LELYSTAD AIRPORT

Impact on CO₂ emissions when using the Noise Abatement Departure Procedure

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LELYSTAD AIRPORT

Impact on CO₂ emissions when using the Noise Abatement Departure Procedure

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PREFACE

In April, seven months ago, I started researching the possibility to use a Noise Abatement Departure Procedure at Lelystad Airport (NADP) to reduce noise and CO₂ emissions locally. The goal was to take advantage of more sustainable departures, which has a positive impact on the operation at Lelystad Airport and surroundings. This project initiated at the request of the sustainability studio of the Amsterdam University of Applied Sciences. I realised that it was good to scope the project down to only Lelystad Airport, as the airport is almost about to open its doors. Focussing on revising the airspace before 2023 makes it relevant to the research of the possibility to use the NADP procedure at Lelystad Airport at this moment.

As Lelystad Airport is an actual topic at the moment of writing, it was hard to find pre-research; however, on the Noise Abatement Departure Procedures, several kinds of research were done. Using these researches, I was able to take steps forward and conclude my findings.

I want to thank my supervisors Dr Falco and Mr Aazami, for their support and guidance during the research. Also, for providing me with the opportunity to start this research and helping me finish it.

Guus Schrameijer

Sustainability studio, Amsterdam 24-11-2019
EXECUTIVE SUMMARY

Because of the enormous growth of the aviation industry, Schiphol requires to expand its operations. The limitation of 500,000 aircraft movements led to an agreement about the expansion of a regional airport to accommodate the overcapacity of Schiphol Airport. Lelystad Airport was chosen as the local airport, which will expand. By using Lelystad Airport in the future, the Dutch aviation industry can handle up to 45,000 additional aircraft movements annually. However, the strong growth in the aviation industry has its consequences on the environment. Worldwide, the aviation sector is responsible for 2 per cent of all emissions. By stating that Lelystad Airport will make use of lower flying routes, it assures the air traffic of Lelystad will not interfere with the air traffic of Schiphol Airport. Expected is that these low flying routes will increase the fuel consumption of the aircraft, resulting in higher CO\textsubscript{2} emissions produced. It is useful to figure out if using a relatively new departure procedure would decrease the emissions and noise nuisance to prevent more use of fuel and more noise nuisance over the flying routes. This research only focusses on the departure procedures to get a better view of the emissions produced when having a low flying departure with a manoeuvre promised to produce less noise and emissions.

This lead to the following research question: “To which extent can Lelystad Airport reduce the impact on noise and CO\textsubscript{2} emissions when creating the new air space routes by using a Noise Abatement Departure Procedure?” The following steps were taken to answer these questions:

1. Analysis of the route structure at Lelystad Airport at the current moment: an important point to look at, as the route structures qualify if it is possible to use the Noise Abatement Departure Procedures as it is right now. Also, the type of aircraft is determined, which will probably be used the most at Lelystad Airport. An assumption had to be made, due to lack of information about the future operations at Lelystad Airport.
2. Explanation of the Noise Abatement Departure Procedures 1 and 2: taking a closer look at both procedures and their differences.
3. Both the procedures set side by side regarding fuel use and noise nuisance.
4. Calculation of the total amount of CO\textsubscript{2} produced at Lelystad Airport annually.
5. Determination of the best-suited procedure for Lelystad Airport at this moment to use as a standard departure procedure.

The settlement of the route structure found place in 2014. There were four route sets possible at Lelystad Airport. Nonetheless, one elected as the preferred route set. In 2014 the departure and arrival routes of Lelystad Airport regarding Flevoland and the surroundings of Flevoland were determined. The finding was: route-set B+ is the best possible at the moment before the revision of the airspace. The types of aircraft to proceed with are the B738 and the Airbus A320 and A319. The A320 and A319.

Now the focus was on the possibility to use a Noise Abatement Departure Procedure (NADP), which should result in a decrease of CO\textsubscript{2} emissions and less noise disturbance further away from the airport. The finding that this NADP procedure is possible and aligned with the regulations made at this moment for the B+ route. The NADP procedure split up in two profiles, NADP 1 and NADP 2. Considering the pros and cons of the NADP profiles, analysing both procedures is of great importance, as both profiles have their advantages and disadvantages.
Procedure NADP 1 creates a noise decrease near the airport. While procedure NADP 2 results in a reduction of fuel burn and noise further away from the airport. NADP 1 is a climb with acceleration and flap retraction beginning at 3,000 feet (914 meters) AGL, which is the noise climb-out procedure for close-in noise monitors. A reduction in fuel burn and noise is both definite in the perspective of an airline, as their fuel costs decrease and in the aspect of sustainability, as fuel burn is parallel with CO₂ emissions produced during a departure.

Determination of the CO₂ reduction and the best departure procedure is possible, after step three. Per take-off, the fuel burn is reduced from 2 to 4 per cent, when using the NADP 2 procedure instead of the NADP 1. From here, calculation of the total CO₂ emissions can start, as the fuel burn is parallel with the CO₂ emissions produced during take-off. The possibility occurs to determine the best departure procedure according to the results of the research. The goal was to reduce CO₂ and gain a reduction in noise nuisance accordingly. As the areas further away from the airport experience more noise disturbance, it was clear the second departure procedure was the best option regarding noise. However, the most crucial goal was to reduce CO₂ emissions when having a take-off. Also, the second departure procedure had better results with both types of aircraft regarding noise reduction and CO₂ reduction.

At last, there are two types of NADP 2 profiles, named NADP 2.1 and NADP 2.2. The difference between these procedures is the moment of cut back to Maximum Climb Thrust setting and flap retraction. NADP 2.1 accelerates and retracts flaps at first, when the aircraft reaches the zero flap setting, the thrust is cut back to the Maximum Climb Thrust setting. On the contrary, the NADP 2.2 procedure first cuts back its thrust, and after the cutback, the aircraft accelerates and retracts the flaps. NADP 2 is a climb with acceleration to flap retraction speed beginning at 1,000 feet (305 meters) AGL, which is the noise climb-out procedure for far-out noise monitors. As a general rule, an aircraft departing with the NADP 2.1 procedure, which has the best overall performance, uses 3 to 4 per cent less fuel compared to a departure with the NADP 1 profile.

Therefore it is advised to make use of the NADP 2.1 procedure at Lelystad Airport, as this procedure has the best overall performance. Each take-off using the NADP 2.1 procedure reduces the CO₂ production with 2 to 4 per cent and creates less noise disturbance for the areas further away. The theoretical maximum reduction of CO₂ is 1133,29 tonnes annually. With the assumption that 100 per cent of the Boeing 738’s and A320’s will use the NADP 2 procedure, which will cover 95 per cent of the total aircraft using Lelystad Airport will make use of the NADP 2 procedure. The amount of CO₂ reduction is the same as 340 cars produce over a year or 64 round trips to Paris Charles de Gaulle from Schiphol Airport.

All in all, it is recommended to create the possibility to make use of the NADP 2 departure, regarding the constraints of the air routes, after the airspace is revised in 2023. Unfortunately, it is not possible to make this procedure mandatory due to safety regulations. Yet, it is possible and advised to encourage to use the appropriate NADP when an airport requests its use to decrease noise and emissions for either a close-in or remote community.
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<td>A320-200</td>
<td>Airbus A320-200</td>
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<tr>
<td>AGL</td>
<td>Above Ground Level</td>
</tr>
<tr>
<td>APU</td>
<td>Auxiliary Power Unit</td>
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<tr>
<td>ATC</td>
<td>Air Traffic Control(lers)</td>
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<tr>
<td>B737</td>
<td>Boeing 737-700</td>
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<tr>
<td>B738</td>
<td>Boeing 737-800</td>
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<tr>
<td>CLSK</td>
<td>Royal Dutch Airforce</td>
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<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
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<td>dB(A)</td>
<td>Decibels</td>
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<td>EPA</td>
<td>Environmental Protection Agency</td>
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<td>FL</td>
<td>Flight Level</td>
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<td>FMC</td>
<td>Flight Management Computers</td>
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<td>ft</td>
<td>Feet</td>
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<td>GHG</td>
<td>Greenhouse Gases</td>
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<td>GWP</td>
<td>Global Warming Potential</td>
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<td>ICAO</td>
<td>International Civil Aviation Organization</td>
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<tr>
<td>KG</td>
<td>Kilograms</td>
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<tr>
<td>KIAS</td>
<td>Knots Indicated Air Speed</td>
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<tr>
<td>KTS</td>
<td>Knots (speed unit)</td>
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<td>LVNL</td>
<td>Air Traffic Control the Netherlands</td>
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<tr>
<td>MCLT</td>
<td>Maximum Climb Thrust</td>
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<tr>
<td>MER</td>
<td>Environmental Effects Report</td>
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<td>NADP</td>
<td>Noise Abatement Departure Procedure</td>
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<tr>
<td>NM</td>
<td>Nautical Mile</td>
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<tr>
<td>NOₓ</td>
<td>Nitric Oxide</td>
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<tr>
<td>PANS-OPS</td>
<td>Procedure for Air Navigation Services - Aircraft OPerationS</td>
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<tr>
<td>RF</td>
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<td>Runway</td>
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<td>SESAR</td>
<td>Single European Sky ATM Research</td>
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<tr>
<td>TMA</td>
<td>Terminal Maneuvering Area</td>
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List of assumptions

1. The same mix of aircraft using Eindhoven Airport is applicable for Lelystad, assuming that the operation at Lelystad Airport is more or less the same as the one on Eindhoven Airport.

2. ICAO research to the noise and CO₂ reduction when using the NADP 1 and NADP 2 procedure, is based on the B737-700. This research substantiates to the Boeing research. Though, research done by Boeing focusses on the B737-800, which is more relevant for the CO₂ reduction research, as this aircraft is probably used the most at Lelystad Airport. Nonetheless, the B737-700 noise and emissions reduction are added as an extra component to get a better insight into fuel reduction.

3. A319 and A320 are combined, assuming that the A320 will be more operated than the A319. Also, the fuel flow of the A320 during a Noise Abatement Departure Procedure is the same as Boeing used for the calculations of the Boeing 737-800. I wasn't able to calculate the exact fuel flow of the A320 during an NADP departure, and it was not available on several types of research online. Thus, the fuel flow of an A320 used to calculate the CO₂ emissions in chapter 6.1.2 will be the same as the fuel flow of a B738, stated by Boeing.

4. Research done by Boeing is more relevant than the research done by ICAO, regarding the B737 series as ICAO focused its research on the Boeing 737-700, while this aircraft will cover less than one per cent of the total aircraft at Lelystad Airport. Boeing focused its research on the Boeing 737-800 Winglets, which comprises 54% of the entire mix of aircraft at Lelystad Airport, resulting in more relevance for this research. However, the study of ICAO is relevant for the emissions produced by the Airbus A320-2 and to substantiate the research done by Boeing, which makes the analysis very useful to calculate the total emissions.

5. The assumption is made that a reduced take-off is possible at Lelystad Airport for both the Boeing 737-800 and the Airbus A320. By making this assumption, all options for the NADP 2 procedure can be analyzed.

6. It is assumed that the departures at Lelystad Airport are 5,000 movements when having an operation of 10,000 movements annually.
1. Introduction

Highlighted in this chapter are the main research objective and sub-objectives. The answer to why this research is initiated will be given, what the research will be about, and what benefits the stakeholders will gain by this research.

1.1 Background

Leading aviation companies, as well as knowledge institutions in the Netherlands, are aiming to become the smartest and most sustainable players in the aviation sector all around the world. The number of commercial air transport movements reached close to its regulated maximum of 500,000 movements, namely 499,444. The total air transport movements increased by 0.5 per cent compared to 2017 (Schiphol Group, 2018). When assuming an annual growth of 1.5 per cent from 2021 until 2030, the expectation is that in 2030 Schiphol Airport traffic accounts for approximately 580,000 aircraft movements (To 70, 2018). As Schiphol reaches its maximum movements each year closer and closer, it is time to find a solution so it can expand its movements.

The limitation of 500,000 aircraft movements led to an agreement about the expansion of a regional airport to accommodate the overcapacity of Schiphol Airport. Lelystad Airport was chosen as the regional airport, which will expand. The upcoming years are meant for the redesign of the air space around Lelystad and Schiphol Airport. The redesign is done to reduce the noise for the environment and to increase the capacity and efficiency, however, the most crucial aspect for the redesign of the air space is to have the least possible interference with the air traffic of Schiphol Airport. When finished, Lelystad Airport can grow to 25,000 air traffic movements in the first phase, in the long term they will be able to have a maximum of 45,000 movements a year (Rijksoverheid, 2018).

The strong growth in the aviation industry has its consequences on the environment. Worldwide, the aviation sector is responsible for 2 per cent of all emissions (Slim en Duurzaam, 2018). The aviation sector is investing in better processes, infrastructure and research programs, getting a more sustainable use of air space to reduce the influence of the aviation sector on the emissions. For example, a possible solution is SESAR and technology behind the aircraft, e.g. Clean Sky. As shown why it is essential to improve the aviation sector, this research project will focus on using better departure procedures, on reducing the emissions and noise during take-off.

A redesign of the air space around Lelystad Airport is needed to create space for civil and military air traffic. Using the airspace more efficiently, and reduction of the annoyance under the flying routes are both consequences of the redesign of the airspace. It will be a complicated process to create a new redesign, where cooperation of the neighbour countries like Germany, Belgium, Denmark and the United Kingdom is needed. The minister and the secretary of state of Holland have decided to base their goal to have no interference with the air traffic of Schiphol Airport. The air traffic of Lelystad Airport will be allowed to make use of the military air space to have no interference with the Schiphol TMA. Due to the allowance of using the military air space, higher-flying routes are available for the departures at Lelystad Airport. The higher flying routes allow the aircraft to climb to their Flight Level with no obstacles during their take-off. At last, the government, civil and military air traffic controllers will create a roadmap for further developments of the air space for the period of 2023 – 2035, to make sure the Dutch airspace will be able to handle the growth and future advancement in the aviation industry (Zwolle Nieuws, 2019).
1.2 Problem Statement

Over the past ten years, the aviation industry has grown enormously. The expectations are that this growth and the demand for more air travel will still increase due to the increasing globalisation. To take Schiphol Airport as an example, Schiphol is feeling the consequences of the growing demand, however, since 2008 Schiphol agreed at the ‘Alderstafel’ on having a maximum of 500,000 air traffic movements over a year until 2020. These maximum movements focus on the large traffic at Schiphol Airport, the so-called trading traffic. The precise meaning of the trading traffic is “traffic flights of airlines who accept individual bookings of passengers, cargo or mail, which use commercial or scheduled flights performed at routes according to a schedule”. (Nieuws Schiphol, 2018)

Figure 1 visualises the growth of the passengers at Schiphol Airport. This figure shows the number of passengers from 2008 until 2018. In 2018 the total amount of passengers was 71 million. Figure 1 illustrates the growth of the aviation industry, concluding from the growth in the number of passengers is the increase in demand for more air travel. Within ten years (2008-2018), the number of passengers is almost doubled from 43.5 million to 71 million passengers travelling via Schiphol. (CBS, 2019)

The second figure shows the total increase of passengers in the Netherlands at all national airports. Figure 2 adds the number of passengers of Eindhoven, Rotterdam the Hague, Maastricht Aachen and Groningen Eelde. Concluding from Figure 2 is the demand for more air traffic movements as not only the main airport is increasing. Also, other national airports increased due to the increasing demand in the aviation industry. The total passengers travelling in 2018 spread over the other domestic airports was 8.3 million passengers, which makes a total of 79 million people travelling spread over the Netherlands. (CBS, 2019)

Figure 2 does not include Lelystad Airport yet. When Schiphol Airport wants to increase their operations, it is mandatory to make use of other national airports. The limitation of 500,000 aircraft movements led to an agreement about the expansion of a regional airport to accommodate the overcapacity of Schiphol Airport. Lelystad Airport was chosen as the regional airport, which will expand. The revision of the air space around Lelystad and Schiphol Airport finishes in 2023. The redesign has its focus on the reduction of noise for the environment and the increase of capacity and efficiency. However, the most critical aspect for the restructuring of the air space is to have the least possible interference with the air traffic of Schiphol Airport.
As Lelystad can’t interfere with the Schiphol TMA, the traffic landing and departing from Lelystad Airport has its altitude restrictions. When finished, Lelystad Airport can grow to 25,000 air traffic movements in the first phase, in the long term they will be able to have a maximum of 45,000 movements a year. The 45,000 air traffic movements correspond to approximately 6.7 million passengers during one year. (Rijksoverheid, 2018)

Due to the increase in the number of passengers, the aviation industry increases, resulting in an increase in flights, resulting in a rise in emissions produced by the aviation industry. Between 2005 and 2017, carbon dioxide emissions increased by 16% and nitrogen oxide emissions went up 25%, according to the second European Aviation Environmental Report (EAER). That is because the number of passenger kilometres has skyrocketed in the same period, increasing by a massive 60%. Although the amount of noise pollution generated by individual flights is going down, thanks to advances in technology, the sheer number of planes in the air means that the number of people impacted by the phenomenon has increased 14% since 2014 alone. Aviation currently accounts for 2-3% of global emissions, and according to forecasts, the number of flights will increase by 42% by 2040. CO₂ and NOₓ emissions could increase by at least 21% and 16%, respectively, in the same period. The EAER report puts a lot of faith in improved and new technology to bring the sector in line with climate commitments like the EU’s 2030 targets and the Paris Agreement (Morgan, 2019). A solution could be having a better departure procedure, causing less noise and emissions when departing from Lelystad Airport. The following research is focused on the departure routes at Lelystad Airport, as there are several restrictions, it is vital to find out if a new departure route is possible to use, which should be more sustainable than the old one.

