Hogeschool van Amsterdam

# THE ESSENTIALS TO FLY

TECHNICAL CONTROLS OF AN AIRPLANE

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# Foreword

The members of the project team are students at the Hogeschool van Amsterdam, Aviation Studies. The project team has 7 members and they were given this project assignment during the third semester of the school year 2011-2012. The project had to be complete within seven school weeks and it involves the flight controls of an airplane. The project gives insight in the different flight control systems. The simple system of the Cessna C-172, the fly-by-wire system of the Airbus A320 and the conventional system of the Boeing 737NG. With that knowledge it is possible to research the differences in operational costs between the modern fly-by-wire system and the conventional system. This seven week during project will be finished with a presentation to the project teacher.

We are J.H. Hogervorst very grateful for his guidance during his project.

Group AVV1-AH, March 13th, 2012.

# Index

# Summary

Amsterdam Leeuwenburg Airlines had ordered group AVI1AH to research the differences between the flight control systems of the Airbus A320 and Boeing 737NG and to find out which system will have the lowest operational costs, when the procedures of three maintenance tasks are compared.

Theory about the creation of lift, boundary layers, changing airflow, creating pressures and wing profiles is needed before the flight controls can be explained. The lift formula is the formula which explains the operation of the flight controls.

There are two types of flight controls, primary and secondary. The primary flight controls are used to control the airplane. Ailerons provide roll movement, the elevator is used for pitching the airplane and the rudder provides yaw movement. The secondary flight controls support the primary flight controls. Flaps and slats are used to decrease the drag or lift and to increase the angle of attack of the airplane. Spoilers can support the ailerons, increase drag and decrease lift. Trim tabs can be used to ensure a stabilized position of the airplane.

All flight controls are restricted to requirements as stated by law. All primary flight controls need backup and some flight controls have to be manually controllable when needed. Each cable used in the system has to be at least 3.2 mm thick and the hydraulic system must be able to handle 1.4 times the used pressure without rupture of the system.

Each flight control system can be divided into different steps. There are 8 steps needed to complete a system. These steps are input, converting, transporting, correcting, strengthen, transporting, output and feedback. Both the aileron system as the spoiler system will be explained with the aid of a morphological research. This morphological research simply shows the differences between the flight control systems of the Airbus A320 and the Boeing 737NG.

The Airbus A320 uses a side stick for signal input, electrical wires for transport, computers for correcting and strengthening the signal and hydraulic pressure for the output. This flight control system is called the fly-by-wire system. The Boeing 737NG uses a steering column for the input, cables for transport, a feel and centering unit and a power control unit for the correcting and strengthening and also hydraulic pressure for the output of the signal. This flight control system is called the conventional system.

With the differences between the two flight control systems clarified, a comparison between the maintenance procedures can be made. First the ABCD-checks of both airplanes are compared, after this both airplanes are compared based on three maintenance tasks. These tasks are: checking aileron and spoiler signal transportation, lubricating spoiler actuator and inspection of spoiler actuator. Following from this research a survey of the costs of the Airbus and Boeing has been made. Here can be seen that the Airbus is less expansive as the Boeing.

This report ends with a recommendation. Here the recommendation to ALA has been given on which airplane they should purchase according to our research. After comparing the Airbus A320 and Boeing 737NG concerning their flight control system, the Airbus A320 is recommended to ALA.

# Prologue

The Amsterdam Leeuwenburg Airlines (ALS) is a low-cost airliner. This airliner wants to buy a couple of new airplanes. They want to buy either an Airbus A320 or a Boeing 737NG. Being a low-cost airliner, ALA's main goal is an airplane that is cheap to purchase and cheap in maintenance as well. The goal for the project group is to advise ALA which of the two airplanes they should buy, based on the best and cheapest flight control system.

This Project group, group AH from Aviation Studies at the university of Amsterdam, consist of seven freshmen students. A project teacher will accompany this group.

Chapter one will be the research about the flight controls. This research will be an important piece of the report, because it is impossible to give a good advice to ALA without having any knowledge about flight controls. In this chapter the flight controls of small and large airplanes will be explained. Larger airplanes differ in flight controls from smaller airplanes. The flight controls are split in primary and secondary flight controls. The primary flight controls are the: aileron, elevator and rudder. The secondary flight controls are the: flaps, slats, flight spoilers, ground spoilers and trim. The operation of these flight controls will be thoroughly explained. Also the requirements and legislation concerning the flight controls will be explained, here the requirements from ALA will be made clearer. The differences between flight controls of a small and large airplane will be made clear. In the functional research, all of the different sub-functions of the complete aileron system will be threated. This functional research will form the base for the morphological research. (**1**)
The second chapter begins with the morphological research of the ailerons. In this research, all of the options for each sub-function will be described. There will also be a morphological research for the spoiler system. Chapter two will also contain a comparison between the Airbus and Boeing hydraulic system. The chapter will end with a conclusion. (**2**)
In chapter three a recommendation will be given. This recommendation will be based on a multiple comparisons, for example the differences in ABCD-checks. The maintenance of both airplanes will also be compared. Comparing the aileron and the spoiler at three different maintenance tasks will be important in this recommendation. The costs will also be compared in a cost and benefit survey. This will give enough information to give a solid recommendation. (**3**)

All of the used terms in the text will be italic and will be explained in the glossary. The sources from which we got our information will be displayed in the bibliography. The bibliography can be found in the appendix. Other things, like the glossary and the process report can also be found in the appendix.

# 1. Flight controls

To make sure an airplane is able to move during flight, it is equipped with certain control surfaces. These control surfaces are called the primary flight controls. Every airplane has three primary flight controls. This is because an airplane has three axes to move around. These axes are the X-axis (*longitudinal axis*), the Y-axis (*lateral axis*) and the Z-axis (*vertical axis*). To make the airplane fly easier, it is equipped with secondary flight controls. There are differences between a small and a large airplane concerning flight controls. For example, a small airplane has less secondary flight controls than a large airplane. There are three of laws attached to the implementation and maintenance of the flight controls.

The first paragraph will focus on the theory on which the flight controls function. Here the deflection of air and the Bernoulli law and continuity law will be discussed. (**1.1**)
When the theory behind the flight controls has been explained, the function and any deviations of the three primary flight controls will be explained. The three primary flight controls consist of the aileron, the elevator and the rudder (**1.2**)
After the primary flight controls, the secondary flight controls will be explained. At first the flight controls that, for example, a Cessna C172 has and after that the secondary flight controls only the larger airplanes have. (**1.3**)
Large and small airplanes have differences in flight controls. What these differences are will also be discussed. An airplane is called small when the weight of the airplane is below 5700 kilogram. A large airplane is above 5700 kilogram. (**1.4**)
As told, there are a couple of requirements and legislations attached to the flight controls. There are also requirement from the client, which the system has to meet. (**1.5**)
This chapter will end with a functional research. In this research, a closer look will be taken at the complete system of the aileron and spoilers. So the steps need to be fulfilled between the action of the pilot and the reaction of the controls. (**1.6**)

## 1.1 Theory primary flight controls

An airplane has to be able to move around through the sky. These motions are controlled by the primary flight controls. These flight controls are, as been told earlier, based on aerodynamic laws and the changing of the airflow. In this paragraph this theory will be explained, but before tis laws can be explained, something has to be told about how an airplane creates lift (**1.1.1**). Another important thing to know before discussing flight controls is the differences in airfoil profiles (**1.1.2**).

### 1.1.1 Creation of lift

Every airplane has different wings, small airplanes have small wings, and larger airplanes have larger wings. These wings differ in sizes, because larger airplanes need more *lift* to get airborne than smaller airplanes. The amount of lift a wing creates depends on three main factors: the lift coefficient (CL), the dynamic pressure and the surface of the wing. These three factors can be put together in a formula, this formula is the lift formula (**formula 1.1**). This formula needs some explanation. There will be explained what the *lift coefficient* means and how it can be influenced (**1.1.1.a**). Also the *dynamic pressure* will be further explained (**1.1.1.b**). At last the definition of a wing surface is explained (**1.1.1.c**).

| | |
|---|---|
| **$L = cl \times \frac{1}{2}\rho v^2 \times S$** | **Cl = Lift coefficient**<br>**ρ = *density* [kg/m$^3$]**<br>**v = speed [m/s]**<br>**S = wing surface [m$^2$]** |

**Formula 1.1 Lift formula**

### 1.1.1.a Lift coefficient

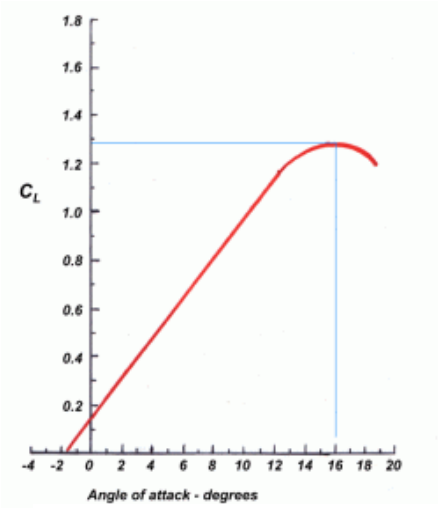
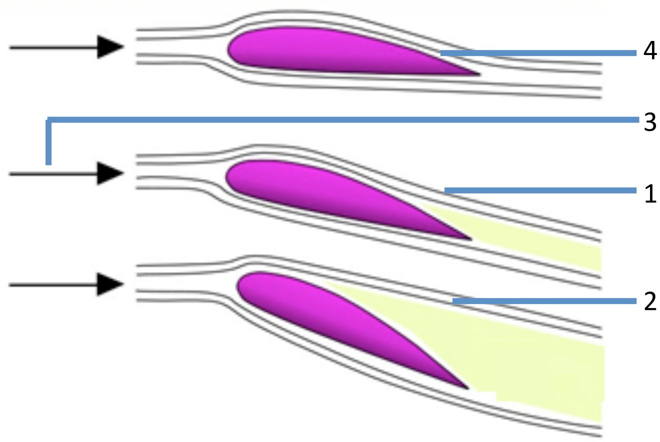


Figure 1.1 CL - α graphic

The lift coefficient is a dimensionless number that gives information about the lift characteristics of a wing. A wing that delivers a lot of lift when the plane is horizontal has a large CL. The size of CL also depends on the *angle of attack* (α). When an airplane flies with a positive angle of attack, the CL of the plane will increase, when an airplane flies with a negative angle of attack the CL will decrease. The size of CL does have a maximum, this is when the plane flies with the greatest possible angle of attack. If the angle of attack will than increase even more, the wing will not deliver any lift anymore. This is, because in that case the airflow is not able to follow the profile of the wing anymore. This has to do with the ***boundary layer*** of the airflow around the airfoil. In **figure 1.1** a CL- α graphic is shown. Here can clearly be seen that that the CL has a maximum at an angle of attack of 16 degrees nose up. When the angle of attack increases a little bit more, the CL decreases and when the angle of attack than increases even more, the wing will not deliver any lift anymore.

- ***Boundary layer***

When an airplane wing flies through the air, a boundary layer arises at the surface of the wing. This boundary layer can be a *laminar* or *turbulent stream*. A stream is laminar when the streamlines do not cross each other. A turbulent stream is when the streamlines do cross each other. Whether it is a laminar or turbulent stream depends on the speed of the airflow, the surface of the wing, the shape of the wing and the angle of attack. In lower speeds, the stream is laminar. At higher speeds, the stream turns turbulent. In **figure 1.2** three profiles with different angles of attack and stream lines around it can be seen. From a specific low speed or with a specific large angle of attack, the boundary layer is almost not capable of holding on to the surface of the wing, when this happens it is flying at the α max. When flying even slower or increasing the angle of attack, the boundary layer begins to separate from the surface of the wing (**1**). This means that the wing starts creating less lift. When the speed gets even lower or the angle of attack larger, the entire boundary layer will separate and the wing will not deliver any lift anymore (**2**) this is the point where the CL – α graphic stops. in the figure, the airflow comes from the left (**3**). There is also a wing with a normal airflow around it (**4**).




