of Alieron	Reference Model.Aileron.Length of Alieron	0.8	
Reference Mode	Aileron	Width of Alieron Left Edge	Reference Model.Aileron.Width of Alieron Left Edge	0.15	
Reference Mode	Aileron	Width of Alieron Right Edge	Reference Model.Aileron.Width of Alieron Right Edge	0.1	
Reference Mode	Aileron	Angle Between Spar line and Aileron	Reference Model.Aileron.Angle Between Spar line and Aileron	**0.730**	[deg]
Elevator					
Reference Mode	Elevator	Dist from Middle Chord	Reference Model.Elevator.Dist from Middle Chord	0.1	
Reference Mode	Elevator	Length of Elevator	Reference Model.Elevator.Length of Elevator	0.9	
Reference Mode	Elevator	Width of Elevator Left Edge	Reference Model.Elevator.Width of Elevator Left Edge	0.09	
Reference Mode	Elevator	Width of Elevator Right Edge	Reference Model.Elevator.Width of Elevator Right Edge	0.09	
Reference Mode	Elevator	Angle Between Spar line and Elevator	Reference Model.Elevator.Angle Between Spar line and Elevator	**0.000**	[deg]
Rudder					
Reference Mode	Rudder	Dist from Root Chord	Reference Model.Rudder.Dist from Root Chord	0.1	
Reference Mode	Rudder	Length of Rudder	Reference Model.Rudder.Length of Rudder	0.6	
Reference Mode	Rudder	Width of Rudder Bottom Edge	Reference Model.Rudder.Width of Rudder Bottom Edge	0.1	
Reference Mode	Rudder	Width of Rudder Top Edge	Reference Model.Rudder.Width of Rudder Top Edge	0.1	
Inboard Flap					
Reference Mode	Inboard Flap	Leading Edge Angle	Reference Model.Inboard Flap.Leading Edge Angle	5	[deg]
Reference Mode	Inboard Flap	Chord of Flap Left Edge	Reference Model.Inboard Flap.Chord of Flap Left Edge	0.185	
Reference Mode	Inboard Flap	Chord of Flap Right Edge	Reference Model.Inboard Flap.Chord of Flap Right Edge	0.217	
Reference Mode	Inboard Flap	Length of Flap	Reference Model.Inboard Flap.Length of Flap	0.9	
Reference Mode	Inboard Flap	Dist from Root Chord	Reference Model.Inboard Flap.Dist from Root Chord	0.3	
Reference Mode	Inboard Flap	Actuator Position	Reference Model.Inboard Flap.Actuator Position	-0.2	
Reference Mode	Inboard Flap	Guide Position	Reference Model.Inboard Flap.Guide Position	-0.1	
Reference Mode	Inboard Flap	Stroke for Actuator	Reference Model.Inboard Flap.Stroke for Actuator	75	[mm]
Reference Mode	Inboard Flap	Cylinder Length	Reference Model.Inboard Flap.Cylinder Length	70	[mm]
Reference Mode	Inboard Flap	Cylinder Dia	Reference Model.Inboard Flap.Cylinder Dia	20	[mm]
Reference Mode	Inboard Flap	Rod Dia	Reference Model.Inboard Flap.Rod Dia	10	[mm]
Reference Mode	Inboard Flap	Flap Angle	Reference Model.Inboard Flap.Flap Angle	**0.184**	[deg]
Outboard Flap					
Reference Mode	Inboard Flap	Leading Edge Angle	Reference Model.Inboard Flap.Leading Edge Angle	5	[deg]
Reference Mode	Inboard Flap	Chord of Flap Left Edge	Reference Model.Inboard Flap.Chord of Flap Left Edge	0.195	
Reference Mode	Inboard Flap	Chord of Flap Right Edge	Reference Model.Inboard Flap.Chord of Flap Right Edge	0.44	
Reference Mode	Inboard Flap	Length of Flap	Reference Model.Inboard Flap.Length of Flap	0.3	
Reference Mode	Inboard Flap	Dist from Root Chord	Reference Model.Inboard Flap.Dist from Root Chord	0.1	
Reference Mode	Inboard Flap	Actuator Position	Reference Model.Inboard Flap.Actuator Position	-0.2	
Reference Mode	Inboard Flap	Guide Position	Reference Model.Inboard Flap.Guide Position	-0.1	
Reference Mode	Inboard Flap	Stroke for Actuator	Reference Model.Inboard Flap.Stroke for Actuator	50	[mm]
Reference Mode	Inboard Flap	Cylinder Length	Reference Model.Inboard Flap.Cylinder Length	20	[mm]
Reference Mode	Inboard Flap	Cylinder Dia	Reference Model.Inboard Flap.Cylinder Dia	20	[mm]
Reference Mode	Inboard Flap	Rod Dia	Reference Model.Inboard Flap.Rod Dia	10	[mm]
Reference Mode	Inboard Flap	Flap Angle 1	Reference Model.Inboard Flap.Flap Angle 1	**0.248**	[deg]
Flap Orientation					
Reference Mode	Structure	Flap Orientation	Reference Model.Structure.Flap Orientation	1	

