PROJECT FLIGHT CONTROLS

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Foreword

The airline Amsterdam Airlines Leeuwenburg (ALA) will expand its fleet with new aircraft. The final selection should be made between the Boeing 737NG or Airbus A320. Before this choice can be made, the board must first insight into the costs for the maintenance of the flight control system of both types.

As a project team of this low-cost carrier was asked us to put together a report on how the flight control systems of both devices are constructed and the differences of operation. Then it's up to us to make the choice for the aircraft with the lowest cost, on the basis of the comparison results from the maintenance tasks.

The information and concepts in this report are taken from various sources, these are listed in the Annex to consult. There is also a glossary where complex terms are clearly explained and described. The pyramid model of our report can be read and further documentation will be available. For this report, a number of meetings preceded the minutes added in the meeting form in the Annex.

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Introduction

The students of project group 1K got an assignment from Amsterdam Leeuwenburg Airlines (ALA). The assignment is to investigate the flight controls of both a Boeing 737 and an Airbus A320.

The report of our project team is made up of the necessary theory, incorporated in the first chapter of this report as well as the laws and requirements that are set here. Amsterdam Leeuwenburg Airlines wants a recommendation about a new to buy aircraft. The project group has to find out which aircraft has the lowest maintenance costs during a long period of time. To investigate this we first investigated each flight control system in how it works **(chapter 1)** with this information we focused more on the maintenance of each flight control system and its components we did this by looking into the standard maintenance and also in unexpected aircraft on ground maintenance and clear the advantages and disadvantages of the different systems **(chapter 2)**.

In **chapter 3** the maintenance of the systems will be discussed, with this information we investigated the costs and benefits of both systems. Finally we could give a final recommendation to Amsterdam Leeuwenburg Airlines.

Summary

This report is a recommendation for the Amsterdam Leeuwenburg Airlines. The recommendation is about the maintenance costs of the flight controls of the Airbus A320 and the Boeing 737-NG. From the research that is done on this matter, it has concluded that the Airbus A320 is more cost-efficient. This has been researched on certain maintenance tasks. Overall the Boeing 737-NG is nearly twice as expensive per year when these tasks are equal to both aircrafts.

Before the research on the maintenance costs of the aircrafts flight controls could be done, we first concentrated on the basics of primary flight controls, the aileron, the elevator and the rudder, as well as the secondary flight controls, the flaps, the slats, the spoilers and the trim systems. We have looked at the control forces and the power steering systems of these large airliners. Also there have been summed a few laws regarding the flight controls.

After this basic research, there has been taken a better look at the A320 and the 737-NG and especially the difference between there flight controls and the systems behind it. There is information about the composition, input, transport and output of the flight controls. There is a deeper focus on the aileron control and the flap control. This information then is used to create an overview of the maintenance tasks linked to these systems. These tasks will be expressed in the amount of man hours it takes to check each system. Each aircraft has certain tasks that has to be done every now an then, this has been summed up and can be used to see what the difference is between both airliners on these checks

To provide an ideal comparison, the costs as well as the benefits of the checks on the Airbus and the Boeing will be compared in one year. This provides a better view on the financial aspect, regarding to maintenance on these aircrafts. There are numerous advantages and disadvantages which determine what aircraft is the most cost-efficient which also have been taken in on the conclusion.

All this information can be used to conclude that the Airbus A320 is more cost-efficient than the Boeing 737-NG. therefore we, project team 1K recommends ALA to buy the A320 to extend their fleet when only looking at the maintenance costs of the flight controls

1. Flight Controls

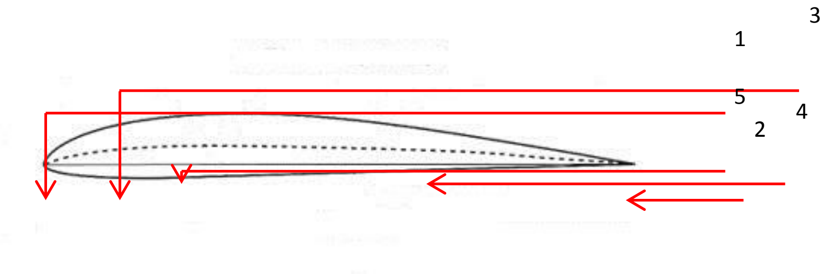
The functions of the Flight Controls can be properly understand and build if we first research into the aerodynamic aspects and the forces acting on a Cessna 172. The basics of the aerodynamic aspects and forces will be described in the theory **(1.1)**. Thereafter, the primary **(1.2)** and secondary **(1.3)** flight controls will be described. In aviation, there is a big difference between a small and a larger aircraft **(1.4)**. There are also a number of laws and requirements **(1.5)** for the flight controls of an aircraft.

1.1 Theory

To later continue on the flight controls, first the basic theory on an aircraft must be discussed. The aerodynamics are very important when flying **(1.1.1)**. According to the aerodynamics, the profiles of an aircraft are very important to get more lift **(1.1.2)**. This lift shall be described in the CL α Graphs **(1.1.3)**. An aircraft needs to be very stable this will be discussed in the stability chapter **(1.1.4).**

1.1.1 Aerodynamics

Aerodynamics means, the study of forces and the resulting motion of objects through the air. The laws of aerodynamics work on almost every object, such as an aircraft, a rocket, but also cars , boats and more. The aerodynamic forces working on an aircraft have both magnitude and a direction. Aircraft wings can be found in all shapes and sizes, but consist of the same basic principle. The picture below **(figure 1)** shows how a basic wing looks like.

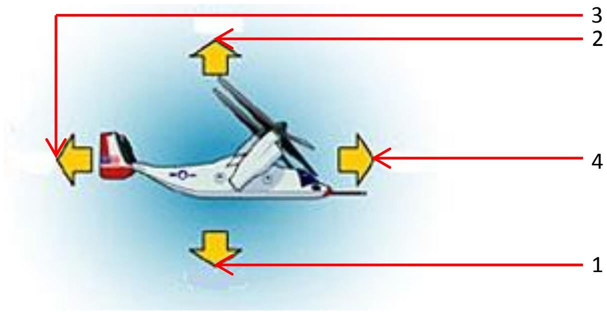


1. Leading edge
2. Trailing edge
3. Chord line
4. Camber line
5. Maximum camber

Figure 1: Airfoil explanation

The straight line, which starts at the leading edge **(1)** and ends in the trailing edge **(2)**, is called the chord or chord line **(3)**. The dashed line connects the center points of the circles between upper and lower airfoil and is called the camber line **(4)**. The maximum chamber is where the distance between the camber line and chord is maximum **(5)**. The Angle of attack is 0% because there is no angle between the chord and normal airflow. The difference between the chord and the camber line is the camber. When the camber line is above the chord, there is a positive cambered airfoil. Conversely, it is a negative cambered airfoil. For a symmetric airfoil, the chord and the camber line the same.

The picture below **(figure 2)** shows the forces acting on an aircraft in flight. These forces are weight **(1)**, lift **(2)**, drag **(3)** and thrust **(4)**.



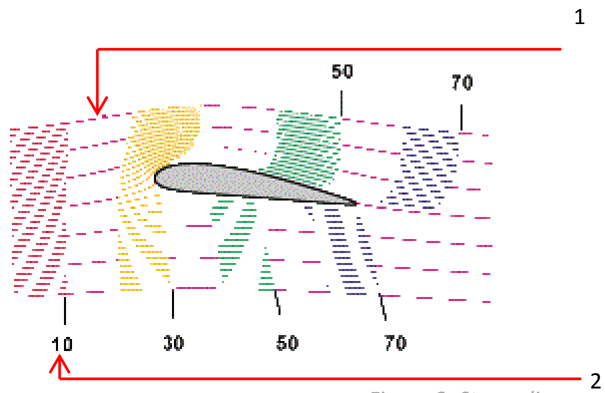
1. Weight
2. Lift
3. Drag
4. Thrust

Figure 2: Weight, lift, drag and thrust

The force of weight is always directed towards the center of the earth. Weight is always present, because each object has mass and this weight is attracted to the earth by gravity.
The gravity pulls the aircraft down so there must be a force which will work in the opposite direction. This force is called Lift. Every flying object must have lift. At an aircraft, the lift is produced by the wings. The wings of aircrafts are curved on the top and flatter on the bottom, so the airflow goes faster over the top than under the bottom. By this conditions, the airflow is reducing the pressure above the wing, so the aircraft makes lift.

Drag is a force that will pull back an object moving forward. Drag provides resistance, so it's harder for an object to move forward. The shape of an aircraft is important for the amount of drag. The opposite force of drag is thrust. Thrust is the forward motion of an object. The thrust comes from the jet engines or a propeller of the aircraft. To keep moving forward an aircraft must have more thrust than drag.

In **(figure 3)** you can see the streamlines **(1)** above the wing are closer together. An air particle needs only a few milliseconds **(2)** to travel from the leading edge to the trailing edge. The law of continuity **(table 1)** explains the surfaces decreases as the velocity increases when comparing two situations.



1. Streamlines
2. Time in milliseconds

Figure 3: Streamlines on an airfoil

The law of Continuity	(Table 1)
$v_1 \cdot A_1 = v_2 \cdot A_2$	v_1 = Velocity situation 1 (m/s)
	A_1 = Surface situation 1 (m^2)
	v_2 = Velocity situation 2 (m/2)
	A_2 = Surface situation 2 (m^2)

To use the law of Continuity, the airflow must be stationary, the flow must be frictionless and the flow must be incompressible.
These rules also apply to the law of Bernoulli **(table 2)**, allowing you to calculate the pressure differences in air flow.

The law of Bernoulli	(Table 2)
$P + \rho \cdot g \cdot h + \frac{1}{2} . \rho . v^2 = \text{constant}$	
dynamic pressure:	$\frac{1}{2} . \rho . v^2$
static pressure:	$P + \rho . g . h$
P [pa]	= Pressure of the environment
ρ [kg/m³]	= Density of air
g [m/s²]	= Gravitational Acceleration of the Earth
h [m]	= Height
v [m/s]	= Velocity of the flow

1.1.2 Profiles

An airfoil has a number of features that will influence the lift of the wing **(figure 4)**. An airfoil **(1)** can be placed at different angles in the air flow. The angle between the chord **(2)** and the undisturbed airflow **(3)** is also called the angle of attack **(4)**. As the angle increases the drag also increases because there is more resistance of the airflow on the airfoil.

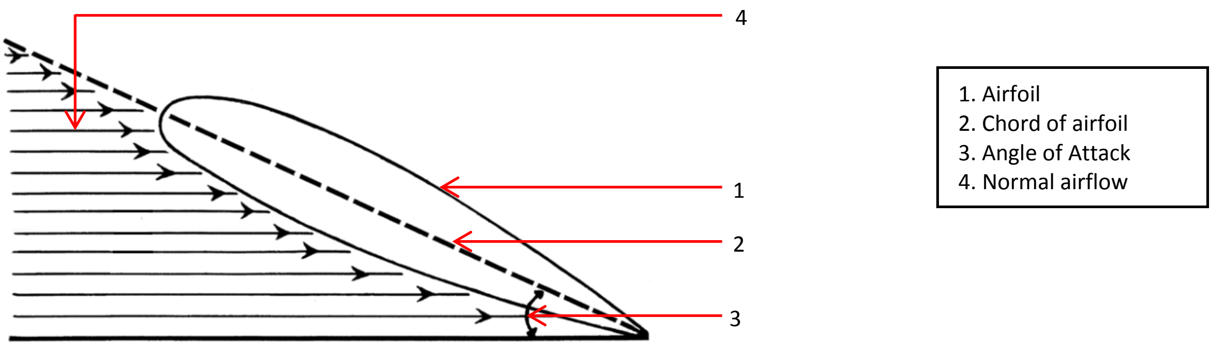


Figure 4: Angle of attack

1.1.3 CL-α graphs

Clα-graphs **(figure 5)** show the lift coefficient **(1)** plotted against the angle of attack α **(2)**. With these graphs, the lift of an airfoil at a given angle of attack can be calculated. It's also possible to calculate the angle of attack needed for a certain amount of lift. For each wing design there is a different CL-α -graph. A CL-α –graph will change when the design, or shape, of the airfoil changes.

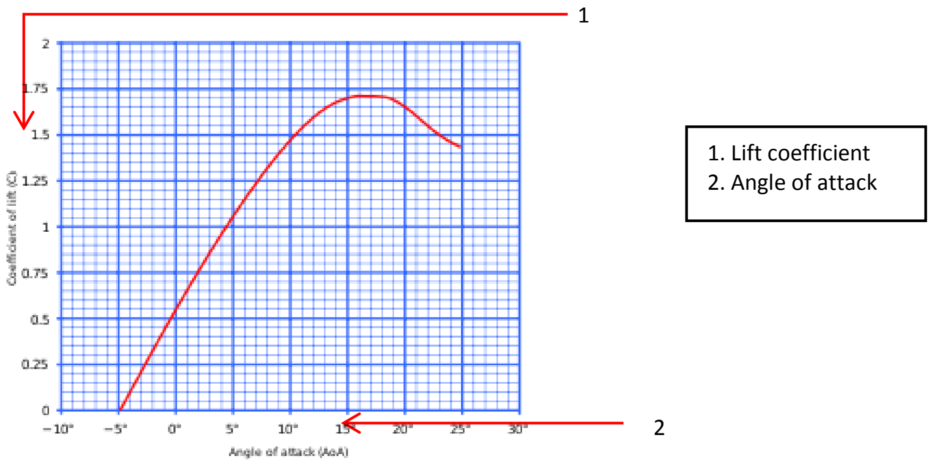


Figure 5: CL-α -graph

1.1.4 Lift

Because of the shape of the airfoil, the airstream that flows over the top of the airfoil has more speed than the airstream that flows under the airfoil. According to the law of Bernoulli, a fast flowing airstream has a lower pressure than a slow moving airstream. Thus, the pressure of the airstream moving over the airfoil is less than the pressure of the airstream moving under the airfoil, making the wing go up. This force is called lift. The formula for lift is:

$$Lift = C_L \times S \times \left(\frac{1}{2} \times p \times v^2\right)$$

C_L = Coefficient of Lift

S = Surface Area

P = Density of the Air (Altitude)

v = Velocity of the Air (TAS)

From the formula we can see that Cl (the lift coefficient) has a very big influence on the amount of lift the wing produces. And as stated, above the cl is very much controlled by the angle of attack of an aircraft.

1.2 Primary Flight Controls

The primary flight controls can be split into three controls. Before these controls will be explained, there is some basic theory (1.2.1) about these controls. After the basic theory the ailerons (1.2.2) will be explained, followed by the elevators (1.2.3) and the rudder(1.2.4).

1.2.1 Basic theory

The primary flight controls on every aircraft consist of three different types of primary control surfaces (figure 6). Each movement of these surfaces causes a movement for one of the three aircrafts axes, the normal or vertical axis (1), the longitudinal axis (2) and the lateral axis (3).

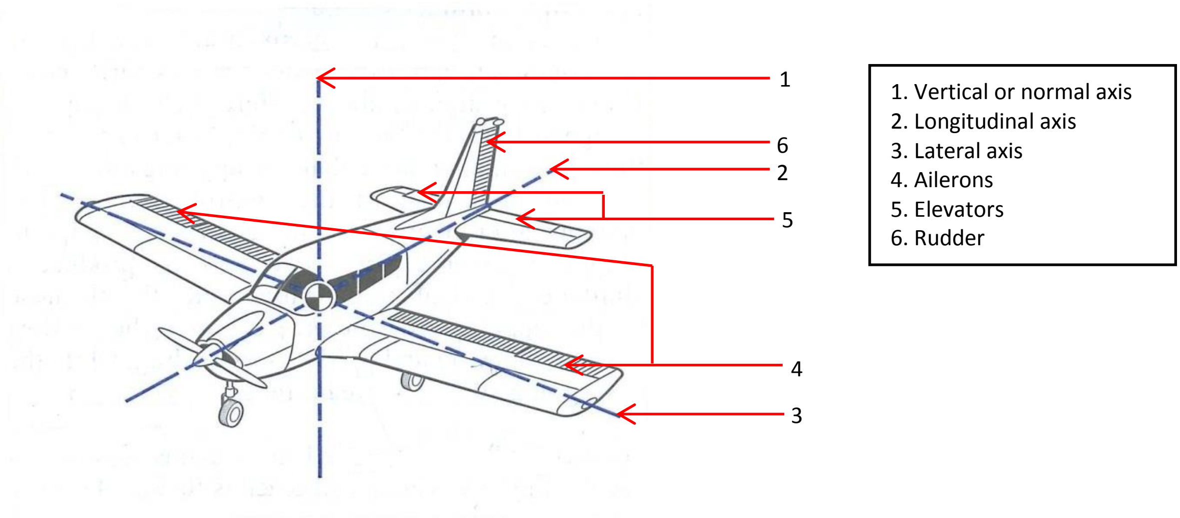


Figure 6: Aircraft's axes and primary flight controls

The ailerons (4) cause the movement on the longitudinal axis and are located at the wing tip. At the horizontal stabilizer of the aircraft you can find the elevators (5) which cause the movement on the lateral axis. The rudder (6) causes the movement on the normal axis, which is also called the vertical axis, and is located in the vertical stabilizer.