1.3 Research Objective
As air traffic is increasing at Schiphol Airport over the last years (see Figure 1), Schiphol needs to extend its operations. Due to the increasing traffic, the maximum capacity of 500,000 flight movements annually reaches its maximum. Schiphol and the Dutch government are required to take action when reaching the maximum movements. If Schiphol still wants to be competitive in the future, it is vital to increase their operation. When searching for options to enhance the operation, it is decided to use Lelystad Airport for leisure traffic. The final target is to have 45,000 air traffic movements annually in the future at Lelystad Airport. However, the flying routes of the Schiphol traffic and the Lelystad Airport traffic are designed not to interfere with each other. Which resulted in lower flying routes for Lelystad Airport, these routes will prevent the traffic of Lelystad from interfering with the Schiphol TMA. Expected is that these low flying routes will increase the fuel consumption of the aircraft, resulting in more CO₂ emissions produced. It is useful to find out if using a relatively new departure procedure would decrease the emissions and noise nuisance, to prevent more use of fuel and more noise nuisance at the flying routes. As there are two different departures procedures possible to use, it is necessary to analyse both regarding their production of noise and emissions. The following main research question will be answered at the end of this research:

“To which extent can Lelystad Airport reduce the impact on noise and CO₂ emissions when creating the new air space routes by using a Noise Abatement Departure Procedure?”
The following sub-questions support the main research question:

- Why is Lelystad Airport chosen as the other national airport?
- Which type of aircraft will be used the most at Lelystad Airport?
- What is the timeline of the air space revision of Lelystad Airport?
- What are the current regulations of the departure procedures at Lelystad Airport?
- Is it possible to use the NADP 2 procedure, regarding the regulations, at Lelystad Airport?
- How does the Noise Abatement Departure Procedures work?
  - Why is 3000 feet such an essential point in the NADP procedure?
- Is it possible to make it an obligation to use such a procedure?
- Are there any negative consequences when using an NADP procedure?
- What is the impact of the NADP on the environment, regarding noise and CO₂ emissions?
- What are the consequences of the CO₂ emissions and noise, if 90-95 per cent of the aircraft of the airport would use this procedure?

1.4 Scope

1.4.1 Lelystad Airport

**Inside**
- Focus on Lelystad Airport route procedures. During the research, the departure routes will be highlighted.
- Schiphol TMA will be included, as the traffic of Schiphol and Lelystad can’t interfere.
- Calculations of this report will be based on the route structure as it is agreed on now (2019). This means the estimates are based on the 10,000 air traffic movements annually, which is before the airspace revision of 2023.

**Outside**
- General aviation is not included in this research.
- The research will focus on only Lelystad Airport, and other national airports are not included in this report.

1.4.2 Route network and airspace

**Inside**
- The focus of the project will be on departure procedures of both runways (RWY 05 and RWT 023).
- Regulations of the departure procedures until 2023, while focusing on the NADP 2 departure procedure.
- The focus will be on the air space design of Lelystad Airport and if this procedure meets the requirements to execute it.

**Outside**
- The arrival procedures won’t be included in this project.
- This research is not focused on airspace optimisation solutions.

1.4.3 Aircraft performance

**Inside**
- Calculations in this research are only based on the B738 and A320, as it is expected these aircraft will cover more than 75 per cent of the total operation at Lelystad Airport.
- The assumption is made that the A320 has the same fuel flow as the B738 during an NADP departure.

**Outside**
- APU pollution is NOT included in the calculations.
- Weather impact on the departure routes isn’t taken into account in the calculations of this research.
1.4.4 Environment

**Inside**
- The focus will be on the environmental impact when using the NADP 2 procedure.
- The scope will be on CO$_2$ emissions reduced by using the NADP 2 procedure. Also, the noise reduction will be taken into account in this research.

**Outside**
- The research is not an environmental report.
- Effects of the extra or less pollution on the environment will not be discussed.
- The focus of this project will not be on research of the possibility to not use or use the NADP 2 procedure because of high buildings in the surrounding environment.
- The focus will not be on NO$_x$ emissions as the aviation industry mostly produces CO$_2$ emissions and the environmental goals stated by the Paris Agreement are mainly focused on the CO$_2$ emissions reduction.

At last, the scope of the project will also be on having 16 – 20,000 words in the research. The project will be around 40 pages, excluded the appendixes.
2. Theoretical Framework

2.1 Sustainability

According to the Cambridge dictionary, the definition of sustainability is: ‘the idea that goods and services should be produced in ways that do not use resources that cannot be replaced and that do not damage the environment.’ (Dictionary Cambridge, 2019).

What does it mean for the aviation industry?

Sustainability in the aviation industry focuses on improving their operations to be less harmful regarding the environment. However, the environment can mean the environment regarding people living surrounding the airports/airway routes or on the environment regarding natural resources. People living in the surroundings of the airports can experience noise nuisance, which could be harmful to their health. As the aviation industry has environmental impacts ranging from the global to the local, from atmospheric contributions to climate change to local noise or health impacts around airports, it is starting to be a more and more important point to focus on. Each party involved in the aviation industry are responsible for making aviation more sustainable.

At this moment, there are five key issue areas prominent (Walton, 2018):

1. Sustainability of fuel sources and a shift towards biofuels, with a view towards an electric aircraft future;
2. Fuel efficiency and the goal of reducing emissions, together with ensuring that altitude emissions cause the least harm;
3. Immediate environmental impacts to people in and around airport areas from noise, pollution and traffic;
4. Reducing inflight waste while increasing inflight recycling, but with notable biosecurity restrictions in many jurisdictions;
5. Increasing recycling and recyclability of aircraft, cabins, seats and systems.

During this research, the focus will be on the local level regarding the departure procedure. The focus will be on reducing noise annoyance and local pollution, by reducing fuel consumption when having a departure, resulting in less CO₂ pollution locally. Also, the second issue regarding fuel efficiency will be taken into account, as improved departure procedures will result in less fuel consumption. While less fuel burn results in less CO₂ emissions produced.

2.1.1 Noise disturbance and consequences

According to Planbureau for the living environment in Holland, the people who experience noise disturbance has been increased with almost 50% since 2004. In 2004 there were only 106,346 people who experienced noise disturbance in the living area around Schiphol Airport. In 2016 155,959 people experienced noise disturbance (PBL, 2018). The consequences of noise disturbance on the health of the people who seem to have it are not specified yet. However, there is an excellent biological plausibility by which noise may affect health in terms of impacts on the autonomic system, annoyance and sleep disturbance. Loud aircraft noise can cause insomnia, concentration disorders and learning difficulties in children. That is why the authorities make every effort to ensure that growth in air traffic does not lead to excessive noise nuisance (Government of the Netherlands, 2019). Aircraft noise can disturb people while sleeping. At the moment, there is not enough research done to specify the relationships between aircraft noise exposure and sleep disturbance. Studies are evocative of impacts on especially hypertension but limited with the quantification of these health issues, with also a small number of studies focused on the problem to this date. There are more studies needed to have a better sight of the exposure-response relationships and the relative importance of night versus daytime noise (NCBI, 2017).
2.2 Route structure Lelystad Airport

To start with the creation of the current routes from and to Lelystad Airport. At first, LVNL and CLSK introduced four different route sets. The sets were called: Route set A, Route set A+, Route set B and Route set B+. However all route sets were supposed to be the best possible, the creators noted that with some the interference with the air traffic of Schiphol Airport is not fully solved. Route set B+ is the most optimal route set at this moment. Route B+ is optimized regarding the living areas as Almere, Zeewolde, Biddinghuizen, Dronten, Kampen and Zwolle. According to calculations initiated by ‘Rijksoverheid’, the route B+ variant seems to be the most sustainable and produces the least amount of noise nuisance compared to the other routes created. The B+ route is designed to avoid flying over the living areas and decrease the chance of interfering with the Schiphol air traffic (Alderstafel Lelystad, 2014). Figure 3 shows the B+ variant of runway 23. Figure 4 illustrates the B+ option of runway 05. The noise contours of the departure and arrival routes of route variant B+ with 25,000 and 45,000 aircraft movements annually are given in Appendix 2 (Hoogoverijssel, 2017).

![Figure 3: Route B+ variant runway 23](Alderstafel Lelystad, 2014)

![Figure 4: Route B+ runway 05](Alderstafel Lelystad, 2014)
As shown, both runway 23 (RWY 23) as runway 05 (RWY 05) will be used to accommodate the air traffic movements. According to the research of dBvision, RWY 23 will be applied the most with assisting 58.5 per cent of the air traffic. This percentage is derived from statistics of the wind direction over 18 years (from 1982 – 2000), illustrated in Figure 5. The statistics are based on 10,000 air traffic movements, and both the revision of the airspace as well as without the review of the airspace are taken into account. In Figure 5, the wind rose is shown, which is used to determine the percentages of runway usage. Table 1 shows the percentages per runway (Rijksoverheid, 2018).

<table>
<thead>
<tr>
<th>Variant</th>
<th>RWY 05 [%]</th>
<th>RWY 23 [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>B+ 10,000 without revision of the airspace</td>
<td>41.5</td>
<td>58.5</td>
</tr>
<tr>
<td>B+ 10,000 with revision of the airspace</td>
<td>41.5</td>
<td>58.5</td>
</tr>
</tbody>
</table>

TABLE 1: Runway usage (Rijksoverheid, 2018)

2.2.1 Standard departure procedures

In 2014 the departure and arrival routes of Lelystad Airport regarding Flevoland and the surroundings of Flevoland were determined. This route set is called B+. Figure 3 and Figure 4 show both the arrival and departure routes of both runways. However, these maps do not display the entire image of the routes. Critical sections are missed in these maps as they don’t show the parts where the air traffic enter or exit the airspace of Lelystad Airport. Figure 6 shows the entry and exit points of the complete B+ routes of the air space. Table 2 highlights the explanation of the route sections (Hoog Overijsseel, 2017).

<table>
<thead>
<tr>
<th>Route section</th>
<th>Location</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAF North</td>
<td>Scheerwolde</td>
<td>Initial Approach Fix North</td>
</tr>
<tr>
<td>IAF South</td>
<td>Lemelerfeld</td>
<td>Initial Approach Fix South</td>
</tr>
<tr>
<td>LES21</td>
<td>Espel</td>
<td>Exit North</td>
</tr>
<tr>
<td>LES06</td>
<td>Wezep</td>
<td>Exit South</td>
</tr>
</tbody>
</table>

TABLE 2: Route section of the route set B+ explanation (Hoog Overijsseel, 2017)
When these routes were shown to the public, it caused some fuss. The fuss was created as the inhibitors of these villages weren’t involved in the design process and had to find out that these routes are going to be low flying routes in large parts of Overijssel. However, the B+ routes within the air space of Lelystad Airport won’t be changed anymore. (Hoog Overijssel, 2017). Necessary for the following research will be the height of the exit points as the Noise Abatement Departure Procedure has the most impact until 3000 ft, after 3000 ft the aircraft will climb to its cruising level. The fuss was about the exit points, which are at 6000 ft. Which is positive for the use of the NADP 2 procedure, as this procedure has the highest impact on the departure before until 3000 ft and exit points are at the Flight Level of 6000 ft.

### 2.2.2 Airspace revision

As there is a lot of fuss by people living around Lelystad Airport and beneath the air space routes stated by the government, the Dutch ministries of infrastructure and defence are cooperating to create a new revised air space. The target to have the revised airspace operational is in 2023. When creating a revised air space, it is proven to be beneficial for reduction of a nuisance to compensate the inhabitants living around the air space routes and Lelystad Airport. Next to the reduction of noise, the capacity and efficiency of the airspace will be improved, which results in better operation and less fuel burn. As there are several complaints about the height of the connecting routes, the revision of the air space locates the connecting routes at higher altitudes to and from Lelystad Airport. In the end, the goal is to have an efficient as possible operation running, which will be sustainable at a local level. Also, the new air space routes are created in a way not to interfere with the Schiphol TMA. (Rijksoverheid, 2018)

### 2.3 Emissions

The real definition of emissions is as follows: ‘pollution (including noise, heat and radiation) discharged into the atmosphere by residential, commercial, and industrial facilities. Pollution discharges into water is called effluent, which is liquid waste flowing out of a factory, farm, commercial establishment, or a household into a water body such as a river, lake, or lagoon, or a sewer system or reservoir. Waste discharged into the air is called emission.’ (Business Dictionary, 2019).

Behind the struggle to address global warming and climate change lies the increase in greenhouse gases in our atmosphere. A greenhouse gas is any gaseous compound in the atmosphere that is capable of absorbing infrared radiation, thereby trapping and holding heat in the atmosphere. By increasing the temperature in the atmosphere, greenhouse gases are responsible for the greenhouse effect, which ultimately leads to global warming. Greenhouse gases are known as gases in the atmosphere that absorb radiation, while they are primarily responsible for the greenhouse effect. The abbreviation of the Greenhouse gases is GHG. These gases trap heat and make the planet warmer. Over the last 150 years, human factors are the cause of the increase of the GHG. Burning fossil fuels is one of the largest sources of production of these gas emissions. The greenhouse effect is one of the most important causes of global warming. The most significant GHG is water vapour (H$_2$O), carbon dioxide (CO$_2$), methane (CH$_4$) and nitrous oxide (N$_2$O), according to the Environmental Protection Agency (EPA) (Lallanilla, 2019).

