KDC MAINPORT SCHIPHOL – CENTRE OF EXCELLENCE
A COLLABORATION WITH THE AVIATION ACADEMY, AMSTERDAM UNIVERSITY OF APPLIED SCIENCES

ATYPICAL APPROACHES

CORRELATING ELEVATED ENERGY TRAJECTORIES WITH HIGH-RISK EVENTS

THESIS

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Thesis

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Abstract

It is currently not known how many flights deviate from the designed approach procedures at Amsterdam Schiphol airport. Neither is it known if there is a relation between go-around occurrences and flights deviating from approach procedures. This thesis main objective tackled this by quantifying the occurrence of these approaches deviating from approaches procedures and identify if these occur more often in go-around occurrences. Examining these types of approaches, also known as atypical approaches, through analysing the energy trajectory of aircraft. Introduced by Delahaye et al. (2018), energy trajectories relate to combining kinetic energy resulting from aircraft motion (speed), and potential energy stemming from aircraft altitude, into a single variable – specific total energy, and analysing this variable during the approach phase.

The definition of atypical approaches as non-nominal approaches, has been elaborated to establish the frame used to identify these atypical approaches in this thesis. Given the energy trajectory methodology used to identify atypical approaches, the approach phase between the Final Approach Fix (FAF), a waypoint set at 6.2 from the runway, and the 3 nm stabilisation has been analysed for runways 18C and 18R at Schiphol. Procedures by LVNL (n.d.) require aircraft to linearly decrease in altitude in this approach phase with an approach path angle of 3-degrees. Whilst also linearly decelerating between 10-20 knots per nm as established by Tremaud (2000). Therefore, a linear loss in specific total energy is expected for a nominal approach in this approach phase. Comparing nominal total specific energy loss against the total specific loss of the aircraft, atypical approaches have been identified through having higher total specific energy losses – higher than the nominal 20 knots per nm threshold.

Findings indicate that 20.2 in 1,000 landings on runways 18C and 18R do exhibit higher-than-nominal total specific energy losses. This phenomenon is approximately 2.5 times more pronounced during go-around occurrences and accounting for approximately 5% of go-arounds (48.4 of 1,000). Approaches via the inbound ARTIP stack, particularly for runway 18C also exhibit higher levels of atypicality.

Previously, two types of approaches have been identified to deviate from procedures: Non-Stabilised Approaches (NSA) and Non-Compliant Approaches (NCA). This thesis included methods to identify NSA's and NCA's through defining identifying criteria, used to determine whether a relationship exists between each individual criterion and the occurrence of atypical approaches.

For criteria identifying NSA's, the following criteria have found to have a significant relation with atypicality:

- Horizontal approach path deviation (323.4 of 1,000 being atypical).
- Bank angle exceeding 30 degrees (254.9 of 1,000 being atypical).
- Vertical approach path deviation (78.5 of 1,000 being atypical).
- Vertical speed exceeding 1,000 ft/min (70.0 of 1,000 being atypical).

For identifying criteria of NCA, the following criteria have been identified to have a significant correlation with atypicality:

- Approaches non-compliant with the indicated airspeed requirement (Non-Adapted) at the FAF (72.7 of 1,000 being atypical).
- A Glide Intercepted From Above (GIFA) for the approach path (43.5 of 1,000 being atypical).

Quantifying atypical approach occurrence at Amsterdam airport Schiphol for runways 18C and 18R, further investigation into factors causing approaches to become atypical is recommended.

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List of Abbreviations

Abbreviation	Definition
AIP	Aeronautical Information Publication
ALT	Altitude
ATC	Air Traffic Control
ATM	Air Traffic Management
BOM	Basic Operating Manual
CFIT	Controlled Flight Into Terrain
CTR	Control Traffic Region
FAF	Final Approach Fix
FIR	Flight Information Region
GA	Glide Angle
GIFA	Glide Intercept From Above
GPWS	Ground Proximity Warning System
GS	Groundspeed
ICAO	International Civil Aviation Organisation
ID	Flight Identification Number
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
J	Joules
KG	Kilogram
KIAS	Knots Indicated Airspeed
KTS	Knots
LVNL	Dutch National Air Traffic Service
MSAW	Minimum Safe Altitude Warning
NCA	Non-Compliant Approach
NM	Nautical Mile
NSA	Non-Stabilised Approach
SOP	Standard Operating Procedure
T	Total
THR	Threshold
TMA	Terminal Manoeuvring Area
VMC	Visual Meteorological Conditions

1 Introduction

Airports Control Traffic Regions (CTR) and Terminal Manoeuvring Areas (TMA) are characterized by a dense flow of air traffic with high complexity levels. In nominal operations, approach flight path safety management consists in procedures which guide the aircraft to intercept the final approach axis and the runway slope. The operator determines the landing configuration based upon factors such as surface wind and aircraft weight.

In 2010, the French Civil Aviation Safety Directorate published a safety assessment on ultimate and undesirable events in commercial aviation (Welterlin, 2010). Ultimate events included occurrences such as Controlled Flight Into Terrain (CFIT), loss of control in flight, runway overruns, inflight collisions, damaged to aircraft in flight among others. Undesired events include runway incursions, unusual positioning, maintenance work on or near a runway, Ground Proximity Warning Systems (GPWS) alarm initiation, Minimum Safe Altitude Warning (MSAW), among others (Welterlin, 2010). The safety assessment also introduced the concept of Non-Compliant Approaches (NCA) and Non-Stabilised Approaches (NSA). This concept was further elaborated by Delahaye et al (2018) for Charles de Gaulle airport.

The safety assessment concluded that for ultimate events or undesirable events to occur, a chain of events must be instigated. Ultimate events are characterized as the final, most critical outcome within the accident sequence which typically involve structural damage to the aircraft, injuries or fatalities. On the other hand, undesirable events are identified as operational deviations from nominal procedures that increase the potential for incident escalation. If the chain of events is instigated, it can lead to ultimate events, in particular CFIT or runway overruns. These ultimate events are preceded by undesirable events typically including GPWS alarm initiation, MSAW or go around occurrences. Additionally, it concluded that such events coincide with NSAs or NCAs.

These undesirable events that occur before ultimate events increase risk and adversely impact safety levels and air traffic flows. For instance, when an aircraft aborts a landing and conducts a go around, the controller must sequence the aircraft into an established traffic flow back to the runway. This whilst ensuring that separation standards between aircraft are met. Often, a go-around means that traffic must be altered and result into greater distances being covered to reach the respective landing runway. As well as adversely affecting the efficiency of arriving traffic at the airports thereafter (Figuet et al., 2023).

Historic aviation accident occurrences between 1958 and 2022 showed that most accidents occur during the approach and landing phase (Airbus, 2023). With the introduction of new generation of aircraft, accident numbers have decreased. Nevertheless, the occurrence levels of accidents are the highest during the high-risk phase of approach and landing. Further research by Tremaud (2000) showed that 75% of these approach and landing accidents include occurrences of CFIT, loss of control, runway overrun, runway excursion and NSAs. With 45% of hull losses in these accidents occurring in the landing phase from the landing runway's outer marker, a waypoint to mark a predefined distance from the landing runway threshold to the completion of the landing roll. Most of these accidents involved significant atypical deviations from nominal approaches, such as atypical speed or atypical altitude.

Furthermore, around 70% of these atypical approaches occurrences in the accident analysis contained elements that the crew should have noticed as improper as per manufacturer standard procedures or operator established procedures and prompted a go-around (Tremaud, 2000). Furthermore, it also showed that when an approach is unstable less than 20% of flight crew initiate a go-around when warranting a go-around decision.

Given the complexity of the CTR and TMA traffic flow and considering that most accidents occur during the final landing phase (Airbus, 2023), it is crucial to avoid these undesirable events at all costs. Identifying and discerning these undesirable events remains a significant issue. A method to identify these undesirable events includes an energy trajectory analysis.

Introduced by Delahaye et al (2018), the concept of energy trajectories relates to analysing the total specific energy of an aircraft for all surveillance radar observations within the approach phase of the aircraft. The energy trajectory being based upon the total specific energy, which includes two categories of energy:

- Specific potential energy.
- Specific kinetic energy.

Specific energy relates to the amount of energy per unit of mass typically expressed in Joules (J) per kilogram (kg). Specific potential energy relates to the stored energy of the aircraft as a product of its altitude. Specific kinetic energy relates to energy by reason of motion. By combining both units of energy into one variable, specific total energy, both aircraft altitude and aircraft energy of an observation can be singularly captured. In turn, analysing the change in specific total energy for an approach trajectory would thus give an indication of changes in aircraft altitude in combination with energy. From which, atypical approaches have been defined as deviating from nominal-approaches.

1.1 Problem statement

The current definition of atypical approaches given by Delahaye et al. (2018) for Paris Charles de Gaulle airport as deviations from nominal approaches does not establish clear boundaries for the approach phase. It is not known what the leading factors of atypical approach occurrences are, nor what the occurrence levels are at Amsterdam's airport Schiphol. Neither is it known if atypical approach occurrences are more likely to lead to go-around occurrences.

1.2 Thesis Objectives

The main objective of this thesis is to provide a definition with clear boundaries of atypical approaches relevant for the procedures at Schiphol airport and use it to identify and quantify their occurrences. The focus is on trajectories that result in a go-around and those that proceed to landing without a go-around, using historical surveillance data for Amsterdam's airport Schiphol's runways 18C and 18R.

From the main objective the following sub objectives have been established:

i. Define distance boundaries in the approach phase, common to both runway 18C and 18R at Schiphol, that establish the expected nominal approach towards the runway. These boundaries will serve as a reference for identifying and quantifying atypical approaches.

ii. Identifying and verify the factors that define the occurrence of NCA and NSA approaches. This aims to quantify the occurrence levels of NCA/ NSA. Aiding to help establish if atypical approaches occur more often with in conjunction with NCA/ NSA.

iii. Determine whether atypical approach observations occur more often in conjunction with factors of NCA and/or NSA occurrences compared to the total number of approach observations. This analysis aims to assess whether there is a relationship between atypical approaches and NCA/ NSA.

iv. Determining whether atypical approach observations occur more often in approach trajectories that instigate a go-around compared to occurrences which do not instigate a go-around. This analysis aims to assess whether a relationship is present between atypical approaches and go-around occurrences relevant to the occurrence levels within the Amsterdam FIR.

1.3 Research Questions

The main research question of this thesis is stated as:

With a definition of clear boundaries of atypical approaches relevant to Schiphol airports procedures, how often do atypical approaches, for both landings and go-around occurrences, occur at Amsterdam airport Schiphol runways 18C and 18R?

From the main question, the following sub research questions have been established:

i. What are the distance boundaries in the approach phase, common to both runway 18C and 18R at Schiphol, that define an expected nominal approach trajectory?

ii. What are the identifying factors of NCA and NSA approaches that can be used to identify NCA/ NSA in the surveillance data?

iii. Do atypical approaches occur more often in conjunction with individual factors of NCA and/ or NSA?

iv. Is the proportion of atypical approaches higher in go-around occurrences?

1.4 Thesis scope

This thesis primarily focuses on defining, identifying and quantifying occurrences of atypical approaches. The main limitation of this thesis is that the current definition of atypical approaches does not have clear boundaries relevant for the procedures at Amsterdam’s airport Schiphol. Through this thesis the definition for atypical approaches will be elaborated to establish clear boundaries. However, this definition may be limited due to the focus on the Amsterdam FIR. Over time, this given definition might require revision as further research and data analysis from other FIRs could reveal additional factors influencing atypical approaches. The scope is limited to defining, identifying and quantifying atypical approach occurrences within the Amsterdam FIR. Specifically, approach trajectories to runways 18R and 18C will be analysed for Amsterdam’s airport Schiphol.

1.5 Thesis structure

Chapter 2 explores the key concepts and methods used in previous studies related to this topic. Next, Chapter 3 explains the methods applied in this thesis. With these methods, the results are presented and analysed in Chapter 4. Thereafter, conclusions and future work recommendations are explained in Chapter 5. Finally, Chapter 6 provides further recommendations based on the findings in this thesis.

2 Review of the Literature

An approach is the phase of flight when the plane is descending towards the destination airport and preparing to land. Approach procedures include a designed approach path guiding the aircraft towards the runway both horizontally and vertically. These approach procedures include Instrument Landing System (ILS) approaches. The ILS guides the aircraft vertically by means of a radio beacon called the glideslope, as shown in Figure 1. ILS approaches guide the aircraft horizontally along the runway centre line to the runway by means of radio signals.

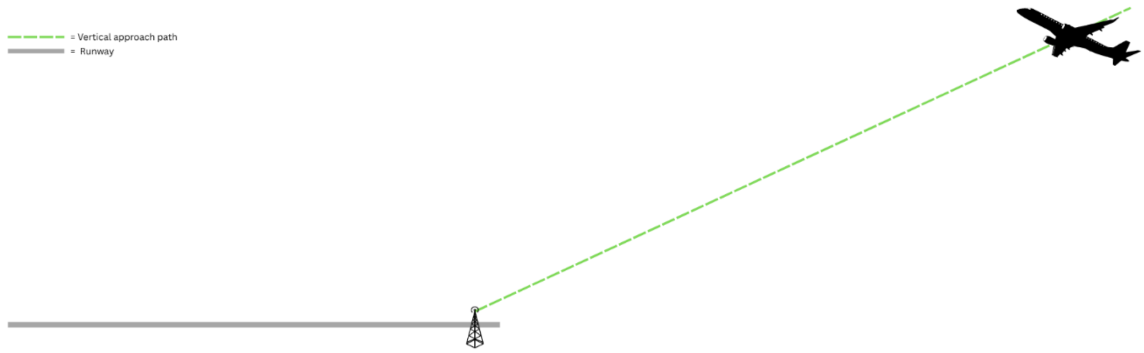


Figure 1 - Instrument Landing System - vertical guidance

The approach flown by an aircraft may deviate from the vertical (altitude) and horizontal (track) approach path (Gong & McNally, 2004). Track and altitude errors define the allowable margins within which the flight trajectory may deviate from the predetermined and published ILS approach procedure, as outlined in the Aeronautical Information Publication (AIP). These deviations are permissible if they remain within the established tolerance limits.

These tolerated track and altitude errors include the so-called dot deviations. According to the International Civil Aviation Organisation (2018a), a dot is used to express the deviation of an aircraft from the designed approach procedure. A 0-dot deviation meaning no deviation, whereas deviation of 1 or 2 dots correspond to fixed geometric offsets from the designed trajectory. The geometric criteria for defining dot deviation depend on various factors. Horizontally, this included the reference runway length used in approach procedure design and the required horizontal width of the ILS signal at the runway threshold, which determines the perpendicular distance at which the signal remains detectable. In this thesis, a one-dot horizontal deviation is calculated to be 0.8 degrees.

Vertically, legislation by the International Civil Aviation Organisation (2018a), requires the geometric offset to be smaller in the definition of a dot. The value can be established by multiplying the horizontal angle by an established factor representing the defined geometric limit vertically. Computing this value, the result equates to an angle just surpassing 0.35 degrees for vertical deflection. A value of 0.36-degrees will serve as the reference for vertical one-dot deflection in this thesis to ensure not undervaluing.

A visualisation of a deviation from the vertical ILS approach path procedure is shown in Figure 2.