1.2.2 The ailerons

The ailerons are operating surfaces which are always located at the tip of a wing from an aircraft. Ailerons are responsible for the movement around the longitudinal axis, called roll. In a Cessna they can be controlled by a yoke, located in the cockpit. The transfer of control is accomplished mechanically **(Annex II)**. They operate with a collection of mechanical parts such as rods, cables, pulleys, and sometimes chains. The ailerons can move upwards and downwards **(figure 7)**.

To roll left you should move the yoke to the left and this will cause the left aileron to move upwards, and the right aileron to move downwards. An aileron moving upwards **(1)** decreases the angle of attack. This will reduce the lift generated by the left wing. On the right wing the aileron moves down **(2)**, increasing the angle of attack. Increasing the angle of the right wing increases the lift on the right wing. This imbalance of lift will cause the aircraft to roll to the left. Rolling right is exactly the same but then reversed.

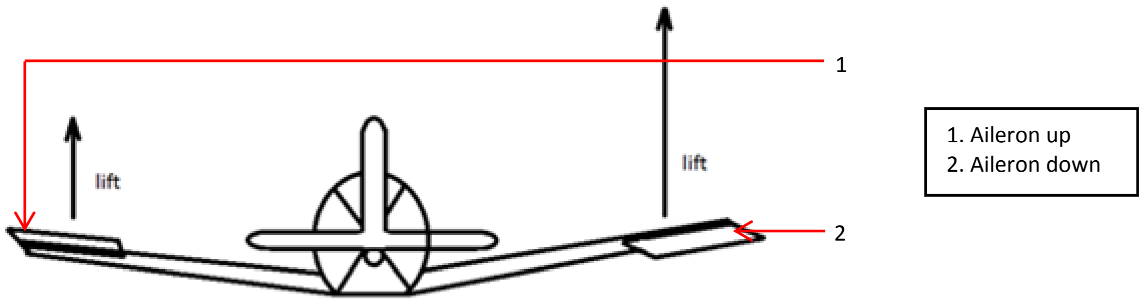


Figure 7: Ailerons

If there is decreased lift, there is also an amount of decreased drag. This causes an imbalance of drag. This is called adverse yaw **(figure 8)**. The right side of the wing produces more drag. Therefore the aircraft tends to move rightwards. To solve this, the pilot has to correct this with the rudder.

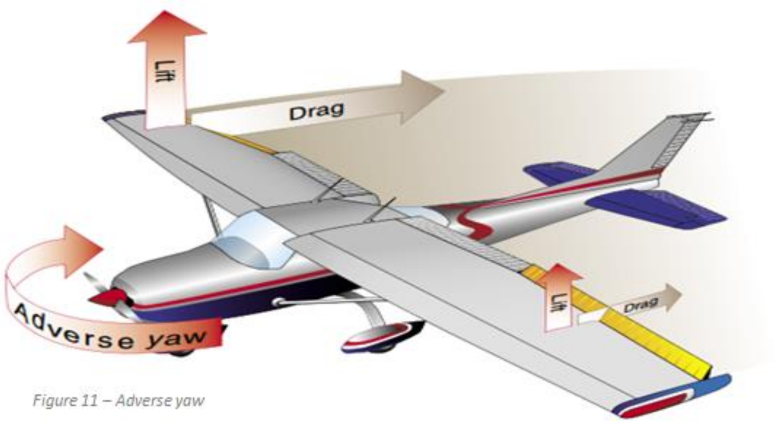


Figure 8: Adverse yaw

There are also different designs of ailerons that do not have this side effect. Placing differential ailerons **(Figure 9)** is one of the possibilities to prevent adverse yaw. The ailerons which goes down creates lift and therefore less drag than the up going aileron. The up going aileron deflects more than the down deflecting aileron. So the aileron which goes upwards creates more drag. This should help keep the two wings generating similar in mounts of drag.

Figure 9: Differential ailerons

Another possibility to prevent adverse yaw is to place frise ailerons **(Figure 10)**. If the aileron is in upwards position there is a part of the aileron that sticks out at the trailing edge **(1)**. This causes more drag and less adverse yaw.

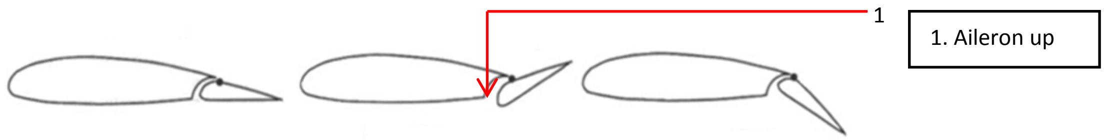


Figure 10: Frise ailerons

1.2.3 The elevators

The elevator is the horizontal operating surface on the tail of an aircraft. The elevator can change the movement from the aircraft about the lateral axis, called pitch. It can also be controlled by the yoke in the Cessna. Same as the ailerons, the transfer is mechanically **(Annex II)**. The elevator can move upwards and downwards.

To climb, the pilot has to pull the yoke backwards, moving the elevator upwards **(figure 11)**. This has the effect of decreasing the angle of attack so that it actually causes lift acting downwards **(1)**. This will push the tail down **(2)**, moving the nose up **(3)**. This will cause the aircraft to climb. To drop the pilot has to push the yoke forward and the elevator moves down. The angle of attack at the tail will increase and this increases the lift at the tail. The tail will be lifted, which will push the nose down and the aircraft will drop.

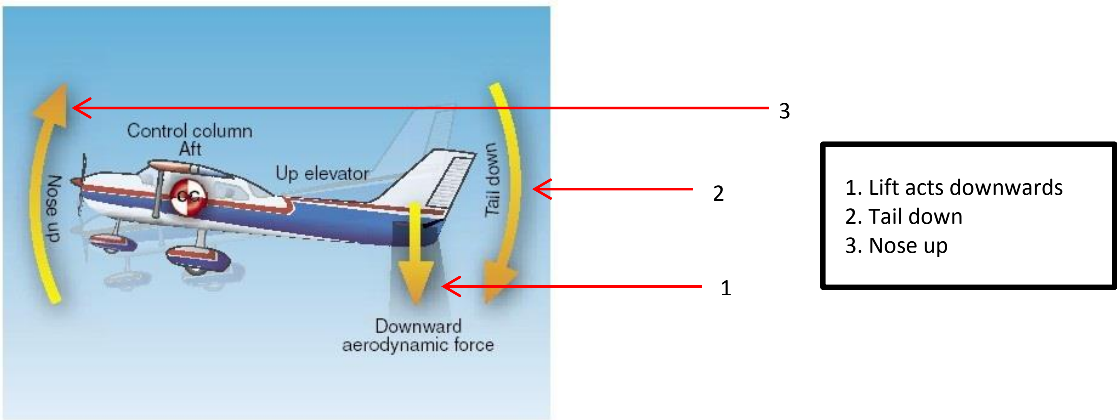


Figure 11: Elevator

1.2.4 The rudder

The rudder **(figure 12, 1)** is placed vertical at the tail of the aircraft. The rudder is a movable surface and is fixed to the vertical stabilizer **(2)**. It is used to make controlled movements about the vertical axis. This movement is called yaw **(3)**. The rudders transfer is going completely mechanical **(Annex II)** and is used to put the nose in the correct position.

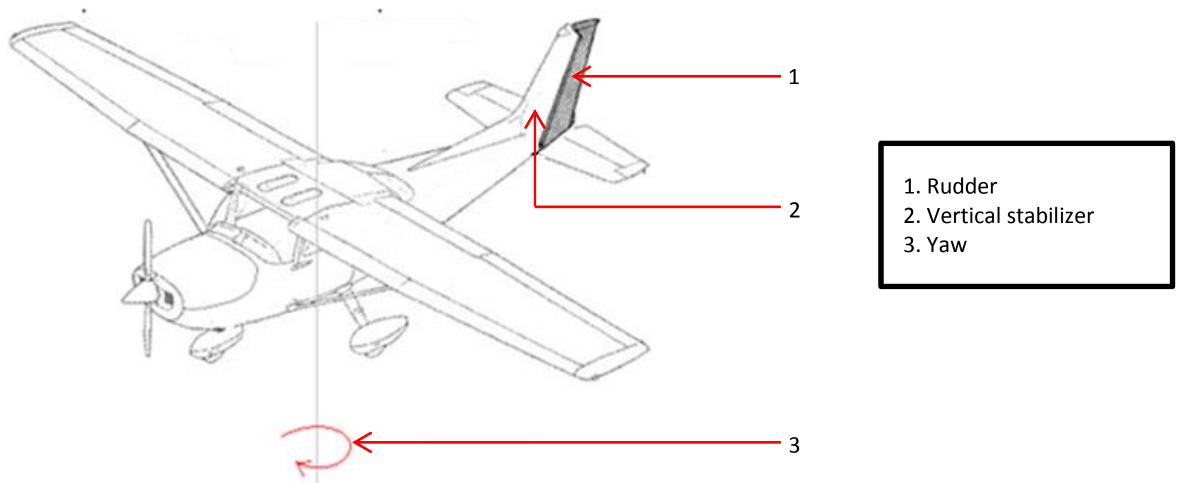


Figure 12: Rudder

The pilot can control the rudder by using the rudder pedals with your feet. Push the right pedal and the rudder will move to the right. This will cause lift **(figure 13)** act on the vertical stabilizer in the left direction **(1)** and that will pull the tail to the left. This yaws the aircraft to the right **(2)**.

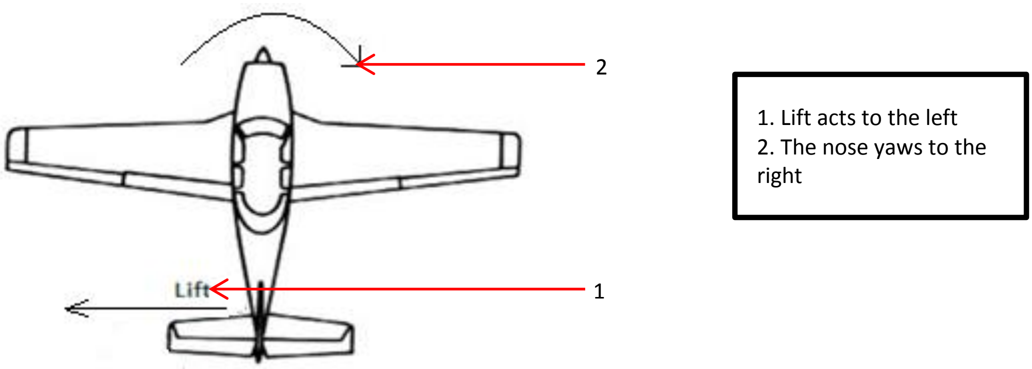


Figure 13: Yaw

The rudder has a side effect. When the aircraft is yawing to the right, the airflow over the left wing is going faster compared the airflow over the right wing. If the airflow goes faster over a wing it will result in more lift. You can see this in the lift formula **(1.1.4)**.
So in this situation the left wing has more lift and this will result in a roll to the right. The primary effect of the rudder is to yaw the aircraft, but the secondary effect is the roll.

1.3 Secondary flight controls

In addition to the primary flight controls, an aircraft also has secondary flight controls. Four secondary flight controls will be explained, the flaps (1.3.1), the spoilers (1.3.2), the slats (1.3.3) and the trim systems (1.3.4).

1.3.1 Flaps

Flaps are moveable surfaces which can be found on the trailing edge of both wings, therefore called trailing edge devices. Flaps are similar in shape to the ailerons, but are usually larger in surface area. Flaps raise the maximum lift coefficient of the aircraft and therefore reduce its stalling speed. Flaps also raise the induced drag and are therefore commonly used for low speed, high angle of attack flight and descent for landing. They may also be used to shorten the takeoff distance and provide a steeper climb path. On the other hand, the flaps can be retracted into the wing's structure when not needed. In that case, the flaps have no further influence on the aircraft.

As mentioned earlier, flaps raise the maximum lift coefficient of the aircraft (figure 15). Every wing has a kind of CL-α line (1), which shows how much CL increases when the angle of attack increases. With flaps lowered (2), the CL-α line will be higher in the diagram. This means an increase of the lift coefficient. With the flaps lowered, the aircraft produces more lift at the same angle of attack than without flaps lowered. The drag isn´t included here.

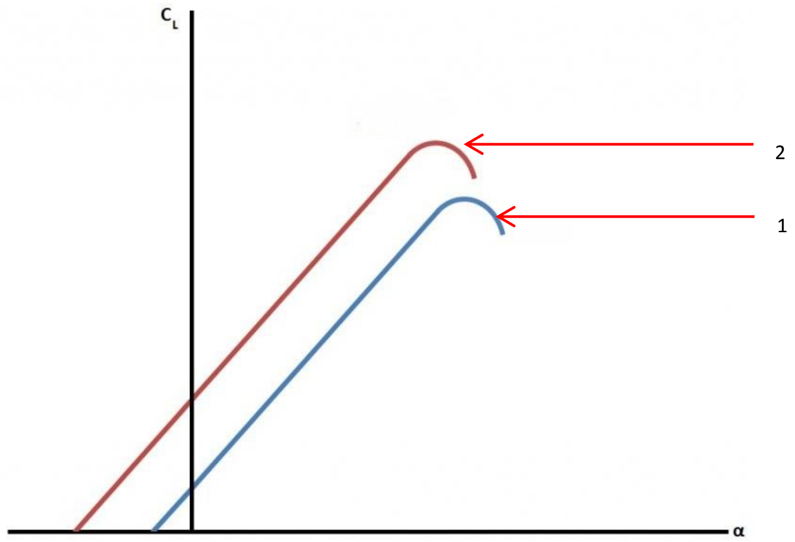


Figure 15: C_L-α diagram

1.Normal wing shape
2. Flap out

With a flap lowered, the chord line of the airfoil changes (figure 16). The chord line of a basic airfoil (1) is in line with the incoming airstream. With the flaps lowered, for example a plain flap (2), the chord line and also the angle of attack changes. The chord line with flaps lowered is above the horizontal and therefore the angle of stall is reached earlier. This can also be seen in figure 1. The diagram line when the flaps are out lies more to the left, therefore stall is reached earlier.

There are many types of flaps for all types of aircraft. The most common flaps are;

- Plain flaps
- Split flaps
- Slotted flaps
- Fowler flaps

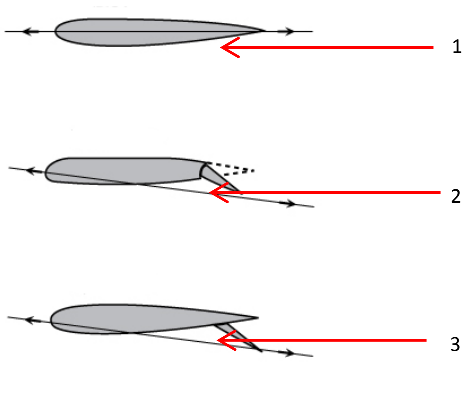
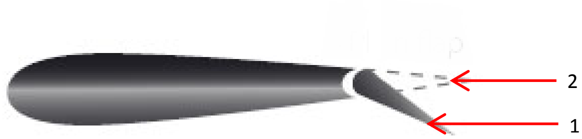


Figure 16: Chord lines

1.Chord line basic airfoil
2. Chord line plain flap
3. Chord line split flap

Ad 1 Plain flaps

The plain flap is the simplest flap of these four types (**figure 17**). When the flap is lowered (1), the airfoil camber is increased, resulting in an increase in the coefficient of lift (C_L) at a certain angle of attack comparing to the normal airfoil **(2)**. It also greatly increases drag. Due to the greater efficiency of other flaps, the plain flap is normally only used where simplicity is required.