Greenhouse Gases warm the Earth by absorbing energy and slowing the rate at which the energy escapes to space; they act like a blanket insulating the Earth. Each gas has a different characteristic that defines its effect on global warming. There are two critical ways in which these gases differ from each other:

- Ability to absorb energy (radiative efficiency)
- How long the gases stay in the atmosphere before the natural processes remove them (lifetime)

A measurement tool is created to get a comparison between the impact of all these different types of gases. It is called the Global Warming Potential (GWP), which measures how much energy the emissions of 1 ton of
a gas will absorb over a given period, relative to the emissions of 1 ton of carbon dioxide (CO$_2$). The larger the GWP is, the more that given gas warms the Earth compared to CO$_2$ over that period, which usually is 100 years (EPA, 2017).

When looking at all the global Greenhouse Gasses, in Figure 7 can be seen that carbon dioxide (CO$_2$) produces the most gas globally. Next to the amount of CO$_2$ produced, carbon dioxide also has the most extended lifetime of all gasses. Carbon dioxide has a lifetime of 100 years. The primary source is the use of fossil fuel in several industries, including the aviation industry (EPA, 2017). As the aviation industry is one of the primary sources of CO$_2$ production, it makes it relevant and useful to investigate the possible use of the NADP 2 procedure at Lelystad Airport. This procedure probably reduces CO$_2$ emissions locally when having a departure.

As commercial aviation accounts for about 2% of global carbon emissions, and about 12% of all CO$_2$ emissions from the transportation sector, it represents a vital sector for global emissions. However, the industry is still growing, as the CO$_2$ emissions from commercial aircraft are on a pace to triple by 2050. The increase in emissions produced results from the growth of both passenger air travel and air freight worldwide (ICCT, 2019).

Figure 8 lists aircraft emissions that are important from an atmospheric perspective, with summaries of the roles that they play. These emissions can be usefully divided into two categories, depending on how they affect climate: Direct, as with CO$_2$ (where the emitted compound is the species that can modify environment), and indirect, where the climate species is not the same as the emitted species—as with modified cirrus cloud coverage resulting from particles and particle precursors. The effect of CO$_2$ on climate change is direct and depends simply on its atmospheric concentration. CO$_2$ molecules absorb outgoing infrared radiation emitted by the Earth’s surface and lower atmosphere. The observed 25-30% increase in atmospheric CO$_2$ concentrations over the past 200 years has caused a warming of the troposphere and a cooling of the stratosphere (Ellis, 1999).
Compared to other modes of transport, such as driving or taking the train, travelling by air has a more significant climate impact per passenger kilometre, even over longer distances (see Figure 9). It’s also the mode of freight transport that produces the most emissions (Suzuki, 2017).

2.3.1 Aircraft emissions
It is vital to know which aircraft is used the most at Lelystad Airport, to determine the number of emissions caused by the planes departing from Lelystad Airport. Eindhoven airport is used as an example to determine the right aircraft for this research, as Lelystad Airport is expected to have an operation more or less similar to Eindhoven. According to research done by ‘Rijksoverheid’, the fleet composition of the airlines which are using Eindhoven airport is representative for Lelystad Airport. Easyjet has been added to Table 3 while they operate from Schiphol Airport and have an operation running which is comparable to the airlines at Eindhoven airport. Expected is that these ‘leisure travel flights’ will be transferred with their operation from Schiphol Airport to Lelystad Airport (Rijksoverheid, 2018).

<table>
<thead>
<tr>
<th>Location</th>
<th>A319</th>
<th>A320</th>
<th>A321</th>
<th>A330-200</th>
<th>A330-300</th>
<th>B737-800</th>
<th>B737-700</th>
<th>B737-MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transavia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>41</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>EasyJet (Group)</td>
<td>136</td>
<td>154</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Ryanair</td>
<td></td>
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<td>1</td>
<td></td>
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<tr>
<td>Corendon (Group)</td>
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<td></td>
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<td></td>
<td>14</td>
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<td></td>
</tr>
<tr>
<td>TUI (Group)</td>
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<td></td>
<td></td>
<td></td>
<td>3</td>
<td>2</td>
<td>93</td>
</tr>
<tr>
<td>Vueling</td>
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<td>85</td>
<td>5</td>
<td></td>
<td></td>
<td>93</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Wizz Air</td>
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<td>64</td>
<td>14</td>
<td></td>
<td></td>
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<td>303</td>
<td>29</td>
<td>3</td>
<td>2</td>
<td>577</td>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td>% Total Aircraft</td>
<td>13%</td>
<td>28%</td>
<td>2%</td>
<td>&lt;1%</td>
<td>&lt;1%</td>
<td>54%</td>
<td>2%</td>
<td>&lt;1%</td>
</tr>
</tbody>
</table>

TABLE 3: OPERATION AT EINDHOVEN AIRPORT (RIJKSOVERHEID, 2018)

As can be seen in Table 3, the B738 is used the most at Eindhoven Airport. Assuming that the operation at Lelystad would be more or less similar to the operation at Eindhoven, the B738 will be used for the calculations in this research. The Airbus A320 is also analysed during the research to CO₂ reduction when using a different departure procedure to cover more than 75 per cent of the total aircraft.

As CO₂ is the most substantial emission produced by an aircraft, it is essential to take a closer look at the source of the production of this gas. The burning of fossil fuels such as gasoline, coal, oil, natural gas in combustion reactions results in the production of carbon dioxide. In the case of an aircraft, when jet fuel is burned, the carbon in the fuel is released and binds with oxygen (O₂) in the air to form carbon dioxide (CO₂). Burning jet fuel also releases water vapour, nitrous oxides, sulphate, and soot. A distinctive characteristic of aircraft emissions is that most of them are produced at cruising altitudes high in the atmosphere. Scientific studies have shown that these high-altitude emissions have a more harmful climate impact because they trigger a series of chemical reactions and atmospheric effects that have a net warming effect. The IPCC, for example, has estimated that the climate impact of aircraft is two to four times greater than the effect of their carbon dioxide emissions alone (Suzuki, 2017).
2.3.2 Airlines and IATA targets

Now focusing on the B738, which will probably be used the most at Lelystad Airport as a leisure traffic aircraft. The B738 is known for its reliability, fuel efficiency and economic performance. It can seat up to 189 passengers, which should lead to more fuel consumption than the B737-700. However, it consumes 7 per cent less fuel while carrying 12 more passengers than the competing model (Rocketroute, 2019). Appendix 1 gets into more detail regarding the engines of the aircraft and its fuel use.

The emissions at a local level caused by take-off and departure can be reduced by using more sustainable procedures than airlines do right now. Every take-off is an opportunity to save fuel. If each take-off and climb is performed efficiently, an airline can realise significant savings over time. In the past, airlines did not concern themselves with fuel consumption in the take-off and climb segment of the flight, as it only represents eight to fifteen per cent of the total time of a medium- to long-range flight. However, times have changed as fuel has become more expensive, and the aviation industry demands to be more sustainable. Fuel is about 40 per cent of a typical airlines’ total operating cost. The aviation industry requires to be more durable as IATA recognises the need to address the global challenge of climate change. So IATA adopted a set of ambitious targets to mitigate CO2 emissions from air transport:

- An average improvement in fuel efficiency of 1.5% per year from 2009 to 2020;
- A cap on net aviation CO2 emissions from 2020 (carbon-neutral growth);
- A reduction in net aviation CO2 emissions of 50% by 2050, relative to 2005 levels (IATA, 2018).

IATA is determined to be part of the solution but insists that a firm commitment is required from all stakeholders working together to achieve these targets. Through the four pillars of the aviation industry strategy:

- Improved technology, including the deployment of sustainable low-carbon fuels;
- More efficient aircraft operations;
- Infrastructure improvements, including modernised air traffic management systems;
- A single global market-based measure to fill the remaining emissions gap (IATA, 2018).

As a result of this, airlines are reviewing all phases of flight to determine how fuel burn savings can be gained in each stage and in total to obtain more efficient aircraft operations (Boeing, 2008). This departure procedure can help the airlines to achieve better fuel efficiency, resulting in less CO2 emissions and helping to get more efficient aircraft operations. Figure 10 shows the steps to be taken in a period to get to the 50% reduction in 2050 (ATAG, 2013).
2.3.3 Flap setting

The flap setting is critical regarding fuel-saving in the first phase of a flight, thus having a more sustainable departure. The lower the flap setting, the lower the drag, resulting in less fuel burned. Table 4 shows that a lower flap setting during take-off for the B738 Winglets results in less fuel consumption when performing the departure procedure. As higher flap setting configurations use more fuel than lower flap configurations, it is useful to have a procedure available which allows this strategy. However, in all cases, the flap setting must be appropriate to ensure the safety of the aircraft and its passengers. Other important factors that determine whether or not it is advisable to change standard take-off settings include obstacles clearance, runway length, airport noise and departure procedures. Another area in the take-off and climb phase where airlines can reduce fuel burn is in the climb-out and cleanup operation. If acceleration and flap retraction is used at a lower attitude than the typical 3000 feet (914 meters), the fuel burn is reduced due to less drag earlier in the climb out phase (Boeing, 2008).

<table>
<thead>
<tr>
<th>AIRPLANE MODEL</th>
<th>TAKE-OFF FLAP SETTING</th>
<th>TAKE-OFF GROSS WEIGHT (KG)</th>
<th>FUEL USED (KG)</th>
<th>FUEL DIFFERENTIAL (KG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B738 Winglets</td>
<td>5</td>
<td>72,575</td>
<td>578</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>72,575</td>
<td>586</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>72,575</td>
<td>588</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 4: Impact of take-off flaps selection on fuel burn (Boeing, 2008)
2.3.4 Comparing the fuel usage of two standard climb profiles

When focusing on the goal of this report, if NADP 2 is possible at Lelystad Airport and what the consequences will be, it is useful to know if the fuel flow of the NADP 2 procedure is better than the fuel flow at the NADP 1 procedure. According to Boeing, the NADP 2 procedure is the most efficient and sustainable procedure possible for the departure. In the following paragraph, both the NADP 1 and the NADP 2 procedures will be compared with each other regarding the fuel flow. The production of emissions during a departure decreases when the aircraft has a smaller fuel flow during this phase of the flight.

Table 5 shows two standard climb profiles for the B738 Winglets. The B737-800 Winglets is the most important aircraft, as this one covers 54 per cent of the operation at Lelystad Airport. According to the outcome, the fuel used with an NADP 2 departure is 67 kg’s less, compared to an NADP 1 departure. As the fuel flow is parallel with emissions, it also results in fewer emissions produced during the departure, which makes the take-off more sustainable regarding the production of GHG during take-off. These simplified profiles are based on the International Civil Aviation Organization (ICAO) Procedures for Air Navigation Services Aircraft Operations (PANS-OPS) Noise Abatement Departure Procedures (NADP) NADP 1 and NADP 2 profiles. Profile 1 (NADP 1) is a climb with acceleration and flap retraction beginning at 3,000 feet (914 meters) AGL, which is the noise climb-out procedure for close-in noise monitors. Profile 2 (NADP 2) is a climb with acceleration to flap retraction speed beginning at 1,000 feet (305 meters) AGL, which is the noise climb-out procedure for far-out noise monitors. Figure 13 illustrates the height profiles of both departure procedures. As a general rule, when aeroplanes fly Profile 2 (NADP 2), they use 3 to 4 per cent less fuel than when flying Profile 1 (NADP 1) (Boeing, 2008).

<table>
<thead>
<tr>
<th>AIRPLANE MODEL</th>
<th>TAKE-OFF GROSS WEIGHT (KG)</th>
<th>PROFILE TYPE</th>
<th>TAKE-OFF FLAP SETTING</th>
<th>FUEL USED (KG)</th>
<th>FUEL DIFFERENTIAL (KG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B738 Winglets</td>
<td>72,575</td>
<td>1</td>
<td>10</td>
<td>2374</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>10</td>
<td>2307</td>
<td>67</td>
</tr>
</tbody>
</table>

**Table 5: Fuel-saving potential of two climb profiles (Boeing, 2008)**

Table 6 shows the combined effect of using a lower take-off flap setting and flying Profile 2, compared to using a higher take-off flap setting and flying Profile 1. Combining a lower take-off flap setting with Profile 2 saves approximately 4 to 5 per cent fuel compared to the more upper take-off flap setting and Profile 1. Also, less noise will be produced due to less air disturbance at the wings when having a lower flap setting (explained in the chapter Noise reduction). Once retracting the flaps, the crew should accelerate to the maximum rate of climb speed (Boeing, 2008).

<table>
<thead>
<tr>
<th>AIRPLANE MODEL</th>
<th>TAKE-OFF GROSS WEIGHT (KG)</th>
<th>PROFILE TYPE</th>
<th>TAKE-OFF FLAP SETTING</th>
<th>FUEL USED (KG)</th>
<th>FUEL DIFFERENTIAL (KG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B738 Winglets</td>
<td>72,575</td>
<td>1</td>
<td>15</td>
<td>2392</td>
<td>-</td>
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<tr>
<td></td>
<td></td>
<td>2</td>
<td>5</td>
<td>2299</td>
<td>93</td>
</tr>
</tbody>
</table>

**Table 6: Effect of combining take-off and climb strategies (Boeing, 2008)**
2.4 NADP 1 & NADP 2

When departing from an airport, there are two procedures possible to use to climb to the right Flight Level. There are two noise abatement procedures available where a stepped departure climb is being used. Both are called a Noise Abatement Departure Procedure (NADP). Airplane operating procedures for the take-off climb shall ensure that the necessary safety of flight operations is maintained while minimising exposure to noise on the ground. The following two examples of operating procedures for the climb have been developed as guidance. The procedures are called NADP 1 and NADP 2, both having a different goal for use. The first procedure, NADP 1, is used where there are noise-sensitive areas close to the departure end of the runway (see Figure 11) The second procedure is used to alleviate noise in an area further away from the start of the airport runway, which will be around 25 kms+ (Figure 12) (Teddington action group, 2017).

2.4.1 Explanation of the procedures

NADP 1: Aircraft to climb to 800 ft and then reduce thrust. Keep flaps lowered in take-off mode and continue climbing as fast as possible to 3000 ft. Then retract flaps, increase thrust and complete the transition to average en-route climb speed. This procedure involves a power reduction at or above the prescribed minimum altitude and the delay of flap/slat retraction until the prescribed maximum altitude is attained.

The NADP 1 will have the following restrictions and steps (Figure 11) according to ICAO DOC 8168 VOL I (ICAO, 2009):

1. The noise abatement procedure is not to be initiated at less than 240 m (800 ft) above aerodrome elevation.
2. The initial climbing speed to the noise abatement initiation point shall not be less than \( V_2 + 20 \) km/h (10 kts).
3. On reaching an altitude at or above 240 m (800 ft) above aerodrome elevation, adjust and maintain engine power/thrust following the noise abatement power/thrust schedule provided in the aircraft operating manual. Maintain a climb speed of \( V_2 + 20 \) to 40 km/h (10 to 20 kts) with flaps and slats in the take-off configuration.
4. At no more than an altitude equivalent to 900 m (3000 ft) above aerodrome elevation, while maintaining a positive rate of climb, accelerate and retract flaps/slats on schedule.
5. At 900 m (3000 ft) above aerodrome elevation, accelerate to en-route climb speed.
**NADP 2:** Aircraft to climb to 800 ft and then reduce thrust. Withdraw flaps at that point and continue at a decreased rate of climb until 3000 ft. Then increase climb and thrust and complete the transition to average en-route climb speed.

This procedure involves the initiation of flap/slat retraction on reaching the minimum prescribed altitude. The flaps/slats are to be retracted on schedule while maintaining a positive rate of climb. The power reduction is to be performed with the initiation of the first flap/slat retraction or when the zero flap/slat configuration is attained. At the prescribed altitude, complete the transition to standard en-route climb procedures.

