Analysis of Vertical Flight Trajectory Efficiency

A quantitative study on the effects of climb restrictions for flights departing Amsterdam Airport Schiphol

Thesis

KDC Mainport Schiphol – Centre of Excellence
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Thesis

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Preface

This report has been written to comply with the graduation requirements of the Bachelor of Science degree in the Aviation Engineering program from the Amsterdam University of Applied Sciences. This bachelor focusses on a wide range of aviation related subjects including gas turbine performance, aviation maintenance management, control theory in automated flight, airframe mechanics and route design and development. This thesis combines all this knowledge and applies it to capacity management at Schiphol.

Graduating at the KDC Mainport was a unique opportunity to follow my interest and passion for air traffic management. The close collaboration with KLM, LVNL and Amsterdam Airport Schiphol provided a one of a kind experience where there was the flexibility to choose and shape the research as I envisioned it.

I would like to thanks my supervisors Janette Bezemer-Nagtegaal and Frenchez Pietersz for their support and guidance during my graduation. Their expertise and visions allowed me to gain tremendous knowledge while also challenging me to stay curious.

Moreover, I would like to express my gratitude towards Alina Zelenevska for her sharp remarks during the weekly SCRUM meetings. Thanks to her patience the research was structured in a way where there would always be a goal which needed to be accomplished every two weeks. She managed to push me out of my comfort zone and not accept no for an answer.

Furthermore, I would like to thank Evert Westerveld, Coen Vlasblom and Boudewijn Lievegoed for their continuous feedback during the bi-weekly sprint reviews. Their guidance ensured the research scope incorporated the goals of the KDC stakeholders.

My thanks are in place for Ferdinand Dijkstra for all his support in providing me with the data required for this research. Besides, his knowledge and enthusiasm regarding the research kept me motivated throughout.

In addition, I want to thank my fellow graduation students Bas Broekstra, Gijs Peters, Martijn Ringelberg, Megan Heijke and Roel Wouters who made the working environment in the office professional and enjoyable. The support from each other managed to increase the quality of each other’s research, including my own.

Finally, I would like to thanks my parents for supporting me and serving as test subjects when explaining what this thesis is about. The patience they had when listening encouraged me that not only I understood this research, but that someone from outside the aviation industry could do as well.

Marc Eijkens

Schiphol, 25-06-2018

Abstract

Preferably a flight departs such that it can fly an uninterrupted climb to the requested cruise altitude, as this is considered most efficient. Due to multiple factors departing flights are not always able to continuously climb to the requested cruise altitude, resulting in increased fuel consumption. The objective of this research is to identify the causes which interrupt the climb profile for flights departing Schiphol and how these affects aircraft operators in terms of fuel consumption. This research determines the location, distance and time spent in level flight during the climb phase for all departures from Schiphol during the months of February and July 2017. This is done by means of quantitative research using radar trajectory data and system flight plans. The level segments are analysed in terms of the location of occurrence, altitude, departure route, departure runway, aircraft type and sector exit point. Finally, the additional fuel consumption induced by the level segments is computed using EUROCONTROL Base of Aircraft Data performance models. The majority of the level segments occur in the Terminal Manoeuvring Area and near the boundaries of the Dutch airspace where flights are transferred to air traffic control in the United Kingdom. It can be concluded that the current hand-over conditions with the neighbouring air navigation service providers negatively impact the vertical efficiency of departures from Schiphol Airport, while the level segments in the Terminal Manoeuvring Area create the most amount of additional fuel due to crossing arrival and departure routes.

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List of Abbreviations

3Di	Three Dimension Inefficiency
ACC	Area Control Centre
ACID	Aircraft Identifier
ADES	Destination aerodrome
ADEP	Departure aerodrome
AFUA	Advanced Flexible Use of Airspace
ANS	Air Navigation Service
ANSP	Air Navigation Service Provider
APM	Aircraft Performance Models
ARP	Aerodrome Reference Point
ATC	Air Traffic Control
ATCo	Air Traffic Controller
ATM	Air Traffic Management
ATS	Air Traffic Services
ATYP	Aircraft Type
BADA	Base of Aircraft Data
CCO	Continuous Climb Operations
CDO	Continuous Descent Operations
COPX	Coordination Exit Point
CPF	Correlated Position report for a Flight
CTA	Control Area
DDR	Demand Data Repository
DoF	Day of Flight
EATM	European Air Traffic Management
ECEF	Earth-Centred, Earth-Fixed
ENU	East North Up
FF	Fuel Flow
FIR	Flight Information Region
FL	Flight Level
FO	Flight Object
FMS	Flight management System
FRA	Free Route Airspace
GPS	Global Positioning System
GS	Groundspeed
IAF	Initial Approach Fix
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
LVNL	Air Traffic Control the Netherlands
LoA	Letter of Agreement
KDC	Knowledge and Development Centre Mainport Schiphol
NADP	Noise Abatement Departure Procedures
NATS	National Air Traffic Services
NGA	National Geospatial-Intelligence Agency
NM	Nautical Mile
PRISME	Pan-European Repository of Information Supporting the Management of EATM
PRU	Performance Review Unit
RFL	Requested Flight Level
RoC	Rate of Climb
SESAR	Single European Sky ATM Research
SFPL	System Flight Plan
SID	Standard Instrument Departure
STAR	Standard Arrival Route
TAS	True Air Speed
TBO	Trajectory Based Operations
TMA	Terminal Manoeuvring Area
ToC	Top of Climb

Definitions of terms

Continuous Climb Operations (CCO)

> “The optimum vertical profile of a departing aircraft is a continuously climbing path with optimal fuel conserving climb rate. The fuel used in climbing to the most fuel efficient level can be a significant part the overall fuel used for the flight. CCO allows the aircraft to reach the initial cruise flight level at optimum air speed with optimal engine thrust settings, thus reducing total fuel burn and emissions for the whole flight. When CCOs are in effect, appropriate airspace design and ATC procedures should be used to avoid the necessity of resolving potential conflicts between the arriving and departing traffic flows through ATC level or speed constraints”. (SKYbrary, 2017)

Vertical flight trajectory efficiency

The extent to which an aircraft is able to continuously climb or descent without any interruptions.

Level segment

Section of a trajectory where the airplane is neither climbing or descending.

Summary

Air Traffic Control the Netherlands is responsible for the management of the civil airspace, focusing primarily on providing air traffic services in the Amsterdam FIR. Air traffic controllers strive to accommodate flights with climb instructions to enable a continuous climb while ensuring safety. However, accommodating a continuous climb is not always possible. A continuous climb departure is a vertical flight profile where an aircraft is able to reach the initial cruise flight level without any interruptions. Such interruptions cause the flight to be unable to continue to climb, resulting in level segments at a sub-optimal altitude. This increases the fuel consumption of aircraft due to flying longer at these sub-optimal altitudes.

The objective of this research is to determine and quantify what causes an interrupted climb profile for flights departing Schiphol and how these affects aircraft operators in terms of additional fuel consumption. This results in the following main research question:

> ***How is vertical flight trajectory efficiency impacted by climb restrictions caused by airspace design and ATC procedures, for flights departing Amsterdam Airport Schiphol?***

The initial research steps of the research focus on the analysis of vertical flight trajectory efficiency in the months of February and July of 2017 to determine the amount and length of level segments. A total of over 40,000 flights are included in the dataset from these two months. Only flights departing from Schiphol are used for the trajectory efficiency analysis, no arrivals are considered in this research. The relationship between the vertical efficiency and airspace design and ATC procedures are analysed using the results from the vertical trajectory efficiency. Finally, the effects of level segments on fuel consumption are determined using aircraft performance data.

A total of 1,920 and 2,052 segments are detected in the months of February and July 2017 respectively, resulting in a total of 9,221 and 10,749 nautical miles spent at intermediate altitudes in each respective month. Affected flights departing Schiphol fly on average for 5 nautical mile level, which approximates to nearly a minute of level flight per affected flight. Analysis on the location of level segments determined that the highest percentage of level segments occurred near the boundary between the Amsterdam FIR and UK airspace. Another highlight are the level segments occurring in the South-West of the Schiphol TMA. The additional fuel consumption caused by the level segments is calculated to be 250,000kg per year. The main contributor to this additional fuel consumption comes from the level segments flown in the Schiphol TMA, followed by the segments at the hand-over altitude with London Control at FL240.

The research concludes that over 90% of the departing flights climb continuously while in the Amsterdam FIR, whereas EUROCONTROL determined that 80% of all flights departing from Schiphol fly a continuous climb departure until cruise. It should be noted that in the EUROCONTROL study the entire climb segment is taken into account, whereas this research only focusses on the trajectory within the lateral boundaries of the Amsterdam FIR. The main cause of climb interruptions are attributed to flights departing via GORLO and BERGI towards the London AC sectors. The hand-over agreements with London AC impose a limitation to continue the climb near the border with the London sectors. Furthermore, flights via GORLO and BERGI are prone to interruptions during their climb segment because of the vertical separation techniques applied by ATC in the TMA. Departures are initially restricted from climbing higher than FL60 after take-off due to crossing departure and arrival routes.

Although the results from this research conclude the main causes for level segments, more research is necessary to determine how continuous climb departures can be achieved by more flights. The following recommendations result from this research:

- Research the vertical flight trajectory efficiency for flights arriving at Schiphol.
- Develop solutions which reduce the effect of crossing departure and arrival routes on the vertical trajectory efficiency.
- Research the hand-over conditions with London AC on how these could be adjusted to accommodate continuous climb departures.

1 Introduction

Paragraph 1.1 opens with a background on flight trajectory efficiency. This is followed by the problem statement in paragraph 1.2, research objectives in paragraph 1.3 and research relevance in paragraph 1.4. Next, the research question and sub-questions are discussed in paragraph 0. Finally, the scope and structure of the thesis are presented in paragraphs 1.6 and 1.7.

1.1 Background

The Dutch airspace, and with it the Amsterdam Flight Information Region (FIR), is relatively small due to the size of the Netherlands. Air Traffic Control the Netherlands is responsible for the management of the civil airspace, focusing primarily on providing air traffic services in the Amsterdam FIR (LVNL, 2018).

Over the past couple of years' significant research has been done in the field of arrival management and the hand-over conditions involved (mainly between Approach and Area Control). A less explored area of research has been the interface between the Area Control Centre (ACC) and the centres that border the Amsterdam FIR. The upscaling of the geographical area of optimisation across sector and centre boundaries are expected to unlock large benefits for airspace users. This upscaling should provide the means to work towards concepts such as Trajectory Based Operations (TBO). TBO should reduce the constraints that airspace has on trajectories and enable a way to design airspace in a flexible manner (European Commission, 2017).

Flights departing the Amsterdam FIR are transferred to one of the adjacent Area Control Centres bordering the Amsterdam FIR according to generic hand-over conditions. These hand-over conditions are mainly determined by airspace classification and areas of responsibility. These hand-over conditions are documented in the Letters of Agreement (LoA's), ranging from generic agreements to specific instructions. Flights are handed over to adjacent centres at specified flight levels (FL) at a specific coordination exit points (COPX) as established in the LoA.

From an operator's perspective, the most ideal trajectory is the one incurring the least amount of costs and taking the shortest time. This would in most cases be a trajectory with the shortest distance, including a continuous climb and descent profile (not taking into account any weather conditions). A smooth trajectory increases fuel efficiency and therefore reducing operational costs. Additionally, emissions are lowered as a result of the reduced fuel-burn.

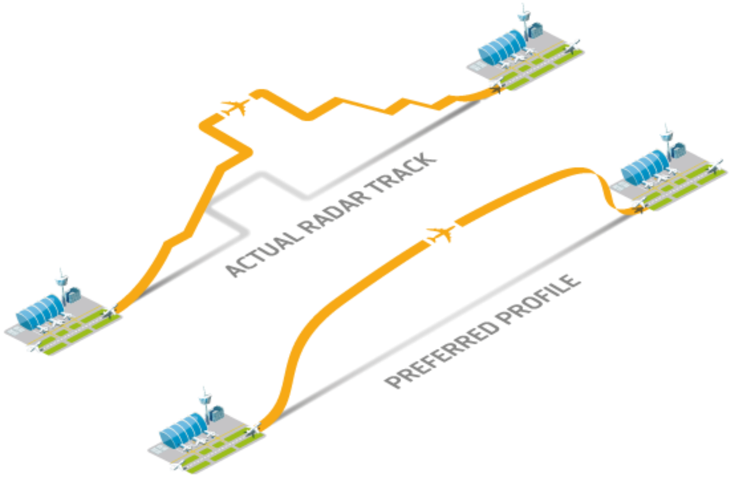

Figure 1 Actual versus preferred flight profile (NATS, 2017)

1.2 Problem statement

Air traffic controllers are not always able to provide flights with the most optimal vertical flight trajectory due to tactical separation instructions or inflexible hand-over conditions with adjacent centres (NATS, 2015). Accommodating these more optimal vertical profiles is not always possible due to the limited airspace and ATC procedures. This causes inefficiencies for departing aircraft resulting in increased fuel consumption. A continuous climb departure is a vertical flight profile where an aircraft is able to reach the initial cruise flight level without any interruptions. Such interruptions causes the flight to be unable to continue the climb, resulting in a level segment at a sub-optimal altitude. Figure 1 presents a preferred profile versus an actual profile which includes level segments. EUROCONTROL estimates that a single continuous climb departure compared to a non-optimised climb profile can result in 50 to 200 kilograms of fuel savings per flight (EUROCONTROL, 2008).

1.3 Research objectives

Air Traffic Control the Netherlands aims to provide means for airlines to fly a safe yet optimal route. The objective of this research is to analyse the vertical flight trajectory efficiency to determine the factors which negatively impact this efficiency. Data analysis should provide insight into the magnitude of vertical flight trajectory efficiency for flights departing Schiphol Airport and locate where the vertical flight trajectory interruptions occur in the Amsterdam FIR. The trajectory efficiency is then used to determine the impact it has on fuel consumption and emissions.

1.4 Research relevance

Airlines are always striving to fly as efficient as possible, by means of using the shortest and most optimal flight trajectory. This enables operators to fly as cost efficient, allowing them to be more competitive. These improved flight trajectories will also have a positive effect on sustainability due to reduced fuel consumption. From this perspective the research is relevant for airlines departing from Schiphol.

Besides the relevancy for airlines, there is an interest from LVNL to explore solutions that could improve the hand-over process, enabling controllers to provide flights with more efficient flight trajectories. Such solutions aim to minimise the negative effect of the coordination, preferably reducing controller workload. This reduction in workload has positive effects on safety and the amount of traffic that can be handled.

The Single European Sky Air Traffic Management Research and Development (SESAR) project aspires to improve air traffic management (ATM) in Europe by providing solutions that will facilitate the safe and environmentally friendly operation of air transport. These solutions are known as the SESAR concepts of operations and are laid out in the European ATM Master Plan. The objectives for the SESAR concepts of operations have been broken down into several implementation objectives, such as Automated Assistance to Controllers during Coordination (European Commission, 2017).

1.5 Research Questions

The goal of the research is to provide an answer to the main research question:

> ***How is vertical flight trajectory efficiency impacted by climb restrictions caused by airspace design and ATC procedures, for flights departing Amsterdam Airport Schiphol?***

To answer this question, it is necessary to define what vertical flight trajectory efficiency and inefficiency means. Next, the factors which affect this efficiency and what the relationship is between these factors and airspace design and ATC procedures are defined. Finally, the effects in terms of fuel consumption can be derived to quantify the impact on airlines.

From these objectives follow the sub-questions (SQ) used to answer the main question:

1. What is the vertical flight trajectory efficiency for flights departing Amsterdam Airport Schiphol currently?
2. What is the relationship between the vertical flight trajectory efficiency and airspace design and ATC procedures?
3. What are the effects of level segments on fuel consumption?

1.6 Research scope

The goal of the research is to define the vertical flight trajectory efficiency of flights departing from Amsterdam Airport Schiphol. Only flights departing from Schiphol are used for the trajectory efficiency analysis, no arrivals are considered in this research. Departures from the regional airports (Rotterdam, Eindhoven, Maastricht, Groningen) will not be taken into account for the research. Only 10.5% of all flights carried out in 2017 departed from or arrived at a regional airport (CBS, 2018). However, the model used in this report could be used to carry out a similar analysis for flights departing from the regional airports.

The research will focus on the months of February and July 2017. These months comprise over 40,000 departures and are a representation of the busiest and least busy months of the year in terms of traffic movements. These months allow for an analysis of the effects of seasonality on the vertical flight trajectory efficiency.

1.7 Thesis structure

This thesis has been structured around the sub-questions in the same order as stated in paragraph 0. The methodology and design of the research is discussed in chapter 2. Chapter 3 presents previously performed research and analysis related to trajectory efficiency. Chapter 4 discusses the methods and results related to the analysis of the vertical flight trajectory efficiency (SQ1). Following from these results chapter 5 presents the relationship between the vertical efficiency and airspace design and ATC procedures. Chapter 6 presents the effects of the vertical efficiency in terms of additional fuel consumption based on EUROCONTROL aircraft performance models. Finally, a conclusion on the impact of climb restrictions on the vertical trajectory efficiency is given in chapter 7.

2 Methodology

This research aims at providing an understanding of the vertical flight trajectory efficiency for flights departing Schiphol and its impact on the airline operators in terms of additional fuel consumption. Paragraph 2.1 describes the structure used to execute the analysis and is followed by the research hypotheses in paragraph 2.2. Next the acquisition of the required data for the research the data sample used are described in paragraphs 2.3 and 2.4 respectively. Paragraph 2.5 describes the techniques and tools used for the analysis of the data.

2.1 Research Design

The research is structured around quantitative research of the three sub-questions as mentioned in paragraph 0. The initial research includes the vertical flight trajectory efficiency calculations to determine the number and length of level segments (SQ1). This is followed by researching the relationship between the vertical efficiency and flight specific variables, including departure route, departure runway and aircraft type (SQ2). Finally, the effects of level segments on fuel consumption are determined using aircraft performance data (SQ3). These steps are presented below in Figure 2.

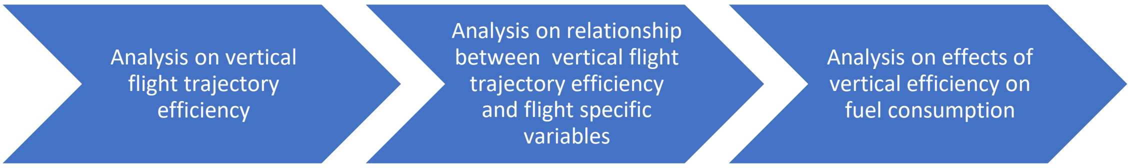

Figure 2 Research structure

2.2 Research Hypotheses

The Performance Review Unit (PRU) has determined that on average flights departing Amsterdam in 2017 were interrupted for 25 seconds in the climb. The percentage of flights considered to have operated a continuous climb departure was calculated to be 77% (EUROCONTROL - Performance Review Unit, 2018). The analysis of the PRU considers the entire climb phase while this research only focuses on the flight trajectory while under control of LVNL. It is therefore expected that the average time spent in level flight in the Amsterdam FIR will be less than 25 seconds and that a higher percentage of the flights will be considered to fly a continuous climb departure.

A single CCO or CDO, when compared with a non-optimised climb profile, can result in fuel savings of up to 200 kilograms of fuel per flight (EUROCONTROL, 2018). Another EUROCONTROL study estimates an additional 50kg of fuel per impacted flight (EUROCONTROL, 2008). As only the climb section of the flight within the Amsterdam FIR is considered it is hypothesised that the savings will be less.

2.3 Data Collection

The sample data used for the analysis is gathered from the radar recordings from LVNL. This data contains information related to the trajectory the aircraft has flown and the flight plan related to each flight. The trajectory data is logged every 5 seconds, resulting in a high accuracy. The initial plan was to use data from the EUROCONTROL Demand Data Repository 2 (DDR2), however this data proved to be not accurate enough.

The Base of Aircraft Data (BADA) Aircraft Performance Models (APM) are used to determine the additional fuel consumption from the level segments. *“The BADA APM is used for simulation and prediction of aircraft trajectories for purposes of ATM research”* (EUROCONTROL, 2015). This data is provided upon approval by EUROCONTROL based on the purposes of the research.

2.4 Sample

The data used for the analysis comprises all departures from Amsterdam in the months of February and July 2017. These two months represent the high and low peaks of the year in terms of flight movements. A total of over 40.000 departures are included in this sample. These two months contain flights which are of no interest to the research, hence a filter has to be applied to remove such flights. These non-concerned flights include police flights, coastguard flights, medical emergency flights, equipment testing and calibration flights and domestic reposition flights. The resulting flights are only flights departing Schiphol to an international destination, which have been under active control of Dutch ATC, while also crossing the Amsterdam FIR boundary to another ANSP. The following filters will be applied to the data.

- Only flights departing EHAM (ICAO code for Schiphol).
    - The reason to consider only flights departing Schiphol is that 89,3% of all commercial flights in the Netherlands arrive or depart from Schiphol (CBS, 2018). The data sample will therefore contain a uniform set of flights. Departures from regional airports are subject to other restrictions and routes.
- Only flights flying under Instrument Flight Rules (IFR).
    - IFR flights are the flights which are under active air traffic control, whereas flights flying under VFR are responsible for their own separation in most circumstances.
- Only flights with a destination airport (ADES) outside of the Amsterdam FIR.
    - This filters out local flights such as those carried out by the coastguard and police, which depart from and arrive at EHAM. It also filters domestic reposition flights to or from any of the regional airports, which usually fly at low altitudes.
- Only flight trajectories within the Amsterdam FIR and below the upper limit of the airspace are considered.
    - Only climb segments within the Amsterdam FIR are of interest to the research, segments which are outside the boundaries are not under control of LVNL ATC and cannot be influenced therefore.
- The climb is considered to start at 3000 feet AGL and end once the requested cruise level is reached.
    - The Noise Abatement Departure Procedures (NADP) as established by ICAO end at 3000 feet (ICAO, 2006).
- An intermediate flight level is defined as a segment at which the vertical speed is equal to or less than 300 feet/minute over a 20 second period (Peeters, Vertical flight efficiency during climb and descent, 2016).
    - A level segment would normally be defined as a portion at which the altitude remains the same. However, the altitude of an airplane is always deviating slightly by several feet. To bypass this limitation, the definition is based on vertical speed.

2.5 Data Analysis

The data analysis is broken down into three parts related to each sub-question used to answer the main research question. Paragraph 2.5.1 focusses on detecting the level segments and determining the vertical flight trajectory efficiency. The methods used to determine the relationship between vertical trajectory efficiency and flight specific variables is discussed in paragraph 2.5.2. Finally, paragraph 2.5.3 follows up on the results from the vertical flight trajectory efficiency by translating the effect of level segments to additional fuel consumption using the BADA APM.

2.5.1 Vertical flight trajectory efficiency

The method used to analyse trajectory efficiency will be according to the EUROCONTROL Air Navigation Service (ANS) Performance Review Unit (PRU). Vertical trajectory efficiency will be analysed based on time spent at an intermediate flight level due to climb restrictions, and the distance flown at an intermediate level. “If the rate of climb or descent between two data points is smaller than or equal to a chosen vertical velocity, that part of the trajectory is considered as a level flight segment. Doing this for the entire climb or descent trajectory, the distance and time flown level can be calculated” (Peeters, Vertical flight efficiency during climb and descent, 2016).

The research is entirely based around numerical data representing historic trajectories and system flight plans. A code to analyse the vertical trajectories is developed in Wolfram Mathematica. This is a software package used for modern technical computing, which is especially useful for data science and visualisations. The visualisation aspect is to be used to demonstrate where and how often level segments occur in the Amsterdam FIR. Level segments are plotted to display where the level segments occur, heat maps are used to illustrate where level segments occur most often.

2.5.2 Relationship with airspace design and ATC procedures

The results from the previous section will be used to analyse the relation between of flight specific variables and vertical trajectory efficiency. Microsoft Excel is used to determine the relationship between the vertical trajectory efficiency and the airspace design and ATC procedures. Bar charts are used to present the relative level distance versus the relative number of flights for each flight specific variable. Besides, bar charts are used to present the average distance spent in level flight versus the total average distance per flight.

2.5.3 Additional fuel consumption

A quantitative analysis will be used to determine the additional fuel consumption caused by level segments in the climb phase. Wolfram Mathematica is used to utilise aircraft performance models to determine additional fuel consumption. The BADA APM models are used to create interpolation functions to calculate fuel consumption at specific altitudes for each aircraft model. BADA family 3 is used for these calculations as it includes all aircraft types found in the dataset. The results from the fuel analysis are displayed using bar charts similar to those used to describe the relationship with airspace design and ATC procedures. The BADA APM contain fuel consumption data related to low, nominal and high aircraft weights. All three weights will be used during the analysis. The results from the high weights are assumed to provide the most accurate results as departing flights still hold the majority of the fuel for the trip.

3 Review of the Literature

The literature review presents previous performed research and analysis related to trajectory efficiency. Paragraph 3.1 and 3.2 present the research done into continuous climb and departure operations. This is followed by the current developments to improve hand-overs in paragraph 3.3. Finally, the airspace design and ATC procedures are explained in paragraph 3.4.

3.1 Flight trajectory efficiency

Over the last decades the main focus of vertical flight profile optimisation for commercial aircraft has been on Terminal Manoeuvring Area (TMA) operations (Dalmau & Prats, 2014). Examples such as continuous descent operations (CDO) and continuous climb operations (CCO) are at the hearth of such studies on this vertical optimisation, but are not limited to TMA operations. Various stakeholders have indicated to be interested in the vertical aspect of flight trajectory efficiency in addition to horizontal efficiency (Peeters, Vertical flight efficiency during climb and descent, 2016).

In 2012 NATS adopted the three-dimension inefficiency score (3Di) concept to measure flight efficiency in the UK. This score establishes a clear indication of the operational performance over time and aims to deliver long term improvements in flight trajectories (NATS, 2017). Similar to the efficiency calculation used by the PRU, NATS scores the vertical efficiency on the number of level flight (in terms of distance) below the requested cruise flight level. The level flight segments are represented by the horizontal segments in Figure 3. The flight is unable to continue the climb profile to the requested cruise altitude. NATS also differentiates based on the altitude at which the level flight segment occurs. A level flight segment at a low altitude is penalised more than one at a higher altitude, see Figure 3.

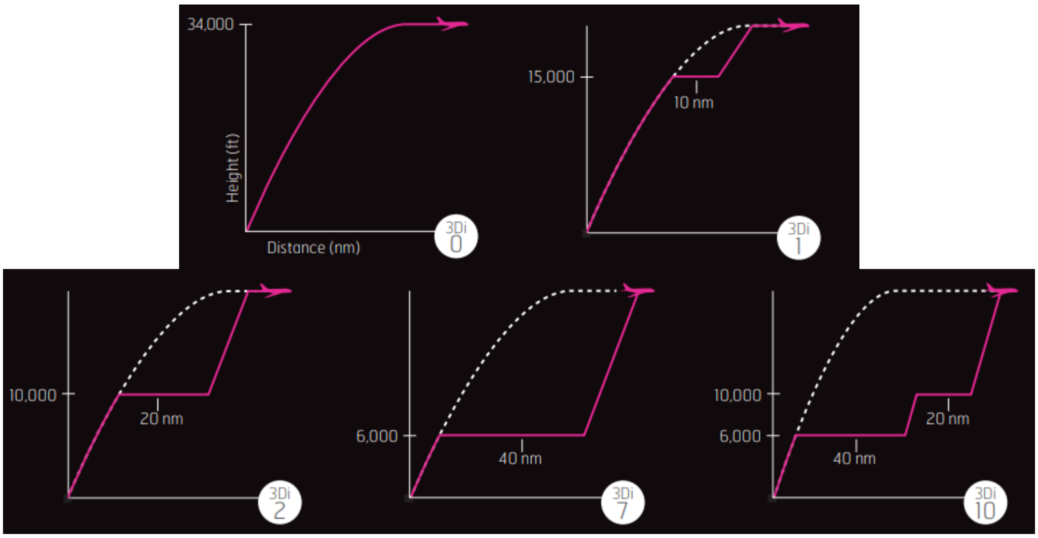

Figure 3 Vertical efficiency 3Di score (NATS, 2015)

The trajectory efficiency affects the operational efficiency of airlines, mainly in terms of fuel consumption and to a lesser extent in terms of time. One of the major goals for the aviation community is to reduce fuel consumption due to environmental concerns and manage the risk related fuel price fluctuations (Ryerson, Hansen, & Bonn, 2011). Scandinavian Airlines System argues that: "*Green departures are much more fuel/emission efficient than green arrivals due to the fact that climb-out is a high energy phase of flight whereas the descent is a low energy phase.*" The conclusion from the statement is that both CCDs and CDAs are beneficial to reduce fuel consumption (Larsson, 2011). A 2008 study on the vertical flight efficiency concluded that 19% of flights departing from European airports experienced an interrupted climb segment. The interrupted climb resulted in an additional fuel consumption of 15 kg per impacted flight. At Schiphol 22% of the flights experienced an interrupted climb (EUROCONTROL, 2008). This averages to 3 kg of additional fuel per flight. A study from 2011 concluded that a 43kg increase of fuel consumption was experienced, due to an imposed 10NM level segment at FL70, on a flight from Copenhagen to Stockholm with an Airbus A321 (Larsson, 2011).

3.2 Performance Review Unit

The Performance Review Unit monitors and reviews the performance of air navigation service providers and systems across Europe, covering all 41 EUROCONTROL Member States. The PRU publishes the vertical flight efficiency on a monthly basis. The data used for the analysis by the PRU is from the Pan-European Repository of Information Supporting the Management of EATM (PRISME). The data used by the PRU consists of Correlated Position reports for a Flight (CPF) to assess the actual trajectories (EUROCONTROL - Performance Review Unit, 2018).

The PRU publishes information regarding average time flown level per flight (Figure 4), percentage of flights considered as CCO or CDO (Figure 5) and the median altitude where level flight segments occur Figure 6.

The average time flown level per flight according to the PRU for flights departing Amsterdam averages at 25 seconds throughout the past years. The PRU analysis considers the entire climb segment from departure until reaching the cruise altitude. The time spent in level flight for arrivals is considerably higher, averaging around 175 seconds per flight.

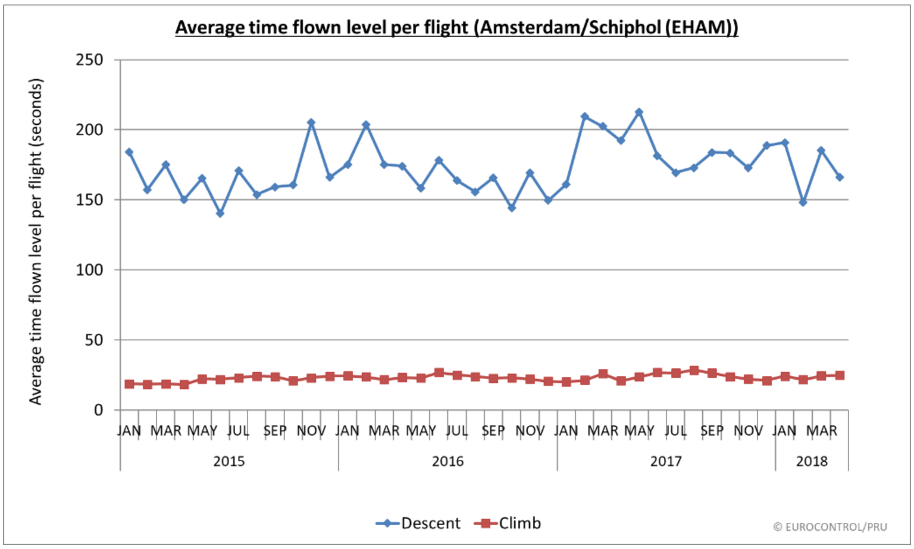

Figure 4 Average time flown level per flight (EUROCONTROL - Performance Review Unit, 2018)

The percentage of flights considered to climb continuously to the requested cruise altitude has been on average below 80% for the previous years, as depicted by the red line in Figure 5. Flights descending into Schiphol are more prone to being interrupted, only a limited share of flights (20%) are able to fly an undisturbed descent as indicated by the blue line below.

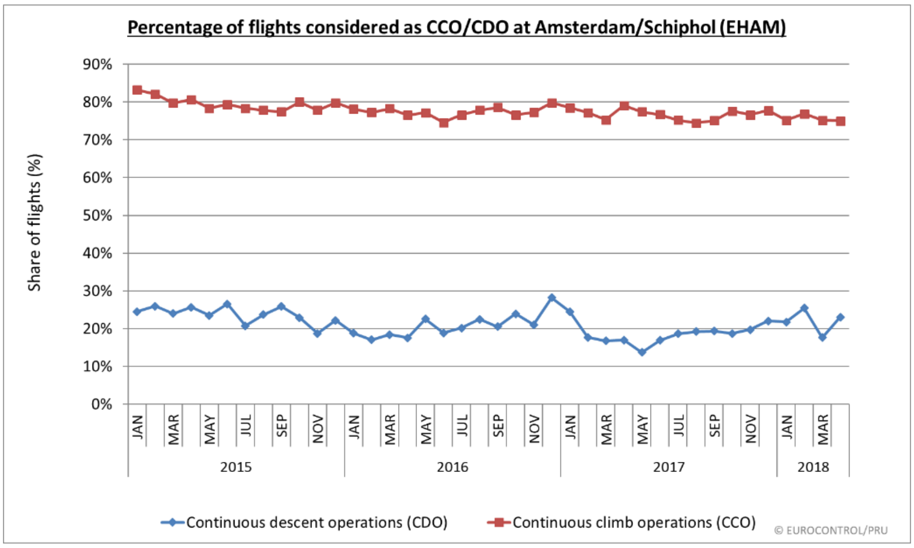

Figure 5 Percentage of flights considered CCO/CDO (EUROCONTROL - Performance Review Unit, 2018)

The median CDO/CCO altitude is the altitude where the median level segment occurs upon departure and descent. For departures from Amsterdam this is mainly occurring at 33,000 or 34,000 feet. The median level segments for arrivals occur during the approach at altitudes between 3,000 and 5,000 feet.

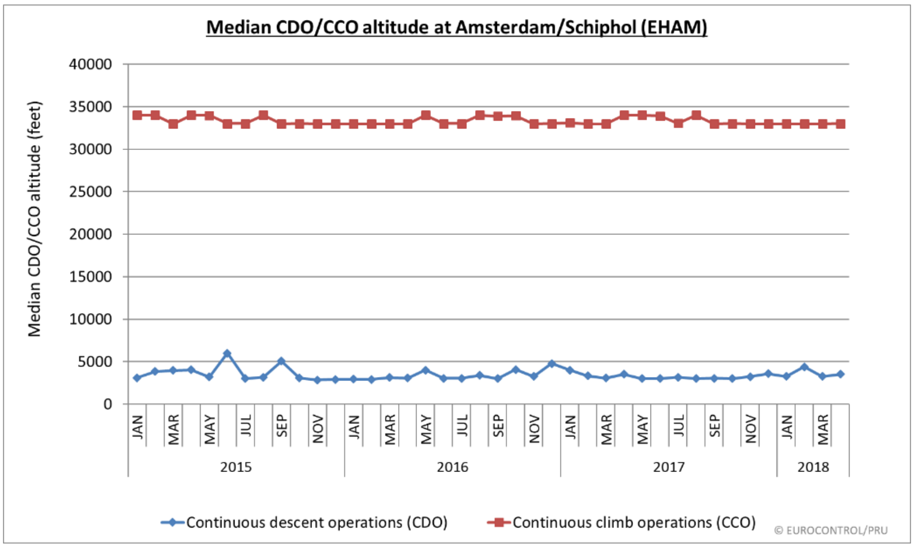

Figure 6 Median CDO/CCO altitude (EUROCONTROL - Performance Review Unit, 2018)

3.3 Solutions for improved hand-overs

One of the solutions is the Advanced Flexible Use of Airspace (AFUA), which focusses on enhancing the efficiency of airspace use by providing the possibility to manage airspace more flexibly. The implementation of AFUA will enable other SESAR concepts, in particular free route airspace (FRA). AFUA includes implementation objectives, such as:

- Electronic Dialogue as Automated Assistance to Controller during Coordination and Transfer;
- Direct routing;
- Free Route Airspace.

These solutions aim to increase operational efficiency by means of savings in route distances and fuel efficiency through increased use of preferred flight profiles. This in turn has a positive effect due to the reduction in emissions. Capacity will also be increased through utilizing airspace more efficiently and reducing ATCo workload (European Commission, 2017).

As part of the SESAR Programme, EUROCONTROL has focused on establishing a network-centric information environment in Europe. Within this network-centric information environment, consistent and up to date flight information is shared between all stakeholders. The concept of the ‘Flight Object’ (FO) was created for this purpose. The FO allows stakeholders to access and share consistent and up to date flight information, allowing for seamless operation among different centres performing coordination and transfer functions (Indra, 2015). Such seamless operation among different controllers enables the possibility to accommodate flights with a more optimised flight trajectory.

3.4 Airspace design and ATC procedures

The Dutch airspace, and with it the Amsterdam Flight Information Region (FIR), is relatively small due to the size of the Netherlands. Paragraph 3.4.1 describes the airspace where the Area Controllers of Air Traffic Control the Netherlands are responsible for the management of air traffic. The standard arrival and departure routes from Amsterdam are described in paragraph 3.4.2. Finally, paragraph 3.4.3 explains how traffic is transferred to the neighbouring ANSPs and the related agreements made between LVNL and the neighbouring ANSPs.