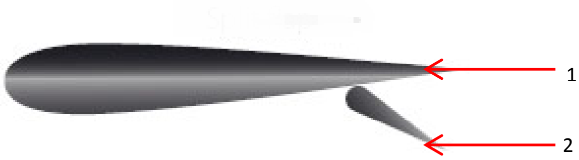


1. Flap lowered
2. Shape of airfoil

Figure 17: Plain flap

Ad 2 Split flaps

The split flap is a separate part of the airfoil, in contrast to the plain flap (**figure 18**). Under the lower surface of the airfoil **(1)**, is the split flap. The split flap **(2)** deflects from the airfoil and produces a slightly greater increase in lift than the plain flap. This flap produces a turbulent air pattern behind the airfoil. Therefore the split flap creates more drag than the plain flap. When fully extended, the plain and split flap both produce high drag with little additional lift.



1.Airfoil
2. Flap lowered

Figure 18: Split flap

Ad 3 Slotted flaps

The most used flap on aircraft today is the slotted flap (**figure 19**). The difference between the normal airfoil **(1)** and when the flaps are lowered **(2)** isn't only the change in camber of the airfoil. When the slotted flap is lowered, a gap between the flap and the wing forces high pressure air from below the wing over the flap helping the airflow remain attached to the flap. The high energy air accelerates the upper surface boundary layer and delays airflow separation. Thus, slotted flaps produces greater increases in maximum coefficient of lift (C_{L-max}) than the plain – or split flap. There are many types of slotted flaps. Large aircraft often have double- and even triple-slotted flaps, which produces even more induced drag without destroying the lift they produce.

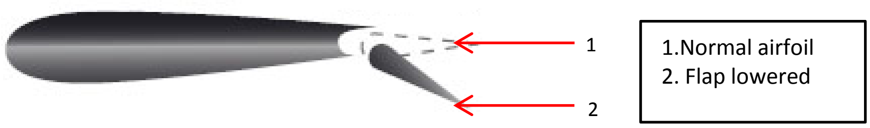


Figure 19: Slotted flap

Ad 4 Fowler flaps

Fowler flaps are a type of slotted slap. As seen in the figure below (**figure 20**), the Fowler flap not only changes the curve of the wing, but also increases the wing area. The flap slides backwards **(1)** and thus increases the wing area comparing to the normal airfoil **(2)**. Firstly, the flap increases much lift because of increasing both area and camber, but very little drag. As the flap lowers more, it deflects downward. During the last part of lowering the flap, it increases drag and little lift.

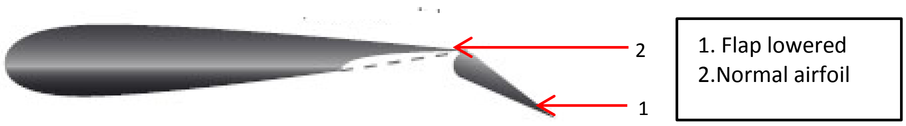


Figure 20: Fowler flap

There are many more types of flaps, but those are all like the above mentioned. Those flaps are usually a combination, as for example a slotted Fowler flap.

1.3.2 Spoilers

Aeronautical spoilers are plates that can be found on top of an aircraft's wing, in front of the aileron and the flaps **(Figure 21)**. Spoilers are used during decent to decrease lift and increase drag. They also can be used to change the roll of the aircraft. The decrease of lift and increase of drag makes it possible to decent, without gaining speed. When deployed, the spoiler plates angle will change **(1)**. Nearly all airliners have spoilers, which can be two kinds; smaller ones or lift dumpers. Smaller ones are several spoiler plates that can move individually from each other. Lift dumpers are mainly used to keep the aircraft from bouncing back in the air after contacting the ground. Both categories help the aircraft staying on ground after landing by reducing lift from the wings, by increasing drag which reduces the speed and increasing the pressure on the landing gear to making the wheel brakes more effective. This also leads to a shorter landing distance.

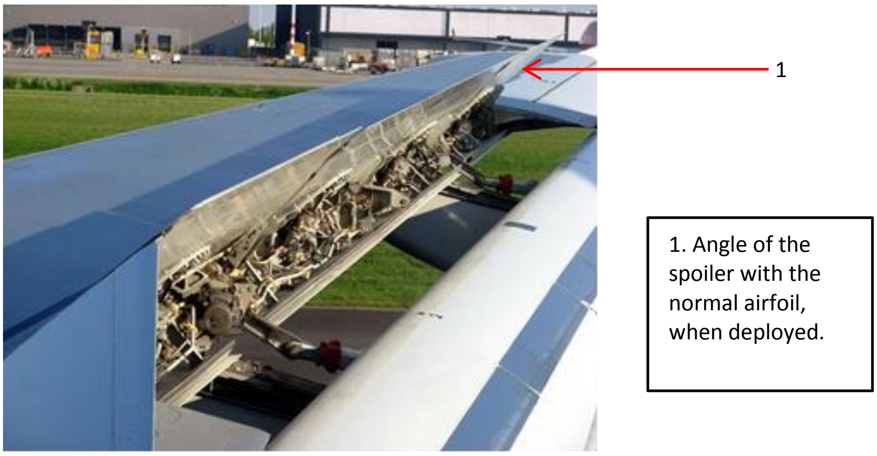


Figure 21: Fully deployed spoilers

1.3.3 Leading Edge Devices

Leading edge devices or slats **(figure 22)** are positioned on the leading edge of the wing **(1)**. Slats are used during landing or other manoeuvres which take the aircraft close to stall or over the normal stall speed or angle. When deployed slats **(2)**, generating more lift and increase the maximum stall angle of attack making it possible to fly lower speeds. It also makes the landing and take-off distance shorter. Extended slats also increase the drag, this is why they are not extended in normal flight. There are several different forms of slats. Just like flaps, there are slotted and extendable slats. There are as well leading edge flaps.

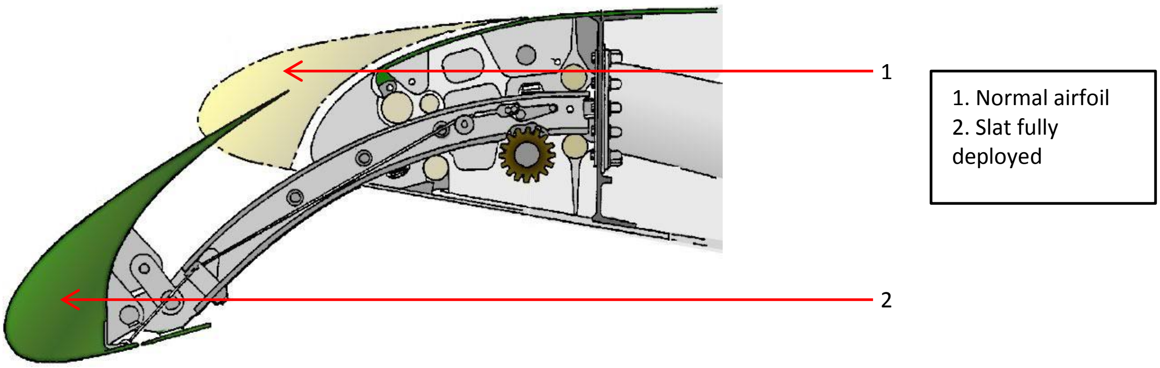
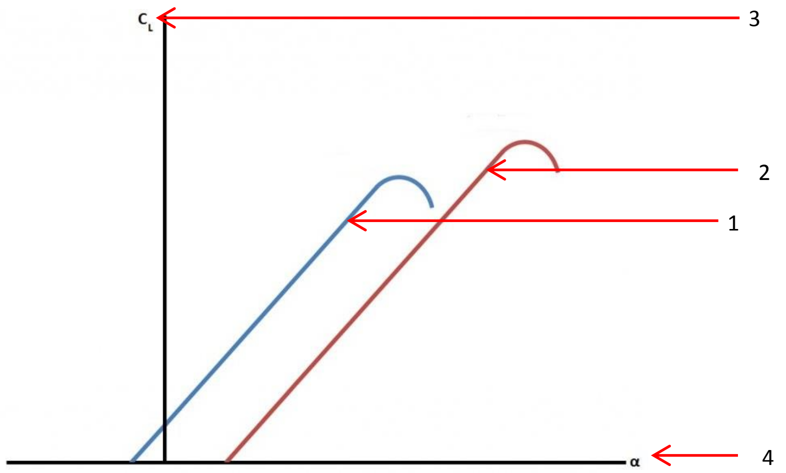


Figure 22: Leading Edge Devices.

As the slat increases the surface and curvature of the airfoil, it also changes the $C_{L\text{-}\alpha}$ graph of the airfoil **(figure 23)**. The difference between the normal airfoil **(1)** and with the slat extended **(2)**, is that the maximum angle of attack increases as also the lift coefficient. So a slat makes it possible to fly the aircraft with as much lift as normal, but with a slower speed.



1. C_L-α graph of a normal airfoil.
2. C_L-α graph with slat extended.
3. Lift coefficient
4. Angle of attack.

Figure 23: C_L-α graph with slat deployed

1.3.4 Trim systems

With trim systems, an aircraft can be designed to fly hands-off. A trim system counteract the aerodynamic forces, and stabilizes the aircraft in a particular attitude. Because of these trim systems it is possible to relieve the pilot of the need to maintain constant pressure on the flight controls. The trim systems usually consists of flight deck controls and small devices attached to the trailing edge of one or more of the primary flight control surfaces.
Common types of trim systems include the following tabs;

- Trim tabs
- Balance tabs
- Antiservo tabs
- Ground adjustable tabs
- Adjustable stabilizer

Ad 1 Trim tabs

A single trim tab is the most common installation on small aircraft. The single trim tab is attached to the trailing edge of the elevator. Most trim tabs are operated manually by a small vertical control wheel. A trim tab **(figure 23)** can be placed in two positions; nose up trim and nose down trim. If the trim tab **(1)** is placed to its up position, the trim control is in the nose down position. To get the aircraft downwards, the elevator **(2)** moves down. Therefore, the trim tab has to go up and into the airstream. Because of this, the aircraft's tail moves up, and the nose down. The trim tab counteracts the aerodynamically force on the elevator. If the trim tab is used correctly, it´s possible for the pilot to fly hands-off because the aircraft remains in the same position. For the nose up trim, this is contrary. The elevator is up and therefore the trim tab moves down. This causes a nose up trim situation. The control of the trim tab is fully owned to the pilot.

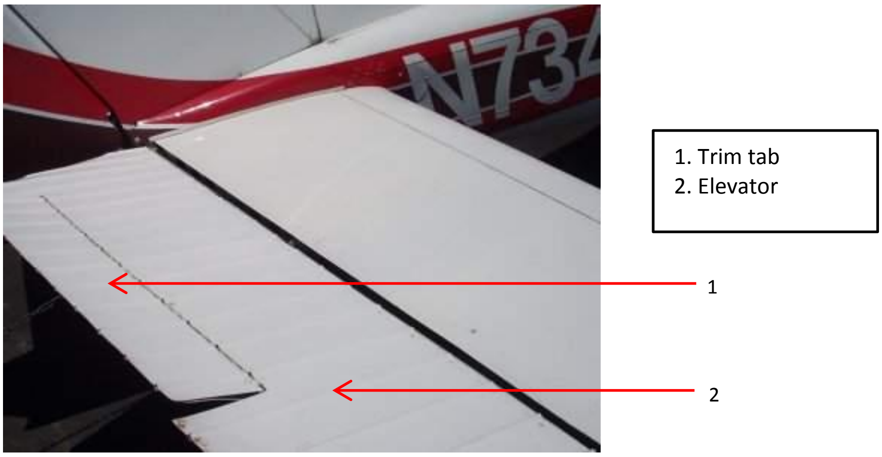


Figure 23: Trim tab and elevator

Ad 2 Balance tabs

Balance tabs are hinged in approximately the same places as trim tabs, but there is a difference between these two kind of tabs. When a primary control surface is moved in any direction, the balanced tab automatically moves in the opposite direction. The air striking the tab counterbalances some of the air pressure against the primary control surface. This provides the pilot to move more easily and hold the control surface in position.

Ad 3 Antiservo tabs

Antiservo tabs move in the same direction as the trailing edge of the stabilator. An antiservo tab attempts to streamline the control surface and makes the stabilator less sensitive by opposing the force exerted by the pilot.

Ad 4 Ground adjustable tabs

A ground adjustable tab is a non-moveable metal trim tab on the rudder. It's used to apply a trim force to the rudder, so that eventually the aircraft no longer skids left or right during normal cruising flight. The ground adjustable tab is bent in one direction or the other, which can be determined by trial and error.

Ad 5 Adjustable stabilizer

In contrast to a moving tab, some aircraft have an adjustable stabilizer. The trimming effect of an adjustable stabilizer is the same as of a trim tab. The adjustable stabilizer is used in most jet transports.

1.4 Difference between small and big aircraft

In this section there will be explained what kind of flight controls can be found on large aircrafts like the Boeing 737-NG and the Airbus A-320. Also there will be some information about other differences between the larger and smaller aircrafts. There will be talked about control forces **(1.4.1)** and power steering systems **(1.4.2)**.

1.4.1 Control Forces

Control forces is the amount of force required to move the a pedal or stick. Pilots use this force when flying, to feel how the aircraft reacts to the pilots movements. If a stick would move by only touching it, that there wouldn't be any force needed, the pilot could easily over steer. The pilot needs feedback when controlling the aircraft, this is why the pedals and sticks in the cockpit need a certain force applied to move the flight controls.

In small aircrafts this already exists by the mechanical connections between the stick or pedal and the control surfaces. The force that is applied directly moves the control surface and gives a feedback by the air putting pressure on the control surface. In larger aircrafts the stick or pedal isn't directly connected to the control surface, this would make steering the aircraft very heavy. So in bigger aircrafts there is a power steering system installed **(1.4.2)** which gives the feedback needed to make a flight smoother and more under control.

1.4.2 Power Steering Systems

In a smaller aircraft the flight controls are generally moved by mechanical movement, like steel cables. This is done without any power steering. But since it would take much more force to move a flight control panel, larger aircrafts do have power steering systems. There are multiple systems that can be used to do this. It can be done with a hydro- mechanical system, where the input from the pilot is transferred mechanically to a hydraulic circuit and as a back-up directly to the flight control surface for manual use.

Another system is the fly-by-wire (FBW) system. Here the input is converted to an electrical signal transmitted to a flight control computer, which can determine how to move the electrical engines connected to the flight controls to make the movement that the pilot wants. The computer also automatically adjusts the flight controls to stabilize the aircraft. A newer version of the fly-by-wire system is the fly-by-optics or fly-by-light, where the signals are transmitted with optic cables instead of electrical wires.

In a Boeing 737-NG the flight controls are moved by an hydro- mechanical system. Here the mechanical part gives feedback to the pilot. The Airbus A320 uses a fly-by-wire system, when the pilot makes extreme movements with the stick the computer will make these movements more realistic for the flight. Both systems have a manual override when the main system fails working correctly. Boeing uses the hydro- mechanical system to keep the pilot in full control. Airbus choose for the fly-by-wire to exclude a big part of human errors on this.

1.5 Laws and requirements

The controls of an airplane have changed a lot over years. To secure safety in the aviation, there are many laws to make sure everything goes as planned. These laws state the requirements of an airplane and the controls. In the Netherlands the Inspectie Leefomgeving en Transport (ILENT) and the European Aviation Safety Agency (EASA) supervises these laws. The EASA is also responsible for making the laws of aviation for all countries that are in the European Union (EU). In the United States of America the laws are made by the Federal Aviation Authorities (FAA). The FAA and the EASA collaborate a lot, to make the laws of Aviation worldwide as much as possible.

The laws, as stated by the EASA, of the flight controls are the: CS-23 and the CS-25. The CS-23 (Certification specifications for Normal Utility, aerobatic and commuter category airplanes) is made for small airplanes and the CS-25 (Certification specifications for large airplanes) is made for larger airplanes. The CS-25.671 amendment twelve contains the laws and requirements for the flight controls of the A320 and the B737NG.

1.5.1 Movement

All Laws of movement are stated in the CS-25 amendment twelve. These laws are there to make sure an airplane can make all the necessary manoeuvres. The most important law of movement is the CS-25.143 (General controllability and manoeuvrability). This law states that an airplane must be safely controllable and manoeuvrable during: Take-off, climb, level flight, descent and landing. The law also states the maximum force of a steering wheel during pitch or yaw.

1.5.2 Control

Boeing and Airbus both deliver airplanes that have a type certificate. This means the airplanes are flight worthy and checked if they comply with the laws. After any modification to the airplane it has to be checked again to ensure the airplane is still flight worthy in technical and law aspects. These checks are executed by the EASA. After the checks, when the airplane is declared flight worthy, it will be given the supplemental type certificate. The certificate is valid in the EU.

1.5.3 Back-Up

When the primary and the secondary flight controls fail there has to be a back-up control system so the pilot is still able to control the airplane. Most systems in an airplane have a redundancy rule, meaning when such a system fails another must be able to take his place. The controls also have a mechanical back-up, this is to ensure the airplane is still controllable after total loss of power.