As there are restrictions with the NADP 1, there are also restrictions and steps for the NADP 2 operation (see Figure 12) according to ICAO DOC 8168 VOL I (ICAO, 2009):

1. The noise abatement procedure is not to be initiated at less than 240 m (800 ft) above aerodrome elevation.
2. The initial climbing speed to the noise abatement initiation point is $V_2 + 20$ to 40 km/h (10 to 20 kts).
3. On reaching an altitude equivalent to at least 240 m (800 ft) above aerodrome elevation, decrease aircraft body angle/angle of the pitch while maintaining a positive rate of climb, accelerate towards $V_{ZF}$ and either:
   a. Reduce power with the initiation of the first flap/slat retraction; or
   b. Reduce power after flap/slat retraction.
4. Maintain a positive rate of climb, and accelerate to and maintain a climb speed of $V_{ZF} + 20$ to 40 km/h (10 to 20 kts) to 900 m (3000 ft) above aerodrome elevation.
5. On reaching 900 m (3000 ft) above aerodrome elevation, a transition to average en-route climb speed is required.
6. An aeroplane should not be diverted from its assigned route unless:
   a. In the case of a departing aircraft it has attained the altitude or height which represents the upper limit for noise abatement procedures; or
   b. It is necessary for the safety of the plane (e.g. severe weather or to resolve a traffic conflict).

![Figure 12: NADP 2 Procedure (ICAO, 2009)](image-url)
Figure 13 shows both procedures to get a clear view of the difference between the NADP 1 and NADP 2 operation.

When using NADP 2, the retracting flaps from 800 ft reduce the air resistance and reduces the fuel consumption during the departure. By using the second procedure, the aircraft will have a less steep climb to its required Flight Level, which causes less noise. However, the noise will be longer heard. The difference in both these procedures is mostly the distance when reaching the required Flight Level according to their flight plan. When using NADP 1 the reduced engine power is longer used, while the flaps are longer used to maintain its required climbing speed, causing more noise close to the airport.

2.4.2 Noise reduction
Minimized noise emissions and fuel efficiencies due to reduced thrust settings are possible with a lower flap extension when atmospheric conditions and flight profiles permit. In accordance with standard operating procedures, pilots are encouraged, where possible, to use minimum flap settings to meet necessary speed restrictions and to minimize the noise during a departure. Managing aircraft speed without using flaps as the primary tool to reach the right altitude can significantly reduce noise emissions. Although a lower flap setting can reduce noise emissions and save significant amounts of fuel over time, it should be emphasized that the first priority is always to manage aircraft energy and be in a position to land at the appropriate time (INMB, 2018). Due to the retracted flaps during take-off, the flaps will create less noise by creating a more efficient airflow. When using flaps at a higher flap setting, the airflow is disturbed, which causes more noise. Figure 14 illustrates the disturbed airflow during flap extraction. The flaps are retracted during the NADP 2 departure, generating less noise further away from the airport (To 70, 2016).
2.4.3 Is it possible to use the NADP 2 procedure according to the regulations of the B+ route?

There are three types of routes for leisure flights at Lelystad Airport:
- Routes close to the airport (called the B+ routes), for both departure and arriving flights from and to Lelystad Airport, which are relevant for this research.
- The connecting routes, which are situated in the medium-high air space meant for aircraft to connect to the higher air space.
- So-called highways, situated in the higher air space, which are existing routes used by mostly Schiphol air traffic.

With 10,000 aircraft movements annually, 15 aircraft will depart, and 15 aircraft will arrive per day in the beginning years of the opening of Lelystad Airport (2020-2023). The 15 arrivals and departures per day result in 2 to 3 approaches from the north-east side of the airport and 12 to 13 from the south-east, due to the wind direction shown in chapter Route structure Lelystad Airport. For the departure routes, this ratio will be more or less the same. The 10,000 aircraft movements annually are the maximum in the starting years possible, without affecting the Schiphol or military traffic.

In 2014 four different route variants were analysed in the MER (Milieu Effect Rapportage). Calculations of 25,000 and 45,000 aircraft movements were made to conclude which route will be the most environmentally friendly. The so-called B+ route variant would produce the least noise disturbance for people living around the arrival and departure routes. The B+ routes are the ones close to the airport, which are essential to analyse for the use of the NADP 2 procedure (Rijksoverheid, 2018).

At the moment of writing, the heights on the maps stated in the Alderstafel agreement, are on the one hand strict height restrictions and on the other hand height agreements between adjacent air traffic units. Currently, there are three height restrictions, which count as in the strict sense:

1. Maximum 2000 ft. and 3000 ft close to the airport, directly after take-off, to prevent that departing air traffic of Lelystad gets into the Schiphol TMA and cause conflicts.
2. Maximum FL060 at some points in and close to the Lelystad TMA, to prevent air traffic of Lelystad gets in conflict with descending aircraft to Schiphol.

The agreements about the height between adjacent air traffic units are made to prevent procedure conflicts. However, these height agreements are not restrictions but work agreements. These heights are not taken into account in the publication of the newly revised airspace. After tactical coordination between the companies responsible for the airspace, it is possible to divert from the agreement if the operational circumstances allow it (LVNL, 2018).

Each air traffic controller will make sure that a departure or arrival flight will climb or descend as late as possible. The agreed heights will be met if the traffic situation won’t allow it to ascent sooner than the aircraft was supposed to, which can be caused by conflicting air traffic of Schiphol Airport or by an active military practising area. Assumptions of the AIP are leading in such causes. One of the premises from the AIP is that Schiphol air traffic or military air traffic has priority over the air traffic of airports like Rotterdam, Eindhoven or Lelystad. So far, it is not possible to make it obligated to use a Noise Abatement Departure Procedure by the airport or the ATC, which is mostly due to safety concerns of the aircraft (To 70, 2016).
2.4.4 Routes
Routes are shown in Appendix 3 as a line, and it is assumed that all aircraft will fly on this line. A plane should be able to fly over this line as the routes are not highways in the air. The demand for flights of Lelystad Airport is to operate as accurate as possible over the stated flying routes. In this case, ‘accurate’ means with a margin of 1 NM (nautical mile)/1852m left or right of the indicated lines (LVNL, 2018).

The approach and departure routes in the close area of Lelystad Airport, called the B+ routes, will be designed as RNAV-1 routes (Area Navigation). The aircraft allowed on Lelystad Airport will be capable enough to fly these routes as accurate as possible. An air traffic controller will have its focus on safety, efficient flight operation and efficient use of airspace when giving orders to the pilots at the connecting routes from and to B+. This could mean that aircraft (temporarily) have to divert from the route to ensure safety and a smooth flow of the air traffic. An optimum flight flow is pursued when ensuring these targets stated by the AIP. If these targets could be met, it will have a positive effect on the flight duration, fuel consumption and noise disturbance (LVNL, 2018).

2.4.5 FL060
FL060 means Flight Level 060, in other words, a flying level at 6000 ft, which is more or less 1800 meter altitude. At Lelystad Airport, this is a critical Flight Level as the departing flights will have to climb to this level after take-off. Also, this is the altitude where all the Schiphol air traffic initially will be cleared. However, in practice, the Schiphol air traffic will climb directly to higher Flight Levels. Also, the air traffic leaving Lelystad Airport will climb to higher altitudes than this Flight Level. The Dutch airspace is primarily focussed on having as few conflicts as possible for the Schiphol air traffic, which could result that the Lelystad air traffic can’t ascend directly to higher airspace as planned. All in all, for the ATC, the essential rule will be to climb where possible (LVNL, 2018).

2.4.6 Departure air traffic
As stated before, the ATC will make sure a flight will climb as soon as possible to the desired altitude. Dependent on the air traffic situation at that very moment, the ATC will preferably let the flight climb to FL060 within the Lelystad TMA. However, the current air space structure won’t always allow a flight to climb to Flight Level 060 within the TMA. Agreements are made by all parties responsible for the air space of Lelystad to prevent chaos (LVNL, 2018).
2.4.7 Height restrictions

Figure 15, shows the height restriction of departure route BERGI 2E. At the Y-axis of the graph, the height restrictions are shown in ft, and at the X-axis the distance from brake release is shown in meters. BERGI 2E is one of the departure routes at Lelystad Airport, according to the route set B+. The first height restriction is 3000 ft, at a distance of 10 km after brake release. The second restriction is 6000 ft from 10 to 62.5 km after brake release. The last one is 10,000 ft from brake release after 62.5 km from the airport (Rijksoverheid, 2018). The first two restrictions are essential for the Noise Abatement Departure Procedures, as this procedure has its most substantial impact on the first 3000 ft after brake release.

3000 ft will be reached at 12.5 km after brake release for the NADP 1 procedure and reached at 17.5 km after brake release for the NADP 2 procedure as can be seen in Figure 16. After that, the aircraft will climb further to 10,000 ft according to the departure procedure. However, it is possible to follow the guidelines of the airspace after 3000 ft with these procedures (To 70, 2016). All in all, it is possible to use the Noise Abatement Departure Procedures according to the guidelines stated in the airspace restrictions as it is right now. Appendix 4 illustrates the distance for route set B+ when reaching 3000 ft after brake release.
3. Methodology

This chapter explains how the research is done to evaluate the reliability and validity of the study. The paper of ICAO, "Effects of PANS-OPS Noise Abatement Departure Procedures on Noise and Gaseous Emissions" was the basis of this research. As this research is based on number-driven data and the aim to produce generalizable knowledge of fuel use during take-off, quantitative analysis is performed. The layout has four main points, which are:

1. Lelystad Airport
   - Explanation of why Lelystad Airport is chosen for this research and background information about potential growth.
2. Route network and airspace
   - Will be analysed as there will be a redesign, which should be considered during a new take-off procedure.
3. Aircraft performance
   - Performance of the B737-800, B737-700 and the A320-200 will be analysed to calculate the possible reduction in noise and gases.
4. Calculation of fuel/gas reduction
   - Amount of fuel difference will be calculated and possible noise reduction when having an NADP 2 take-off.

3.1 Research strategy

As the research strategy is adjusted on the sub-questions, all questions will be repeated and categorised in the four main points (Figure 17: Research strategy):

- [1] Why is Lelystad Airport chosen as the other national airport?
- [1] Which type of aircraft will be used the most at Lelystad Airport?
- [2] What is the timeline of the air space revision of Lelystad Airport?
- [2] What are the current regulations of the departure procedures at Lelystad Airport?
- [1] Is it possible to use the NADP 2 procedure, regarding the regulations, at Lelystad Airport?
- [2] How does the Noise Abatement Departure Procedures work?
  o Why is 3000 feet such an essential point in the NADP procedure?
- [2] Is it possible to make it an obligation to use such a procedure?
- [3][4] Are there any negative consequences when using an NADP procedure?
- [3][4] What is the impact of the NADP on the environment, regarding noise and CO₂ emissions?
- [3][4] What are the consequences of the CO₂ emissions and noise, if 90-95 per cent of the aircraft of the airport would use this procedure?

All sub-questions will be elaborated during the research, by using appropriate literature and other studies executed by other consultancy’s. All questions are categorised in the four main points, to get a clear overview of all the sub-questions. Each sub-question has a number in colour at the beginning, which equals one of the four main points.
3.1.1 Desk research

Desk research is another name for secondary research. It is an analysis of secondary data gained from other studies or reports, the researcher is reviewing what other people have done already and in the end after reviewing previous research findings, gain a broad understanding of the field (Travis, 2016).

The data used in this research is based on pre-researched findings, which can contribute to getting an answer to the main question of this project. Secondary data in this research can be obtained in the form of governmental reports, annual reports, company reports, scientific articles, business journals, libraries, interviews, archives and databases (Business Jargons, 2019).

As it comes to this research, there are three steps to be taken to get to the conclusion. Each step will have its sources, which are used the most to get to the outcome of the project.

3.1.2 Determination of all available data of the departure procedures at Lelystad Airport

The first step is to get an overview of the airspace routes as it currently is at Lelystad. By determining these departure routes, an overview of all the possibilities and the height profiles is stated, which is essential for the NADP 2 procedure. This step is vital for the project since all the final calculations of fuel burn will be based on the scenario at Lelystad Airport. Because the NADP 2 is a different procedure than usual, it is essential to know if it is possible to use this procedure or not. The following sources are used to gather this information:

- Alderstafel/MER
- Rijksoverheid

Alderstafel agreement or the MER (milieueffectrapport Lelystad) are both used for arguments regards the current route structure and what the possible effects will be for the environment. It shows the weak points, which are the points that should be improved for the revision of the airspace. It also analyses all the possible routes given at this moment, which will be examined during this research. At the Rijksoverheid, the documents of the government can be used for extra information about the route structure at this moment and to follow the official statements about the developments of the airspace revision.
3.1.3 Determination of all the available data of the NADP 2 procedure

During the second step of the report, all possible information of the NADP 2 procedure is determined. To start with the comparison of two different methods, NADP 1 and NADP 2, to make sure the second procedure suits the best regarding the goals of this research. The use and definition of the systems will be highlighted. Also, the possible consequences of the usage of the NADP 2 procedure will be obtained to make sure this procedure suits the targets of this research, to decrease the fuel flow and production of less noise during the departure. The following reports are used:

- ICAO
- Boeing
- To70

The ICAO documents give insight into the fuel usage during the NADP 2 procedure, which is useful for further calculations. Next to the document of ICAO, Boeing created a company report of different type of aircraft, regarding the fuel used during the NADP procedures. Both NADP 1 and NADP 2 are highlighted in this company report, which is useful when comparing both methods with each other. Also, the Boeing report is focused on the aircraft, which probably will be used the most at Lelystad Airport. At last, the focus of the To70 report is on the noise produced during the usage of the NADP procedure, both NADP 1 and NADP 2 procedures are highlighted in this advice report. This report is used for extra information on Lelystad Airport and the usage of the NADP procedures.

3.1.4 Fuel and noise reduction calculation

At last, the fuel and noise reduction when using the NADP 2 procedure is calculated. The fuel burn calculations are done by Boeing and ICAO based on aircraft performance data from the ICAO Aircraft Engine Emission Databank and data given by Boeing. The fuel difference between using an NADP 1 departure procedure and the NADP 2 procedure is used to calculate the produced emissions. Noise reduction is harder to calculate; however, research done by To70 and ICAO gives an insight into possible noise reduction when using the NADP 2 procedure. ICAO calculated the noise reduction in dBA at two different points during the departure:

- Maximum close in noise difference (dBA)
- Maximum distant noise difference (dBA)

Also, the research of ICAO highlights the crossover point at which the sign of the difference changes regarding the noise.

At last, the emissions are calculated by using data from the ICAO document: “Effects of PANS-OPS Noise Abatement Departure Procedures on Noise and Gaseous Emissions” and fuel burn data derived by Boeing. From the fuel burn data given by Boeing, the CO₂ emissions are calculated according to the formula stated by ICAO.
3.1.5 Research layout

To gain a clear view, regarding the buildup of the research of Boeing and ICAO, Figure 18 is added to show how both types of research substantiate each other and how they are linked. The left side of the figure shows the input data and the right the output data. The analysis of the emissions reduction and noise difference done by ICAO is based on the B737-700 and the A320-200. ICAO provides the reduction in noise and emissions when using the NADP 2 procedure instead of the NADP 1 procedure. However, the fuel burn is not given for both types of aircraft. The assumption is made that the fuel burn of the A320 is the same as the B738 when using an NADP 2 take-off, to get an outcome in exact numbers of the CO₂ reduction for the A320. Research done by Boeing states the fuel burn for the B738. Based on the fuel burn of the B738, it is possible to calculate the precise result of annual fuel burn and emissions for the A320. The study of the Boeing 737-700 done by ICAO is to substantiate the analysis of Boeing. The numbers of the B737-700 aren’t used for the output of the Boeing 737-800, as the 700 series will not be used at Lelystad Airport. However, it confirms the reduction of emissions when using an NADP 2 procedure, which is essential. The output of the B737-800 is based on the research done by Boeing, as this is the most accurate data for this research.