3.4.1 Areas of responsibility

The Amsterdam Flight Information Region covers the airspace above the Netherlands and extends for a large part over the North Sea. Within the Amsterdam FIR both LVNL and the Royal Netherlands Air Force are responsible for providing air traffic services to both civil and military airspace users.

The control areas (CTA) of the Amsterdam ACC are presented in Figure 7 and comprise:

- The Amsterdam CTA East 1 and 2, CTA South 1 and 2, CTA West, excluding the areas in which Amsterdam ACC has delegated ATS permanently to an adjacent centre (red border);
- The Amsterdam UTA above the Amsterdam CTA's, up to FL245, excluding the areas in which Amsterdam ACC has delegated ATS permanently to an adjacent centre (red border);
- Areas in which ATS has been delegated permanently to Amsterdam ACC (blue border area).

A common ATC boundary is used to serve as the border between the areas of responsibility, instead of using the FIR border (green border in Figure 7).

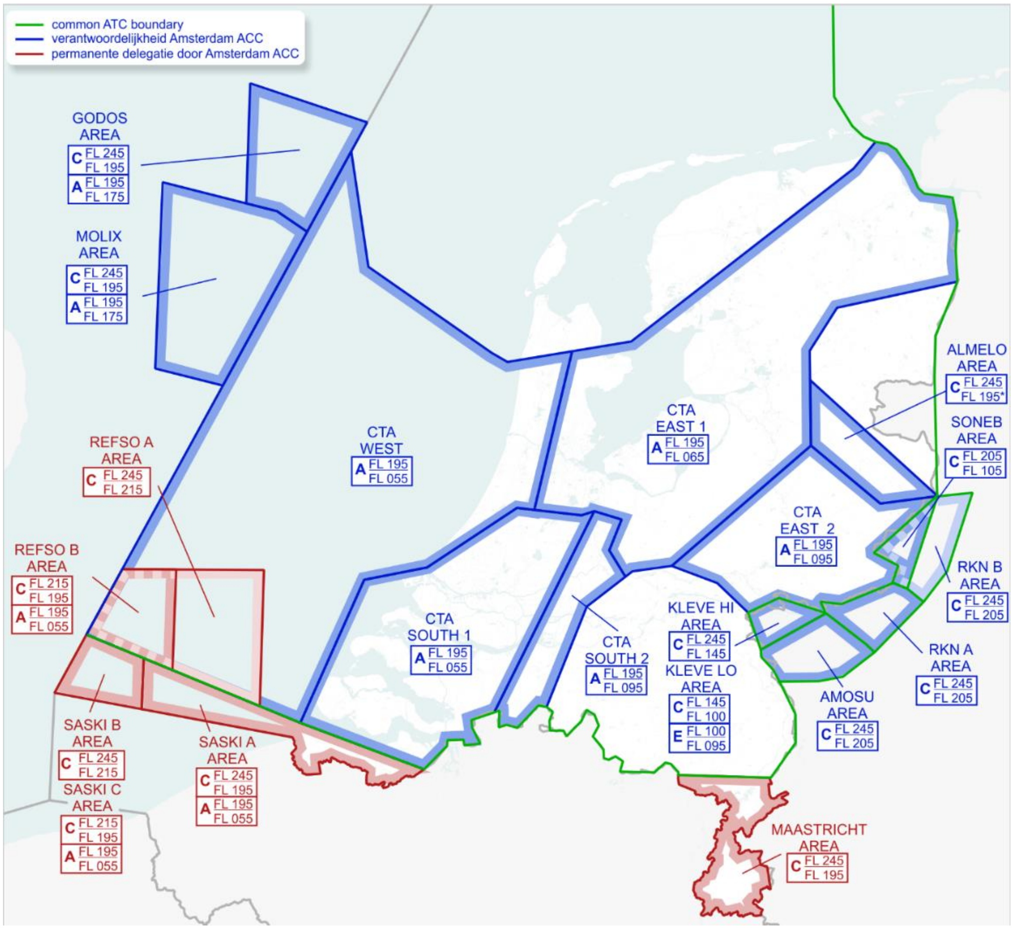

Figure 7 Areas of responsibility and classification (LVNL, 2018)

3.4.2 Standard Instrument Departure and Arrival routes

The goal of air traffic control is to maintain separation between flights to ensure a safe and efficient flight. This separation can be established through either lateral/horizontal or vertical separation. The inbound and outbound trajectories do cross each other in some locations in the Amsterdam FIR, especially in the Schiphol TMA as depicted in Figure 8. Specific departure and arrival routes are designed to keep these crossings to a minimum.

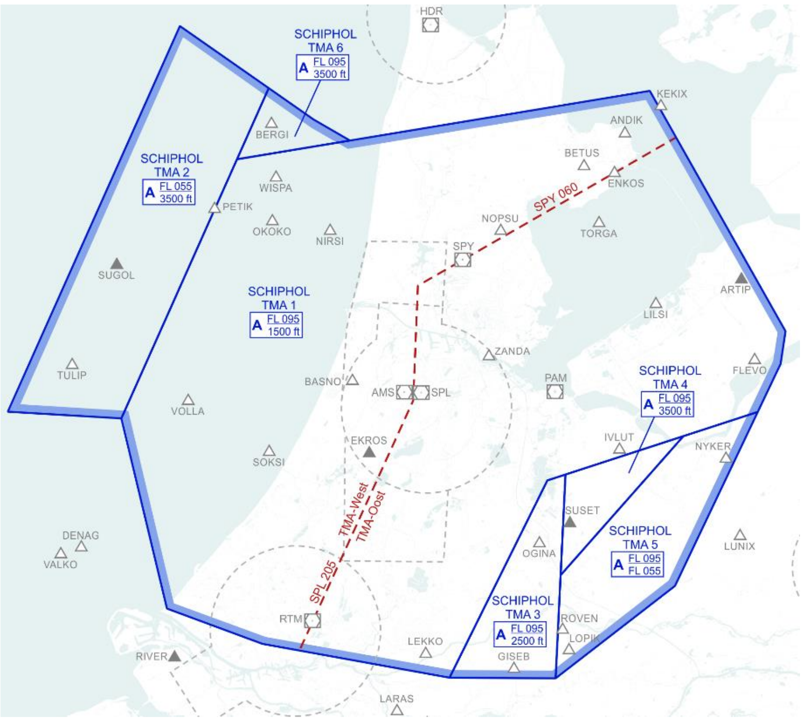

Figure 8 Schiphol TMA (LVNL, 2018)

After departure, flights will initially fly a Standard Instrument Departure (SID), a predefined route leading to an entry point of an airway. Figure 9 displays the general direction to where the SIDs lead. The SIDs are designed to ensure in- and outbound flights are separated and for noise abatement. The airways are used for the remainder of the flight to route towards the destination airport. Each departure runway has at least one unique SID towards each airway entry point. The airway entry points for departures from Amsterdam are:

- ANDIK (North-East)
- ARNEM (East)
- BERGI (North-West)
- EDUPO (East)
- GORLO (West)
- WOODY (South)
- LOPIK (South-East)

Flights inbound to Schiphol enter the Amsterdam FIR and fly standard routes to one of three Initial Approach Fixes (IAF):

- ARTIP (East)
- RIVER (South)
- SUGOL (West)

The routes towards the IAF are the Standard Arrival Routes (STAR). These STARs are designed to keep inbound and outbound flights separated as much as possible. From the IAF, flights enter the Schiphol TMA and will receive vectors (instructions to fly specific headings) towards the landing runway. See Figure 10 for the standard arrival routes into Amsterdam. Full size and more detailed versions of the SID and STAR charts are found in Appendix II Standard instrument arrival and departure chart.

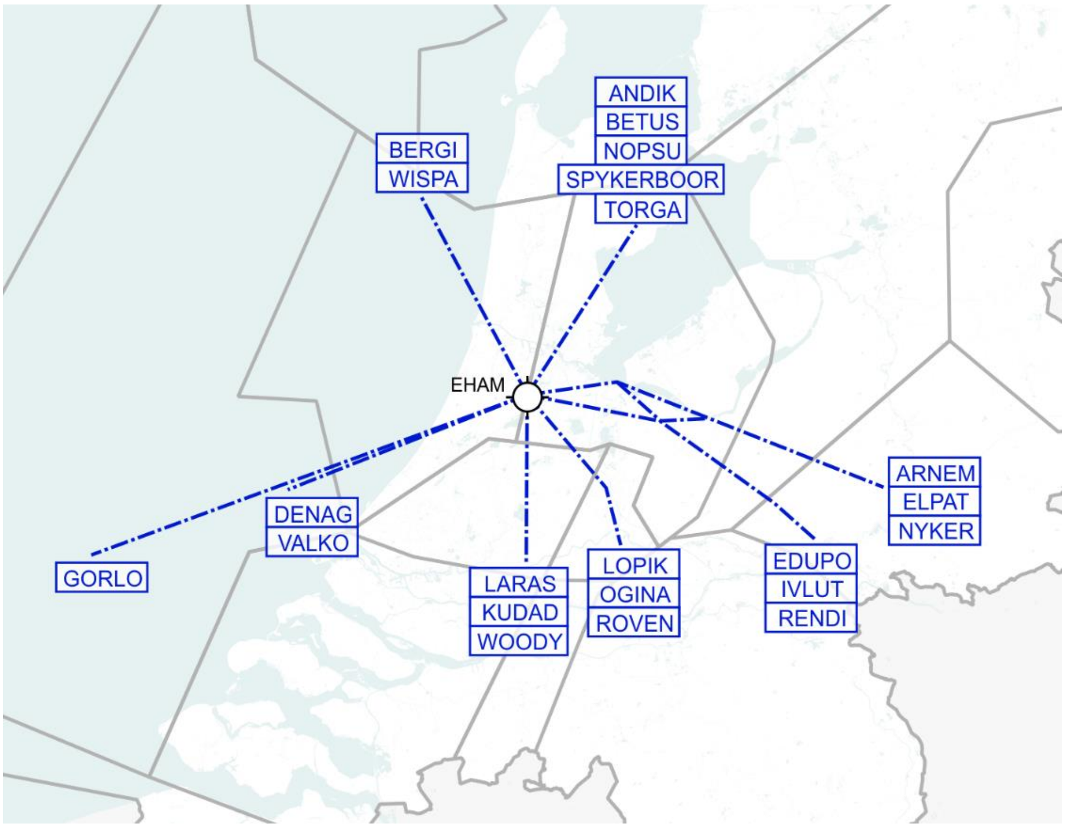

Figure 9 Schiphol Standard Departure Chart – Instrument (LVNL, 2018)

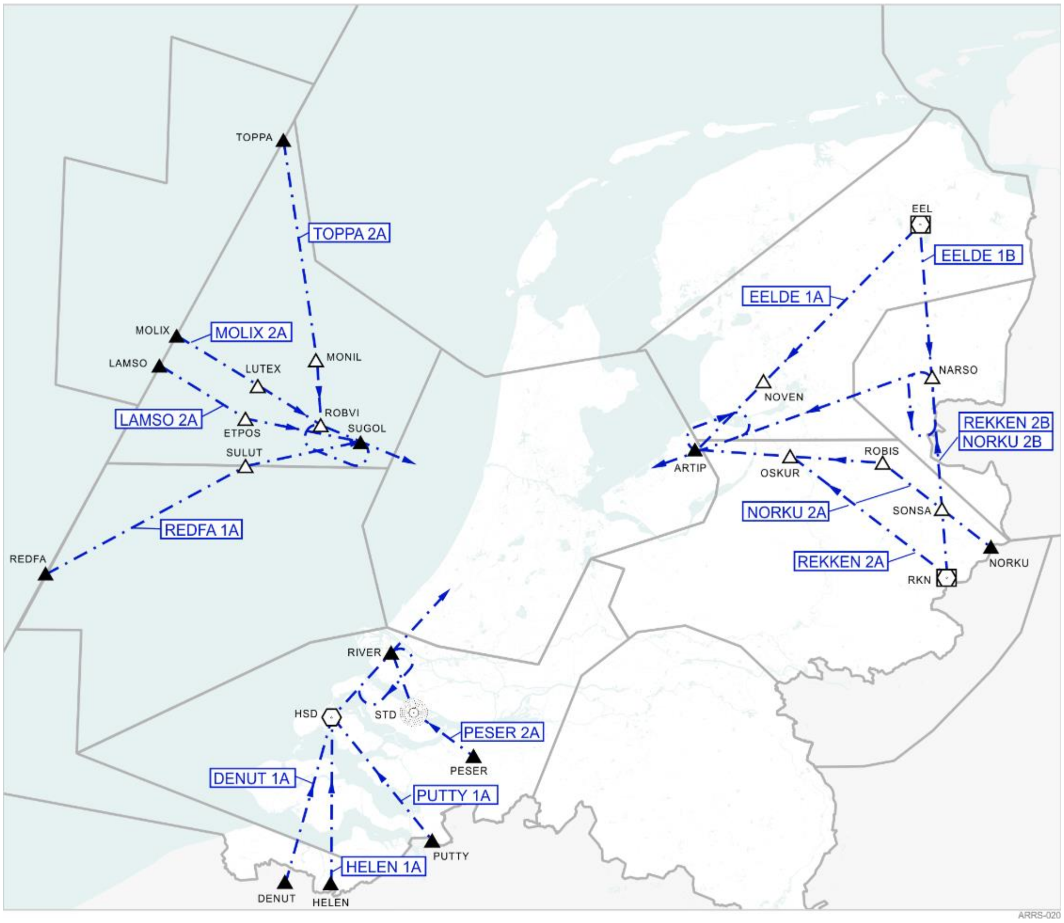

Figure 10 Standard Arrival Routes Schiphol

The separation of inbound and outbound flights is mainly an issue within the Schiphol TMA. Inbound and outbound flights are vertically separated as departures will initially climb to FL60, while arrivals are cleared to descend to FL70 upon entry into the TMA. This ensures the minimum required vertical separation of 1000ft. In some cases, the inbound and outbound traffic flows do cross.

Figure 11 presents a runway configuration where inbound and outbound routes cross. In the figure the orange dashed lines represent the arrival route and the green and red lines represent the departure route in the TMA. Flights depart from the Kaagbaan (depicted in red) and land on the Polderbaan (depicted in blue). This is one of the preferred runway configurations as these produce the least amount of noise for the surrounding areas. However, the flights arriving from the south (RIVER, see Figure 10) will cross the departure routes towards West (VALKO1S departure route) and North-West (BERGI1S departure route).

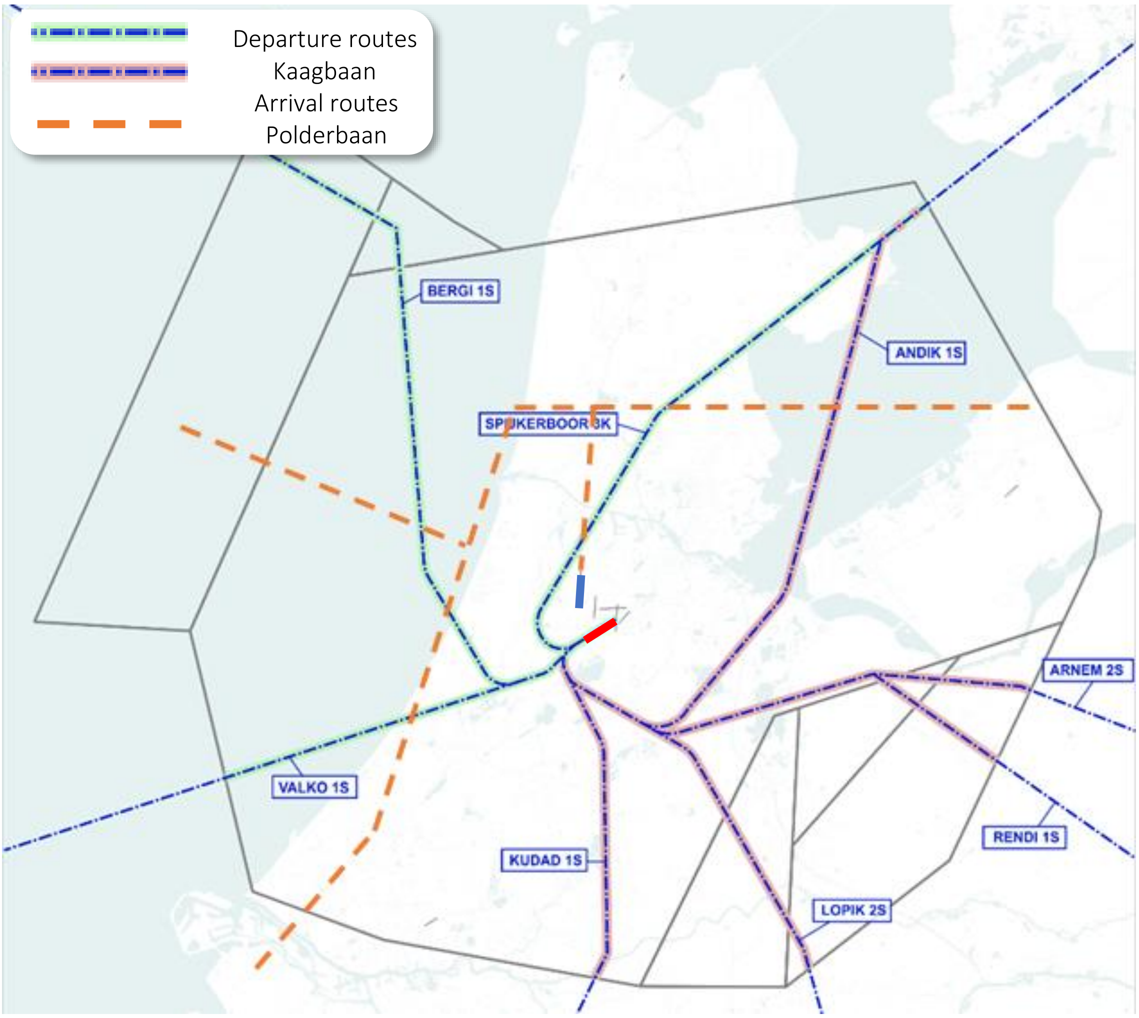

Figure 11 Preferred runway configuration, departures Kaagbaan + arrivals Polderbaan (LVNL, 2018)

3.4.3 Letters of Agreement

Flights departing the Amsterdam FIR are transferred to the neighbouring ATC upon crossing the boundary of the area of responsibility. This transfer of control follows certain standard rules which are laid down in a Letter of Agreement (LoA). The purpose of a Letter of Agreement is to define the co-ordination procedures to be applied between two ANSPs or Area Control Centres when providing air traffic services to general air traffic (flights which are conducted in accordance with rules and procedures of ICAO and/or the national civil aviation regulations and legislation). These procedures are supplementary to those specified in ICAO, EUROCNTROL and/or national documents. The LoA contains details on:

1. Areas of common interest
2. Exchange of Flight Data
3. Procedures for Co-ordination
4. Transfer of Control and Transfer of Communications
5. Radar based Co-ordination procedures
6. Contingency Arrangements

Amsterdam ACC has Letters of Agreements with the following neighbouring Area Control Centres:

• Brussels ACC	(Belgium)
• Langen ACC	(Germany)
• Bremen ACC	(Germany)
• London AC Swanwick	(United Kingdom)
• London TC Swanwick	(United Kingdom)
• RAF(U) Swanwick	(United Kingdom)
• Scottish AC	(United Kingdom)
• Copenhagen	(Denmark)
• Maastricht UAC	(Belgium, Germany, Luxembourg, the Netherlands)
• MilATCC Schiphol	(the Netherlands)

See Appendix III *Letters of Agreement* for a summary of the procedural agreements with the neighbouring air navigation service providers.

4 Analysis of Vertical Flight Trajectory Efficiency

The analysis for the vertical flight trajectory efficiency is broken down in four steps. First of all the radar track data and system flight plans (SFPL) are correlated in paragraph 4.1. Paragraph 4.2 describes the used to filter the track data to only include the trajectory within the Dutch airspace boundary controlled by LVNL. Next, the trajectory is analysed to identify the climb phase of the trajectory until reaching the Top of Climb (ToC) in paragraph 4.3. The method used to detect level segments are discussed in paragraph 4.4. This process is illustrated in Figure 12. The results from the efficiency calculations are described in paragraph 4.5. These results are used to answer sub-question 1: *“What is the vertical flight trajectory efficiency for flights departing Amsterdam Airport Schiphol currently?”*

Figure 12 Trajectory efficiency process

4.1 Correlate flight plan to track data

Two sets of data are used which will need to be linked for the further analysis. As further elaborated on in paragraph 4.3, this correlation is necessary to identify the climb phase of the flight. The first set of data is the radar track data contained within the radar recordings from LVNL. This track data is logged at a five second interval from the moment the aircraft is airborne. Each data entry contains a timestamp, aircraft identifier (ACID), x and y location in relation to point of reference and altitude in flight levels (FL). Additionally, groundspeed (GS) in knots and rate of climb (ROC) in feet per minute are logged from the mode-S as reported by the Flight Management System (FMS). See Table 1 for an example of a fictional log entry.

Table 1 Example radar track data

Timestamp	ACID	X (NM)	Y (NM)	FL	GS	ROC
123456789	KLM123	1.2345	5.4321	100	300	1500

The second set of data contains the system flight plans. Each SFPL contains information related to the intent of the flight for a specific day (DoF). This intent contains the departure aerodrome (ADEP), destination aerodrome (ADES), route and requested cruise altitude (RFL). It also includes the aircraft type (ATYP) and call sign (ACID) to be used for the flight. Finally, the departure runway (RWY), standard instrument departure (SID) route and coordination exit point (COPX) are appended. An example of a SFPL is presented in Table 2.

Table 2 Example system flight plan

Timestamp	DoF	ACID	ADEP	ADES	ATYP	RWY	SID	RFL	COPX
123456789	01/01/2017	KLM123	EHAM	EGLL	B738	36L	GRL3V	240	REFSO

Implementation in code

The track data contains all flights which have been identified by the radar, however not all of these flights have a flight plan. Besides, it is also possible that a flight plan was filed, but the flight was cancelled or refiled for a later time. Only flights which have been logged by the radar and are matched with a SFPL are used in the analysis.

Each unique flight is initially given an index number which defines the starting position for that flight. This is done by comparing the ACID of consecutive radar track data entries. A new index is created when the ACIDs differ, see Figure 13. These indices are used throughout the code to address each unique flight; they are considered keys to open the data for each flight.

Timestamp	ACID	X (NM)	Y (NM)	FL	GS	ROC
1483273250	AAL203	-135.199	60.67	340	393.97	-162
1483273255	AAL203	-135.712	60.782	340	393.97	-162
1483299856	ABW351R	-1.469	-1.461	4	183.91	2369
1483299861	ABW351R	-1.686	-1.598	6	183.91	1950

Do nothing
Create index
Do nothing

Figure 13 Create position index start flight

The ACID of each flight in the track data is matched with the ACID in the SFPL data of the corresponding DoF, since the same ACID is used on multiple days throughout the year for recurring flights. This matching is done within Mathematica. First it checks whether the ACID from the track data is present in the list of flights on that day. Next it returns the position of the SFPL and appends this to a list which tracks the position of the flight plans.

4.2 Flight filter

In the previous step, the track data was matched with the SFPLS. Several flights are removed because no SFPL was present for a tracked flight or vice-versa. However, there are some other flights which will also need to be removed from the dataset. Flights flying to a domestic destination (any airport within the Amsterdam FIR) are removed as such flights are either test flights, non-commercial flights or for reposition purposes. These flights usually do not follow the regular flight routes. Other flights which are filtered this way include flights operated by police helicopters (ZXP) and national coastguard (NCG) flights. These will fly at lower altitudes and will not enter the higher controlled layers of the airspace.

Any SFPLs containing an ADES code for a Dutch airport will require filtering. Each airport is given a unique four-character code according to ICAO standards. The prefix of this code (either the first or first two characters) is used for a specific country or region. For the Netherlands this prefix is EH. For example, the ICAO airport code for Amsterdam is EHAM. The filter removes SFPLs when the ADES contains EH**, where ** represents any combination of characters.

4.3 Identification of climb phase

A flight is considered to be in the climb phase until it reaches it the Top of Climb. The altitude at ToC is in most cases the optimal cruise altitude and equal to the requested cruise altitude as filed in the system flight plan. In general, the distance required from airport to RFL requires less than 200 NM (Peeters & Guastalla, 2017). The distance required mainly depends on the RFL (a lower RFL is reached quicker than a higher one) and the aircraft performance. In general, heavier aircraft will have a lower vertical speed. This is due to the increased lift needed to remain airborne, which requires a higher forward speed. This means more thrust is required to maintain the higher forward speed, which can’t be used for climbing.

The method proposed by the PRU is *“to limit to the parts of the trajectories within a 200 NM radius around the departure airport”* (Peeters & Guastalla, 2017). This part of the trajectory will still contain the ToC while not including any step climbs that might occur afterwards. For the purposes of this research this method does not suffice, as only the trajectory within the airspace controlled by LVNL is of interest. Due to the limited size of the Amsterdam FIR, it is not possible for this 200NM radius crossing point to be in this airspace, see Figure 14 below.

Figure 14 FIR boundary vs 200 NM radius Schiphol

To define the climb phase within the Amsterdam FIR, only the part that is within the lateral and vertical boundaries of FIR are considered. These boundaries are explained in paragraph 3.4.1. The actual upper boundary of the airspace is FL245, where control is delegated to Maastricht Upper Area Control. A higher vertical boundary of FL265 used to display level segments occurring at FL250 and FL260, which happen to be the altitudes used to transfer traffic to the neighbouring sectors in the South and East.

Implementation in code

An iterative method is used to determine which part of the trajectory is within the lateral and vertical limits of the airspace controlled by LVNL. A polygon representing the Amsterdam FIR is created, represented as the greyed out area of Figure 14, to define the lateral limits. Next, the altitude of the flight is checked against the RFL and the vertical boundary as displayed in Figure 15. The following steps are used to identify the climb phase.

1. Evaluate whether coordinate is no longer within lateral or vertical boundaries or approaching RFL at less than 1000ft.
    a. If false, evaluate next coordinate.
        i. If next coordinate is not part of trajectory, return previous coordinate a beak evaluation.
    b. If true, return position of previous coordinate and break evaluation.
2. Append to index the position of the last accepted coordinate.
3. Evaluate next flight using the steps above until all flights have been evaluated

Now the index contains the positions (keys) to indicate the start and end coordinates of a trajectory which is within the boundaries of the controlled airspace and in the climb phase.

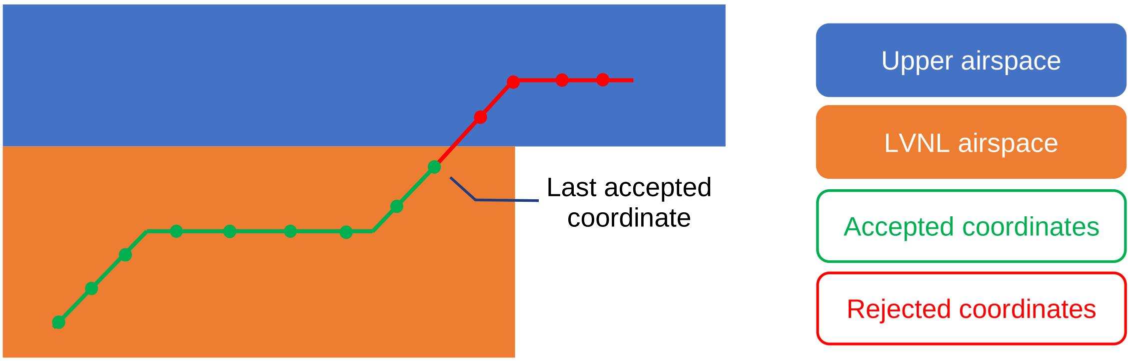

Figure 15 Identification of climb phase within airspace

To decrease the computing time, an algorithm is applied to reduce the evaluation time by a factor eight. This algorithm evaluates coordinates in decreasing intervals, to reduce the total number of coordinates that need to be evaluated. The following steps explain this algorithm.

1. Evaluate coordinates in steps of 64.
2. If coordinate does not comply with rules, return to last accepted coordinate.
3. Evaluate coordinates in steps of 32.
4. If coordinate does not comply with rules, return to last accepted coordinate.
5. Repeat pattern while decreasing the step size with a factor two each time until the final coordinate has been found.

4.4 Detect level segments

Level flight is defined as a flight segment with a vertical climb rate of 300 feet per minute or less. This rate of climb has been chosen based on consultation with the CCO/CDO Task Force (Peeters & Guastalla, 2017). A 20 second interval is used to dampen the data to reduce the effects of sudden turbulence or other disturbances which might cause a change in RoC. This 20 second window is represented by the orange box in Figure 16.

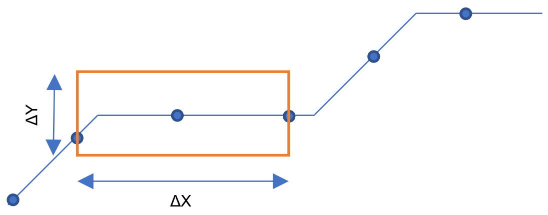

Figure 16 Level segment detection

The RoC is determined based on the altitude difference (ΔY) over the 20 second interval (ΔX). This 20 second interval entails five coordinates (5 second logging rate). No interpolation is used to determine intermediate altitudes in between the 5 second interval, as the 5 second interval is considered accurate enough. The following steps, in combination with equation (1), are used to detect the level segments during the climb phase.

$$\frac{\Delta Y}{\Delta X} \leq 300\ feet\ per\ minute \tag{1}$$

1. Calculate RoC over 20 second interval (e.g. coordinate 1 – 5).
2. If RoC is below threshold value of 300 feet per minute start level segment.
3. Create start of segment with first coordinate of the interval.
4. Evaluate whether ROC for the next 20 second interval (e.g. coordinate 2-6) is still below threshold value.
    a. If true, repeat evaluation for consecutive 20 second intervals.
    b. If false, return coordinate of last segment.
5. Append returned coordinate to starting coordinate to create the segment interval.

4.5 Research findings level segments

The level segments detected during the analysis contain data regarding the distance and altitude at which it is detected. An overview of vertical flight trajectory efficiency for the months of February and July 2017 is presented in Table 3. The horizontal segments, as flown by all departures from Amsterdam in February and July 2017, are presented below in Figure 17. A heat map of equally sized hexagons depicts the areas where level segments occur most often is presented in Figure 18.

Table 3 Overview of results vertical flight trajectory efficiency

	February	*July*
Number of flights	16,910	23,505
Percentage of affected flights	9.9%	7.8%
Number of segments detected	1,920	2,052
Total level segment time (minutes)	1,665	1,882
Total level segment distance (NM)	9,221	10,749
Median level segment altitude (FL)	230	210
Average distance per flight (NM)	0.55	0.46
Average time per flight (seconds)	5.9	4.8

Level segments

The level segments clearly depict the standard departure routes towards the airway entry waypoints as described in paragraph 3.4.2. The total time spent at level segments and distance travelled level was higher in July than February. While this is to be expected as 39% more flights departed in July than in February 2017, only 6% more level segments were detected in July 2017. This observation is also substantiated by the higher percentage of affected flights in February. This makes the average distance and time spent at level segments per flight 20% higher in February. No definitive explanation can be given for this difference.

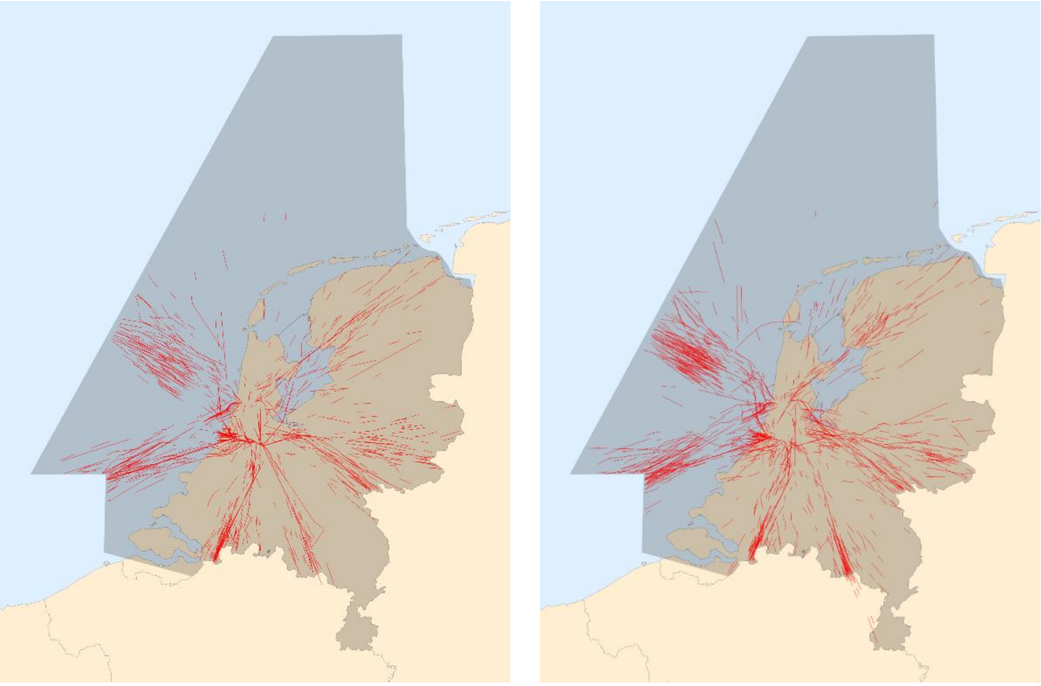

Figure 17 Level segments February (left) and July (right) 2017

Rate of occurrence level segments

The heat map indicates a high proportion of level segments in the South-Western and Western sections of the Schiphol TMA in both February and July. Additionally, departures via GORLO (South-West) and BERGI (North-West) display a significant rate of occurrence in July, whereas departures via WOODY (South) are more prominent in February. The other departure routes to the East and North-East are less pronounced.

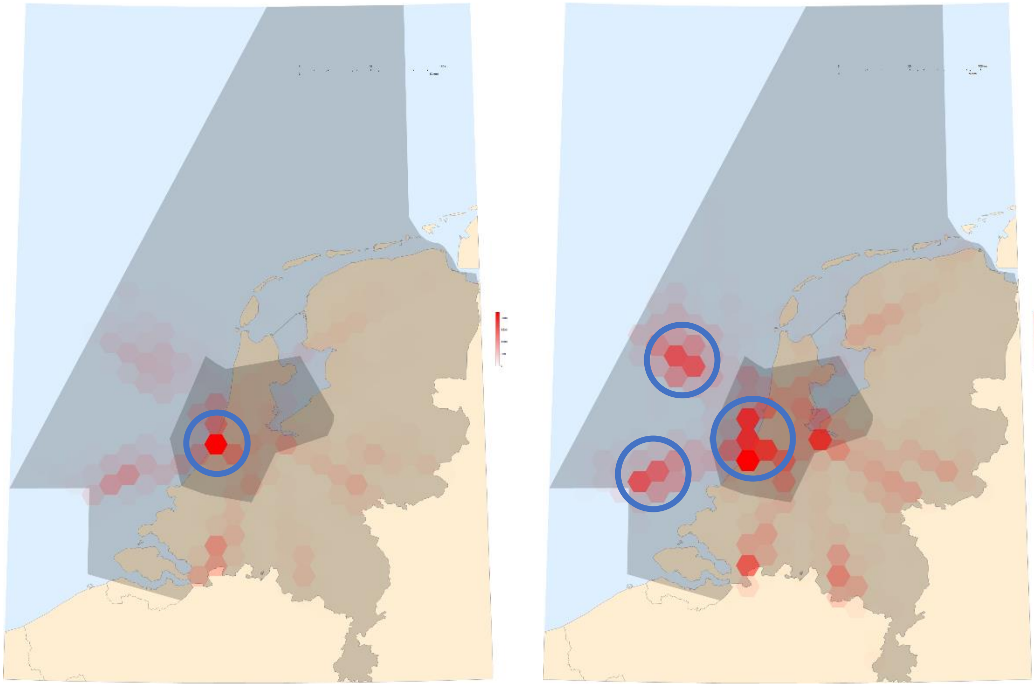

Figure 18 Heat map level segments February (left) July (right) 2017

5 Analysis of Relation Level Segments with Airspace Design and ATC Procedures

The vertical trajectory efficiency is affected airspace design and ATC procedures. This chapter presents the effects of several of such factors affecting the efficiency and whether seasonality influences the vertical trajectory efficiency. Paragraph 5.1 depicts the distribution of level segment length. The results of the altitude at which the level segments occur is presented in paragraph 5.2. Paragraphs 5.3, 5.4 and 5.5 give an overview of the effects of the departure route, departure runway and coordination exit point. Finally, paragraph 5.6 presents the effects of aircraft type on the occurrence of level segments. These results provide an answers to the sub-question: “*What is the relationship between the vertical flight trajectory efficiency and airspace design and ATC procedures?”*

5.1 Distribution of segment lengths and time

The detected level segments have been categorised in in terms of distance relative to the total level segment distance presenting the distribution of segment length. The same categorization is used to show the number of segment relative to the total number of segments. A class size of 2 NM is used as this approximates to the minimum segment time of 20 seconds at FL150 (the median flight level for the data range). See Figure 20 and Figure 21 for the distributions in February and July 2017 respectively.

Both months present an inversely proportional relation, except for the segments with a length smaller than 2 NM and larger than 20 NM. An explanation for this observation is that a minimum segment time of 20 seconds is used to detect a segment, resulting in segments smaller than 2 NM when the true airspeed is low. The increase for the segments larger than 20 NM is related to there being no upper limit for the last class. This inversely proportional relation is to be expected as the rate of occurrence of longer segments decreases because ATC will seek to accommodate the continuous climb of a flight.