1. Separation boundary layer
2. Complete separation
3. Direction of the airflow
4. Wing with normal boundary layer

Figure 1.2 Boundary layer

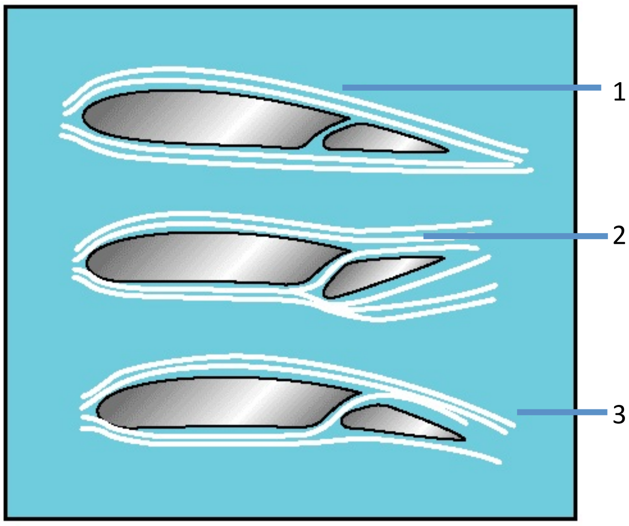
### 1.1.1.b dynamic pressure

The dynamic pressure in the lift formula claims that if the density of the air (ρ) increases, an airplane can deliver more lift. An airplane wing basically cuts through the air with its wings, because the air has a certain density a wing will experience that some pressure is needed to cut through it. This

pressure is needed for the creation of lift. So if the density of the air increases, the dynamic pressure and hence the lift will increase. If the density of the air decreases, the dynamic pressure and hence the lift will decrease.
The dynamic pressure in the lift formula also claims that if the speed (v) of the airflow increases, an airplane can deliver more lift. So with the more speed an airplane wing travels through the air, the more lift it creates. The speed of the airflow has a great impact on the dynamic pressure. This is because in the dynamic pressure formula the speed is squared. So if the speed increases, the dynamic pressure increases quadratic. If the speed decreases, the dynamic pressure will decrease quadratic.
The control surfaces on an airplane partially use the dynamic pressure to control the airplane. this occurs with the **changing in the airflow**.

- ***Changing the airflow***

When the captain uses his flight controls, somewhere on the wing or tail of the airplane a control surface will move. This control surface will cause a deflection of the airflow in some way. For example, when a control surface behind the wing changes from a horizontal stance to a stance facing 15° downward, the control surface will cause the airflow to deflect downwards. This will create an opposite force upwards, following from Newton's third law, action is minus reaction. With this principle it is able to control an airplane. In **figure 1.3**, three airplane wings are shown. The upper wing has its control surface in a normal position, it is not causing any deflection of the air (**1**). The middle wing has its flight controls facing upward. It is clear to see that the streamlines deflect upwards, resulting in a force downwards (**2**). The last wing has its flight control facing downward (**3**). Here the air is deflected downwards, resulting in an upward force.




1. Normal situation
2. Upward control surface
3. Downward control surface

**Figure 1.3 Deflection of the air**

### 1.1.1.c Wing surface

The amount of lift a wing delivers also depends on the surface of the wing. The surface of the wing can be calculated with the span times the mean geometric *chord* line. The chord line of a wing is the line between the *leading edge* and the *trailing edge* of the wing. The leading edge is de front-side of a wing, the trailing edge is the back-side. If the chord line gets larger, the surface of the wing gets larger and the wing will therefore deliver more lift. Flight controls also use this principle to move the airplane. When the flight controls move they change the lift of the surface, this is called pressure distribution.
A wing, for example, creates lift because the airflow will go around the airfoil. The streamlines above the wing get compressed and the streamlines under the wing will travel further apart from each other. Therefore the airflow above the wing will travel faster than the airflow beneath the wing, this can be explained following the **continuity law**. **The Bernoulli law** than claims that if the air will travel

faster, the pressure will drop. This will cause an under-pressure above the wing. On the underside of the wing the opposite will occur, and there will be an over-pressure. The greater the surface of the wing, the more this pressure deferens will occur.
So if a control surface changes from a horizontal stance to a stance facing downward, the chord will increase and therefore the surface of that wing will increase and that wing will deliver more lift. If a control surface changes to a stance facing downward, the chord will decrease and therefore the amount of lift decreases.

- ***Continuity law***

This law claims that if an airflow flows through an "imaginary" pipe, this flow has a constant *mass flow*. This law than claims that the density, the speed and the surface of the flow can change, but the mass flow will stay constant. This is shown in (**formula 1.2**). When an airplane wing flies through the air, the surface the streamlines can travel through also changes just like in that imaginary pipe. The surface which the streamlines can travel through above the wing decreases and the surface which the streamlines can travel through under the wing increases. Therefore the speed of the airflow above the wing increases and the speed of the airflow underneath the wing decreases.

| | |
|---|---|
| $\rho_1 \cdot v_1 \cdot A_1 = \rho_2 \cdot v_2 \cdot A_2$ | ρ = density [kg/m$^3$]<br>v = speed [m/s]<br>A = surface [m$^2$] |

**Formula 1.2 Continuity law**

- ***Bernoulli law***

This law says that the sum of the potential, dynamic and kinetic energy stays equal to the total amount of energy in a flow. This means that if the speed of an airflow gets higher, the pressure of this flow will get lower and vice versa. This law is show in (**formula 1.3**). As just told, when the surface which the streamlines can travel through decreases above the wing, the speed will increase. This Bernoulli law than claims that if the speed increases, the pressure will decrease. This means that the pressure above the wing will decrease. Underneath the wing the opposite will occur and there the pressure will increase. This means that the airplane wing wants to go up, creating lift.

| | |
|---|---|
| • $P_1 + \rho \cdot g \cdot h_1 + ½ \cdot \rho \cdot v_1^2 = P_2 + \rho \cdot g \cdot h_2 + ½ \cdot \rho \cdot v_2^2$<br>• $P_1 + ½ \cdot \rho \cdot v_1^2 = P_2 + ½ \cdot \rho \cdot v_2^2$ | P = pressure [N/m$^2$]<br>ρ = density [kg/m$^3$]<br>g = gravitational force [9.81 m/s$^2$]<br>h = altitude [m]<br>v = speed [m/s] |

**Formula 1.3 Bernoulli law**

The Bernoulli and continuity law can only be used when they comply with some conditions. These conditions are, that the gas, which will be researched, is: not compressible, the molecules will exert no friction on each other, *adiabatic* and that it is a stationary stream. As been told earlier, a stream can also be turbulent. This depends on the speed of the airplane. Airplanes often fly with speeds causing a turbulent stream at the wings. This means that the continuity and Bernoulli law do not fully comply. Furthermore the gas airplanes fly through in real life are compressible and the molecules do exert friction on each other. However the Bernoulli and continuity law do not fully comply in real life, the principle of creating lift stays the same.

### 1.1.2 Airfoil profiles

As has just been told, another influence on the lift that an airplane can create is the *airfoil profile*. There are three main types of airfoils, the *conventional profile* (**1.1.2.a**), the *symmetrical profile* (**1.1.2.b**) and the *supercritical profile* (**1.1.2.c**). These different profiles have different lift properties.

### 1.1.2.a Conventional profile

The conventional profile has more bulging at the upper side of the airfoil than at the underside of the airfoil. This means that the distance the air has got to travel over the airfoil is much greater than the distance the air has got to travel under the airfoil. This is very favourable for the amount of lift the wing delivers.

### 1.1.2.b Symmetrical profile

The symmetrical profile has the same amount of bulging at the upper side of the wing as at the underside of the wing. Therefor the airflow above the wing has got to travel the same distance as the airflow under the wing. This means it creates less lift as the conventional profile, but it is easier to handle because the boundary layer will separate at lower speeds.

### 1.1.2.c Supercritical profile

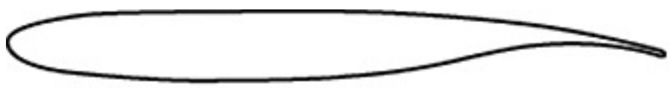


Figure 1.4 Supercritical airfoil

The supercritical profile is, as shown in figure 1.4, almost the same as a conventional profile, only it has got a dent at the underside of the wing. This wing delivers less lift than a conventional airfoil and it is much more difficult to fly. The airflow will separate at higher speeds, so the airplane must fly pretty fast to deliver enough lift. Even though this airfoil profile is commonly used at commercial airplanes, this is because they create little drag which is favourable for fuel consumption.

## 1.2 Primary Flight Controls

Every airplane has three primary flight controls. These flight controls are needed to control the airplane around his axes. *The ailerons* (1.2.1) move the airplane around the longitudinal axis, this movement is called *rolling*. *The rudder* (1.2.2) provides *yaw*, this turns the airplane around its vertical axis. The last primary flight control are *the elevators* (1.2.3), the elevators provides *pitch* around the lateral axis.

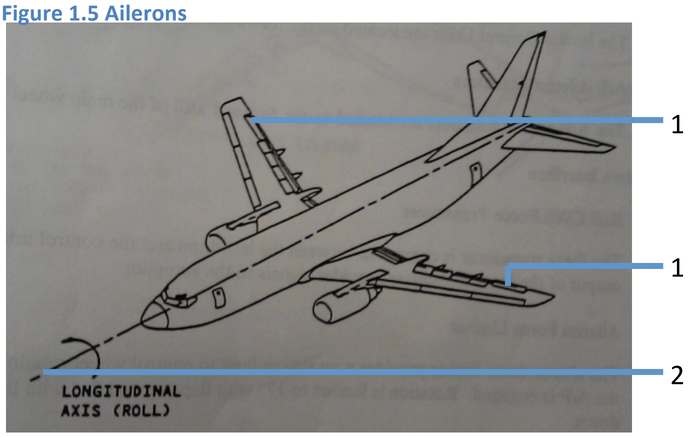
## 1.2.1 Ailerons

Each airplane has the ability to roll due to the ailerons, this is because the ailerons deflect the airflow and therefore create pressure differences (1.2.1.a). But this rolling is not just positive, it has certain side effects (1.2.1.b).

### 1.2.1.a Operation

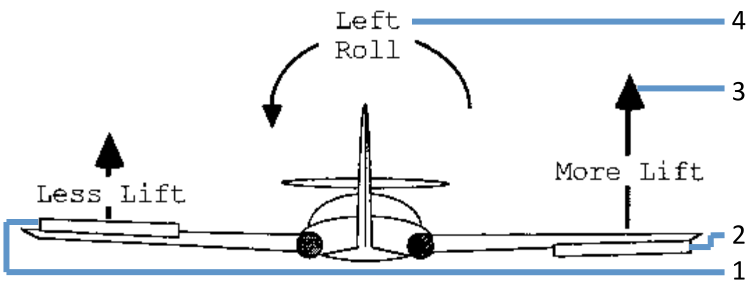
The ailerons (figure 1.5) are located at the end of the wings (1) and are capable of moving up- and downwards and cause a movement around the longitudinal axis (2).

Figure 1.5 Ailerons




1. Ailerons
2. Longitudinal axis

If the airplane is moving in a straight line the ailerons will be ‘flat’, that means they are in one line with the wing. The pilot will move the *steering column* to the left if he wants to make a roll to the left (**figure 1.6**). With a left roll the aileron on the left wing will move upwards (**1**). At the same time the aileron on the right wing will make the same movement, only downwards (**2**). The air stream under the right wing will have a longer distance to travel due to the downwards deflected aileron, so the air will flow slower, compared to the air above the wing. This will result in a larger pressure under the wing and an increase of lift. This increase of lift is on the right wing larger (**3**) than on the left wing, causing the airplane to roll to the left (**4**). Together with an increase of the lift, the drag will increase. This is because a deflection of the aileron changes the surface of the wing. A larger surface creates more lift, as the lift formula states. But a larger surface ‘catches’ also more air, so the drag will increase.