Figure 7.2: CATIA User Interface

7.2 Dymola User Interface

Interface integration is made by creating a customized framework in Excel for CATIA and Dymola. The Workbook is divided into the following sheets:

- Design Parameter sheet in which the user can modify the control surface features in the CATIA_Excel_Dymola section as shown in Figure 7.3.
- Actuator library sheet with physical data to estimate weight.
- Torque calculation sheet for a known weight of the actuator.

			Characteristics			Center of Gravity			Inertia					
Inboard Flap														
			Volume	0.5760	[m^3]	**Gx**	32776.6808	[m]	I_{0xG}	2678.4148	[kgxm^2]	I_{xyG}	-127.8964	[kgxm^2]
Diameter	**0.100**	[m]	**Area**	72.3963	[m^2]	**Gy**	7214.1137	[m]	I_{0yG}	635.4379	[kgxm^2]	I_{xzG}	0.1239	[kgxm^2]
Length	**0.700**	[m]	**Mass**	1560.8752	[kg]	**Gz**	-2006.9482	[m]	I_{0zG}	3233.0908	[kgxm^2]	I_{yzG}	-265.0914	[kgxm^2]
		[m]	**Density**	2710	[kg/m^3]									
Outboard Flap														
			Volume	0.5760	[m^3]	**Gx**	32776.6808	[m]	I_{0xG}	2678.4148	[kgxm^2]	I_{xyG}	-127.8964	[kgxm^2]
Diameter	**0.100**	[m]	**Area**	72.3963	[m^2]	**Gy**	7214.1137	[m]	I_{0yG}	635.4379	[kgxm^2]	I_{xzG}	0.1239	[kgxm^2]
Length	**0.700**	[m]	**Mass**	1560.8752	[kg]	**Gz**	-2006.9482	[m]	I_{0zG}	3233.0908	[kgxm^2]	I_{yzG}	-265.0914	[kgxm^2]
		[m]	**Density**	2710	[kg/m^3]									
Aileron														
			Volume	0.5760	[m^3]	**Gx**	32776.6808	[m]	I_{0xG}	2678.4148	[kgxm^2]	I_{xyG}	-127.8964	[kgxm^2]
Diameter	**0.100**	[m]	**Area**	72.3963	[m^2]	**Gy**	7214.1137	[m]	I_{0yG}	635.4379	[kgxm^2]	I_{xzG}	0.1239	[kgxm^2]
Length	**0.700**	[m]	**Mass**	1560.8752	[kg]	**Gz**	-2006.9482	[m]	I_{0zG}	3233.0908	[kgxm^2]	I_{yzG}	-265.0914	[kgxm^2]
		[m]	**Density**	2710	[kg/m^3]									
Elevator														
			Volume	0.5760	[m^3]	**Gx**	32776.6808	[m]	I_{0xG}	2678.4148	[kgxm^2]	I_{xyG}	-127.8964	[kgxm^2]
Diameter	**0.100**	[m]	**Area**	72.3963	[m^2]	**Gy**	7214.1137	[m]	I_{0yG}	635.4379	[kgxm^2]	I_{xzG}	0.1239	[kgxm^2]
Length	**0.700**	[m]	**Mass**	1560.8752	[kg]	**Gz**	-2006.9482	[m]	I_{0zG}	3233.0908	[kgxm^2]	I_{yzG}	-265.0914	[kgxm^2]
		[m]	**Density**	2710	[kg/m^3]									
Rudder														
			Volume	0.5760	[m^3]	**Gx**	32776.6808	[m]	I_{0xG}	2678.4148	[kgxm^2]	I_{xyG}	-127.8964	[kgxm^2]
Diameter	**0.100**	[m]	**Area**	72.3963	[m^2]	**Gy**	7214.1137	[m]	I_{0yG}	635.4379	[kgxm^2]	I_{xzG}	0.1239	[kgxm^2]
Length	**0.700**	[m]	**Mass**	1560.8752	[kg]	**Gz**	-2006.9482	[m]	I_{0zG}	3233.0908	[kgxm^2]	I_{yzG}	-265.0914	[kgxm^2]
		[m]	**Density**	2710	[kg/m^3]									

```
simulateModel("ACS_Package.EMA", stopTime=10, method="dassl", resultFile="EMA");
```

Figure 7.3: Excel user interface for control surface design for Dymola

The geometrical parameters are taken from the CAD model and then exported to the Dynamic model.