![Research Layout Diagram]

**Figure 18: Research Layout**
4. Boeing Analysis

Research done by Boeing is used to calculate the effects of the use of a different departure procedure. At first, this chapter shows the difference of fuel used with the NADP 1 and NADP 2 procedures. After analysing the fuel difference between both methods, further calculations are possible. A smaller fuel flow results in less CO$_2$ emissions during a take-off. Boeing states the fuel flow per departure procedure for the Boeing 737-800 Winglets. By using the fuel reported by Boeing, the calculation of the CO$_2$ emissions according to the ICAO standards is possible. At last, the chapter states the noise comparison between the NADP 1 and NADP 2 procedures, which will indicate if it produces less noise according to researches done by Boeing and ICAO.

4.1 Fuel difference NADP 1 & NADP 2

4.1.1 Flap setting difference

According to the official research done by Boeing, there are two different departure profiles which reduce the amount of fuel used during take-off. Besides the fuel reduction, there is also a noise reduction when using these two procedures. NADP 1 is a climb with acceleration and flap retraction beginning at 3,000 feet AGL, which is the noise climb-out procedure for close-in noise monitors. Profile 2 (NADP 2) is a climb with acceleration to flap retraction speed beginning at 1,000 feet AGL, which is the noise climb-out procedure for far-out noise monitors. As a general rule, when aeroplanes fly Profile 2 (NADP 2), they use 3 to 4 per cent less fuel than when flying Profile 1 (NADP 1).

At first, we will take a closer look at the fuel flow difference when using three different flap settings. According to research done by Boeing a lower flap setting results in less fuel burn during a take-off (Boeing, 2008). Figure 19 shows the difference in fuel burn during a regular take-off until 3000 ft. The fuel used is based on take-off with a gross take-off weight of 72,575 KG, with a B738 Winglets. The difference of the fuel burn between flap setting 15 (highest) and flap setting 5 (lowest) during take-off is 10 Kilograms. The decrease is 1.73 per cent when using flap setting five compared to flap setting 15. The fuel used is calculated until 3000 ft using a standard departure.

![FUEL USED (KG)](image)

**Figure 19: Fuel used with different flap settings (Boeing, 2008)**
As shown in Figure 19 a lower flap setting results in less fuel burn during take-off, as long as the flap setting meets the take-off performance requirements, it is possible to use the lowest setting as possible. A lower flap setting results in less drag, better climb performance, and the aircraft spends less time at low altitudes, which all result in less fuel burn during the take-off (Anderson, 2006).

The Noise Abatement Departure Procedures use the concept of having a lower take-off flap setting. However, a lower flap angle results in an increased take-off distance, which could result in more noise at a further range of the airport. See chapter Noise reduction for the explanation.

4.1.2 The fuel-saving potential of two climb profiles
After proving that a different flap setting results in a lower fuel burn during take-off, the research is taking a closer look at the fuel differential between the two Noise Abatement Departure Procedures. All research uses a B738 Winglets with a gross take-off weight of 72,575 Kilograms. Both departure procedures apply the medium flap setting of 10. The research done by Boeing is responsible for the results, to prove that there is a fuel differential between the different departure procedures. Figure 20 shows that the fuel used with a B738 Winglets differs between the two departure procedures when both executed with the same flap setting of 10. The difference between both methods is 67 Kilograms of fuel during the take-off. Which is a decrease of 2.9 per cent. The fuel used is calculated until 3000 ft using both departure procedures.

![Figure 20: Fuel used with the flap setting 10 (Boeing, 2008)](image)

4.1.3 Effect of combining take-off and climb strategies
In Figure 21 is shown what the consequences are of using a lower take-off flap setting when using the second Noise Abatement Departure Procedure instead of using flap setting 10. This comparison is between the highest take-off flap setting of 15 versus the lowest possible of 5. As shown in the chapter of fuel-saving potential of the two climb profiles, the second procedure uses approximately 3 per cent less fuel than when flying the NADP 1. Combining the second departure procedure with a lower flap setting should result in an, even more, lower fuel burn during the take-off as both are proven more efficient. The following results are available, according to research done by Boeing:
The study of Boeing made use of a B738 Winglets with a gross take-off weight of 72,575 kg. As both departure procedures require a different flap setting, both NADP 1 and NADP 2 use a different flap setting suited for their departure. As seen in Figure 21, the first departure procedure uses the highest flap setting of 15 and second departure procedure uses the lowest flap setting of 5.

When using the lowest flap setting with the NADP 2 procedure resulted in a decrease of approximately 4 per cent fuel used during the take-off. The four per cent showed that the fuel use per take-off is significantly less when using the NADP 2 departure instead of the NADP 1. The fuel used is calculated until 3000 ft using both departure procedures.

![Figure 21: Fuel used with NADP 1 flap setting 15, NADP 2 flap setting 5 (Boeing, 2008)](image)

4.1.4 Impact of less fuel burn on the emissions produced

As shown in Figure 21, the fuel burn is 4 per cent less when using the NADP 2 procedure compared to the standard procedure NADP 1. Now focusing on Lelystad Airport departures, what does this mean for the total departures over a year at Lelystad?

As shown in chapter Route structure Lelystad Airport of this research, the total amount of aircraft movements annually will be 10,000 at the beginning of the opening of Lelystad Airport. With 10,000 aircraft movements annually, 15 aircraft will depart, and 15 aircraft will arrive per day in the beginning years of the opening of Lelystad Airport (2020-2023). The 15 arrivals result in 2 to 3 approaches from the north-east side of the airport and 12 to 13 from the south-east. For the departure routes, this ratio will be more or less the same. The 10,000 aircraft movements annually are the maximum in the starting years possible, without affecting the Schiphol or military traffic.

Assuming that approximately 15 aircraft will depart from Lelystad Airport, during a 24/7 operation, resulting in 365 days annually. It results in about $15 \times 365 = 5475$ aircraft departing annually. If this amount counts for both departure and arrival, it exceeds the 10,000 aircraft movements annually. As both arrival and departure will be more or less the same, the assumption is that both departure and arrival will be around 5000 movements.
As shown in Table 3, the total amount of aircraft using the airport will be 1065. Now assuming that the operation at Lelystad Airport will be more or less the same as Eindhoven Airport, the percentage of the total B737 using the airport is: \( \frac{577 \times 100}{1065} = 54\% \).

The total amount of departure aircraft is 5000 movements; 54 per cent of these movements will be a B737. 54 per cent of 5000 movements result in \( \frac{54 \times 5000}{100} = 2700 \) departures of a B737.

Now focusing only on the Boeing 737, while this aircraft covers 54 per cent of the total operation at Lelystad Airport, the total amount of fuel burned during all take-offs annually can be calculated. The total amount of fuel consumed by the NADP 1 and NADP 2 procedures shows the difference when using one of the profiles. A comparison between the amount of B737’s using the NADP 2 procedure. The comparison will be from 0 to 100 per cent adoption of this procedure. Figure 22 shows a graph with the total amount of fuel burn of all aircraft using both the NADP 1 and NADP 2 procedures. All calculations are based on the fuel burn provided by Boeing (Boeing, 2008).

Table 7 provides inside in the total difference between the fuel consumption between the NADP 1 and NADP 2 procedure.

![Figure 22: Annual fuel burn difference B738 when using the NADP 2 procedure vs NADP 1](image-url)
Figure 23 shows the total amount of fuel burned with different percentages of usage of each procedure. According to the Boeing report, an NADP 2 procedure uses 93 kg’s less fuel than the NADP 1 procedure during the departure. This results in an increasing difference between the total amount of fuel burned when more aircraft uses the second departure procedure. Lelystad Airport is interested in the difference between the 80% and 100% use of both methods, to show that a 3 – 4 % decrease per B738 departure has a significant influence on the total amount of fuel burn annually.

Figure 23 confirms that a 3 – 4 per cent decrease in fuel burn annually has a tremendous impact on the total amount. Table 7 provides the exact amount of fuel burn. The annual fuel burn for the NADP 1 procedure is calculated by the formula: $2700 \times 2392 = 6,458,400 \, KG$. The second procedure uses the same method to calculate the total yearly amount of fuel burned, including all B738’s. The difference between both these departure procedures is 4%, which results in a fuel burn difference of 251,100 KG annually, which is a significant number to calculate the emissions produced during the departure.

**Figure 23: B737-8 total fuel burn**

**Table 7: Fuel burn difference B737-8**

<table>
<thead>
<tr>
<th>PROFILE</th>
<th>#AIRCRAFT</th>
<th>FUEL BURN/AC</th>
<th>TOTAL FUEL BURN (KG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NADP 1 (100%)</td>
<td>2700</td>
<td>2392</td>
<td>6,458,400</td>
</tr>
<tr>
<td>NADP 2 (100%)</td>
<td>2700</td>
<td>2299</td>
<td>6,207,300</td>
</tr>
<tr>
<td>Difference</td>
<td>-</td>
<td>4%</td>
<td>251,100</td>
</tr>
</tbody>
</table>
4.2 Emissions

According to research done by ICAO in 2014, there is a fixed number to calculate the amount of CO₂ produced by an aircraft regarding the amount of fuel burned. The total fuel burn of each trajectory is added up for a total amount of fuel burn of each procedure. The CO₂ emissions follow directly from the amount of fuel burned. The linear function since the constant representing the number of tonnes of CO₂ produced by burning a tonne of aviation fuel is 3.157 (ICAO, 2014).

Following the 3.157 as the constant representing the number of tonnes of CO₂ produced by burning a tonne of aviation fuel, the total amount of carbon dioxide produced at Lelystad Airport can be calculated.

Table 7 shows the total amount of fuel burned at both departure procedures NADP 1 and NADP 2 when both methods are used 100% by the B737-8’s. The calculation of produced CO₂ of all B738’s is focused on the difference between the two departure procedures to show the CO₂ reduction when using the second one.

The amount of carbon dioxide reduced is based on the 251,100 KG fuel difference, which is 251.1 tonnes of aviation fuel. This amount of fuel burn difference results in $251.1 \times 3.157 = 792.72$ tonnes of CO₂ reduction when using the NADP 2 procedure at Lelystad Airport (only focusing on the B738’s) — shown in Table 8. The graph in Figure 24 shows the difference in the amount of CO₂ emissions produced when having a take-off. For example, 20% of the B738’s using Lelystad Airport, departs with an NADP 2 procedure instead of an NADP 1 results in a decrease of 158.54 tonnes CO₂.

To show that the NADP 2 procedure is used more and more often, the usage forecast of Schiphol Airport of several airlines is also stated in Figure 24. This usage forecast illustrates that the usage of this procedure is increasing every year, the outcome provided in this figure is based on the usage of the NADP 2 procedure at Schiphol Airport (Rijksoverheid, 2016) (Rijksoverheid, 2017) (Rijksoverheid, 2018). Assuming that the increase of usage of this procedure will be more or less the same at Lelystad Airport, displays a theoretical and potential forecast for the coming years, regarding the possible CO₂ reduction when for example, 50% of the B738’s make use of the procedure, the reduction will be 400 tonnes CO₂.

<table>
<thead>
<tr>
<th>B738</th>
<th>Outcome in tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel burn</td>
<td>251.1</td>
</tr>
<tr>
<td>CO₂ difference</td>
<td>792.72</td>
</tr>
</tbody>
</table>

Table 8: CO₂ difference after using the NADP 2 departure instead of the NADP 1 with the B738

![Image: CO₂ difference in tonnes graph](https://example.com/co2_graph.png)

**Figure 24: Annual CO₂ reduction when using the NADP 2 departure vs NADP 1 of the B738**
5. ICAO Analysis

5.1 Introduction

Next to the research Boeing did with their B738 Winglets, ICAO did their research on the Noise Abatement Departure Procedures. By analysing and comparing both types of research, the outcome gets more validate. The emissions and noise chapter is entirely based on research done by ICAO. The focus will be on the Boeing 737-700 and the Airbus A320-200, as the A320-200 covers almost 30% of the operation at Lelystad Airport and as the B737-700 is comparable with the B738, which substantiates the research done by Boeing. Also, the B737-700 is the only B737 series available of the research done by ICAO. For the departure operations considered in this study, the emissions source are the main aircraft engines. For a given aircraft the operational emissions depend on the aeroplane and engine types, engine thrust setting and operating time to “study evaluation” altitudes of 1000 ft and 3000 ft, and adjusted top of climb (ICAO, 2008). By assuming that the reduced thrust take-off setting is possible at Lelystad Airport, all options can be analysed in this research.

<table>
<thead>
<tr>
<th>TABLE 9: AIRCRAFT TYPES INCLUDED IN THIS RESEARCH (ICAO, 2008)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aircraft category</td>
</tr>
<tr>
<td>--------------------</td>
</tr>
<tr>
<td>Narrow body</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

The emissions focused on in this research are both the NOx and CO2 emissions. The Flight Level of 1000 ft presents the total NOx emissions produced for each take-off procedure, which is the typical limiting altitude for NO2 concerns. As well as Flight Level 3000 ft AGL, which is the standard boundary layer mixing height and the ICAO landing/take-off altitude limit. The total CO2 emissions produced for each take-off procedure are presented at a common mission point after the top of climb (adjusted top of climb, see Figure 25). Emissions were calculated by individual aeroplane manufacturer propriety aircraft performance methods that provided aeroplane flight path and fuel burn. Flight profiles were computed using aeroplane manufacturer in-house performance engineering software, done by ICAO.

Also, noise reduction is analysed in this research, as both emissions and noise influence the environment. It will show if noise reduction can be combined with the decline of gaseous emissions. Noise levels were computed for these profiles using in-house noise calculation tools, compliant with SAE AIR-1845. CO2 production was calculated directly from fuel burn. NOx production was determined via fuel flow methods and certified engine emissions data (ICAO, 2008).
5.2 Graphical representation of the noise and emissions data

Figure 25 is an example (not based on real data) that illustrates the graphical representation of the noise and emissions data in the appendixes 5–8. The graphs show the effects of noise and emissions per aircraft and per pair of NADP procedures. As an example, in Figure 25, the procedures are named Procedure Y and Procedure Z. In the appendixes 5–8, the Y could mean, e.g. Procedure 1 and the X could mean Procedure 3, Y = 1 and X = 3. It will be named above the graph, which procedures are taken into account for that graph. The title of each figure specifies the aircraft type and the assumed take-off weight.

Noise levels are demonstrated per procedure through noise profiles, showing noise underneath the flight path as a function of distance from brake release. These profiles provide insight into the decrease in noise levels with increased distance from brake release. The applied noise metric is the maximum A-weighted noise level (L\text{Amax}). A relative scale is used for these profiles.

A third profile provides the difference between the noise levels of the two procedures, which allows rapid assessment of the amount and the sign of the difference as a function of distance from brake release. The third profile has three distinct characteristics, all of which are important in the selection of noise abatement departure procedures:

- a) a “close-in” noise difference zone, typically extending from the point of initiation of the procedure up to the crossover point;
- b) a “crossover point”, which is generally the point at which the sign of the difference changes; and
- c) a “distant” noise difference zone, extending from the crossover point.

**Figure 25: Graphical representation of the effects on noise and emissions for two procedures (ICAO, 2008)**
Emissions levels are represented by means of bar charts. The charts provide the total amount of NO\textsubscript{x} emitted between brake release and altitudes of 1000 ft or 3000 ft AGL, respectively “1000 ft NO\textsubscript{x}” and “3000 ft NO\textsubscript{x}” in Figure 25. A third quantity provided in the bar chart is the total amount of CO\textsubscript{2} emitted between brake release and the adjusted start of the cruise, referred to as “Point ‘X’ CO\textsubscript{2}” in the bar chart. All results are given as a percentage relative to the first of the two procedures in the chart and are printed above the bar charts to facilitate appraisal of the differences.