See Appendix IX Excel results relationships level segments with airspace design and ATC procedures July 2017 for the data used in the creation of the Figure 20 and Figure 21.

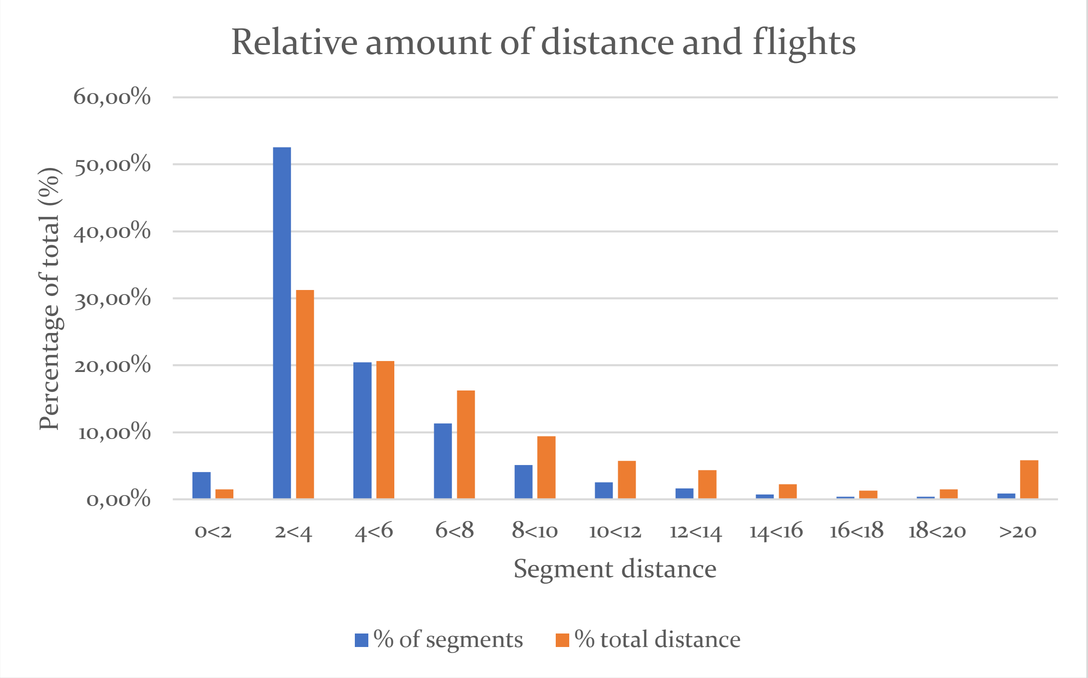

Figure 19 Distribution of segment February 2017

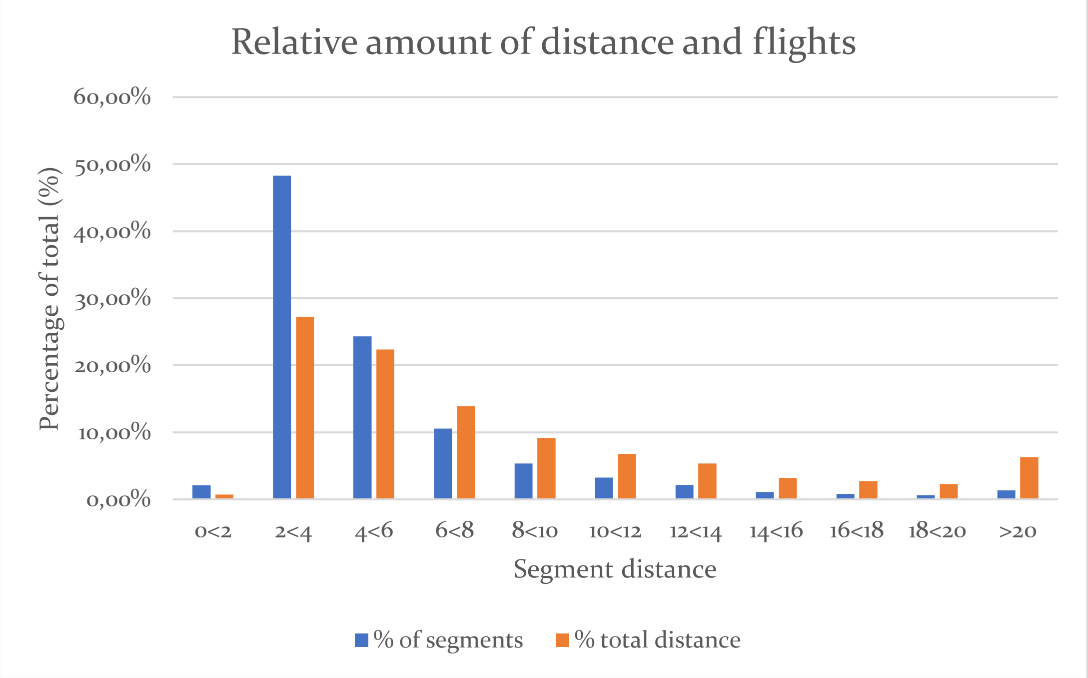

Figure 20 Distribution of segments July 2017

5.2 Analysis of level segment altitudes

The level segments occur at different altitudes within the Amsterdam FIR. The rate of occurrence and the percentage of the total segment distance are compared in paragraph 5.2.1. Next, the average segment length is displayed to illustrate the effects of altitude on segment distance in paragraph 5.2.2.

5.2.1 Relative level distance

The results from the level segments at the respective flight levels are presented in Figure 22 and Figure 23. Both months present a similar distribution of level segments at all specific flight levels. Two major peaks are distinguishable, at FL60 and FL240. Some less pronounced peaks appear at FL250 and FL260. Appendix VIII Level segments at specific levels July 2017 presents the heat maps of where the level segments at these specific flight levels occur.

The level segments at FL60 occur primarily within the TMA, especially for departures towards the South-West (GORLO) as can be seen in the heat map for segments at FL60 in Appendix VIII Level segments at specific levels July 2017. The location of these segments correspond with the crossing departure and arrival routes in certain runway configurations, such as the one presented in Figure 11 in paragraph 3.4.

The segments at FL240 are primarily located near the edges of the CTA of Sectors 4 and 5. These departures are handed over to London Control. The hand-over altitude used is FL240, as stated in the LoA. This hand-over condition is the most likely cause of these level segments.

The segments at FL250 also occur predominantly near the borders of the CTA, mainly towards the East (EDUPO) and South-East (LOPIK). Again, FL250 is the agreed hand-over altitude for departures towards those exits.

The level segments at FL260 occur mainly for departures via WOODY, with a hand-over altitude at FL260. Other segments also occur for departures via GORLO, ANDIK and LOPIK. However, for these departures flights are no longer under control by LVNL controllers.

The similar distributions of level segments and level segment distance conclude that seasonality does not affect the altitude where level segments occur.

More details regarding the distribution of level segments per flight level is found in Appendix IX Excel results relationships level segments with airspace design and ATC procedures July 2017.

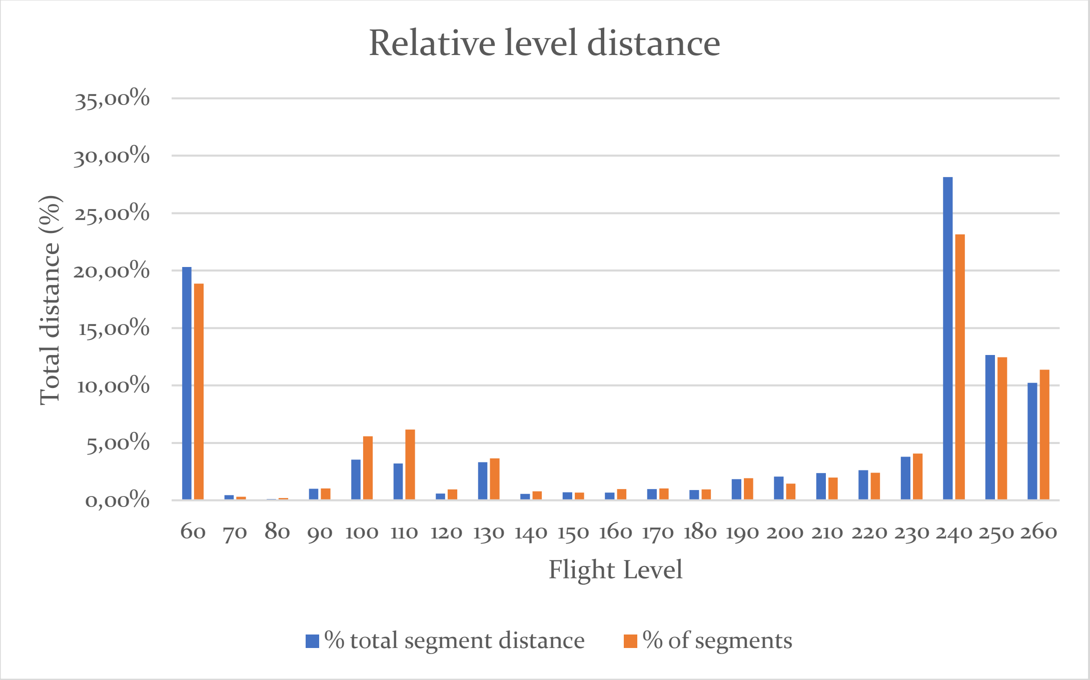

Figure 21 Relative level distance at flight levels February 2017

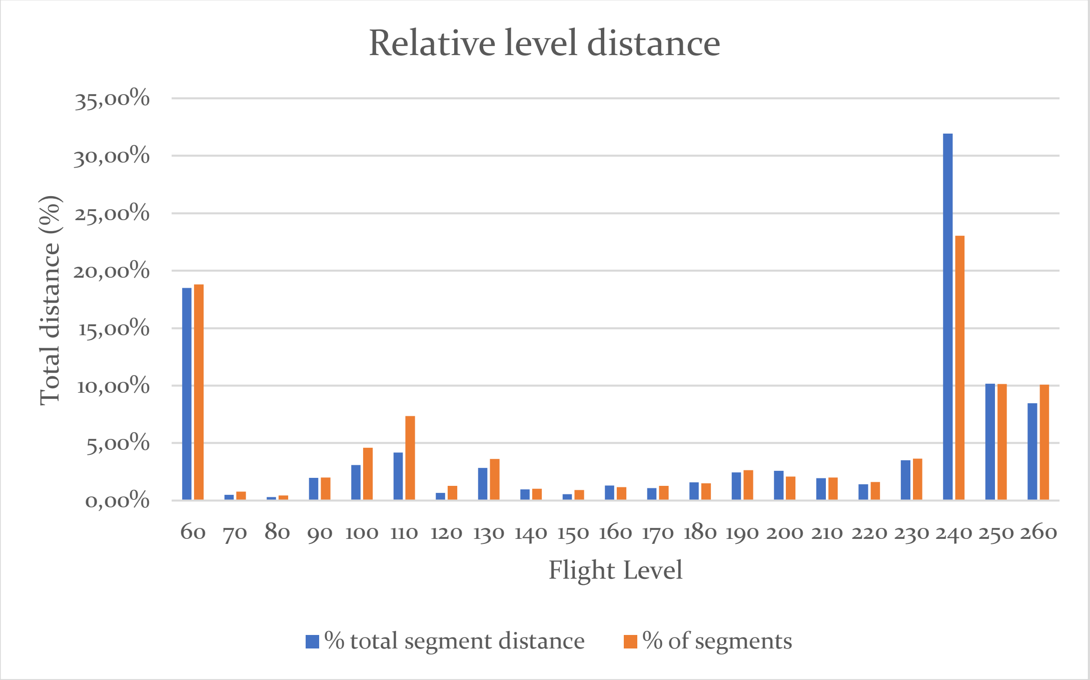

Figure 22 Relative level distance at flight levels July 2017

5.2.2 Average segment distance

The average segment distance is slightly higher in July (5,2 NM) as compared to February (4,8 NM). Only a handful of altitudes display an average segment distance which is higher than the total average. These higher than total average distances, especially those from FL240, affect the total average due to the high occurrence of the segments at FL240 (see previous paragraph).

Significant deviations from the average are seen at FL200 and FL240 for both months, as well for a significant peak at FL70 in July. The number of level segments at FL70 in July are insignificant (less than 1 percent of total level segments), so this can be considered an outlier in February.

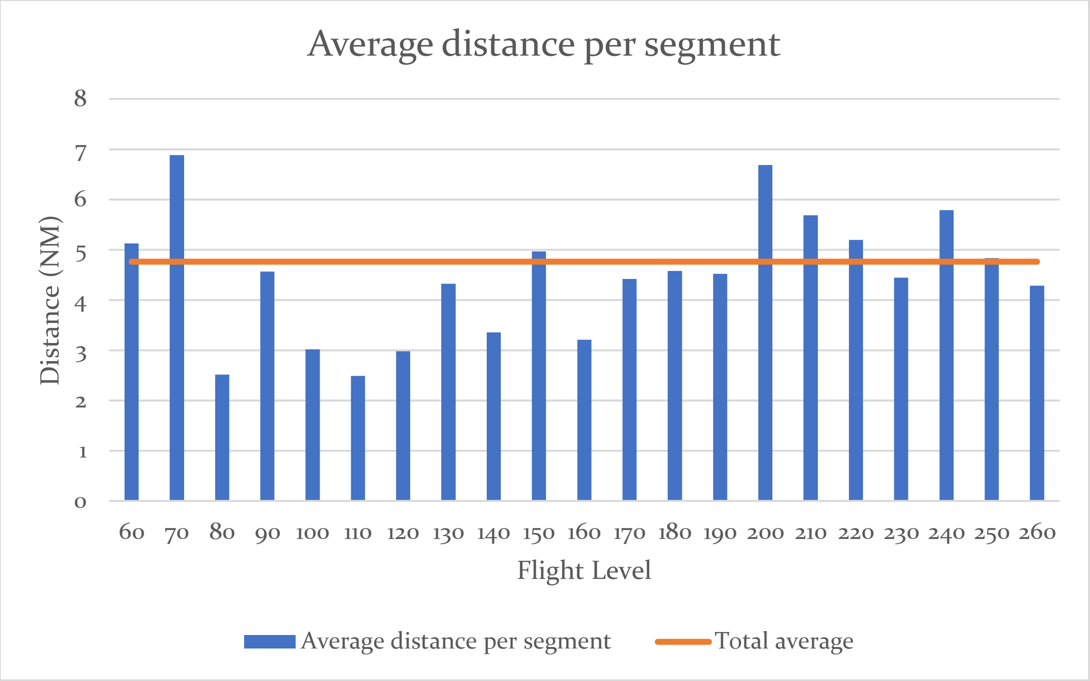

Figure 23 Average distance per segment at flight levels February 2017

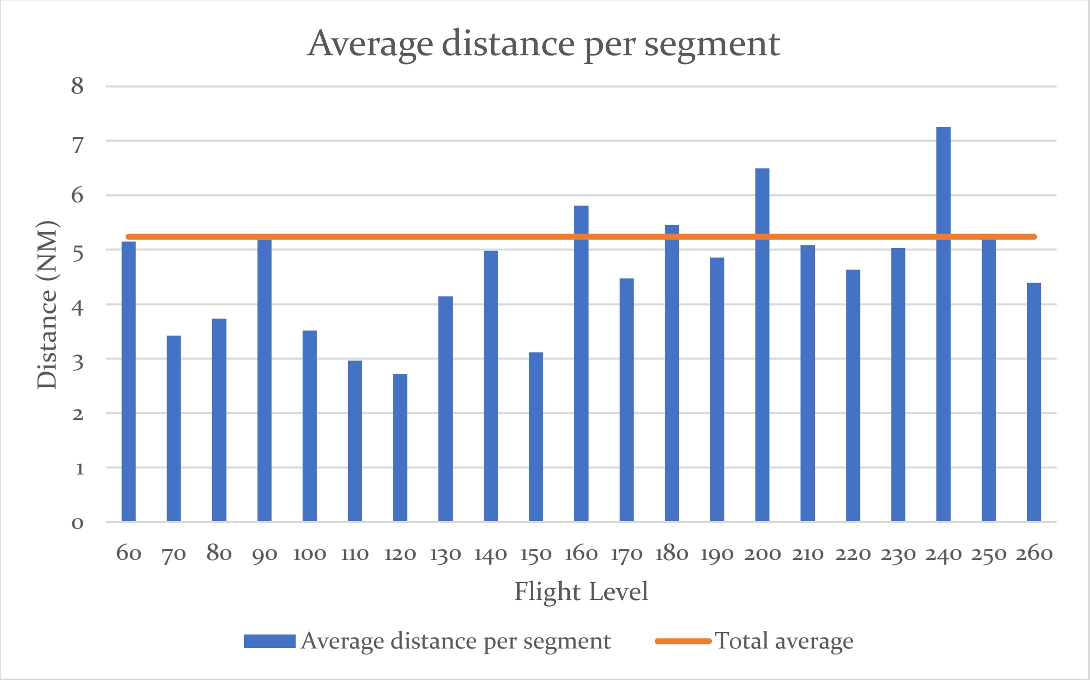

Figure 24 Average distance per segment at flight levels July 2017

5.3 Analysis of Standard Instrument Departure

The effects of the standard instrument departure routes are discussed in the following sections. Paragraph 5.3.1 presents the distribution of flights per departure route direction and the total level segment distance on these routes. The average segment distance per SID are presented in paragraph 5.3.2.

5.3.1 Relative level distance

Figure 26 and Figure 27 reveal that the highest percentages of level segment distance are produced by flights departing via GORLO and BERGI in both months. The next neighbouring sector for most of these departures is London Control. The number of flights via GORLO and BERGI are less than those via WOODY (south) or EDUPO (east).

An explanation for the high proportion of segment distance for the GORLO and BERGI departures are the handover conditions specified in the LoA with London AC. The hand-over altitude for these departures is FL240. A peak at this FL is also observed in Figure 21 and Figure 22.

Another reason is that departure routes via GORLO and BERGI cross arrival routes in some runway configurations, like the one presented in Figure 11. For those crossing arrival and departures routes flights are vertically separated in the TMA, resulting mainly in level segments at FL60. This represented by the peak at FL60 in Figure 21 and Figure 22.

The difference in level distance and number of flights is most obvious in July, where the percentage of level distance for GORLO departures is more than twice as much as the percentage of flights. The opposite goes for departures via WOODY, which contribute to only 10% of the total distance while 20% of the flights depart via this waypoint.

More details regarding the distribution of level segments for each specific SID is found in Appendix IX Excel results relationships level segments with airspace design and ATC procedures July 2017.

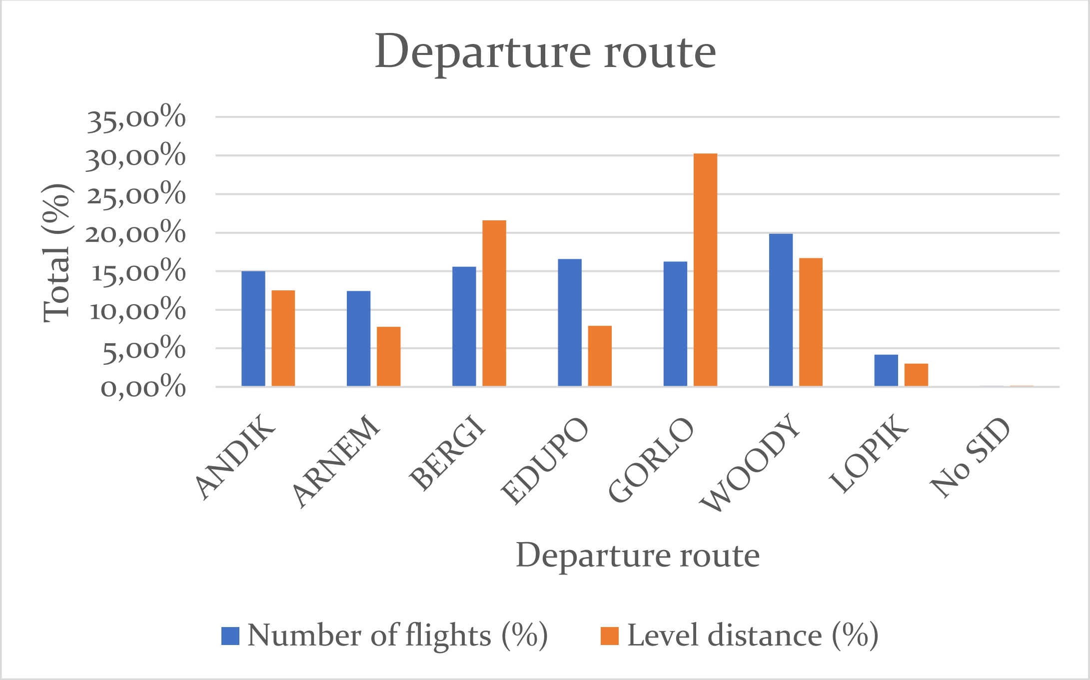

Figure 25 Relative level distance per departure direction February 2017

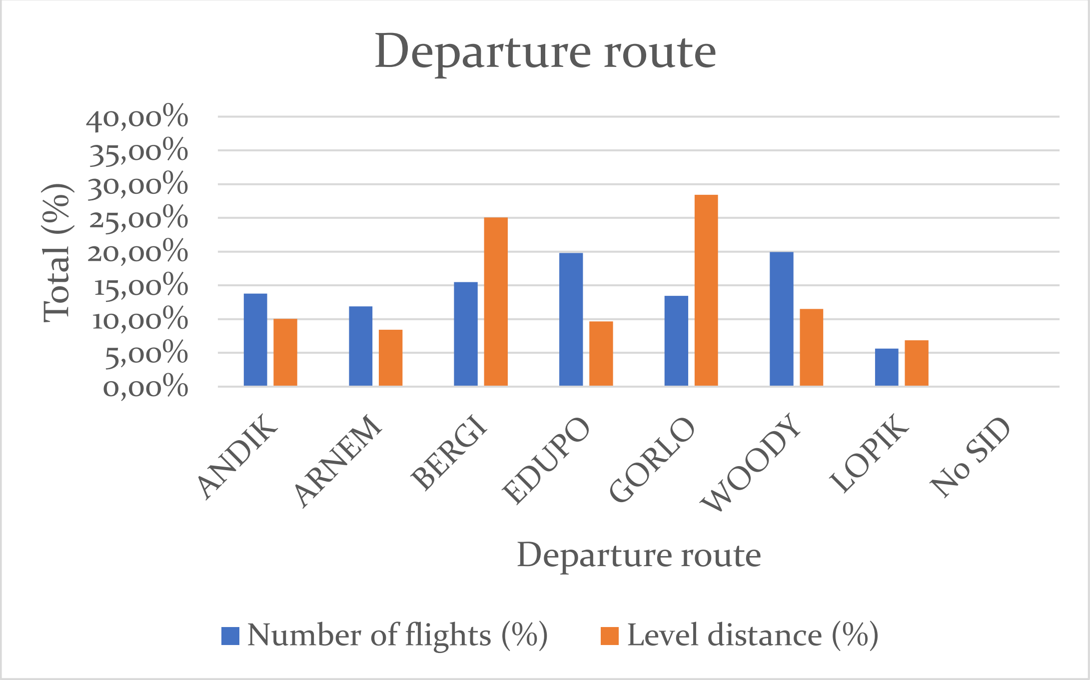

Figure 26 Relative level distance per departure direction July 2017

5.3.2 Average segment distance

Figure 28 and Figure 29 present the average segment distance per flight per departure route. The total average segment distance per flight is higher in February (0,545 NM) than July (0,457 NM). This is contrary to the expectations as the amount of traffic in July is nearly 40% higher in July. However, this difference can be explained by the fact that the total average segment distance per flight is lower because the total segment distance is spread out over more flights.

The departures via BERGI and GORLO display a significant deviation from the total average segment distance per flight. This is in line with the results from the previous paragraph, where GORLO and BERGI departures created the highest number of level segment distance compared to the number of flights via those routes. In July the average values deviate

Departures via EDUPO incur the least of level segment distance per flight in both months. This is explained by the relatively high amount of flights via this route, which compensate the level segments that occur on these departures.

The most significant difference between February and July is presented by the average values for LOPIK departures. This specific departure direction is by default only used in the weekend when LVNL operates under the reduced coordination, because the military airspace is open for usage. Departures via LOPIK happen to cross the military airspace, thus can only be used in such cases. No definitive reason is found which causes this difference in average distance in these two months.

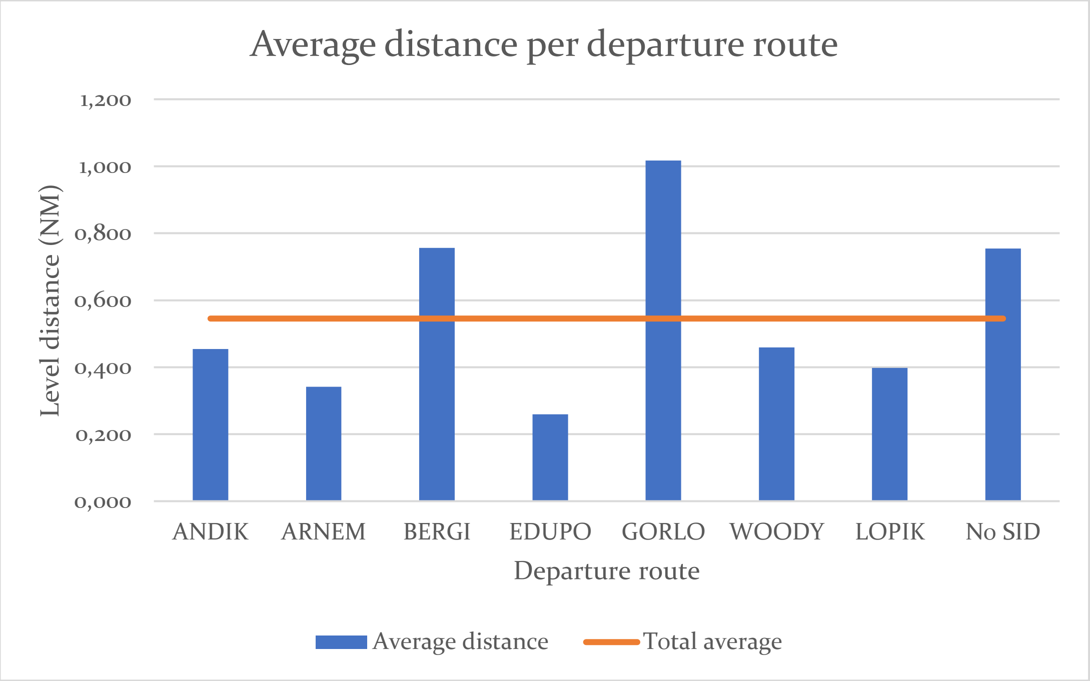

Figure 27 Average distance per segment at flight levels February 2017

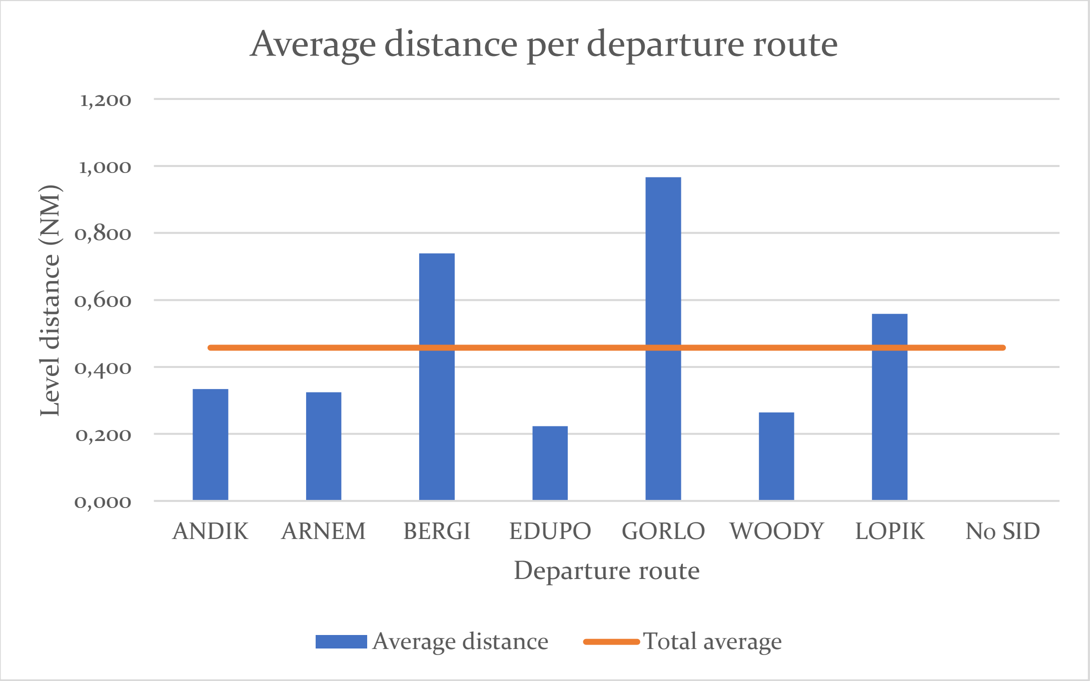

Figure 28 Average distance per segment at flight levels July 2017

5.4 Analysis of departure runway

The effects of the departure runway on level segments are discussed in the following sections. Paragraph 5.4.1 presents the distribution of flights per departure runway and the total level segment distance for departures via these runways. The average segment distance per departure runway are presented in paragraph 5.4.2.

5.4.1 Relative level distance

Figure 30 and Figure 31 reveal that Runway 24 (Kaagbaan) was used most frequently in both February and July, followed by runway 36L (Polderbaan) and runway 18L (Aalsmeerbaan). These runways are the preferred runways to be used for departure as they create the least amount of disturbance for the surrounding areas.

The proportion of level distance, when compared with the number of flights, differs most for runway 24 and runway 18L. Whereas departures from runway 24 produce a higher amount of level distance this is the opposite for runway 18L. As it so happens, these runways are used in conjunction with each other during an outbound peak (two departure runways). Flights departing from each of these runways is distributed according to the departure direction. ANDIK, BERGI and GORLO departures will use runway 24, all other departures use runway 18L. The BERGI and GORLO departures happened to produce the highest amount of level segments, as observed in the previous section. This could explain the difference on these runways. A similar explanation can be used to explain the difference between runway 36L and 36C, as an identical distribution of the flights is used when those two runways are used for outbound peaks.

The difference in level distance and number of flights is visible for departures from the Oostbaan (04 and 22). Only a small percentage of all departures use this runway is primarily, as it is used only by general aviation flights (business jets). These flights need to be merged into the traffic flows from the main departure runways used by all commercial flights. This causes problems for ATC to maintain separation, which is solved by levelling off the business jets to maintain vertical separation.

Barely any flights departed from runway 06 and 27 in February and July. These runways are primarily used for landing hence that there were no departures from these runways. Operating a runway in mixed mode (for departure and arrival at the same time) does not occur often at Schiphol. Runway 27 is only used for departures in case of strong Westerly winds or when other runways cannot be used due to maintenance.

More details regarding the distribution of level segments for each runway is found in Appendix IX Excel results relationships level segments with airspace design and ATC procedures July 2017.

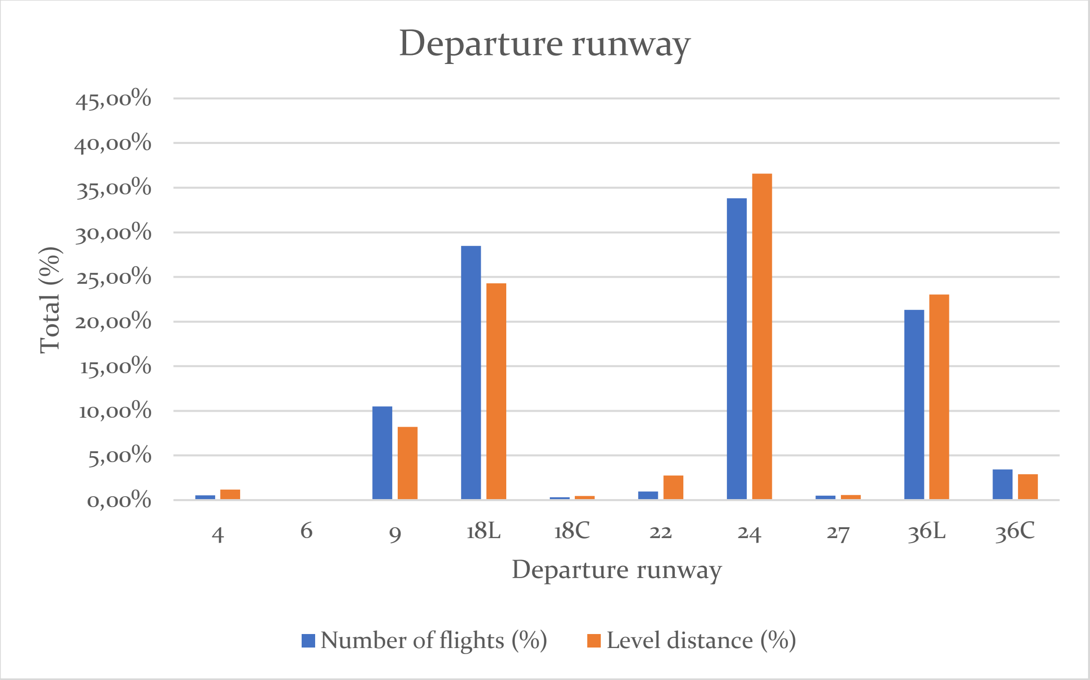

Figure 29 Relative level distance per departure direction February 2017

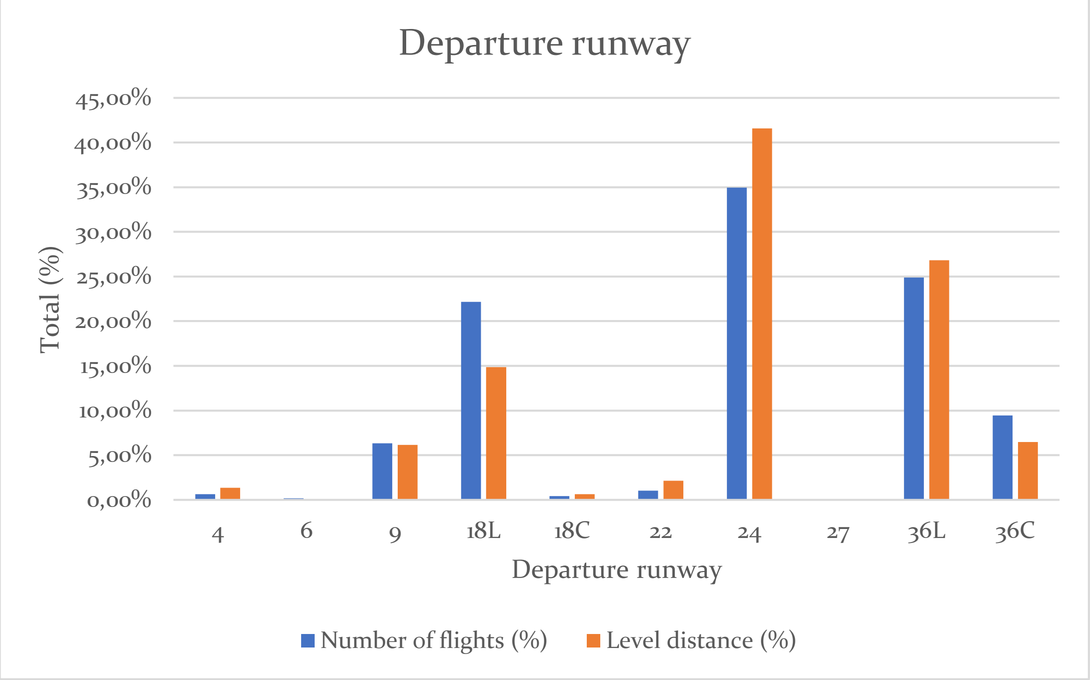

Figure 30 Relative level distance per departure direction July 2017

5.4.2 Average segment distance

Figure 32 and Figure 33 present the average distance per flight departing from a specific runway. In both months the departures from runway 04 and 22 deviate significantly from the overall average segment length per flight. As explained previously, this runway handles primarily business jets, which fly different departures routes than those from the main departure runway. Such flights need to be merged with the main traffic flows.

The deviation from the average for departures from runways 18L and 36C are related to the distribution of departure routes over multiple departure runways. Flights towards the South and East will depart from these runways in case of an outbound-peak (2 departure runways) in most runway configurations. As was determined in paragraph 5.3.1, departures towards these directions occurred less level segments when compared to the other directions.