1.5.4 Maintenance

There are laws for maintenance to ensure an airplane stays airworthy after a flight or reparation. These laws are listed in part-145 of the commission regulation of EASA. One of the more relevant laws are: subpart D (maintenance standards) , subpart F (maintenance organisation).

1.5.5 MMEL

The laws of maintenance are not the only requirement of maintenance. The Master Minimum Equipment List (MMEL) is also a factor as Boeing and Airbus use different MMEL's. MMEL's are lists that are defined on a specific aircraft type. The MMEL gives a list of airplane instruments and systems that do not have to function during flight, or have to be replaced after a set amount of time after it does not function anymore, every other instrument or system that is not listed in the MMEL needs to function before it is allowed to take off.

2 Airbus A320 versus Boeing 737NG

This chapter focuses on how two types of aircraft, the Airbus A320 and the Boeing 737NG, are build up **(2.1)** . The main focus lies on the flight control systems within these types of aircraft with a deeper focus on the aileron control and the flap control. This information will then be used to create an overview of the maintenance tasks linked to these systems **(2.2)**. These tasks will be expressed in the amount of man hours it takes to check each system.

2.1 Flight Controls

The Airbus A320 is a medium-ranged narrow-body commercial jet airliner, and is the first airliner to introduce the fly-by-wire system, as well as a side stick controller rather than a conventional steering wheel. The Boeing 737NG is a new generation narrow-body jet airliner. The new generation series consists of 737-6XX to 737-9XX. Although the new generation 737s are renewed and have modern cockpits, the flight controls are still controlled mechanically. The Boeing 737-800 is the Airbus A320's competitor and these two types of aircraft are going to be compared in this chapter. The comparison is divided into 4 subchapters; Composition **(2.1.1)**, Input **(2.1.2)**, Transport **(2.1.3)**, Output **(2.1.4)**. In this last chapter the main focus lies with one primary flight control, the ailerons, and one secondary flight control, the flaps.

2.1.1 Composition

Each of the two types of aircraft uses a different system to control the flight controls, therefore the composition of each aircraft type differs from another.

2.1.1a Airbus A320

The flight controls within the A320 aircraft are managed by a system called the Fly-by-wire system. Basically this means that all flight controls are all electrically controlled, rather than mechanically. This has a direct influence on the composition of flight controls within the aircraft. The pilot will still be able to manually control the aircraft from within the cockpit, but all commands are transferred by use of electrical signals to different onboard computers. These computers then send the command to the according hydraulic actuators which control the control surfaces.

2.1.1b Boeing 737NG

The flight controls within the Boeing 737NG are conventional. The ailerons and elevators have a stiff connection which can be controlled without the hydraulic system. The 737NG uses two systems A and B which will be further explained in chapter 2.1.3.

2.1.2 Input

The flight controls on the aircraft adjust to the signals sent from the cockpit, whether the signal comes from the pilot or the autopilot. The matter of how these signals are controlled differs between the two types of aircraft.

2.1.2a Airbus A320

The controls of the Airbus A320 are divided by the side stick controller and the central pedestal.

Figure 24 – A320 Side stick Controller

Side Stick Controller

Within the cockpit remain two sets of primary flight control decks, one for the captain and the other for the First Officer. In between the two decks remains a center pedestal containing flight controls both pilots can use.
The two primary control decks consist of the following instruments:

- A side stick controller
- A pair of pedals

Ad 1 Side stick controller

Each pilot has a side stick controller **(Fig. 24)** to manually operate the pitch and roll movement of the aircraft. The two side stick controllers are not mechanically linked, so they send separate signals to the flight control computers.

Ad 2 Pedals

The pedals each pilot possess control the rudder. The pedals are mechanically linked to the rudder but also electrically to the flight computers. The two pairs of pedals are interconnected with each other.

The Central Pedestal

The center pedestal **(Fig. 25)** contains:

- A speedbrake lever
- A set of mechanically interconnected handwheels
- A rudder trim switch

Ad 1 Speedbreak lever

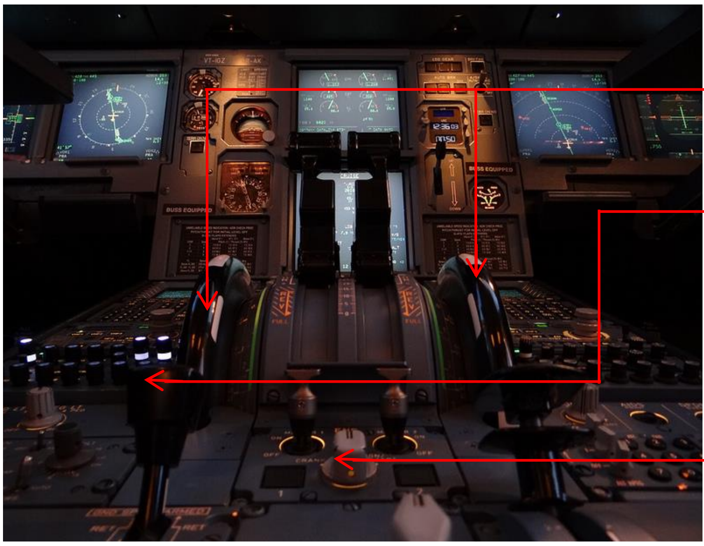
The speedbrake lever, **(1)** can be used by both pilots to manually engage the speedbrake.

Ad 2 Handwheels

The hand wheels **(2)** on the center pedestal can be used by both pilots to control the trimmable horizontal stabilizer.

Ad 3 Trim switch

The rudder trim switch **(3)** is used by the pilot to manually apply rudder trim.



1. Hand wheels
2. Speed brake
3. Trim switch

Figure 25 - A320 Central pedestal

2.1.3b Boeing 737NG

The input of the flight controls is transferred by the steering wheel and control column **(Fig. 26).** The flight deck consists of:

- Two control columns
- Two control wheels
- Two times left and right rudder pedals

The primary flight control system uses a conventional control wheel, column and pedals linked mechanically to hydraulic cylinders that control the ailerons, elevators and the rudder. If required the ailerons and elevators can be operated manually.

Figure 26 – Control Wheel

Ad 1 Control columns

The control columns and wheels are connected through transfer mechanisms, which gives the pilots the possibility to bypass a jammed control.

Ad 2 Control wheels

The Captains´ and First Officers´ control wheels **(Fig. 26)** are connected by a transfer mechanism. This creates the possibility to control the aircraft together when in event of hydraulic failure.

Ad 3 Rudder pedals

Each set of rudder pedals are used to control corners and to brake with the landing gear. To do this, both rudders have to be pressed at the same time.

2.1.3 Transport

The main difference between the Airbus A320 and the Boeing 737NG is the manner of how the input signals from the cockpit are transferred to the several flight control surfaces.

2.1.3a Airbus A320

All the manual and auto-pilot signals are sent to different onboard computers which process the signals and control the different hydraulic actuators. There are a total of seven flight control computers, which can be categorized into three different computers. There's the Elevator Aileron Computer (ELAC), the Spoilers Elevator Computer (SEC) and the Flight Augmentation Computer (FAC). Autopilot commands are sent by the Flight Management and Guidance System (FMGS). The fly-by-wire system has a special build-in safety system.

Elevator Aileron Computers

The ELAC computers control the pitch and roll of the aircraft by sending signals to both a SEC computer and a FAC computer. Next to that they directly control the ailerons and the elevators of the aircraft. There are a total of two ELAC computers on board of the aircraft, if both computers fail, pitch control shifts to a SEC computer.

Spoilers Elevator Computers

The SEC computers control the spoilers and the standby elevator but they can control the horizontal stabilizer as well. There are a total of three SEC computers on board, each runs independently, unlike the ELAC computers. The SEC computers are number from one to three. The SEC computers process the signal input from the ELAC computer into an output which activates the according hydraulic system actuators. Each SEC computer controls a different spoiler actuator. These actuators activate the outside control surfaces. The ELAC calculates which of the three SEC computers is used for each desired command.

Flight Augmentation Computers

The FAC computers control the rudder. There are a total two FAC computers which work the same way the ELAC computers do, with only one of them being active at a time. The FAC computers process the input given by the ELAC computers and determine which of the rudder hydraulic actuators should be activated.

Safety

All electrically managed flight controls have a build-in safety system, called laws. Laws prevent extreme movement limits, such as a maximum pitch angle, a maximum rolling speed and next to that the laws can stabilize an aircraft when it is not being controlled manually.

2.1.3b Boeing 737NG

In the Boeing 737NG are two hydraulic sources; systems A and B. Each hydraulic system can operate all primary flight controls. The ailerons and elevators can be operated manually if required. The rudder can be operated by the standby hydraulic system if system A and B pressure is not available. The secondary flight controls, consisting of flaps and slats, are powered hydraulically by system B. If failed, the trailing edge flaps can be operated electrically.

System A and B

Both system A and B are hydraulic sources **(Fig. 27)**. These sources control the pressure for the aircrafts movements. All primary flight controls (ailerons, elevator and rudder) are controlled by system A, the secondary flight controls (trailing edge flaps, leading edge flaps and slats) are powered by system B. In case system B fails, the trailing edge flaps can be operated electrically.

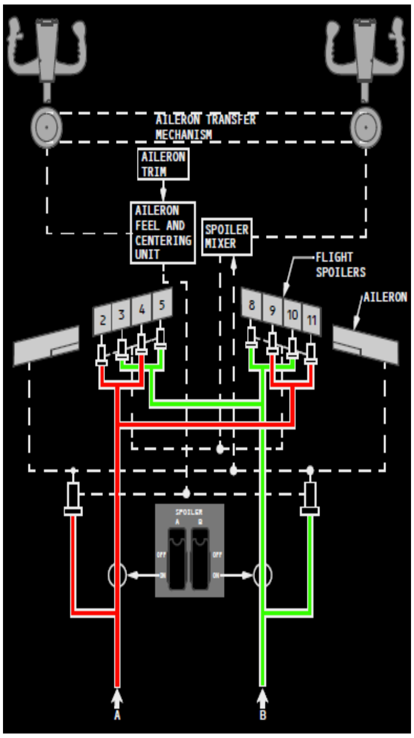


Figure 27– Hydraulic schematics B737NG

Power Control Unit (PCU)

The main power control unit consists of two independent rod inputs, two individual control valves and two independent actuators; one for system A and one for system B. The standby rudder power control unit is controlled by a separate input rod and control valve and powered by the standby hydraulic system. To control hydraulic system A and B correctly, the main PCU contains a Force Fight Monitor (FFM) that detects opposing pressure between A and B actuators, this may occur if one of the systems is jammed.

Ailerons

The captain's control wheel is connected by cables to the aileron power control units through the aileron feel and centering unit **(Fig.28)**. The First Officer's control wheel is connected by cables to the spoiler PCUs through the spoiler mixer. The two control wheels are connected by a cable drive system which allows actuation of both ailerons and spoiler by either control wheel. When the hydraulic system fails the ailerons can be used mechanically by rotating the pilot's control wheel. The control forces are higher due to friction and aerodynamic resistance, this makes the plane harder to control.

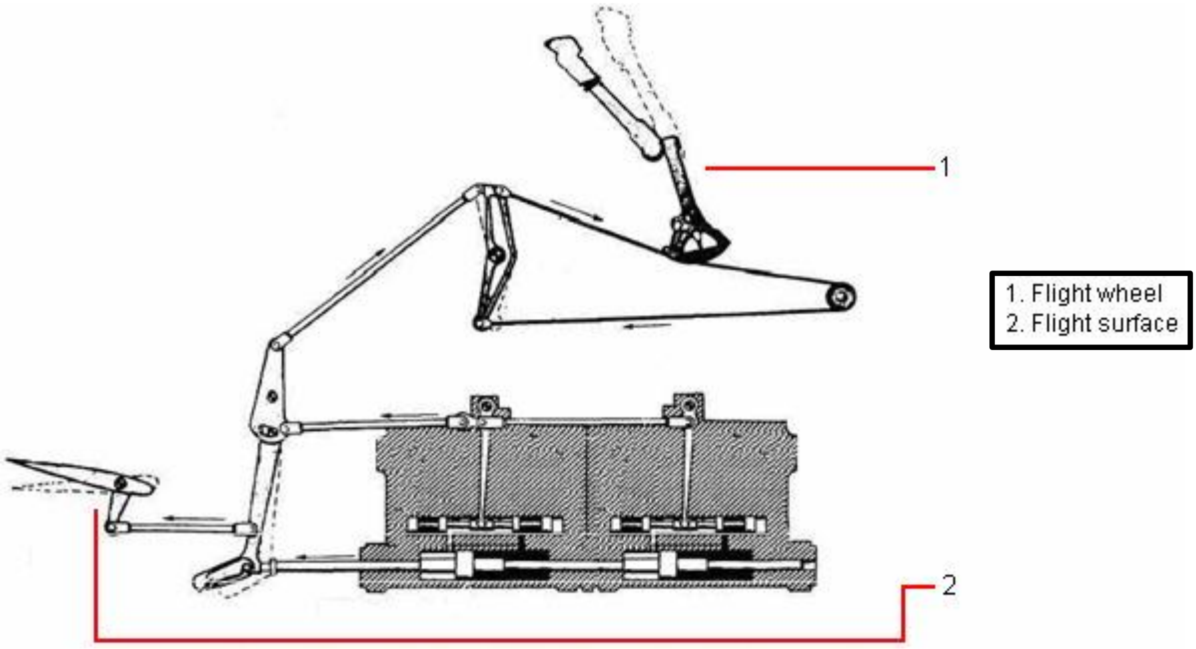


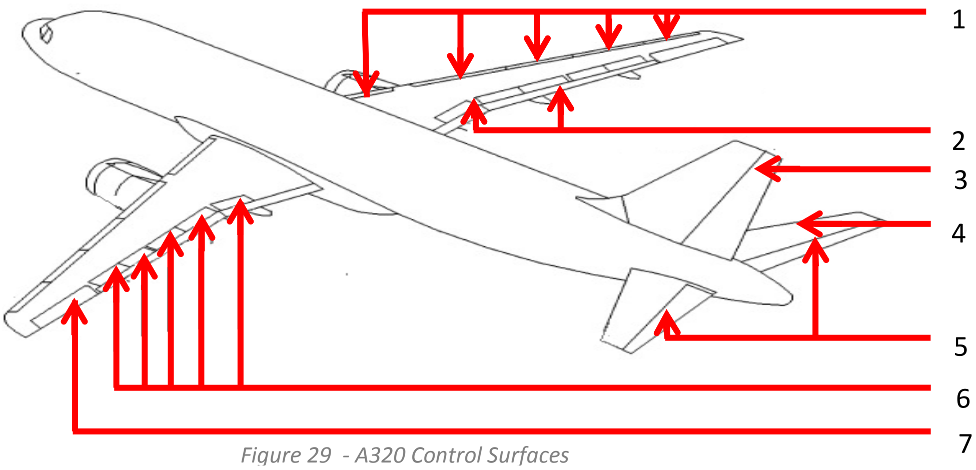
Figure 28 –Flight control schematics

2.1.4 Output

Because there are many parts in the aircraft that handle the flight controls, only the ailerons of the primary flight controls and only the flaps of the secondary flight controls are treated. This is done for much more profound information.

2.1.4a Airbus A320

The A320 has seven different control surfaces **(Fig. 29)**, of which the ailerons and flaps will be discussed this chapter.



1. Slats
2. Flaps
3. Rudder
4. Stabilizer
5. Elevators
6. Spoilers
7. Aileron

Figure 29 - A320 Control Surfaces

Ailerons

Ailerons are used to create a rolling movement around the aircraft's longitudinal axis, which basically makes the aircraft turn into a different direction. To start a roll, either a pilot or the autopilot has to send a command to do so. Both pilots have a side stick controller, which sends out an electrical signal towards the primary flight control computer, which is called the Elevator Aileron Computer (ELAC). Autopilot commands are also electrically send to the ELAC computer. In short, the input commands are send through and electrical wire to the ELAC computer **(Fig. 30)**. This computer is positioned below the cockpit, behind the pilots. It is not within visible range but can be easily reached and replaced when necessary.

There are a total of two ELAC computers on board the A320, with one of them being active, while the other operates in damping mode, which means it is standing by in case the main ELAC computer fails. The ELAC computer processes the commands given by the side stick controllers and the autopilot and calculates which of the flight control surfaces need to be activated. In case of a roll movement, the ELAC computer directly sends commands towards the hydraulic actuators of the ailerons, because like the name says, the ELAC computer controls the hydraulic actuators of both the elevators and the ailerons. There are two different flight computers to control the hydraulic system of the spoilers and the rudder.