5.3 Procedure descriptions

Within the Noise Abatement Departure Procedures 1 and 2, there are two different options to use. Table 10 shows the four variants of departure procedures designed by PANS-OPS that are evaluated in this chapter. The four variants include two NADP 1 variants (procedures 1 and 2) and two NADP 2 variants (procedures 3 and 4). Both take-off procedures include the departure climb up to 10,000 ft AGL in Table 10, to evaluate the noise assessment. Figure 26 provides a schematic description of the succeeding climb-out to the adjusted top of climb.

Procedures 1 and 2 illustrate the effect of cutback height. Procedures 3 and 4 show the impact of thrust cutback at the beginning and end of the acceleration and flap retraction phase. The selected procedures also allow comparison between NADP 1 and NADP 2, which is described in more detail in chapter 5.3.1 Comparing all procedures. MCLT is the Maximum Climb Thrust (engine setting usually selected for climb-out phase).

Table 10: Variants of Departure Procedures (ICAO, 2008)

<table>
<thead>
<tr>
<th>Procedure 1</th>
<th>Procedure 2</th>
<th>Procedure 3</th>
<th>Procedure 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take-off thrust, lowest flap setting(^1)</td>
<td>Take-off thrust, lowest flap setting(^1)</td>
<td>Take-off thrust, lowest flap setting(^1)</td>
<td>Take-off thrust, lowest flap setting(^1)</td>
</tr>
<tr>
<td>Climb at $V_2 + 15$ KIAS(^2) to 800 ft AGL</td>
<td>Climb at $V_2 + 15$ KIAS(^2) to 1500 ft AGL</td>
<td>Climb at $V_2 + 15$ KIAS(^2) to 800 ft AGL</td>
<td>Climb at $V_2 + 15$ KIAS(^2) to 800 ft AGL</td>
</tr>
<tr>
<td>Cut back to MCLT</td>
<td>Cut back to MCLT</td>
<td>Cut back to MCLT</td>
<td>Cut back to MCLT(^4)</td>
</tr>
<tr>
<td>Constant speed climb to 3000 ft AGL</td>
<td>Constant speed climb to 3000 ft AGL</td>
<td>Constant speed climb to 3000 ft AGL</td>
<td>Constant speed climb to 3000 ft AGL</td>
</tr>
<tr>
<td>Accelerate to 250 KIAS while retracting flaps(^3)</td>
<td>Accelerate to 250 KIAS while retracting flaps(^3)</td>
<td>Accelerate to 250 KIAS(^3)</td>
<td>Accelerate to 250 KIAS(^3)</td>
</tr>
<tr>
<td>Climb at constant speed to 10 000 ft AGL</td>
<td>Climb at constant speed to 10 000 ft AGL</td>
<td>Climb at constant speed to 10 000 ft AGL</td>
<td>Climb at constant speed to 10 000 ft AGL</td>
</tr>
<tr>
<td>End profile at 10 000 ft(^5)</td>
<td>End profile at 10 000 ft(^5)</td>
<td>End profile at 10 000 ft(^5)</td>
<td>End profile at 10 000 ft(^5)</td>
</tr>
</tbody>
</table>

\(^1\) Flaps/pat setting according to the most commonly used flap/pat setting for a given aircraft type.
\(^2\) $V_2 + 15$ kt is considered the default, unless the aircraft operations manual recommends another take-off speed.
\(^3\) During the acceleration phases, the energy share between acceleration and climb performance is as applied by the manufacturer for the given aircraft.
\(^4\) The moment at which the cutback made is compatible with the performance of a specific aircraft in the study and in line with manufacturer’s standard operating procedures.
\(^5\) For noise predictions the profile end is assumed at 10 000 ft. For the CO\textsubscript{2} analysis the profile continues until the adapted start-of-cruise point.
Figure 26 provides a schematic representation of the vertical procedures from brake release. Take-off to the adjusted top of climb represents the portion of the flight profile that is dependent on the choice of departure procedure. Flight profiles after the adjusted top of climb are assumed to be typical for each aircraft type and therefore are not modelled in this study (Researchgate, 2018).

5.3.1 Comparing all procedures
The procedures described in Procedure descriptions are evaluated in pairs. For both the B737 and A320, four comparisons are made to demonstrate the effects of the different procedures. Also, the influence of the timing and altitude at which the thrust cutback occurs are demonstrated. The comparisons and their objectives are as follows:

a) Procedure 1 versus Procedure 2: reflects the influence of cutback height for NADP 1.

b) Procedure 1 versus Procedure 3: compares NADP 1 to NADP 2 (NADP 2 features a late cutback).

c) Procedure 1 versus Procedure 4: compares NADP 1 to NADP 2 (NADP 2 features an early cutback).

d) Procedure 3 versus Procedure 4: demonstrates the influence of the timing of the cutback for NADP 2.

Comparison of Procedure 1 to Procedures 3 and 4 demonstrates the difference between NADP 1 and NADP 2 procedures, which is the most relevant comparison for the research of using the NADP procedure at Lelystad Airport. Two variants of the NADP 2 procedures are used because these procedures are believed to be quite sensitive to the timing of thrust cutback.

Comparison of Procedures 3 and 4 demonstrates the impact on noise and emissions of the timing of thrust cutback in an NADP 2 procedure. From here, a conclusion can be made which type of procedure fits the best for Lelystad Airport. The following chapters will highlight the differences between the procedures. The appendixes provide two graphs per procedure, to give a more specific overview of the differences and results. These appendixes are focused on noise differences, NOx differences at 1000 ft and 3000 ft and last, the differences in produced CO2 emissions. The appendixes also provide the height profile per procedure. The corresponding appendix will be stated at each procedure. All results and graphs are retrieved from the research Effects of PANS-OPS Noise Abatement Departure Procedures on Noise and Gaseous Emissions done by ICAO.
5.3.2 Procedure NADP 1.1 vs procedure NADP 1.2
To start with the comparison of Procedures 1 and 2, which assesses the influence of cutback height on noise for a close-in noise abatement departure procedure. Cutback height varies from 800 ft AGL, the minimum altitude according to the guidance, to 1,500 ft AGL, the maximum cutback height observed in most of the currently applied departure procedures.

- Comparison of Procedures 1 and 2 allows the effect of a change in cutback height (respectively 800 and 1,500 ft AGL) for two NADP 1 type procedures to be determined. The height profiles in the appendixes show the steeper climb profiles for Procedure 2 for all cases, due to the delayed cutback.
- Table 11 provides the noise and emissions differences per aircraft type for both full and reduced take-off thrust.
- The results in Table 11 indicate similar trends for the different aircraft types. The results suggest that performing the cutback at 800 ft AGL rather than at 1,500 ft AGL leads to a noise reduction close-in, which can be attributed to the reduction in engine source noise. The magnitude of this noise reduction varies for the aircraft in this data set from 0.8 dBA to 5.0 dBA for the A320 and B737.
- For distant zones, the 800 ft AGL cutback leads to more noise than the 1,500 ft cutback, due to the steeper climb-out of the latter. The “distant” noise differences are considerably smaller than the “close-in” differences. After peak differences ranging from -0.2 dBA to -1.8 dBA, the noise differences gradually reduce throughout the remainder of the climb-out phase.
- The crossover point between the noise profiles varies between 2.4 and 3.0 NM.
- The emissions data in Table 11 show that, compared to Procedure 1, Procedure 2 produces differences in NOx of -0.1 to +1.4 per cent through 1000 ft and +0.5 to +1.4 per cent through 3000 ft AGL. Procedure 2 reduces CO2 by as much as 0.2 per cent through the adjusted top of climb.

Corresponding graphs for the Airbus A320-200 can be found in Appendixes: 5.1, 6.1. Corresponding graphs for the Boeing 737-700 can be found in Appendixes: 7.1, 8.1.

**Table 11: Noise and emissions differences between Procedures NADP1.1 and NADP1.2 (ICAO, 2008)**

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Aircraft</th>
<th>Take-off thrust</th>
<th>Maximum close-in noise difference (dBA)</th>
<th>Crossover point (NM)</th>
<th>Maximum distant noise difference (dBA)</th>
<th>NOx difference 1000 ft (per cent)</th>
<th>NOx difference 3000 ft (per cent)</th>
<th>CO2 difference Point X (per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procedure 2-1 A320-200 FULL</td>
<td>+5.0</td>
<td>2.5</td>
<td>-1.8</td>
<td>+1.4</td>
<td>+1.4</td>
<td>-0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Procedure 2-1 B737-700 FULL</td>
<td>+0.8</td>
<td>2.6</td>
<td>-0.2</td>
<td>-0.1</td>
<td>+0.5</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Procedure 2-1 A320-200 REDUCED</td>
<td>+2.6</td>
<td>2.4</td>
<td>-1.6</td>
<td>+1.2</td>
<td>+0.7</td>
<td>-1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Procedure 2-1 B737-700 REDUCED</td>
<td>+1.2</td>
<td>3.0</td>
<td>-0.6</td>
<td>+0.3</td>
<td>+1.2</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.3.3 Procedure NADP 1 vs procedure NADP 2.1

The comparison of Procedures 1 and 3 is second. With the comparison of Procedures 1 and 3, the difference between an NADP 1 and an NADP 2 procedure can be determined in terms of their effects on noise and emissions. Procedure 3 features a cutback at the end of the acceleration and flap retraction phase.

- The height profiles in the appendixes indicate better climb performance for Procedure 1 up to about 3000 ft AGL, but better overall climb performance up to 10,000 ft for Procedure 3, which results in a faster climb to the required Flight Level.
- The results in Table 12 indicate the “close-in” noise reduction obtained with Procedure 1 compared to Procedure 3. The peak values of noise difference in the “close-in” area before the crossover point vary from 3.5 to 7.7 dBA.
- In the “distant” area beyond the crossover point, noise differences are smaller, with peak differences between –0.3 and –2.7 dBA, and are spread out over a larger area.
- The crossover point ranges from 7.0 to 8.1 NM from brake release for the A320 and B737.
- The emissions data in Table 12 show that Procedure 3 produces up to 16.9 per cent more NOx through 1000 ft for the A320-200 Full thrust and up to 13.3 per cent more NOx through 3000 ft AGL, also for the A320-200 Full thrust. Procedure 3, however, leads to a reduction of CO2 of as much as 2.3 per cent through the adjusted top of climb, again for the A320-200 Full thrust.

Corresponding graphs for the Airbus A320-200 can be found in Appendixes: 5.2, 6.2.
Corresponding graphs for the Boeing 737-700 can be found in Appendixes: 7.2, 8.2.

**TABLE 12: NOISE AND EMISSIONS DIFFERENCES BETWEEN PROCEDURES NADP1.1 AND NADP2.1 (ICAO, 2008)**

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Aircraft</th>
<th>Take-off thrust</th>
<th>Maximum close-in noise difference (dBA)</th>
<th>Crossover point (NM)</th>
<th>Maximum distant noise difference (dBA)</th>
<th>NOx difference 1000 ft (per cent)</th>
<th>NOx difference 3000 ft (per cent)</th>
<th>CO2 difference Point X (per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procedure 3-1</td>
<td>A320-200</td>
<td>FULL</td>
<td>+7.7</td>
<td>7.2</td>
<td>-2.7</td>
<td>+16.6</td>
<td>+13.3</td>
<td>-2.3</td>
</tr>
<tr>
<td>Procedure 3-1</td>
<td>B737-700</td>
<td>FULL</td>
<td>+3.5</td>
<td>7.6</td>
<td>-0.3</td>
<td>+11.2</td>
<td>+7.2</td>
<td>-1.7</td>
</tr>
<tr>
<td>Procedure 3-1</td>
<td>A320-200</td>
<td>REDUCED</td>
<td>+6.2</td>
<td>7.0</td>
<td>-2.1</td>
<td>+16.9</td>
<td>+11.2</td>
<td>-2.2</td>
</tr>
<tr>
<td>Procedure 3-1</td>
<td>B737-700</td>
<td>REDUCED</td>
<td>+3.6</td>
<td>8.1</td>
<td>-0.5</td>
<td>+10.7</td>
<td>+7.7</td>
<td>-1.9</td>
</tr>
</tbody>
</table>
5.3.4 Procedure NADP 1 vs procedure NADP 2.2
The third comparison is between Procedure 1 and 4. Again, it is a comparison with between the NADP 1 and the NADP 2 procedure. As with the other comparison, the comparison of Procedures 1 and 4 enables the noise and emissions differences between these procedures. NADP 2 Procedure 4 features a cutback at the beginning of the acceleration and flap retraction phase. Although climbing out less steeply than Procedure 1 in the initial stage, Procedure 4 provides a steeper overall profile up to 10,000 ft AGL. The steeper overall profile results in reaching the 10,000 ft AGL altitude faster than using one of the other procedures.

- The noise results summarised in Table 13 indicate similar trends as in the other comparison between procedure one and procedure 3. Compared to Procedure 4, Procedure 1 provides noise reduction in the “close-in” area, with peak differences ranging from 3.0 to 7.0 dBA.
- In the “distant” area, overall Procedure 4 produces less noise, with peak noise differences reaching −1.6 dBA. For both aircraft, distant noise reduction is marginal and less well developed compared to the case of Procedure 1 versus Procedure 3.
- The crossover point ranges from 7.8 to 9.0 NM for the A320 and B737. Overall the crossover occurs later than for the comparison between Procedures 3 and 1.
- The emissions data in Table 13 show that Procedure 4 produces up to 15.5 per cent more NOx through 1000 ft and up to 9.9 per cent more NOx through 3000 ft AGL. Procedure 4, however, leads to a reduction of CO2 of as much as 2.0 per cent through the adjusted top of climb.

Corresponding graphs for the Airbus A320-200 can be found in Appendixes: 5.3, 6.3.
Corresponding graphs for the Boeing 737-700 can be found in Appendixes: 7.3, 8.3.

**Table 13: Noise and Emissions Differences between Procedures NADP1.1 and NADP2.2 (ICAO, 2008)**

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Aircraft</th>
<th>Take-off thrust</th>
<th>Maximum close-in noise difference (dBA)</th>
<th>Crossover point (NM)</th>
<th>Maximum distant noise difference (dBA)</th>
<th>NOx difference 1000 ft (per cent)</th>
<th>NOx difference 3000 ft (per cent)</th>
<th>CO2 difference Point X (per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procedure 4-1</td>
<td>A320-200</td>
<td>FULL</td>
<td>+7.0</td>
<td>8.1</td>
<td>-1.6</td>
<td>+14.6</td>
<td>+9.9</td>
<td>-2.0</td>
</tr>
<tr>
<td>Procedure 4-1</td>
<td>B737-700</td>
<td>FULL</td>
<td>+3.1</td>
<td>8.0</td>
<td>-0.1</td>
<td>+10.2</td>
<td>+5.7</td>
<td>-1.7</td>
</tr>
<tr>
<td>Procedure 4-1</td>
<td>A320-200</td>
<td>REDUCED</td>
<td>+6.6</td>
<td>7.8</td>
<td>-1.3</td>
<td>+15.5</td>
<td>+9.7</td>
<td>-2.0</td>
</tr>
<tr>
<td>Procedure 4-1</td>
<td>B737-700</td>
<td>REDUCED</td>
<td>+3.0</td>
<td>9.0</td>
<td>-0.2</td>
<td>+9.7</td>
<td>+5.3</td>
<td>-1.9</td>
</tr>
</tbody>
</table>
5.3.5 Procedure NADP 2.1 vs Procedure NADP 2.2

The comparison between Procedure 3 and 4 is the last one. The comparison of procedure 3 and 4 enables the effect of the timing of cutback during the acceleration and flap retraction phase for an NADP 2 procedure. Procedure 3 features a cutback to climb thrust at the end of the acceleration and flap retraction phase, whereas procedure 4 has a cutback at the beginning. The difference in cutback results overall in a steeper climb-out profile for procedure 3.