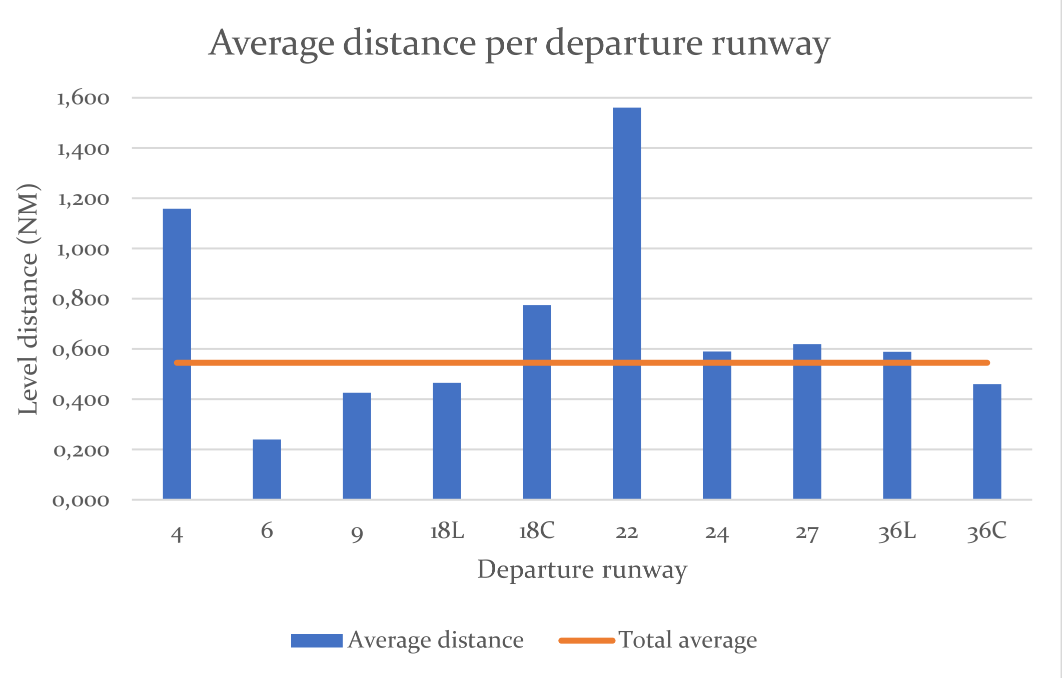

Figure 31 Average distance per segment at flight levels February 2017

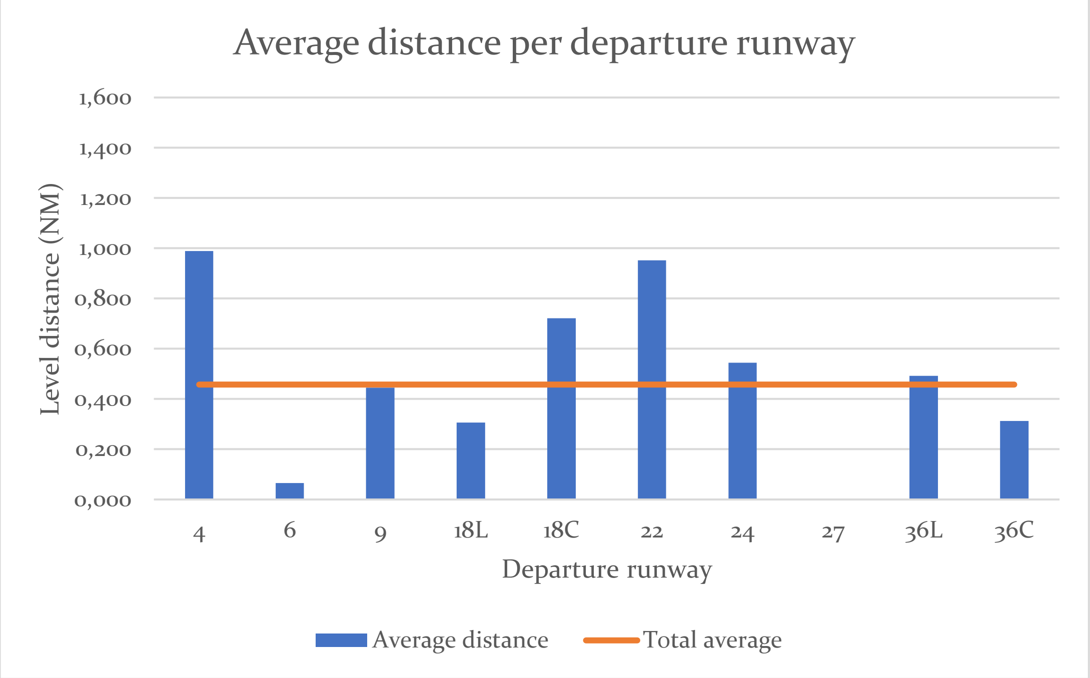

Figure 32 Average distance per segment at flight levels July 2017

5.5 Analysis of Coordination Exit Point

The effects of the coordination Exit Point (COPX), from which a flight leaves the Amsterdam FIR, on level segments are discussed in the following sections. These exit points have been grouped based on the ACC sector in which the COPX is located. These sectors are shown in Appendix VI ACC sectors. Paragraph 5.5.1 presents the distribution of flights per exit sector and the total level segment distance for departures via these sectors. The average segment distance per sector are presented in paragraph 5.5.2.

5.5.1 Relative level distance

Figure 34 and Figure 35 present in both months a relatively high percentage of the total distance for the number of flights departing via Sectors 4 and 5. A relatively low percentage of level segment distance occurred in Sector 2 compared to the high number of flights exiting from this sector. The high amount in Sectors 4 and 5 can be contributed to the departures routes

The specific COPX from Sector 5 (see Appendix IV Coordination Exit Points with London AC and Scottish AC) which produce a high amount of level distance or those via waypoints KOLAG and MIMVA. Flights departing via these two COPX are transferred to London AC. Therefore, flights departing via BERGI and mainly affect when handed over to London AC/TC whereas those to Scottish Control are barely affected.

More details regarding the distribution of level segments for each specific exit point is found in Appendix IX Excel results relationships level segments with airspace design and ATC procedures July 2017.

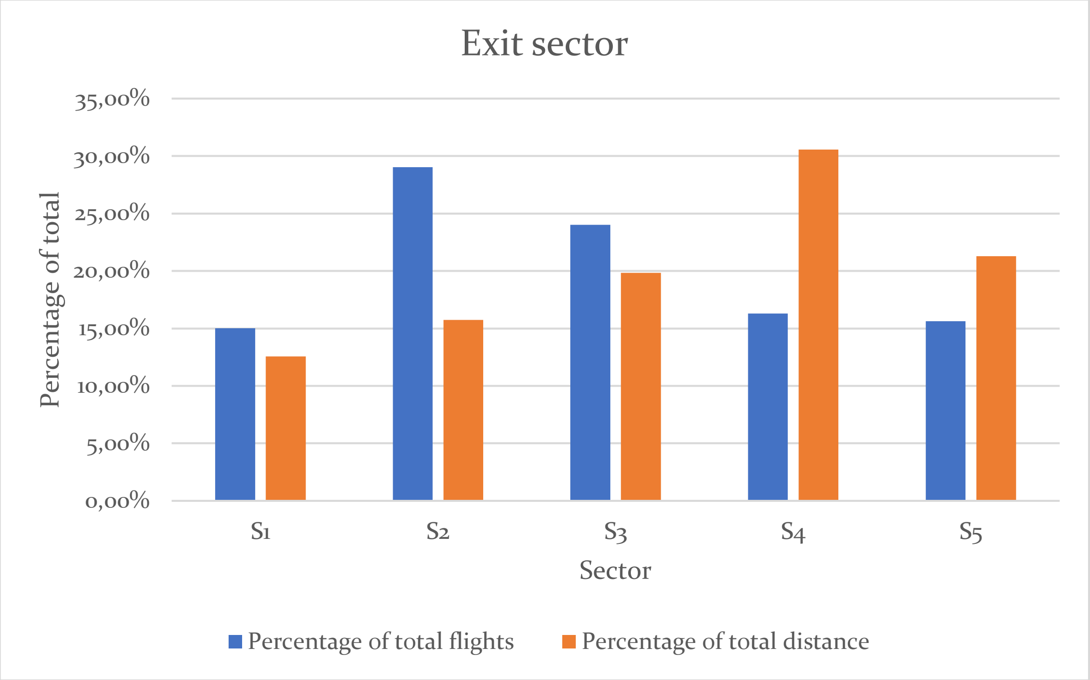

Figure 33 Relative level distance per exit sector February 2017

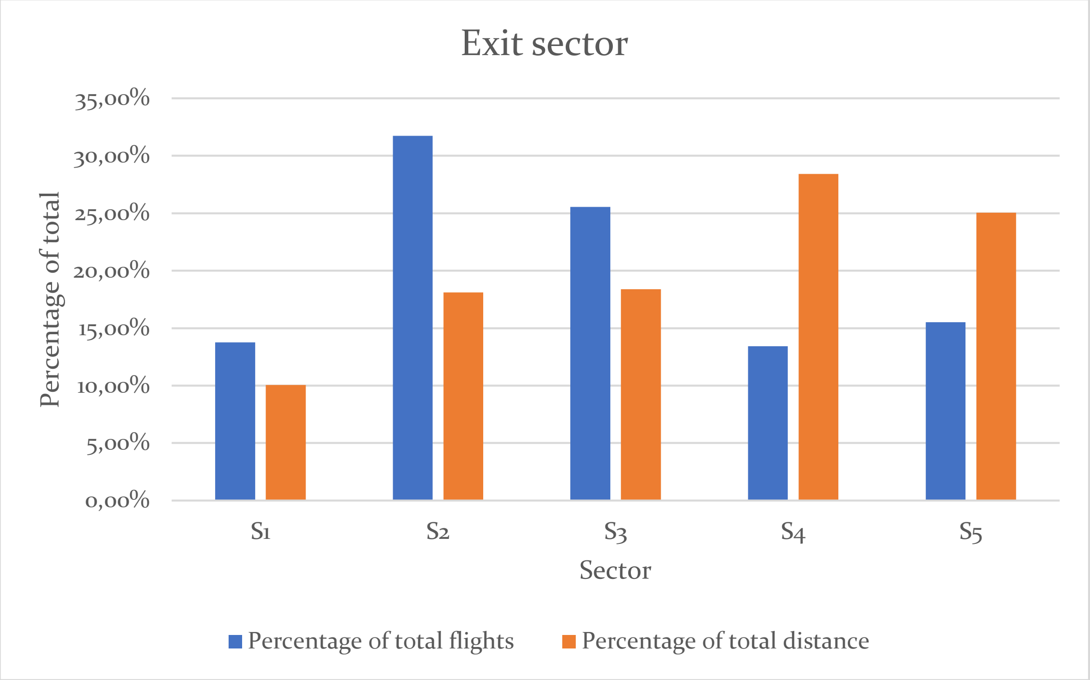

Figure 34 Relative level distance per exit sector July 2017

5.5.2 Average segment distance

Figure 36 and Figure 37 present the average distance per flight via a specific ACC sector. A similar distribution is presented as that in the previous paragraph. Flights departing via Sectors 4 and 5 are deviate most from the total average segment distance. This is to be expected those two sectors produce the highest amount of level segment distance, while only comprising a some of the least number of the total flights.

On the contrary, flights departing via Sector 2 fly the least amount of level distance per flights. This can be attributed to the high number of flights passing through this sector, reducing the average per flight.

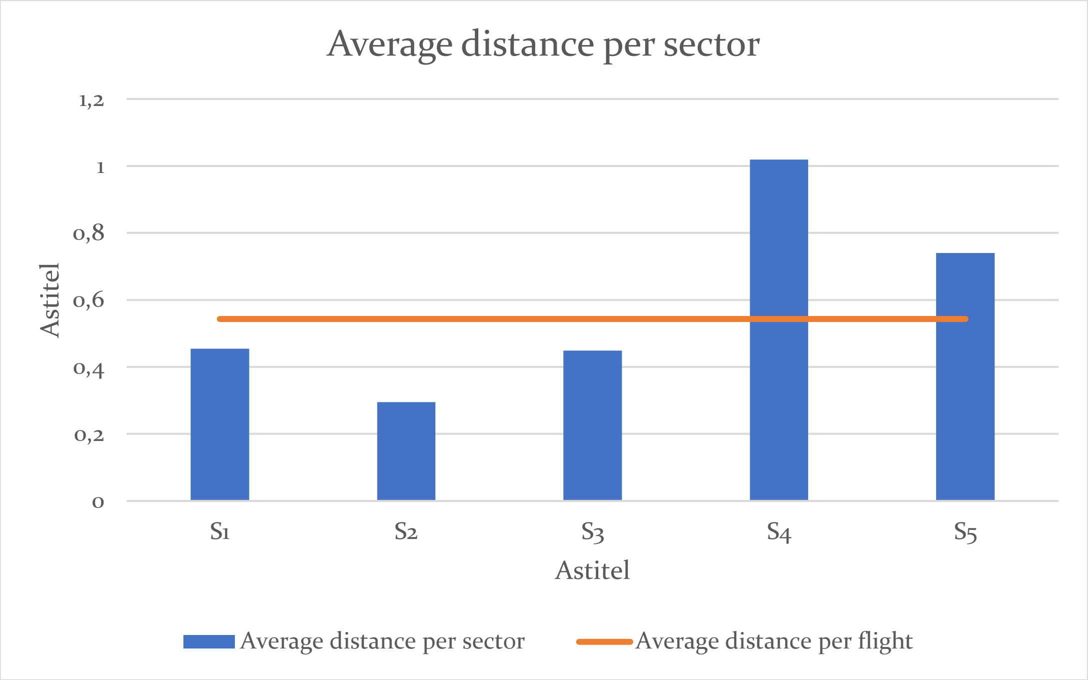

Figure 35 Average distance per exit sector February 2017

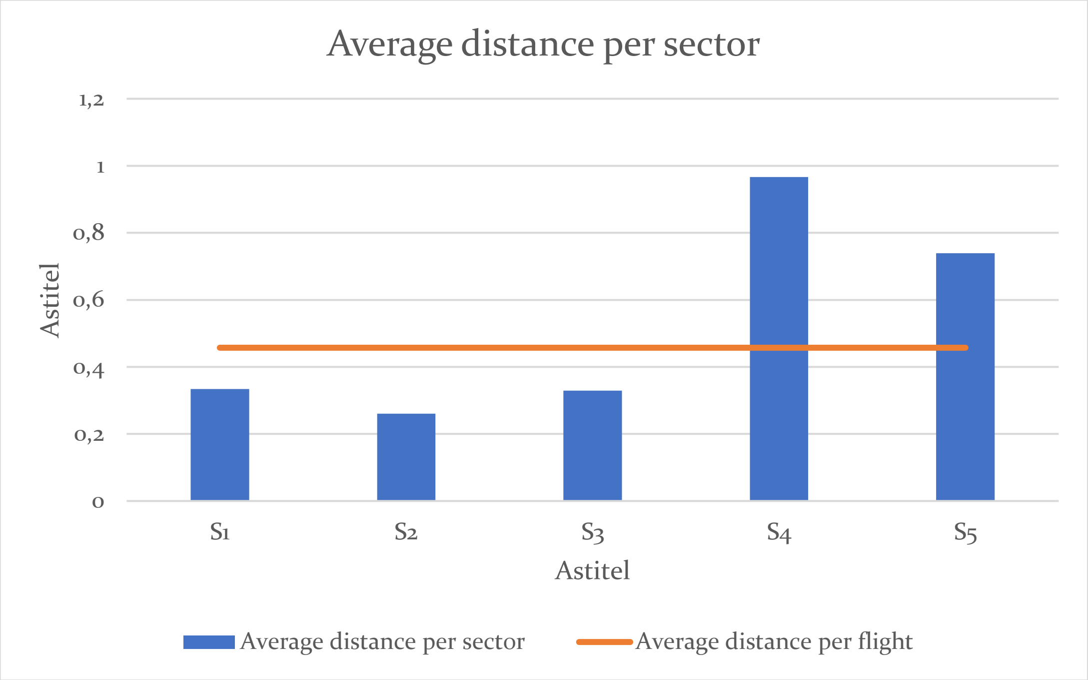

Figure 36 Average distance per exit sector July 2017

5.6 Analysis of aircraft type

This sections shows the effects of aircraft type on level segments. The aircraft are categorised based on RECAT-EU, the European Wake Vortex Re-categorization. This is a new and more precise categorisation of aircraft than the traditional ICAO one. A list of aircraft types with the respective RECAT-EU classification is found in Appendix X RECAT-EU. Paragraph 5.6.1 presents the distribution of flights per RECAT-EU category and the total level segment distance for each category. The average segment distance per RECAT-EU category are presented in paragraph 5.6.2.

5.6.1 Relative level distance

Figure 38 and Figure 33 present the distribution of flights and level distance. This distribution is similar in both February and July. The highest percentage of flights (over 50%) are executed using Category D aircraft, which include the Boeing 737 and Airbus A320, while only contributing to just over 40% of the distance. This is followed by the Category E aircraft, which are mainly represented by the Fokker and Embraer jets. These Category E aircraft represent a relatively high percentage of the total level distance (37.5%) while only representing 29% of the flights.

The Category F aircraft appear to contribute a high percentage of segment distance compared to the number of flights with these aircraft types. The Category F aircraft are mainly business jets. As explained in paragraph 5.4.1 business jets depart from the Oostbaan and need to be merged with the regular traffic from the main departure runway.

Category C aircraft also contribute a relatively high amount of segment distance compared to the percentage of flights. The predominant aircraft in Category C are the Boeing 757 and 767 families and Airbus A300 and A310 families. The majority of these aircraft types fly to destinations in North America. Departures will be flying either a GORLO or BERGI departure to North America and it was concluded in paragraph 5.3.1 that these routes incurred a high amount of level segment distance. This could relate why the Category C aircraft also display this relatively high amount of segment distance.

More details regarding the distribution of level segments for each specific aircraft type is found in Appendix IX Excel results relationships level segments with airspace design and ATC procedures July 2017.

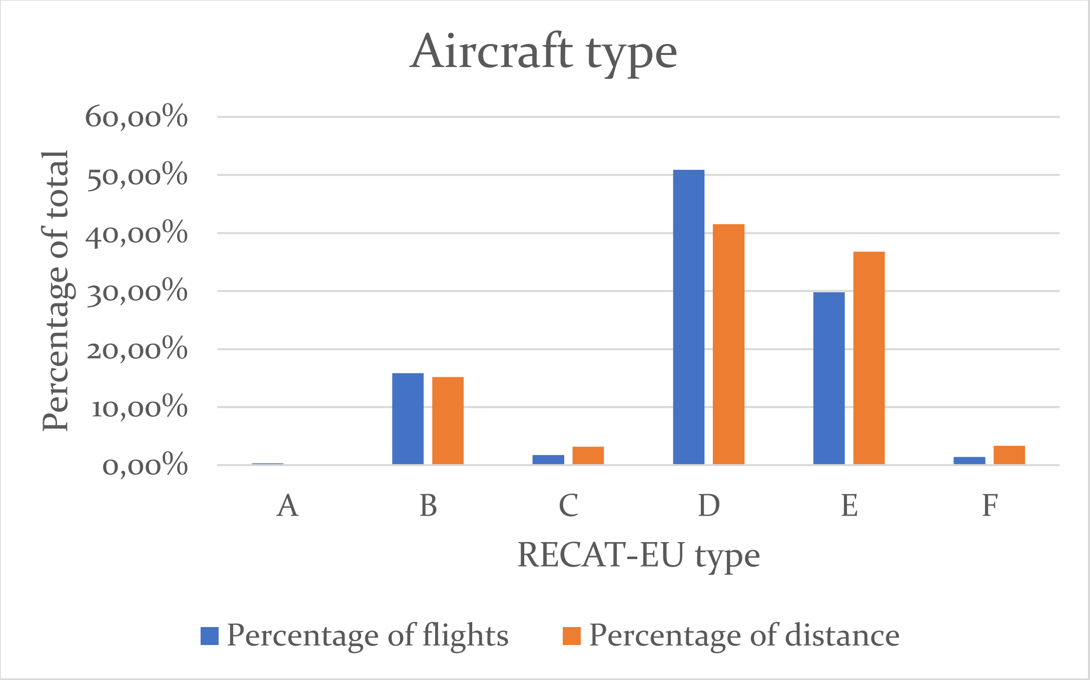

Figure 37 Relative level distance per aircraft category February 2017

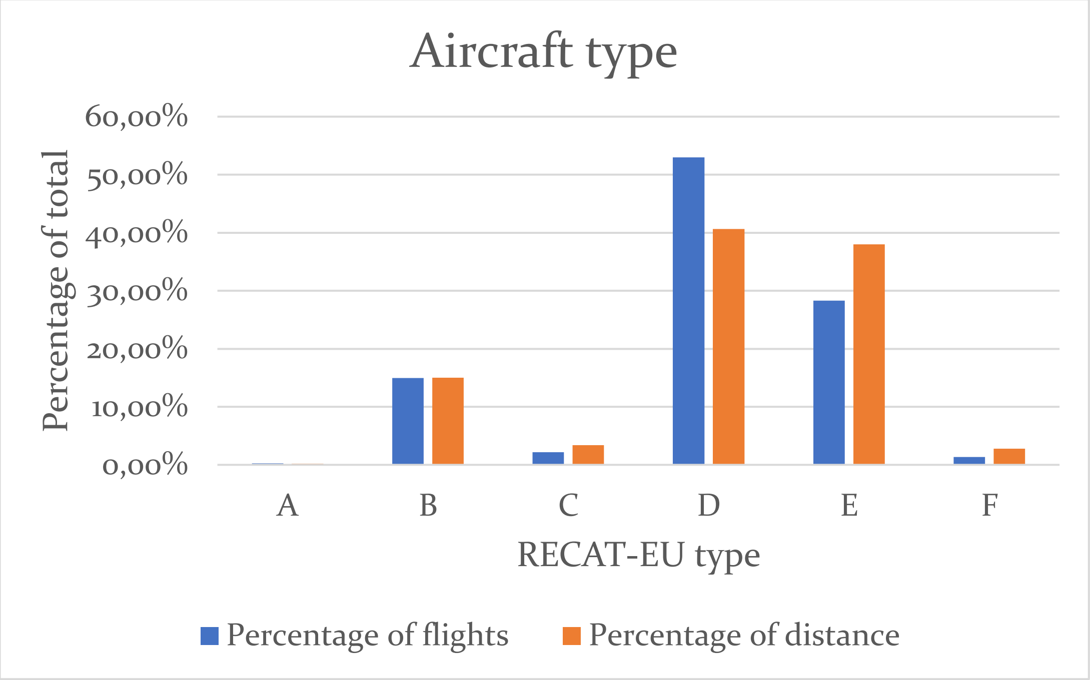

Figure 38 Relative level distance per aircraft category July 2017

5.6.2 Average segment distance

Figure 40 and Figure 41 presents the average distance per flights of a specific RECAT-EU category. The results below show that category C and F aircraft deviate from the total average level distance per flight. The reasons for this deviation are the same for those explained in the previous paragraphs and are related to the type of aircraft and destinations of these aircraft types in these categories.

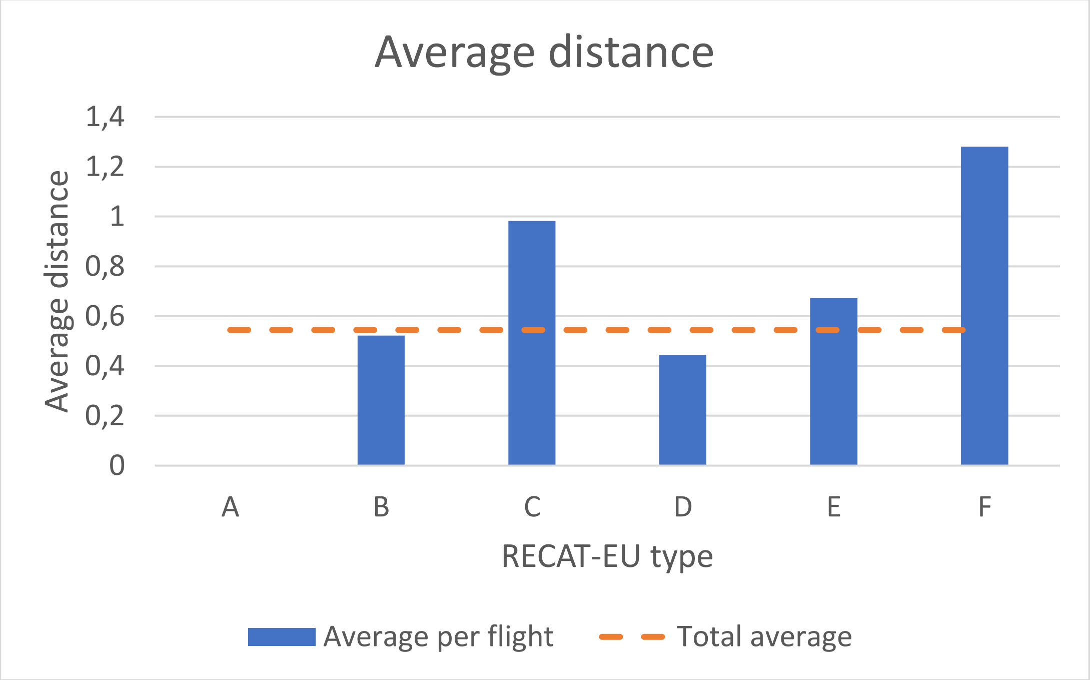

Figure 39 Average distance per aircraft category February 2017

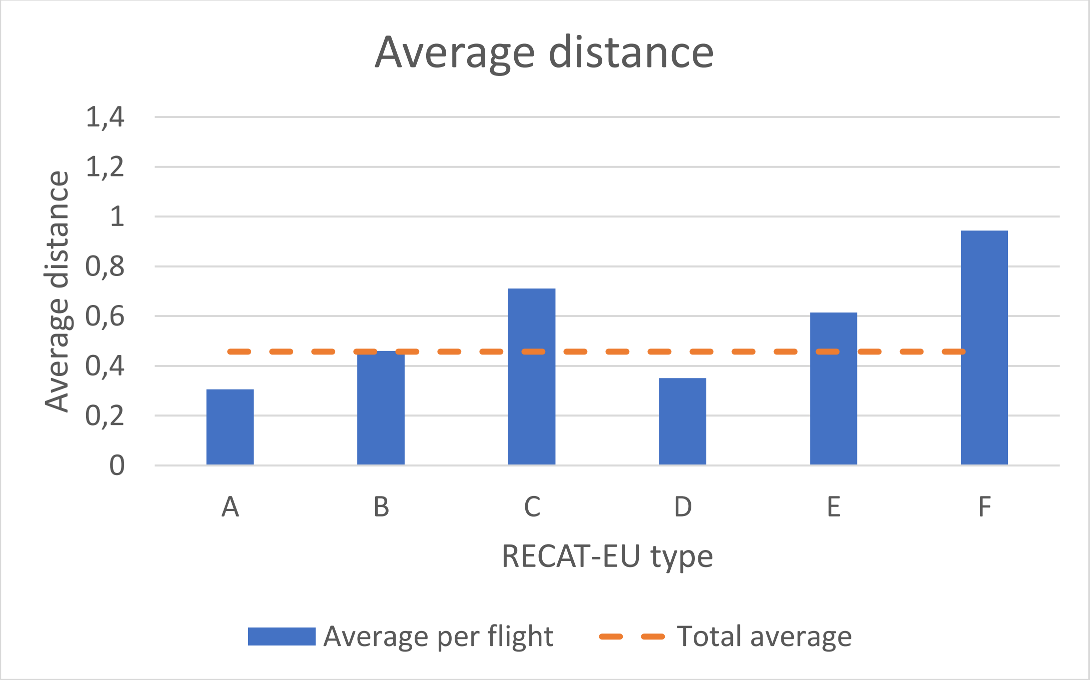

Figure 40 Average distance per aircraft category July 2017

6 Analysis of Vertical Efficiency Effects on Fuel Consumption

The level segments have a negative impact on the fuel economy of a flight, resulting in increased fuel consumption and emissions. The EUROCONTROL Base of Aircraft Data (BADA) Aircraft Performance Models (APM) are used to quantify the additional fuel consumption as a result of the level segments. Paragraph 6.1 describes the contents of the performance models used. The method used to calculate equivalent fuel flows is explained in paragraph 6.2. Finally, the results from the level segments on fuel consumption are presented in paragraph 6.3. These results provide an answer to the sub-question: *"What are the effects of level segments on fuel consumption?"*

6.1 Aircraft Performance Model

Currently there are two families of BADA APM, Family 3 and Family 4. Both families *"are based on the Total Energy Model, equating the rate of work done by forces acting on the aircraft with the rate of increase in potential and kinetic energy"* (EUROCONTROL, 2015). The BADA 3 Aircraft performance Model (APM) is used to determine fuel consumption for most aircraft models present in the track data since the BADA Family 3 provides close to 95% coverage of all aircraft types in the ECAC area (EUROCONTROL, 2015). BADA Family 4 is a newly developed model with a higher level of accuracy in the modelling over the entire flight envelope, however only includes 70% coverage of the current aircraft types.

The APM datasets include the Performance Table Files (.PTF), specifying cruise, climb and descent performance at different flights levels within the normal operations envelope of the aircraft. These tables provide fuel consumption at different altitudes for different weights (low, nominal, high) and the average true airspeed flown at these altitudes. Data for these altitudes is available at intervals of 2000ft, therefore interpolation is needed for all intermediate altitudes. See Appendix V BADA Performance table example for an example .PTF performance table.

6.2 Equivalent fuel flow

To quantify the additional fuel consumption, it is necessary to know the fuel flow at the optimal altitude as well as that during the level segment. The performance tables are used to create fuel flow (FF) as a function of flight level for each of the given weight variants. The function for a generic jet aircraft is shown below in Figure 41. It should be noted that the fuel flow shown below is not only at a specific flight level but also for a specific true airspeed. Due to the reduced air density (ρ) at higher altitudes an aircraft can and needs to increase velocity (v) to generate the same amount of lift (L) while it climbs, this is derived from the lift equation (2) below.

$$L = C_L \frac{1}{2} \rho v^2 S \tag{2}$$

Under normal sub-sonic circumstances fuel flow increases when an aircrafts' velocity increases. The relation between fuel flow and true airspeed of a generic jet airplane performance is shown below in Figure 41. For the purposes of this research the cruise fuel consumption data is used to determine the fuel flow during a level segment. It should be noted that a more precise calculation is achieved when incorporating the climb data as well. To transition from a level segment to a climb the aircraft will need to increase thrust to increase lift. This increase in thrust requires a higher fuel flow. This additional transition fuel has not been quantified in this research.

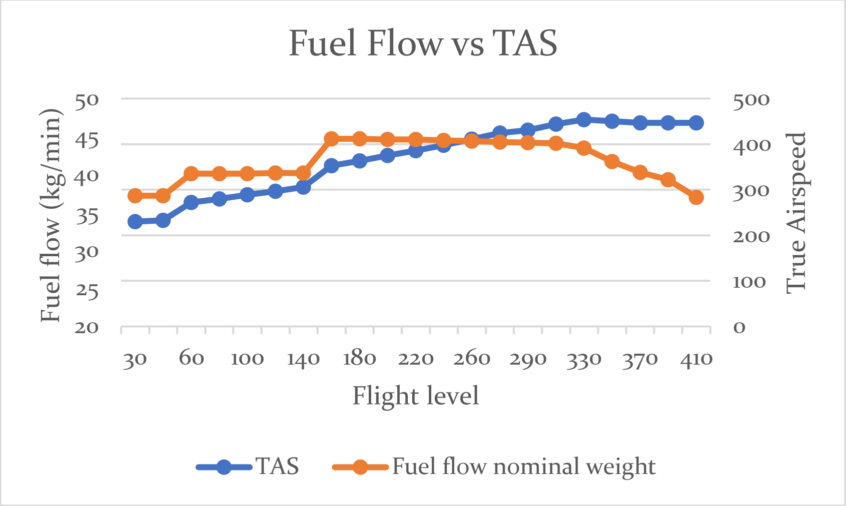

Figure 41 Interpolated fuel flow and true airspeed of a generic jet aircraft

To compare the fuel consumption between two altitudes it is necessary to take into account the difference in velocity. E.g. a 15 NM level segment at FL100 may take three minutes for the generic jet airplane. Flying this same distance in cruise at FL300 would have a duration of two minutes, this is considered the equivalent cruise time. As such, the higher fuel flow at the higher level is compensated by the increased velocity. The TAS and FF are combined through division to define the equivalent fuel required to fly a nautical mile at a specific altitude. See Figure 42 for the equivalent fuel consumption for a generic jet aircraft.

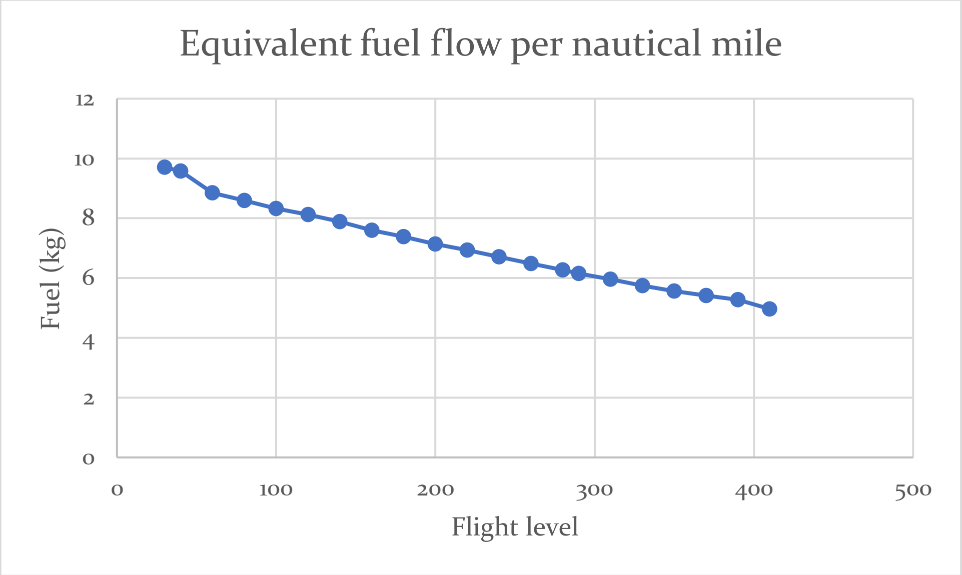

Figure 42 Equivalent fuel flow per nautical mile

The difference in fuel consumption per nautical mile is derived by subtracting the equivalent fuel flow at cruise level (*eq* FF_{CL}) from the fuel flow at the level segment altitude(FF_{LS}). This difference is multiplied by the level segment distance to calculate the additional fuel burn imposed by the level segment, see equation (3). The optimal cruise level is assumed to be the RFL as filed in the SFPL. The additional fuel consumption is proportional with level segment distance.

$$\Delta Fuel = (FF_{LS} - eq\ FF_{CL}) \times distance \tag{3}$$

6.3 Effects on fuel consumption

The additional fuel consumption caused by the level segments is shown below in Table 4. These results are based on the aircraft performance model from the EUROCONTROL BADA. The performance models provided data for three weights: High, Nominal and Low. Departing flights still contain the majority of their fuel, a high weight is therefore considered to be the most accurate indication for the actual situation.

The results indicate that each month over 20,000 kilograms of fuel is consumed additionally due to the creation of level segments in the Amsterdam FIR. The additional fuel consumption in July is 5.5 percent higher than February of that same year. This is unexpected as July saw nearly 40 percent more departures than February. However, the number of level segments July was only 6 percent higher than in February which would explain the similar values.

Table 4 Additional fuel consumption caused by level segments at different aircraft weights

	Additional fuel consumption (kg) February	Additional fuel consumption (kg) July	Additional fuel consumption (kg) Estimate 2017
High	20,027	21,138	246,989
Nominal	18,217	19,040	223,546
Low	16,903	17,455	206,153

s

6.3.1 Additional fuel consumption at altitude

The distribution of the additional fuel consumption is similar to that of the distribution of level segments at each specific flight level in Figure 22 and Figure 23. However, a large difference is observed with the additional fuel consumption from the level segments at FL60. These segments produce over 35 percent of the total additional fuel, while the level segments distance at FL60 caused approximately 20 percent of the total level segment distance. On the contrary, the segments at FL240 only produce 22 percent of the additional fuel, while responsible for 30% of the level segment distance. This difference is related to the effects of height on fuel consumption. Level segments at lower altitudes affect fuel consumption more, as the efficiency at these lower altitudes is less than at the higher altitudes.