8. DISCUSSION AND CONCLUSION

Parametric Aircraft framework is conducted at the department of machine design using in house facilities. It consists of parametric models which represent a large variety of aircraft concepts and has been increased by adding parametric control surfaces. The main components in this approach are:

- An extremely variable geometrical model that is capable of showing a wide range of variants parametrically.
- A parametric dynamic simulation model that represent the CAD model
- A framework for incorporation of the models and execution of the design process through one User interface.

The CAD model and Inverse dynamic model developed and discussed in sections 5 and 6 illustrates the following:

- Visualizing the shape of the parametric geometric model.
- A kinematic model in CAITA able to simulate the motion of the control surfaces.
- The inverse dynamic model in Dymola showing the aircraft dynamic performance.
- The mass data can be obtained from the parametric model in CATIA and sent to the dynamic model in Dymola.

The analysis in section 9.1 shows that the control surfaces can be adapted for different range of aircrafts such as Cessna CJ4, Embraer 145, and Boeing 777 etc. An Inverse dynamic model of the actuator system is developed using the data obtained from the CAD model, such as mass, inertia and center of gravity. These values are then transferred to the dynamic model through the User interface.

It has also been illustrated that by using the User interface the critical design parameters can be managed in one spreadsheet. Changing the design parameters in the User interface, automatically executes the required CAD and dynamic model within a short period of time. EMA is considered in the dynamic model. EMAs are used in primary flight control by considering their power, density, cost and weight factors. Further research can be done on automatic selection of mechanism and actuators for the proposed aircraft configuration.

9. APPENDIX

9.1 Different aircraft configurations

In this section different types of aircraft configurations are shown to emphasis on the mobility of the control surfaces. (For the source of figures on the left hand side refer [31])