1. Aileron “up”
2. Aileron “down”
3. Larger lift
4. Left roll

**Figure 1.6 Roll**

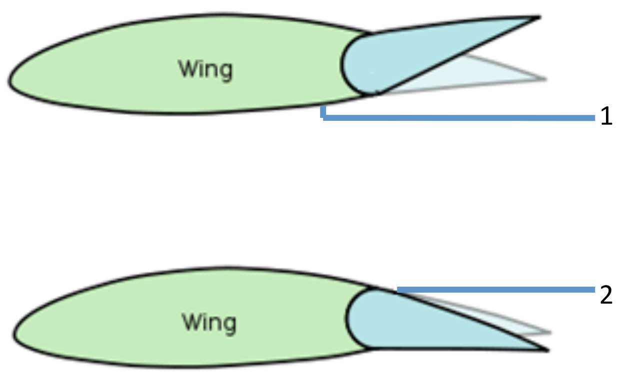
### 1.2.1.b Side effects

The roll movement, as caused by the ailerons, can bring some side effects with it:

1. *Adverse yaw*
2. *Dutch Roll*

- ***Adverse yaw***

Increased drag as a result from a larger lift, will causes a wing to ‘slow down’. When the airplane makes a roll to the left, the right wing will ‘slow down’ more than the left wing and this will turn the airplane, around the vertical axis, to the right. This side effect is called ‘adverse yaw’. This adverse yaw (**figure 1.7**) can be countered by using differential ailerons. Using differential ailerons, the aileron moving upwards (**1**) will move a little bit further than the aileron moving downwards (**2**).
This will cause more drag so the difference in drag between the wings is less. This will reduce a great part of the side effect. Though the rudder is needed to fully correct adverse yaw.




1. Upwards moving aileron
2. Downwards moving aileron

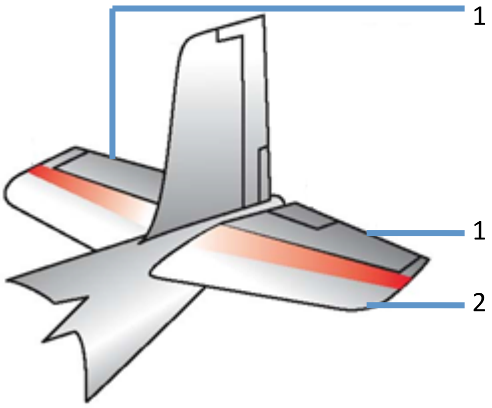
**Figure 1.7 Differential ailerons**

- ***Dutch roll***

The Dutch roll is a natural side effect that appears when the ailerons and the rudder are used at the same time. This means that the wings will turn in a circle around the lateral axis. This can occur when making a turn. When the airplane rolls to the left to make a left turn, the airplane will yaw to the right. When the rudder is used to correct this, a Dutch roll can occur. This happens when the rudder keeps changing the angle with the airflow. So when the rudder makes a movement and goes back to his neutral position and this action repeats itself several times. Therefore the airplane will keep yawing. Because the airplane also rolls, this will result in a continuous combined movement of yawing and rolling. This is called the Dutch roll. Using a yaw damper can prevent the Dutch roll.

### 1.2.2 Elevators

In **figure 1.8** the elevators are shown. The elevators (**1**) are located at the tail of the airplane and they are a part of the horizontal stabilizer (**2**).



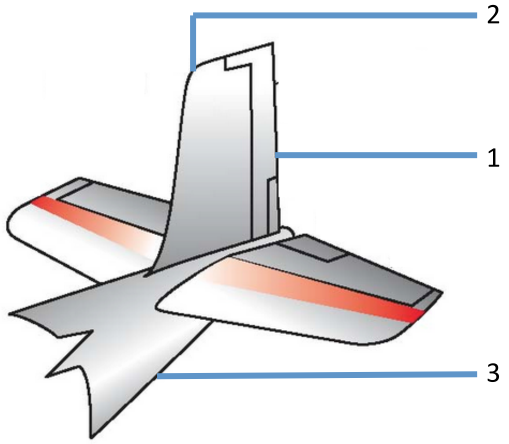

1. Elevators
2. Horizontal stabilizer

**Figure 1.8 Elevators**

The elevators are capable of moving up- and downwards. Elevator movement causes pitch around the lateral axis. If the pilot wants to climb, he has to pull the steering column towards him, the elevators will move upwards. To descent the pilot has to push the steering column away from him. The elevators move simultaneously in the same direction, not in the opposite direction like the ailerons. The elevators and the horizontal stabilizer have a negative lift. This means that they want to 'push' the airplane downwards. The wings produce positive lift, they want to 'push' the airplane upwards. These two types of lift have to be in balance for a horizontal flight.
When the elevators move upwards, the air stream under the elevator will have a shorter distance to travel, so the air will flow faster, compared to the air above the elevator. This will result in a lower pressure so the air will stream from above the elevator under the elevator. This causes a force pushing the tail down and the nose of the airplane will pitch up. The opposite will happen when the elevator moves downwards.

### 1.2.3 Rudder

As shown in **figure 1.9**, the rudder (**1**) is located at the tail of the airplane and is part of the vertical stabilizer (**2**). All these surfaces, including the elevator and the horizontal stabilizer, are part of the *empennage* (**3**).




1. Rudder
2. Vertical stabilizer
3. Empennage

**Figure 1.9 Rudder**

The rudder turns the airplane around the vertical axis and is controlled with pedals. Each pilot has two foot-pedals. Applying pressure to the right pedal makes the nose swing to the right, applying pressure to the left pedal swings the nose to the left. The rudder will deflect to the right to swing the nose to the right. When the rudder deflects to the right, it will bend the air flow like the ailerons and the elevators. It creates a high pressure at the right side of the rudder and a low pressure at the left side (These pressures are relatively high and low). This will cause the air to flow from the right side to the left side, pushing the tail to the left and causing the airplane to turn to the right.
In flight, however, the rudder is not used to turn the airplane. Either the ailerons or flight spoilers are used. The rudder is used to control the turn and to prevent the airplane of experiencing adverse yaw. The combination of ailerons and a correctly used rudder in a turn is called a coordinated turn.

## 1.3 Secondary flight controls

A large airplane contains, beside the primary flight controls, secondary flight controls. Secondary flight controls are not needed to keep an airplane airborne, but they make flying easier and safer. At first the secondary flight controls of the Cessna-172 will be explained (**1.3.1**). Secondly the secondary flight controls of a large airplane will be explained (**1.3.2**). The secondary flight controls of a large airplane are trim, flaps and slats, elevator- and rudder *trim taps*.

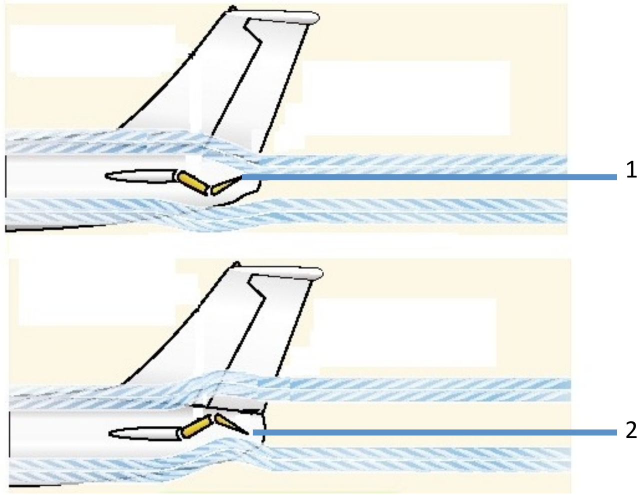
### 1.3.1 Secondary flight controls Cessna-172

In order to get an airplane stabilised in flight or to be able to fly at lower speed, secondary flight controls are needed. There are two secondary flight controls on the Cessna 172: the trim tab (**1.3.1.a**) and the flaps (**1.3.1.b**).

#### 1.3.1.a Trim tab

Trim tabs are located on the trailing edge of the elevators and are movable surfaces. The main goal of a trim tab is to ensure a stabilized position of the airplane without any force on the control column. To move the trim tab a turn wheel is used. When the pilot operates the turn wheel in the cockpit a degree partitioning will indicate the results of the trim wheel. The trim tab will move the opposite way of the elevator. The airflow will than cause the elevator to move to the correct position as can be seen in **figure 1.10**. The upper image shows the trim tab in an upward position, causing the elevator to move down and therefore causing the nose of the airplane to pitch down(**1**). The second image shows the trim tab in a downward position causing the elevator to move upward and therefore causing the nose of the airplane to pitch up (**2**). When the trim tab is applied and the position of the airplane is stable, the pilot does not have to use the control column to keep that position. But if the position of the airplane due to any reason disrupts, the pilot must operate the

control column for the rest of the flight to fly a horizontal and stabilized path. By adjusting the trim tab the airplane can be stabilized and the pilot does not have to use the control column.

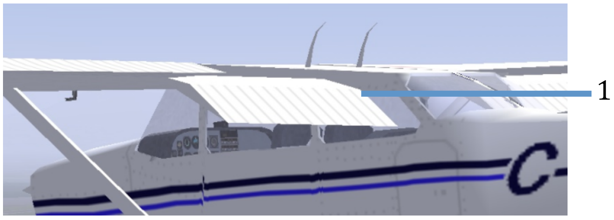



1. Trim tab facing upward
2. Trim tab facing downward

Figure 2.10

### 1.3.1.b Flaps

Flaps of a Cessna-172 are located at the trailing edge of the wings and are movable surfaces (**figure 1.11**). The main goal of the flaps is to increase the chord and camber of a wing. When the surface of the wing increases, the lift will increase. This will cause the critical angle of attack to increase. When flaps are moved, they always will move symmetrically. The pilot is able to adjust the flaps in the cockpit by using the flap lever. During start, flaps are applied to increase the lift at a low speed. During cruise flaps aren't applied, this is due to the large drag that will generate the flap. During landing, flaps are applied to increase lift. Also the speed of the airplane will decrease because of the huge amount of drag.




1. Flaps

Figure 1.11 Flaps

## 1.3.2 Secondary flight controls large airplane

The *secondary flight controls*, shown in **figure 1.12**, of a large airplane are flaps (**1**) (**1.3.2.a**) and slats (**2**) (**1.3.2.b**), which influence the take-off and landing speed. The elevator-trim (**3**) and rudder-trim (**4**) keep the plane in a certain position to relieve the pilot of keeping pressure on the controls. And the flight and ground spoilers (**5**) make it possible to turn and create a shorter braking distance (**1.3.2.c**) .