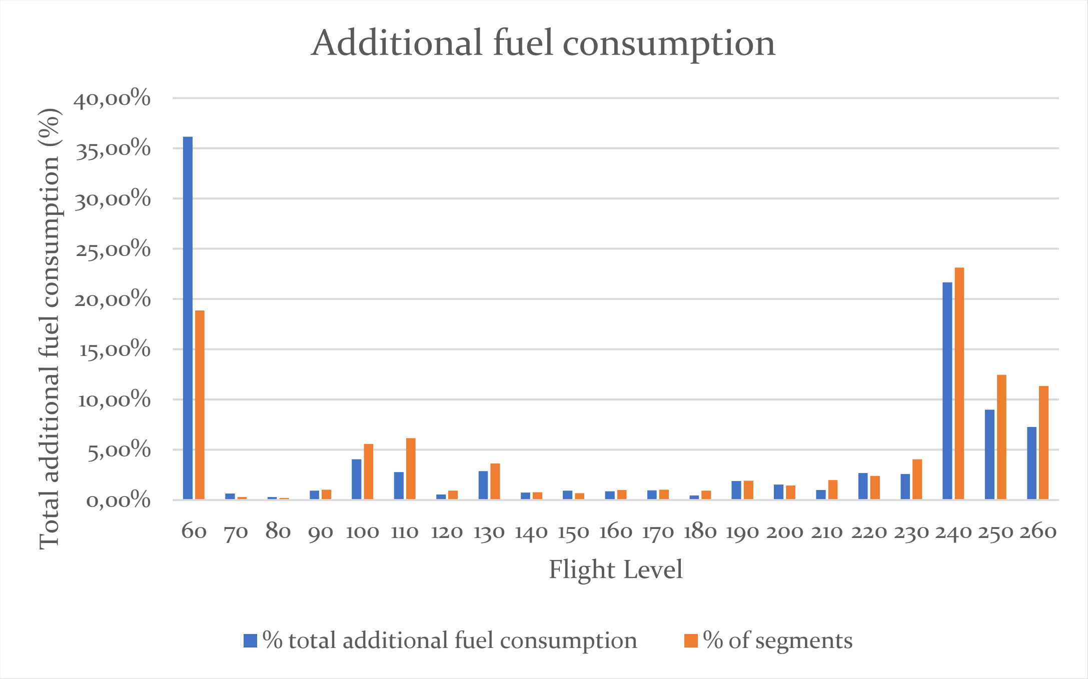

Figure 43 Additional fuel consumption at flight levels February 2017

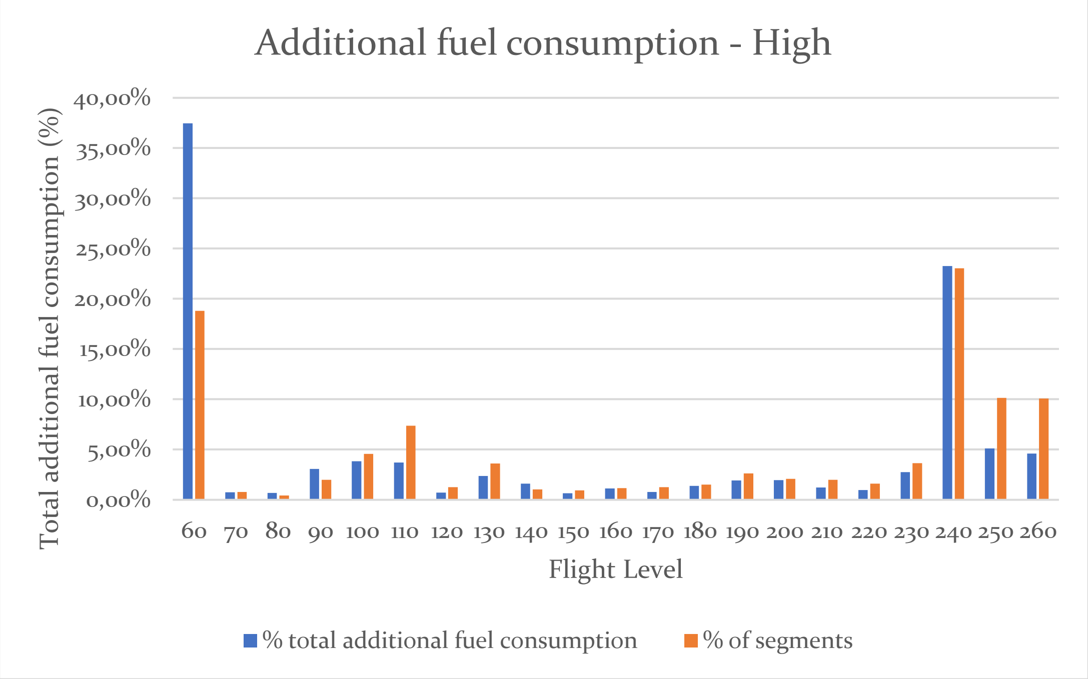

Figure 44 Additional fuel consumption at flight levels July 2017

6.3.2 Average additional fuel consumption at altitude

The figures below indicate that segments at the lowest altitudes cause the highest amount of additional fuel per level segment. As was explained in the previous section, this is due to the efficiency at the different altitudes.

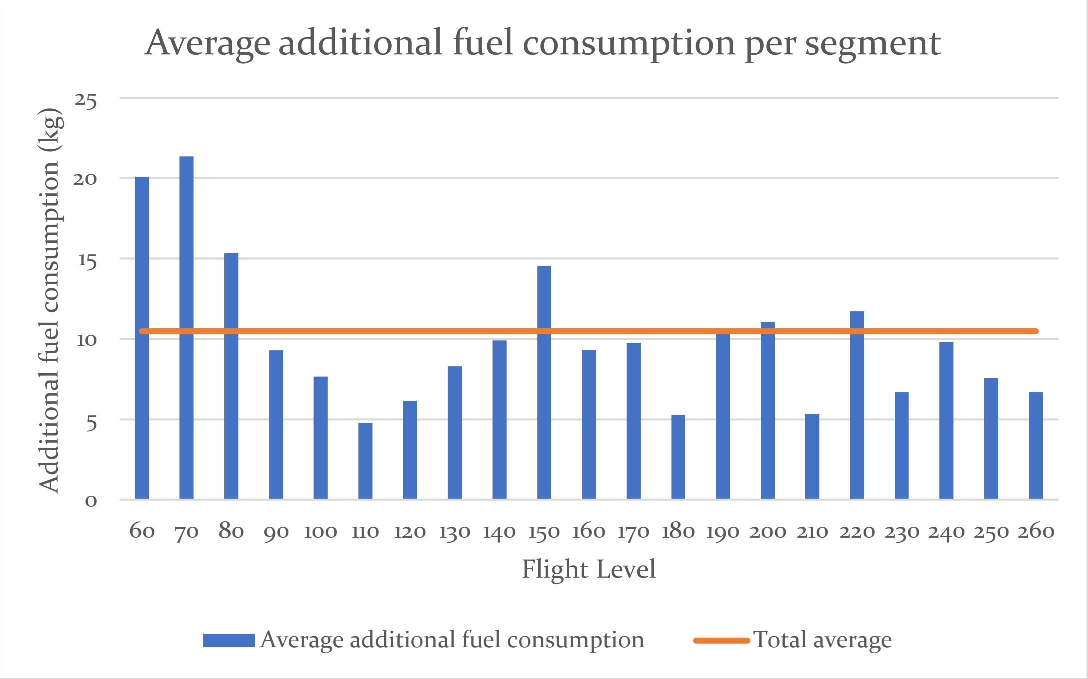

Figure 45 Average additional fuel consumption per segment at flight levels February 2017

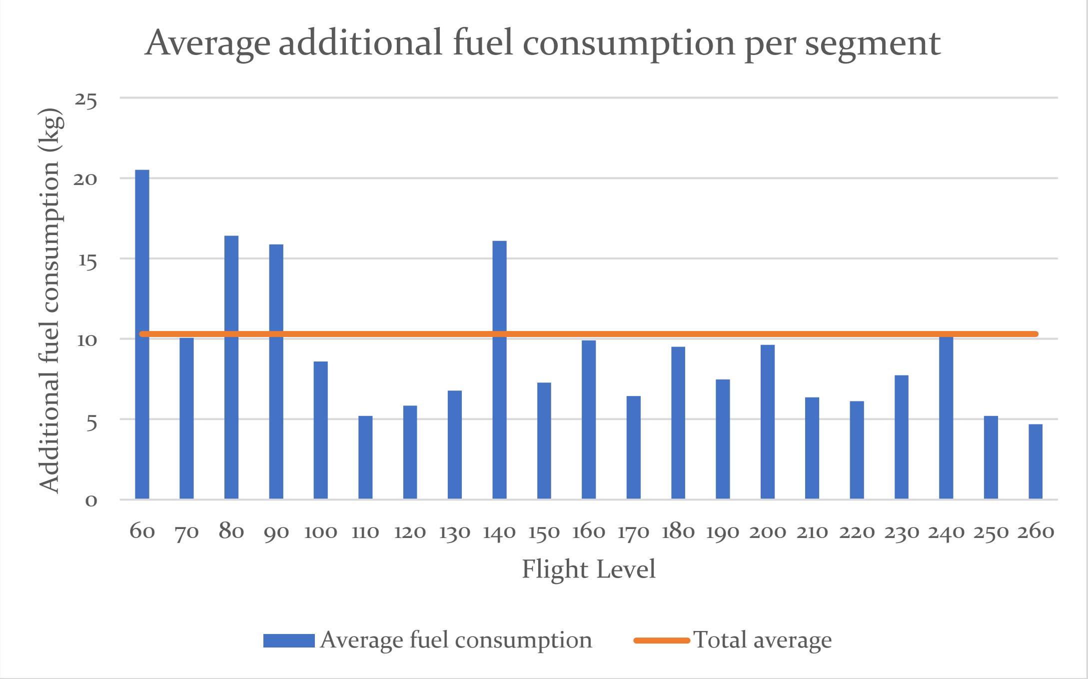

Figure 46 Average additional fuel consumption per segment at flight levels July 2017

7 Conclusions

The aim of this research is to answer the main research question: ***"How is vertical flight trajectory efficiency impacted by climb restrictions, caused by airspace design and ATC procedures, for flights departing Amsterdam Airport Schiphol?"*.** The conclusions to this question are derived from the combination of literature review and quantitative analysis used to answer the sub-questions:

- What is the vertical flight trajectory efficiency for flights departing Amsterdam Airport Schiphol currently?
- What is the relationship between the vertical flight trajectory efficiency and airspace design and ATC procedures?
- What are the effects of level segments on fuel consumption?

7.1 Vertical flight trajectory efficiency

The Performance Review Unit determined that flights departing Schiphol fly on average 25 seconds in level flight. This is significantly more than the time computed from this analysis, which yields less than 6 seconds per flight. Similarly, over 90 percent of the flights climb continuously, whereas the PRU detected that less than 80 percent of the flights operate a continuous climb departure. The reason for this inconsistency is that the PRU includes the entire climb segment in their analysis, whereas this research only takes into account the climb section within the Amsterdam FIR.

A total of 1,920 and 2,052 level segments are detected in the months of February and July 2017 respectively. These level segments result in a total of 9,221 and 10,749 nautical miles spent at intermediate altitudes between take-off and top of climb in each respective month. Each interrupted flight departing Schiphol encounters on average 5 nautical miles of level flight during the climb, lasting nearly a minute.

	February	*July*
Number of flights	16,910	23,505
Percentage of affected flights	9.9%	7.8%
Number of segments detected	1,920	2,052
Segment time (minutes)	1,665	1,882
Segment distance (NM)	9,221	10,749
Median segment altitude (FL)	230	210
Average distance per flight (NM)	0.545	0.457
Average time per flight (seconds)	5.91	4.80

7.2 Airspace design and ATC procedure

Climbs are interrupted throughout the entire Amsterdam FIR, however some locations are more prone for level segments than others. The analysis demonstrates that a definitive relationship is present between vertical trajectory efficiency, airspace design and ATC procedures. The most dominant cause of level segments is the hand-over altitude with London AC resulting in 30% of the total level distance flown in July 2017. This is followed by the level segments at the initial climb altitude of FL60 (20% of total level distance) and the hand-over altitudes with the other neighbouring ANSPs in Belgium and Germany (12% and 10% of total level distance at FL250 and FL260 respectively).

The distribution of level segments per departure route confirms the observations above. The GORLO and BERGI departure routes, those heading towards the London and Scottish sectors, represent on average 30% of all flights. However, these two departure routes cause over 50% of the total level distance in the Amsterdam FIR. The majority of these level segments occur near the FIR boundaries with London AC and locations where departure and arrival routes intersect in the TMA.

The results per runway indicate that departures from runway 24 produce a higher proportion of level segment distance relative to the number of departures. This difference is compensated by a lower proportion of level distance for departures from runway 18L. These two runways are used in conjunction during an outbound-peak runway configuration. Departures towards GORLO and BERGI will depart from runway 24 in this configuration and cause this shift in distribution of level segments. The same distribution of departure routes is used in an outbound-peak configuration with runways 36L and 36C, causing a disproportionate distribution in level segments from these runways. Departures from the Oostbaan (04/22) deviate most from the total average level segment distance. Aircrafts departing from this runway are primarily business jets.

The effect of aircraft type on level segments confirm the conclusion of the increased segment length for flights departing from the Oostbaan. The average segment distance per RECAT-EU category F airplane is twice as long as the total average segment distance. The RECAT-EU F airplanes are mainly business jets and general aviation airplanes. Aircraft of the RECAT-EU C category also display a significantly higher average segment distance per flight. Airplanes in this category are mainly represented in the data by the Boeing 757 and 767 families. These airplanes fly primarily to destinations in North America. Once again, such flights will primarily depart via GORLO and BERGI.

7.3 Additional fuel consumption

A model using the EUROCONTROL Base of Aircraft Data validates that the interrupted climb segments increase the aircraft fuel consumption. On average, this increase in fuel consumption amounts to over 20,000 kilogram of fuel per month. This totals to nearly 250 metric tons of additional fuel consumption on a yearly basis. For each flight not continuously climbing this results in an average of 12 kilogram of additional fuel consumption.

The majority of the additional fuel consumption (37%) is caused by level segments at FL60 due to the vertical separation of crossing inbound and outbound flows. Whereas the majority of the level segment distance occurred at FL240 (30% total segment distance), only 22 percent of the total additional fuel consumption resulted from these segments. It is concluded that the most gain in terms of reducing fuel consumption, can be made by reducing the number of level segments occurring at FL60, even though these segments are not the ones occurring most often.

7.4 Final conclusion

The answers to the sub-questions indicate that flights departing Schiphol are interrupted during the climb due to various reason. The resulting effect on fuel consumption increases the operational efficiency of flights departing from Schiphol. The insights and results of the analysis can now be used to answer the main research question.

> ***How is vertical flight trajectory efficiency impacted by climb restrictions, caused by airspace design and ATC procedures, for flights departing Amsterdam Airport Schiphol?***

The research concludes that over 90% of the departing flights climb continuously while in the Amsterdam FIR. The main cause of climb interruptions is attributed to flights departing via GORLO and BERGI towards the London AC sectors. The hand-over agreements made with London AC impose a limitation to continue the climb near the border of the London sectors. Furthermore, flights via GORLO and BERGI are prone to interruptions during their climb segment because of the vertical separation techniques applied by ATC in the TMA. Due to crossing arrival and departure routes, departures are initially restricted from climbing higher than FL60 after departure.

This research does not verify that all level segments are to be attributed to the previously stated causes, as level segments can always be caused by tactical intervention from ATC to separate traffic. However, overall it can be concluded that the vertical flight trajectory efficiency is mainly impacted by the initial climb altitude and the hand-over agreements with the neighbouring ANSPs.

8 Discussion

The research analysis and results provide insight in the causes of level segments for flights departing Schiphol. For this research certain assumptions are made to determine the conclusions of this research, primarily when determining the causes of level segments. These causes are based on the observed relationship with several airspace design factors and ATC procedures. In this section the research method and interpretation of the results are discussed and how these can be improved.

First of all, the trajectory data used for the research contains a number of issues related to the way it was logged. Flights logged near the end of a day are cut off after 23:59:59 local time. This causes flights which depart after 23:30 local time to miss certain sections of the trajectory. These flights are still included and processed to detect the level segments, however not all segments which may have occurred in the flight may be present in the data. This only affects a minimal number of flights, so the effects should not be directly visible in the results. A recommendation on bypassing this issue is presented in the next chapter.

Other issues with the data are related to the system flight plans. In some cases, a flight trajectory was logged while no system flight plan was available. This is only the case for less than one percent of the total number of flights. In other cases, multiple flight plans were available for a single flight. It is possible that a flight plan is refiled for numerous reasons. The method used correlates the first flight plan which matches the callsign in the trajectory data. It is possible that certain parameters from this first found flight plan do not reflect the actual flight parameters, such as the requested cruise altitude.

The relationship between the level segments and the airspace design factors (SID, departure runway, exit sector) appear to all be linked together. Certain departure routes are observed to incur a relatively high number of level segments. As it so happens, these departure routes are used more often on certain runways. This in turn results in an observation of increased level segment occurrence on these specific runways. Concluding whether the level segment distance is caused by any of these factors is not entirely possible due to this interrelation between the various factors. The same conclusion can be derived from the altitude where level segments occur.

A similar relation is observed relating to aircraft type and SID. The Category C aircraft induce a relatively high amount of level segment distance for the number of flights that are performed by these aircraft. However, these aircraft types happen to be used primarily for flights towards destinations in North America. Such destinations fly the departure routes which produce the largest quantity of level segment distance. It is therefore difficult to conclude whether the aircraft type is the explanatory variable for the occurrence of level segments.

Finally, there is one cause for level segments which is not discussed in the results. Level segments can always occur due to tactical instructions from ATC to separate flights. It is not possible to detect such segments using the applied methods. The error from such segments is included in the results and it is unknown how large this error is. It is suggested to develop a method which is able to detect whether level segments occur because of instructions from ATC.

9 Recommendations

The analysis of the vertical flight trajectory efficiency for the months of February and July of 2017 determined that 10% of the flight departing Schiphol are interrupted during the climb within the Amsterdam FIR. The ideal situation would be to accommodate all flights with a continuous climb departure. As mentioned this is not always possible. The main causes that inhibit continuous climb departures for all flights are the separation minima used by ATC and the hand-over agreements with neighbouring ANSPs.

The analysis of where the level segments occur, in terms of altitude and location, determined that crossing arrival and departure routes inhibit continuous climbs in specific runway configurations. This is especially the case for departures towards the West and North-West. A solution is to change the location of arrival routes so the crossings are moved to new locations, allowing for departures to climb over arrivals. However, this would most likely have a negative effect for arriving traffic in terms of a continuous descent. When redesigning the airspace, the continuous climb and descent operations should be taken into consideration. Further research is recommended to determine the effects on arriving traffic and how this traffic is inhibited from flying a continuous descent. Methods to analyse continuous descents are already established by EUROCONTROL and follow a similar methodology as used in this research. The focus would be on the descent phase located in the TMA, as this is where the crossings with departure routes occur. With such an analysis a better understanding is created of what the real causes are which affect continuous climbs (as well as continuous descents) in the TMA. These results are then used to develop solutions considering the cost and benefits for both arriving and departing traffic from Schiphol. In this research it is also recommended to take into account the flights from Rotterdam, as such flights do also operate in the Schiphol TMA.

Analysis of the multiple airspace design factors and ATC procedures concluded that departures towards the West and North-West experience level segments most often, particularly at the hand-over altitude of FL240 near the boundary with London Area Control. The hand-over conditions are designed to reduce controller workload while ensuring vertical separation between flights. Additional research is recommended to determine whether these hand-over conditions can be made more flexible to accommodate continuous climb departures.

As discussed in the previous chapter, a number of flight trajectories were incomplete due to the data ending after 23:59:59 local time. This is due to the way the data is logged. This causes the level segments which may have taken place during a flight to be absent in the data. While only a small number of flights occur in this time period it is suggested to redefine the methodology to exclude flights for which the trajectory data is incomplete.

The final recommendation is to develop a method which is able to detect level segments caused by tactical intervention from ATC. While all level segments that occurred were detected in this research, it was not possible to determine the exact cause of a level segment. Developing a method which is able to detect whether a climb was interrupted due to other traffic would increase the accuracy of determining the cause of level segments.

In short, the following recommendations result from this research:

- Perform research on the vertical flight trajectory efficiency for flights arriving at Schiphol.
- Develop solutions which reduce the effect of crossing departure and arrival routes on the vertical trajectory efficiency.
- Perform research on the hand-over conditions with London AC and how these could be made more flexible to accommodate continuous climb departures.
- Determine a method to increase the accuracy and detection of level segments caused by tactical intervention from ATC.

10 References

Air Traffic Control the Netherlands. (2018, March 29). *AIP Netherlands.* Opgehaald van Standard instrument departure chart: http://ais-netherlands.nl/aim/

Air Traffic Control the Netherlands. (2018, May 29). *EHAM AD 2.2 AERODROME GEOGRAPHICAL AND ADMINISTRATIVE ATA.* Opgehaald van Integrated Aeronautical Information Package: http://www.ais-netherlands.nl/aim/2018-05-10-AIRAC/html/index-en-GB.html

Austin, R. (2010, Februari 18). *ECEF ENU Longitude Latitude relationships.* Opgehaald van Wikimedia Commons: https://commons.wikimedia.org/wiki/File:ECEF_ENU_Longitude_Latitude_relationships.svg

Bowring, B. (1976). Transformation from spatial to geographical coordinates. *Survey Review, 23*, 323-327.

CBS. (2018, maart 30). *StatLine, Luchtvaar; maandcijfers Nederlandse luchthavens van nationaal belang*. Opgehaald van Centraal Bureau voor de Statistiek: https://opendata.cbs.nl/statline/#/CBS/nl/dataset/37478hvv/table?dl=67A4

Dalmau, R., & Prats, X. (2014). *How much fuel and time can be saved in a perfect flight trajectory.* Istanbul: International Conference on Research in Air Transportation.

EUROCONTROL - Performance Review Unit. (2018, May 26). *Pan-European ANS Performance data repository.* Opgehaald van Performance Review Unit: http://ansperformance.eu/data/performancearea/

EUROCONTROL. (2008). *Vertical Flight Efficiency.* Brussels: Performance Review Commission.

EUROCONTROL. (2010). *EUROCONTROL Specification for On-Line Data Interchange (OLDI).* Brussels: EUROCONTROL.

EUROCONTROL. (2010). *EUROCONTROL STANDARD DOCUMENT FOR SURVEILLANCE DATA EXCHANGE Part 14 : Category 020 Multilateration Target Reports.* Brussels: EUROCONTROl.

EUROCONTROL. (2015). *Base of Aircraft Data (BADA) Factsheet.* Brussels: EUROCONTROL. Opgehaald van EUROCONTROL: http://www.eurocontrol.int/sites/default/files/field_tabs/content/documents/sesar/bada-overview.pdf

EUROCONTROL. (2018). *ATM Architecture Information Management*. Opgehaald van EUROCONTROl: http://www.eurocontrol.int/atm-architecture-information-management

EUROCONTROL. (2018, June 1). *Continuous Climb and Descent Operations*. Opgehaald van EUROCONTROL: http://www.eurocontrol.int/articles/continuous-climb-and-descent-operations

European Commission. (2017). *European ATM Master Plan 2017.* Brussels: SESAR.

Holmes, J. C. (1982). *Airport and air traffic control System.* Washington, DC: Office of Technology Assessment.

Hopkin, V. D. (1982). *Human factors in air traffic control.* Neuilly-Sur-Seine: AGARD.

ICAO. (2006). *DOC 8168 Aircraft Operations Volume I Flight Procedures.* International Civil Aviation Organization.

Indra. (2015). *Flight Object IOP System Requirements & Validation.* Brussels: SESAR JOINT UNDERTAKING. Opgehaald van SESAR Joint Undertaking.

KDC Management. (2017). *KDC Reserach Agenda 2018.* Schiphol: Knowledge & Development Centre, Mainport Schiphol.

Košecká, J., Tomlin, C., Pappas, G., & Sastry, S. (1995). *Generation of Conflict Resolution Maneuvers for Air Traffic Management.* Berkeley: University of California at Berkeley.

Larsson, P. (2011). CCD versus CDA. *Scandinavian Airlines System*.

LVNL. (2018). *Air Traffic Control the Netherlands*. Opgehaald van Air Traffic Control the Netherlands: https://en.lvnl.nl/

Mogford, R. H., Guttman, J. A., Morrow, S. L., & Kopardekar, P. (1995). *The Complexity Construct in Air Traffic Control: A review and Synthesis of the Literature.* Washington, DC: U.S. Department of Transportation Federal Aviation Administration.

NATS. (2015). *Understanding how the 3Di score works.* Opgehaald van NATS: https://www.nats.aero/wp-content/uploads/2015/06/3Di_score.pdf

NATS. (2017). *Responsible Business Report 2016-17.* Opgehaald van National Air Traffic Service: https://www.nats.aero/environment/3di/

NATS. (2018). *Environment Performance*. Opgehaald van NATS: https://www.nats.aero/environment/3di/

Peeters, S. (2016). *Vertical flight efficiency during climb and descent.* Brussels: Performance Review Unit.

Peeters, S., & Guastalla, G. (2017). *Analysis of vertical flight efficiency during climb and descent.* Brussels: EUROCONTROL.

Rooseleer, F., & Treve, V. (2018). *"RECAT-EU" European Wake Turbulence Categorisation.* Brussels: EUROCONTROL.

Ryerson, M. S., Hansen, M., & Bonn, J. (2011). Fuel Consumption and Operational Performance. *Europe Air Traffic Management Research and Development Seminar*.

Shen et al., D. (2011). *Pursuit-evasion orbital game for satellite interception and collision avoidance.* International Society for Optics and Photonics.

SKYbrary. (2017, July 25). *Continuous Climb Operations (CCO)*. Opgehaald van SKYbrary: https://www.skybrary.aero/index.php/Continuous_Climb_Operations_(CCO)

Zhu, J. (1994). Conversion of Earth-centered Earth-fixed coordinates to geodetic coordinates. *IEEE Transactions on Aerospace and Electronic Systems, vol. 30, no. 3*, 957-961.

Analysis of Vertical Flight Trajectory Efficiency

A quantitative study on the effects of climb restrictions for flights departing Amsterdam Airport Schiphol

Appendices

KDC Mainport Schiphol – Centre of Excellence
A collaboration with the Aviation Academy, Amsterdam University of Applied Sciences

Author: Marc Eijkens

Date and location: Schiphol, 25-06-2018
Version: V1.0

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Appendix I Reflection

This reflection follows the STARR method(Situation, Task, Action, Result and Reflection). The reflection will discuss the primary used and developed during my graduation. Additionally I reflect on the SCRUM method used to give structure to the way the research was executed.

Primary skills

This research focused on quantitative research by means of processing large quantities of data. The skills used and developed during this research are mainly related to programming and visualising data.

Situation

The initial plan was to use DDR2 data from EUROCONTROL to determine vertical trajectory efficiency, however this proved to be not accurate enough. It was therefore decided to use the trajectory data available at the LVNL, which had a much higher level of accuracy. The format of this data was however new to me, so it required additional time to understand how this data could be used for my goals.

Task

Processing large amounts of data is part of the curriculum, however this is not something which focused on a lot, especially when writing your own code is required. For the assignments that did require programming during my study, I usually was the person to take this upon myself. I think that programming is a skill which is required increasingly more in the future. I set the goal for this research to teach myself to become a better programmer and challenge myself. While I was offered options where others would process the data, I decided against it, even though this meant a lot of self-study and trial and error.

Action

Writing the actual code to analyse the trajectory data proved to be a challenge, especially due to the structure and planning of the research (more on that later). Every two weeks results needed to be presented. While I was offered options where others would process the data, I decided against it, even though this meant a lot of self-study and trial and error.

Result

The result from all the programming resulted in a piece of code which was able to process millions of coordinates to determine the level segments in the vertical trajectories of flights. Every two weeks more sub-results could be delivered and discussed during the bi-weekly sprint reviews.

Reflection

Initially I thought that it would not be too difficult to process all the data required to detect level segments. During previous assignments which required programming I was able to always go the extra mile. For example, I wrote a piece of code which used an informed search algorithm to optimize horizontal trajectories. This was supplemented by a stunning visualisation of how the algorithm actually worked. This assignment encouraged me to tackle the vertical trajectory analysis. The big problems in developing the code for this research was that the data required many more steps than before, including errors within the data itself. These are problems which you are unable to predict when designing the research. For future work I think it would be suggested to request more help instead of figuring everything out by myself. However, I will continue to teach myself to become a better programmer.

SCRUM/Sprint Review

During my studies I have completed numerous projects. One of the most difficult aspects of a project is the management of time and working towards a deadline. I know myself to be someone who works on many things at the same time. The SCRUM method we used throughout the graduation period turned out to be a successful way to work in a structured way.

Situation

Every week two Scrum meetings took place in the office, one on Monday morning and the other on Thursday. These meetings were used to discuss the goals and progress of the results that were to be presented at the end of a two week period. These Scrum sessions were chaired by a Scrum master and attended by all graduation students.

Task

Every two weeks a Sprint review was organised, during which the progress and results of the research were discussed with the KDC stakeholders. The stakeholders would give input regarding the direction of the research, while also giving suggestions for further research. The Scrum sessions would be used to

Action

To keep track of the progress, a Scrum board was used. This board focused on the “user-story” which described the objective for the coming weeks. The steps required to answer the user-story are based on several “to-do” tasks. The goal was to only work on one of the to-do tasks at a time, ensuring a focused approach. This task would be placed on the “doing” section of the board. Once a task was completed the to-do task would be moved to the “done” section. Once this finished work is discussed and accepted by the stakeholders during the sprint review, the task can be removed from the board.

Result

The Scrum method proved to be an effective way to give structure to the research. Each two weeks it would be clear what was to be expected and how this would be accomplished. It also ensured the other students were notified of what I would be working on. In some cases certain tasks would overlap with other students and collaboration would take place.

Reflection

The main benefit of using Scrum were the bi-weekly deadlines for the sprint-reviews. Even though these no actual results needed to be delivered on these dates, it forced me to want to present interesting results from my research and was very motivating. I must admit that during the last weeks when the majority of the analysis was done the focus on Scrum deteriorated and that the board was no longer updated regularly. In all, the Scrum method provided a way to work in a very organised and transparent way.

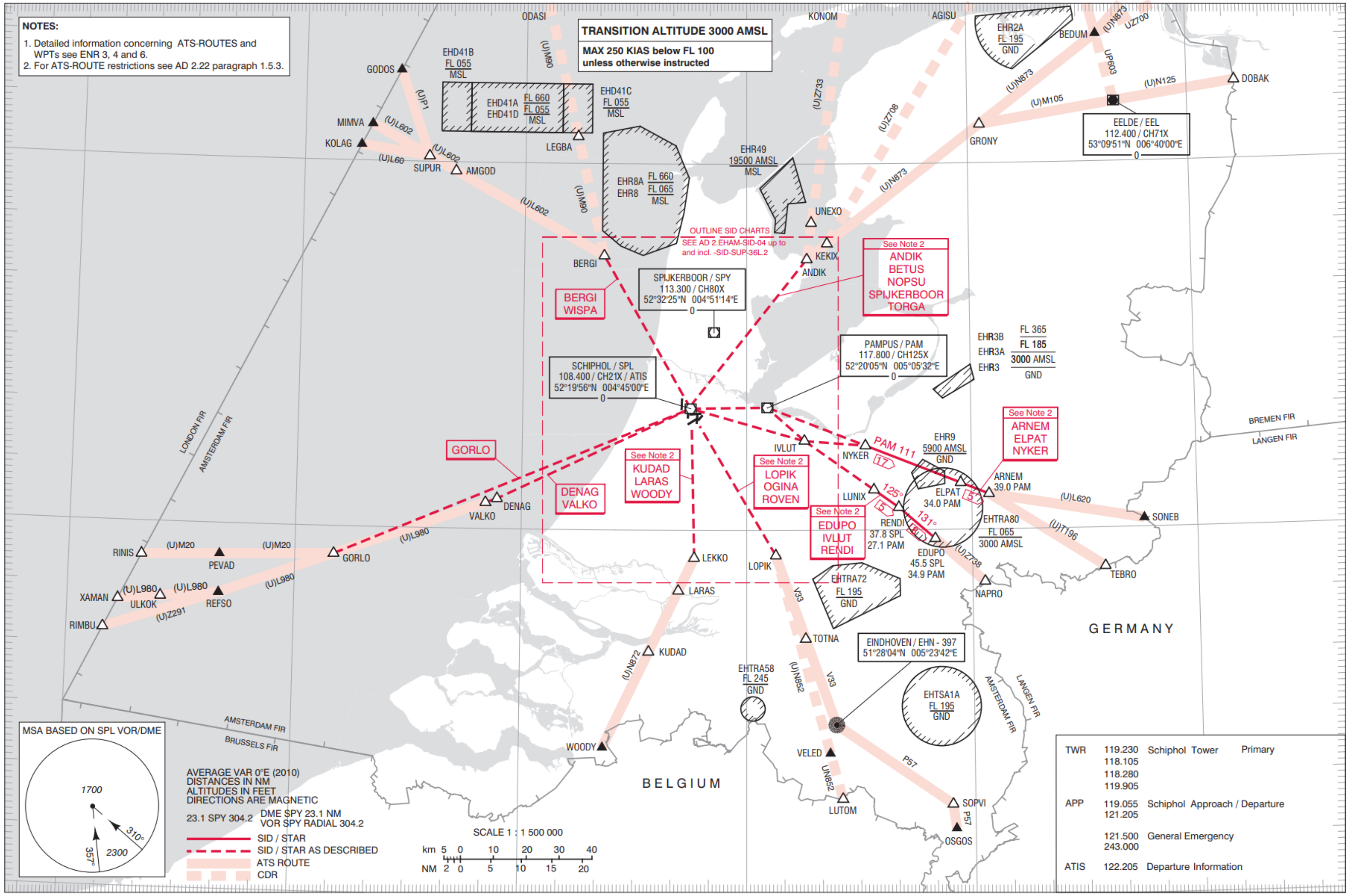
Overall reflection

The journey of this thesis began with writing a research proposal on chain optimization and the capacity benefits of optimised hand-over conditions. The focus of this proposal was on cross-border arrival management, a method to extend arrival management to en-route airspace of adjacent sectors. During the initial weeks the direction of this thesis completely changed, focussing on departures instead of arrivals. This was because of an observation related to the hand-over conditions.

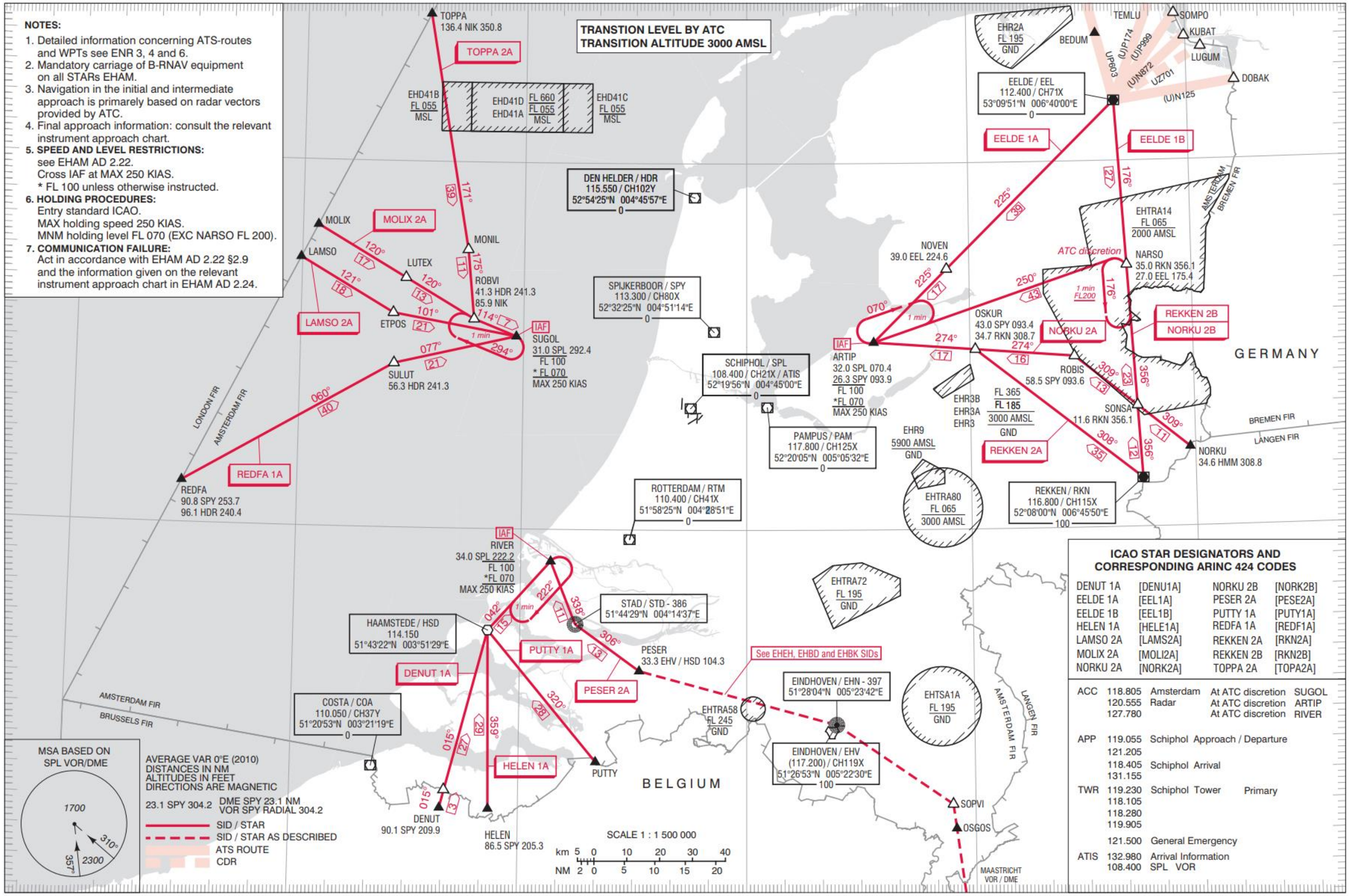
Now, near the end of my graduation period with the KDC I have been doing additional research with regards to a trial that will be performed on cross-border arrival management, the initial subject for my thesis. With that we have come full circle.

Appendix II Standard instrument arrival and departure chart

Standard Instrument Departures (LVNL, 2018)



Standard Arrival Routes (LVNL, 2018)



NOTES:

1. Detailed information concerning ATS-routes and WPTs see ENR 3, 4 and 6.
2. Mandatory carriage of B-RNAV equipment on all STARs EHAM.
3. Navigation in the initial and intermediate approach is primarely based on radar vectors provided by ATC.
4. Final approach information: consult the relevant instrument approach chart.
5. **SPEED AND LEVEL RESTRICTIONS:**
   see EHAM AD 2.22.
   Cross IAF at MAX 250 KIAS.
   * FL 100 unless otherwise instructed.
6. **HOLDING PROCEDURES:**
   Entry standard ICAO.
   MAX holding speed 250 KIAS.
   MNM holding level FL 070 (EXC NARSO FL 200).
7. **COMMUNICATION FAILURE:**
   Act in accordance with EHAM AD 2.22 §2.9 and the information given on the relevant instrument approach chart in EHAM AD 2.24.