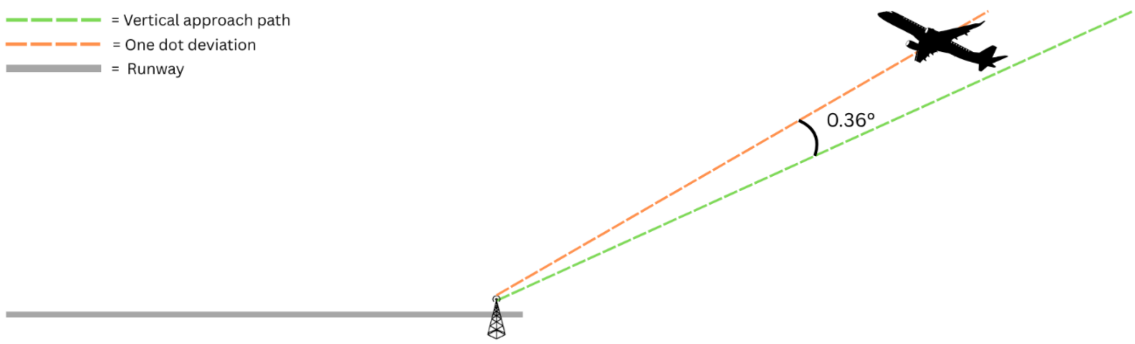


Figure 2 - Vertical approach path deviation - 1 dot

Horizontal deviation from the ILS approach path is shown in Figure 3.

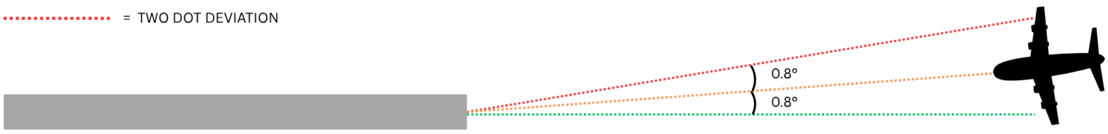
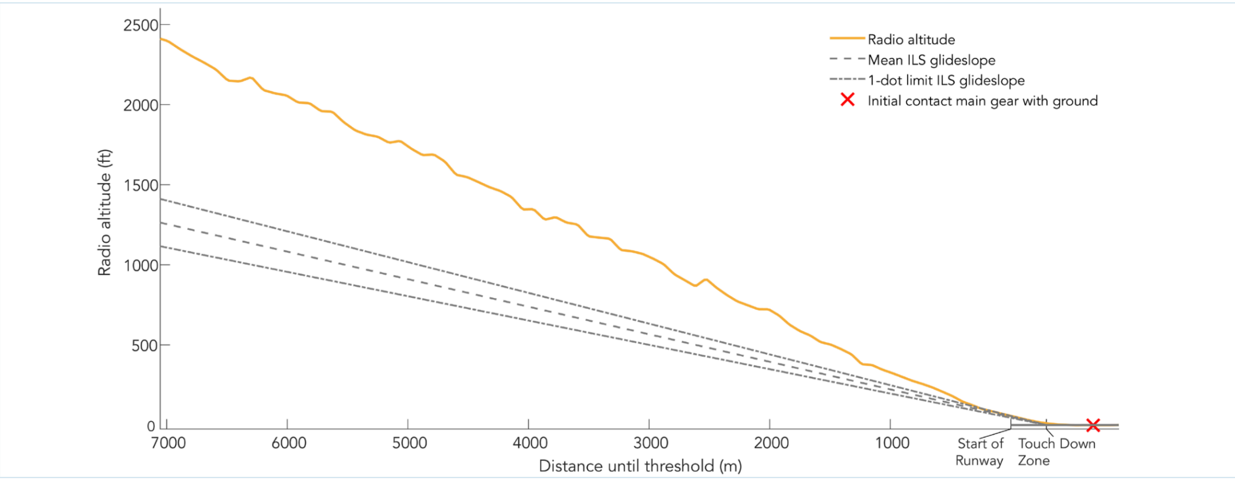


Figure 3 - Horizontal approach path deviation - 1 dot

Certain abnormal approaches that deviated from the designed approach procedures have been observed in previous studies. These include both Non-Stabilized Approaches (NSA) and Non-Compliant Approaches (NCAs).

An NSA is characterised by the failure to establish and maintain the runway centre line tracking glide path, glide path angle, and indicated airspeed. The latter from a given point on the approach established by the aircraft operator and defined in height based on the destination surrounding terrain whilst incorporating speed requirements outlined in the approach procedure (Welterlin, 2010). As stated by Flight Safety Foundation (2000a) the stabilisation criteria are outlined in the Standard Operating Procedures (SOP) of an airline. An example non-stabilised approach, investigated by the Dutch Safety Board (2019), is shown in Figure 4.



The flight profile of the approach of the Embraer ERJ 190-100 STD.

Figure 4 - Non-stabilised approach example sourced from Dutch Safety Board (2019), Quarterly Aviation Report: 3rd Quarter 2019.

Figure 4 showing the approach trajectory, expressing the aircraft altitude with the orange line, against the designed approach path shown by the dotted line. The aircraft touching down with the main gears on the ground in the last quarter of the runway.

NCA relate to aircraft conducting an approach based on Instrument Flight Rules (IFR) procedures that do not comply with prescribed final approach joining conditions as per Aeronautical Information Publication (AIP) procedures (Welterlin, 2010). A previous report published by Vernay (n.d.) defined the criteria for a non-compliant approach based upon the instrument approach procedures set out by the French Air Traffic Service. A visual representation of these criteria is shown in Figure 5.

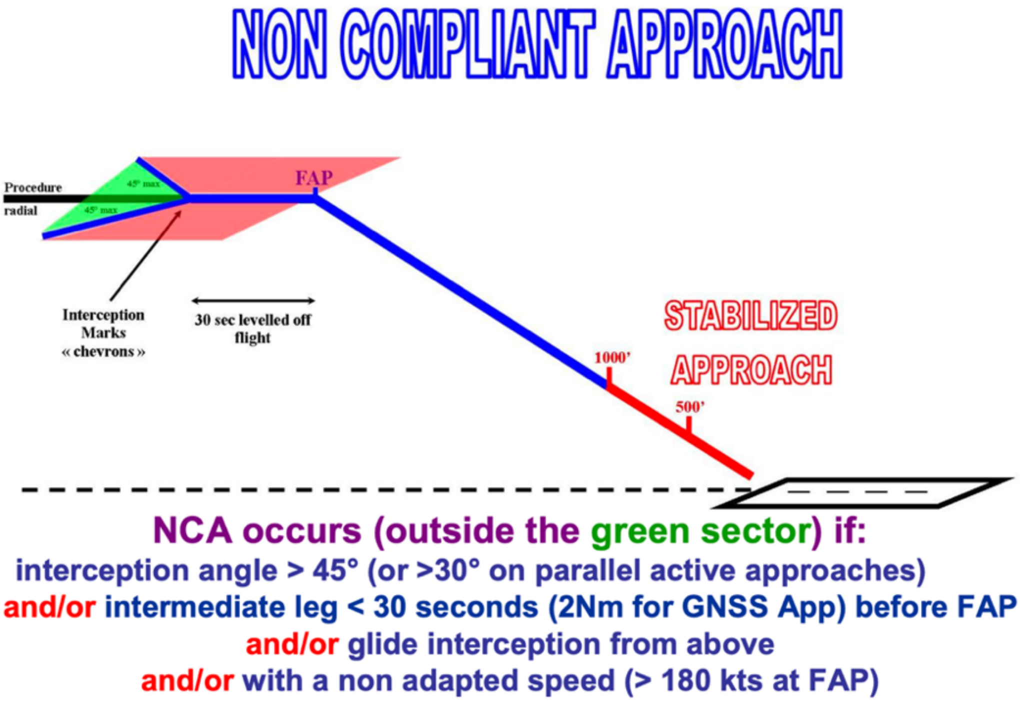


Figure 5 – Non-Compliant Approach criteria sourced from Vernay (n.d.), The big <<C>> for Compliance.

These state that the interception angles, shaped like a chevron (V-shaped), is outlined to a maximum of 45-degrees compared to the horizontal approach path. This maximum angle is reduced to 30-degrees when parallel approaches are active. It means the intercept aircraft approaches the FAF at no more than max angle (45/30 degrees) relative to its direction of travel. It also requires the aircraft to be in level-flight for 30 seconds prior to intercepting the Final Approach Point (FAP), a synonym for the FAF. And, requiring the indicated airspeed of the aircraft to be below 180 knots at the FAP, requiring the vertical approach path to be intercepted from below. Any of these criteria not being met, an approach is non-compliant. Through a safety analysis conducted by Welterlin (2010), the concepts of NSA and NCA have been integrated into the chain of events that must take place for undesirable or ultimate event to occur.

With the established tolerated errors and concepts of NSA and NCA, the respective approach phase on which the analysis is conducted will be explained.

The approach phase

The designed approach procedures by LVNL (n.d.) for runways 18C and 18R has segmented the approach into different phases – the initial approach phase, the intermediate approach phase and final approach phase. This thesis studies the final approach phase. This phase starts at the Final Approach Fix (FAF), a waypoint set 6.2 nautical mile from the runway threshold.

The final approach has been chosen, as prior to the FAF the aircraft is allowed to deviate from the approach procedures when being vectored. Vectoring relating to instructions given from Air Traffic Control (ATC) for an aircraft stating direction, and/or altitude, and/or speed requirements for an aircraft to follow guiding them towards the FAF. From the FAF, the aircraft is expected to follow the ILS approach procedure without any vectoring. Aircraft equipped with GPS systems may also follow an Area Navigation (RNAV) approach procedure. Procedures for RNAV approaches are identical to ILS approaches in the final approach phase and therefore are also included in this thesis.

The final approach phase includes the so-called stabilisation point. At this point, the aircraft should be in the landing configuration as required by the operators SOP. It should also be at the speed at which the aircraft will touch down on the runway and no longer decelerate after reaching this point. For runways 18C and 18R this is stabilisation point is set at 3 nm from the runway. In this thesis, the final approach phase between the FAF and the 3 nm stabilisation point will be studied as shown in Figure 6.

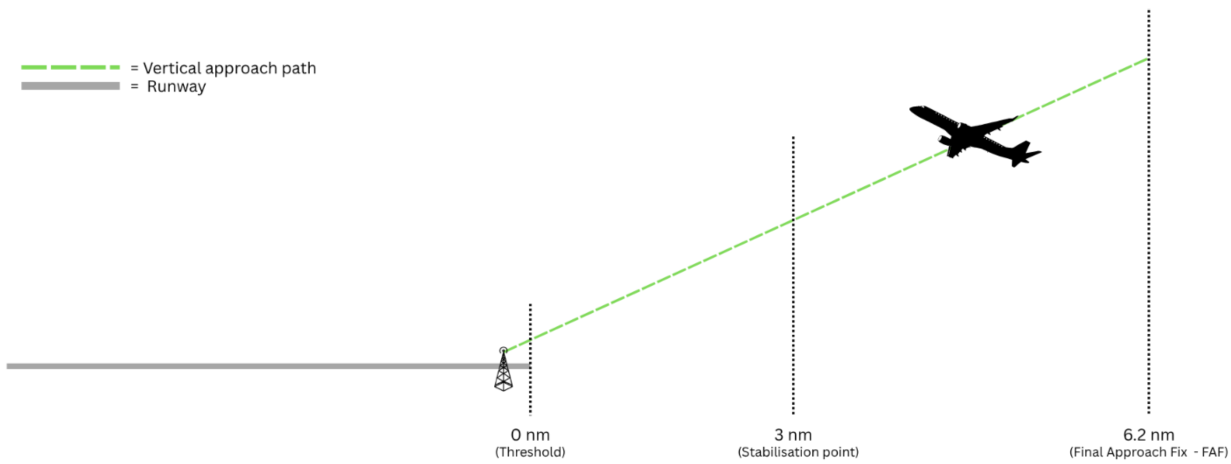


Figure 6 - Approach phase from FAF to stabilisation point

Figure 7 – Example approach trajectory

With the approach phase studied in this thesis having been outlined, next the concept of curvilinear distance will be explained.

Curvilinear distance

An approach may not follow a linear path to the runway threshold, as shown in Figure 7. Since linear distance to does not account for the total distance flown, it cannot reliably define the studied approach phase. Figure 8 provides a further illustration of this concept.

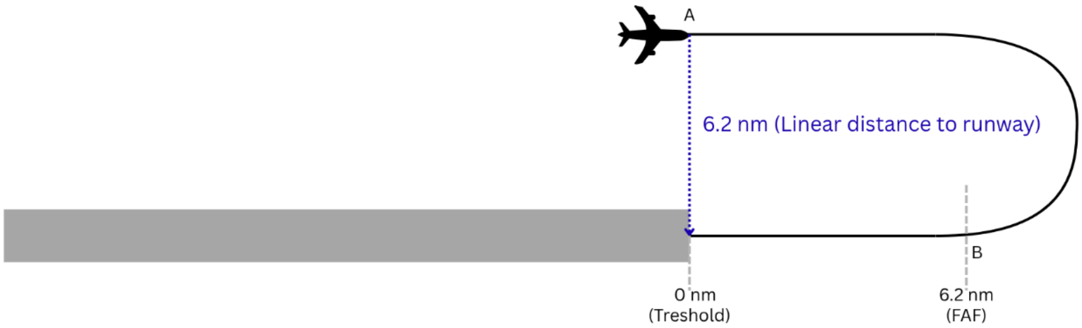


Figure 8 - Limitation linear distance to runway

At point A, the aircraft direct linear distance to the runway is 6.2 nm. However, because the aircraft is flying parallel to the runway it is not the point at which it reaches the FAF. Instead, the aircraft will arrive at the FAF (point B) at a later stage in the approach. To accurately determine the non-linear distance flown, the concept of curvilinear distance will be used. This includes both curvilinear distance to the runway and curvilinear distance to touchdown.

As explained by Lee et al. (2002), curvilinear distance relates to expressing non-linear distances. As shown in Figure 9, the distance between two points, as shown by part -b-, can be connected by a straight line. This would give the straight-line distance, also known as Euclidian distance between the points. However, this does not represent the distance along the curve. Curvilinear distance, also known as geodesic distance, represented by -c-, can be calculated to represent the distance along the curve.

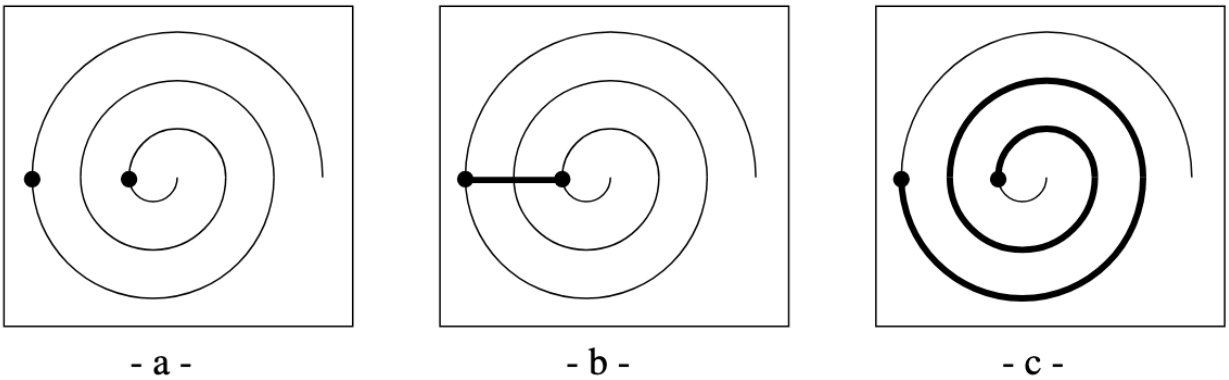


Figure 9 - Curvilinear distance concept sourced from Lee et al. (2002), Curvilinear Distance Analysis versus Isomap.

Curvilinear distance has been applied to express the distance the approach trajectory will follow until the runway threshold or touchdown point has been reached. With the touchdown point being set abeam the glide slope antenna.

With the curvilinear distance, the surveillance data between the FAF and the 3 nm stabilisation point can be identified. In this thesis, the surveillance data where the curvilinear distance to the threshold is between 6.2 nm and 3 nm inclusive are used as the frame of the observations between the FAF and stabilisation point.