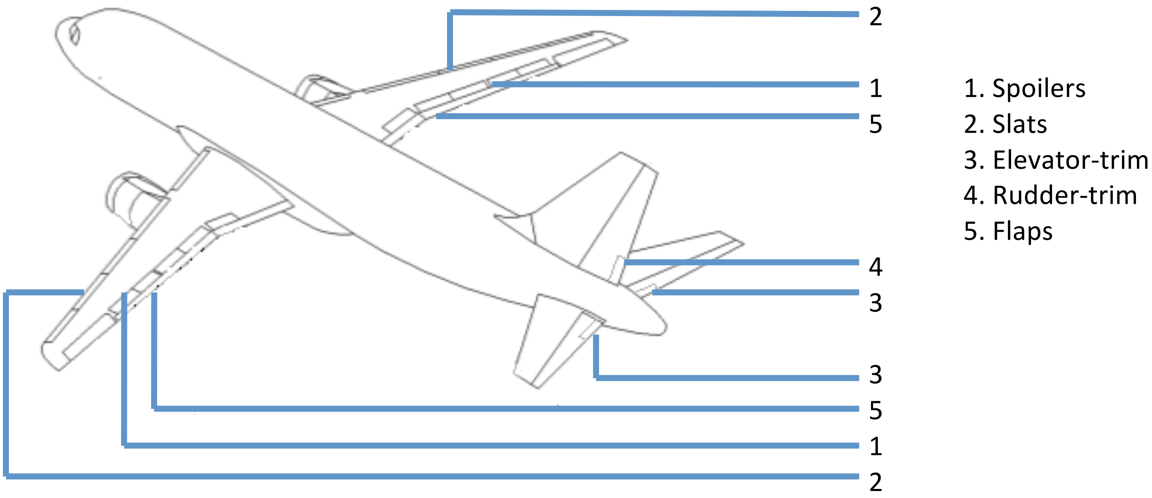



Figure 1.12 Secondary flight controls

### 1.3.2.a Flaps

Flaps are panels on the wing that make the wing surface larger by pulling out. Flaps can be located at the trailing edge as well at the leading edge. The main goal of using flaps is to increase the camber of the wing. As a result both lift and drag will increase, so it is possible to fly with a lower speed. The critical angle of attack will decrease as a result of the increased camber. This is also a positive effect for landing performance. At the start the drag cannot be too great, in proportion to the lift. At the landing the opposite happens, the flaps are used to create a great amount of drag.
There are four main kinds of flaps: the ***conventional flap***, the ***split flap***, the ***fowler flap*** and the ***slotted flap***.

- ***Conventional flap***

The conventional flap (figure 1.13) is the simplest flap there is. There is a part and the end of the wing that can be moved downwards.

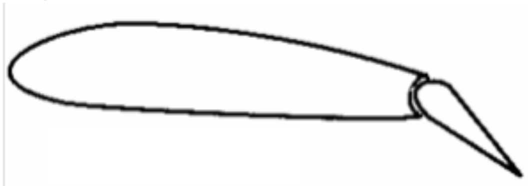


Figure 1.13 Conventional flap

- ***Split flap***

The split flap (figure 1.14) has two parts, a top part and a part under the wing. The part under the wing can move, the top part is attached to the wing and cannot move.

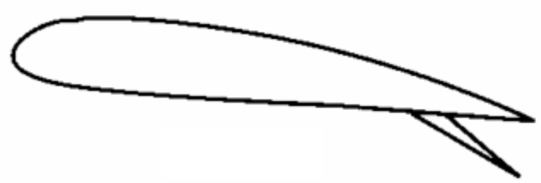


Figure 1.14 Split flap

- ***Fowler flap***

The fowler flap (**figure 1.15**) does not only increase drag, but it also increases the surface. This is because the flap can also be extended, besides just move downwards.

**Figure 1.15 Fowler flap**

- ***Slotted flap***

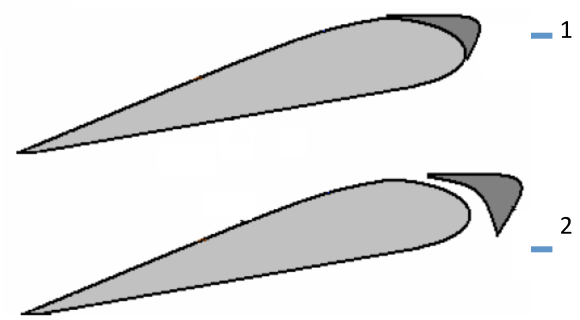
The slotted flap (**figure 1.16**) does not differ much from the conventional flap. The only difference is that the slotted flap has a opening when the flap moves downwards. The opening works like a venturi, the air is compressed en accelerates when it goes through the opening. The opening will cause the boundary layer to hold on to the wing longer.

**Figure 1.16 Slotted flap**

There are few more different flaps, these are shown in **appendix I**.

### 1.3.2.b Slats

*Slats* are always at the leading edge. Slats are used by takeoff and landing to create, same as at a small airplane, a larger wing surface to increase lift at a slower speed. When a slat (**1**) is activated, and it has moved out, there arises an opening (**figure 1.17**). This is called a slot (**2**). A slot creates a larger *stalling-angle*. This allows the pilot to fly with a bigger angle of attack compared to no use of slats. Because the use of slats change the stall behavior, the effect of slots is very useful.




1. Slat
2. Slot

**Figure 1.17 Slats**

### 1.3.2.c Flight and ground spoilers

The *spoilers* are on the top of the wing located. There are two types of spoilers. Spoilers that are used both in flight and on the ground are called ***flight spoilers***. Spoilers only used during touchdown are called ***ground spoilers***. Spoilers can also be used as **speed brakes**.

- ***Flight spoilers***

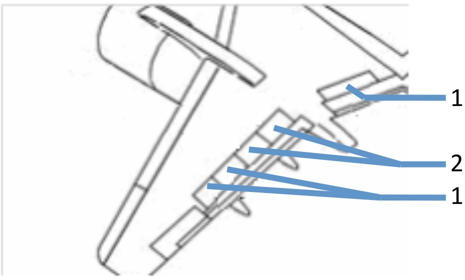
Flight spoilers (1) are located on the wing and are in connection with the ailerons (figure 1.18). When fully deflected, they provide the major amount of *roll control* by reducing drag of the lower wing. With narrow wings, it is not possible to use large ailerons. The force on the ailerons would be too large. Therefore spoilers are used to assist the smaller ailerons during roll.

- ***Ground spoilers***

Ground spoilers are located on the wing (2). When an airplane comes close to the ground, the air underneath the wings will be compressed. This effect is called the ´*ground-effect*´. As a result, more lift is created. The ground spoilers are used to ´destroy´ this lift. The ground spoilers push the plane down by bending the airflow up. They can only be extended near the ground during landing.

- ***Speed brakes***

The *speed brakes* are same surfaces as the flight spoilers, only when they act as speed brakes, they are not fully deflected. As soon as the airplane touches the ground, the speed brakes are extended. This will cause a greater drag and reduced braking distance. The speed brakes can also be used during a high-speed descent. This is because the speed brakes increase the drag, but do not influence the airflow around the wing.




1. Ground spoilers
2. Flight spoilers

**Figure 1.18 Spoilers**

## 1.4 Legislation and Requirements

Both airplanes, Boeing 737NG and the Airbus A320, that the company ALA wants to purchase are restricted to certain laws. These laws are based on the European Aviation Safety Agency (EASA). The laws can be found in legislation (1.4.1). Furthermore ALA has some requirements that need to be fulfilled (1.4.2).

### 1.4.1 Legislation

There are two important categories in the civil aviation. Light airplanes, such as the Cessna, are airplanes that are below the weight of 5700 kg have to meet EASA certification specification (CS) 23 (1.4.1.a). Heavy airplanes are above 5700 kg, these airplanes have to meet EASA CS-25 (1.4.1.b). The law ensures the reliability of the controls.

#### 1.4.1.a CS-23

The light airplanes follow the EASA legislation of certification specification 23. The sub paragraph 23 of the legislation of EASA specifies light airplanes. The laws that concerns to this research can be divided in to: aileron, elevator and rudder. A general law that applies to all of the 'light' flight control is that the forces can be amplified between 100% and 125% of the computed moments, depending on the accuracy. The maximum forces that the aileron, elevator and the rudder may endure during moving or torques are shown in table 1.1.

| | Maximum force during moving or torques of a stick control | Maximum force during moving or torques of a wheel control |
|---|---|---|
| Aileron | 298 N | 222 DNm |
| Elevator | 890 N | 890 N |
| Rudder | 890 N | |

**Table 1.1 maximum forces**

The D at DNm is wheel diameter in metres. Furthermore the forces of an elevator can be calculated during the turn of the airplane. For the stick control the weight divided by 14 N and for the wheel control it is the weight divided by 10 N.

### 1.4.1.b CS-25

Heavy airplanes follow the sub paragraph 25 of the legislation of EASA. The laws that are needed for this research can be divided into **motion and effect of cockpit controls**, **backup or redundancy laws**, **cable laws**, **hydraulic laws**, **aileron laws**, **elevator laws** and **rudder laws**.

#### *Ad1 Motion and effect of cockpit controls*

Cockpit controls must designed in accordance to the following movements and resulting move:

- When the flight control is moved to the right (clockwise) the aileron moves downwards.
- When the flight control is pulled rearward the elevator moves and the nose moves up.
- When the right pedal is pushed down the rudder moves to right and the nose moves the right.
- When the flight control is moved forward the wing-flaps is going up.
- When the flight controls is moved rearwards the flaps go down.
- When the trim tab is trimmed the airplane rotates similar to the axis of the trim tabs

#### *Ad2 Backup or redundancy*

Redundancy or backup systems are needed for all of the below controls or system. The minimum amount of backup or redundancy for any single failure are two or more backup systems.

#### *Ad3 Cable system*

Each cable is not smaller than 3.2 mm in diameter. Each cable system must be designed so there will be no hazardous during operation when going trough tension or temperature changes.

#### *Ad4 Hydraulic system*

The design of hydraulic system can resist rupture up to a factor of 1.4 of the operating pressure. Secondly it may not permanent deformation. Thirdly it can withstand the fatigue effects off al effects that it is design for. Lastly it can perform under all environmental condition that the plane is certificated for.

The laws for the maximum forces of the aileron, elevator and the rudder are shown in **table 1.2**.

*Table 1.2*

| | Maximum force during moving or torques of a stick control | Maximum force during moving or torques of a wheel control |
|---|---|---|
| Aileron | 445 N | 356 DNm |
| Elevator | 1112 N | 1335 N |
| Rudder | 1335 N | |

### 1.4.2 Requirements

The airplanes are, beside the law, restricted to ALA requirements. ALA has assigned the team to investigate the Boeing 737NG and the Airbus A320. The flight controls of these airplanes need to be researched for their construction and operation. Additionally they need to be researched for differences in operational costs. ALA also wants to know which airplane, Boeing 737NG or Airbus A320, will have the lowest operational costs. The comparison will be between the three most important maintenance procedures according to a four different aspects: safety, cost, maintenance time and durability (**table 1.3**). The four aspects are given a weighting factor between one and three. A weight of one is less important, a weight of two is important and a weight of three is most important. Safety has a weight of three, because the safety of the crew and the passengers is the most important. The law demands a certain safety of the systems, but it can never be safe enough. Therefore it still gets a weight of three. The cost has weight of three, because ALA is a low budget company it has to keep an eye on the expenses. Maintenance time has a weight of two, this is the time an airplane is on the ground for maintenance. Durability has a weight of one, this is the time that a component can last before it is needed to repair, check or replace it.

| **Aspect** | **Weight** |
|---|---|
| Safety | 3 |
| Cost | 3 |
| Maintenance time | 2 |
| Durability | 1 |

**Table 1.3 weight factors**

## 1.5 Differences between large and small airplane

The main differences between small and large airplanes are the size, flight speed, weight and the therefore required lift. An airplane is called ‘small’ when it applies to the CS-23 safety regulations. When an airplane applies to the CS-25 safety regulations is called a large airplane. To create enough lift by low speed at a large airplane, leading edge devices are commonly used (**1.5.1**). Large airplanes have spoilers because of their higher speed (**1.5.2**). The *hydraulic system* ensures that the flight controls can be used without a lot of force required from the pilot (**1.5.3**).

### 1.5.1 Leading Edge Devices

Leadings edge (LE) devices can be leading edge flaps or slats. These devices create, the same way as flaps do, a larger wing surface to create more lift at slower speed. Only large airplanes have those devices because they need more lift to get their weight off the ground.

### 1.5.2 Spoilers

Because of the weight and speed of a large airplane the take-off- and braking distance are much longer. To decrease the braking distance, a large airplane uses ground spoilers. To reduce speed in flight, flight spoilers can be used. Flight spoilers are also used to support the ailerons by rolling the airplane. This reduces the amount of forces on the ailerons. The reason small airplanes do not have spoilers is the low speed they fly with.