The aileron hydraulic actuators in the wings receive the electrical signal transported from the ELAC computer. The actuators translate this signal into the desired position of the ailerons. There are a total of two hydraulic actuators attached to each aileron, each actuator has its own hydraulic source. The hydraulic power in the A320 consists of three different systems, the Blue (B), yellow (Y) and Green (G) system. The two aileron actuators are powered by the Blue and Green systems. One of the actuators is always active while the other runs in damping mode, which is a standby mode. In case of huge amounts of pressure on the one actuator, or in case of failure, the second actuator becomes active. If the primary actuator fails, it is automatically switched to damping mode while the second actuator becomes active.

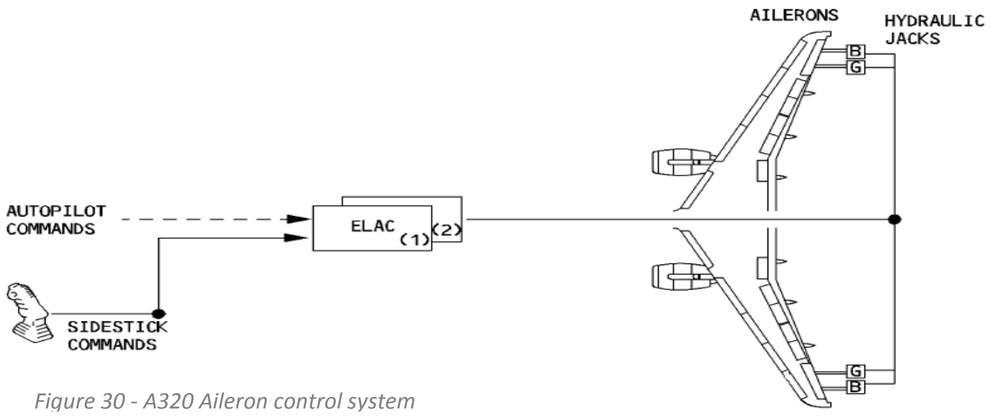


Figure 30 - A320 Aileron control system

Backup

In case of an ELAC failure, the computer is immediately shut down and the second ELAC computer will take over his function. In case of extreme failure when both ELAC computers are failing, aileron control is immediately switched to damping mode, which means they cannot be activated anymore. Roll control has to be maintained by the spoilers at this point. In case of a hydraulic system failure, all control by that system is immediately switched to damping mode and the second hydraulic system will take over control. **(Fig. 31)**

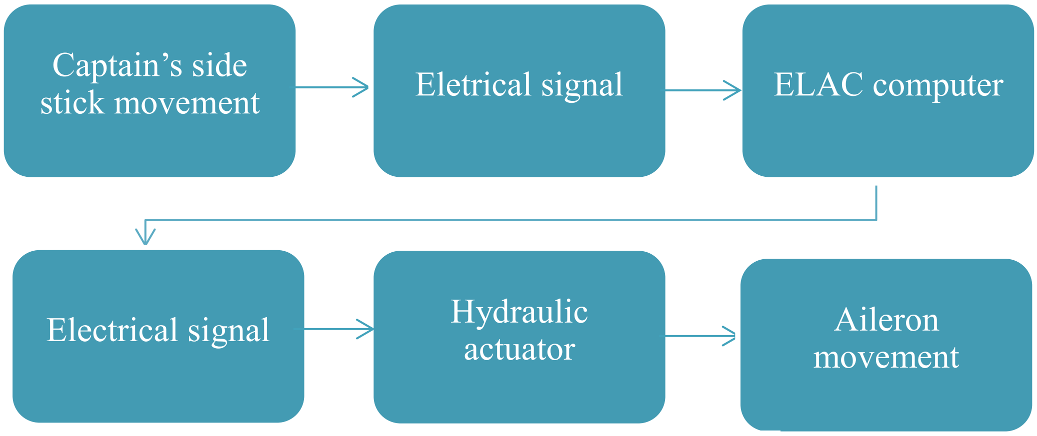


Figure 31 - A320 Aileron block diagram

Flaps

The pilot controls the flaps with a lever on the center pedestal of the cockpit. The lever configures both the slat and flap positions simultaneously. When the lever is pushed, it sends out an electrical signal to one of the two identical Slat Flap Control Computers (SFCC) **(Fig. 32)**. Each of these computers has two channels, one for the flaps and one for the slats. Each SFCC computer controls a different flap drive system containing a hydraulic motor to actuate the flaps. One SFCC computer controls the left hand flaps, while the other controls the right hand flaps. **(Fig. 33)**
Within the SFCC there is a valve block, which consists of three solenoid valves. Two of these solenoid valves are directional valves and operate the Control Valve Spool (CVS). The CVS controls the extension and retraction of the flaps. The third valve, called the Enable Solenoid Valve (ESV), operates the Press Off Brake (POB). If the flaps are in the correct position, the POB makes sure that they maintain their position.

The green hydraulic system provides the left hand side with hydraulic power, while the right hand side is being powered by the yellow hydraulic system. The two hydraulic motors which control the flaps are linked together with a differential gearbox. When the flaps are in position, an Asymmetry Position Pick-Off Unit (APPU) on each wing sends feedback to the SFCC computers to check if any irregularities occur between the two wings and in such a case the SFCC will recalibrate the flap positions to line up perfectly with each other.

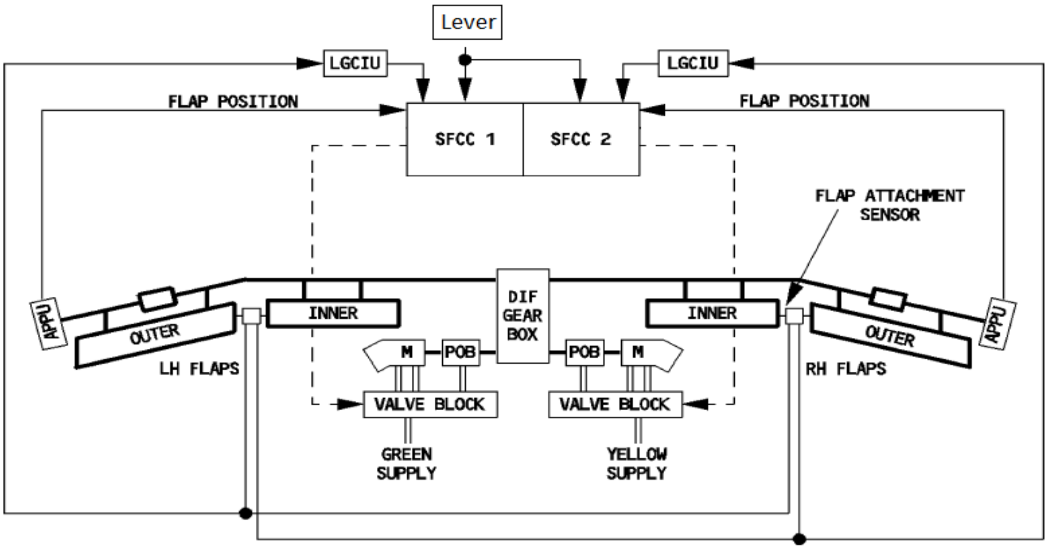


Figure 32 - A320 Flap control

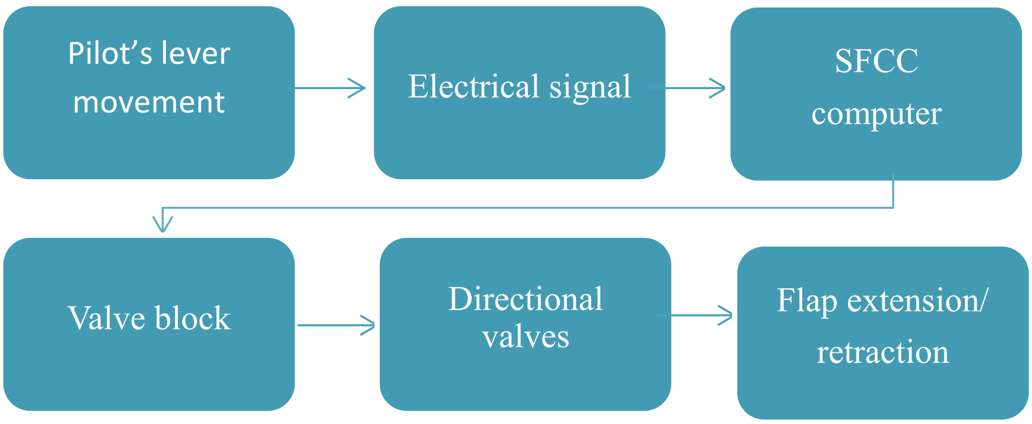


Figure 33 - A320 Flap Block Diagram

2.1.4b Boeing 737NG
The Boeing 737NG contains the following outputting controls and surfaces **(Fig. 34)**:

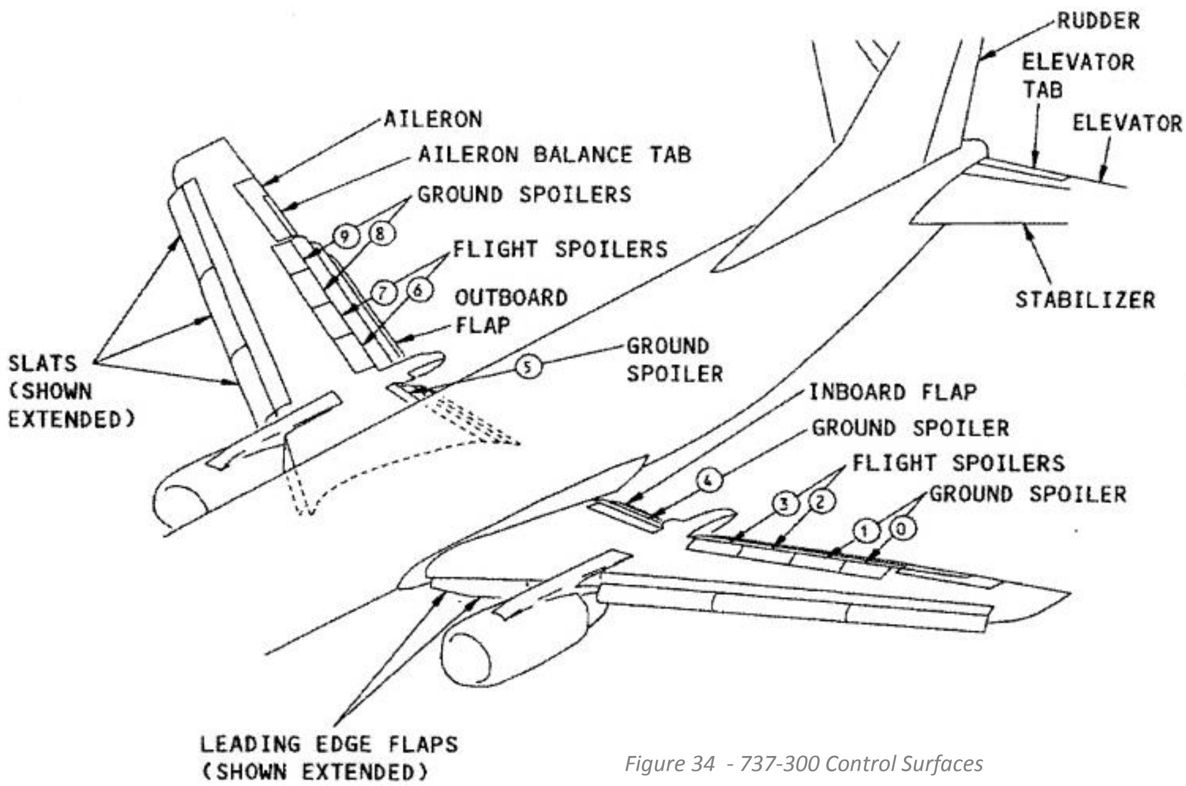


Figure 34 - 737-300 Control Surfaces

- Ailerons
- Flight spoilers
- Two elevators
- Rudder
- TE Flaps
- LE Flaps
- Slats
- Stabilizer

Ailerons
Boeing still uses the conventional system in the 737NG. It operates with a mechanical system and ends with a hydraulic system. **(Fig. 35)**
Both of the pilots their control wheels are interconnected by bus cables, making the controls move the same direction at the same time. The aileron cables are attached to the captain's control drum and run aft on the left side of the aircraft to a quadrant assembly above the left main wheel well. The quadrant assembly torque tube, centering spring and trim mechanism, electric trim actuator, ailerons power units and aileron control bus drums are located on the left forward wall of the main wheel well.

When the captain's control wheel turns left, the movement of the control wheel is converted in the aileron control drum. Those cables get into a separate hydraulic power control unit for each aileron, hydraulic system A and B. They provide the pressure to operate the ailerons. In the cockpit are two switches, one for hydraulic system A and one for hydraulic system B. Turning the switch on causes the valves to shutoff the hydraulic pressure for each aileron. The hydraulic systems also provide hydraulic pressure for the rudder and the elevators.

In event of failure of either system A or B, the control wheel needs to be rotated. This drives the left ailerons cables and rotates the aileron quadrant assembly. This causes input rods to actuate individual A and B hydraulic power control units. Movement of the power control units operates the cable system that positions the ailerons and the spring cartridge which drives the spoiler control quadrant assembly and inputs to the spoiler mixer. The spoiler mixer linkage moves the cables that operate the flight spoilers. The right spoiler cables complete the follow up to the first officer's control drum through the lost motion device. In the event of a total hydraulic failure, lateral control is maintained manually through the cables directly to the ailerons. Control forces are minimized by ailerons balance tabs and balance panels.

The spoilers assist the aileron system in maintaining lateral control. If a normal input to the ailerons system is above a particular amount of control wheel movement, the flight spoilers will activate. When the plane turns left or right, the cables, which are connected from the aileron drum to the aileron control quadrant, move the top part of the aileron control quadrant. Hydraulic pressure is created in the aileron power units and runs by valves towards the hydraulic control module. This module moves the aileron up and down. The aileron needs to be in balance under extreme forces, therefore a lot of force is necessary. To keep the ailerons balanced, a constant pressure of 3000PSI is used. The pressure is provided by the hydraulic control module. All components are sorted chronologically in a block diagram **(Fig. 36)**

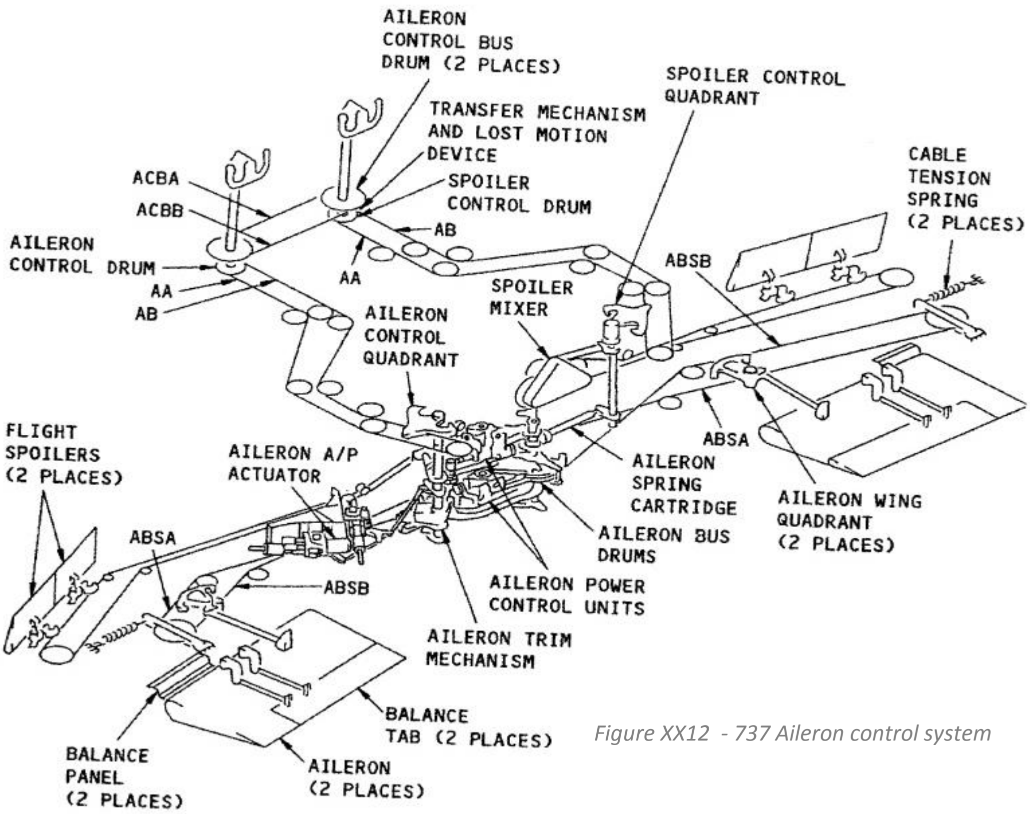


Figure XX12 - 737 Aileron control system

Backup

The base of the first officer’s control column is equipped with a transfer mechanism and lost motion device which allows normal control wheel motion to be transmitted through the left aileron cables only. If a malfunction occurs which jams the aileron control system, lateral control is accomplished by positioning the flight spoilers through the right spoiler cables controlled from the first officer’s control wheel.