Next, inbound routes to Amsterdam airport Schiphol will be explained.

Stacks

To standardise the inbound routes towards Schiphol airport and the approach stacks have been designed. These stacks include ARTIP, SUGOL and RIVER as shown in Figure 10.

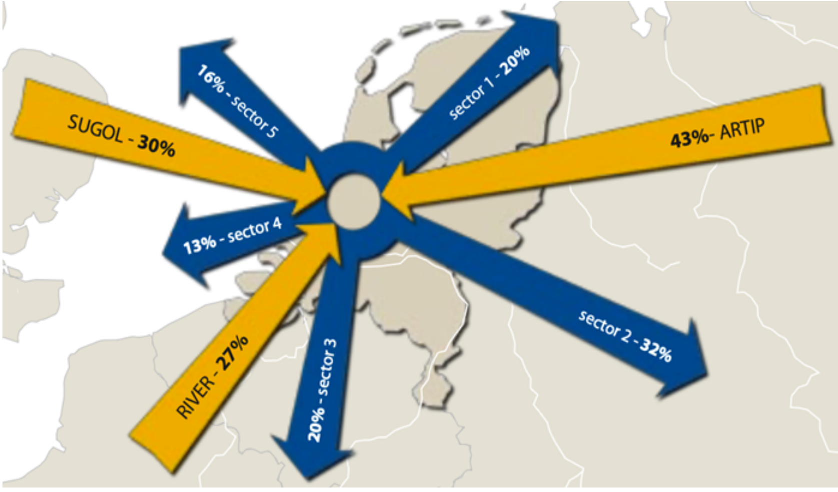


Figure 10 - Inbound stacks to Amsterdam airport sourced from Vooren (2013), Gebruiksprognose 2013 - Experiment Nieuw Normen- en Handhavingsstelsel.

Where SUGOL connects the approaches coming in from a northwestern direction, RIVER connects approaches coming in via the south and ARTIP connecting approaches from the east.

Next, the energy trajectory used to identify deviations from procedures will be explained.

Energy trajectory

The concept of atypical approaches has been introduced by Delahaye et al. (2018) through an energy trajectory analysis on approach trajectories at Paris Charles de Gaulle airport. Through analysing total specific energy, a capture of both potential (altitude) and kinetic energy (speed) changes, atypical approaches can be identified.

To use the energy method to analyse approach trajectories reference values for nominal approach energy levels are required. Tremaud (2000) outlined aircraft deceleration characteristics during this approach and landing phase. Specifically, for those during the landing phase of an aircraft given different configurations. It states that the deceleration on a 3-degreee flight path, nominally the aircraft will descent 10 to 20 kts per nm from the final approach fix to the 3 nm stabilisation point. This conclusion is used as reference for the energy method used in this thesis to analyse approach trajectories.

The energy trajectory analysis was further elaborated by Delahaye et al. (2019). It focussed on analysing 14,846 Airbus A320 approach trajectories throughout France and Algeria. It found that per 100 flights, 2.1 flights have higher than nominal total specific energy levels.

To establish what nominal total specific energy levels are, some background information is given.

Background information nominal energy trajectory

For the final approach phase, instrument approach procedures by LVNL (n.d.) have been designed to incorporate a deceleration in aircraft velocity from the FAF to the 3 nm stabilisation point. This approach procedure also incorporates a designed vertical approach descent being equal to a glide path angle of three-degrees.

During the approach phase, the aircraft is expected to linearly decelerate in groundspeed as established by Tremaud (2000). This horizontal motion is directly proportional to the vertical motion, as explained by Pythagoras' theorem, when descending under a fixed glide path angle. Therefore, the kinetic energy is expected to linearly decrease in this phase of flight.

Secondly, altitude is expected to linearly decrease to maintain a three-degree flight path angle, leading to a corresponding linear reduction in potential energy. As a result, the total specific energy would reduce in an ideal nominal approach from the FAF to the 3 nm stabilisation point.

With this linear deceleration, there is a corresponding loss in total specific energy. By examining the cumulative energy changes between the FAF and the 3 nm stabilisation point, the total energy loss can be quantified. This serves as the key criterion for identifying higher than nominal energy levels.

Next, the definition of atypical approaches will be tailored to the procedures at Amsterdam airport Schiphol.

Definition atypical approaches

Previously, atypical approaches have been identified as having higher than nominal energy levels (Delahaye et al., 2018). Specifically, higher than nominal energy levels are defined as those surpassing the 20 kts per nm threshold, which represents the maximum nominal deceleration rate from the FAF to the 3 nm stabilization point (Tremaud, 2000). To define atypical approaches at Amsterdam Airport, a comparative analysis was conducted with procedures at Paris Charles de Gaulle Airport, where the preceding analysis on atypical approaches had been performed.

The instrument approach procedures, as set out by Direction Générale de l'Aviation Civile (2025), for Paris Charles de Gaulle airport and the procedures, set out by LVNL (n.d.), for Schiphol airport are identical in the sense that both designs include the intent for aircraft to decelerate from the FAF from the 3 nm stabilisation point. Given the identicality, and that the cumulative total specific energy loss is the identifying criteria used in this thesis for atypicality, the following definition will be used in this thesis:

An atypical approach occurs if an approach trajectory's cumulative total specific energy loss exceeds the 20 knots per nautical mile threshold in the approach phase from the final approach fix to the 3 nautical mile stabilisation point.

With the given definition to atypical approaches, next the methods used in this thesis to identify these atypical approaches will be explained.

3 Methodology

3.1 Structure methodology

The thesis is structured according to several main phases as shown in Figure 11.

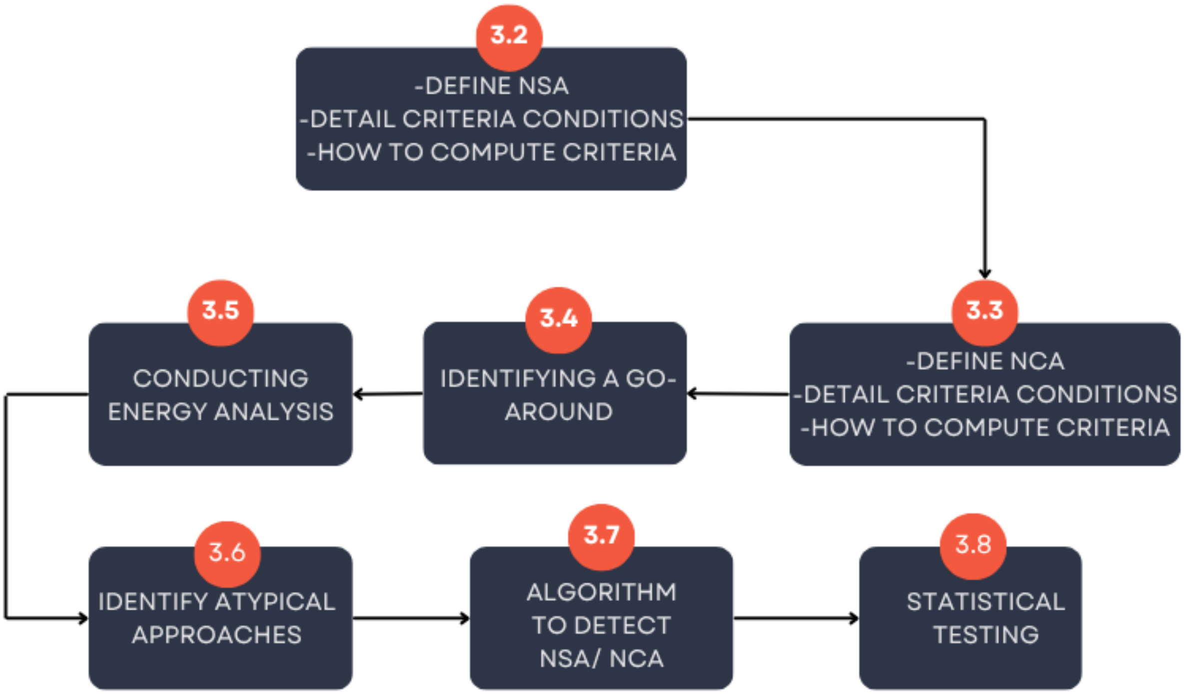


Figure 11 - Thesis methodology structure in phases

In sub-chapter 3.2, Non-Stabilised Approaches will be defined outlying the criteria from which NSA can be identified in this thesis. The first segment of the sub-chapter will include motivating to why individual criteria have been chosen in the definition and where these have been sourced from. The second segment will include methods to compute the criteria or motivate the choice to what source of surveillance data will be used to analyse the identifying criteria.

Sub-chapter 0 will follow the same structure as the second sub-chapter: defining Non-Compliant Approaches, motivating individual criteria followed by explaining methods to compute the criteria, or motivating the choice to what source of surveillance data will be used to analyse the identifying criteria.

In sub-chapter 3.4, factors outlining go-around occurrences will be explained. Along with what criteria have been included to decide which go-arounds to analyse in this thesis.

Sub-chapter 3.5 relates to explaining the methodology used to conduct the energy analysis. This included methods to calculate individual components of the energy analysis and steps taken to compare the observed empirical values against nominal. From which, sub-chapter 3.6, the energy analysis will be concluded with the methods to identify atypical approaches.

Having identified atypical approaches, sub-chapter 3.7 will relate to explaining the methods in which the algorithm detected individual components of NCA and NSA.

Concluding this the motivation for a choice of a statistical test used in this thesis will be explained in sub-chapter 3.8.

The methodology will include the following four types of values throughout: observed, empirical, expected and nominal. Each referring to the following:

- Observed value refers to the value obtained from surveillance data stemming from the approach radar facility at Amsterdam airport Schiphol.
- Empirical value refers to the computed value for a given surveillance observation.
- Expected value refers to the value used to compare the empirical against, based upon certain constraints. E.g. the expected value for a 1-dot deviation glide angle would refer to the maximum glide angle value allowed for a given distance from the runway.
- Nominal value refers to the value expected assuming ideal values. E.g. nominal values for deceleration refer to ideal values for an ideal deceleration.

3.2 Non-Stabilised Approaches

3.2.1 Definition Non-Stabilised Approach

For this thesis the following definition, tailored to criteria verifiable with the surveillance data used, of a non-stabilised approach will be used:

An approach is considered non-stabilised if any of the following criteria occur:

NSA_C1 • Vertical speed exceeds 1,000 ft/min at any point between the FAF and 3 nm stabilisation point.
NSA_C2 • Vertical speed exceeds 50% of the targeted vertical speed at any point between the FAF and 3 nm stabilisation point.
NSA_C3 • Bank angle exceeds 30 degrees at any point between the FAF and 3 nm stabilisation point.
NSA_C4 • Vertical ILS path deviation exceeds 1 dot at any point between the FAF and 3 nm stabilisation point.
NSA_C5 • Horizontal ILS path deviation exceeds 1 dot at any point between the FAF and 3 nm stabilisation point.
NSA_C6 • The indicated airspeed varies more than +10 knots or -5 knots in the trend towards KIAS approach speed.

3.2.2 Details of criteria conditions

Stabilisation criteria are outlined in the Basic Operating Manual (BOM) and vary per airline (Flight Safety Foundation, 2000a). To define criteria identifying non-stabilised approaches, stabilisation criteria for three airlines at Schiphol have been obtained. These three airlines are responsible for most of the approach trajectories at Schiphol. By basing the definition on the criteria from these three airlines, the criteria are considered complete as it covers most approaches at Schiphol.

Through Person X, a former airline pilot at Airline 1, insights have been obtained regarding the chapter in the BOM that outlines the stabilisation criteria at Airline 1. When given the stabilisation criteria from the airline, it became apparent that the stabilisation criteria must be tailored with respect to the surveillance data used to analyse the approach trajectories. This because certain criteria are based upon variables including airplane configuration requirements (e.g. flap setting and completion of checklists), which are not verifiable through surveillance data. Some factors in the criteria also outline variables not relevant for the instrument approach procedures for runways 18C and 18R, which have been removed.

To verify and potentially elaborate the criteria, Person Y, deputy technical pilot at Airline 2, and Person Z, pilot at Airline 3, have been contacted per mail. Person Y emailed the respective segment of the BOM that outlines stabilisation criteria at Airline 2. These segments containing the stabilisation criteria at Airline 1 and 2 can be found in Appendix II and Appendix III respectively.

Person Z stated these criteria at Airline 3 include:

At 1000ft latest in both IMC and VMC:
- Speed max 10 kts above approach speed, no allowance below approach speed.
- Thrust not idle.
- Airplane in landing configuration.
- Checklist all completed.
- Max 1 dot vertical and horizontal deviation.
- Max 75ft vertical on non-precision approaches.

Next, details on how to compute each criterion is explained.

3.2.3 Details how to compute criteria

This segment will motivate which source of surveillance data will be analysed for each individual criterion. If the surveillance data does not include a variable that can directly be used to analyse the stabilisation criteria, methods will be explained to compute the metric which can be used to analyse the criteria.

3.2.3.1 NSA_C1 - Vertical speed > 1,000 ft/min

Both the approach radar surveillance data and Mode-S surveillance data include vertical speed variables. For the vertical speed criteria, approach radar (observed) vertical speed is analysed rather than Mode-S vertical speed. As through random sampling observed vertical speed demonstrates less fluctuations compared to Mode-S vertical speed observations as shown in Figure 12.

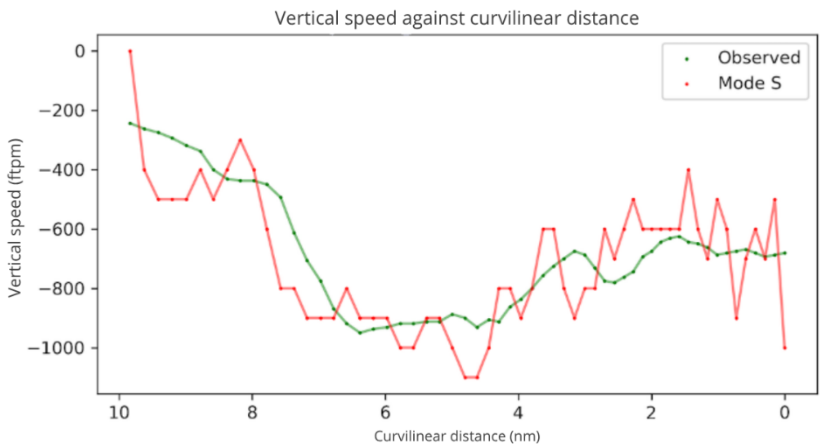


Figure 12 - Observed vertical speed and Mode S vertical speed

Stabilisation criteria also include criteria on limits for vertical speed against a targeted vertical speed. Next, details on how to compute this target will be explained.

3.2.3.2 NSA_C2 - Vertical speed 50% of target

Targeted vertical speed relates to the vertical speed required to maintain the vertical reference approach path, set at a 3-degree flight path angle, for a given groundspeed. To identify if deviation from this stabilisation requirement is present, the following steps are taken:

Step 1 – Identify groundspeed
For each observation identify the observed groundspeed.

Step 2 – Calculate vertical speed
To calculate the target vertical speed (V_{S_T}), interpolation is done comparing observed groundspeed against the published targeted vertical speeds outlined by the instrument approach procedures by LVNL (n.d.). As shown in Appendix IV – Vertical speed.

Step 3 – Calculate maximum expected vertical speed.
Next, the maximum expected vertical speed ($V_{S_{Max,Exp}}$) is calculated as expressed in Equation 1.

$$V_{S_{Max,Exp}} = 1.5 * V_{S_T} \tag{1}$$

Where V_{S_T} is the vertical speed target. Maximum expected vertical speed can be compared against the observed vertical speed to verify an approach is non-stabilised.