- The results in Table 14 show that performing the cutback to climb thrust at the beginning of the acceleration phase is always better for close-in noise reduction but ever worse for distant noise reduction. The noise reduction obtained “close-in” with Procedure 4 ranges from –0.8 to –5.4 dBA and can be attributed to a reduced engine noise level.
- The maximum noise differences in the “distant” zone vary between 0.6 and 4.2 dBA and can be attributed to differences in height profile. Unlike the trade-off in close-in and distant noise reductions when comparing Procedure 1 to Procedures 2, 3 or 4, here the magnitude of peak close-in and remote noise differences are very similar.
- The crossover point ranges from 3.5 to 3.7 NM and, which locates close to the point where cutback for Procedure 3 takes place.
- The emissions data in Table 14 show that Procedure 4 produces up to 1.7 per cent less NOx through 1000 ft and up to 2.9 per cent less NOx through 3000 ft AGL. Procedure 4, however, leads to an increase of CO2 of as much as 0.3 per cent through the adjusted top of climb.

Corresponding graphs for the Airbus A320-200 can be found in Appendixes: 5.4, 6.4. Corresponding graphs for the Boeing 737-700 can be found in Appendixes: 7.4, 8.4.

### Table 14: Noise and Emissions Differences between Procedures NADP2.1 and NADP2.2 (ICAO, 2008)

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Aircraft</th>
<th>Take-off thrust</th>
<th>Maximum close-in noise difference (dBA)</th>
<th>Crossover point (NM)</th>
<th>Maximum distant noise difference (dBA)</th>
<th>NOx difference 1000 ft (per cent)</th>
<th>NOx difference 3000 ft (per cent)</th>
<th>CO2 difference Point X (per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procedure 4-3</td>
<td>A320-200</td>
<td>FULL</td>
<td>-5.4</td>
<td>3.7</td>
<td>+4.2</td>
<td>-1.7</td>
<td>-2.9</td>
<td>+0.3</td>
</tr>
<tr>
<td>Procedure 4-3</td>
<td>B737-700</td>
<td>FULL</td>
<td>-0.6</td>
<td>3.5</td>
<td>+0.6</td>
<td>-0.9</td>
<td>-1.4</td>
<td>0.0</td>
</tr>
<tr>
<td>Procedure 4-3</td>
<td>A320-200</td>
<td>REDUCED</td>
<td>-2.9</td>
<td>3.5</td>
<td>+2.6</td>
<td>-1.2</td>
<td>-1.3</td>
<td>+0.2</td>
</tr>
<tr>
<td>Procedure 4-3</td>
<td>B737-700</td>
<td>REDUCED</td>
<td>-1.3</td>
<td>3.6</td>
<td>+1.3</td>
<td>-0.9</td>
<td>-2.3</td>
<td>0.0</td>
</tr>
</tbody>
</table>
6. Total emissions

This chapter will highlight the total emissions produced at Lelystad Airport. As both the B738 and the Airbus A320 are analysed, an estimation of the total emissions can be made, regarding the reduction of CO\textsubscript{2} emissions when using a Noise Abatement Departure Procedure. At first, the total reduction of both aircraft is shown. Also, the differences in both types of research will be highlighted regarding the CO\textsubscript{2} reduction, noise difference and NO\textsubscript{x} difference. Finally, the best procedure will be shown and explained why this procedure is the best recommendation for Lelystad Airport. All results of the total CO\textsubscript{2} reduction are theoretical and based on a 100 per cent use of the NADP 2 procedure at Lelystad Airport.

6.1 Total emissions at Lelystad Airport

6.1.1 B738

For the total amount of emissions produced at Lelystad Airport, this research will be using the results of Boeing for the B738 instead of the results of ICAO of the B737, as the B738 will probably be used the most at Lelystad (see chapter Emissions). As calculated in the chapter Impact of less fuel burn on the emissions produced, the fuel burn difference between the NADP 1 and NADP 2 procedure for the B738 is 251 100 kilograms. Which resulted in a CO\textsubscript{2} difference of 792.72 tonnes annually.

6.1.2 Airbus A320-200

The calculation of the total CO\textsubscript{2} emissions of the Airbus is a bit more difficult as the fuel burn during an NADP departure isn’t given by ICAO or Airbus. To calculate the reduction, which is proven at the chapter of Emissions, some assumptions are made regarding the fuel flow.

As shown in Table 3, the total amount of aircraft using the airport will be 1065. Now assuming that the operation at Lelystad Airport will be more or less the same as Eindhoven Airport, the percentage of the total A320 combined with the A319 using the airport is: \[(\frac{303+141}{1065}) \times 100 = 41\%\].

Assumed that the total amount of departure aircraft is 5000 movements; 41 per cent of these movements will be an Airbus A319/A320. This results in \[\frac{41 \times 5000}{100} = 2050\] departures of the Airbuses.

As the A320 and the B737 are comparable aircraft, it is assumed that the A320 has the same fuel burn during the NADP 1 departure. The reduction of CO\textsubscript{2} is based on the difference between procedure 1 and procedure 3, as the reduction of CO\textsubscript{2} is the most between these procedures of the NADP 1 and NADP 2 (see Table 12). The total fuel burn is calculated while having a take-off thrust reduction of 12 per cent, as this setting is more likely to be used during the departure, according to ICAO. Multiplying the number of aircraft with the fuel burn per aircraft, assuming that the fuel burn is the same as a B738, provides the total amount of fuel burned annually (as can be found in Table 15).

**Table 15: Annual fuel burn of all Airbus A320’s at Lelystad Airport**

<table>
<thead>
<tr>
<th>PROFILE</th>
<th>#AIRCRAFT</th>
<th>FUEL BURN/AC</th>
<th>TOTAL FUEL BURN (KG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NADP 1</td>
<td>2050</td>
<td>2392</td>
<td>4,903,600</td>
</tr>
</tbody>
</table>
From the total amount of fuel burned, the total amount of CO₂ emissions can be calculated. The CO₂ emissions follow directly from the amount of fuel burned. This is a linear function since the constant representing the number of tonnes of CO₂ produced by burning a tonne of aviation fuel is 3.157 (ICAO, 2014). The CO₂ difference is shown in Table 16. The CO₂ reduction is based on the number of -2.2 of procedure 3 compared to procedure 1.

**Table 16: Produced CO₂ difference between NADP 1 and NADP 2 of the A320**

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>The outcome in tonnes/year*</th>
</tr>
</thead>
<tbody>
<tr>
<td>A320-200</td>
<td>4903.6</td>
</tr>
<tr>
<td>CO₂ NADP 1¹</td>
<td>15,480.67</td>
</tr>
<tr>
<td>CO₂ NADP 2¹</td>
<td>15,140.09</td>
</tr>
<tr>
<td>CO₂ difference¹</td>
<td>340.57</td>
</tr>
</tbody>
</table>

*Calculations:*
1. Total fuel burn (KG/year)/1000 = fuel burn of A320-200 (tonnes/year)
2. Fuel burn¹ × 3.157 = CO₂ of NADP 1 (tonnes/year)
3. CO₂ NADP 1 (tonnes/year) × 0.978 (reduction percentage) = CO₂ of NADP 2 (tonnes/year)
4. CO₂ NADP 1 – CO₂ NADP 2 = CO₂ difference (tonnes/year) between the NADP 1 and NADP 2 procedure.

**6.1.3 Total emissions combined**

When combining both the B738 emissions and Airbus A319/A320 emissions, the overall theoretical reduction of CO₂ of these aircraft is shown. This will cover 95 per cent of the total aircraft using Lelystad Airport. Table 17 shows the total amount of CO₂ reduction annually at Lelystad when using the NADP 2 procedure instead of having a take-off with the NADP 1 procedure.

**Table 17: Total amount of CO₂ reduction at Lelystad Airport with 95% of the aircraft using the NADP 2.1 procedure**

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>CO₂ reduction (in tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A320</td>
<td>341</td>
</tr>
<tr>
<td>B738</td>
<td>793</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1133</td>
</tr>
</tbody>
</table>

**TOTAL CO₂ reduction with 100% implementation**

![Graph showing total CO₂ reduction with 100% implementation](image-url)
The total CO\(_2\) reduction is compared with a round trip from Amsterdam Schiphol Airport to Paris Charles De Gaulle to gain a better view of the decline. According to the CO\(_2\) calculator of ICAO, the total amount of CO\(_2\) produced by an A320 having a load factor of 80 per cent is 17797.6 Kilograms (ICAO, 2016). Which is the same as 17.8 tonnes of CO\(_2\) produced during a round trip. On other words; \(\frac{1133.29}{17.8} \approx 64\) round trips from AMS to CDG are saved annually when all aircraft will use an NADP 2 departure instead of an NADP 1 take-off.

Another comparison can be made regarding the CO\(_2\) production of a car annually. An average car, which drives 15,000 kilometres annually, produces 3360 kg CO\(_2\) a year. When only using the NADP 2 departure procedures, the CO\(_2\) reduction of Lelystad Airport is the same as the CO\(_2\) production of the equivalent amount of cars annually, by just using a different departure procedure. (Renewergy, 2019)

### 6.2 Differences in results between Boeing and ICAO

The effects of using a different departure procedure differ between the researches done at Boeing and ICAO. This chapter will focus on the difference in the outcome of CO\(_2\) reduction when using the NADP 2 procedure between both types of research and in the result of NO\(_x\) reduction/increase between the different procedures of the research done by ICAO.

#### 6.2.1 The difference in CO\(_2\) reduction

The CO\(_2\) reduction at the research done by Boeing (using the B738) is 4% when using the NADP 2 procedure instead of the NADP 1 procedure. However, according to ICAO (using the B737-700), the highest decrease in fuel burn and CO\(_2\) reduction is 1.9% when having a reduced take-off thrust setting. The difference between both pieces of research is the use of another Boeing 737 series. Boeing uses a B738 winglets as their example while ICAO uses a B737. The B737 series is 5.9 meters shorter in length, which results in less capacity regarding the seats, 40 seats less when having a Boeing with the maximum amount of seats. Both aircraft are using a CFM-56 engine while having a different total thrust. This could result in a different outcome regarding the CO\(_2\) decrease when using another procedure. In the end, both types of research conclude in a CO\(_2\) reduction with the use of an NADP 2 procedure. The most significant decrease for this research is the 4 per cent decrease for the B737-800 Winglets as this aircraft covers 54% of the operation at Lelystad Airport on the contrary of the B737-700, which covers only 2% of the total operation.

Also, the result with an Airbus 320-2 is positive regarding the reduction of CO\(_2\) when using the second Noise Abatement Departure Procedure. The maximum amount of CO\(_2\) reduction with the Airbus is a decrease of 2.3 per cent when using full thrust during take-off. When using 12 per cent less thrust during the take-off and using the NADP 2 procedure, the reduction of CO\(_2\) for the Airbus is 2.2 per cent, which is still a positive outcome. All specifications of the Boeing 737-700 and B738 can be found in Table 18.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Seats (2-class)</td>
<td>126</td>
<td>162</td>
</tr>
<tr>
<td>Maximum seats</td>
<td>149</td>
<td>189</td>
</tr>
<tr>
<td>Length</td>
<td>33.6 m</td>
<td>39.5 m</td>
</tr>
<tr>
<td>Wingspan</td>
<td>35.8 m</td>
<td>35.8 m</td>
</tr>
<tr>
<td>Height</td>
<td>12.5 m</td>
<td>12.5 m</td>
</tr>
<tr>
<td>Engine</td>
<td>CFM-56</td>
<td>CFM-56</td>
</tr>
<tr>
<td>Total thrust</td>
<td>48,400 lb(_f)</td>
<td>54,600 lb(_f)</td>
</tr>
</tbody>
</table>
6.2.2 NO\textsubscript{x} difference between the procedures

Chapter 5.3.1 Comparing all procedures shows the difference in noise and emissions when using a different procedure during the take-off. However, it was expected that the CO\textsubscript{2} emissions would decrease when using the NADP 2 procedure, it was less expected that the NO\textsubscript{x} emissions would increase with such high percentages between 5.3 and 16.9 per cent. Which is the reason why this is highlighted, even though the NO\textsubscript{x} difference is out of the scope of the research.

According to research done by NASA, the increase of NO\textsubscript{x} is correlated in the increase of an engine power setting. NO\textsubscript{x} emissions occur primarily at high engine power settings and during the cruise portion of the flight and are the result of high combustion temperatures. NO\textsubscript{x} is highest for subsonic aircraft during the take-off phase of flight. For a given engine, NO\textsubscript{x} increases with power setting as depicted in Figure 27, and NO\textsubscript{x} for modern production engines increases with rated thrust. This could be the reason why there is such a large difference between the different NO\textsubscript{x} production regarding the four different departure procedures. Each procedure accelerates at a different Flight Level to the requested altitude. The NO\textsubscript{x} aircraft emissions are released predominantly at high altitudes and constitute a relatively larger proportion of the local NO\textsubscript{x} levels.

At present, there is considerable uncertainty with regards to the complex chemical reactions involving NO\textsubscript{x} emissions at high altitudes. NO\textsubscript{x} emissions in the upper troposphere and lower stratosphere, where current subsonic aircraft cruise, may lead to ozone formation and consequently contribute to global warming. However, NO\textsubscript{x} releases at these altitudes may also reduce the residence time of other gases that contribute to global warming (NASA, 1994).

All in all, it is useful to take this into account for upcoming researches, as the NO\textsubscript{x} increases when using one of the Noise Abatement Departure Procedures. The increase of these emissions is correlated with the use of the engines regarding the thrust setting. With the NADP 2 procedure, the thrust cutback of the engine occurs later during the take-off compared to an NADP 1 take-off. This could be the reason for the increase of NO\textsubscript{x} emissions during the NADP 2 departure and is worth investigating. Especially given the fact that NO\textsubscript{x} is regulated at the EU level and countries have to abide by those regulations. For example, currently, in the Netherlands, it is a top priority in 2019 and coming years to reduce the NO\textsubscript{x} production, while at the same time Lelystad Airport is supposed to be opened around April 2020.
6.3 Noise difference

Noise difference is analyzed by ICAO at two points during the take-off. The first point is the maximum close-in distance, which is typically the zone extending from the point of initiation of the procedure up to the crossover point. The second measure point during the take-off with an NADP procedure is the maximum distant noise difference zone, which is the zone extending from the crossover point. The crossover point is the zone, which is generally the point at which the sign of the difference changes.

The first thing that comes up is that the difference at the maximum close-in point is always higher when comparing the NADP 2 procedure with the NADP 1 procedure. However, the second point, the maximum distant noise difference is always lower when comparing the two procedures. The third difference is the difference in the crossover point during the departure. The NADP 1.1 procedure is the procedure which is compared with the NADP 2.1 and the NADP 2.2 procedure regarding the noise difference. The close-in noise is always higher when using the second procedure than in the first procedure. The increase of the noise at the close-in point differs from +3.5 to +7.7 dBA when using the NADP 2.1 departure procedure. However, the decrease at the distant noise point with this procedure is lower than the increase at the close-in point. It differs from a decrease of -0.3 to -2.7 dBA. At last, the crossover point of the noise difference is in between 7.0 and 8.1 NM. All things considered, there is a noise decrease at the distant noise point when using the NADP 2.1 procedure. Consideration should be made if the people are living within a range of 8.1 NM from the airport experience more noise than the people living near the airport. If so, the NADP 2.1 procedure will produce less noise from that point, which is a positive outcome for the people living 8.1 NM from the airport.