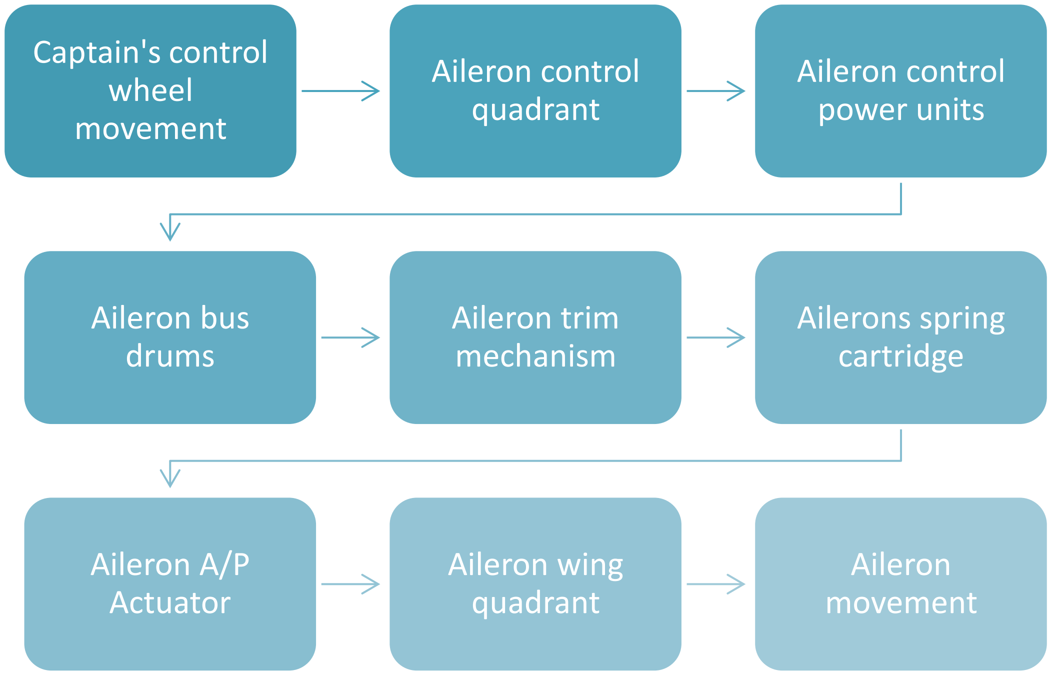


Figure 36 - 737 Aileron block diagram

Flaps

The new generation Boeing 737’s has two sets of mechanically linked double slotted span flaps on each wing. Each set of flaps consists of a Fore Flap and an Aft Flap that are mechanically separated to form slots when extended. A hydraulic motor drives all trailing edge flaps by a torque-tube drive system connected to two ball bearing drive screws on each flap assembly. This motor has an automatic shutoff feature in case of either flap asymmetry cable tension loss. An electric motor serves as a backup for trailing edge flap extension and retraction. The Flaps/Slats Electronics Unit (PSEU) protects the trailing edge flaps from excessive air loads by automatically retracting flaps from fully extended landing position when a predetermined airspeed is exceeded. When the airspeed is reduced the flaps automatically return to the fully extended position.
Normal operation of the Boeing 737NG’s trailing edge flaps is hydraulically powered by System B and controlled by the flap lever. Alternate operation is by an electric motor controlled by two switches on the overhead panel. The entire chapter details the trailing edge flaps.

Flap control unit

The flap control unit is installed to contain the flap control valves and associated mechanical linkages that regulate hydraulic operation of the flaps. The flap control unit incorporates the mechanical linkage that operates both the trailing edge flap control valve and the leading edge flap control valve. These valves are mounted on the control unit, as well as a cable operated follow-up drum that operates three cams. Seven cam operated electric switches are mounted on the forward side of the control unit. The flap control unit is mounted on the right wheel well ceiling. **(Fig. 37)**

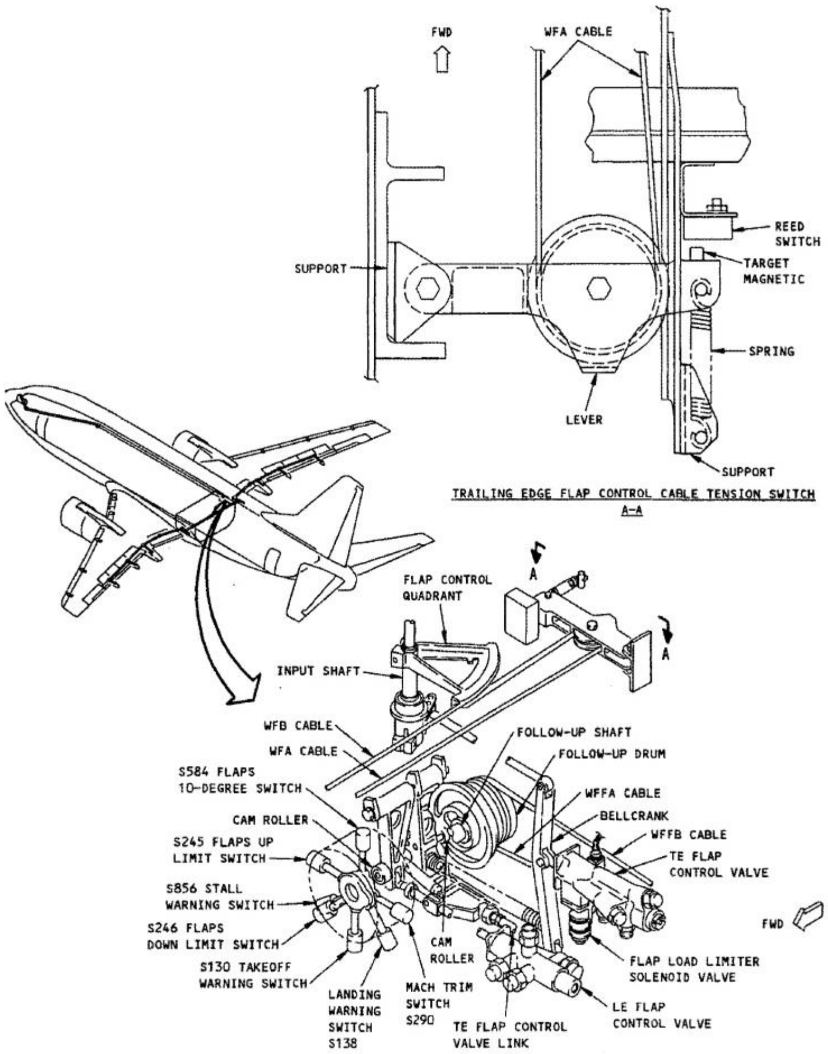


Figure 37 - 737 Flap control unit

Normal operation

The trailing edge flaps are normally hydraulically operated. Rotation of the control lever actuates the flap control unit linkage through the cables. This positions the trailing edge control valve to port System B hydraulic pressure to the flap hydraulic motor. The hydraulic motor powers the torque tube drive system to position the flaps. Hydraulic motor operation positions cables, which rotate the follow-up drum on the control unit. The follow-up drum positions three cams. One cam returns the trailing edge control valve to null and stops the flaps at the desired position. The second cam positions the leading edge control valve and the third actuates the respective electric switches.

Actual trailing edge flap position is monitored by seven cam operated switches on the flap control unit, actuated by the follow-up system. The seven switches include:

- Alternate drive limit switches
- Takeoff warning switch
- Landing warning switch
- Leading edge indication switch
- Mach trim switch
- Stall warning switch

Individual switch operation will be active when the specific circuit is covered. **(Fig. 37)**

Backup

Normal hydraulic control of the trailing edge flaps is by cables from the flap control lever that operate the input linkage tot the trailing edge flap control valve. The flap control unit controls the control valves of the leading edge flaps as well. A flap control cable tension switch is located below the cabin floor, near the flap control unit quadrant. Tension on the flap control cables causes the spring loaded cable support lever to hold a target near a reed switch. A cable break allows the spring to pull the target away and activate the switch. This causes the flap bypass valve to move to the bypass position and prevents hydraulic operation of the flap power unit.

Flap power unit

The flap power unit transfers mechanical energy from the flap hydraulic motor or alternate drive electric motor to the trailing edge flap system. The flap power unit is an aluminum housing containing the gearing necessary to drive the output shaft and the follow-up system. The flap hydraulic motor and alternate drive electric motor are mounted on the power unit.
During normal flap system operation, power from the hydraulic power motor is transmitted through a pinion gear to a reduction gear splined to the output shaft. During flap alternate drive operation, power from the electric motor is transmitted through a second pinion gear tot the same reduction gear. The reduction gear drives the flap torque tube drive through the output shaft.

Stick shaker

If the aircraft threatens to stall. The stick shaker, which is used to indicate the pilot that he soon enters a stall position. The motor of the stick shaker is unbalanced so when activated it starts to shake. It is fitted inside the control column. Also when the stall is almost reached, starts a vocal warning in the cockpit to indicate that something is going wrong. This system is called the aircraft's stall protection system. Sensors are mounted on the wings and look at the angle of attack of the plane. These sensors are called angle of attack sensors. This information is send to an air data computer, which in the Boeing is called an Adiru. The Adiru gathers all kind of information. When the Adiru notices that the aircraft soon enters a stall. He sends a signal to the electric motor of the stick shaker. And the stick shaker will vibrate.

Backup

A flap alternate drive unit operates the flaps electrically when required instead of hydraulic power. Two switches operate the system; the alternate flaps arm switch and the alternate flaps control switch on the pilot's forward overhead panel. Actuating the alternate flaps arm switch to ARM supplies 28 Volts DC power to the control switch and simultaneously positions the bypass valve to BYPASS. The hydraulic motor is disengaged because both lines at the motor are connected to the same port of the control valve. Moving the control switch up or down activates the respective relay

when the applicable limit switch is closed. The motor is powered by 115 Volts AC through the relay contacts until the limit switch opens of the control switch is returned OFF.
When the control switch is placed down to extend the trailing edge flaps electrically, the leading edge standby shutoff valve relay is activated. The valve opens and standby hydraulic system pressure extends the leading edge flaps and slats.
All components are sorted chronologically in a block diagram (Fig. 38)

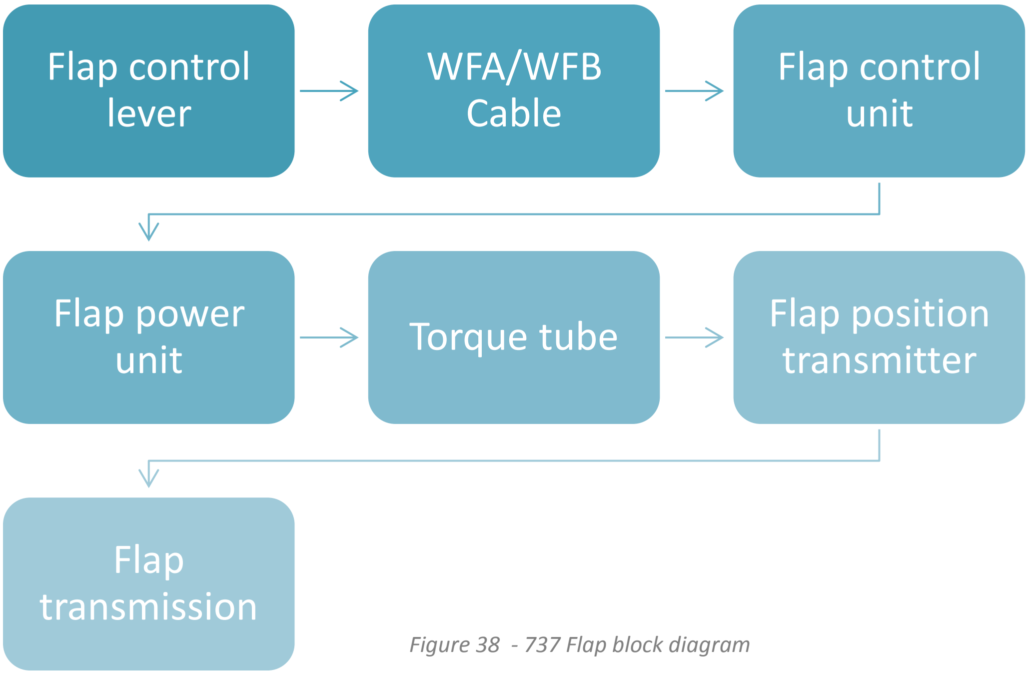


Figure 38 - 737 Flap block diagram

2.2 Maintenance Checks

It is important to check an aircraft often, so the flights will safely succeed. There are differences in checks by an Airbus A320 and a Boeing 737NG. To show you what the differences can be, there will be looked at a primary flight control check by an Airbus (2.2.1) but also by the Boeing (2.2.2) and after that the differences between the two (2.2.3) will be lightened up. Also a secondary flight control check will be spoken by an Airbus (2.2.4) and a Boeing (2.2.5) and the differences (2.2.6) will again be lightened up.

2.2.1 Airbus A320 Aileron Check

With the aileron check there will be looked at the hinges and parts of the hinges that are connected to the ailerons. This is done because the forces that may impact the aileron during a flight are very large. So the hinges could cause some damage. At first the ailerons must be removed to get access to these hinges. This check will take four man-hours and it will be done every twelve thousand flight hours or every twenty-four months. This depends on what comes first.

Just as the Boeing aileron check, the Airbus aileron check can be divided into two consecutive categories:

- Removal of the ailerons
- Hinge inspection and check

Ad 1 Removal of the ailerons

Before the ailerons can be removed, there are some systems that have to be shut down. The flaps must be fully retracted and the flap control lever must be locked. The blue and green hydraulic system and their reservoirs must been depressurized and the safety collars of the circuit breakers at the flight deck must be removed. Next it has to be placed on a platform so the mechanics can get access to the ailerons. The mechanics have to remove the bolts, nuts, pins, washers and locking plates. The actuators also have to be fully retracted.

Ad 2 Hinge inspection and check

The hinge inspection and check is the same as for a Boeing. Only the service limits of the Airbus are different than for a Boeing.

$$4 \; man \; hours = every \; 12000 \; flight \; hours \; or \; every \; 24 \; months$$

2.2.2 Boeing 737 Aileron Check

Following the AMM, the ailerons will be checked on the Boeing 737. In this check, both the aileron parts and hinges will be checked. The reason to do this is to check if they operate within the manufacturers specifications. During a flight, the forces that work on the ailerons are significant. So it's important this check will be done precisely. The first step is to remove the ailerons, then the check can be done. The interval between the aileron check is twelve thousand flight cycles or 48 months depending on which one comes first. The required man-hours for this test is six hours.

The aileron check can be divided into two consecutive categories:

- Removal of the ailerons
- Hinge inspection and check

Ad1 Removal of the ailerons

Maintenance panels must be opened before the ailerons can be removed. A crane must be located under the wing in the area of the ailerons at the trailing edge. The hinge covers can be seen when the panels are opened and will be removed. All the hydraulics must be cut off before removing each one of the hinges. To do this, each pin, seal, nut and bolt will be removed. When these steps are followed, the inspection of the hinges can be performed.

Ad 2 Hinge inspection and check

Specific instrument and equipment is needed for this inspection such as a micrometer and a vernier with caliper from 0-6 inches. All parts need to be checked for worn. When a part is worn, this part needs to be replaced if has been determined that after measurement the wear is more than the maximum limitations of the Boeing manufacturer. When each of the parts is checked and if necessary replaced, the ailerons can be placed back on the wing.

$$6 \; man \; hours = every \; 12000 \; flight \; cycles \; or \; every \; 48 \; months$$

2.2.3 Comparison Aileron Check

The main difference of the aileron check between the Boeing 737NG and the Airbus A320 is that for the check of the Boeing 737NG there are a lot more mechanical components to be checked. For example, before a 737NG aileron can be checked, more panels need to be removed, which results in more man-hour work on the Boeing check. Both the Airbus and the Boeing's hydraulic system needs to be depressurized, so in this part of the check they are quite similar. The hinges, which also are checked, are more or less similar on the Boeing and the Airbus so the time needed for this check is equal.