3.2.3.3 NSA_C3 - Bank angle

Part of the stabilisation criteria states that the bank angle is not allowed to exceed 30 degrees from the FAF until the 3 nm stabilisation point. As Mode-S surveillance data includes the bank angle of the aircraft, and the approach radar data does not include such information, Mode-S data is analysed.

3.2.3.4 NSA_C4 - Vertical ILS path deviation

To verify the compliance of the ILS path in the vertical plane, the concept of glide angle compliance introduced by Delahaye et al. (2018) will be used. This corresponds to the slope to join the touchdown point from the current observation. The touchdown point set directly perpendicular from the vertical ILS glideslope antenna just beyond the runway threshold. It is implemented using Equation 2:

$$GA = \tan^{-1}\left(\frac{Alt_m}{d_{to\ TD,m}}\right) \tag{2}$$

Where Alt_m represents the altitude in meters and $d_{to\ TD,m}$ represents the curvelinear distance to the touchdown point on the runway expressed in meters. Given the curvature of the earth, an altitude correction should be done as shown in Figure 13.

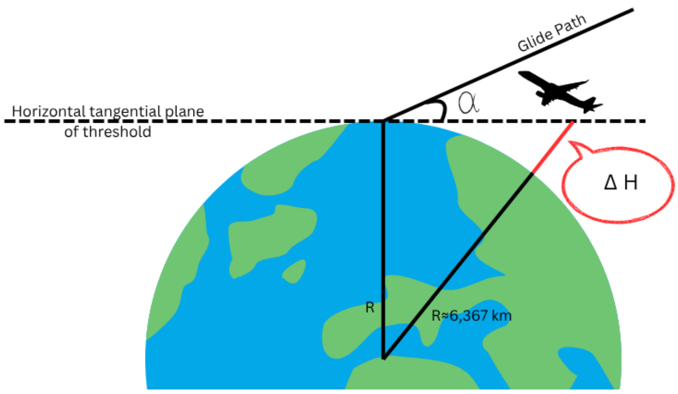


Figure 13 - Altitude difference curvature of the earth

However, given the insignificance of this curvature on the distance between the FAF and 3 nm stabilisation point, this has not been incorporated. Therefore, the $d_{to\,TD,m}$ is assumed to be equal to the horizontal tangential of the threshold.

With the glide angle, one can analyse if the angle to the touchdown reference point is within tolerance levels of the designed reference vertical approach path. A visual representation of this criteria compliance indicator is shown in Figure 14.

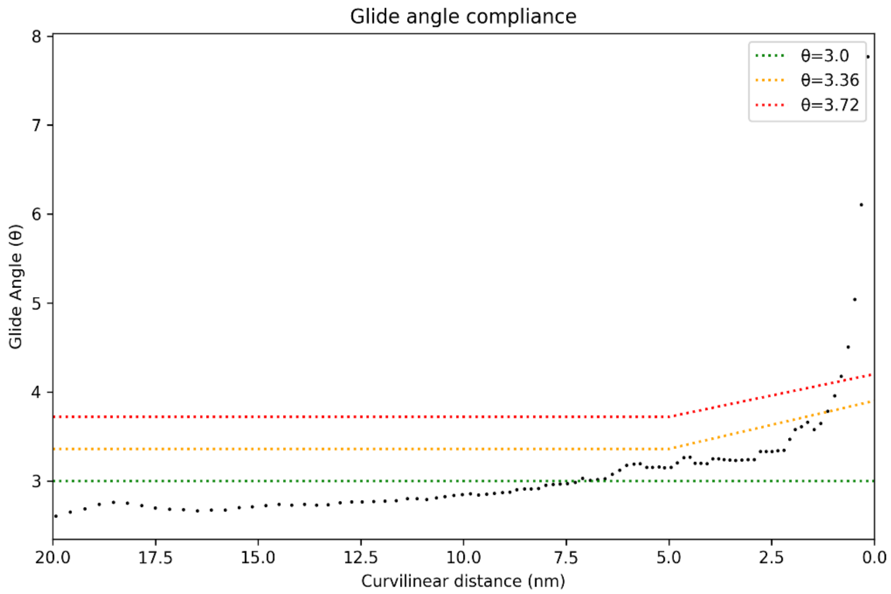


Figure 14 - Glide Angle compliance

The tangent function tends to produce large values when the value divided by gets close to zero as seen by the black dots in Figure 14. This phenomenon is referred to as asymptotic behaviour. To compensate for this asymptotic behaviour, the graph is skewed upwards to 3.9 degrees for one dot deviation and 4.2 degrees for two dot deviation. This upwards skewing starting at 5 nautical miles respectively as per methodology of Delahaye et al. (2018).

Given the skewing of the graph, empirical glide angle values can no longer be compared against the geometric values defining the tolerance levels. Therefore, expected values must be established for both 1-dot deviation and 2-dot deviation. Expected values are calculated in the following two steps:

Step 1 – Identify curvilinear distance

For each observation identify the curvilinear distance to the touchdown point.

Step 2 – Calculate the expected value

If the curvilinear distance is greater than 5 nm, the expected value is set to the one-dot or two-dot geometric limit (3.36 and 3.72-degrees respectively).

If equal to or less than 5 nm, expected values are calculated through linear interpolation of the curvilinear distance within the range 5 – 0 to estimate the glide angle between 3.36-3.90 degrees for one-dot deviation. For two dot deviation the glide angle is estimated between 3.72-4.20 degrees.

These expected values will be referred to as expected glide angle for 1 dot deviation and expected glide angle for 2 dot deviation in this thesis.
Next, methods to identify horizontal deviation angles is introduced.

3.2.3.5 NSA_C5 - Horizontal ILS path deviation

Horizontal deviation angles relating to the angle between the line of the approach horizontal path and the line connecting the observed latitude and longitude (OBS (Lat & Lon)) to the runway threshold (THR) as shown in Figure 15.

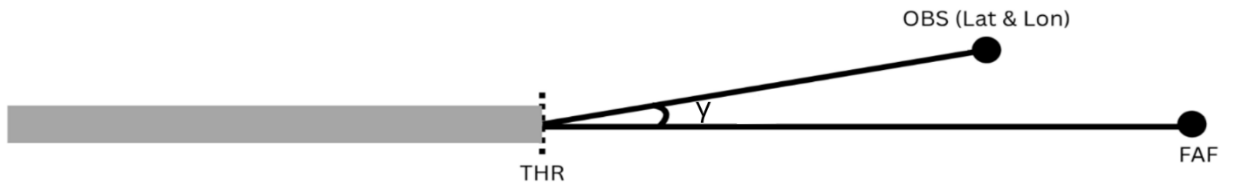


Figure 15 - Horizonal deviation angle

To compute the horizontal deviation angle, this section applies the concept of the dot product with vectors. Mathematically, the dot product equals the product of the magnitudes of the two vectors and the cosine of the angle between them (Harnew, 2012). This can be used to quantify the directional similarity between two vectors as shown in Figure 16.

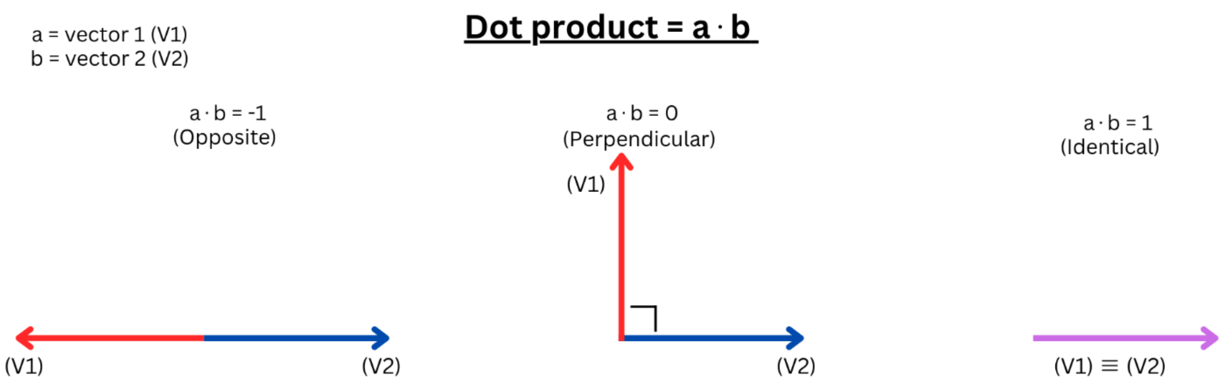


Figure 16 - Dot product visualisation

A dot product of -1 implies to two opposite vectors (180-degrees apart), 0 denotes two perpendicular vectors (angle of 90-degrees) and a dot product of 1 implying two identical vectors (angle of 0-degrees between the vectors). This assuming vectors of both same size (magnitude).

In this application, Vector 1 (V1) is defined as the vector from a surveillance data observation to the runway threshold and Vector 2 (V2) from the FAF to the runway threshold as shown in Figure 17.

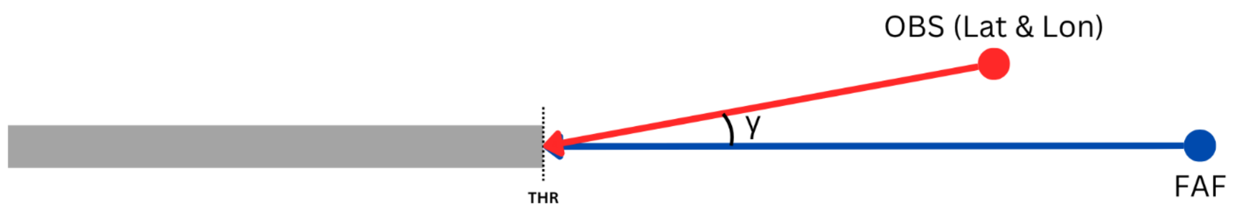


Figure 17 - Horizontal deviation angle visualisation including vectors

However, since the aim is to find the angle between the two vectors, and the vectors used are unlikely to not have the same size, normalised unit vectors will be used. This means both vectors are adjusted by means of magnitude, allowing to determine the vector angle only. A visual representation of these normalised unit vectors is shown in Figure 18.

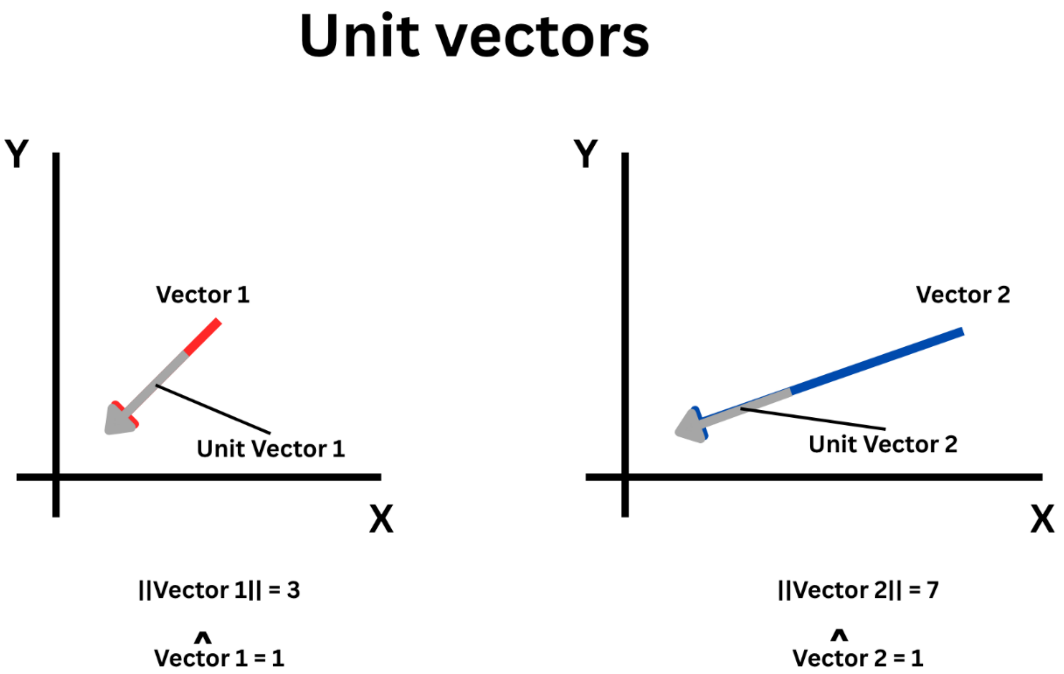


Figure 18 - Unit vectors visualisation

Figure 18 showing that the magnitude for vector 1 (||Vector 1||) does not equal the magnitude of vectors 2 (||Vector 2||), but the magnitude of unit vectors denoted by $\widehat{Vector}$ are identical.
By applying the dot product for normalised unit vectors, horizontal deviation angles can be calculated through the following steps:

<u>Step 1 – Find vector from observation to runway threshold</u>
The first step relates to finding the vectors between the observed latitude and longitude and the runway threshold coordinates.

Given that the earth's longitude lines are not equally spaced around the globe, a longitude correction needs to be done for the position of the observations (Veness, 2022). To include this, the following horizontal (X) and vertical (Y) vector components have been calculated as expressed in Equation 3 and Equation 4:

$$X_1 = (OBS_{lon} - THR_{lon}) * \cos(\frac{OBS_{lat} - THR_{lat}}{2}) \quad (3)$$

Where OBS_{lon} represents the observed longitude value, and THR_{lon} represents the longitude value of the runway threshold. And $\cos(\frac{OBS_{lat}-THR_{lat}}{2})$ representing the scaling correction based upon the midpoint of the latitudes between the two coordinates.

$$Y_1 = OBS_{lat} - THR_{lat} \quad (4)$$

Where OBS_{lat} represents the observed latitude and THR_{lat} representing the latitude at the runway threshold coordinates.

Next vector components from the FAF to the runway threshold need to be calculated.

Step 2 – Find vector from FAF to runway threshold

The horizontal and vertical component of the vector are calculated as expressed in Equation 5 and Equation 6 respectively:

$$X_2 = (FAF_{lon} - THR_{lon}) * \cos(\frac{FAF_{lat} - THR_{lat}}{2}) \quad (5)$$

Where FAF_{lon} represents the observed longitude value, and THR_{lon} represents the longitude value of the runway threshold. And $\cos(\frac{FAF_{lat}-THR_{lat}}{2})$ representing the scaling correction based upon the midpoint of the latitudes between the two coordinates.

$$Y_2 = FAF_{lat} - THR_{lat} \quad (6)$$

Where FAF_{lat} represents the observed latitude and THR_{lat} representing the latitude at the runway threshold coordinates.
With the vector components for both vectors, the next step would be to calculate the dot product.

Step 3 – Calculate the dot product

With the respective vectors having been established, the dot product is calculated as expressed in Equation 7:

$$V_1 \cdot V_2 = X_1X_2 + Y_1Y_2 \quad (7)$$

Where X_1 and Y_1 represent the vector components from the observed coordinates to the runway threshold. And X_2 and Y_2 represent the vector components from the FAF to the runway threshold.

The next step required prior to establishing the angle is to calculate the magnitude for both vectors.

Step 4 – Determine magnitude of vector

The magnitude for each vector is calculated as expressed in Equation 8:

$$||V_i|| = \sqrt{{X_i}^2 + {Y_i}^2} \quad (8)$$

Where X_i represents the horizontal component of the respective vector and Y_i represents the vertical component of the respective vector.

The magnitude is calculated from both vectors. The magnitude of the vector from the observed latitude and longitude to the runway threshold will be referred to as $||V_1||$. The magnitude of the vector from the FAF to the runway threshold will be referred to as $||V_2||$.

With the magnitude for both vectors and the dot product, the angle between the vectors can be computed.