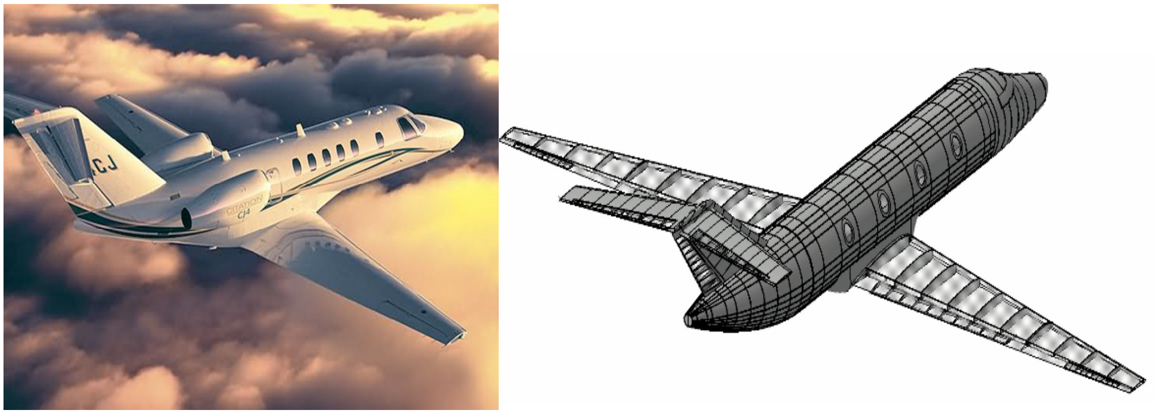


Figure 9.1: Cessna Citation

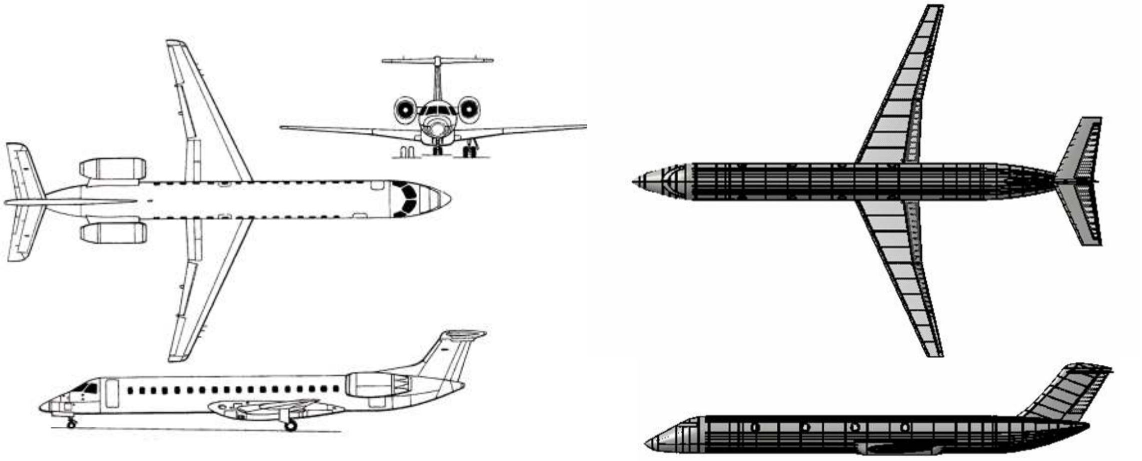


Figure 9.2: Embraer 145

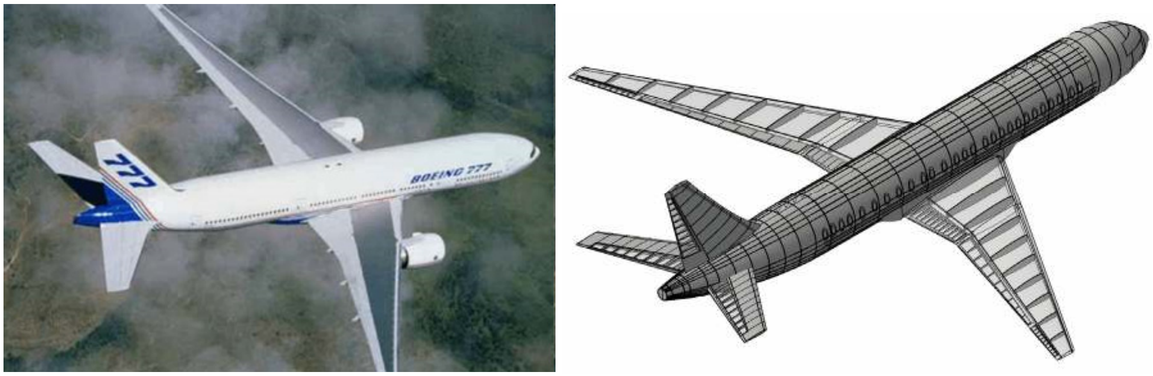
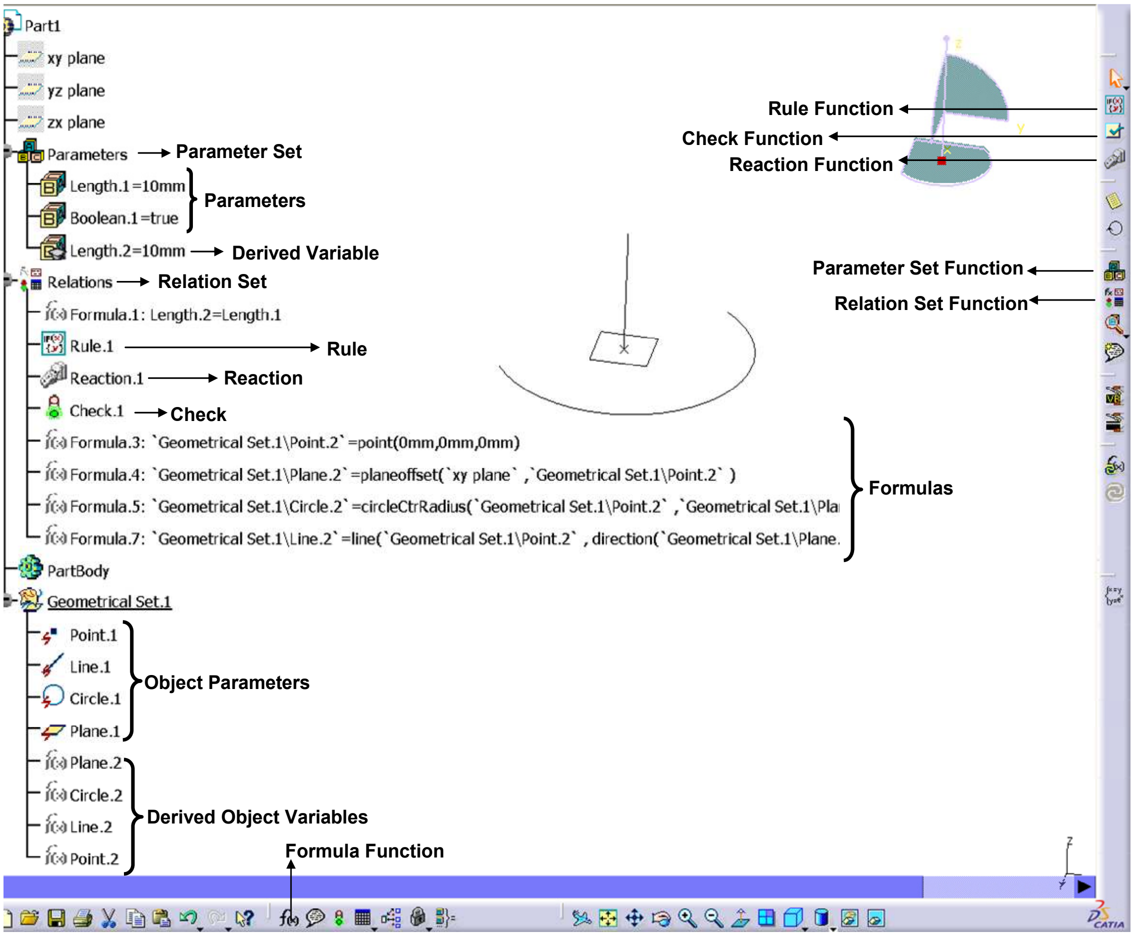