## 1.5.3 Hydraulic System

The control surfaces of a large airplane are very difficult to operate or to control using human muscle power only. Therefore a hydraulic power assistance system is needed to overcome the enormous forces acting on the plane and to operate the flight controls.
When comparing flight controls system of a large airplane with a small one such as the Cessna 172, significant differences can be seen in design and size. The flight controls of a Cessna are controlled by cables, push pull *rods* and quadrants. Such constructions of flight control systems are rarely used at larger airplanes. Large airplanes use a mechanical cable or electrical wire to transport the pilots input to a hydraulic actuator. This actuator moves the control surfaces.
When the pilot moves one of his flight controls, in a large airplane, it is enhanced by a hydraulic system, because the amount of force that is too great to move for a human being. The hydraulics of an airplane work on the laws of Pascal (**1.5.3.a**). The basics of a hydraulic system are shown in (**1.5.3.b**).

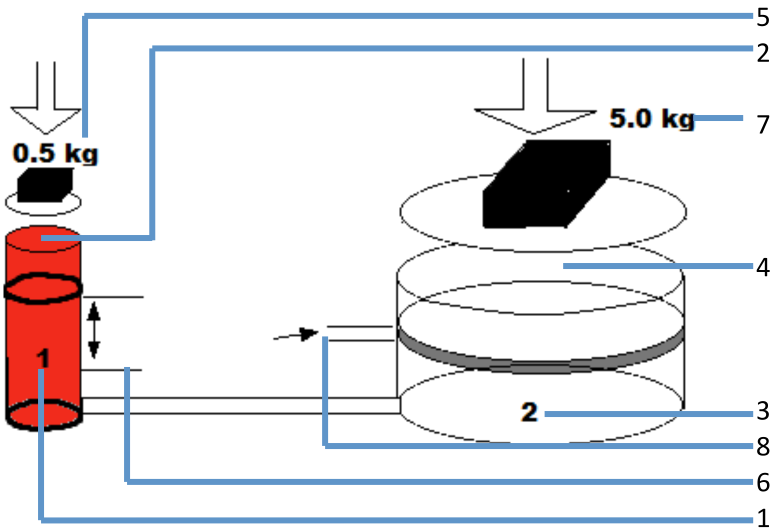
### 1.5.3.a Theory hydraulics

The flight controls of large airplanes operate using hydraulic pressure. The hydraulics of an airplane works on the law of Pascal. Pascal law is determined by the fluid density, gravitation force and the height of the fluid. The fluid density [**ρ**] is different for every fluid. Airplanes use an incompressible petroleum based fluid. When the airplane flies from one location to another, the gravitation force [**g**] is constantly changing. The height [**Δh**] is the distance of the fluid compared to the bottom of the cylinder. The formula that can be diverted out the statement is shown in **formula 1.3**.

| | |
|---|---|
| **$\Delta P = \rho g (\Delta h)$** | **p = hydraulic pressure [N/m$^2$]**<br>**ρ = fluid density [kg/m3]**<br>**g = gravitation force [m/s2]**<br>**Δh = height [m]** |

**Formula 1.3 Pascal law**

For example two combined cylinders (**figure 1.19**), cylinder 1 (**1**) which has a diameter of 0.025m (**2**) and cylinder 2 (**3**) which has a diameter of 0.25m (**4**). In this set up the two cylinders are combined, so the pressure in cylinder 1 is equal to the pressure in cylinder 2. When a weight of 0.5kg (**5**) is put on cylinder 1, the height of the fluid in the system decreases by 0.25m (**6**). Because an incompressible fluid is used, the fluid height of cylinder 2 increases, because the pressure is distributed equally throughout the system. As a result, the cylinder on the right is able to move ten times the original weight, a weight of 5kg (**7**) over a distance of 0.025m (**8**). This means, a ratio of 1 to 10 is applied in the system.

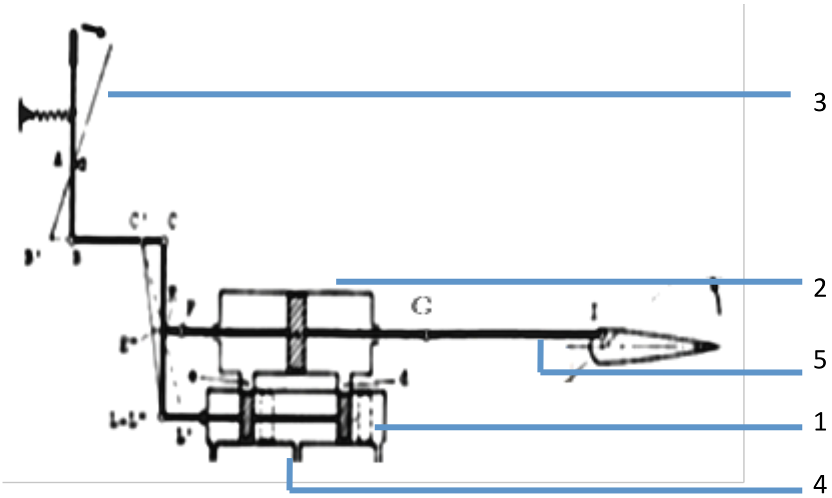



1. Cylinder 1
2. Diameter Cylinder 1
3. Cylinder 2
4. Diameter Cylinder 2
5. Weight on Cylinder 1
6. Height difference Cylinder 1
7. Weight on Cylinder 2
8. Height difference Cylinder 2

**Figure 1.19 Two combined cylinders**

### 1.5.3.b Basic Hydraulic system

The hydraulic power control is the most common used method to operate the flight control surfaces, with a *full powered controls* (**Figure 1.20**). When an input is given, it will be translated into a movement of, for example, the rudder. The operation of the system will be further described.
The two main parts of the hydraulic power system are the servo control valve (**1**) and the actuator (**2**). The actuator movement result in a deflection of the rudder, which has been operated by a servo control valve. The operation of the system is activated by an input, by pulling the steering column (**3**) through the points B, C and L this points will displace to the B', C' and L'. This will lead to a connection of the servo valve with the actuator connections "e" and "d". When this connection is made, through the pressurised hydraulic fluid (**4**), this will move the actuator from the right side to the left side. The rod (**5**), which is connected to the actuator, will also displace to the left, during this movement, the control surface of the rudder will deflect. As result of this, point E will translate to E' making L' to move to its initial position L. As be seen from the graph, the connection of the servo valve "e" and "d'' will be closed and the movement of the actuator is stopped.
The system has one drawback; the pilot does not experience any aerodynamic feedback, but just the resistance of the servo valve. When there is no aerodynamic feedback, the pilot could damage the airplane by great deflection of the control surfaces at high speeds. So an artificial feeling must be introduced into the system. This can be done by springs that are attached to the steering column. An artificial feel will be experienced when the input is pushed or pulled.




1. Servo Control Valve
2. Actuator
3. Steering Column
4. Pressure Valve
5. Actuator rob

**Figure 1.20 Full Powered Control**

Beside the full powered controls, there is also a system called *power assisted controls* (**Figure 1.21**). The only difference is that an extra rod (**6**), which is placed on the upper side of the actuator. This extra rod connects G and C through D. As the operation of the system is identical to the full powered controls, only now, the pilot's inputs are connected with, for example, the rudder. This means, in a situation where the actuator fails to work, the pilot can still operate the rudder.

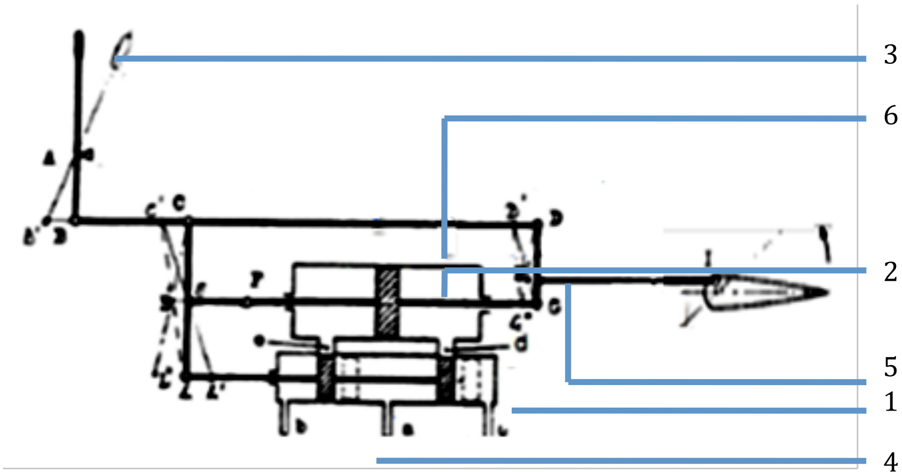



**Figure 1.21: Power assisted controls**

## 1.6 Functional research

Concerning the functional research, the way the flight controls move will be explained from the start until the end. This will be restricted to only one primary flight control and one secondary flight control, the ailerons and the spoilers. The needed functions will be clarified by a table (figure 1.22). The schematic steps of the system of the ailerons and the spoilers will be exactly the same as given beneath. Therefore the system of the aileron and the spoiler is explained in the same steps. The steps are as following:

1. Input
2. Converting
3. Transporting
4. Correcting
5. Strengthen
6. Transporting
7. Output
8. Feedback

### *Ad1 Input*

The input consists of the force from the pilot. This will cause a movement on the control wheel or levers, where the ailerons and spoilers are being controlled.

### *Ad2 Converting*

The input of the pilot on the control wheel will be converted into a signal. The conversion of this force will take place within the mechanism of the control wheel.

### *Ad 3 Transporting*

After the force is converted, the signal needs to be transported to a corrector. The cable that will be used for transportation depends on the properties of the signal.

### *Ad 4 Correcting*

Because of the errors or deviations that take place during converting or transportation of the signal, there is a correction made to take out these errors.

### *Ad 5 Strengthen*

After the correction of a signal, the signal is too weak for controlling a flight control. This is where the signal gets strengthened.

### *Ad 6 Transporting*

The strengthened signal will be transported to the output.

### *Ad 7 Output*

After the signal is transported, the ailerons and spoilers can be controlled.

### *Ad 8 Feedback*

The pilot feels the forces that the ailerons have to endure through feedback.


**Figure 1.22 Functional research**

# 2 Processing system

In order to make a good comparison between the flight control systems of the Airbus A320 and the Boeing 737NG, the research will be restricted to one primary flight control and one secondary flight control. The ailerons will be used as a primary flight control and the entire aileron system will be explained with a morphological research (2.1). The spoilers will be used as a secondary flight controls and the spoiler system will also be explained with a morphological research (2.2). These flight controls work with the aid of hydraulic power. Therefore the different hydraulic systems and the differences between the hydraulic systems will be explained (2.3). This chapter will end with a summary (2.4).

## 2.1 Morphological research ailerons

In the morphological research the different sub-functions, from the input to the feedback, of the aileron system will be examined. There are eight different sub-functions which together make the complete system of an aileron. These different functions are: Input (2.1.1), converting (2.1.2), transporting (2.1.3), correcting (2.1.4), strengthen (2.1.5), transporting (2.1.6), output (2.1.7) and feedback (2.1.8). Al of these functions will be examined and explained. This paragraph will end with a complete survey of the Airbus (fly-by-wire) and Boeing (conventional) aileron system (2.1.9).

### 2.1.1 Input

The input can be done with a **conventional steering column** or by a ***side stick***. With the input, commandos will be given at which the ailerons must react.

- ***Conventional steering column***

The conventional steering column is a long column with a steering wheel attached to it. The whole column is able to move forward and backwards. The captain's steering column is connected to the ailerons and the first officers steering column is connected to the spoilers. But the steering columns are also connected to each other, to ensure the captain can activate the spoilers and the first officer the ailerons. They are also connected to ensure the two steering columns make the same movement.

- ***Side stick***

The side stick is a stick that can be moved around, it look like a joystick used for computers. Different from the conventional steering column is the fact that the side stick is operated using only one hand. By moving the side stick to the left or the right the ailerons, or the spoilers when needed, will be activated.