Step 5 – Determine deviation angle

With the dot product, the vectors and their respective magnitudes having been established the deviation angle can be computed. As explained by Harnew (2012) this is calculated by normalised unit vectors as expressed in Equation 9:

$$\gamma = \cos^{-1}\left(\frac{V_1 \cdot V_2}{\|V_1\| * \|V_2\|}\right) \tag{9}$$

Variable $\|V_1\|$ represents the magnitude of the vector from the observed latitude and longitude to the runway threshold. And $\|V_2\|$ represents the vector from the FAF to the runway threshold. Dividing the dot product by the multiple of the vector magnitudes ($\|V_1\| * \|V_2\|$) scales the comparison. This operation effectively normalises both vectors treating them as unit vectors and allows for the determination of the angle between them solely based on their direction. A visual representation of computed horizontal deviation angles for an approach trajectory is shown in Figure 19.

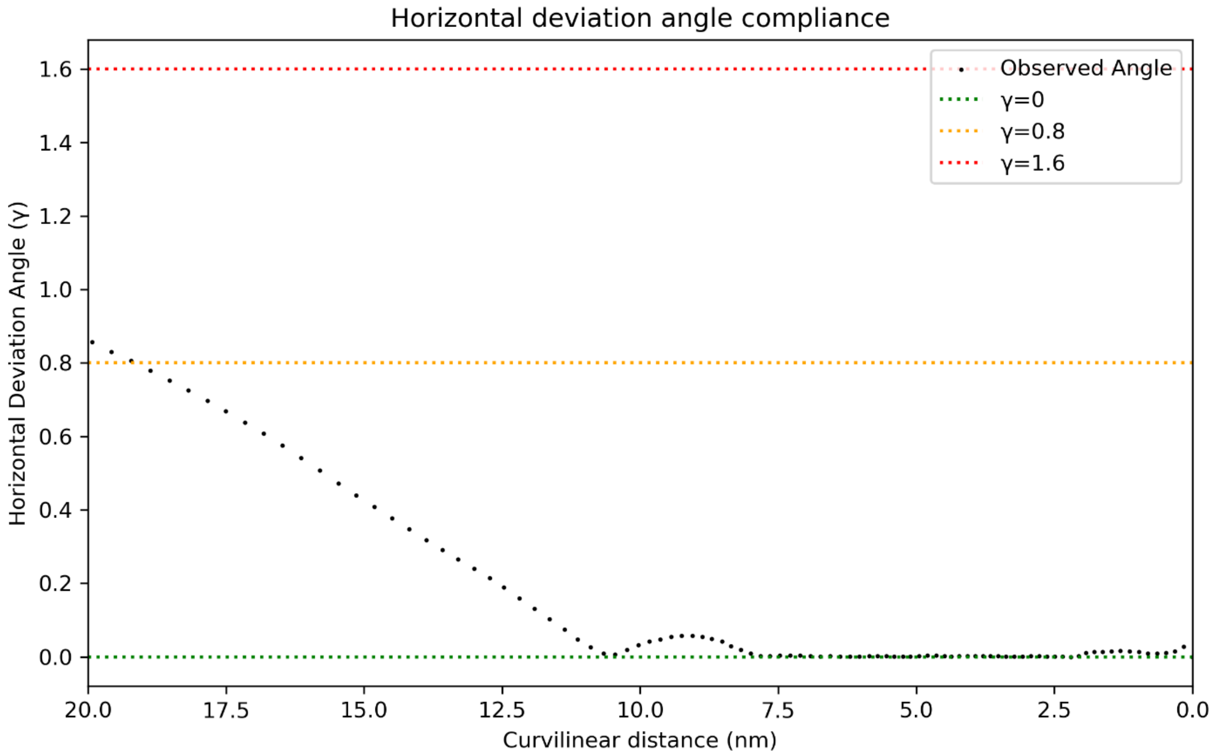


Figure 19 - Horizontal angle compliance

3.2.3.6 NSA_C6 - Indicated airspeed

Part of the stabilisation criteria states includes requirements on the indicated airspeed (KIAS). As Mode-S surveillance data includes the indicated airspeed of the aircraft, and the approach radar data does not include such information, Mode-S data is analysed. As the criteria includes comparing the KIAS value against the trend, the following step has been taken to calculate the trend value.

Step 1 – Calculate KIAS trend

To calculate the trend, a moving average has been used to generalise the trend in the KIAS variations. This concept relates to finding the overall trend through applying an arithmetic average over a fixed number of observation increments (Nau, 2014). This concept has been implemented using Equation 10:

$$\widehat{KIAS}_{i+1} = \frac{(KIAS_i + KIAS_{i+1} + \cdots + \ KIAS_{i+n_w-1})}{n_w} \tag{10}$$

Where n_w is the widow size on which the moving average is applied. And $KIAS_{i_i}$ referring to the KIAS current observation, the $KIAS_{i+1}$ referring to the KIAS for the next observation and $KIAS_{i+n_w-1}$ the last groundspeed observation based upon the window size applied. For the trend this window size is set to five. A window size of five has been established through trial and error, as higher values tended to be too generic and smaller window sizes tended to be more sensitive to fluctuations.

Enhancement – Mean moving average correction

With the mean moving average, consecutive proceeding values are used to compute the value for a given observation. The number of consecutive values based upon the window size. However, given the deceleration in the phase from the FAF until the 3 nm stabilisation point, this would underestimate the actual value due to the averaging effect of all values for the given window size. An upward adjustment has been made by the upwards rounded value of half the window size. This adjustment value being a value of 3. This adjustment ensures that the computed values are more representative of the actual indicated airspeed values by incorporating both past and future observations more evenly.

These calculated KIAS trend values will be referred to as empirical KIAS values in this thesis. The KIAS values from Mode-S will be referred to as KIAS values.

Next, non-complaint approaches will be defined.

3.3 Non-Compliant approaches

3.3.1 Definition Non-Compliant Approaches

In this thesis, the following definition of the non-compliance criteria will be used:

An approach is considered non-compliant if any of the following occur:

NCA_C1 • FAF interception angle is greater than 45 degrees
• Reduced to 30 degrees if parallel runway approaches are active
NCA_C2 • Speed is not adapted at the FAF to 180 KIAS.
NCA_C3 • Speed falls below 160 KIAS before 4 nm from threshold.
NCA_C4 • The vertical ILS glide path is intercepted from above.

3.3.2 Details of criteria conditions

When comparing the defined NCA criteria by Vernay (n.d.) against the instrument approach procedures at Schiphol airport for runway's 18C and 18R, it became apparent the procedures are not identical. As outlined in the procedures by LVNL (n.d.), the 30 seconds of level of flight is not included in the procedures prior to the FAF for runway 18R. As for runway 18C, this is level of flight occurs at 2,000 ft and is not a requirement but based upon ATC discretion. Therefore, this criterion will not be included in the definition given for procedures at Schiphol.

When comparing the criterion of adapted speed requirements against the procedures published at Schiphol, aircraft are required to have adapted the knots indicated airspeed (KIAS) to a value below or equal to 180 knots at the FAF. Therefore, the criterion is included in the definition.

Further study of the procedures showed that aircraft are required to maintain an indicated airspeed more than 160 KIAS until 4 miles from the runway threshold. This requirement will also be included in the definition given to non-compliance.

For the intercepting angle criterion, the instrument approach procedures have been studied. None of the procedures show a direct interception angle greater than 45 and 30 degrees to the FAF.

However, situations in which approach procedures can be deviated from occur through vectoring towards the FAF. Vectoring relating to aircraft being instructed by ATC through heading, altitude or airspeed instructions to guide aircraft towards a certain position. To verify the criterion on interception angle as set out by the regulations, publications by the International Civil Aviation Organisation (2007) on vectoring requirements have been studied. These state that the interception angle with respect to the FAF is limited to 45 degrees, or 30 degrees in case of active parallel runway approaches. This being identical to the criterion by Vernay (n.d.), this requirement will be incorporated in the definition of non-compliance.

The criterion on glide intercept from above have been included by Vernay (n.d.) because the navigation equipment onboard aircraft has been designed and optimised for an approach and intercept from below the approach vertical path and not above. Therefore, this criterion will be included in the definition of non-compliance.

Next, the methods used to identify variables to analyse individual criteria compliance is introduced.

3.3.3 Details how to compute criteria

Additionally, the selection of which surveillance data source variables will be explained in this section.

3.3.3.1 NCA_C1 - Interception angle

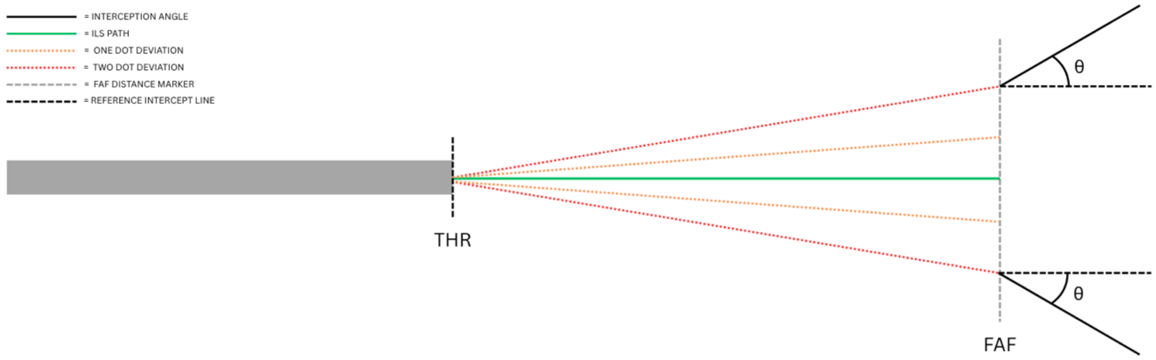


Figure 20 - FAF interception angle

As per methodology of Delahaye et al. (2018), interception angles are set to start from the two-dot horizontal deviation angle at the FAF as shown in Figure 20.

To identify intercepting angle compliance, horizontal deviation angles are used. To analyse the non-compliance, expected horizontal deviation angles for a certain interception angle must be established. Interception angles also imply certain expected angles at given distances as shown in Figure 21.

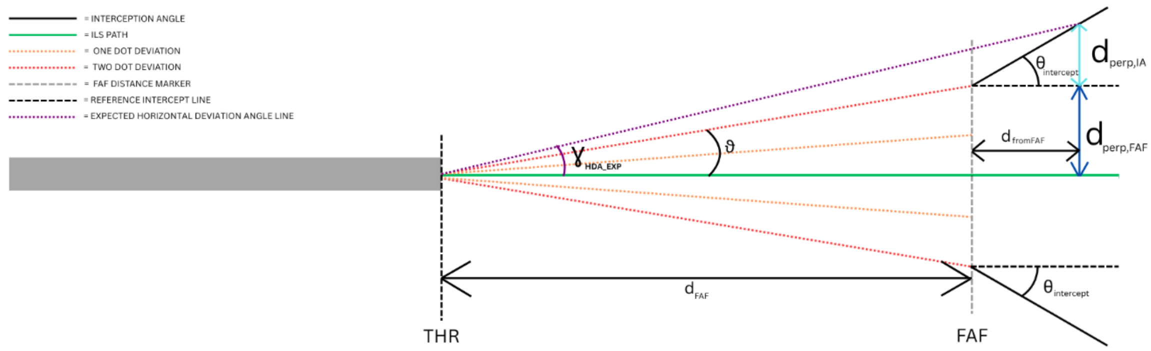


Figure 21 - Expected horizontal deviation angles visualisation

Comparing the empirical horizontal deviation angles against these values will be the identifying factor in compliance.

The first step in identifying compliance would be to calculate expected deviation angles.

Step 1 – Calculate expected deviation angles

Expected deviation angles are calculated as expressed in Equation 11:

$$\gamma_{HD\_EXP} = \frac{d_{perp,FAF} + d_{perp,IA}}{d_{toTHR}} \tag{11}$$

Where d_{toTHR} represents the curvilinear distance to the runway threshold. And $d_{perp,FAF}$, calculated as expressed in Equation 12, representing the perpendicular distance from the ILS horizontal ILS path reference at start of the interception angle. Complimented by $d_{perp,IA}$, computed as expressed in Equation 13, representing the perpendicular distance from the interception angle.

$$d_{perp,FAF} = \mathrm{d}_{FAF} * \tan(\vartheta) \tag{12}$$

Where d_{FAF} represents the distance from the runway threshold at which the FAF is set (6.2 nm) and ϑ representing the two dots angle (1.6-degrees).

$$d_{perp,IA} = d_{fromFAF} * \tan(\theta_{intercept}) \tag{13}$$

Where $d_{fromFAF}$ represents the curvilinear distance to the FAF from the current observation (d_{toTHR} – 6.2 nm). And $\theta_{intercept}$ represents the respective intercept angle (45 or 30 degrees).

The computed expected deviation angles will be referred to as expected intercept horizontal deviation angles.

Next, the surveillance data source used to verify the speed adaption requirement will be explained.

3.3.3.2 NCA_C2 - KIAS speed adaptation

As Mode-S surveillance data includes the indicated airspeed of the aircraft, and the approach radar data does not include such information, Mode-S data is analysed for this criterion. Empirical KIAS values, as calculated in Chapter 3.7.2.5 using Equation 10, will be used to remove effects of KIAS fluctuations.

Next, the variable used to verify Glide Intercept From Above will be explained.

3.3.3.3 NCA_C3 - Glide Intercept From Above

GIFA relates through intercepting the vertical ILS path from above, rather than below at the FAF. To identify approach trajectories in which this phenomenon occurs the glide angle, as explained in Chapter 3.2.3.4 and calculated using Equation 2, is used.

Next, the method used to identify a go-around is explained.

3.4 Go-Around identification

Approach trajectories that initiate a go-around have been identified through an algorithm in the preprocessing process of the surveillance data before it is stored in the database.

A go-around may occur at any point during the approach phase. The applied energy analysis in this thesis is applied between the FAF and the 3 nm stabilisation point. To ensure the energy analysis can be done on go-arounds the following steps have been taken:

<u>Step 1 – Remove initiated go-around occurrences before stabilisation point</u>
Go-arounds are excluded if the aircraft never comes within 3 nautical miles of the runway threshold.

<u>Step 2 – Remove surveillance data after go-around is initiated</u>
Initial sampling of go-arounds showed that flights that initiate a go-around do not necessary land on the same runway as initially intended to land. Therefore, the energy analysis on go-arounds will only be done on the initial approach prior to the go-around on the intended landing runway's 18C and 18R.

To remove the data after the initiation of a go-around, each observation after 3 nm to the runway threshold has been analysed. The go-around is identified if:

- The next five consecutive observations show positive vertical speed,
- These vertical speeds are increasing,
- And if the groundspeed for next five consecutive observations is also increasing

If the above three conditions are all true for an observation, all surveillance data for the approach trajectory after the observation have been removed. These conditions were determined by analysing different go-arounds.

Next, the methods for the energy analysis will be explained.

3.5 Energy analysis

A flowchart of the energy analysis model used in this thesis, including steps taken to identify atypicality, is shown in Figure 22. With this model, observed total specific energy loss will be the criterion variable for determining atypicality.

Energy loss is directly proportional to mass. As fuel is burned throughout the flight, the aircraft's mass gradually decreases, leading to a corresponding reduction in energy levels. To analyse the energy levels of aircraft in the approach phase it is assumed that mass constant. Given the assumption, energy is expressed in Joules (J) per kilogram (kg).