Figure 9.3: Boeing 777

9.2 Knowledge advisor



Formula.3: `Geometrical Set.1\Point.2` =point(0mm,0mm,0mm)

Formula.4: `Geometrical Set.1\Plane.2` =planeoffset(`xy plane` ,`Geometrical Set.1\Point.2`)

Formula.5: `Geometrical Set.1\Circle.2` =circleCtrRadius(`Geometrical Set.1\Point.2` ,`Geometrical Set.1\Pla

Formula.7: `Geometrical Set.1\Line.2` =line(`Geometrical Set.1\Point.2` , direction(`Geometrical Set.1\Plane.

Figure 9.4 user interface of Knowledge Advisor

9.3 Adaptability of the aileron

Figure 9.5: Aileron leading edge parallel to the rear spar of the wing

Figure 9.6: Constant-Percent chord (refer Figure 1.4)

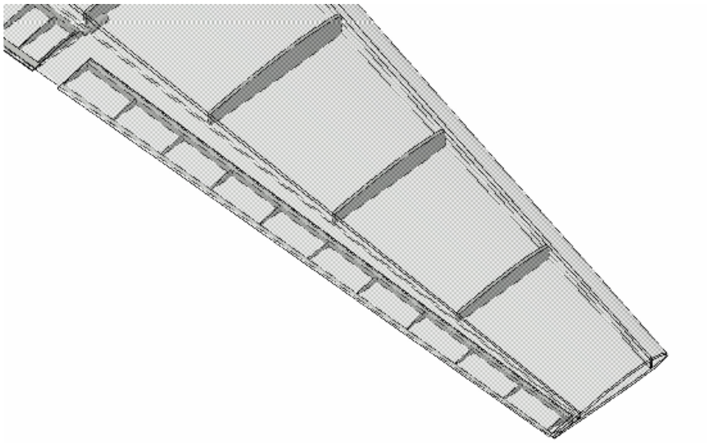


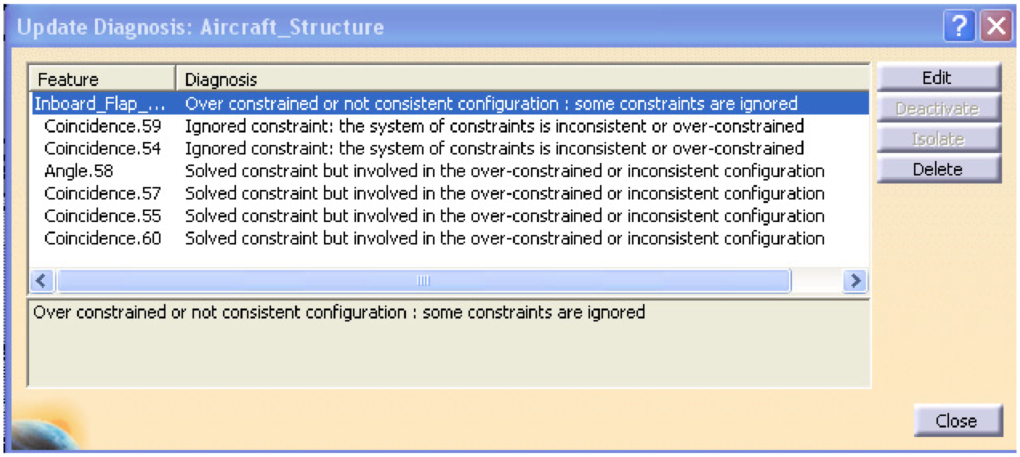
Figure 9.7: Square aileron extending until trailing edge

9.4 Procedure for modification of the mechanism

A brief procedure is provided for modification of mechanism to suit with the different aircraft models. The procedure is shown for the In-board flaps and the same follows for the Out-board flaps.