Focusing on the second NADP 2 procedure, the same conclusions can be made as to the first NADP 2 procedure. The close-in point the noise difference is always an increase regarding the noise difference between the NADP 1 and NADP 2.2 procedure. The increase differs from +3.0 to +7.0 dBA, thus a lower increase in noise than with the use of the NADP 2.1 procedure. However, the crossover point is at a further distance away from the airport when using the NADP 2.2 procedure compared to the NADP 2.1 procedure. It differs from 7.8 to 9.0 NM. The decrease at the maximum distant noise differs from -0.1 to -1.6 dBA after the crossover point, which is a smaller decrease in noise than at the NADP 2.1 procedure.
6.4 Best procedure available

6.4.1 A320-200

When considering the noise and CO$_2$ difference at both types of aircraft, it can be concluded that the reduced thrust option of the NADP 2.1 procedure is the best. With the A320-2, this procedure has the lowest increase at the maximum close-in noise point. Also, the crossover point is the closest to the airport. The difference in a decrease of noise at the maximum distant noise point between the reduced and full thrust option is 0.6 dBA, which can be neglected as the difference at the close-in point is much larger (+1.5 dBA). The CO$_2$ difference between the full thrust and reduced thrust is -0.1 which can also be neglected as a measuring point, concluding the NADP 2.1 procedure is the best option available for the A320-2. All outcomes can be found in Figure 28. Appendix 5.4 and Appendix 6.4 provides an overview of the differences between both procedures shown as a graph.

The focus of the table is between procedure 3 (NADP 2.1) and procedure 1 (NADP 1.1) regarding both full and reduced thrust. The other comparison is between procedure 4 (NADP 2.2) vs procedure 1 (NADP 1.1 also regarding both full and reduced thrust.

![A320-2 Table](image)

**Figure 28: A320-2 Best Procedures Analyses**
6.4.2 B737

Furthermore, the NADP 2.1 departure using reduced thrust with the B737 series isn’t the best option regarding the maximum close-in noise difference. It has the highest increase in noise of all options available for the Boeing. However, the difference between the lowest increase of noise at this point is +0.6 dBA. Nonetheless, the crossover point with the NADP 2.1 reduced thrust departure is closer to the airport than the NADP 2.2 departure using reduced thrust. Also, the decrease at the maximum distant noise point is the highest with the NADP 2.1 reduced thrust departure. The CO$_2$ decrease is more or less the same at both departure procedures. Both departure procedures are almost equal from this point of view. The consideration is made based on the A320-2, while it is easier to have a standard departure procedure for all aircraft. Concluding that the NADP 2.1 reduced thrust procedure is also suitable for the B737 series. All outcomes can be found in Figure 29. Appendix 7.4 and Appendix 8.4 provides an overview of the differences between both procedures shown as a graph.

The focus of the table is between procedure 3 (NADP 2.1) and procedure 1 (NADP 1.1) regarding both full and reduced thrust. The other comparison is between procedure 4 (NADP 2.2) vs procedure 1 (NADP 1.1 also regarding both full and reduced thrust.

![Figure 29: B737 best procedures analyses](image)
7. Conclusion

The effects of the use of noise abatement departure procedures (NADP), designed according to PANS-OPS guidance, on noise and emissions have been analyzed for both the Boeing 737 series and the A320 at Lelystad Airport. The goal was to determine if the NADP procedures reduce the noise and emissions during the take-off and if it is possible to use these procedures regarding the regulations of the airspace of Lelystad. By analysing both, NADP 1 and NADP 2 procedures, for two types of aircraft, it is determined which of the profiles suits best at Lelystad Airport. The second departure procedure seems to be the best option available regarding noise and emissions reduction. According to the usage forecasts of the Schiphol Group, the usage of the NADP 2 procedure has increased with 50 to 80 per cent from 2016 until 2019. The increase of use shows that the procedure is accepted by the airlines at Schiphol Airport. Expected is that the usage percentage of this procedure will be comparable at Lelystad Airport.

The procedures evaluated include two NADP 1 and two NADP 2 variants. The analysis confirms that NADP 1 minimises the noise in a zone relatively close to the brake release point, whereas NADP 2 minimises the noise in the area further away from brake release. Close-in noise differences between NADP 1 and NADP 2 are generally more significant than distant noise differences. Usage of the second departure procedure always results in a noise increase closer to the airport. The difference in noise nuisance is an important consideration to determine which procedure will suits best, whereas it is not the purpose that people living closer to the airport will be the victim of the use of another procedure.

The point where the noise difference changes sign is called the crossover point and is shown to occur between 7.0 to 9.0 NM distance from brake release for the A320-200 and B737. The cutback height has a significant influence on noise for both NADP 1 and NADP 2. It determines both the location of noise reduction areas and the amount of noise reduction in those areas. The magnitude of the noise differences for procedures using full thrust is more substantial than those with reduced thrust. However, the use of full thrust and maximum take-off weight will not be encountered frequently in operation.

NADP 2 tends to produce less CO₂ and more NOₓ compared to NADP 1. In terms of accumulated NOₓ up to 3000 ft above ground level, NADP 2 appears to generate between 5 to 13 per cent more NOₓ than NADP 1 for the A320 and B737. In terms of accumulated CO₂ up to the adjusted top of climb, NADP 2 variants appear to produce 1.7 to 2.3 per cent less CO₂ than NADP 1 according to the ICAO research. However, the study of Boeing concludes a decrease of up to 4% of CO₂ reduction when using NADP 2 instead of NADP 1. The difference between both types of research can result from the use of a different Boeing 737 series, as Boeing did the study with a B737-800. The B737-800 covers 54 per cent of the total operation at Lelystad Airport, which makes this research more relevant as ICAO analysed a B737-700 series, which covers 2 per cent of the entire operation. Nonetheless, there is a decrease of CO₂ when using the NADP 2 procedure for both types of aircraft of the Boeing 737 series.

If up to 95 per cent of the operation at Lelystad Airport, which includes all Boeing 737’s and A320’s, use the NADP 2 procedure during take-off, the total decrease annually with 10,000 aircraft movements will be 1133,29 tonnes of CO₂. 1133,29 tonnes of CO₂ is the same amount of CO₂ production of 340 cars annually, as well as 64 round trips from Schiphol Amsterdam Airport to Paris Charles de Gaulle. The results indicate that, of the procedures included in this study, no single departure procedure minimises overall noise and emissions simultaneously. Depending on local airport requirements, trade-offs must be made between close-in versus distant noise, NOₓ versus CO₂ emissions and, finally, noise versus gaseous emissions.
8. Recommendation

The objective of this research was to create an overview of the possible CO\textsubscript{2} reduction when using a different departure procedure. The departure procedures, included in this research, are the Noise Abatement Departure Procedures 1 and 2. Both procedures are analysed and compared regarding the noise and CO\textsubscript{2} reductions based on other researches of Boeing and ICAO. After the analysis, a recommendation can be made to use or not to use one of these procedures and to take or not to take them into account for the airspace revision.

The current design of the route structures of Lelystad Airport allows the use of the Noise Abatement Departure Procedures. However, after the revision, it is advised to look at the possibility to still have the option to use this procedure during the take-off. In 2023 the review of the airspace should focus on the minimum flying altitude during the departures to have the opportunity to use the NADP 2 procedure. The focus of the revision should be on the aircraft types B737-8 and the A320-2, as these aircraft will probably be used the most at Lelystad Airport. Both these aircraft have their requirements, regarding the climb speed of \( V_2 + 15 \) Knots Indicated Air Speed to 800 ft Above Ground Level. The climb speed should still be possible after the revision of the airspace. Also, the option to accelerate from 3000 ft Above Ground Level to a speed of 250 Knots Indicated Air Speed should be in consideration when revising the airspace to be still able to use the NADP 2 procedure. From there on, the aircraft will climb with a constant speed to 10,000 ft where the procedure ends. However, the first climb to 3000 ft is the essential part of this procedure, and after that, it is not obliged to have a constant climb to 10,000 ft if not possible regarding the Schiphol TMA. Concluding that the revision should be focused mostly on the first 3000 ft, after that, the ATC is free to proceed this procedure, or in case it is not possible, it can use another departure route.

Research in the difference between the NADP 1 procedure and the NADP 2 procedure shows that both the procedures have their pros and cons. In this case, the goal was to have a decrease in CO\textsubscript{2} production, where the second procedure has the most significant reduction in CO\textsubscript{2}. However, using this procedure will lead to a reduction of CO\textsubscript{2}; it also increases NO\textsubscript{x} production. The close-in noise is also increased, using the second departure procedure on the contrary, distant noise decreases. In the case of Lelystad Airport, the distant noise is more critical as there are more people to experience noise disturbance, in which case the second departure procedure is again the best option. A consideration between the decrease of CO\textsubscript{2}, distant noise and the increase of NO\textsubscript{x}, close-in noise should be made. The recommendation of this report is to use the second departure procedure, as the primary goal was to decrease the CO\textsubscript{2} production during take-off. Also, the decrease in noise further away from the airport is definite for the people living beneath or near the departure routes. As this procedure decreases the amount of CO\textsubscript{2} and decreases noise nuisance, it is useful to take it into account while revising the airspace of Lelystad Airport.

When recommending the second departure procedure as the best option, there are still two different procedures possible within the NADP 2 procedure. After comparing the NADP 2.1 and NADP 2.2 procedure with the differences between these two and the NADP 1.1 procedure, it resulted in an overall best procedure for both types of aircraft. The NADP 2.1 reduced thrust procedure had an overall most substantial decrease in CO\textsubscript{2}, most significant reduction in the maximum distant noise, best crossover point of 7 NM for the A320-2 and the smallest increase of noise at the maximum close-in point from brake release. Overall, this procedure was the best for both types of aircraft. It is recommended to use the NADP 2.1 reduced thrust procedure at Lelystad Airport to have a decrease of 2.2% CO\textsubscript{2} production for the A320-2 and a decrease of 4% CO\textsubscript{2} production for the B737-8 per take-off. During the revision of the airspace, it is advised to consider this to make it possible to decrease the pollution of the local environment and get a step closer meeting the
requirements of the Paris Environmental Agreement which entered into force on the 4\textsuperscript{th} of November 2016 (Britannica, 2019).

At last, it is recommended to have further research in a NO\textsubscript{x} reduction during the landing and take-off cycle, as profit can be made during this cycle regarding the NO\textsubscript{x} emissions. The NO\textsubscript{x} production will increase when using an NADP departure, which makes it necessary to focus on both CO\textsubscript{2} and NO\textsubscript{x} emissions during the departure procedure. This research is focused on the reduction of CO\textsubscript{2} during a take-off. However, the significant increase in NO\textsubscript{x} was not something which was expected when starting the research. The reduction of these emissions mostly depends on how the engines are used and if the manufactures improve the engines. Further research about the use of engines during take-off and what the future brings, regarding improved engines or use of biofuels, which produce fewer emissions, is recommended.
Bibliography


Appendixes

1. B738 engines

In April 2009, Boeing and CFM introduced the New CFM56-7BE engine enhancements program to coincide with 737 airframe improvements. The combination reduces fuel consumption by two per cent. CFM’s engine hardware changes will improve airflow, and the engine will run at cooler temperatures resulting in a one per cent reduction in fuel consumption. Boeing’s aeroplane structural improvements will reduce drag, reducing fuel use by about one per cent. The combined gains also equal a two per cent reduction in carbon emissions.

The 737-800 incorporates an advanced-technology wing design that helps increase fuel capacity and efficiency, both of which increase range. Besides, advanced-technology Blended Winglets are offered as a production option on the 737-800. These eight-foot long wingtip extensions enhance range, fuel efficiency and take-off performance while lowering carbon emissions, engine maintenance costs and noise. Performance benefits include fuel consumption and emissions reductions of up to 3.5 per cent (Rocketroute, 2019).
2. Noise contours

2.1 Noise contours 25,000 movements

2.2 Noise contours 45,000 movements
3. Overview B+ routes and connection routes
4. Departure and approach heights

Red line: departure route
Green line: approach route

4.1 Route B+ RWY 23 Height

4.2 Route B+ RWY 5 Height
4.3 MER Routevariant B+ RWY 05 Heights

- Optimisatie op omgeving
- Raderingsroutes verlegd ter hoogte van Biddinghuizen en Kampen

4.4 MER Routevariant B+ RWY 23 Heights

- Optimisatie op omgeving
- Vlietreknoten voor deze baan verlegd ter hoogte van Zeewolde, Biddinghuizen en Kampen
5. Airbus A320-200 Full Thrust

5.1 Airbus A320-200 Full Thrust P1 & P2

A320-214, CFM56-5B4/P
- Full thrust (TOGA)
- MTOW = 169,800 lb

Comparison of Procedures 1 and 2
5.2 Airbus A320-200 Full Thrust P1 & P3

A320-214, CFM56-5B4/P
- Full thrust (TOGA)
- MTOW = 169 800 lb

Comparison of Procedures 1 and 3

A320-214 / T77 t — $L_{max}$ below flight path
- Difference (3-1)
- Procedure 1 (Full thrust)
- Procedure 3 (Full thrust)

A320-214 / T77 t — Flight path
- Procedure 1 (Full thrust)
- Procedure 3 (Full thrust)
5.3 Airbus A320-200 Full Thrust P1 & P4

A320-214, CFM56-5B4/P
- Full thrust (TOGA)
- MTOW = 169,800 lb

**Comparison of Procedures 1 and 4**

![Graph](image1)

![Graph](image2)
5.4 Airbus A320-200 Full Thrust P3 & P4

A320-214, CFM56-5B4/P
- Full thrust (TOGA)
- MTOW = 169,800 lb

Comparison of Procedures 3 and 4

![Graph comparing emissions and noise levels for Procedures 3 and 4](image)

![Graph showing height and distance for Procedures 3 and 4](image)
6. Airbus A320-200 12 per cent reduced thrust
6.1 Airbus A320-200 12 per cent reduced thrust P1 & P2
6.2 Airbus A320-200 12 per cent reduced thrust P1 & P3
6.3 Airbus A320-200 12 per cent reduced thrust P1 & P4
6.4 Airbus A320-200 12 per cent reduced thrust P3 & P4
7. Boeing 737-700 Full Thrust

7.1 Boeing 737-700 Full Thrust P1 & P2
7.2 Boeing 737-700 Full Thrust P1 & P3

737-700/CFM56-7E24
- Full power thrust
- MTOW = 154 500 lb

Comparison of Procedures 1 and 3

Flight path
- Procedure 1 (Full thrust)
- Procedure 3 (Full thrust)
7.3 Boeing 737-700 Full Thrust P1 & P4
7.4 Boeing 737-700 Full Thrust P3 & P4

**737-700/CFM56-7B24**
- Full power thrust
- MTOW = 154 500 lb

**Comparison of Procedures 3 and 4**

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**Graph 1:**
- **737-700 / MTOW — $l_{max}$ below flight path**
- Difference (4-3)
- Procedure 3 (Full thrust)
- Procedure 4 (Full thrust)

**Graph 2:**
- **Flight path**
- Procedure 3 (Full thrust)
- Procedure 4 (Full thrust)
8. Boeing 737-700 10 per cent reduced thrust

8.1 Boeing 737-700 10 per cent reduced thrust P1 & P2
8.2 Boeing 737-700 10 per cent reduced thrust P1 & P3
8.3 Boeing 737-700 10 per cent reduced thrust P1 & P4
8.4 Boeing 737-700 10 per cent reduced thrust P3 & P4