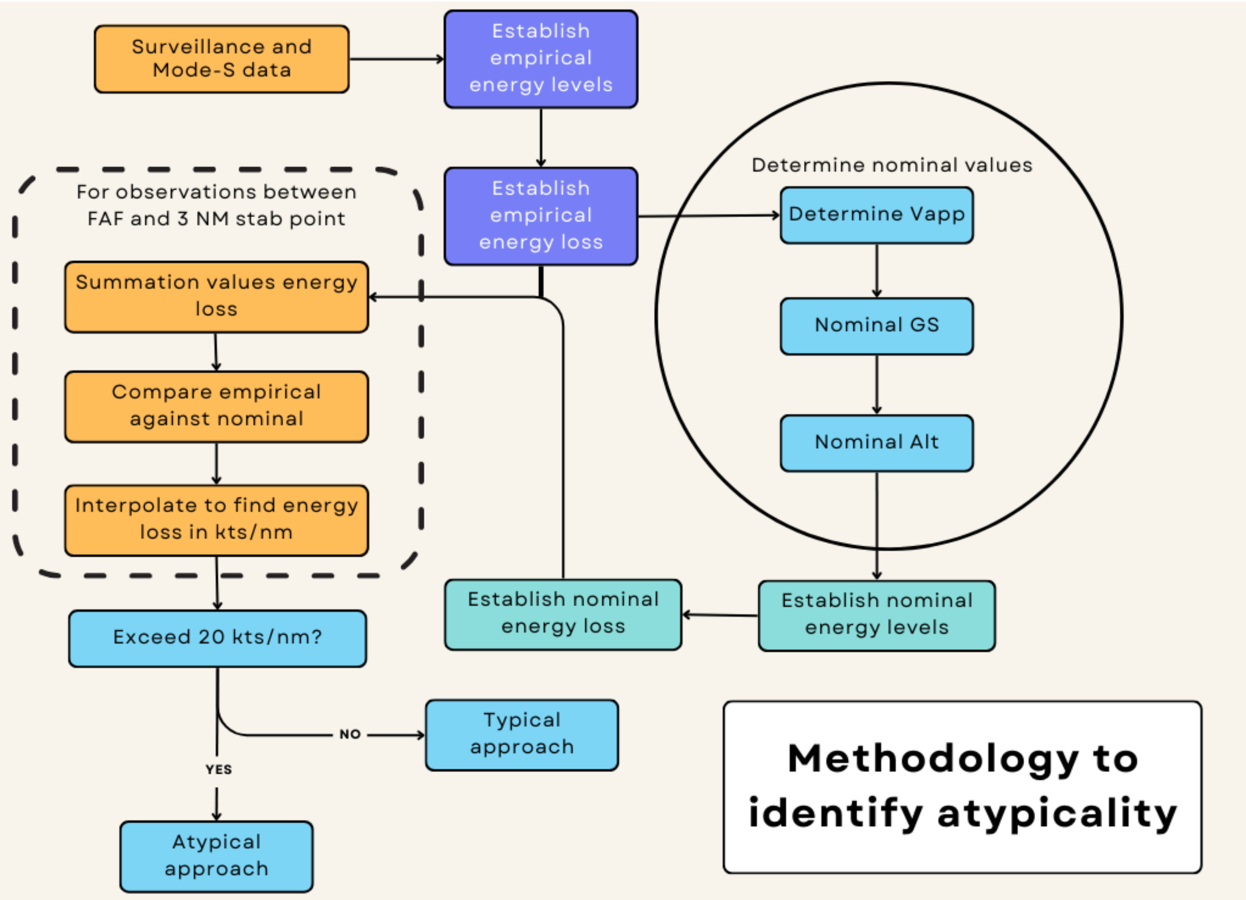


Figure 22 - Flowchart energy model

3.5.1 Compute empirical energy levels

The first step is to calculate the energy levels for the observations between the FAF and the 3 nm stabilisation point. Total specific energy (E_T) per observation is calculated with Equation 14:

$$E_T = E_C + E_P \tag{14}$$

Where E_C is the specific kinetic energy and E_P the specific potential energy.
To be able to compute the total specific energy, specific kinetic energy and specific potential energy will be computed. Firstly, specific kinetic energy computed as expressed in Equation 15:

$$E_C = \frac{1}{2} * ({G_S}^2 + {V_Z}^2) \tag{15}$$

Where G_S represents the aircrafts' groundspeed in meters per second. And is the V_Z representing the aircrafts' vertical speed in meters per second. Secondly, the specific potential energy is computed as expressed in Equation 16:

$$E_P = g * h \tag{16}$$

Where g represents the gravitational acceleration equal to 9.81 meters per second squared. And h representing the aircrafts' height (altitude) in meters based upon the current regional altimeter pressure setting at Amsterdam airport at the time of the observation.

The computed total specific, specific potential and specific kinetic energy will be referred to as empirical total specific energy, empirical specific potential energy and empirical specific kinetic energy respectively.

The total specific energy levels of one observation singularly combine altitude and kinetic energy, in both the horizontal axis through groundspeed and vertical axis through vertical speed.

3.5.2 Establish empirical energy loss

Having calculated the empirical total specific energy, the next step would be to calculate the empirical total specific energy loss.

Step 1:
For the first observation in a group, the total specific energy loss is set to zero as there is no previous observation to calculate the energy loss.

Step 2:
For the other observations in the group, the total specific energy loss is calculated as expressed in Equation 17:

$$E_{T_{Loss}} = E_{T_i} - E_{T_{i-1}} \tag{17}$$

Where E_{T_i} represent the total (*T*) specific energy at the current observation *i*, and $E_{T_{i-1}}$ representing the total specific energy at the previous observation.

Empirical total energy loss expresses changes in total specific energy levels of an aircraft. In turn this would give an indication, if consecutively analysed, of the trajectory flown. Any deviations in procedures can be analysed if changes in empirical specific energy loss deviate from nominal values.

Enhancement – Groundspeed mean moving average
In preliminary results analysis on 44,581 approach trajectories, parameters including groundspeed have been visualised. With this visualisation, it became apparent that certain trajectories showed significant fluctuations in groundspeed in the surveillance data

observations, possibly due to external environmental factors such as the wind velocity and direction. An example of such fluctuations is shown in Figure 23.

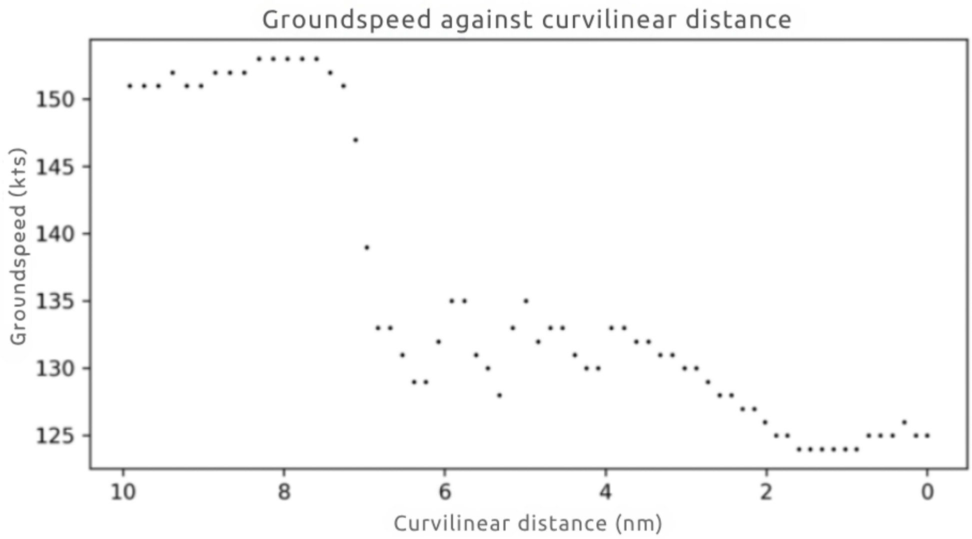


Figure 23 - Fluctuations in groundspeed

These fluctuations in aircraft groundspeed would also result into fluctuations in empirical total specific energy as groundspeed is one variable used to establish total specific energy. Specifically, an increase in groundspeed compared to the previous measure could result into a positive empirical energy loss value. Consequently, rather than experiencing a total specific energy loss, the aircraft can 'gain' total specific energy – contrary to the expected behaviour during a nominal approach. To mitigate the effects of the fluctuation, the concept of mean moving average has been used as explained in Chapter 3.2.3.6 with Equation 10.

This concept has been incorporated with a window size of both three and five. As a result, the fluctuations in groundspeed have been minimalised as seen in Figure 24 where the red line represents the change in the mean moving average compared to the previous observation for a window size of three. The purple line representing the change in the mean moving average for a window size of five.

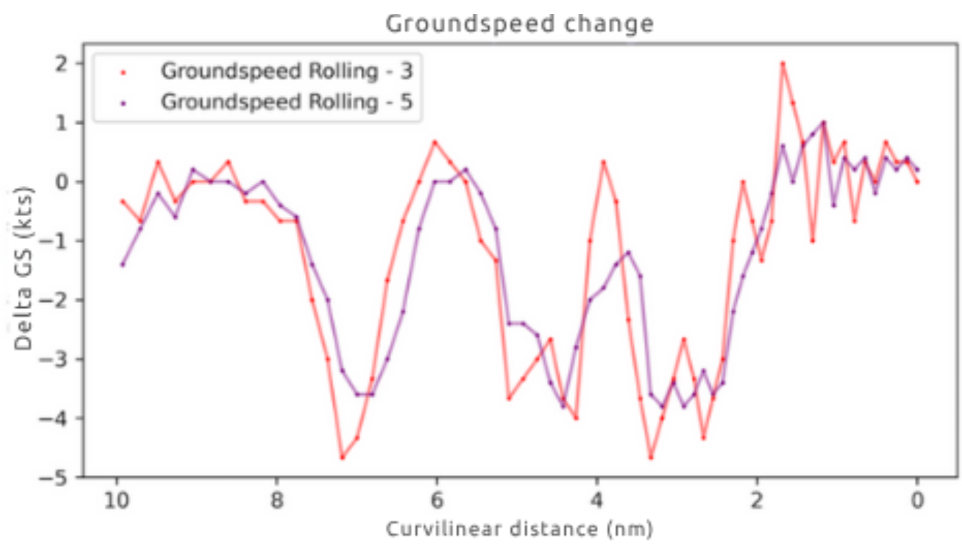


Figure 24 - Moving average groundspeed comparison

Figure 24 shows that a window size of three is more sensitive to fluctuations compared to a window size of five. For this reason, the moving average with a window size of five will be used in this thesis.

The mean moving average applied includes proceeding values (four for a window size of five). In turn, this would underestimate the groundspeed values for each observation given the averaging effect, as shown in Figure 25.

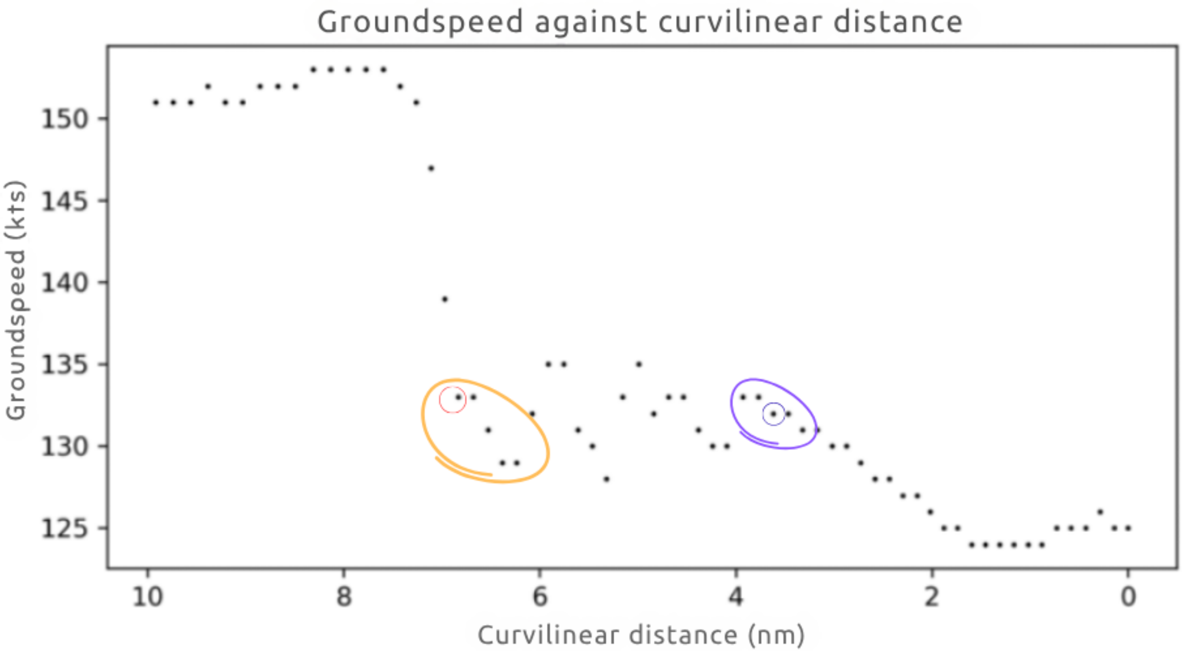


Figure 25 - Mean moving average application on groundspeed visualisation.

Where the red circle represents an observation, and the orange circle represents values included to compute the mean moving average for the red-circle groundspeed value. To correct for this underestimation, an upward adjustment of 3 has been made ensuring computed values are more representative of the actual groundspeed values by incorporating past and future observations. As shown by the purple circle showing all observations included to compute the mean moving average for the observation circled in blue.

3.5.3 Determine nominal values

To establish nominal energy values for each surveillance data observation, nominal deceleration needs to be established. Nominal deceleration has been established by Tremaud (2000) as 10 to 20 knots per nm from the FAF to the 3nm stabilisation point. In this thesis, reference nominal deceleration values will be taken as 10, 15, 17.5 and 20 knots per nm to establish nominal total specific energy losses. Where 10 represents the lower limit, 15 the median nominal value, 17,5 the cautionary limit and 20 the critical limit with respect to the nominal deceleration margin.

3.5.3.1 Determine nominal approach speed (Vapp)

The approach speed (Vapp) for an aircraft is dependent on various factors including the aircraft mass, aircraft configuration which includes flaps settings, and environmental factors such as wind velocity, wind direction, temperature and aerodrome elevation (Flight Safety Foundation, 2000b). These factors are absent in the surveillance data, which led to the following method to determine the nominal approach speed.

In a nominal approach, the aircraft would be expected to have reached the approach speed at the stabilisation point. Thereafter, a nominal approach is expected to no longer decelerate from the stabilisation point to touchdown. To establish the nominal approach, speed the average groundspeed from the 3 nm stabilisation point to the runway threshold is taken. An average has been taken to remove any singular fluctuations in groundspeed caused by environmental factors such as the wind velocity and direction. This speed is calculated as expressed in Equation 18:

$$V_{APP} = \frac{1}{n_i}\sum_{i=1}^{n_i} x_i \ for\ G_{s_{at\ THR}} \le x_i \le G_{s_{at\ 3nm}} \qquad (18)$$

Where n_i is the number of observations in the frame of observations between the 3 nm stabilisation point to the runway threshold. And x_i is representing the value of groundspeed for each observation. $G_{s_{at\ THR}}$ refers to the groundspeed at the runway threshold and $G_{s_{at\ 3nm}}$ refers to the groundspeed at the 3 nm stabilisation point.

Next, the reference nominal approach speed will be used to compute expected nominal groundspeed values for the respective surveillance data observations.

3.5.3.2 Determine expected nominal groundspeed

Expected nominal groundspeed values are determined for observations between the 3 nm stabilisation point and runway threshold, and for observations between the FAF and the 3 nm stabilisation point.

Step 1:

For any of the observations between the threshold and the 3 nm stabilisation point the groundspeed is set to V_{APP}.

Step 2:

For all observations, nominal groundspeed values can be calculated using Equation 19:

$$G_{S_{Nom}} = V_{APP} + Inc_{Ref} * (d_{toTHR} - 3) \qquad (19)$$

Where Inc_{Ref} represents the respective nominal deceleration increment in knots per nm (the 10, 15, 17.5 and 20 knots per nm). And d_{toTHR} representing the curvilinear distance to the runway threshold expressed in nm. From this curvilinear distance a value of three is subtracted to compensating for the fact that the groundspeed after the stabilisation is set to equal to V_{APP}.