- Export the values through the User Interface to CATIA, Update the model in CATIA. Export the values of the control surfaces and update in CATIA.

- An error occurs when updating the CAD model, deactivate the Ignored constraint in the In-board or Out-board Mechanism assembly and update the CAD model. Update diagnosis of the CAD model is shown in Figure 9.8, deactivate the ignored constraints and update the model.



Update Diagnosis: Aircraft_Structure

Feature	Diagnosis
Inboard_Flap_...	Over constrained or not consistent configuration : some constraints are ignored
Coincidence.59	Ignored constraint: the system of constraints is inconsistent or over-constrained
Coincidence.54	Ignored constraint: the system of constraints is inconsistent or over-constrained
Angle.58	Solved constraint but involved in the over-constrained or inconsistent configuration
Coincidence.57	Solved constraint but involved in the over-constrained or inconsistent configuration
Coincidence.55	Solved constraint but involved in the over-constrained or inconsistent configuration
Coincidence.60	Solved constraint but involved in the over-constrained or inconsistent configuration

Over constrained or not consistent configuration : some constraints are ignored

Figure 9.8: Ignored constraints

- Open the Inboad_Flap_Mechanism.Assembly in a new window; use the Hide/Show button to see the mechanism. The mechanism will look as shown in Figure 9.9.

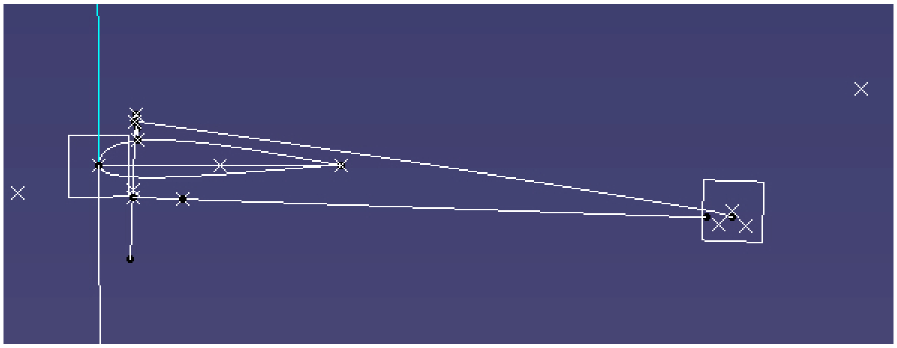


Figure 9.9: In-board flap mechanism before modifying

- Increase length of the chord of the aerofoil and length of the Link, also activate constrains that were previously deactivated and update the model. The model is as shown in Figure 9.10.

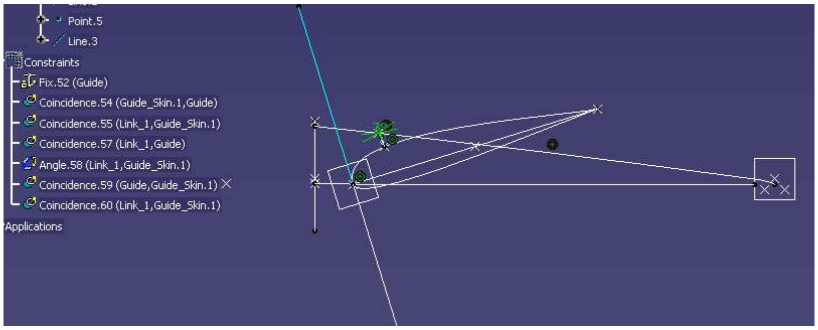


Figure 9.10: In-board flap mechanism after changing values

- If the flap is not oriented properly [Figure 9.10] then increase the length of the link. Later modify the 'Angle.58' in constrains so that the chord of the flap is parallel to the guide line as shown in Figure 5.16.