ICAO STAR DESIGNATORS AND CORRESPONDING ARINC 424 CODES

DENUT 1A	[DENU1A]	NORKU 2B	[NORK2B]
EELDE 1A	[EEL1A]	PESER 2A	[PESE2A]
EELDE 1B	[EEL1B]	PUTTY 1A	[PUTY1A]
HELEN 1A	[HELE1A]	REDFA 1A	[REDF1A]
LAMSO 2A	[LAMS2A]	REKKEN 2A	[RKN2A]
MOLIX 2A	[MOLI2A]	REKKEN 2B	[RKN2B]
NORKU 2A	[NORK2A]	TOPPA 2A	[TOPA2A]

ACC	118.805	Amsterdam	At ATC discretion	SUGOL
	120.555	Radar	At ATC discretion	ARTIP
	127.780		At ATC discretion	RIVER
APP	119.055	Schiphol Approach / Departure		
	121.205			
	118.405	Schiphol Arrival		
	131.155			
TWR	119.230	Schiphol Tower	Primary	
	118.105			
	118.280			
	119.905			
	121.500	General Emergency		
ATIS	132.980	Arrival Information		
	108.400	SPL VOR		

Appendix III *Letters of Agreement*

Maastricht UAC

- General agreements
    - Amsterdam ACC and Maastricht UAC are allowed to hand traffic over without verbal coordination, if the distance between flights on parallel tracks is and remains 5 NM, or if this distance increases. The centre handing the traffic over instructs the pilot to report the assigned heading upon initial radio contact with the receiving centre. Flights are vectored parallel to the ATS-route.
    - Amsterdam ACC and Maastricht UAC ensure flights do not deviate more than 2,5 NM from the ATS-route, unless flights are handed over on parallel tracks.
    - FL 250 can only be used in the Amsterdam for flights going from Amsterdam ACC to Maastricht UAC.

Hand-over conditions Jever sector

Amsterdam ACC hands flights over to the Jever sector in accordance with the following hand-over conditions.

Via sector	**Route**	**COP**	**Hand-over altitude**	**Crossing conditions for outbounds Amsterdam FIR**	**Special conditions**
1	UN873, UP603, UZ700	BEDUM	FL 250	-	• Amsterdam ACC clears outbounds EHRD in the SPY/PAM area only to FL 250 after verbal approval from the Delta sector. • Amsterdam ACC clears flights via UN125 that are handed over by Bremen ACC, only to FL 250 after verbal approval from the Delta sector.
	UM105, UN125	EEL	FL 250	-	
	UZ708	AGISU	FL 250	AGISU FL 250 or higher	
	UZ733	KONOM	FL 250		

Hand-over conditions Munster and Ruhr sectors

Amsterdam ACC hands flights over to the Munster or Ruhr sector in accordance with the following hand-over conditions.

Via sector	Route	COP	Hand-over altitude	Crossing conditions for outbounds Amsterdam FIR	Special conditions
2	UL620	SONEB	FL 250	• SONEB: FL 210 or higher • OLDOD: FL 250 or higher	
	UZ738	NAPRO	FL 250	• EDUPO: FL 150 or higher • DEPAD: FL 210 or higher • AMOSU: FL 250 or higher	

Hand-over conditions Delta sector

Amsterdam ACC hands flights over to the Delta sector in accordance with the following hand-over conditions.

Via sector	Route	COP	Hand-over altitude	Crossing conditions for outbounds Amsterdam FIR	Special conditions
1,2	UL980, UN872	PAM	FL 250	-	Amsterdam ACC clears outbounds EHGG only via PAM to FL 250 after verbal approval from the Delta sector.
1,3	UN125, UN873 and SID's from EHGG via SPY	SPY	FL 250	-	
2	UL602, UP64	TENLI	FL 250	-	Amsterdam ACC clears outbounds Langen FIR, which enters the Delta sector via RKN, SONEB or on a direct routing, only to FL 250 upon passing the common ATC boundary.
3	SID's from EHBD and EHEH via HSD	HSD	FL 250	-	
	UT601	OKIDU	FL 250	-	
	UN873	STD		-	Amsterdam ACC clears outbounds Brussels FIR only to FL 250 after passing the common ATC boundary.
4	UL620	TULIP	FL 250	-	
5	UM90	ODASI	FL 250	-	

Hand-over conditions Nicky and Olno sectors

Amsterdam ACC hands flights over to the Nicky or Olno sector in accordance with the following hand-over conditions.

Via sector	Route	COP	Hand-over altitude	Crossing conditions for outbounds Amsterdam FIR	Special conditions
3	UN872	WOODY	FL 260	• WOODY: FL 240 or higher; • 5 NM DME north of NIK: FL 260 or higher If unable to comply, see hand-over conditions with Brussels.	• Amsterdam ACC ensures that outbounds from the Amsterdam FIR with a RCL above FL 245 cross HSD radial 090 at FL250 or lower. • Maastricht UAC Delta sector coordinates overflying GAT- and OAT-flights at FL 260 south of HSD radial 090 with sector 3.
	UN852	BROGY	FL 250	• VELED: FL 250 or higher If unable to comply, see hand-over conditions with Brussels.	-

Bremen ACC

- Hand-over conditions

  Amsterdam ACC hands flights over to the Bremen ACC in accordance with the following hand-over conditions.

Via sector	Route	COP	Hand-over altitude	Crossing conditions for outbounds Amsterdam FIR	Special conditions
1	(U)N873	BEDUM	FL 070 – FL 230	-	Bremen ACC is allowed to deviate from the route under the following conditions: • The flight has passed EEL/BEDUM, and • The flight stays within an area within: ○ 2,5 NM north of the line BEDUM – JUIST ○ 2,5 NM south of line EEL – DOBAK.
	(U)M105, (U)N125	EEL	FL 070 – FL 230	-	

Langen ACC

- Hand-over conditions

  Amsterdam ACC hands flights over to the Langen ACC in accordance with the following hand-over conditions.

Via sector	Route	COP	Hand-over altitude	Crossing conditions for outbounds Amsterdam FIR	Special conditions
2	((U)L620, Z841	SONEB	FL 110 –FL 130 FL 170 – FL 230	-	Inbounds EDDK, EDLP, or EDLW: • At or descending to FL 210. • Flights are released for descent to FL 180. Inbounds EDDG: • At FL 110
	(U)T196, (U)P62	TEBRO	FL 110 – FL 170	-	Inbounds EDDL, EDLN and EDLV: • At or descending to FL 170. • Flights are released for descent. • Flights are released for right turns.
	(U)Z738, Z739, T150	NAPRO	FL 110 – FL 230 FL 110 – FL 190 only for inbounds EDDF, EDFE, EDFH or ETOU	-	-
3	UT601	DIBIR	FL 110 FL 210 – FL 230	-	Inbounds EDDK, ETNG or ETNN: • At or descending to FL 110

Brussels ACC

- Hand-over conditions

Amsterdam ACC hands flights over to the Brussels ACC in accordance with the following hand-over conditions.

Via sector	Route	COP	Hand-over altitude	Crossing conditions for outbounds Amsterdam FIR	Special conditions*
3	UN852	BROGY	FL 210 – FL 230	-	• South of HSD radial 090 released for climb. • VELED at or above FL 200.
	(U)N872, (U)Z310	WOODY**	FL 070 – FL 230	Outbounds Amsterdam FIR: • At or climb to FL 090 – FL 230. • If RCL > 185: WOODY at or above FL 190. South of HSD radial 090 released for climb.	Inbounds Brussels TMA (except EBAW): • At or descending to FL 150 or FL 170 (or RCL if lower). • WOODY at or below FL 180. • Released for descent to FL 110. Inbounds EBAW: • At or descending to FL 070. • WOODY at or below FL 090. • Released for descent. • Cleared via WOODY – ANT.
	(U)Z310	WOODY**	FL 070 – FL 230	-	Inbounds Lille group (LFAV, LFQI, LFQO, LFQQ, LFQT): • At FL 210 or FL 230. • Released for descent to FL 110.
	Z311	BEKEM	FL 150	-	Inbounds Brussels TMA: • Released for descent to FL 110.
	Inbounds EBOS	COA	FL 070	-	• At or descending to FL 070. • COA at or below FL 090. • Released for descent.

* All flights above FL 095 are released for left turns, as long as remain west of the line which corresponds to the border between the Amsterdam CTA South 2 and the nieuw Milligen TMA D and/or EHTRA12 (except for flights via UN82).
** Transfer of control to Brussels ACC takes place at WOODY for flights via (U)N872 and flights via (U)Z310.

The following applies in the case when an ACT message has already been sent to Maastricht UAC, for an outbound from the Amsterdam FIR via UN852 or UN872, but is unable to adhere to the published climb restriction:

- Amsterdam ACC sends an ACT messages at or climb to FL230 to Brussels ACC before the flight crosses HSD radial 090, and hands the flight withouth verbal coordination to Brussels ACC. The flight is released for climb.
- Amsterdam ACC informs Maastricht UAC that the flight will be handed over to Brussels ACC.

London AC

- Flight level revisions
  - If the RCL changes from above FL 215 (London AC) to below FL 215 (London TC after sending the ACT , Amsterdam ACC only coordinates with London TC.
  - If the RCL changes from below FL 215 (London TC) to above FL 215 (London AC) after sending the ACT, Amsterdam ACC only coordinates with London AC.
- Hand-over on parallel tracks
  - Amsterdam ACC and London AC are allowed to hand traffic over without verbal coordination, if the distance between flights on parallel tracks is and remains 5 NM, or if this distance increases. The centre handing the traffic over instructs to pilot to report the assigned heading upon initial radio contact with the receiving centre.
  - Amsterdam ACC ensures flights via GORLO enter the REFSO A area no further than 5 NM west of GORLO. Amsterdam ACC assigns tracks such that the tracks point towards PEVAD or REFSO.
  - Amsterdam ACC vectors flights via MIMVA or KOLAG not north of MIMVA or south of RAVLO. Amsterdam ACC assigns tracks such that the tracks run parallel to the (U)L602.
  - London AC vectors flights via LAMSO no more than 2,5NM south of LAMSO or 5 NM north of LAMSO. London AC assigns tracks such as they are around 110°.
  - London AC vectors flights via REDFA no more than 5 NM north or south of REDFA. London AC chooses tracks such as they are around 065°.
- Hand-over conditions

  Amsterdam ACC hands flights over to the London AC in accordance with the following hand-over conditions.

Via sector	Route	COP	Hand-over altitude	Crossing conditions for outbounds Amsterdam FIR	Special conditions
4	(U)Z291, (U)L980	REFSO	FL 220 – FL 240	-	• Flights at or climbing to FL 240 with a RCL above FL 245 are released for climb. • Flights are released for turns, provided that: - Flight are not vectored north of (U)M20; and - Flights remain at least 2,5 NM clear of sector 3.
	(U)M20	PEVAD	FL 220 – FL 240	-	
5	(U)L602	MIMVA	FL 240	-	• Flights shall cross MIMVA or KOLAG at or above FL 180. • Amsterdam ACC achieves transfer of communication to ensures the western boundary of the MOLIX area can be crossed at or above FL 250. • Flights at or climbing to FL 240 with a RCL above FL 245 are released for climb. Inbounds EGSH: • After KOLAG released for descent.
	(U)L60	KOLAG	FL 180 – FL 240	-	

London TC

- General agreements
- Flight level revisions
  - If the RCL changes from above FL 215 (London AC) to below FL 215 (London TC after sending the ACT , Amsterdam ACC only coordinates with London TC.
  - If the RCL changes from below FL 215 (London TC) to above FL 215 (London AC) after sending the ACT, Amsterdam ACC only coordinates with London AC.
- Hand-over on parallel tracks
  - Amsterdam ACC and London TC are allowed to hand traffic over without verbal coordination, if the distance between flights on parallel tracks is and remains 5 NM, or if this distance increases. The centre handing the traffic over instructs the pilot to report the assigned heading upon initial radio contact with the receiving centre.
  - Amsterdam ACC ensures flights via GORLO enter the REFSO A area no further than 5 NM west of GORLO. Amsterdam ACC assigns tracks such that the tracks point towards PEVAD or REFSO.
  - London TC vectors flights via REDFA no more than 5 NM north or south of REDFA. London AC chooses tracks such as they are around 065°.

- Hand-over conditions

  Amsterdam ACC hands flights over to the London AC in accordance with the following hand-over conditions.

Via sector	Route	COP	Hand-over altitude	Crossing conditions for outbounds Amsterdam FIR	Special conditions
4	(U)M20	PEVAD	FL 120 – FL 200	-	• Flights are released for turns, provided that: - Flight are not vectored north of (U)M20; and - Flights remain at least 2,5 NM clear of sector 3.
	(U)L980	REFSO	FL 080 – FL 200	-	

Scottish AC

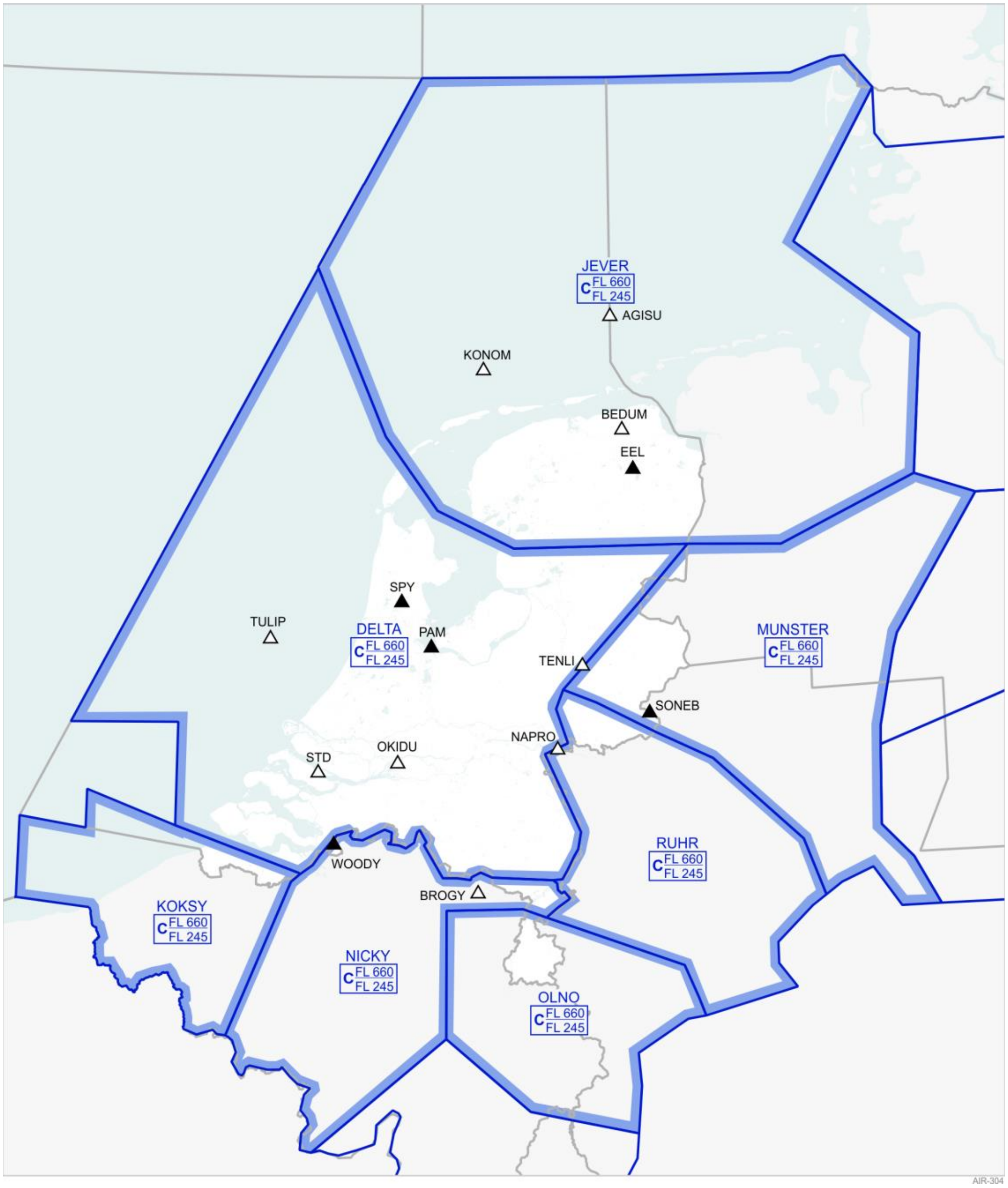
- Hand-over conditions

  Amsterdam ACC hands flights over to the Bremen ACC in accordance with the following hand-over conditions.

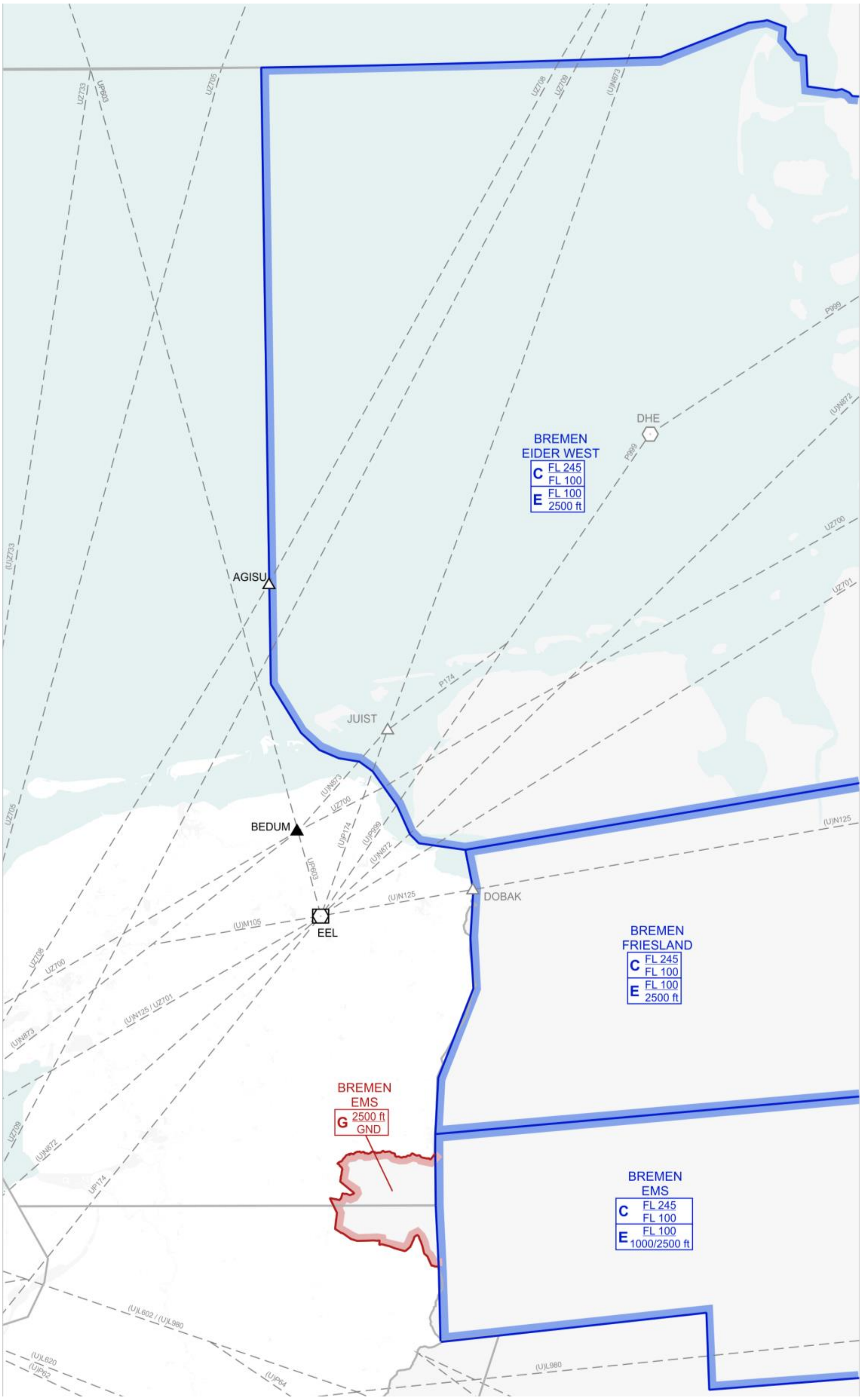
Via sector	**Route**	**COP**	**Hand-over altitude**	**Crossing conditions for outbounds Amsterdam FIR**	**Special conditions**
5	(U)P1, (U)M981	GODOS	FL 240	-	• Flight shall cross GODOS at or above FL 180. • Flight via (U)P1 shall cross ROKAN at FL 240 • Flights via (U)M981 are handed over accordingly to ensure ROXAT can be crossed at or above FL 250. • Flights with RCL above FL 245 climbing to FL 240 are released for climb.

Appendix IV Coordination Exit Points

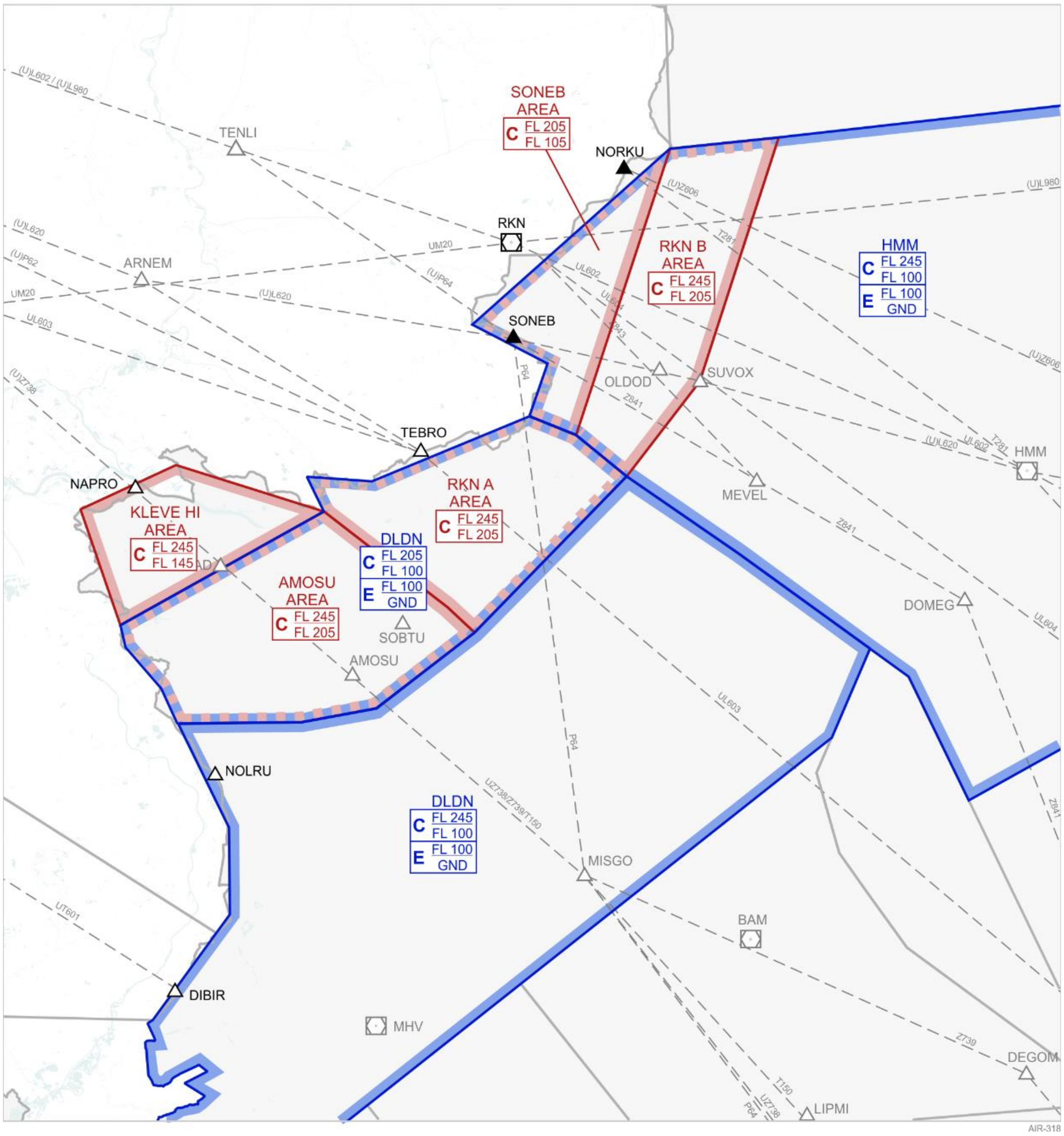
Maastricht UAC



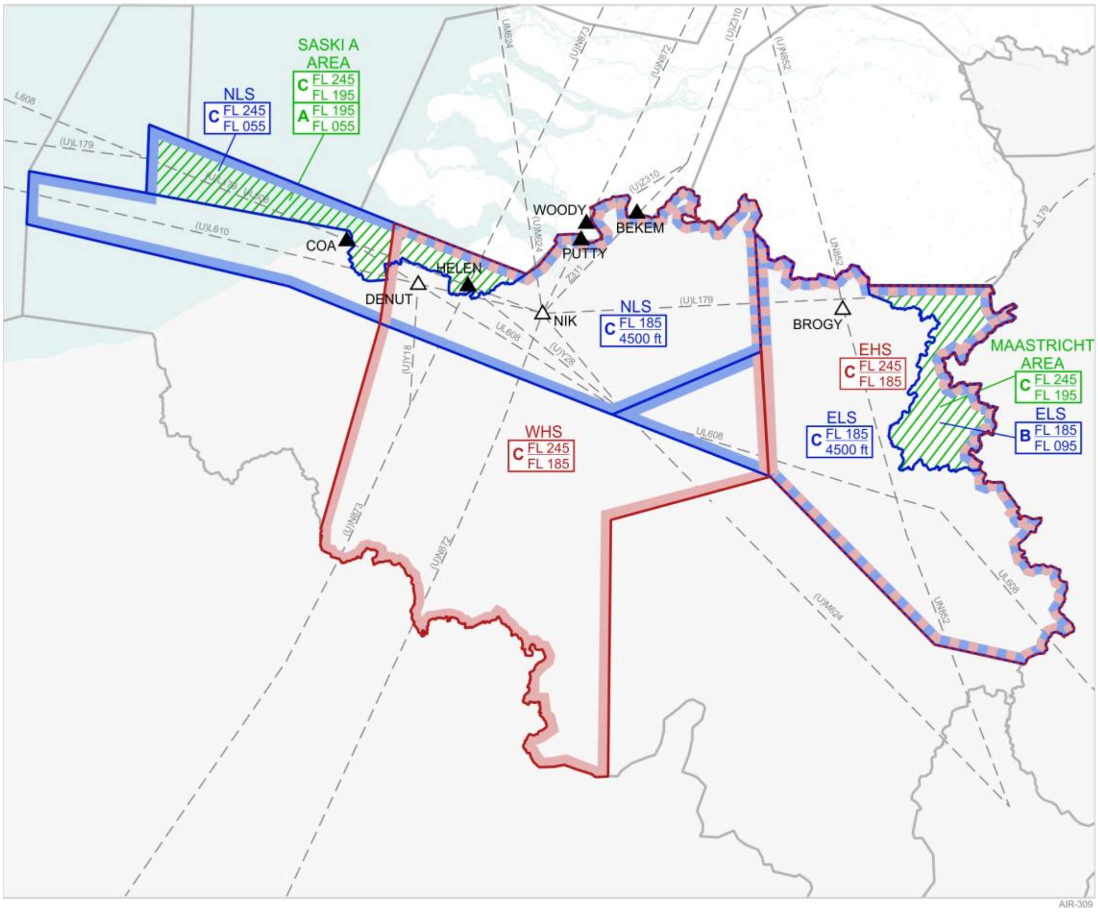
Bremen ACC


BREMEN
EIDER WEST
C FL 245
FL 100
E FL 100
2500 ft
DHE
BREMEN
FRIESLAND
C FL 245
FL 100
E FL 100
2500 ft
BREMEN
EMS
G 2500 ft
GND
BREMEN
EMS
C FL 245
FL 100
E FL 100
1000/2500 ft
AGISU
JUIST
BEDUM
EEL
DOBAK
UZ733
UP603
UZ705
UZ708
UZ709
(U)N873
P999
(U)N872
UZ700
UZ701
P174
(U)UZ733
(U)N125
(U)M105
(U)N125 / UZ701
UP174
(U)P999
(U)L602 / (U)L980
(U)L620
(U)P62
(U)P64
(U)L980

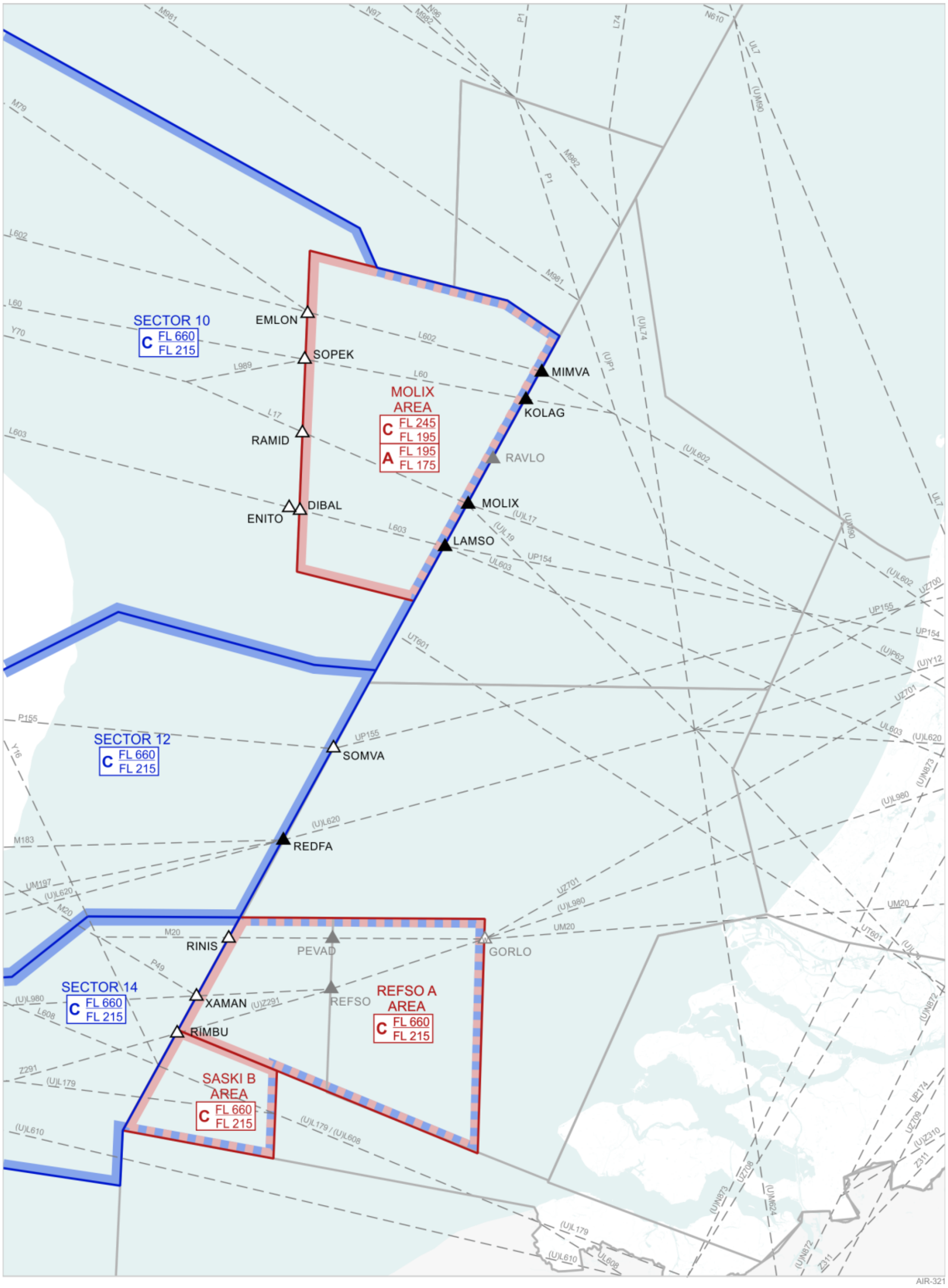
Langen ACC


SONEB AREA
C FL 205 FL 105
NORKU
TENLI
(U)L602 / (U)L980
RKN
ARNEM
(U)L620
(U)P62
UM20
UL603
(U)Z738
UM20
(U)P64
(U)L620
SONEB
RKN B AREA
C FL 245 FL 205
(U)Z606
(U)L980
T281
UL602
HMM
C FL 245 FL 100
E FL 100 GND
OLDOD
SUVOX
Z841
P64
TEBRO
NAPRO
KLEVE HI AREA
C FL 245 FL 145
RKN A AREA
C FL 245 FL 205
DLDN
C FL 205 FL 100
E FL 100 GND
AMOSU AREA
C FL 245 FL 205
SOBTU
AMOSU
MEVEL
HMM
DOMEG
UL604
UL603
NOLRU
DLDN
C FL 245 FL 100
E FL 100 GND
UZ738/Z739/T150
MISGO
BAM
UT601
DIBIR
MHV
Z739
DEGOM
T150
UZ738
P64
LIPMI
Z841
AIR-318