3.5.3.3 Determine expected nominal vertical speed

Having calculated the expected nominal groundspeed values, the expected nominal vertical speed values can now be calculated for the observations.

For this the published vertical speed and groundspeed pairs in the landing procedures publications found in the AIP by LVNL (n.d.) will be used. These groundspeed and vertical speed pairs publish the vertical speeds required to maintain a three-degree glide-path angle for a given groundspeed. The groundspeeds published start at 100 knots and go up in increments of 20 knots until the maximum of 220 knots. The vertical speeds respectively increase from 530 ft per minute at 100 knots to 1165 ft per minute at 220 knots. As shown in Appendix IV – Vertical speed.

Using linear interpolation, the expected nominal vertical speed for a 3-degree glide slope can be calculated using the expected nominal groundspeed for each observation.

3.5.3.4 Determine expected nominal altitude

With an expected nominal groundspeed and vertical speed, the final variable required to determine reference energy levels is to calculate expected nominal altitude. Expected reference altitude is calculated as expressed in Equation 20:

$$Alt_{ref} = (d_{toTHR} * tan(3°) * 1852) \tag{20}$$

Where d_{toTHR} represents the curvilinear distance to the runway threshold expressed in nm. And $tan(3°)$ represents the trigonometric factor used to determine the altitude based upon the published procedures of a 3-degree glide slope (LVNL, n.d.). As the distance is expressed in nm it must be converted into meters by multiplying by a factor of 1852.

3.5.3.5 Determine nominal energy levels

Having calculated the expected reference altitude values (Alt_{ref}), groundspeed values ($G_{S_{Nom}}$), and vertical speed ($V_{S_{Nom}}$) values, the next step would be to calculate expected nominal energy levels, and nominal energy loss values for each approach trajectory. This is done in the following steps:

Step 1:

From Equation 20, nominal specific potential energy is established by substituting defined nominal altitude values into Equation 16.

Step 2:

From Equation 19 and the nominal vertical speed established in Chapter 3.5.3.3, nominal specific kinetic energy is established by substituting defined nominal groundspeed and vertical speed values into Equation 15.

Step 3:

Nominal specific total energy is established using Equation 14 with nominal specific kinetic and potential energy values.

3.5.3.6 Determine nominal energy loss

The respective nominal total specific energy loss can be calculated using nominal total specific energy as expressed in Equation 17.

Next, deceleration and atypicality will be established by comparing the empirical energy losses against nominal energy losses.

3.6 Identify deceleration rates and atypicality

The energy lost by an aircraft in the approach phase studies has a direct linear correlation with the deceleration rates as explained in Chapter 2. The first step in identifying deceleration rates and atypicality is done through a summation of the empirical energy losses and nominal energy losses.

3.6.1 Energy loss comparison

The summation is based on all the surveillance data observations between the FAF and the 3 nm stabilisation point. The cumulative total specific loss being calculated as expressed by Equation 21:

$$Cumulative\ total\ specific\ energy\ loss\ E_T = \sum_{i=FAF}^{3\ nm} E_{T_{LOSS}}(i) \tag{21}$$

Where $E_{T_{LOSS}}(i)$ is the total specific energy loss for the current observation *i*, a point in the trajectory.

This equation is also applied to the nominal values to establish reference nominal cumulative energy loss values. An example of these values is shown in Table 1, for an approach trajectory with an approach groundspeed of 142.9 knots.

	Cumulative total specific energy loss (J/kg)
Empirical cumulative total specific energy loss	-10,321.6
Nominal cumulative total specific energy loss (10 kts/nm)	-8,615.8
Nominal cumulative total specific energy loss (15 kts/nm)	-9,895.3
Nominal cumulative total specific energy loss (17.5 kts/nm)	-10,546.9
Nominal cumulative total specific energy loss (20 kts/nm)	-11,198.3

Table 1 - Cumulative energy loss example

With the empirical and nominal cumulative total specific energy losses, deceleration can be established.

3.6.2 Establishing deceleration

The deceleration rate of an aircraft is directly linked to its cumulative total specific energy loss, following a linear correlation. By applying interpolation or extrapolation, it is possible to determine the deceleration rate based on this relationship. Specifically, comparing the actual (empirical) total specific energy loss of an aircraft to the nominal values allows for the estimation of its deceleration.

An example of this is shown in Figure 26, in which through interpolation of the cumulative empirical against nominal total specific energy losses, the deceleration is established to be 16.6 kts/nm from the FAF until the 3 nm stabilisation point.

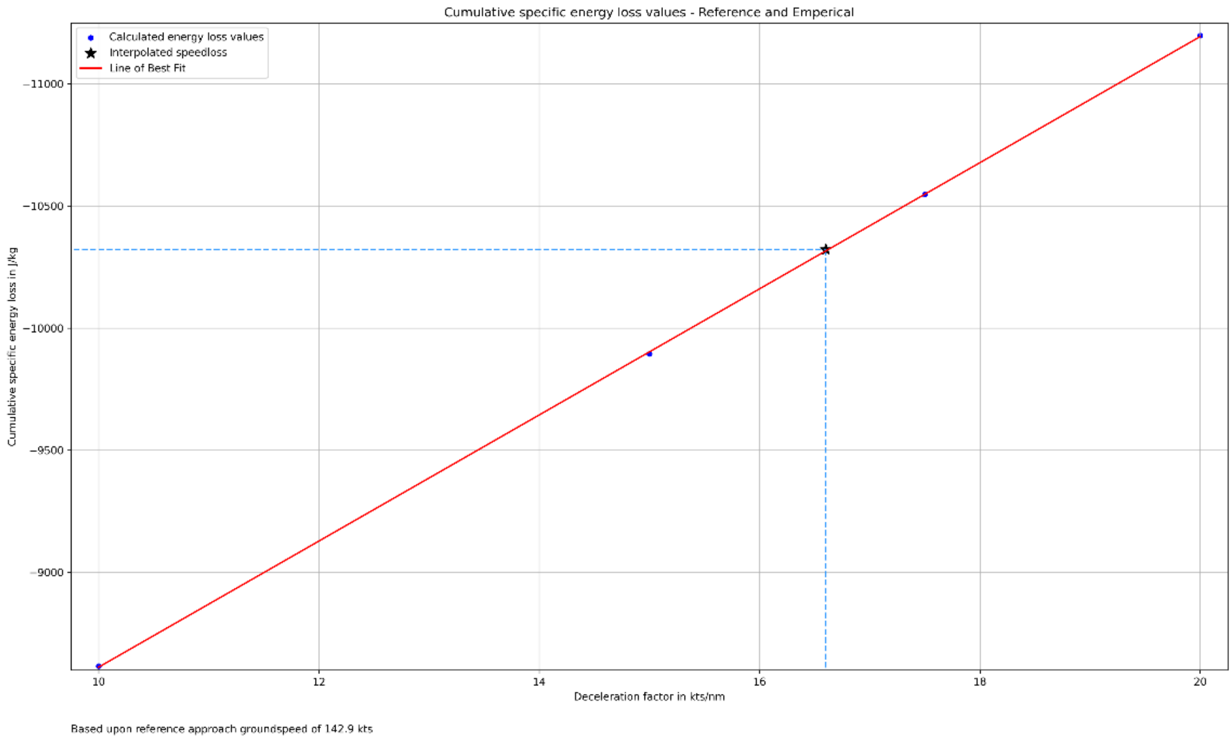


Figure 26 – Cumulative total specific energy losses, interpolation to establish deceleration in kts/nm.

With the deceleration rate, atypicality can be identified.

3.6.3 Identifying atypicality

If the deceleration rate is below or equal to 20 knots, the approach is nominal. If the deceleration rate exceeds 20 knots the approach is identified as atypical.

Having established if an approach trajectory is identified as atypical, the next sub-chapter will include details on the algorithm used to identify NCA and NSA.

3.7 Algorithm

This chapter will outline the steps taken to analyse individual NSA/ NCA criteria using the variables established in Chapter 3.2.3 and Chapter 3.3.3. Firstly, the structure of the surveillance data will be explained.

3.7.1 Structure data

The surveillance data is composed of flight id, longitude, latitude, altitude, groundspeed, time, vertical speed, heading, bank angle, indicated airspeed, aircraft type, aircraft operator, aircraft registration, aircraft observed wind velocity and aircraft observed wind direction. Also included is a timestamp of the observation. Data has already been pre-processed before it's added to the database. This pre-processing process also includes algorithms having determined the respective landing runway for each unique flight id and complemented it to the dataset. The surveillance data is recorded once every 4 seconds.

Before the surveillance data is analysed, the data is first grouped per flight identification (id) number. A group would thus represent all the observations in the data for one unique flight id. This is followed by sorting the observations chronologically in the group based upon the individual timestamp of each observation. This ensures aircraft surveillance data is chronologically sorted for each approach trajectory allowing for analysis.

3.7.2 Stabilisation criteria

Stabilisation criteria, as outlined in Chapter 3.2.1, can be split into the following five categories:

- Vertical speed criteria
- Bank angle criteria
- Vertical ILS path deviation angles
- Horizontal ILS path deviation angles
- KIAS requirements

The analysis of all stabilisation criteria categories will consider all observations between the FAF and the 3 nm stabilisation point.

Firstly, criteria on vertical speed will be analysed to identify non-stabilised approaches.

3.7.2.1 Vertical speed

3.7.2.1.1 NSA_C1 - Vertical speed > 1,000 ft/min

If any of the observed vertical speed exceeds 1,000 ft per minute, the approach trajectory is identified as non-stabilised for vertical speed exceeding 1,000 ft per minute.

Algorithm enhancement – Vertical speed segmentation

The analysis on non-stabilisation criteria revealed that vertical speed exceeding 1,000 ft per minute between the FAF and stabilisation point does occur within the sample approach trajectories. The sample based upon preliminary results of 44,581 approach trajectories analysed. However, the results do not specify the exact segment of the final approach where these high levels of vertical speed occur. To address this, the analysis has been refined by introducing three distinct approach phases. These being:

- Entire segment - From the FAF (6.2 nm) to the 3 nm stabilisation point.
- Last two miles - From 5 nm to the 3 nm stabilisation point.
- Last mile - From 4 nm to the 3 nm stabilisation point.

By segmenting the approach, the analysis provides greater insight into where instances of vertical speed exceeding 1,000 ft per minute occur.

Next, identification of the second criterion on vertical speed is explained.

3.7.2.1.2 NSA_C2 - Vertical speed > 50% of targeted vertical speed

If any of the observed vertical speeds exceed the expected maximum target vertical speed, the approach trajectory is identified as non-stabilised for targeted vertical speed.

Next, NSA criteria on bank angle will be analysed.

3.7.2.2 NSA_C3 - Bank angle

If for any of the observations the bank angle exceeds 30 degrees, the approach trajectory is identified as non-stabilised for bank angle.

Next, vertical and horizontal approach path deviation is analysed.

3.7.2.3 NSA_C4 - Vertical approach path deviation

If any of the empirical glide angle values exceed the expected glide angle for 1 dot deviation, the approach trajectory is identified as non-stabilised for vertical approach path deviation.

3.7.2.4 NSA_C5 - Horizontal approach path deviation

If any of the empirical horizontal deviation angles exceed 0.8-degrees (1-dot), the approach trajectory is identified as non-stabilised for horizontal approach path deviation.

Algorithm enhancement – Horizontal deviation segmentation

Horizontal deviation angle segments have also been incorporated into the algorithm. By applying segments to the horizontal deviation angle, approach path intercepts between the FAF and the stabilisation point could be identified. The three distinct approach phases used in the vertical speed analysis (Chapter 3.7.2.1) have been included in this segmentation.

Next, the criterion on indicated airspeed is analysed.

3.7.2.5 NSA_C6 - KIAS

KIAS values for each observation are compared against the empirical KIAS values. If any of the KIAS values exceed the +10/-5 difference threshold compared against empirical values, the approach trajectory is identified as non-stabilised for KIAS variations.

Next, methods for detecting non-compliant approaches through analysing individual compliance criteria will be introduced.

3.7.3 Non-compliant approaches

Compliance criteria, as outlined in Chapter 3.3.1, can be split into the following categories:

- Intercept angles
- KIAS speed adaption requirements
- Glide Intercept From Above.

Firstly, criteria on intercept angles will be analysed. For this all observations between 7.2 curvilinear to the runway threshold and the FAF will be analysed.

3.7.3.1 NCA_C1 - Intercept angle

An approach is identified as non-compliant for intercept angle if all the empirical horizontal deviation angles exceed the expected intercept horizontal deviation angles.

Next, criteria on speed adaption will be analysed. For this all observations between the FAF and 3 nm stabilisation point will be analysed.

3.7.3.2 NCA_C2 - KIAS speed adaptation

To be able to identify speed adaption compliance at given distances, the following steps are taken:

Step 1 – Identify surveillance data observation

The observation nearest to but still below the reference distance for FAF (6.2 nm) is analysed.

For the speed requirement at 4 nm before the runway threshold, the last observation where curvilinear distance to the runway is greater than 4.0 nm is taken.

Step 2 – Identify compliance

Speed adaptation FAF

An approach trajectory is identified as non-compliant (non-adapted) for the FAF speed restriction if the empirical KIAS speed exceeds the 180 knots. In this thesis, it will be referred to non-compliant given non-adapted KIAS at the FAF.

Speed adaption requirement 4 nm threshold

The approach trajectory is identified non-adapted for the 4 nm speed restriction if the empirical KIAS value is below the 160 knots restriction before 4 nm curvilinear to the threshold. In this thesis, it will be referred to non-compliant given non-adapted KIAS at the 4 nm from runway threshold.

Algorithm enhancement – Speed adaption ranges

An analysis on preliminary results of 44,581 approach reveals that non-speed adaption at the FAF does occur within the sample approach trajectories. However, the results do not specify the extent to which the speed adaptation requirements are breached. Specifically, it does not indicate the difference between the empirical KIAS at the FAF and the required 180 knots or below. To address this, speed adaptation has been introduced in three defined ranges:

- Speed adaptation at the FAF for 180 knots.
- Speed adaptation for 182.5 knots.
- Speed adaptation for 185 knots.

By incorporating these ranges into the algorithm, the speed deviations at the FAF can be clearly identified. In turn providing a structured representation of the observed differences from the required speed.

Next, compliance criteria on Glide Intercept From Above (GIFA) will be analysed. This will include analysis of all observations between 9.4 and 6.4 curvilinear to the runway threshold. The reference starting distance of 9.4 nm curvilinear has been chosen due to it being the distance for both runway 18C and 18R where an approach waypoint has been set prior to the FAF which is still on the extended horizontal ILS path.

However, this may exclude flights in which GIFA phenomenon is present, but only in the latter stage of the approach before the FAF. Therefore, a second GIFA indicator has been introduced – GIFA short.

3.7.3.3 NCA_C4 - GIFA

For the approaches at Amsterdam airport Schiphol, the nominal reference vertical ILS path is set at 3-degrees (LVNL, n.d.). Therefore, any approach where the glide angle consistently exceeding 3-degrees prior to the FAF intercepts the glide path from above.

An approach is identified as non-complaint for GIFA if the glide angle exceeds 3-degrees for all observations.

An approach is identified as non-compliant for GIFA-short if the glide angle exceeds 3-degrees for all observations between 7.2 nm curvilinear to the threshold and the FAF.

Algorithm enhancement – One dot and two dot deviations GIFA

GIFA has previously been stated to occur when a glide angle consistently exceeds 3-degrees for observations between 9.4 and 6.2 curvilinear to the runway. However, this does not give insight by how much the glide angle exceeds the 3-degree reference. Therefore, for both GIFA and GIFA short, dot deviations have been included in the GIFA analysis. Where the angle of one dot deviation is set to 3.36-degrees and two dots deviation is set to 3.72-degrees.