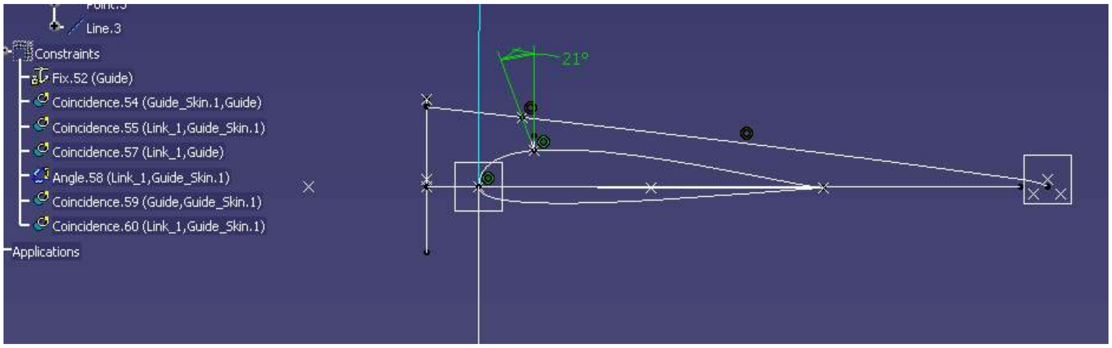


Figure 9.11: In-board flap mechanism after modifying

- The final modified mechanism is as shown in Figure 9.11. Figure 9.12 shows the modified parametric model from Citron CJ4 to Embraer 145.

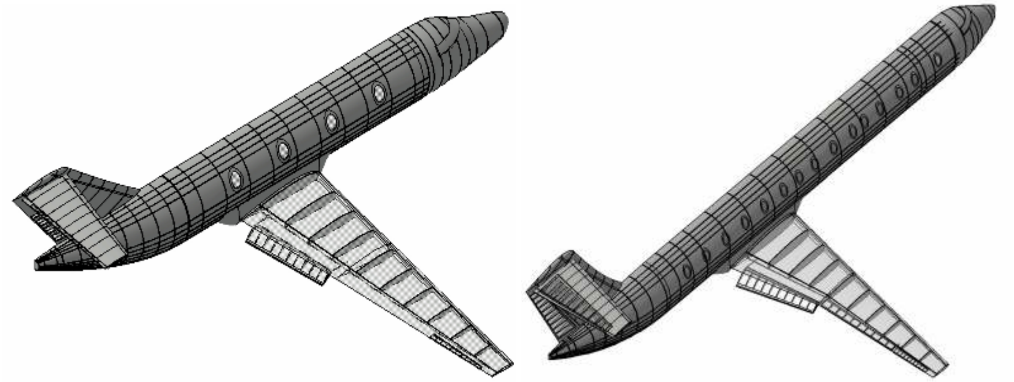


Figure 9.12: Citron CJ4 to the left and Embraer 145 to the right.

9.5 Dynamic simulation model

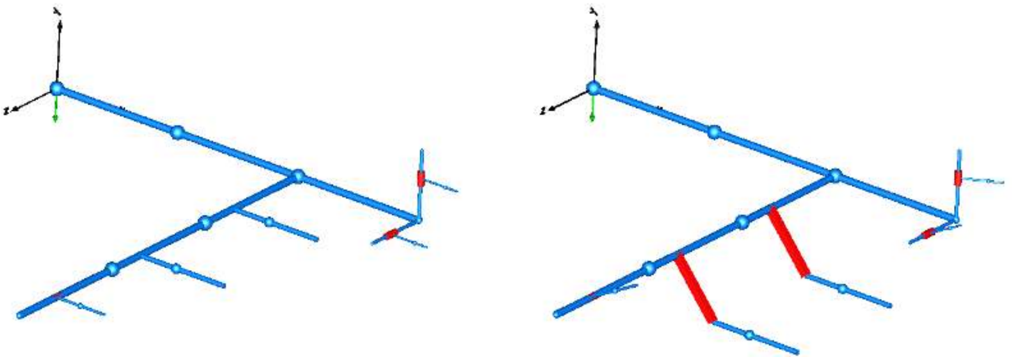


Figure 9.13(a) Aircraft dynamic simulation model with default parameters (before and after simulation)

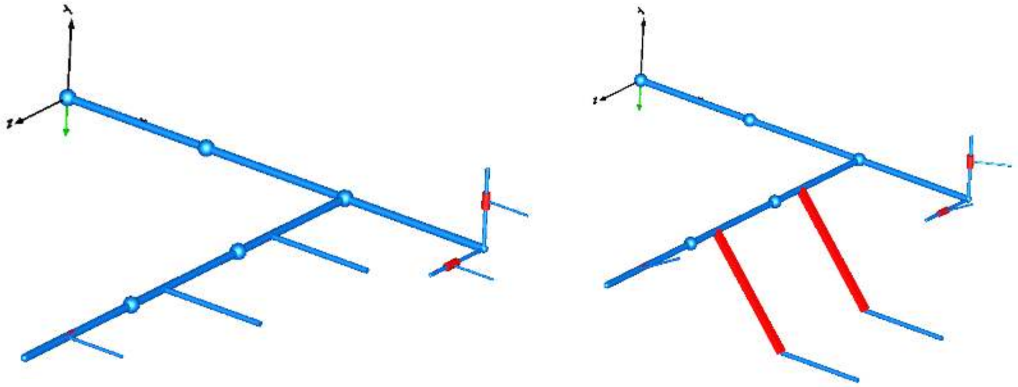


Figure 9.13(b) Aircraft dynamic simulation model with mass data from CATIA (before and after simulation)