2.2.4 Airbus A320 Flap System Check

To check the slat and flap system, a mechanic uses an Aircraft Maintenance Manual for an Airbus. This is also called AMM. The AMM outlines which steps have to be done in what order, to check the slat and flap system. The check will take half an hour and it will be done every two thousand flight hours or every twelve months. This depends on what comes first.

The check consists of the movement of the slats and flaps. It will be performed in the cockpit. The control lever will be put in different positions that are indicated by the AMM. The result of the slats and flaps will be displayed to a standby monitor and compared with the predetermined results listed in the AMM. If the results match, the test is positive. To be sure this check will be repeated three times. There are six steps in the AMM that have to be done by a mechanic. **(Fig. 39)**

	Action	Expected Result
1	Move the control lever to position one, and then to position two. Wait at both notches until the flaps are in their new position.	The flaps move to their new position.
2	Move the control lever to position three.	The flaps move to their new position.
3	Move the control lever to its full position.	The flaps move to their new position.
4	Move the control lever back to position three.	The flaps move to their new position.
5	Move the control lever back to position two.	The flaps move to their new position.
6	Move the control lever to position one and position zero. Wait at both notches until the flaps and slats are in their new position.	The flaps and slats move to their new position.

$$0{,}5\ man\ hours = every\ 2000\ flight\ hours\ or\ every\ 12\ months$$

Figure 39 - A320 flapy system check

2.2.5 Boeing 737 Flap System Check

The test of the operation of the flaps on a Boeing 737 are being done by selecting a couple times the different stages of them to the max and minimum position. When the flaps are moved, the mechanics check at each stage if they moved correctly and at the right angle. To check this, the instrument or monitor in the cockpit is checked by a mechanic while a mechanic outside the aircraft checks if the value given by the monitor relates to the stand of the flap. The Boeing check is being done by the AMM (Aircraft Maintenance Manual). Both the standard and the back-up system will be checked if the AMM is followed. This check needs to be done every 6000 flight cycles or every 24 months to prevent the system of failures.

2.2.5a Boeing 737 Standard System Check
The standard or main system is checked by the steps of the AMM. The mechanic in the cockpit, checks when he lowers the flaps, if the deflection of the flaps and correspondent with the monitor or the instrument. **(Fig. 40)**

	Action	Result
1	The flap control stick is moved from one, two, five, fifteen, twenty-five, thirty and forty degrees	The flaps will move according by the selected stage.
2	The control stick moves to the maximum up position	The flaps retreat to their minimum position.

Figure 40 - 737 Standard system check

2.2.5b Boeing 737 Backup System Check
At every check of these systems, the backup system is also checked according to the AMM. When the backup system is about to be checked, the main system is switched off manually by the mechanic. This check is also being done from within the cockpit and is checked on the monitors to make sure the deflection correspondents. **(Fig. 41)**

	Action	Result
1	The flap control lever is moved to the max up position	Flaps move to full up position
2	The flap control lever is moved to the max down position	Flaps moved to full down position
3	Lever is placed back to neutral	Flaps moved to the neutral position
4	Standby system is switched off	Main system is turned on and backup system is turned off

$$1\ man\ hour = every\ 6000\ flight\ cycles\ or\ every\ 24\ months$$

Figure 41 - 737 Backup system check

2.2.6 Comparison Flap System Check
The main difference between the flap check of a Boeing 737 and an Airbus A320 is that for a Boeing they check the main and back-up system and for the Airbus they only check the main system. So the check of the Boeing will take more time and involve more man-hour costs. With the Boeing we see that it will take one man-hour and for the Airbus it will take half a man-hour. There also is a difference between the frequencies of the checks. With Boeing it will be done every two years and with an Airbus it will be done every year.

2.3 Aircraft On Ground Maintenance

There's always the possibility of a defect on an aircraft outside the maintenance checks, for example just before takeoff. Usually, this problem has to be solved to continue the flight. Therefore, the aircraft has to stay on ground, because of this unexpected maintenance. For a more complete research in the difference between Airbus' and Boeing's maintenance man-hours, there's also chosen for a comparison in unexpected aircraft on ground maintenance tasks. First, there'll be looked at unexpected maintenance of a primary flight control **(3.3.1)**. After that, an unexpected maintenance task on a secondary flight control will be explained **(3.3.2)**.

2.3.1 Unexpected Maintenance Ailerons

Although the maintenance checks counteracts almost all possible problems on an aircraft, there´s always the possibility of a defect or an error just before take-off. This causes time to repair the defect and Aircraft on Ground (AOG) time. For the comparison on the primary flight controls of both aircraft's there is chosen for a defect Power Control Unit on the aileron.

2.3.1a Airbus A320

For the Airbus, the time to replace the Power Control Unit (PCU) on the aileron amounts 1.00 man-hour and two mechanics. Therefore, for the comparison, we'll assume this equals 2.00 man-hours. The access to the PCU amounts 0.19 man-hour. Therefore, the total amount of time for this replacement is:

$$2.00 + 0.19 = 2.19\ man\ hour$$

This will cause as much AOG time. Therefore, the AOG time will be 2.19 hour for the replacement of the PCU of an aileron.

2.3.1b Boeing 737NG

The replacement of the PCU of the aileron on a Boeing 737NG takes 3.60 man-hours. The access to the PCU takes almost as much time as on the Airbus: 0.16 man-hour. Therefore the total replacement time of the PCU of the aileron on a Boeing will take:

$$3.60 + 0.16 = 3.76\ man\ hour$$

As seen above, the replacement time on the Boeing takes quite more time than on an Airbus. The AOG time on the Boeing 737NG is 3.76 hour.

2.3.2 Unexpected Maintenance Flaps

Just as an unexpected maintenance task for a primary flight control, there'll also be explained an unexpected maintenance task on a secondary flight control. For the comparison there's chosen for the removal of the flap rotary actuator. Below will be shown how much time this removal will take on an Airbus A320 **(3.3.2.a)** and on a Boeing 737NG **(3.3.2.b)**.

2.3.2a Airbus A320

The removal of a flap rotary actuator costs 4.00 man-hours on the Airbus A320. This 4.00 man-hours is only for the replacement of the flap rotary actuator. Before the mechanic can get at the defect, a number of things must be taken into account. Firstly, the flaps must be fully extended. This also costs 0.02 man-hour on an Airbus A320. Even so, the access to the flap rotary actuator isn't free. The access to the flap rotary actuator requires another 0.2 man-hour. This brings the total man-hour to:

$$4.00 + 0.02 + 0.2 = 4.22\ man\ hour$$

As the aircraft has to stand on the ground unexpected, the defect also causes unexpected aircraft on ground costs. Assuming the mechanics can get at the aircraft directly, the defect causes as much aircraft on ground time as man-hour to solve the defect. Therefore, the AOG time raises to 4.22 hour extra.

2.3.2b Boeing 737NG

The removal of just a flap rotary actuator costs 1.80 man-hours on an Boeing 737NG. Comparing to the 4.00 man-hours on the Airbus A320, this is quite a lot quicker. But, the Boeing has it's disadvantages. To access the flap rotary actuator, two panels has to be opened and closed. This panels, 567BT and 567 ET, takes both 0.7 man-hour to open and close **(annex 7)**. This makes the total man-hour time on the replacement of a flap rotary actuator:

$$1.80 + 0.7 + 0.7 = 3.20\ man\ hour$$

As the defect is an unexpected maintenance task, this task produces AOG time. The AOG time is 3.20 hour.

3 Maintenance program and costs

Firstly, the maintenance procedures of the Airbus A320 and the Boeing 737NG will be discussed (3.1). Secondly, the advantages and disadvantages of the Airbus A320 and the Boeing 737NG systems will be discussed (3.2). Thereafter, the costs and benefits of both systems will be shown (3.3). Finally, a recommendation will be made (3.4).

3.1 Maintenance procedures

Every aircraft has different maintenance procedures. However, every procedure can be assigned to one of the four checks. Each of these checks, the A-, B-, C-, and D-check, has to be done after a certain time and/or flight hours. The precise maintenance program per aircraft will be discussed in paragraph 3.1.1. the exact A-, B-, C-, D-checks from the aircraft will be discussed in paragraph 3.1.2.

Ad 1 A check

The A check has to be done every 500-800 flight hours. It takes from 20 to 100 man hours and is usually performed overnight at a gate or hangar. The occurrence depends on the cycle count (one take-off and one landing equals one cycle) and aircraft type, or the total amount of flying hours. Sometimes these checks can be delayed by the airline if certain conditions are met, for example checks to be carried out during the pre-flight checks.

Ad 2 B check

The B check is done every 4 to 6 months and takes about 150 man hours. The entire procedure takes about 3 days and is done in a hangar. This check is, sometimes, performed in the A and C check and pre-flight checks which makes the B check often unnecessary.

Ad 3. C check

The C check is done every 15 to 21 months (depending on aircraft cycle) or a specific amount of flight hours, this amount is set by the manufacturer. The C check is much more extensive than the more frequent D check. It's so extensive that the aircraft has to be put out of service for 2 weeks. The entire check can take up to 6000 man hours.

Ad 4 D check

This check is also known as a Heavy Maintenance Visit (HMV). This check is done approximately every 5 years. Basically, the entire airplane gets taken apart in this check. Even the paint gets completely removed off the aircraft. Because this check is so extensive it can take up to 40.000 man hours and up to 2 months to complete. The entire check can take up to a million dollars. An aircraft makes it 2 to 3 D checks before being retired from service.

3.1.1.a Maintenance program Airbus A320

During maintenance of the flight controls on the Airbus a320, many things can be done by computer, thanks to the fly-by-wire system. Many of the maintenance tasks require to check if the computer is still working properly, and the flight control surfaces move corresponding. These checks don't take long to complete and reduce the man hours on the maintenance. All maintenance tasks can be found in the Maintenance Planning Document (MPD) of the Airbus A320. Airbus says in its MPD: the A check has a target interval of 750 flight hours, 750 flight cycles or 4 months, whichever comes first. The C check has a target interval of 7500 flight hours, 5000 flight cycles or 24 months.

These intervals have a maximum variation of time. These variations are recommended by Airbus and are based on Temporary Guidance Leaflet N˚ 26 established by the JAA. Airbus also gives a planning

AIRBUS A318/A319/A320/A321 MAINTENANCE PLANNING DOCUMENT

A/C Utilisation Data : 2800 FH & 2 FH/FC — EVENTS every 750 FH

TASK NUMBER	SAMPLE THRESHOLD	SAMPLE INTERVAL	100% THRESHOLD	100% INTERVAL	APPLICABILITY	NC	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
200010-01-1				36 MO	PRE 20463 (S/-10865)												X											X					
200010-02-1				72 MO	ALL																							X					
200020-01-1				36 MO	ALL												X											X					
200030-01-1				72 MO	ALL																							X					
200030-02-1				72 MO	ALL																							X					
200030-03-1				72 MO	ALL																							X					
201210-01-1				72 MO	ALL																							X					
201210-02-1				48 MO	ALL															X													
201210-03-1				72 MO	ALL																							X					
201210-04-1				72 MO	ALL																							X					
201250-01-1				72 MO	A/C WITHOUT ENTRANCE STAIRS																							X					

example in its MPD, which gives three examples for planning (Figure 42). These are for aircrafts which make 2000 flight hours per year, 2800 flight hours per year or 3500 flight hours per year. The interval for checks gets smaller when the aircraft makes more flight hours per year.

Column	Explanation
1. Task Number:	Specifies the MPD reference of the concerned task
2. Sample Threshold:	Threshold for sampling aircraft (S)
3. Sample Interval:	Interval for sampling aircarft (S)
4. 100% Threshold:	Threshold for all aircraft not selected for sampling (X)
5. 100% Interval:	Repeat interval (X)
6. Applicability:	Defines the technical status of the aircraft to which the task is applicable
7. NC:	Tasks not considered in the scope of this example or which need to be added by the operator

Figure 42: Maintenance planning example Airbus

3.1.1b maintenance program Boeing 737NG

The Boeing 737's maintenance program is developed so all tasks are arranged at multiple phases of intervals. One phase (P1) is around 500 flight hours, or four months. Other tasks have different intervals for example a task with a p2 intervals has to be done every 1000 flight hours, a p10 interval every 5000 flight hours and so on. These tasks are always planned in these intervals so the operators can group them together, so the aircraft can be in serviced more efficient.

The operators still have the freedom to plan their own maintenance. They can plan all the phases together in blocks, or they can do a more equalized program with the checks spread over a longer period of time with the aircraft being in normal service between the checks.
The biggest maintenance tasks (for example a D check) have intervals of up to P80 or 40.000 flight hours.

All of the maintenance tasks can be found in the 737's MPD(maintenance planning document). In the MPD the tasks are divided in multiple columns each column giving a certain piece of information about a certain task as can be seen in **(fig. 43)**

BOEING 737-600/700/800/900/900ER MAINTENANCE PLANNING DOCUMENT

SYSTEMS AND POWERPLANT MAINTENANCE PROGRAM

MPD ITEM NUMBER	AMM REFERENCE	CAT	TASK	INTERVAL THRES.	INTERVAL REPEAT	ZONE	ACCESS	APPLICABILITY APL	APPLICABILITY ENG	MAN-HOURS	TASK DESCRIPTION
XX-XXX-XX											MPD POSITION NUMBER MPD SEQUENCE NUMBER FIRST TWO DIGITS = ATA CHAPTER
20-030-01	05-55-23-200	8	DVI	10000 FH	10000 FH	133 191 510 520 550 560 730	191FL 431AL 431AR 431AT 431CR 511AB	ALL	ALL	1.00	Perform a detail visual inspection of the HIRF/L sensitive connectors outside the pressure vessel on the left side of airplane.

EXAMPLE

D98257 S0006122727_V1

Figure 1-1 SYSTEMS AND POWERPLANT MAINTENANCE PROGRAM EXAMPLE PAGE

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Figure 43: Maintenance planning example Boeing 737

The first column of the MPD contains numbers which are used to search certain maintenance procedures. The second column is the AMM reference, the AMM Reference provides chapter, section, subject and page block location of the appropriate AMM procedure to accomplish the task requirement. The third column is the cat failure effect category and regulatory requirements. All tasks listed in this section have a "category" identification as follows:

• 5 - Evident, Safety
• 6 - Evident, Economic (Operational)
• 7 - Evident, Economic (Non-Operational)
• 8 - Hidden, Safety
• 9 - Hidden, Non-Safety
• 0 - Regulatory Authority required task

The third column notes the interval at which the task has to be done. This can be showed in flight hours, aircraft cycles or calendar time. The fourth column notes the zone on the aircraft at which this procedure has to be executed. The fifth column notes the access panels which are required to open during this procedure. The sixth column notes witch aircraft models this procedure is required for

(for example: b737-600/700 or b737-800/900). The seventh column notes the amount of man hours it takes to complete the task and the final column gives a small task description.

3.1.2a A,B,C,D checks Airbus

As any other aircraft, the Airbus A320 has the standard A, B, C and D checks. The difference is in what tasks have to be done at each check.

Ad 1. A check

The A check has an interval time of 750 flight hours for the Airbus A320. During the A-check tasks like: checking if the computers still works properly, the flight control surfaces move correspondingly and checking hydraulic systems, will be performed. The inspections are easy tasks and can be done in a low amount of time.

Ad 2. B check

The B check should be done around every 2000 flight hours. When a B check is executed there are just a few maintenance tasks concerning the flight controls, for example checking the mechanical back-up of the rudder.

Ad 3. C check

After every 7500 flight hours the C check should be done. During the C check, the tasks are more detailed inspections like: checking the flaps for any water ingress or wearing marks, checking the aileron servo control and hinge bearings for excessive play/condition or lubricate certain area's and checking for leakage.

Ad 4. D check

Every six years the D check has to be performed. The D check consists of many tasks. Things like completely removing flight controls for thorough inspection. This can be done, since the complete aircraft will be disassembled. The full D check will take around two months.

3.1.2b A,B,C,D checks Boeing

In this paragraph some of the maintenance checks and what will be executed in these checks, will be discussed.

Ad 1. A check

The A check of the Boeing 737NG is very short and needs to be done about every 500 Flight Hours. However, most of the companies using the Boeing 737NG are doing pieces of the checks during stops at different airports, in between flights. This reduces the aircraft on ground time and therefore the companies can keep the aircraft in the air instead of on the ground. An example of a procedure done during the A-check is looking if the flap asymmetry system is still working.