### 2.1.2 Converting

The input given by the pilot must be converted into a signal that can be transported to the ailerons. This conversion can be done with a **control wheel drum** or with a **flight control computer**.

- ***Control wheel drum***

The control wheel drum converts the movements of the steering wheel in a movement of a cable. This conversion is done by a system of pulley's and levers.

- ***Flight control computer***

The flight control computer converts the movement of the side stick in an electrical signal. This device measures the movement of the side stick and based on that creates an electrical signal which is send to the next step in the aileron system.

### 2.1.3 Transporting

The signal created by the converter must be transported to the next step in the system. This transportation can either be done with a **cable**, or with an **electrical wire**.

- ***Cable***

The signal, made by the control wheel drum, is transported by a cable. This cable is made of strong steel. This is because it must not break during flight.

- ***Electrical wire***

The signal, made by the flight control computer, is transported by an electrical wire. This wire is made of copper cable because this conducts electricity well.

### 2.1.4 Correcting

The transported signal can contain errors, therefore it has to be corrected. This correcting can either be done with a **feel and centering unit**, or with an **elevator and aileron computer**.

- ***Feel and centering unit***

The steel cable is connected to a feel and centering unit. This unit gives the pilot the feeling of the actual forces on the ailerons. This unit also makes sure that the ailerons will be pushed back into the neutral position.

- ***Elevator and aileron computer***

The elevator and aileron computer (ELAC) receives the signal from the electrical wire and will calculate how much the ailerons have to be deflected, based on the speed. The *ELAC* is programmed so, that the same movement of the side stick will generate the same turn movement, with every speed.

### 2.1.5 Strengthen

The corrected signal is to weak and has to be strengthened. This can either be done with a **power control unit**, or with an **elevator and aileron computer**.

- ***Power control unit***

To strengthen the signal from the feel and centering unit, a power control unit is used. This unit strengthens the mechanical signal with the aid of hydraulic pressure. Therefore, a pressure of over 200 bar is used.

- ***Elevator and aileron computer***

The ELAC corrects the received signal and also strengthens it. The received electric signal is strengthened to a much stronger electric signal.

### 2.1.6 Transporting

The strengthened signal has to be transported before it can be performed. This transportation can either be done with a **cable**, or with an **electrical wire**.

- ***Cable***

The strengthened mechanical signal is transported with a strong steel cable. This is because it must not break during flight.

- ***Electrical wire***

The strengthened electric signal is transported with an ARINC 429 cable. This cable can handle much stronger electric signals than a copper wire.

### 2.1.7 Output

The strengthened signal will be used to activate the ailerons. This can either be done with an **aileron-actuator** or with an **servo-mechanism**.

- ***Aileron-actuator***

The PCU is connected to the aileron through an actuator. This actuator controls the aileron. Each aileron has its own actuator. A switch in the cockpit can be used to open or close the valves in the hydraulic system, so each aileron can be isolated from hydraulic pressure, if necessary.

- ***Servo-mechanism***

After the strengthened signal from the ELAC is transported, the signal will end at a servo-mechanism. The servo-mechanism converts the electric signal to a movement. The principle of the servo-mechanism is based on an electric motor that cause a movement in a pushing or rotating run, with the aid of hydraulic pressure.

### 2.1.8 Feedback

After the output, the pilot feels the forces that act on the steering column or side stick through resistance. This feedback can be produced through a **feel and centering unit** or through an **artificial feel mechanism**.

- ***Feel and centering unit***

The feel and centering unit gives the pilot the feeling of the actual forces on the ailerons. This unit receives feedback from the actuator and transports it to the steering column.

- ***Artificial feel mechanism***

The artificial feel mechanism is located under the sidestick. This mechanism offers resistance to the movement of the sidestick through springs and gives the pilot the actual feeling of the forces that act on the ailerons.

### 2.1.9 Survey aileron systems

The aileron system of the Airbus and Boeing are different from each other. In **figure 2.1** the complete Airbus aileron system is shown, in **figure 2.2** the complete Boeing system is shown.


**Figure 2.1 Complete Airbus aileron system**

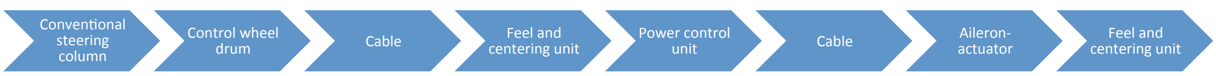



**Figure 2.2 Complete Boeing aileron system**

## 2.2 Morphological research spoilers

In this morphological research the different sub-functions, from the input to the output, of the spoiler system will be examined. There are eight different sub-functions which together make the complete system of a spoiler. These different functions are: Input (**2.2.1**), converting (**2.2.2**), transporting (**2.2.3**), correcting (**2.2.4**), strengthen (**2.2.5**), correcting 2 (**2.2.6**), transporting (**2.2.7**) and output (**2.2.8**). Al of these functions will be examined and explained. A lot of these functions are

the same as, or work the same as the aileron systems. This paragraph will end with a complete survey of the Airbus (fly-by-wire) and Boeing (conventional) spoiler system (2.2.9).

### 2.2.1 Input

The input can be done with a **conventional steering column** or by a **side stick**. With the input, commandos will be given at which the ailerons must react.

- ***Conventional steering column***

The conventional steering column is a long column with a steering wheel attached to it. The whole column is able to move forward and backwards. The captain's steering column is connected to the ailerons and the first officers steering column is connected to the spoilers. But the steering columns are also connected to each other, to ensure the captain can activate the spoilers and the first officer the ailerons. They are also connected to ensure the two steering columns make the same movement.

- ***Side stick***

The side stick is a stick that you can move around, it look like a joystick used for computers. Different from the conventional steering column is the fact that the side stick is operated using only one hand. By moving the side stick to the left or the right the ailerons, or the spoilers when needed, will be activated.

### 2.2.2 Converting

The input given by the pilot must be converted into a signal that can be transported to the spoilers. This conversion can be done with a **control wheel drum** or with a **flight control computer**.

- ***Control wheel drum***

The control wheel drum converts the movements of the steering wheel in a movement of a cable. This conversion is done by a system of pulley's and levers.

- ***Flight control computer***

The flight control computer converts the movement of the side stick in an electrical signal. This device measures the movement of the side stick and based on that creates an electrical signal that is send to the next step in the spoiler system.

### 2.2.3 Transporting

The signal created by the converter must be transported to the next step in the system. This transportation can either be done with a **cable**, or with an **electrical wire**.

- ***Cable***

The signal, made by the control wheel drum, is transported by a cable. This cable is made of strong steel. This is because it must not break during flight.

- ***Electrical wire***

The signal, made by the flight control computer, is transported by an electrical wire. This wire is made of copper cable because this conducts electricity well.

### 2.2.4 Correcting

The transported signal can contain errors, therefore it has to be corrected. This correcting can either be done with a **feel and centering unit**, or with an **elevator and aileron computer**.

- ***Feel and centering unit***

The steel cable is connected to a feel and centering unit. This unit gives the pilot the feeling of the actual forces and corrects the signal.

- ***Elevator and aileron computer***

The elevator and aileron computer (ELAC) receives the signal from the electrical wire and will calculate how much the spoilers have to be deflected, based on the speed. The ELAC is programmed so, that the same movement of the side stick will generate the same turn movement, with every speed.

### 2.2.5 Strengthen

The corrected signal is to weak and has to be strengthened. This can either be done with a **power control unit**, or with an **elevator and aileron computer**.

- ***Power control unit***

To strengthen the signal from the feel and centering unit, a power control unit is used. This unit strengthens the mechanical signal with the aid of hydraulic pressure. Therefore, a pressure of over 200 bar is used.

- ***Elevator and aileron computer***

The ELAC corrects the received signal and also strengthens it. The received electric signal is strengthened to a much stronger electric signal.

### 2.2.6 Correcting 2

The strengthened signal is corrected for a second time with the spoiler system. This second correction also determines which spoilers will be deflected. This second correction can either be done with a **spoiler mixer and ratio changer**, or with a **spoiler elevator computer**.

- ***Spoiler mixer and ratio changer***

The spoiler mixer and ratio changer corrects the strengthened signal and determines which spoilers have to be deflected to get the desired roll. After that, the signal goes to the actuators of the spoilers that have to deflect.

- ***Spoiler elevator computer***

The spoiler elevator computer (SEC) receives the signal from the elevator and aileron computer and will determine which spoilers have to be deflected to get the desired roll. After that, the signal goes to the actuators of the spoilers that have to deflect.

### 2.2.7 Transporting

The strengthened signal from the second correction has to be transported before it can be performed. This transportation can either be done with a **cable**, or with an **electrical wire**.

- ***Cable***

The strengthened and corrected mechanical signal is transported with a strong steel cable. This is because it must not break during flight.

- ***Electrical wire***

The strengthened and corrected electric signal is transported with an ARINC 429 cable. This cable can handle much stronger electric signals than a copper wire.

### 2.2.8 Output

Finally the signal will be used to activate the spoilers. This can either be done with an **spoiler actuator** or with an **servo-mechanism.**

- ***Spoiler actuator***

The spoiler mixer is connected to the spoiler through a spoiler actuator. Each spoiler has it own actuator that controls the spoiler. A switch in the cockpit can be used to open or close the valves in the hydraulic system, so each spoiler can be isolated from hydraulic pressure.

- ***Servo-mechanism***

After the signal from the SEC is transported, the signal will end at a servo-mechanism. The servo-mechanism converts the electric signal to a movement. The principle of the servo-mechanism is based on an electric motor that cause a movement in a pushing or rotating run, with the aid of hydraulic pressure.

### 2.2.9 Survey spoilers system

The spoiler system of the Airbus and Boeing are different from each other. In **figure 2.3** the complete Airbus spoiler system is shown, in **figure 2.4** the complete Boeing system is shown.


**Figure 2.3 Complete Airbus spoiler system**


**Figure 2.4 Complete Boeing spoiler system**

## 2.3 Hydraulic systems

Manufactures Airbus and Boeing both use two different hydraulic systems to control the ailerons and spoilers. To understand the operation of these controls, first the main differences of the hydraulic system of the ailerons and spoilers from Airbus (**2.3.1**) and Boeing (**2.3.2**) must be clear. After this research the differences of both systems will be discussed (**2.3.3**).

### 2.3.1 Main hydraulic system Airbus

The hydraulic system of an Airbus consists of three separate systems. These systems are called the green (**2.3.1.a**), blue (**2.3.1.b**) and yellow (**2.3.1.c**) system. They all have their own hydraulic reservoir and there is no possibility to transfer hydraulic fluid from one to another system. The reason for separating the hydraulic system is for safety reasons (**2.3.1.d**).

#### 2.3.1.a Green system

A pump, driven by engine 1, is pressurizing the green hydraulic system. This system powers on both sides one of the aileron cylinders. This system also supplies hydraulic pressure to the left and right spoilers 1 and 5. Signals to activate these controls are coming from ELAC 1 and 2.

#### 2.3.1.b Blue system

An electric pump is pressurizing the blue system. In case of an emergency, a pump driven by *the ram air turbine* (RAT) keeps the blue system pressurized. Because this is the back-up system, all of the

primary flight controls are connected. This system also supplies hydraulic pressure to left and right aileron 3. Signals to activate these controls are coming from ELAC 1 and 2, and SEC 1.

#### 2.3.1.c Yellow system

A pump, driven by engine 2, is pressurizing the yellow hydraulic system. An electric pump can also pressurize this system to be able to use hydraulics on ground when the engines have stopped. Left and right spoilers 2 and 4 are powered by this system. Signals to activate these controls are coming from SEC 1 and 3.

#### 2.3.1.d Separation for safety

The separation of hydraulic systems among the ailerons and spoilers are there for safety reasons. If an ELAC or SEC becomes damaged, another one can take over. This is the same for the hydraulic systems. If one of three becomes damaged the ailerons and spoilers are not uncontrollable because another could take over.