Figure 9.13: Dynamic simulation model

9.6 Visual Basic code for automatic instantiation of the ribs

9.6.1 Deleting Instantiate of ribs

```
Sub main

Set documents1 = CATIA.Documents

Dim stringPartName
stringPartName = "Inboard_Flap_Ribs"

Set partDocument1 = documents1.Item(stringPartName & ".CATPart")

Set part1 = partDocument1.Part
Set parameters1 = part1.Parameters
Set Relations1 = part1.Relations
Set hybridBodies1 = part1.HybridBodies
Set productDocument1 = CATIA.ActiveDocument
Set selection1 = productDocument1.Selection
```

```
selection1.Clear

Set stringlParam1 = parameters1.Item("To_Initiate")
Set stringlParamName = parameters1.Item("Hybrid_Name")
Set stringlParamParam =  parameters1.Item("Parameter_to_Initiate")
Set realParamNr = parameters1.Item(stringlParam1.value)
Set realParamNew_Nr = parameters1.Item("New_" & stringlParam1.value)
Set realParamInitiate = parameters1.Item("Initiate")

if realParamNr.value<realParamNew_Nr.value then

For I_nr = realParamNr.value+1 To realParamNew_Nr.value
Set R1 = Relations1.Item("Product_Relations." & I_nr )
selection1.Add R1
selection1.Delete

Set hybridBody1 = hybridBodies1.Item(stringlParamName.value & "." & I_nr)
selection1.Add hybridBody1
selection1.Delete

Set realParam3 = parameters1.Item(stringPartName &"\" & stringlParamParam.value &
"." & I_nr )
selection1.Add realParam3
selection1.Delete
Next

realParamNew_Nr.value = realParamNr.value
part1.Update

Elseif realParamNr.value > realParamNew_Nr.value then

For I_nr = realParamNew_Nr.value +1 To realParamNr.value
Set hybridBody1 = hybridBodies1.Add()
hybridBody1.name = stringlParamName.value & "." & I_nr
realParamInitiate.value = realParamInitiate.value + 1
Next

realParamNew_Nr.Value = realParamNr.Value
part1.Update

End if

End sub
```

9.6.2 Instantiation of ribs

```
Sub main

Set documents1 = CATIA.Documents
Set partDocument1 = documents1.Item("Inboard_Flap_Ribs.CATPart")
Set PartDest= partDocument1.Part

Catia.SystemService.Print "Retrieve the factory of the current part"
```

```
Dim factory As InstanceFactory
Set factory = PartDest.GetCustomerFactory("InstanceFactory")

Catia.SystemService.Print "BeginInstanceFactory"

factory.BeginInstanceFactory
"Initiate_UDF", "e:\tmp\ Inboard_Flap_Ribs.CATPart"

Catia.SystemService.Print "Begin Instantiation"

factory.BeginInstantiate

Catia.SystemService.Print "Instantiate"

Dim Instance As ShapeInstance
Set Instance = factory.Instantiate

Catia.SystemService.Print "End of Instantiation"
factory.EndInstantiate

Catia.SystemService.Print "Release the reference document"
factory.EndInstanceFactory

Catia.SystemService.Print "Update"
PartDest.Update

End sub
```

9.7 Torque calculations in Dymola

```
model Actuator_calculations_1

Modelica.SIunits.Torque Tau;

   parameter Modelica.SIunits.Diameter d2=0.018;
  parameter Modelica.SIunits.Radius r2=0.009;

    Modelica.SIunits.Angle phi;

    parameter Modelica.SIunits.Length p=0.004;
    constant Real pi=3.14159265358979323846264338327950288419716939937510;

    Modelica.SIunits.Angle rho;

    parameter Modelica.SIunits.CoefficientOfFriction mu=0.15;
    parameter Modelica.SIunits.Angle alpha=15;

Modelica.SIunits.Power P;

  Modelica.SIunits.AngularVelocity Omega;
  parameter Modelica.SIunits.Frequency n=60;

  Modelica.Blocks.Interfaces.RealInput F annotation (extent=[-102,-12; -62,28]);
equation
```

```
phi=arctan(p/(pi*d2));

rho=arctan(mu/cos(alpha));

Tau=abs(F)*r2*tan(phi+rho);

Omega=( 2 * pi * n)/60;

P=Omega*Tau;

  annotation (Diagram);
end Actuator_calculations_1;
```

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