Ad 2. B check

The B check is a little more intense and has an interval of 750 flight hours and will take a full night to perform. The reason this check takes longer is that the items needed to check are harder to reach on the aircraft. Tasks done in the b check include: checking of the flap skew system and the auto slat system, a check to see if the standby hydraulic system for the trailing edge devices is still working. Besides these checks, other systems have to be lubricated. For example, the stabilizer trim system.

Ad 3. C check

The C check, has a bigger interval than the B-check but it takes longer to complete. To complete the C-check it normally takes around 2 weeks to complete. In the C-check, almost every system gets lubricated and checked but the systems still stay roughly intact on the aircraft.

Ad 4. D check

However, in a D check (also known as a heavy maintenance visit) the entire aircraft gets stripped. Even the paint gets removed and all the parts in numerous systems get checked independently. Because this check is so tough, it takes almost a month to complete.

3.2 Advantages and disadvantages

There are numerous advantages and disadvantages which determine what aircraft is the most cost-efficient. The Boeing 737NG has the old conventional mechanical system and the Airbus A320 has a modern Fly-By-Wire control system. In this paragraph the pros and cons of each system will be analysed.

3.2a Airbus A320

The Pros

- The Airbus A320 uses the fly-by-wire system, making the amount of mechanical parts it contains less than the Boeing 737NG. Less parts means less maintenance
- The wires which run through the A320 are easily replaced and very cost efficient
- The flight control computers are easily accessible and can effortlessly be retracted for maintenance or replacement
- All flight controls are controlled electrically, which has the benefit of having the computers check the input by the pilot for extreme movements, making it harder for pilots to make big control mistakes and thus making flying safer.
- The fly-by-wire system is more resistant to friction damage and has less chance of separate parts being damaged by moving objects.

The Cons

- The fly-by-wire system is more sensitive to electrical interference
- It takes different kind of engineers to do the maintenance than a more convenient aircraft

Maintenance	Man-hours	Notes
Aileron and hydraulic actuation		
Operational check for damping measurement by bite	0.10	
Check aileron servo control and hinge bearings for excessive play and condition	1.00	
Check aileron servo controls fluid reserve piston position with hydraulic reservoir depressurized	0.20	
Flaps		
Operational check of WTB/POB	0.30	**NOTE: Flap surfaces move automatically**
Operational check of flap interconnecting strut and flap	0.10	

disconnect proximity sensors		
Check of flaps transmission shafting integrity, including inspection of seal witness drains	0.40	
Detailed inspection of inboard flap trunnions for evidence of wear marks (trunnion/half-shells)	0.50	PREPERATIONAL NOTE: Flaps extended NOTE: Consult CN 96-271-092 for reference to the relevant SB which gives the inspection areas and the interval for repeat inspections, dependent on initial findings and mod status
Check flap attachment bearing no.1 for liner migration	0.20	NOTE : if both flap attachment pendulum assemblies replacement are replaced by new pendulum assembly p/n d575-72240-00400, the inspection is no longer applicable.
Visual inspection of the inner flap drive trunnion clamp-type steel rubbing pads for wear	0.20	NOTE: Task may be accomplished together with 575221-02-1 if interval not exceeded
Flap/Slat command sensor unit Remove CSU for workshop check of friction brake	0.30	
Detailed inspection of interconnecting strut and attachments	0.30	
Detailed inspection of transmission assy	1.00	
Flap tracks		PREPERATIONAL NOTE: Flaps extended, slats fully extended
Lubricate all carriage rollers on all flap tracks	0.40	
Detailed inspection of tracks, rollers and spherical bearings (as far as visible)	0.30	
Detailed inspection of spherical bearing installations at flap tracke 2,3 and 4 in accordance with SB 57-1027	0.15	
Detailed inspection of tracks, rollers, spherical bearing and tab drive kinematic (as far as visible)	TBD	NOTE: Credit can be taken from previous accomplishment of task 275446-02-1
Actuator assembly		
Check flap rotary actuator assembly at track 2 for evidence of water ingress	0.50	
Check flap rotary actuator assemblies at track 1,3 and 4 for evidence of water ingress	1.00	
Drain and refill offset gearboxes of rotary actuators with semi-fluid	1.00	
Detailed inspection of the input shaft of the offset gearbox at track no.1 for evidence of lateral play	0.50	
Remove flap rotary actuator assemblies for regreasing	4.00	
Drain and refill flap actuator assemblies with semi-fluid	4.00	
Flap power control unit Replenish PCU gearbox to confirm fluid level	0.10	

Figure 44 – A320 Aileron and Flap maintenance list

3.2b Boeing 737NG

The Pros

- The Boeing 737NG does not have disturbances due to power or computer errors.
- The captain's and first officer's feeling through the control column is natural this makes it safer for the occupants.
- The captain and first officer can see and feel each other moving the control columns thus makes it easier to adapt to the pilot and to train new pilots for this aircraft

The Cons

- Because of the mechanical components it's possible to exceed the limits of the aircraft, for example with sudden wheel movements.
- The mechanical system weights a lot. This makes the aircraft less fuel efficient and therefore more expensive.
- It takes a long time to lubricate all of the mechanical components which is more expensive.
- The mechanical components have a lot of friction which can make the moving parts wear out. Therefore the aircraft needs a lot of maintenance

Maintenance	Man-hours	Notes
Visual inspection Ailerons	0.50	
Left or right wing aileron mechanical components from aileron PCU to the aileron and flight spoiler mechanical control path	0.60	
Functionally check the A and B system aileron power control unit internal leakage in a loaded condition.	1.00	
Lubricate the left wing aileron mechanical control path and aileron power control units.	0.50	**SPECIAL NOTE: CMR Task (27-CMR-11) interval for this task is 4000 FH or 12 Months**
Functionally check the left or right wing trailing edge flaps ballscrew actuator backlash.	2.00	**ACCESS NOTE: Flaps deployed.**
Lubricate the left or right wing trailing edge flap actuation mechanism.	0.60	**INTERVAL NOTE: Whichever occurs first. ACCESS NOTE: Flaps deployed.**
Perform a detail visual inspection of the left or right wing trailing edge flap actuation mechanism to include: 1. Aft flap drive rods. 2. Aft flap push rods. 3. Inboard carriage rollers. 4. Outboard carriage rollers. 5. Bellcranks. 6. Inboard carriage forward attach fitting. 7. Inboard carriage attach link. 8. Outboard carriage forward	0.40	**ACCESS NOTE: Flaps deployed.**

attach fitting. 9. Outboard carriage attach link. 10. Inboard programming roller. 11. Aft flap track attach fitting. 12. Aft flap track rollers. 13. Outboard programming roller.		
Perform a detail visual inspection of all internal portions of the flight control cable runs.	2.60	INTERVAL NOTE: Whichever occurs first. ACCESS NOTE: Passenger cabin floor panels between B.S. 663.75 and B.S. 727

Figure 45 – 737NG Aileron and Flap maintenance list

3.3 Costs and benefits

To provide an ideal comparison, the costs of the checks on the Airbus and the Boeing will be compared in one year. This provides a better view on the financial aspect, regarding to maintenance on these aircrafts. Firstly, the costs of the A-, B-, C- and D- check of the Airbus A320 and Boeing 737NG will be compared **(3.3.1)**. After, the maintenance costs on a PFC and a SFC of an Airbus A320 and the Boeing 737NG will be compared **(3.3.2)**. Subsequently, a comparison on unexpected maintenance will be made **(3.3.3)**. To conclude, an overview of the total costs will be made of the Airbus A320 and the Boeing 737NG **(3.3.4)**.

3.3.1. Costs a-, b-, c-, d-checks Airbus versus Boeing

The first comparison of the Airbus A320 and Boeing 737NG will be done on the normal A-, B-, C- and D-checks. First will be looked at the Airbus A320 **(3.3.1a)**, and thereafter at the Boeing 737NG **(3.3.1b)**.

3.3.1a Costs a-,b-,c-,d-checks Airbus A320

For the comparison, we've assumed a couple data. Firstly, this tables are based on, both the Airbus A320 and the Boeing 737NG, 3000 flight hours a year. The costs per hour of a mechanic amounts €50. The costs of an aircraft on ground amounts €2500 a day. The calculations in the table below, are based on these data.

The a-check on an Airbus A320 has to be made each 750 flight hours. Based on 3000 flight hours a year, this takes four a-checks in one year. Assuming one a-check takes 60 man hour on average, the a-check takes 240 man hour a year for the A320. The aircraft has to stay a half day on the ground for the a-check.

The b-check takes place every 2000 flight hours and has to be done 1,5 time a year. A b-check takes 150 man hours average, thus 225 man hours a year. The aircraft has to stay 4,5 day on the ground. The c-check has to be done every 7500 flight hours. This means the c-check's doesn't has to be done each year, but for the comparison we've expressed the costs in one year. Therefore, the c –check has to be done 0,4 times a year and costs 6000 man hours. This means the c-check costs 2400 man hours a year and the aircraft stands 5,6 days on ground.
Just as the c-check, the d-check doesn't has to be done each year. The d-check takes place each 6

years, or 0,167 times a year, including 40.000 man hour. This means 6666,67 man hour a year. The aircraft has to stay 10,2 days on the ground.

And so, see table below, the a, b, c and d-check costs €413.384 a year.

Airbus A320	Times per year	AOG	Man hours p/y	AOG costs p/d	Total costs
A check	4	0,5 days	240	€2500,-	€13.250,-
B check	1,5	4,5 days	225	€2500,-	€22.500,-
C check	0,4	5,6 days	2400	€2500,-	€18.800,-
D check	0,167	10,2 days	6666,67	€2500,-	€358.834,-
				Total:	€413.384,-

Figure 46 - Airbus A, B, C and D check costs

3.3.1b Costs a,b,c,d checks Boeing 737NG

For the Boeing, the same numbers are taken: AOG €2500 a day and mechanics costs €50 per hour. The a-check of the Boeing 737NG takes place each 500 flight hours and takes 60 man hours average. This means the a-check has to be done 6 times a year, in other words 360 man hours a year and leaving the aircraft out of the air for 0,75 days.

The b-check has to be done every 750 flight hours. This means the check has to be done 4 times a year. One b-check costs 150 man hours average, which means the b-check costs 600 man hours a year and the aircraft stays 4,5 days on the ground.

A c-check takes place every 18,5 month. This means the c-check has to be done 0,65 times a year and taking 6000 man hours per check. This means the c-check costs 3891,89 man hours a year average and 9,1 days on ground.

The d-check interval is 5 years and costs 40.000 man hour. On average, the d-check has to be done 0,25 times a year and therefore the total man hours amount 10.000 a year and 7,75 days on ground. This means, see table below, the total costs of the a-,b-,c- and d-check of a Boeing 737NG are €779.096 per year.

Boeing 737NG	Times per year	AOG	Man hours p/y	AOG costs p/d	Total costs
A check	6	0,75 days	360	€2500,-	€19.875,-
B check	4	4,5 days	225	€2500,-	€22.500,-
C check	0,65	9,1 days	3891,89	€2500,-	€217.345,-
D check	0,25	7,75 days	10000	€2500,-	€519.375,-
				Total:	€779.096,-

Figure 47 - Boeing A, B, C and D check costs

3.3.2. Maintenance checks Airbus versus Boeing

Below, the maintenance checks on respectively the Airbus A320 and the Boeing 737NG will be compared. The maintenance checks are based on the check of one primary – and one secondary flight control and the time is based on one mechanic working. The AOG costs are €2500 a day. Firstly the Airbus A320 will be mentioned **(3.3.2a)** and afterwards the Boeing 737NG **(3.3.2b)**.

3.3.2a Maintenance checks Airbus A320

As in 3.3.1, the costs of a mechanic is €50 per hour. The comparison on maintenance checks, is based on the checks of the ailerons and the flaps, respectively a primary- and a secondary flight control on both Airbus A320 and Boeing 737NG. The aileron-check takes 24 months on the Airbus A320. The check takes about 4 man hours and therefore costs 2 man hour a year average.

The flaps-check has to be done every year and takes 0,5 man hours. Because of these checks, the aircraft has to stay 2,5 hour on the ground. This brings the total costs of the aileron- and flaps-check to €460,41.

Airbus A320	Times per year	Man hours p/y	AOG Costs	Total costs
Aileron	0,5	2	€208,33	€383,33
Flaps	1	0,5	€52,08	€77,08
			Total:	€460,41

Figure 48 - Airbus Flap and Aileron maintenance costs

3.3.2b Maintenance checks Boeing 737NG

The aileron-check on the Boeing 737NG has to be done every 48 months and takes 6 man hours. This means an average of 0,25 times a year, equals 1,5 man hours.

The flaps-check takes 1 man hour every 24 months, thus 0,5 man hours a year. The aircraft has to stay 2 hours on the ground in total. This causes a total cost of €308,33 of the maintenance checks on the Boeing 737NG.

Boeing 737NG	Times per year	Man hours p/y	AOG Costs	Total costs
Aileron	0,25	1,5	€156,25	€231,25
Flaps	0,5	0,5	€52,08	€77,08
			Total:	€308,33

Figure 49 - Boeing Aileron-Flaps maintenance costs

3.3.3. Unexpected maintenance Airbus versus Boeing

There's always the possibility of an error or defect just before flight. Therefore, unexpected maintenance costs will also be compared. The AOG costs are €2500 a day average and the mechanics costs are €50 per hour. As usual, first the Airbus A320 will be discussed **(3.3.3a)** and after the Boeing 737NG **(3.3.3b)**.

3.3.3a Unexpected maintenance Airbus A320

The replacement of an PCU of the aileron takes 2,19 man hours on an Airbus A320. This causes as much aircraft on ground time. The replacement of an flap rotary actuator takes 4,22 man hours on the Airbus A320, with as much AOG time. This brings the total costs of unexpected maintenance on the ailerons and flaps to €988,71, see the table below.

Airbus A320	Man hours	AOG Costs	Total costs
Ailerons	**2,19**	€228,125	€338,11
Flaps	**4,22**	€439,58	€650,60
		Total:	€988,71

Figure 50 - Airbus Aileron-Flaps maintenance costs

3.3.3.b Unexpected maintenance Boeing 737NG

Replacing a PCU of the aileron on a Boeing 737NG takes 3,76 man hours and the replacement of a flap rotary actuator takes 3,20 man hours. This will bring the unexpected maintenance costs to €1073 on a Boeing 737NG.

Boeing 737NG	Man hours	AOG Costs	Total costs
Ailerons	3,76	€391,67	€579,67
Flaps	3,20	€333,33	€493,33
		Total:	€1073

Figure 51 - Boeing unexpected maintenance costs

3.3.4. Overview Airbus versus Boeing

For the ease of use, the total costs on the Airbus A320 and the Boeing 737NG are displayed below in two tables. These two tables show all the costs on the Airbus and the Boeing, and under each table the total costs.

Airbus A320	Costs per year
A check	€13.250,-
B check	€22.500,-
C check	€18.800,-
D check	€358.834,-
Aileron check	€383,33
Flap check	€77,08
Unexpected aileron replacement	€338,11
Unexpected flap replacement	€650,60
Total:	€414.833,12

Boeing 737NG	Costs per year
A check	€19.875,-
B check	€22.500,-
C check	€217.345,-
D check	€519.375,-
Aileron check	€75,-
Flap check	€25,-
Unexpected aileron replacement	€579,67
Unexpected flap replacement	€493,33
Total:	€780.268,-

Figure 52 - Airbus versus Boeing maintenance costs

3.4 Conclusion and Recommendation

After lining up all of the results from the research, provided in all the previous chapters, it is finally possible to reach a conclusion. After all the entire project was set in motion with a purpose, which was to find out which of the two types of aircraft, the Airbus A320 or the Boeing 737NG, contains a more cost-efficient flight control system when it comes to maintenance. Even though there are several big differences between these two systems, especially when it comes to flying the aircrafts, the conclusion of the project is still solely based on the costs.

Chapter **3.3: Costs and benefits** tells us that it is the Airbus A320 which is the aircraft that is cheaper to maintain than the Boeing 737NG. These costs are based upon the mandatory A,B,C and D-checks, several part-specific checks and the unexpected replacement of these parts. Taking all these things into account and comparing the two types of aircraft equally, the result is more than obvious. The Boeing 737NG has almost the double amount of maintenance costs of the Airbus A320 and thus the A320 is the more cost-efficient of the two.

Therefore the research group **1K** from the Hogeschool van Amsterdam recommends ALA to purchase the Airbus A320 for their new fleet. This obviously is the most cost-efficient of the two types of aircraft you asked us to research. All of our research leads to conclude to this fact and thus we recommend this aircraft to you.