### 2.3.2 Main hydraulic system Boeing

The hydraulic system of a Boeing 737NG also consists of three systems. The three systems power the different flight control units. These systems are called the system A (**2.3.2.a**), system B (**2.3.2.b**) and the standby system (**2.3.2.c**). Each hydraulic system has a fluid reservoir located in the main wheel well area. The standby system is available in case of a hydraulic failure. They all have their own hydraulic reservoir and there is possibility to transfer hydraulic fluid from system B to the standby system (**2.3.2.d**).

#### 2.3.2.a System A

A pump, driven by engine 1, is pressurizing the system A. System A can also be driven by an AC electrical motor-driven pump. This system powers on both sides one of the aileron cylinders and the flight spoilers (two on each wing).

#### 2.3.2.b System B

A pump, driven by engine 2, is pressurizing the system B. System B can also be driven by an AC electrical motor-driven pump. This system powers on both sides one of the aileron cylinders and the flight spoilers (two on each wing).

#### 2.3.2.c Standby hydraulic system

The standby hydraulic system is a backup system if system A and/or B fails. This system can be activated automatically or manually. It works by a single electric motor-driver pump. The electric motor driven pump powers the thrust reversers, the rudder, the leading edge flaps and slats (extend only) and the standby yaw damper.

#### 2.3.2.d Extra back-up for safety

There is an extra backup in the hydraulic standby system. This system is used in case of a hydraulic leakage of the standby system. For example when there is a leakage in the standby system the back-up system takes over. The pressure of system B pressurizes this back-up system.
Ailerons and spoilers are not included in the standby system. The only option to roll the airplane is by using manually aileron control. This means spoilers cannot be used during an failure in system A and B.

### 2.3.3 Differences between hydraulic system Airbus and Boeing

The main difference between both systems is the working of the three systems in a hydraulic system. Airbus uses three separate colored systems and the Boeing uses the three cooperating systems. In case of a leakage in the hydraulic back-up system, Boeing can transfer fluid from the B system to the

standby system. This can be seen as an extra back-up system. The last possibility to control the airplane, in case of failure, is by using human force.
These options are not possible by the Airbus. Airbus has instead of this, the possibility to pressurize the hydraulic system by using the RAT. In case of a broken flight computer such as an ELAC or SEC, there is always one left to take over.

## 2.4 Summary

Manufactures Airbus and Boeing both use a different flight control system. Airbus uses a fully electrical system. This means the system is from the input, created by a side-stick, till the hydraulic system actuator electrical. This is called a fly-by-wire system. Boeing uses a flight control system that uses steel cables to transport the input, created by a steering column, to the actuator and flight controls. By Boeing the pilot can feel the amount of force put on the flight controls in his steering column. This is called a conventional system.
The hydraulic system of Airbus consists out of three separate systems. All three systems are used during flight but one is at the same time the back-up system and does only pressurizes all primary flight controls by using an electrical pump. Power to keep this pump running, in case of an emergency, is provided by the ram air turbine (RAT). Boeing also uses three systems, but has one only used in case of an emergency. This system is called the standby-system. If there is a leakage in the standby- system, one of the main systems can supply the standby-system of hydraulic fluid and pressure.
Because Boeing has also connected the steel cables to the flight controls, they can still control the airplane by human force in case of lost hydraulic pressure. Airbus therefore keeps the back-up system pressurized by power provided by the RAT.

# 3. Maintenance and costs

In the previous chapter, research has been done about the implementation of the Airbus A320 and the Boeing 737NG. In this chapter research will be done which of these two airplanes conforms the most to the demands of ALA.
For this research, first a comparison between the differences in ABCD-check from the Airbus and the Boeing will be made. (3.1).
Three different maintenance tasks, concerning the aileron and spoiler, which must be performed on both airplanes will be compared. The comparison will be made based on the differences in the time needed and the costs made during this maintenance. (3.2)
Keeping both airplanes operational will cost ALA money. Which of the two airplanes will cost ALA the least amount of money during operation will be examined by analyzing the costs and bates of both airplanes. (3.3)
Following from this research one of the two airplanes will have the best operational costs. Together with the outcomes of other comparisons between both planes a recommendation will be given to ALA. (3.4)

## 3.1 Maintenance checks

All airplanes have to get checked every once in a while to ensure the airplane is still able to operate correctly. However, it is not necessary to take the entire plane apart, because this will cost a lot of time and money. Therefore there are a couple of different checks. In one check only the most important components are checked, this check will often occur. In another check the entire plane is taken apart, this check will almost never occur. In this paragraph these checks for Airbus A320 (3.1.1) and Boeing B737NG (3.1.2) will be described. Further the differences between these two airplanes will be explained (3.1.3).

### 3.1.1 Checks Airbus A320

The Airbus checks are divided into three different checks, the A-check (3.1.1.a), the C-check (3.1.1.b) and the D-check (3.1.1.c). With each of these different checks, a different inspection will be done.

#### 3.1.1.a A-check

The A-check from the Airbus A320 has to be done either every 600 flight hours or 90 days. This check can be at the gate. For example: when an airplane stays at the gate all night, the A-check can be done. This check will take approximately ten to eleven hours when no big errors are found. The A-check contains an engine inspection and some other minor inspections.

#### 3.1.1.b C-check

The C-check has to be done either every 6000 flight hours, eighteen to twenty months or after 3000 flight cycles. This check has to be done in the hangar. The C-check takes approximately from three days up to one week. It depends on the amount of components or parts that needs to be replaced or repaired. With this check, for example, a structural inspection of the airframe will be done.

#### 3.1.1.c D-check

The D-check has to be done every six years. This check only has to be done every six years, because the entire airplane will be taken apart. All of the components will be checked and some components will be replaced. This check will take approximately one month and has to be done in a hangar.

### 3.1.2 Checks Boeing 737NG

For a Boeing 737NG there are three different checks. These checks are; the A-check (3.1.2.a), the C-check (3.1.2.b) and the D-check (3.1.2.c). These checks differ in time and inspections.

#### 3.1.2.a A-check

The A-check must be executed every 600 flight hours, 300 flight cycles or after 70 days. It depends on when one of these three limits are reached first. The A-check has eight different programmes, the programmes start from A1 till A8. Just like the Airbus, the A-check will be executed at the gate.

#### 3.1.2.b C-check

The C-check will be performed every 6000 flight hours, 24 months or 3500 flight cycles. Just like the A-check, the C-check will be done when the first limit is reached, it does not matter whether this is the flight hours, flight cycles or time. The C-check is divided in twelve different programmes, starting from C1 till C12. The C-check is just like the check for an Airbus, it is done in a hangar and it takes approximately the same amount of time.

#### 3.1.2.c D-check

The D-check has to be done every ten years. At this check every piece and part of the aircraft will be checked. The whole procedure takes a minimum of whole month. This check will be performed in a hangar, just like for an Airbus.

### 3.1.3 Differences ABCD-checks between Airbus A320 and Boeing 737NG

There are not many differences between the Airbus and the Boeing when it comes down to the ABCD-checks. The A-checks of both airplanes are basically the same. The C-check of the Airbus has to be done earlier than the C-check of the Boeing when it comes down to time or flight cycles. When it comes down to flight hours, the interval of both airplanes is the same with the C-check. With the D-checks the airplanes do differ from each other. The Airbus has to have a D-check every six years, whereas the Boeing needs a D-check every ten years. However, the Airbus D-check takes a maximum of one month, where the D-check of the Boeing takes at least one month. The airplanes differ the most in the D-check.

## 3.2 Three Maintenance tasks

To maintain the airworthiness of an airplane maintenance task have to be done. Maintenance task of the Airbus and Boeing differ in time and task. Airbus and Boeing use different signal transportation mechanisms, because of this some maintenance task do not occur on both systems (3.2.1). The spoiler actuator is the device that creates the movement of the spoiler. To ensure the spoiler is operable is needed to inspect the spoiler actuator (3.2.3).

### 3.2.1 Maintenance check aileron and spoiler signal transportation

Because Airbus and Boeing both use a different transportation system for the aileron and spoiler signal, different maintenance is needed. Airbus (3.2.1.a) uses an electronic fly-by-wire system and Boeing (3.2.1.b) uses a conventional system with cables. A fly-by-wire system can check itself and does not have moving parts. Boeing instead, has moving parts that have to be checked and greased.

#### 3.2.1.a Aileron and spoiler signal transportation components of Airbus

Airbus uses an electrical flight control system. Because of this, there are no moving parts such as steel-cables. Therefore lubrication of cables is not needed. To check the electrical wires of Airbus the *Centralized Fault Display System (CFDS).* This system includes the *built-in test equipment (BITE)*. The purpose of this system is to make maintenance tasks easier by displaying default messages. This system can check each electronic system and shows any faults or failures on the display. The ATA reference number is also shown, this to search the task in the maintenance manual more convenient. Checks are automatically done on ground and in flight.

#### 3.2.1.b Aileron and spoiler signal transportation components of Boeing

This subparagraph uses an example of a general inspection of the flight control cable system. Because of the share amount of cables, the mechanics has to check the cable identification in the maintenance manual before any maintenance task can be done. So the first step, with any of the cable maintenance tasks is to identify which of the cables belong to the relevant flight control. Once the relevant cables are found, the inspection can begin. Every cable with a different purpose has different specification of length, thickness and material composition. The cable has to be within a certain dimension of length and thickness. If the cable is not in the correct dimension, the cable has to be removed and replaced. This is the second step. If the cables are in the correct dimension the cables need to be cleaned. The third maintenance step is to remove the filth and the old grease. The old grease and filth is removed from the surfaces of the full length of the cables with a cotton wiper. When the cables are clean they need to be lubricated. Some of the control cables do not need to be lubricated, because the cables are made of stainless steel. The grease or oil can damage the internal surfaces of the stainless steel cables, which decreases the durability of the cable. So only the carbon steel and corrosion resistant steel (CRES) are lubricated. The mechanic has to apply a light even grease on the cables. Certain areas, like the air pressure seals and the quadrants, don’t need to be lubricated, because they will receive grease during the cable movement. After the grease is applied, the excessive grease is removed with a clean cloth. The final step is to adjust the cables. The cables tension has to be adjusted to the right amount of force in Newton’s.

### 3.2.2 Lubrication spoiler actuation

The actuator of the spoilers is the part that converts the hydraulic pressure into a movement. This part can be seen as a cylinder. Because this is a metal-to-metal construction, lubrication is needed. Airbus (3.2.2.a) and Boeing (3.2.2.b) both use the same method of moving the spoilers.

#### 3.2.2.a Lubrication spoiler actuation of Airbus

Lubrication of the spoiler servo-controls 1 to 5 has to be done every two thousand flight hours, or fifteen months by an Airbus A320. Flaps and slats have to be fully extended as preparation for this task. After preparation, the mechanic has to be at the trailing edge of the wing underneath the spoiler-surface. At first the piston must be cleaned so there is no old grease and dirt on it. Then the servo-control bearings have to be lubricated until the new grease comes out. The unwanted grease that flows out has to be removed from the servo-control. This task takes 0,25 man-hours each actuator.

#### 3.2.2.b Lubrication spoiler actuator of Boeing

The lubrication of the spoiler actuator can be divided between ground and flight spoiler lubrication. They differ in the preparation and which parts need to be lubricated. The preparation of maintenance tasks starts, for both the ground and flight spoiler, with supplying electrical power to the airplane. This is needed to activate the hydraulic systems A and B. After the preparation the ground and flight spoiler differ in maintenance.