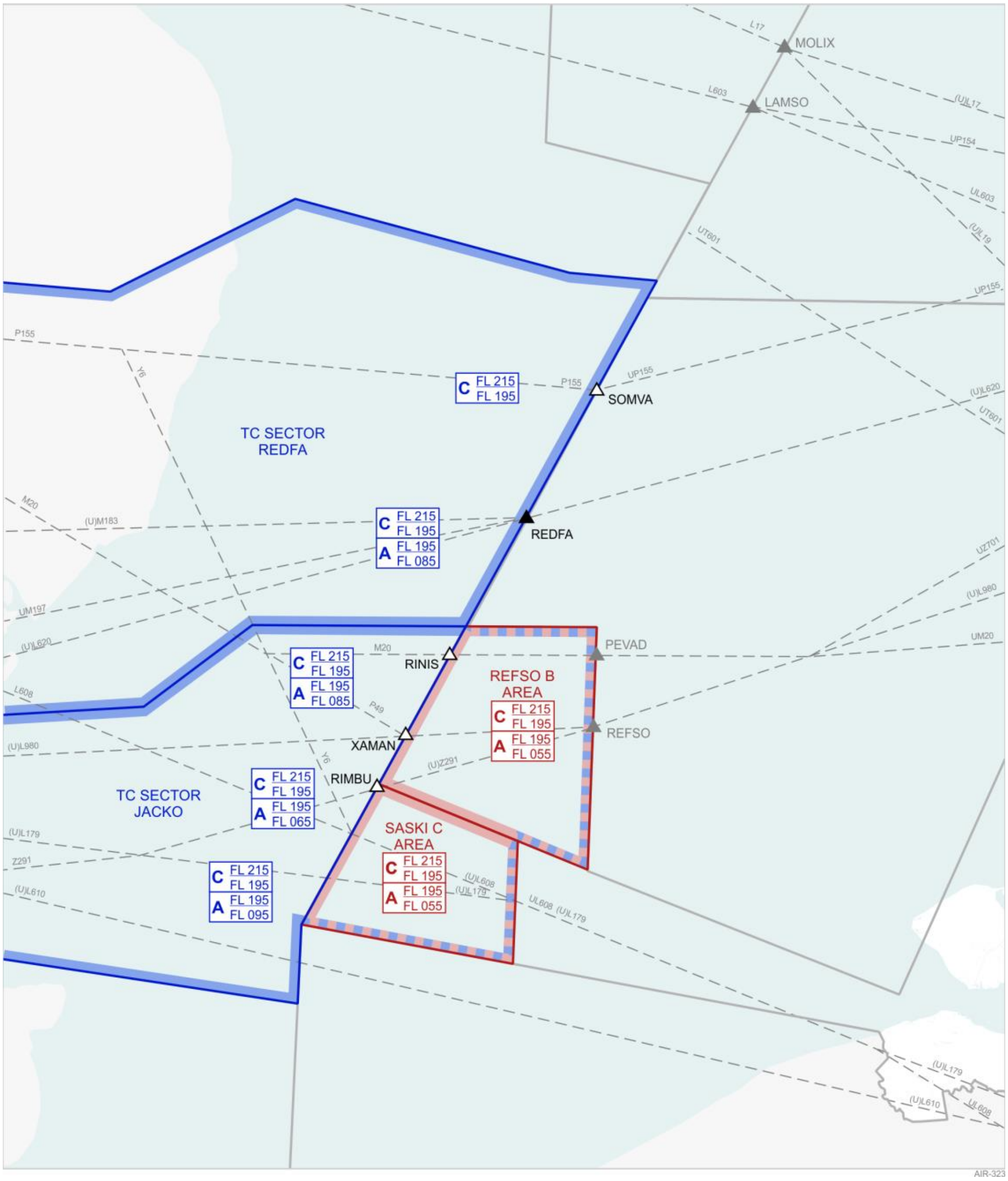
Brussels ACC



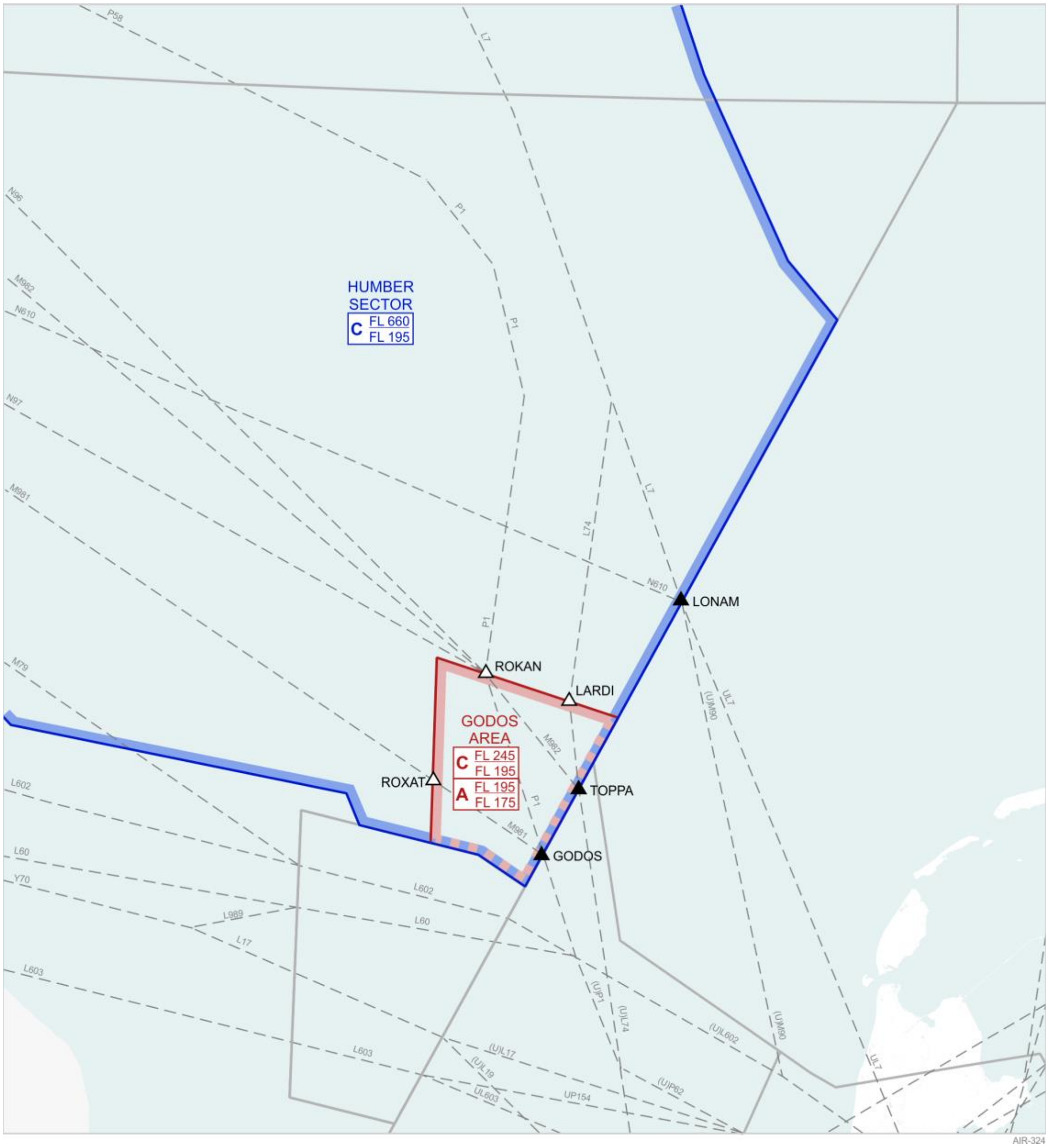
London AC


SECTOR 10
C FL 660 FL 215
EMLON
SOPEK
RAMID
ENITO
DIBAL
MOLIX AREA
C FL 245 FL 195
A FL 195 FL 175
MIMVA
KOLAG
RAVLO
MOLIX
LAMSO
SECTOR 12
C FL 660 FL 215
SOMVA
REDFA
RINIS
PEVAD
GORLO
SECTOR 14
C FL 660 FL 215
XAMAN
REFSO
REFSO A AREA
C FL 660 FL 215
RIMBU
SASKI B AREA
C FL 660 FL 215
M981
N97
M982
N96
P1
L74
N610
UL7
(U)M90
M79
L602
L60
Y70
L989
L17
L603
(U)L74
(U)P1
(U)L602
(U)L17
(U)L19
UP154
(U)L603
UP155
(U)Y12
(U)P62
UZ700
UZ701
UT601
UL603
(U)L620
(U)N873
(U)L980
UM20
P155
Y6
M183
UM197
M20
P49
L608
(U)Z291
Z291
(U)L179
(U)L610
(U)L179 / (U)L608
(U)N872
UP174
UZ709
(U)Z310
Z311
(U)M624
UZ708
AIR-321

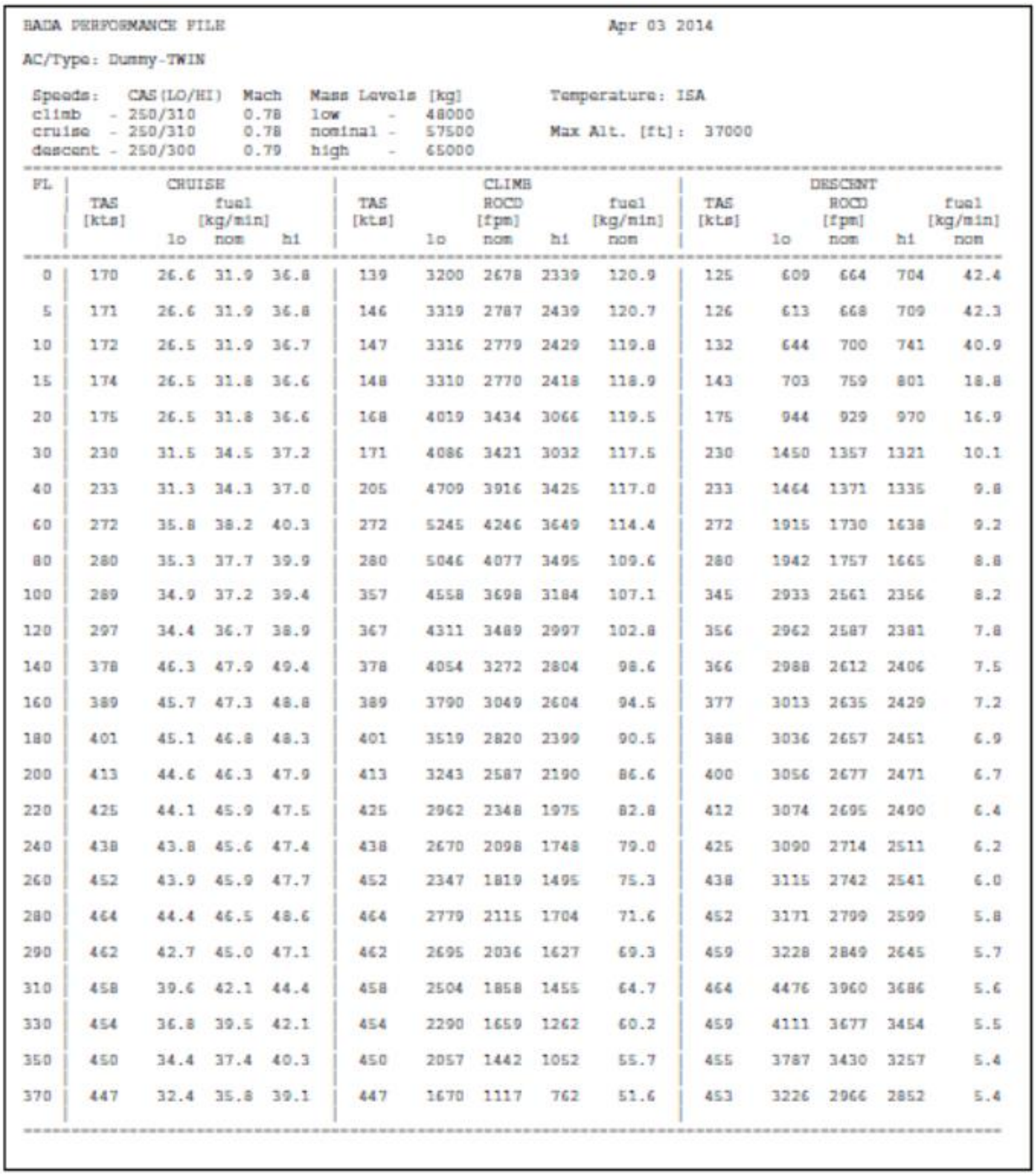
London TC


L17
MOLIX
L603
LAMSO
(U)L17
UP154
UL603
(U)L19
UT601
UP155
P155
Y6
C FL 215 FL 195
P155
UP155
SOMVA
(U)L620
UT601
TC SECTOR REDFA
M20
(U)M183
C FL 215 FL 195
A FL 195 FL 085
REDFA
UZ701
(U)L980
UM197
(U)L620
UM20
M20
C FL 215 FL 195
A FL 195 FL 085
RINIS
PEVAD
REFSO B AREA
C FL 215 FL 195
A FL 195 FL 055
L608
P49
XAMAN
REFSO
(U)L980
Y6
(U)Z291
RIMBU
C FL 215 FL 195
A FL 195 FL 065
TC SECTOR JACKO
SASKI C AREA
C FL 215 FL 195
A FL 195 FL 055
(U)L179
Z291
C FL 215 FL 195
A FL 195 FL 095
(U)L610
(U)L608
(U)L179
UL608
(U)L179
(U)L179
(U)L610
UL608
AIR-323

Scottish AC


HUMBER SECTOR
C FL 660 FL 195
GODOS AREA
C FL 245 FL 195
A FL 195 FL 175
ROKAN
LARDI
LONAM
ROXAT
TOPPA
GODOS
P58
L7
P1
N96
M982
N610
N97
M981
M70
L74
ULT
(U)M90
L602
L60
Y70
L989
L17
L603
(U)P1
(U)L74
(U)L602
(U)M90
(U)L17
(U)L19
UL603
UP154
(U)P62
AIR-324

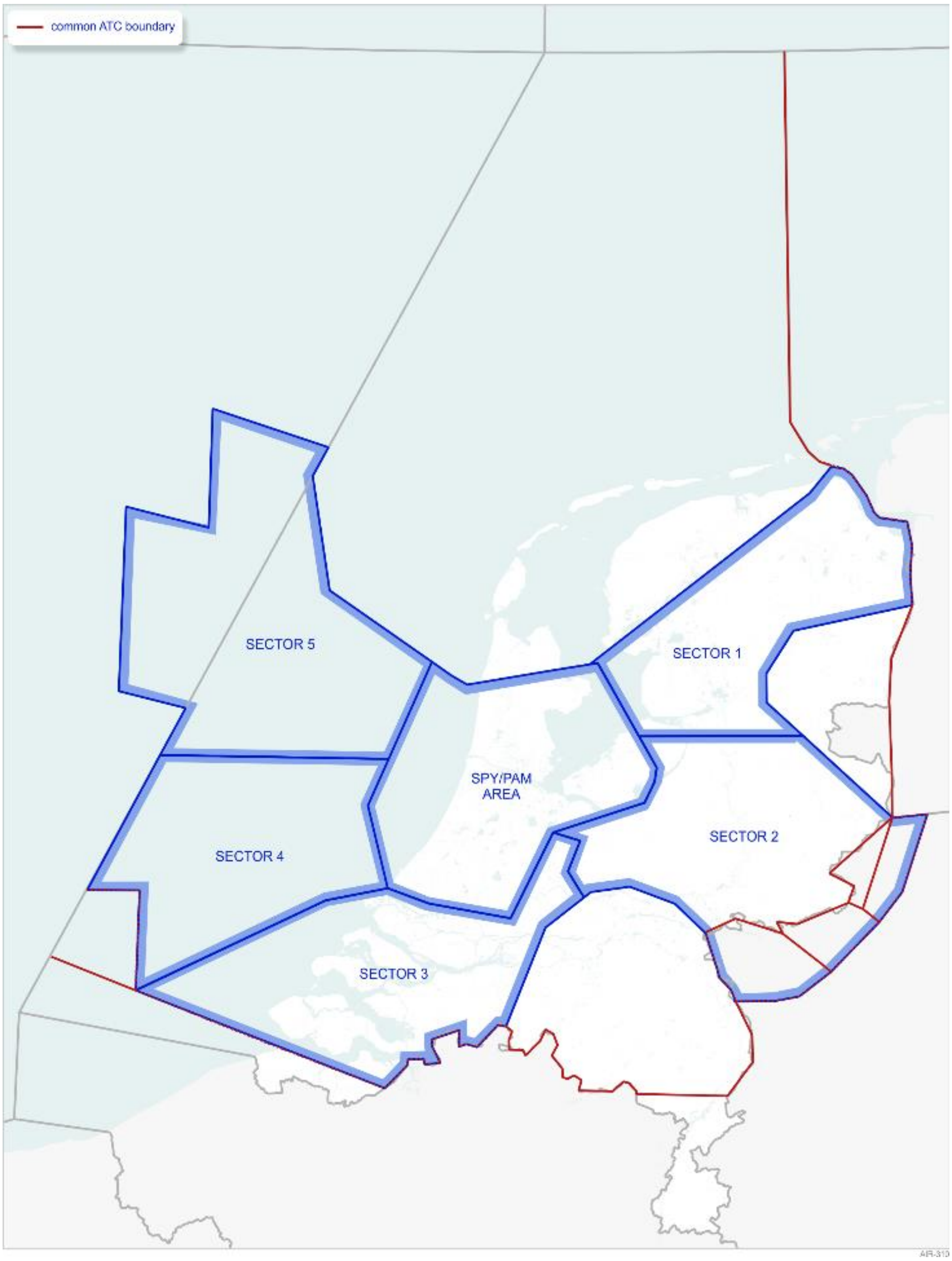
Appendix V BADA Performance table example



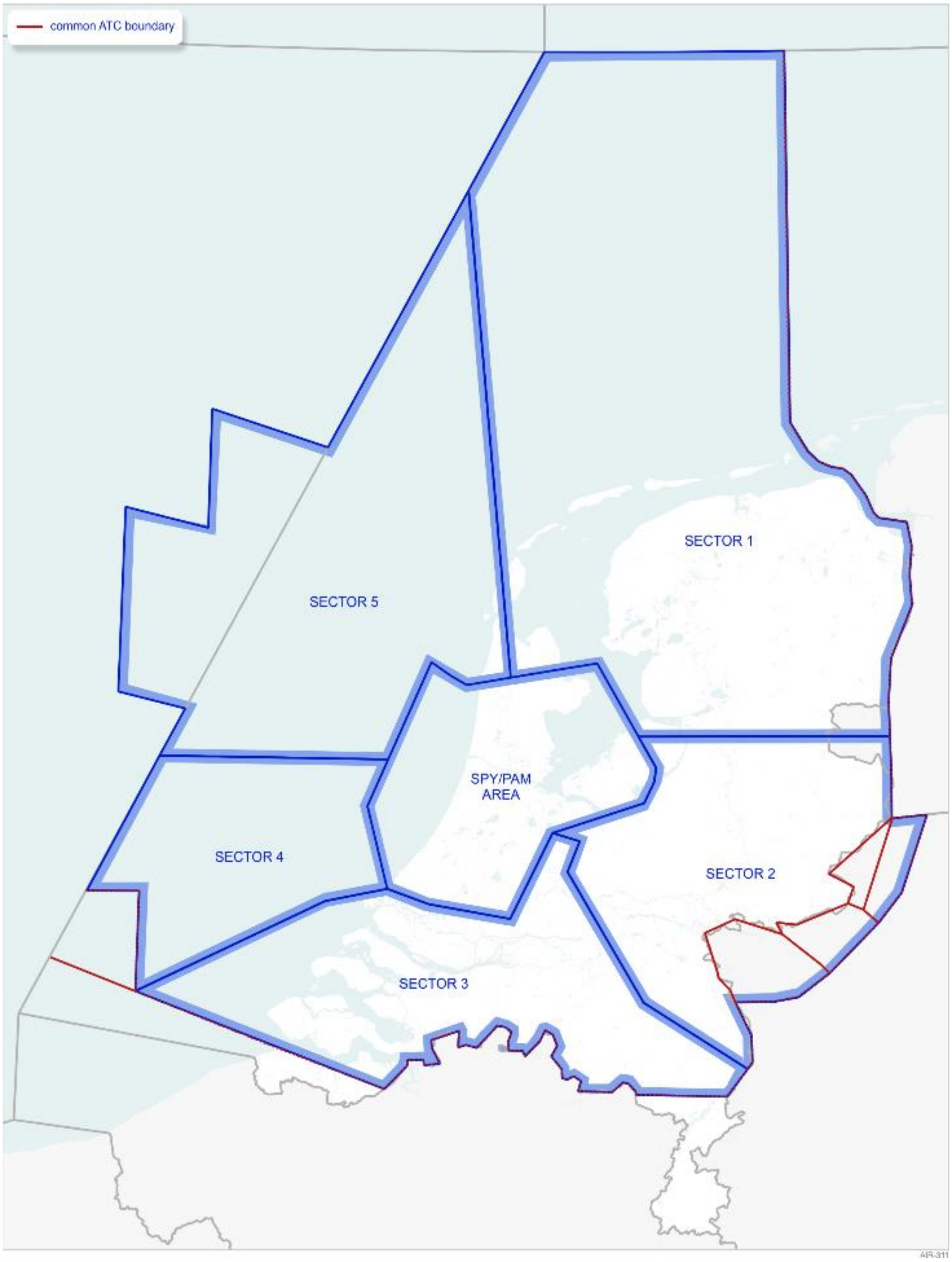
```
BADA PERFORMANCE FILE                                        Apr 03 2014

AC/Type: Dummy-TWIN

 Speeds:   CAS(LO/HI)  Mach   Mass Levels [kg]         Temperature: ISA
 climb   - 250/310     0.78   low     -  48000
 cruise  - 250/310     0.78   nominal -  57500         Max Alt. [ft]:  37000
 descent - 250/300     0.79   high    -  65000
==============================================================================
 FL |          CRUISE         |              CLIMB              |              DESCENT
    |  TAS          fuel      |  TAS          ROCD         fuel |  TAS          ROCD          fuel
    | [kts]      [kg/min]     | [kts]         [fpm]    [kg/min] | [kts]         [fpm]       [kg/min]
    |          lo   nom   hi  |          lo   nom   hi     nom  |          lo   nom   hi      nom
==============================================================================
  0 |  170   26.6  31.9  36.8 |  139   3200  2678  2339  120.9 |  125    609   664   704    42.4
    |                         |                                |
  5 |  171   26.6  31.9  36.8 |  146   3319  2787  2439  120.7 |  126    613   668   709    42.3
    |                         |                                |
 10 |  172   26.5  31.9  36.7 |  147   3316  2779  2429  119.8 |  132    644   700   741    40.9
    |                         |                                |
 15 |  174   26.5  31.8  36.6 |  148   3310  2770  2418  118.9 |  143    703   759   801    18.8
    |                         |                                |
 20 |  175   26.5  31.8  36.6 |  168   4019  3434  3066  119.5 |  175    944   929   970    16.9
    |                         |                                |
 30 |  230   31.5  34.5  37.2 |  171   4086  3421  3032  117.5 |  230   1450  1357  1321    10.1
    |                         |                                |
 40 |  233   31.3  34.3  37.0 |  205   4709  3916  3425  117.0 |  233   1464  1371  1335     9.8
    |                         |                                |
 60 |  272   35.8  38.2  40.3 |  272   5245  4246  3649  114.4 |  272   1915  1730  1638     9.2
    |                         |                                |
 80 |  280   35.3  37.7  39.9 |  280   5046  4077  3495  109.6 |  280   1942  1757  1665     8.8
    |                         |                                |
100 |  289   34.9  37.2  39.4 |  357   4558  3698  3184  107.1 |  345   2933  2561  2356     8.2
    |                         |                                |
120 |  297   34.4  36.7  38.9 |  367   4311  3489  2997  102.8 |  356   2962  2587  2381     7.8
    |                         |                                |
140 |  378   46.3  47.9  49.4 |  378   4054  3272  2804   98.6 |  366   2988  2612  2406     7.5
    |                         |                                |
160 |  389   45.7  47.3  48.8 |  389   3790  3049  2604   94.5 |  377   3013  2635  2429     7.2
    |                         |                                |
180 |  401   45.1  46.8  48.3 |  401   3519  2820  2399   90.5 |  388   3036  2657  2451     6.9
    |                         |                                |
200 |  413   44.6  46.3  47.9 |  413   3243  2587  2190   86.6 |  400   3056  2677  2471     6.7
    |                         |                                |
220 |  425   44.1  45.9  47.5 |  425   2962  2348  1975   82.8 |  412   3074  2695  2490     6.4
    |                         |                                |
240 |  438   43.8  45.6  47.4 |  438   2670  2098  1748   79.0 |  425   3090  2714  2511     6.2
    |                         |                                |
260 |  452   43.9  45.9  47.7 |  452   2347  1819  1495   75.3 |  438   3115  2742  2541     6.0
    |                         |                                |
280 |  464   44.4  46.5  48.6 |  464   2779  2115  1704   71.6 |  452   3171  2799  2599     5.8
    |                         |                                |
290 |  462   42.7  45.0  47.1 |  462   2695  2036  1627   69.3 |  459   3228  2849  2645     5.7
    |                         |                                |
310 |  458   39.6  42.1  44.4 |  458   2504  1858  1455   64.7 |  464   4476  3960  3686     5.6
    |                         |                                |
330 |  454   36.8  39.5  42.1 |  454   2290  1659  1262   60.2 |  459   4111  3677  3454     5.5
    |                         |                                |
350 |  450   34.4  37.4  40.3 |  450   2057  1442  1052   55.7 |  455   3787  3430  3257     5.4
    |                         |                                |
370 |  447   32.4  35.8  39.1 |  447   1670  1117   762   51.6 |  453   3226  2966  2852     5.4
    |                         |                                |
==============================================================================
```

Appendix VI ACC sectors

Normal operations sectors



Reduced coordination sectors outside military operating hours.



Appendix VII Mathematica code

```
(*Import data files*)
SetDirectory[NotebookDirectory[]];
test=Array[trackData, 31]; trackData[1] =
  Import["Data Feb and Jul/20170701.tracks.txt.gz","Table","FieldSeparators"→";"];
trackData[2] =Import["Data Feb and Jul/20170702.tracks.txt.gz",
   "Table", "FieldSeparators"→";"];
trackData[3] =Import["Data Feb and Jul/20170703.tracks.txt.gz", "Table",
   "FieldSeparators"→";"];
trackData[4] =Import["Data Feb and Jul/20170704.tracks.txt.gz", "Table",
   "FieldSeparators"→";"];
trackData[5] =Import["Data Feb and Jul/20170705.tracks.txt.gz", "Table",
   "FieldSeparators"→";"];
trackData[6] =Import["Data Feb and Jul/20170706.tracks.txt.gz", "Table",
   "FieldSeparators"→";"];
trackData[7] =Import["Data Feb and Jul/20170707.tracks.txt.gz", "Table",
   "FieldSeparators"→";"];
trackData[8] =Import["Data Feb and Jul/20170708.tracks.txt.gz", "Table",
   "FieldSeparators"→";"];
trackData[9] =Import["Data Feb and Jul/20170709.tracks.txt.gz", "Table",
   "FieldSeparators"→";"];
trackData[10] =Import["Data Feb and Jul/20170710.tracks.txt.gz", "Table",
   "FieldSeparators"→";"];
trackData[11] =Import["Data Feb and Jul/20170711.tracks.txt.gz", "Table",
   "FieldSeparators"→";"];
trackData[12] =Import["Data Feb and Jul/20170712.tracks.txt.gz", "Table",
   "FieldSeparators"→";"];
trackData[13] =Import["Data Feb and Jul/20170713.tracks.txt.gz", "Table",
   "FieldSeparators"→";"];
trackData[14] =Import["Data Feb and Jul/20170714.tracks.txt.gz", "Table",
   "FieldSeparators"→";"];
trackData[15] =Import["Data Feb and Jul/20170715.tracks.txt.gz", "Table",
   "FieldSeparators"→";"];
trackData[16] =Import["Data Feb and Jul/20170716.tracks.txt.gz", "Table",
   "FieldSeparators"→";"];
trackData[17] =Import["Data Feb and Jul/20170717.tracks.txt.gz", "Table",
   "FieldSeparators"→";"];
trackData[18] =Import["Data Feb and Jul/20170718.tracks.txt.gz", "Table",
   "FieldSeparators"→";"];
trackData[19] =Import["Data Feb and Jul/20170719.tracks.txt.gz", "Table",
   "FieldSeparators"→";"];
trackData[20] =Import["Data Feb and Jul/20170720.tracks.txt.gz", "Table",
   "FieldSeparators"→";"];
trackData[21] =Import["Data Feb and Jul/20170721.tracks.txt.gz", "Table",
   "FieldSeparators"→";"];
trackData[22] =Import["Data Feb and Jul/20170722.tracks.txt.gz", "Table",
   "FieldSeparators"→";"];
trackData[23] =Import["Data Feb and Jul/20170723.tracks.txt.gz", "Table",
   "FieldSeparators"→";"];
trackData[24] =Import["Data Feb and Jul/20170724.tracks.txt.gz", "Table",
   "FieldSeparators"→";"];
trackData[25] =Import["Data Feb and Jul/20170725.tracks.txt.gz", "Table",
   "FieldSeparators"→";"];
trackData[26] =Import["Data Feb and Jul/20170726.tracks.txt.gz", "Table",
   "FieldSeparators"→";"];
```

```
trackData[27] =Import["Data Feb and Jul/20170727.tracks.txt.gz",
   "Table",  "FieldSeparators"→";"];
trackData[28] =Import["Data Feb and Jul/20170728.tracks.txt.gz",
   "Table",  "FieldSeparators"→";"];
trackData[29] =Import["Data Feb and Jul/20170729.tracks.txt.gz",
   "Table",  "FieldSeparators"→";"];
trackData[30] =Import["Data Feb and Jul/20170730.tracks.txt.gz",
   "Table",  "FieldSeparators"→";"];
trackData[31] =Import["Data Feb and Jul/20170731.tracks.txt.gz",
   "Table",  "FieldSeparators"→";"];
trackdata=Join[trackData[1],  trackData[2],  trackData[3],  trackData[4],
   trackData[5],trackData[6],trackData[7],trackData[8],trackData[9],
   trackData[10],trackData[11],trackData[12],trackData[13],
   trackData[14],trackData[15],trackData[16],trackData[17],
   trackData[18], trackData[19], trackData[20], trackData[21], trackData[22],
   trackData[23], trackData[24], trackData[25], trackData[26], trackData[27],
   trackData[28],trackData[29],trackData[30],trackData[31]];
fpdata=Import["Data Feb and Jul/fpdata2017 02-07 with COPX.txt", "Data"];

(*Define position index for Flight Plans for one day*)
fpIndex= {1};
For[i=1, i<Length[fpdata], i++,
 If[fpdata[[i, 2]]≠fpdata[[i+1, 2]], AppendTo[fpIndex, i+1]
 ]
]
AppendTo[fpIndex,  Length[fpdata]];

(*Define position index for start of a day*)
dayIndex= {1};
For[i=1, i<31, i++,
 AppendTo[dayIndex,  dayIndex[[-1]]  +Length[trackData[i]]
  ];
]
AppendTo[dayIndex,  Length[trackdata]];

(*Define position index for start new flight*)
index= {1};
For[i=1, i<Length[trackdata], i++,
 If[trackdata[[i, 2]]≠trackdata[[i+1, 2]], AppendTo[index, i+1]
 ]
]
AppendTo[index,  Length[trackdata]];

(*define number of flights per day*)
dailyFlights= {1};
For[n=1, n≤31, n++,
 AppendTo[dailyFlights,  Flatten[Position[index,  dayIndex[[n+1]]]]]
]
dailyFlights=Flatten[dailyFlights];

(*define number of flights*)
amountflights=Length[index]  -1;

(*define reference point for Amsterdam*)
refpoint= {FromDMS[{52, 18, 29}], FromDMS[{4, 45, 41}]};
```

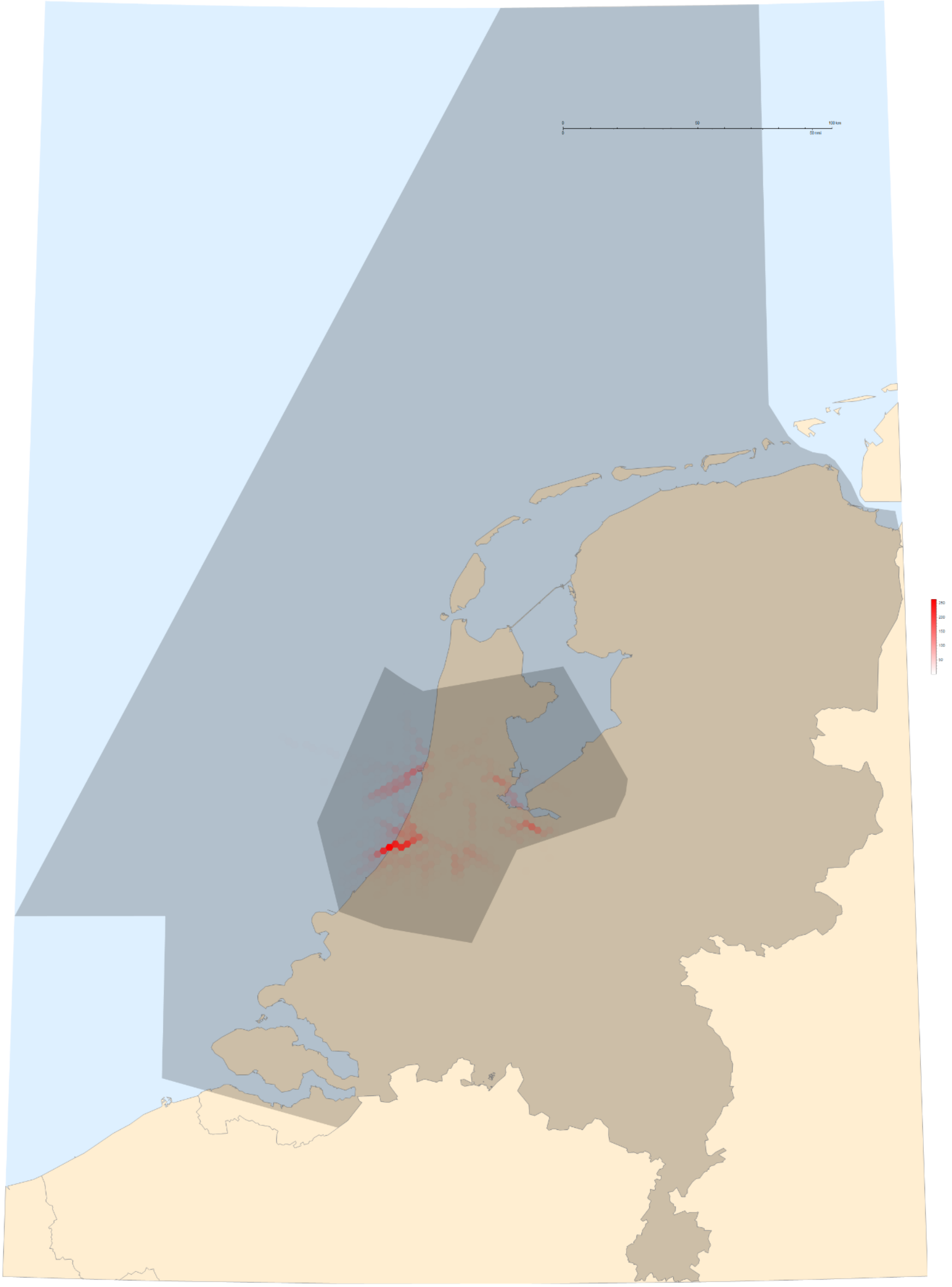
```
(*define Amsterdam FIR*)
amsterdamFIR=Join[{{FromDMS[{55, 0, 0}], FromDMS[{5, 0, 0}]},
    {FromDMS[{55, 0, 0}], FromDMS[{6, 30, 0}]},{FromDMS[{53, 40, 0}],
      FromDMS[{6, 30, 0}]},{FromDMS[{53, 33, 38}], FromDMS[{6, 36, 24}]},
     {FromDMS[{53, 31, 22}], FromDMS[{6, 40, 20}]},{FromDMS[{53, 30, 15}],
      FromDMS[{6, 44, 30}]},{FromDMS[{53, 29, 45}], FromDMS[{6, 48, 59}]},
     {FromDMS[{53, 28, 28}], FromDMS[{6, 51, 49}]},{FromDMS[{53, 23, 56}],
      FromDMS[{6, 56, 58}]},{FromDMS[{53, 20, 11}], FromDMS[{6, 59, 37}]},
    {FromDMS[{53, 19, 0}], FromDMS[{7, 1, 30}]},{FromDMS[{53, 18, 0}],
      FromDMS[{7, 11, 30}]},{FromDMS[{53, 12, 48}], FromDMS[{7, 13, 1}]}},
    Entity["Country","Netherlands"]["FullCoordinates"][[1,571;;860]],
    {{FromDMS[{50, 45, 15.44}], FromDMS[{6, 1, 15.63}]}},
    Entity["Country","Netherlands"]["FullCoordinates"][[1,861;;1064]],
   {{FromDMS[{51, 16, 10.20}], FromDMS[{4, 6, 50.72}]},
    {FromDMS[{51, 25, 30.89}], FromDMS[{3, 10, 18.61}]},
    {FromDMS[{51, 57, 56.44}], FromDMS[{3, 10, 18.61}]},
    {FromDMS[{51, 57, 02.16}], FromDMS[{2, 21, 22.62}]}}
  ];

(*Remove flight segments below FL270 or at RFL and remove flights
 without correlated flightplan to create valid index positions*)
flightIndex=Array[flightindex,  amountflights];
flightPlans=Array[flightplan,  amountflights];
k= {};
For[n=1, n≤31, n++,
 For[i=dailyFlights[[n]],  i<dailyFlights[[n+1]],  i++,
  If[MemberQ[fpdata[[fpIndex[[n+28]];;fpIndex[[n+29]]-1,4]],
     trackdata[[index[[i]], 2]]]==True,
   If[fpdata[[Flatten[Position[fpdata[[fpIndex[[n+28]];;  fpIndex[[n+29]]  -1,  4]],
            trackdata[[index[[i]],2]]]]+fpIndex[[n+28]]-1,-2]][[1]]>100&&
     StringMatchQ[fpdata[[Flatten[Position[fpdata[[fpIndex[[n+28]];;
                fpIndex[[n+29]]-1,4]],trackdata[[index[[i]],2]]]]+
           fpIndex[[n+28]] -1, 6]][[1]], "EH**"]==False,
    j=index[[i]] +64;
    callsign=trackdata[[index[[i]],  2]];
    rfl=
     fpdata[[Flatten[Position[fpdata[[fpIndex[[n+28]];;  fpIndex[[n+29]]  -1,  4]],
          callsign]]  +fpIndex[[n+28]]  -1,-2]][[1]];
    flightplan[i]   =fpdata[[Flatten[Position[fpdata[[fpIndex[[n+28]];;
             fpIndex[[n+29]]-1,4]],callsign]]+fpIndex[[n+28]]-1]][[1]];
    While[j<index[[i+1]],
     If[trackdata[[j,   5]]≥rfl-10||RegionMember[Polygon[amsterdamFIR],
         trackdata[[j,8;;9]]]==False,If[j==index[[i]],Break[],j=j-64;
       Break[]],
      j+=64]];
    While[j<index[[i+1]],
     If[trackdata[[j,   5]]≥rfl-10||RegionMember[Polygon[amsterdamFIR],
         trackdata[[j,8;;9]]]==False,If[j==index[[i]],Break[],j=j-32;
       Break[]],
      j+=32]];
    While[j<index[[i+1]],
     If[trackdata[[j,   5]]≥rfl-10||RegionMember[Polygon[amsterdamFIR],
         trackdata[[j, 8 ;; 9]]]==False, If[j==index[[i]], Break[], j=j-16;
       Break[]],
              j+=16]];
           While[j<index[[i+1]],
```

```
     If[trackdata[[j,  5]]≥rfl-10||RegionMember[Polygon[amsterdamFIR],
         trackdata[[j, 8 ;; 9]]]==False, If[j==index[[i]], Break[], j=j-8;
       Break[]],
      j+=8]];
    While[j<index[[i+1]],
     If[trackdata[[j,  5]]≥rfl-10||RegionMember[Polygon[amsterdamFIR],
         trackdata[[j, 8 ;; 9]]]==False, If[j==index[[i]], Break[], j=j-1;
       Break[]],
      j++]];
    flightindex[i] = {index[[i]], j},
    AppendTo[k,{i}];
    amountflights=amountflights-1
   ],
   AppendTo[k,{i}];  amountflights=amountflights-1
  ]
 ]
]

flightIndex=Delete[flightIndex,  k];
flightPlans=Delete[flightPlans,  k];

(*Create list of level segments for each flight*)
levelSegmentsIndex=Array[levelsegmentsindex,
amountflights]; For□i=1, i≤amountflights, i++,
 levelsegmentsindex[i] = {};
 For□j=flightIndex[[i, 1]] +4, j<flightIndex[[i, 2]], j++,
  If□□□trackdata[[j, 5]] -trackdata[[j-4, 5]]□ □20□*60≤3 &&
    55≤trackdata[[j,
   5]]≤263,
   startsegment=j-4;
   While□□□trackdata[[j, 5]] -trackdata[[j-4, 5]]□ □20□*60≤3,
    If[j+1==flightIndex[[i, 2]], Break[], j++]□;
   AppendTo[levelsegmentsindex[i], Range[startsegment, j]]□
 □
□


(*Create GeoPath for level segments longer than 0.5
 NM for each flight and shorter than 50 NM. Create list of
 level segments including length of segment and altitude*)
segmentPoints={};
segmentList=Array[segmentlist,
amountflights];
levelDistance=Array[leveldistance,  amountflights];
averageAltitude=Array[averagealtitude,  amountflights];
realSegmentIndex=Array[realsegmentindex,  amountflights];
For[i=1, i≤amountflights, i++,
 segmentlist[i] = {};
 leveldistance[i] = {};
 averagealtitude[i] = {};
 realsegmentindex[i] =
 {};
 For[j=1,  j<=Length[levelSegmentsIndex[[i]]],  j++,
  segmentpoints={};
  For[k=1, k<=Length[levelSegmentsIndex[[i, j]]], k++,
   AppendTo[segmentpoints, GeoPosition[{trackdata[[levelSegmentsIndex[[i, j, k]],
```