If the mechanic has to lubricate the flight spoiler, the mechanic has to extend the trailing edge flaps. Once the trailing edge flaps are extended, the speed brake lever has to be turn to the up position. The flight actuators are now exposed. The mechanic has to grease the rod end 1 and rod end 2. Once

the lubrication is done, the mechanic has to retract the trailing edge flaps. After the retraction of the trailing edge flaps the speed brake lever has to be moved to the down position. Then the mechanic needs to shut off hydraulic pressure A and B.
If the mechanic has to lubricate the ground spoiler, the mechanic starts with switching the switch of spoiler A and spoiler B to the off position. This will remove the hydraulic pressures from the flight spoiler. After this, the mechanic has to extend to trailing edge flap and put the speed brake lever to the up position. The ground spoiler actuators are now exposed. The mechanic has to grease the pillow blocks of the actuator. Once the lubrication is done, the trailing edge flaps needs to be retracted. The mechanic then has to put the lever to the down position and shut of the hydraulic pressure A and B. After this the switches of spoiler A and B have to be switched to the on position. At the end of both the ground and flight spoiler maintenance, the external electrical power has to be removed and the maintenance task is finished.

### 3.2.3 Inspection of spoiler control

The spoiler servo control units are located on the trailing edge of the wing with the piston connected to the spoilers. This component controls the movement of the spoiler depending from a signal from the SEC by Airbus (**3.2.3.a**) or by the feel and centering unit by Boeing (**3.2.3.b**).

#### 3.2.3.a Spoiler servo control check Airbus

An Airbus has two types of spoiler servo control units, the inboard type for spoiler 1, 2 and 3 and the outboard type for spoiler 4 and 5. The outboard type is bigger than the inboard but requires the same maintenance.
To check the spoiler actuator an operational task is used. This task starts with putting safety devices into place, such as safety tags on the side stick. The travel ranges around the flight control surfaces must also be free for the pressurization of the hydraulic systems. When the system is energized, the electronic instrument system (EIS) has to be started. From now on the check can be done using the electronic centralized aircraft monitor (ECAM) and the side stick in the cockpit.

#### 3.2.3.b Actuator inspection Boeing

The inspection of the spoiler actuator begins with supplying the mechanics with the appropriate tools. Special tools are required for measuring, these are a micrometre and a calliper. These tools allow the mechanic to measure the parts to a 1000th of a millimetre. There are a total of eight spoiler actuators on the Boeing. In order to inspect the spoiler actuator, the actuator needs to be removed. Twelve bolts and bushing of the actuator have to be inspected. The mechanic has to dissemble the spoiler actuator and remove the parts that are needed for inspection. To decide if the parts are worn, the mechanics need to measure the parts and compare them to the permitted dimensions. If the parts are worn or obviously broken, the part is replaced or repaired. After the inspection off all the parts, the actuator needs to be reassembled and reinstalled. This process repeats itself eight times for each of the spoiler actuator.

## 3.3 Costs analysis

The costs analysis will contain a research of the ratio in costs between the two types of airplanes. About these costs you can comprehend will be explained in costs (**3.3.1**). The important differences in costs between the airplanes will be explained in the conclusion (**3.3.3**). This chapter will be ended with a conclusion of the costs (**3.3.4**)

### 3.3.1 Costs

The total costs will be all the expenditures that have to be paid. These expenditures will consist out of three fields in costs. Costs that will be paid continuously are called fixed costs (**3.3.1.a**), costs that are not fixed and depends on time or variable purchases are called variable costs (**3.3.1.b**). The third

one will be operational costs, these costs arise from the needed components at maintenance tasks (**3.3.1.c**). In general a cost formula will consist out of the given parts (**formula 3.1**).

| | |
|---|---|
| **Y = AX + B** | **Y = estimated total costs**<br>**A = estimated costs per time unit**<br>**X = the amount of time unit**<br>**B = estimated fixed costs** |

**Formula 3.1 General cost formula**

### 3.3.1.a Fixed costs

*Fixed costs* are called fixed when the costs are not changing when the duration of time changes. The fixed costs that matter for the most maintenance tasks are:

- Salary of the employees. The pay out of engineers is part of the fixed costs because they are also fixed employees, so they are paid per month.
- Hangar use. The use of a hanger is part of fixed costs because the airliner ALA has to pay per month a certain amount of money.
- Maintenance and also the ABCD-checks. The maintenance costs consist of the components from what have to be replaced on the airplane and the maintenance costs are related to the salary of employees and the use of a hangar.

### 3.3.1.b Variable costs

*Variable costs* are called variable when the costs change as a result of a change in the quantity of time. The most important variable costs are costs of the Aircraft On Ground (AOG). When a component needs to be replaced or repaired outside of the maintenance checks, it means that the flight will be delayed or the flight could be cancelled. The components that may have to be replaced bring extra costs with them. A delay of the flight can cost even more money, because of the extra fuel to make up some of the delay. A cancellation can bring a lot of costs with it, because of the claims passengers can present.

## 3.3.2 Operational costs

The *operational costs* of the Airbus A320 and Boeing B737NG will be described. Further the differences in costs between these two airplanes will be explained. At first, the differences in ABCD-checks will be described (**3.3.2.a**). After this, the three maintenance tasks will be described. These three tasks are aileron and spoiler check (**3.3.2.b**), lubrication spoiler actuator (**3.3.2.c**) and inspection of spoiler actuator (**3.3.2.d**).

### 3.3.2.a ABCD-checks

The most important difference between the ABCD-checks of the Airbus and the Boeing is at the D-check. The Airbus D-check must be performed four years earlier than the D-check of the Boeing. In twenty years' time, this means that the airbus has had 3.33 D-checks. The Boeing will only have two D-checks in that time. This means a difference of 1.33 D-checks detrimental to the Airbus, because this will mean a lot of extra costs for the Airbus.

### 3.3.2.b Check aileron and spoiler signal transportation

At an Airbus, the signal transportation check is performed by BITE. This system makes sure that the ground engineers do not have to manually search for the error. Boeing does not have this system, therefore they have to manually search for the error. This means that this check is much easier to perform at an Airbus, this means that this check will be cheaper at an Airbus.

#### 3.3.2.c Lubrication spoiler actuation

At an Airbus, lubricating the spoiler actuator can be performed faster than at a Boeing. The Airbus has two spoilers less than a Boeing. This saves two times the preparation time to get to a spoiler actuator, resulting in fewer expenses for the Airbus.

#### 3.3.2.d Inspection of spoiler actuator

At an Airbus the inspection of the spoiler actuator can be performed faster than at a Boeing, because of the ECAM system the Airbus has. For checking the Boeing spoiler actuator, the complete spoiler must be taken apart and must then be checked manually. This makes the Airbus easier to inspect the spoiler actuator.

### 3.3.4 Conclusion of the costs

Comparing the Airbus and the Boeing based on the operational costs, the airbus comes out as the advantageous airplane to choose. The Boeing is, compared to the Airbus, only better at the costs of the D-check. The Airbus is better at the rest of all of our other investigated maintenance tasks.

## 3.4 Recommendation

The big advantage of the Boeing 737NG is, that it is always controllable because of its cable system. When hydraulic pressure fails, the backup cable system will provide airplane control. But this cable system also has a disadvantage. The cables need intensive maintenance. Maintenance on the Boeing needs, in general, more time than maintenance than on the Airbus. Only the D-check has to be performed four years later then the Airbus D-check.
Less maintenance is needed on the Airbus A320, because the Airbus has less moving parts. The maintenance on the Airbus can save time while computers can take over most of the maintenance tasks, due to the use of electrical wires. These computers can isolate faults quicker than mechanics can.
Based on the three chosen maintenance tasks, our recommendation is that the Airbus A320 entails lower operational costs than the Boeing 737NG. The ABCD-checks from the Boeing do not differ much from the ABCD-checks from the Airbus, with exception of the D-check. But based on the three chosen maintenance tasks, the Airbus has lower operational costs. The maintenance tasks can be performed faster and faults in the system are easier to find. This provides lower AOG times, resulting in more flight hours and more possibilities to be profitable for Amsterdam Leeuwenburg Airlines.

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# List of terms

| Term | Translation to Dutch | Page |
|---|---|---|
| Longitudinal axis | Lengte as | 1.0 |
| Lateral axis | Dwars as | 1.0 |
| Vertical axis | Verticale as | 1.0 |
| Lift | Opwaartse druk | 1.1.1 |
| Lift coefficient | Liftcoëfficiënt | 1.1.1 |
| Dynamic pressure | Dynamische druk | 1.1.1 |
| Density | Dichtheid | 1.1.1 |
| Angle of attack | Invalshoek | 1.1.1.a |
| Boundary layer | Grenslaag | 1.1.1.a |
| Laminar stream | Laminaire stroming | 1.1.1.a |
| Turbulent stream | Turbulente stroming | 1.1.1.a |
| Chord | Koorde | 1.1.1.c |
| Trailing edge | Achterste rand | 1.1.1.c |
| Leading edge | Voorste rand | 1.1.1.c |
| Mass flow | Massastroom | 1.1.1.c |
| Adiabatic gas | Adiabatisch gas | 1.1.1.c |
| Airfoil profile | Vleugelprofiel | 1.1.2 |
| Conventional profile | Conventioneel profiel | 1.1.2.a |
| Laminar profile | Laminair profiel | 1.1.2.b |
| Supercritical profile | Supercritisch profiel | 1.1.2.c |
| Aileron | Rolroer | 1.2 |
| Elevator | Hoogteroer | 1.2 |
| Rudder | Richtingsroer | 1.2 |
| Roll | Rollen | 1.2 |
| Yaw | Gieren | 1.2 |
| Pitch | Stampen | 1.2 |
| Adverse yaw | Nadelige giering | 1.2.1.b |
| Dutch roll | Nederlandse rol | 1.2.1.b |
| Empennage | Staart | 1.2.3 |
| Elevator trim | Hoogteroer afstelling | 1.3 |
| Rudder trim | Richtingsroer afstelling | 1.3 |
| Trim tab | Trim tab | 1.3.1 |
| Trailing edge | Achterrand | 1.3.1.a |
| Flaps | vleugelklep | 1.3.1 |
| Secondary flight controls | Secundaire vliegtuig besturing | 1.3.2 |
| Conventional flap | Conventionele vleugelklep | 1.3.2 |
| Split flap | Gespleten vleugelklep | 1.3.2 |
| Fowler flap | Fowler vleugelklep | 1.3.2 |
| Slotted flap | Spleet vleugelklep | 1.3.2 |
| Slats | Neusvleugel | 1.3.2.b |
| Stalling-angle | Overslag hoek | 1.3.2.b |
| Flight spoilers | Vlieg spoilers | 1.3.2.c |
| Ground spoilers | Grond spoilers | 1.3.2.c |

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|---|---|---|
| Roll control | Rol besturing | 1.3.2.c |
| Ground-effect | Grond effect | 1.3.2.c |
| Speedbrakes | Remmen | 1.3.2.c |
| Hydraulic system | Hydraulische systeem | 1.5 |
| Steering column | Stuurkolom | 1.5 |
| Rod | Staaf | 1.5.3 |
| Full powered controls | Volledige versterkte bestuurbekrachtiging | 1.5.3.b |
| Power assisted controls | Besturingsorgaan met stuurbekrachtiging | 1.5.3.b |
| Side stick | Besturings staaf | 2.1.1 |
| Steering column | Stuurkolom | 2.1.1 |
| Elevator eleron computer (ELAC) | Computer van de elevator en de aileron | 2.1.1 |
| Fly-by-wire | Vliegen op elektrisch signaal | 2.1.8 |
| Spoiler elevator computer (SEC) | Computer van de spoiler en standy aileron | 2.2.6 |
| Ram air turbine | Luchtdruk turbine | 2.3.1.b |
| Centralized fault display system (CFDS) | Centraal fout weergave systeem | 3.2.1.a |
| Built-in test equipment (BITE) | Ingebouwd test systeem | 3.2.1.a |
| Fixed cost | Vaste kosten | 3.3.1.a |
| Variable costs | Variabele kosten | 3.3.1.b |
| Operational costs | Operationele kosten | 3.3.2 |