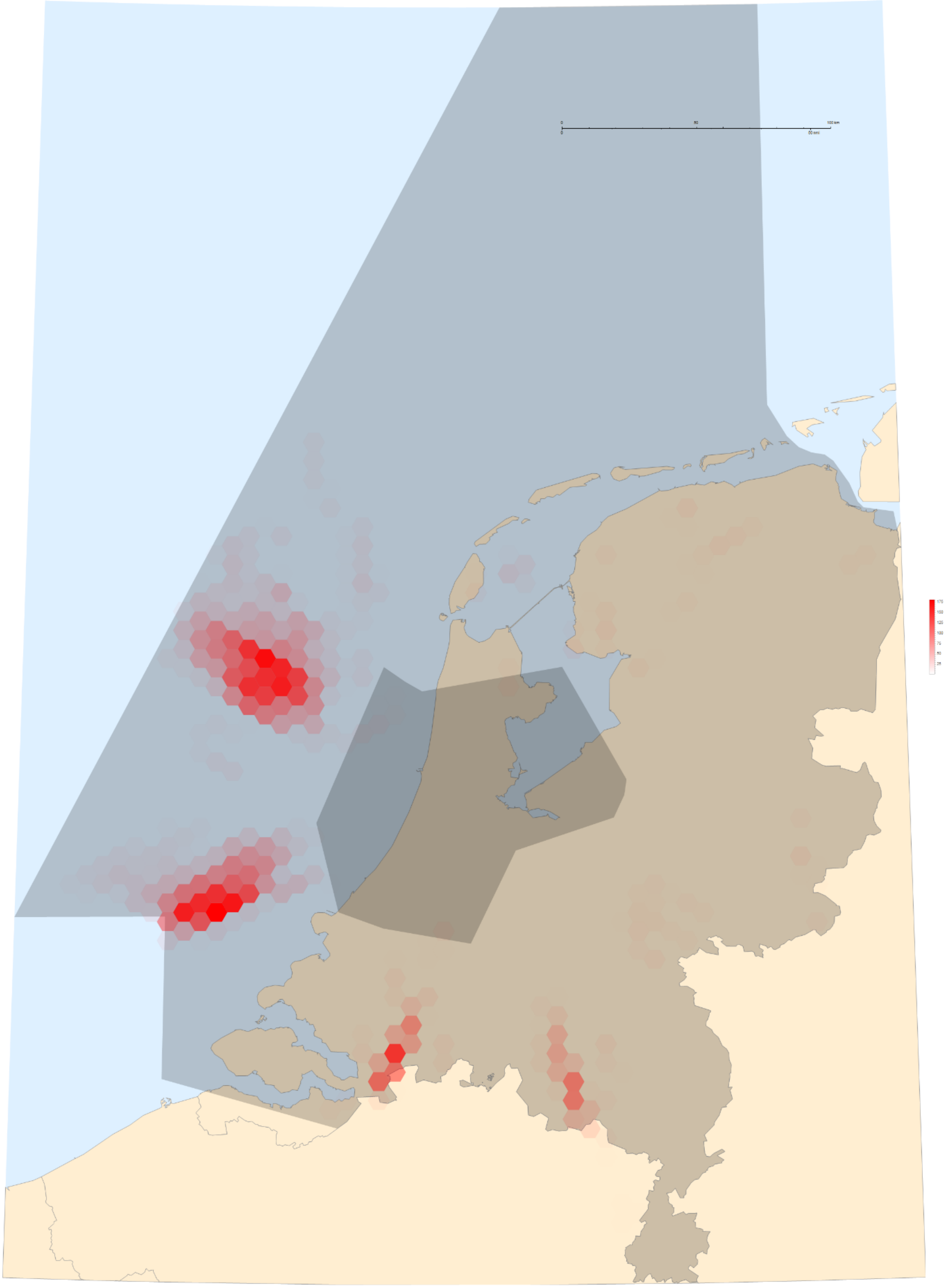
```
            8]], trackdata[[levelSegmentsIndex[[i,j,k]],9]],
          trackdata[[levelSegmentsIndex[[i,j,k]],5]]}]]


  ];
  If[Length[segmentpoints]≠0,
   AppendTo[realsegmentindex[i], levelSegmentsIndex[[i, j]]];
   AppendTo[segmentPoints, segmentpoints];
   AppendTo[segmentlist[i], GeoPath[segmentpoints]];
   AppendTo[leveldistance[i], QuantityMagnitude[
     UnitConvert[Total[GeoDistanceList[segmentpoints]], "NauticalMiles"]]];
   AppendTo[averagealtitude[i], Round[
     Mean[trackdata[[levelSegmentsIndex[[i,j]],5]]],10]];
  ]
 ]
]

(*Remove segments that don't reach requested cruise level*)
segmentPositions=Flatten[Position[levelDistance,{ },1]];

continueClimb={};
For[i=1,i≤Length[segmentPositions],i++,
 lastSegmentLevel=
  trackdata[[realSegmentIndex[[segmentPositions[[i]],-1,-1]], 5]];
 For[j=realSegmentIndex[[segmentPositions[[i]],-1,-1]],
  j<index[[Position[index,flightIndex[[segmentPositions[[i]],1]]][[1,1]]+1]],
  j++,
  If[trackdata[[j,5]]>lastSegmentLevel+5,AppendTo[continueClimb,i];
   Break[],j++]
 ]
]

notReachedCruise=Delete[segmentPositions, Split[continueClimb]];
transposeList={};
Do[AppendTo[transposeList,-1], Length[notReachedCruise]];
removeLastSegment=Transpose[{notReachedCruise, transposeList}];
finalLevelDistance=Delete[levelDistance, removeLastSegment];
finalAverageAltitude=Delete[averageAltitude, removeLastSegment];
finalSegmentPoints=Delete[segmentPoints, removeLastSegment];
finalSegmentList=Delete[segmentList, removeLastSegment];
finalSegmentIndex=Delete[realSegmentIndex, removeLastSegment];
```

Appendix VIII Level segments at specific levels July 2017

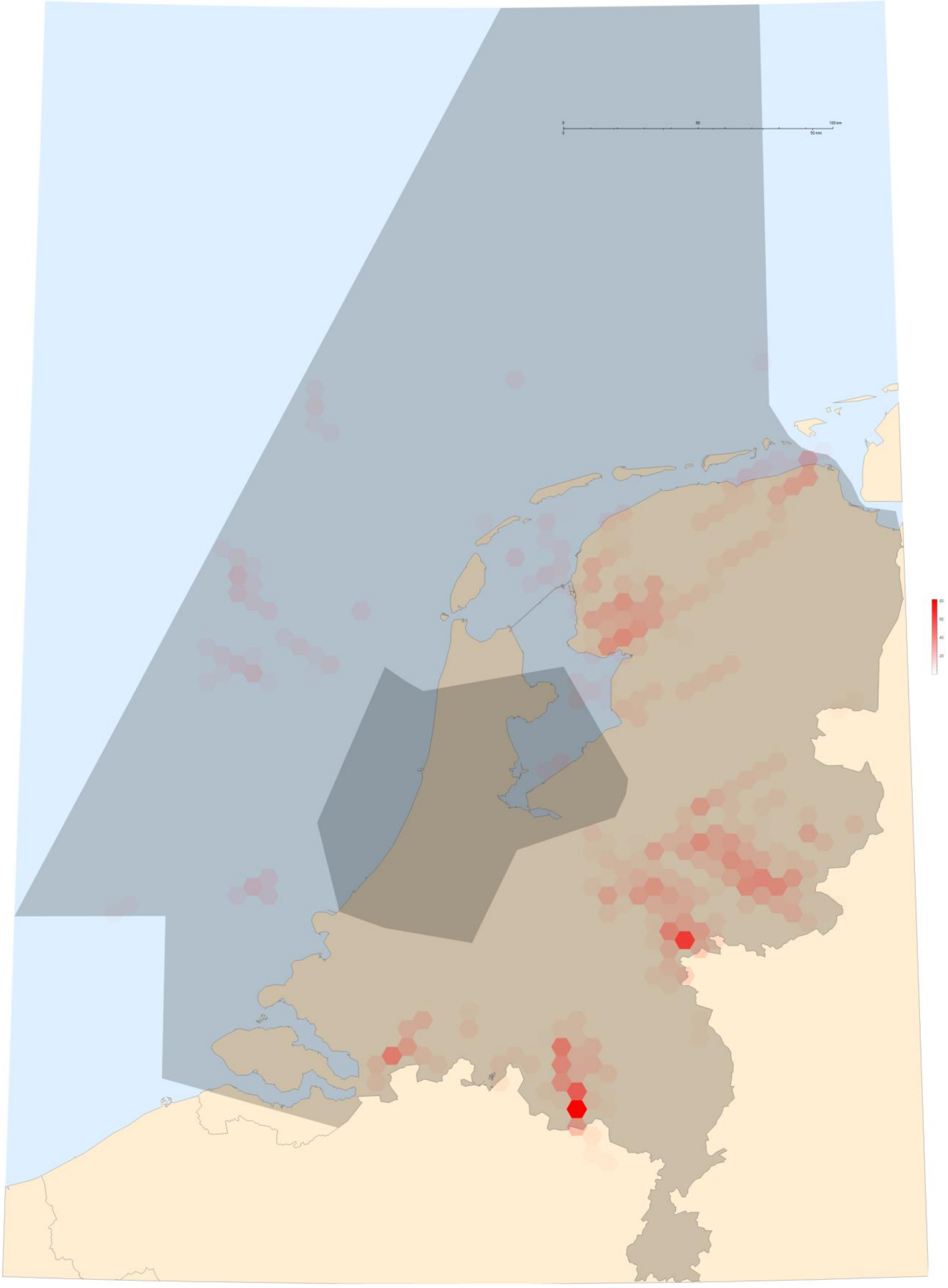
Level segments at FL60



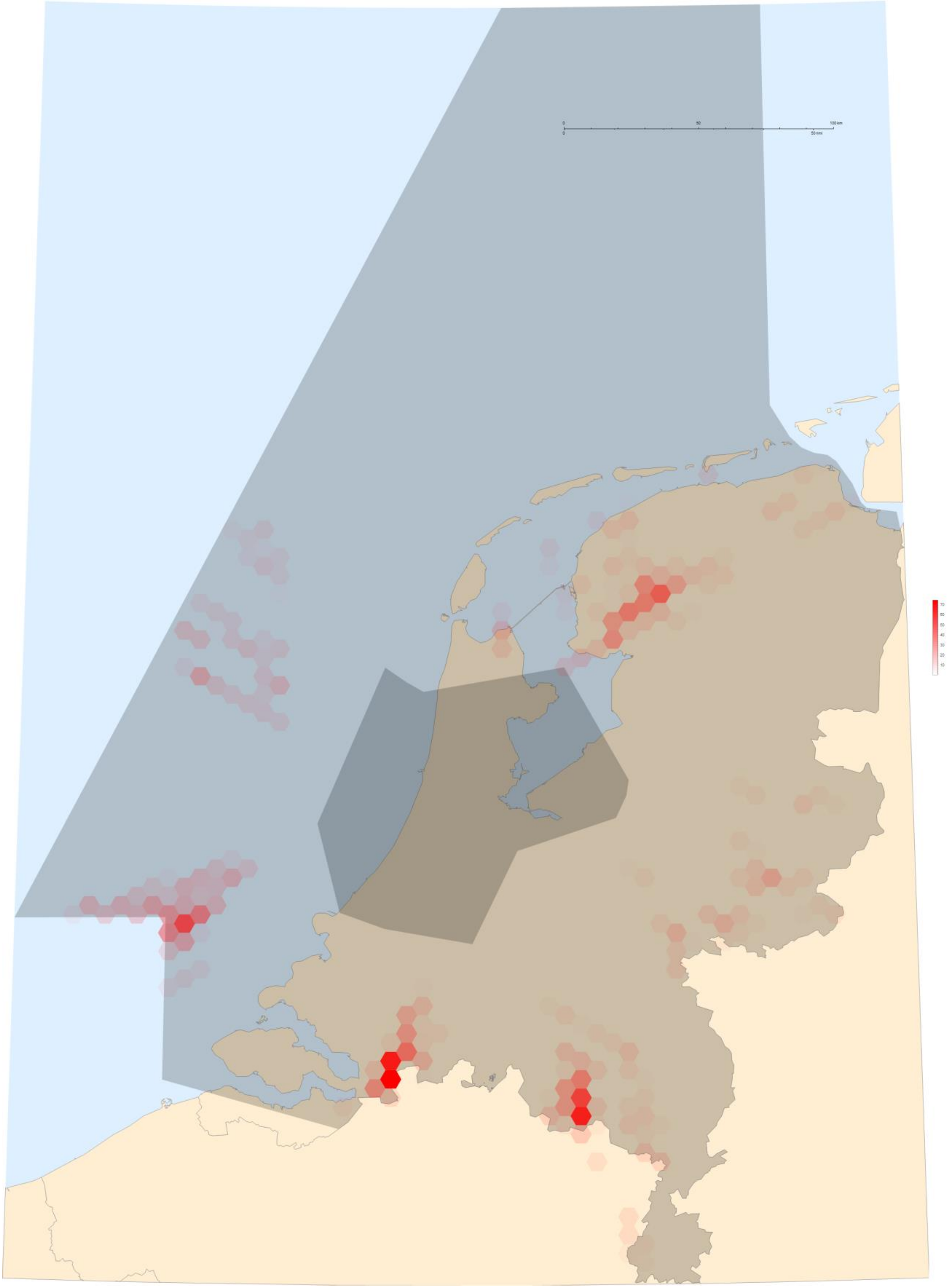
Level segments at FL240



Level segments at FL250

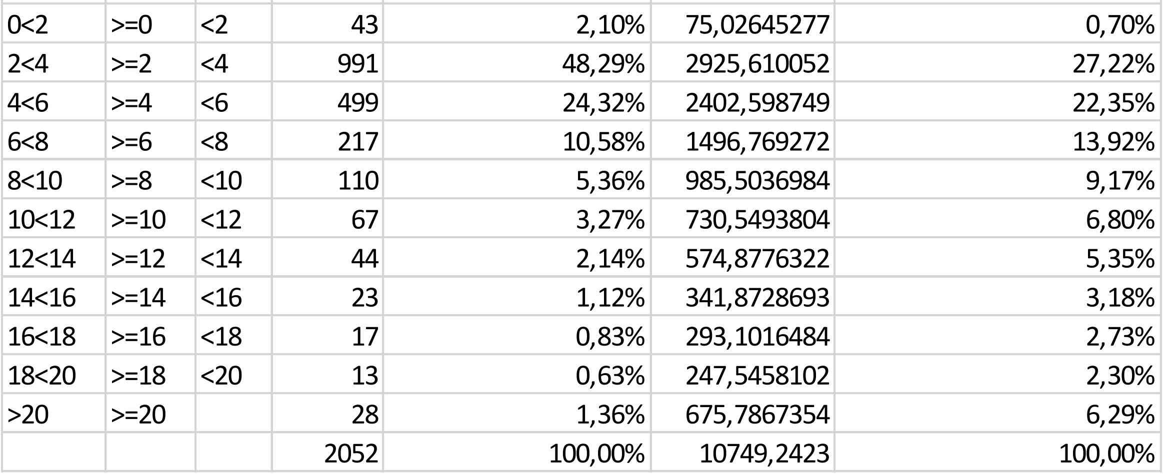


Level segments at FL260



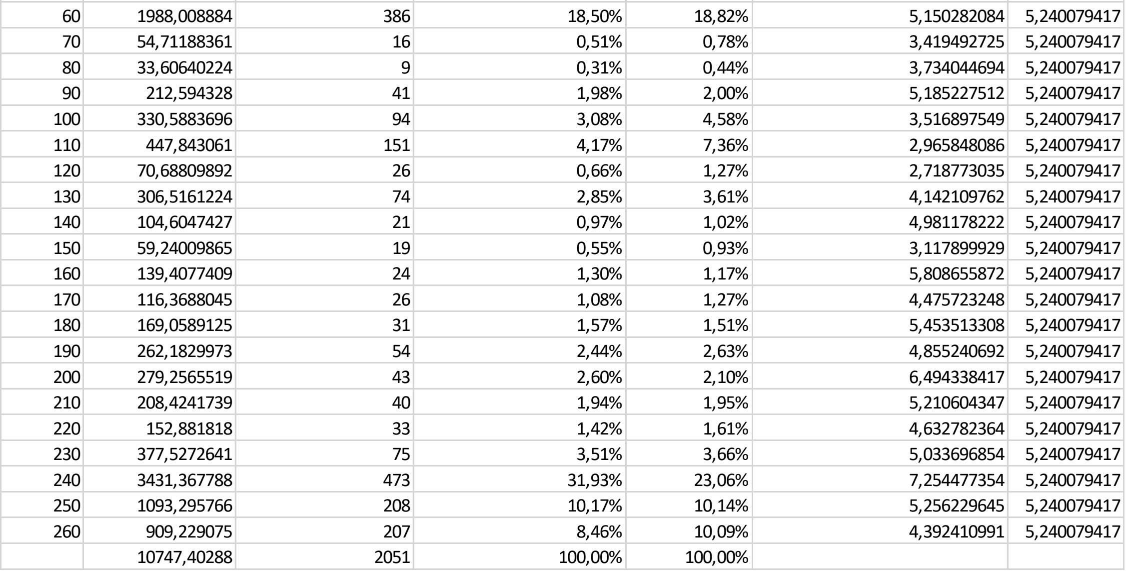
Appendix IX Excel results relationships level segments with airspace design and ATC procedures July 2017

Distribution of level segment distance



Range	Min	Max	Amount	% of segments	Total distance	% total distance
0<2	>=0	<2	43	2,10%	75,02645277	0,70%
2<4	>=2	<4	991	48,29%	2925,610052	27,22%
4<6	>=4	<6	499	24,32%	2402,598749	22,35%
6<8	>=6	<8	217	10,58%	1496,769272	13,92%
8<10	>=8	<10	110	5,36%	985,5036984	9,17%
10<12	>=10	<12	67	3,27%	730,5493804	6,80%
12<14	>=12	<14	44	2,14%	574,8776322	5,35%
14<16	>=14	<16	23	1,12%	341,8728693	3,18%
16<18	>=16	<18	17	0,83%	293,1016484	2,73%
18<20	>=18	<20	13	0,63%	247,5458102	2,30%
>20	>=20		28	1,36%	675,7867354	6,29%
			2052	100,00%	10749,2423	100,00%

Relationship FL on level segments



FL	Segment distance	Amount of segments	% total segment distance	% of segments	Average distance per segment	Total average
60	1988,008884	386	18,50%	18,82%	5,150282084	5,240079417
70	54,71188361	16	0,51%	0,78%	3,419492725	5,240079417
80	33,60640224	9	0,31%	0,44%	3,734044694	5,240079417
90	212,594328	41	1,98%	2,00%	5,185227512	5,240079417
100	330,5883696	94	3,08%	4,58%	3,516897549	5,240079417
110	447,843061	151	4,17%	7,36%	2,965848086	5,240079417
120	70,68809892	26	0,66%	1,27%	2,718773035	5,240079417
130	306,5161224	74	2,85%	3,61%	4,142109762	5,240079417
140	104,6047427	21	0,97%	1,02%	4,981178222	5,240079417
150	59,24009865	19	0,55%	0,93%	3,117899929	5,240079417
160	139,4077409	24	1,30%	1,17%	5,808655872	5,240079417
170	116,3688045	26	1,08%	1,27%	4,475723248	5,240079417
180	169,0589125	31	1,57%	1,51%	5,453513308	5,240079417
190	262,1829973	54	2,44%	2,63%	4,855240692	5,240079417
200	279,2565519	43	2,60%	2,10%	6,494338417	5,240079417
210	208,4241739	40	1,94%	1,95%	5,210604347	5,240079417
220	152,881818	33	1,42%	1,61%	4,632782364	5,240079417
230	377,5272641	75	3,51%	3,66%	5,033696854	5,240079417
240	3431,367788	473	31,93%	23,06%	7,254477354	5,240079417
250	1093,295766	208	10,17%	10,14%	5,256229645	5,240079417
260	909,229075	207	8,46%	10,09%	4,392410991	5,240079417
	10747,40288	2051	100,00%	100,00%		

Relationship departure runway and SID on level segments

	ANDIK	ARNEM	BERGI	EDUPO	GORLO	WOODY	LOPIK	No SID
4	AND2F	ARN2F	BER1F	REN1F	GRL2F	KDD1F	LOP1F	
6	AND1T	ARN2T	BER2R	REN1T	GRL2R	KDD1T	LOP1R	
	AND2R	ARN2R		REN1R		KDD1R		
9	AND1N	ARN2N	BER2N	REN1N	GRL2N	KDD1N	LOP1N	
					VAL3M			
18L	AND2E	ARN3E	BER3E	REN1E	VAL3E	KDD1E	LOP3E	
18C	BTS3Y	ELP2X	WIS1X	EPO2X	DNG3X	LAR1X	RVN2X	
	TGA1X							
22	AND2G	ARN3G	BER1G	REN1G	VAL1G	KDD1G	LOP1G	
24	AND1S	ARN2S	BER1S	REN1S	VAL1S	KDD1S	LOP2S	
	SPY2K							
27	SPY1P	ARN2P	BER1P	REN1P	GRL1P	KDD1P	LOP1P	
36L	SPY2V	ARN1V	BER3V	REN1V	GRL3V	KDD1V	LOP3V	
		ARN1Z	BER1Z	REN1Z	GRL1Z	KDD1Z	LOP1Z	
36C	NSU1W	NYK3W		IVL2W		WDY1W	OGI2W	

	ANDIK	ARNEM	BERGI	EDUPO	GORLO	WOODY	LOPIK	No SID	SUM	SUM rwy	%	Number of flights (%	
4	8	13	8	41	31	41	5	0	147	147	0,63%	0,63%	0,63%
	0	0	0	0	0	0	0	0	0		0,00%		
6	3	7	2	11	5	9	3	0	40	40	0,17%	0,17%	0,17%
	0	0	0	0	0	0	0	0	0		0,00%		
9	41	345	27	428	13	488	118	0	1460	1487	6,21%	6,33%	6,33%
	0	0	0	0	27	0	0	0	27		0,11%		
18L	73	1180	22	1802	32	1560	541	0	5210	5210	22,17%	22,17%	22,17%
	0	0	0	0	0	0	0	0	0		0,00%		
18C	7	9	33	10	21	6	1	0	87	95	0,37%	0,40%	0,40%
	8	0	0	0	0	0	0	0	8		0,03%		
22	18	17	15	49	45	81	15	0	240	240	1,02%	1,02%	1,02%
	0	0	0	0	0	0	0	0	0		0,00%		
24	349	473	1990	911	1697	1178	278	0	6876	8214	29,25%	34,95%	34,95%
	1338	0	0	0	0	0	0	0	1338		5,69%		
27	0	0	0	0	0	0	0	0	0	0	0,00%	0,00%	0,00%
	0	0	0	0	0	0	0	0	0		0,00%		
36L	1352	229	1499	486	1250	475	144	0	5435	5853	23,12%	24,90%	24,90%
	0	62	50	124	38	113	31	0	418		1,78%		
36C	38	462	0	797	0	737	184	1	2219	2219	9,44%	9,44%	9,44%
	0	0	0	0	0	0	0	0	0		0,00%		
SUM	3235	2797	3646	4659	3159	4688	1320	1	23505	23505	100,00%	100,00%	
Number c	13,76%	11,90%	15,51%	19,82%	13,44%	19,94%	5,62%	0,00%	100,00%				

	ANDIK	ARNEM	BERGI	EDUPO	GORLO	WOODY	LOPIK	No SID	SUM	SUM rwy	%	Level distance (%)	
4	0,0	17,9	7,9	36,8	57,1	25,6	0,0	0,0	145,3	145,29	1,35%	1,35%	1,35%
	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0		0,00%		
6	0,0	0,0	0,0	0,0	2,6	0,0	0,0	0,0	2,6	2,61	0,02%	0,02%	0,02%
	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0		0,00%		
9	19,7	144,5	62,6	124,9	32,0	153,6	74,5	0,0	611,8	660,87	5,69%	6,15%	6,15%
	0,0	0,0	0,0	0,0	49,1	0,0	0,0	0,0	49,1		0,46%		
18L	22,9	300,5	19,4	300,3	53,3	498,4	401,1	0,0	1596,0	1595,95	14,85%	14,85%	14,85%
	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0		0,00%		
18C	0,0	0,0	40,9	4,1	11,7	11,8	0,0	0,0	68,5	68,54	0,64%	0,64%	0,64%
	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0		0,00%		
22	22,9	2,9	23,8	0,0	106,3	69,1	3,6	0,0	228,6	228,59	2,13%	2,13%	2,13%
	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0		0,00%		
24	127,2	154,4	1691,7	140,2	1514,0	193,0	139,4	0,0	3960,0	4471,14	36,84%	41,59%	41,59%
	511,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	511,1		4,75%		
27	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,00	0,00%	0,00%	0,00%
	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0		0,00%		
36L	362,5	72,1	814,9	197,7	1211,3	88,1	43,1	0,0	2789,7	2881,82	25,95%	26,81%	26,81%
	0,0	12,2	31,9	11,0	16,5	18,3	2,2	0,0	92,1		0,86%		
36C	14,8	202,7	0,0	222,9	0,0	180,2	73,8	0,0	694,4	694,43	6,46%	6,46%	6,46%
	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0		0,00%		
SUM	1081,1	907,2	2693,1	1038,0	3053,9	1238,3	737,7	0,0	10749,2	10749,2	100,00%	100,00%	
Level dist	10,06%	8,44%	25,05%	9,66%	28,41%	11,52%	6,86%	0,00%	100,00%				

	ANDIK	ARNEM	BERGI	EDUPO	GORLO	WOODY	LOPIK	No SID	Average	Average rwy		
4	0,000	1,380	0,987	0,896	1,844	0,623	0,000	0,000	0,988	0,988	0,988	0,457
	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000		0,000	0,457
6	0,000	0,000	0,000	0,000	0,522	0,000	0,000	0,000	0,065	0,065	0,065	0,457
	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000		0,000	0,457
9	0,481	0,419	2,319	0,292	2,459	0,315	0,631	0,000	0,419	0,444	0,444	0,457
	0,000	0,000	0,000	0,000	1,817	0,000	0,000	0,000	1,817		0,000	0,457
18L	0,314	0,255	0,882	0,167	1,666	0,319	0,741	0,000	0,306	0,306	0,306	0,457
	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000		0,000	0,457
18C	0,000	0,000	1,240	0,411	0,557	1,968	0,000	0,000	0,788	0,721	0,721	0,457
	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000		0,000	0,457
22	1,271	0,168	1,587	0,000	2,363	0,854	0,240	0,000	0,952	0,952	0,952	0,457
	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000		0,000	0,457
24	0,364	0,326	0,850	0,154	0,892	0,164	0,502	0,000	0,576	0,544	0,544	0,457
	0,382	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,382		0,000	0,457
27	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,457
	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000		0,000	0,457
36L	0,268	0,315	0,544	0,407	0,969	0,186	0,299	0,000	0,513	0,492	0,492	0,457
	0,000	0,197	0,637	0,089	0,433	0,162	0,071	0,000	0,220		0,000	0,457
36C	0,389	0,439	0,000	0,280	0,000	0,245	0,401	0,000	0,313	0,313	0,313	0,457
	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000		0,000	0,457
SUM	0,334	0,324	0,739	0,223	0,967	0,264	0,559	0,000	0,457	0,457		
Average	0,457	0,457	0,457	0,457	0,457	0,457	0,457	0,457				

Relationship COPX on level segments

S1	S2	S3	S4	S5	
EEL	NAPRO	WOODY	REFSO	MIMVA	
BEDUM	SONEB	BROGY	PEVAD	GODOS	
KONOM	TEBRO	BEKEM		KOLAG	
AGISU		PUTTY		ODASI	
GREFI					
S1	S2	S3	S4	S5	
410	4659	4584	2824	1109	
2167	2641	1416	335	1217	
451	156	5	0	1231	
207	0	3	0	89	
1	0	0	0	0	
3236	**7456**	**6008**	**3159**	**3646**	**23505**
S1	S2	S3	S4	S5	
155,0416	1037,955	1164,709	2899,282	841,8545	
775,6002	871,0773	805,4927	154,6024	571,2598	
112,5669	36,12045	5,818823	0	1243,202	
37,87578	0	0	0	36,78357	
0	0	0	0	0	
1081,084	**1945,152**	**1976,021**	**3053,884**	**2693,1**	**10749,24**
S1	S2	S3	S4	S5	
0,37815	0,222785	0,254081	1,026658	0,759111	
0,357914	0,329829	0,568851	0,4615	0,4694	
0,249594	0,231541	1,163765	0	1,009913	
0,182975	0	0	0	0,413299	
0	0	0	0	0	
0,33408	**0,260884**	**0,328898**	**0,966725**	**0,738645**	**0,457317**
0,457317	0,457317	0,457317	0,457317	0,457317	

Relationship aircraft type on level segments

Type	RECAT	Amount of flights	Percentage of flight	Total distance	Percentage of distar	Average per flight
A20N	D	22	0,09%	14,2671054	0,13%	0,648504791
A306	C	64	0,27%	11,79252524	0,11%	0,184258207
A310	C	10	0,04%	3,025064783	0,03%	0,302506478
A318	D	5	0,02%	0	0,00%	0
A319	D	1581	6,73%	828,6956439	7,71%	0,524159168
A320	D	2271	9,66%	679,5017595	6,32%	0,299208172
A321	D	711	3,02%	220,9205048	2,06%	0,31071801
A332	B	508	2,16%	207,6644052	1,93%	0,408788199
A333	B	638	2,71%	289,4745069	2,69%	0,453721798
A343	B	34	0,14%	8,878273574	0,08%	0,261125693
A359	B	50	0,21%	11,70181093	0,11%	0,234036219
A388	A	62	0,26%	18,95117349	0,18%	0,305664089
ASTR	F	2	0,01%	0	0,00%	0
AT72	E	2	0,01%	0	0,00%	0
AT75	E	2	0,01%	5,413491679	0,05%	2,70674584
B350	F	2	0,01%	0	0,00%	0
B733	E	92	0,39%	69,58741292	0,65%	0,756384923
B734	E	42	0,18%	7,534046062	0,07%	0,179382049
B735	E	68	0,29%	8,012897746	0,07%	0,117836732
B736	D	32	0,14%	2,913143334	0,03%	0,091035729
B737	D	1825	7,76%	1054,047779	9,81%	0,577560427
B738	D	5559	23,65%	1438,974388	13,39%	0,2588549
B739	D	443	1,88%	129,448896	1,20%	0,292209698
B744	B	588	2,50%	204,5903455	1,90%	0,347942764
B748	B	117	0,50%	23,73755699	0,22%	0,202885102
B752	C	121	0,51%	106,542493	0,99%	0,880516471
B753	C	9	0,04%	0	0,00%	0
B763	C	281	1,20%	232,4242558	2,16%	0,827132583
B764	C	31	0,13%	13,41798321	0,12%	0,432838168
B772	B	448	1,91%	272,0823043	2,53%	0,607326572
B77L	B	260	1,11%	91,19869059	0,85%	0,350764195
B77W	B	470	2,00%	263,013012	2,45%	0,559602153
B788	B	142	0,60%	86,68675896	0,81%	0,610470133
B789	B	257	1,09%	156,0143871	1,45%	0,607059872
BCS1	E	2	0,01%	0	0,00%	0
BCS3	E	28	0,12%	0	0,00%	0
BE20	F	1	0,00%	2,674946536	0,02%	2,674946536
BE40	F	3	0,01%	0	0,00%	0
C25A	F	31	0,13%	23,68049542	0,22%	0,763886949
C25B	F	15	0,06%	34,99220274	0,33%	2,332813516
C25C	F	11	0,05%	8,25142227	0,08%	0,750129297
C25M	F	2	0,01%	4,493899454	0,04%	2,246949727
C510	F	19	0,08%	5,297620388	0,05%	0,278822126
C525	F	7	0,03%	0	0,00%	0
C550	F	9	0,04%	0	0,00%	0
C551	F	3	0,01%	2,723951117	0,03%	0,907983706
C560	F	1	0,00%	0	0,00%	0
C56X	F	63	0,27%	48,57209902	0,45%	0,770985699
C650	F	2	0,01%	0	0,00%	0

C680	F	20	0,09%	22,14527885	0,21%	1,107263942
CL30	E	8	0,03%	6,632480994	0,06%	0,829060124
CL35	E	13	0,06%	5,258816995	0,05%	0,404524384
CL60	E	5	0,02%	5,097902198	0,05%	1,01958044
CRJ2	E	2	0,01%	0	0,00%	0
CRJ7	E	10	0,04%	2,353467476	0,02%	0,235346748
CRJ9	E	189	0,80%	117,3809161	1,09%	0,621063048
CRJX	E	54	0,23%	43,12455868	0,40%	0,798602939
D328	F	8	0,03%	1,693592531	0,02%	0,211699066
DH8D	E	383	1,63%	200,7409213	1,87%	0,524127732
E145	E	134	0,57%	32,45209131	0,30%	0,242179786
E170	E	1213	5,16%	1007,78995	9,38%	0,830824361
E190	E	3200	13,61%	2032,006078	18,90%	0,635001899
E195	E	29	0,12%	0	0,00%	0
E35L	E	10	0,04%	5,119637573	0,05%	0,511963757
E50P	F	5	0,02%	20,2001503	0,19%	4,04003006
E545	E	1	0,00%	0	0,00%	0
E55P	F	9	0,04%	0	0,00%	0
F100	E	9	0,04%	0	0,00%	0
F2TH	F	19	0,08%	19,785747	0,18%	1,041355105
F70	E	850	3,62%	376,7206974	3,50%	0,44320082
F900	F	18	0,08%	54,29024335	0,51%	3,01612463
FA50	E	2	0,01%	0	0,00%	0
FA7X	E	18	0,08%	12,31132036	0,11%	0,683962242
FA8X	E	1	0,00%	0	0,00%	0
G150	F	1	0,00%	0	0,00%	0
G280	E	4	0,02%	0	0,00%	0
GL5T	E	2	0,01%	6,138245914	0,06%	3,069122957
GLEX	E	19	0,08%	0	0,00%	0
GLF4	E	11	0,05%	5,42488707	0,05%	0,493171552
GLF5	E	17	0,07%	45,97760066	0,43%	2,704564745
GLF6	E	2	0,01%	0	0,00%	0
H25B	F	14	0,06%	17,02154127	0,16%	1,215824376
J328	E	2	0,01%	0	0,00%	0
LJ35	F	5	0,02%	0	0,00%	0
LJ40	F	2	0,01%	12,38589525	0,12%	6,192947624
LJ45	F	3	0,01%	0	0,00%	0
LJ60	F	2	0,01%	0	0,00%	0
P180	F	3	0,01%	0	0,00%	0
PC12	F	9	0,04%	9,654421661	0,09%	1,072713518
PRM1	F	5	0,02%	0	0,00%	0
R721	D	2	0,01%	0	0,00%	0
RJ85	E	226	0,96%	87,72819436	0,82%	0,388177851
S22T	F	1	0,00%	0	0,00%	0
SB20	F	16	0,07%	8,608410515	0,08%	0,538025657
TBM8	F	1	0,00%	0	0,00%	0
TBM9	F	2	0,01%	0	0,00%	0
		23505	100,00%	10749,2423	100,00%	0,457317264

Appendix X RECAT-EU

‘Super Heavy’	’Upper Heavy’	‘Lower Heavy’	‘Upper Medium’	‘Lower Medium’	‘Light’
‘CAT-A’	‘CAT-B’	‘CAT-C’	‘CAT-D’	‘CAT-E’	‘CAT-F’
A388	A332	A306	A318	AT43	FA10
A124	A333	A30B	A319	AT45	FA20
(…)	A343	A310	A320	AT72	D328
	A345	B703	A321	B712	E120
	A346	B752	AN12	B732	BE40
	A359	B753	B736	B733	BE45
	B744	B762	B737	B734	H25B
	B748	B763	B738	B735	JS32
	B772	B764	B739	CL60	JS41
	B773	B783	C130	CRJ1	LJ35
	B77L	C135	IL18	CRJ2	LJ60
	B77W	DC10	MD81	CRJ7	SF34
	B788	DC85	MD82	CRJ9	P180
	B789	IL76	MD83	DH8D	C650
	IL96	MD11	MD87	E135	C525
	(…)	TU22	MD88	E145	C180
		TU95	MD90	E170	C152
		(…)	T204	E175	(…)
			TU16	E190	
			(…)	E195	
				F70	
				F100	
				GLF4	
				RJ85	
				RJ1H	
				(…)	

(Rooseleer & Treve, 2018)