By including GIFA for one dot (glide angles consistently exceeding 3.36 degrees) and two dots (exceeding 3.72 degrees), the analysis provides insight into the extent to which the approach intercepts the vertical ILS path from above.

3.8 Statistics

The seventh and final phase relates to statistically testing the relation between atypical approaches with individual NCA criteria, individual NSA criteria and go-around occurrences.

Atypicality may still occur with flights that proceed to land. It is expected that atypicality differ between approaches that instigate a go-around compared to those that conclude in a landing. This anticipated difference motivates an investigation into whether a correlation exits between higher-than-nominal total specific energy losses and go-around occurrences. To assess this potential relationship, statistical testing will be conducted.

Furthermore, statistical testing will also be used to establish if a correlation is present between individual non-compliance criteria, individual non-stabilisation criteria and atypicality. Through testing, correlation between these individual criteria and atypicality can be established.

In this thesis, a one-tailed z-test for proportions will be used to determine statistical significance. This statistical testing method is used because:

- It can be assumed that aircraft deceleration rates are normally distributed. As the shape of the curve shown in Figure 27, of a sample of the total number of approach trajectories analysed, is symmetric.
- Atypicality refers to the deceleration rates exceeding 20 knots per nm and being a proportion of the sample population.
- One approach having been identified as atypical does not affect another approach trajectory. Each have been studied separately to identify atypicality.
- The number of approach trajectories analysed will exceed 30.

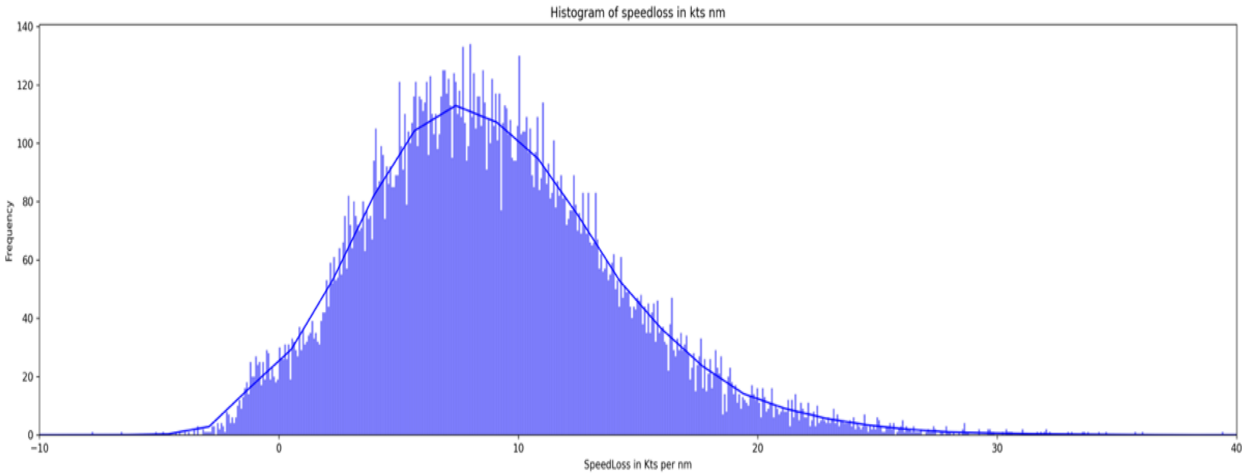


Figure 27 - Deceleration rates of sample approach trajectories

For the statistical test, the following steps are taken:

Step 1 - State null hypothesis and alternative hypothesis

In the first step, the hypothesis will be stated as. In the hypothesis two groups will be analysed. Group 1 refers to approaches that proceed to land. Group 2 refers to the approaches analysed where a certain condition is met. An example condition could be of a group could be all the approaches that initiate a go-around, all the approaches that are non-speed adapted at the FAF, etc. The hypotheses are stated:

H_O : $There\ is\ no\ significant\ difference\ in\ atypicality\ occurrence\ between\ Group\ 1\ and\ Group\ 2\ (p_1 = p_2).$

H_A : $The\ occurence\ of\ atypicality\ is\ significantly\ higher\ in\ Group\ 2\ compared\ to\ Group\ 1\ (p_2 > p_1).$

Where p_1 and p_2 relate to the proportion of Group 1 and Group 2 respectively.

With the hypotheses, the next step would be to determine the alpha level for the test.

Step 2 – Determine alpha level

In this thesis, an alpha level of 0.05 (5%) will be taken. In other words, the statistical testing results would be with 95% certainty that the test conclusion is correct.

With the alpha level for the test having been established, the next step would be to find the critical z value for the statistical test.

Step 3 – Find critical Z value

As explained by Mendenhall et al. (2008), the critical z value is based upon the standard normal distribution table. Computing this for a one tailed z test this critical z-value for an alpha level of 0.05 equates to:

$$Z_{critical} = 1.645$$

With the critical z value, the next step would be to calculate the z test statistic value.

Step 4 – Calculate Z test statistic value

The Z-test statistical value, for sample sizes less than 10% of the population, is calculated as expressed in Equation 22:

$$Z_{test\ value} = \frac{p_1 - p_2}{\sqrt{\frac{p_2(1-p_2)}{n}}} \tag{22}$$

For sample sizes greater than 10% of the population, a correction needs to be done. This correction is referred to as the Finite Population correction. The z-test statistical value is calculated as expressed in Equation 23:

$$Z_{test\ value} = \frac{p_1 - p_2}{\sqrt{\frac{p_2(1-p_2)}{n}} * \sqrt{\frac{N-n}{N-1}}} \tag{23}$$

Where n is the sample size and N referring to the population size.

With the Z-test statistical value, the next step would be to compare the test value against the critical value.

Step 5 – Compare test statistic against critical value - Reject or accept hypothesis

With both the Z-test value and the critical Z value, statistical significance can be determined through comparing the test statistic against the critical value. From the comparison, the null hypothesis can either be accepted or rejected:

Reject alternative hypothesis: The alternative hypothesis is rejected if the z-test statistical value is less than the critical z-value.

Accept alternative hypothesis: The alternative hypothesis is accepted if the z-test statistical value is greater than the critical z-value.

4 Results and Discussion

4.1 Results analysis

In this thesis, historical surveillance data of 312,100 approach trajectories at Amsterdam Airport Schiphol have been analysed between May 2022 and April 2025. These includes 537 go-around occurrences. First, a visualisation of approaches identified as atypical for both runway 18C and 18R are shown.

4.1.1 Visualisation atypical approaches

A visualisation of approaches identified as atypical for runway 18C is shown in Figure 28.

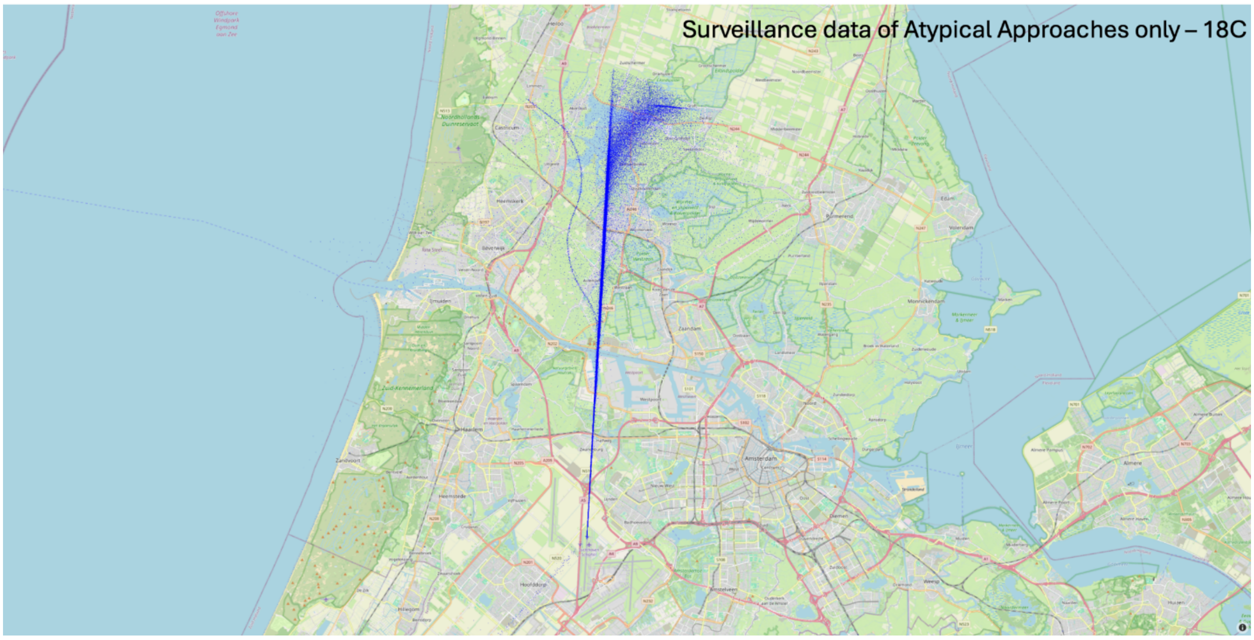


Figure 28 - Visualisation identified atypical approaches for runway 18C

A visualisation of approaches identified as atypical for runway 18R is shown in Figure 29.

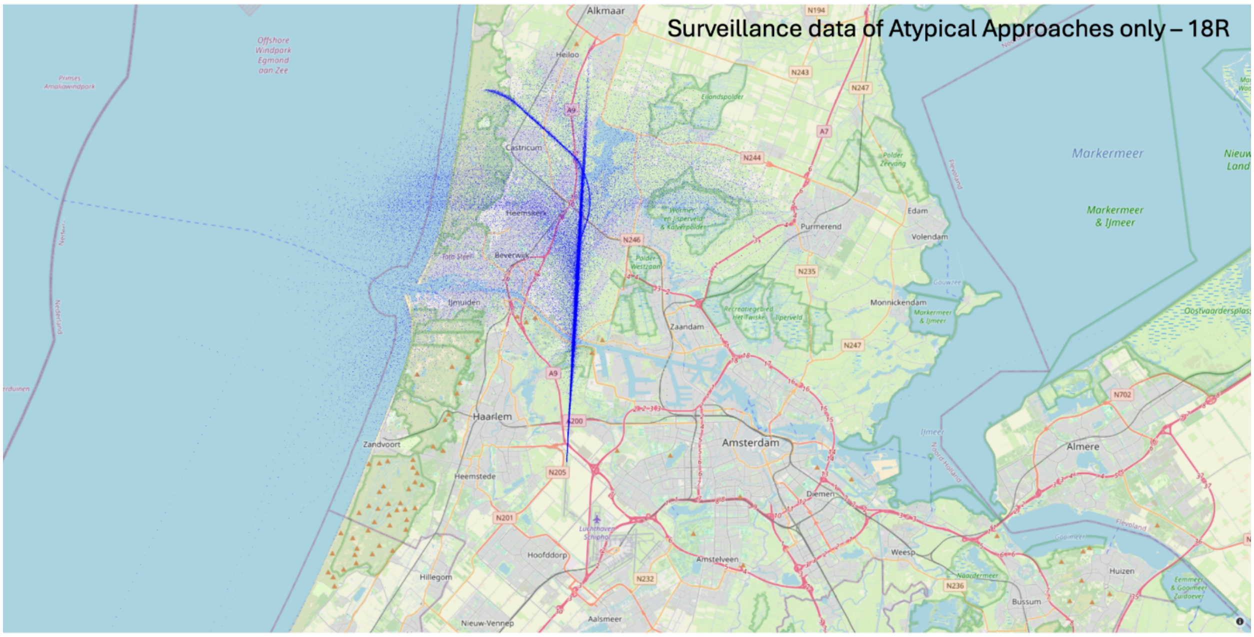


Figure 29 - Visualisation identified atypical approaches for runway 18R

In both figures, a surveillance data observation is represented by a blue dot. The more observations are close to one another, the darker the colour blue. By analysing the pattern of the darker blue surveillance observations, the trajectories can be interpreted.

In Figure 28, this showed a clear pattern of atypical approaches turning onto the final approach path from the east for runway 18C.

In Figure 29, this showed a clear pattern of atypical approaches turning onto the final approach path from the west for runway 18R. Particularly a turn onto the approach path overflying the town Heemskerk. Also, a particular pattern is seen in the night procedure to join the approach path by the apparent darker blue line showing approach path join through flying around towns such as Castricum as per night procedure design.

In the vertical plane, the altitude profiles for approaches identified as atypical for runway 18C is shown in Figure 30.

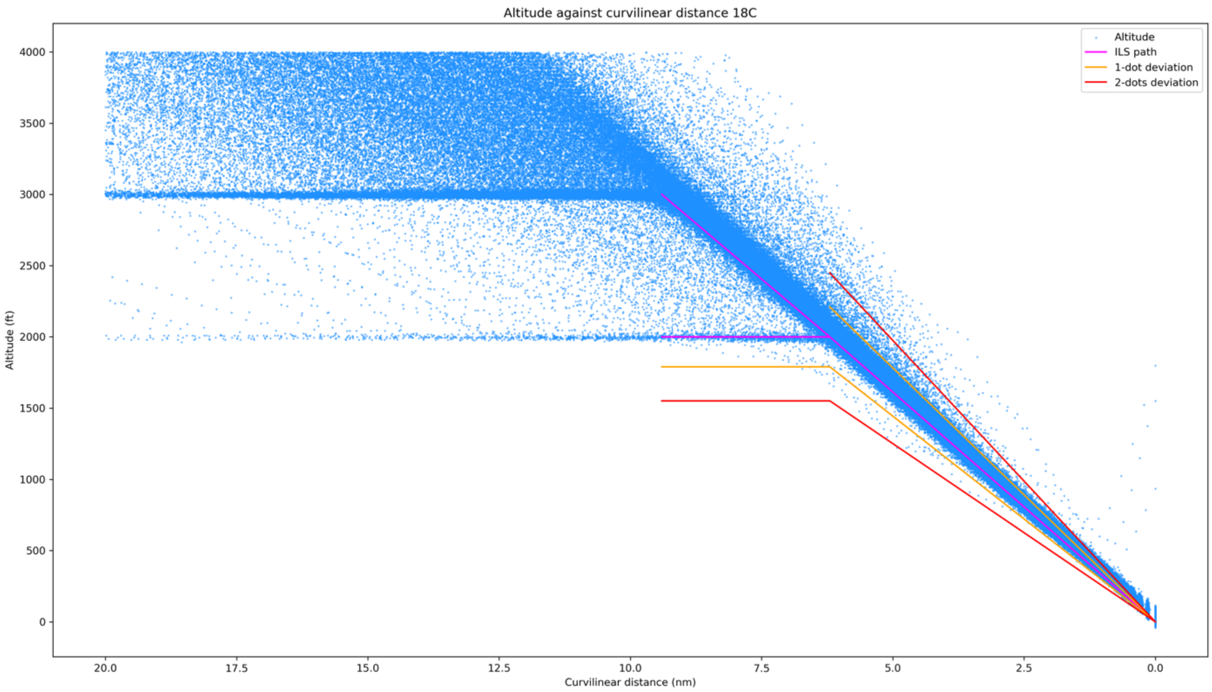


Figure 30 - Altitude profiles for identified atypical approaches for runway 18C

Where each blue dot represents an altitude observation of an approach identified as atypical. Results showed two distinct features in the altitude profile of atypical approaches:

- Majority of atypical approaches altitude profile is slightly above the designed ILS approach path.
- A distinct number of approaches maintain 3,000 ft until approximately 9 nm to the runway before descending. Possibly with a higher speed to maintain separation.

Next, the altitude profile of approaches identified as atypical for runway 18R is shown in **Error! Reference source not found.**.

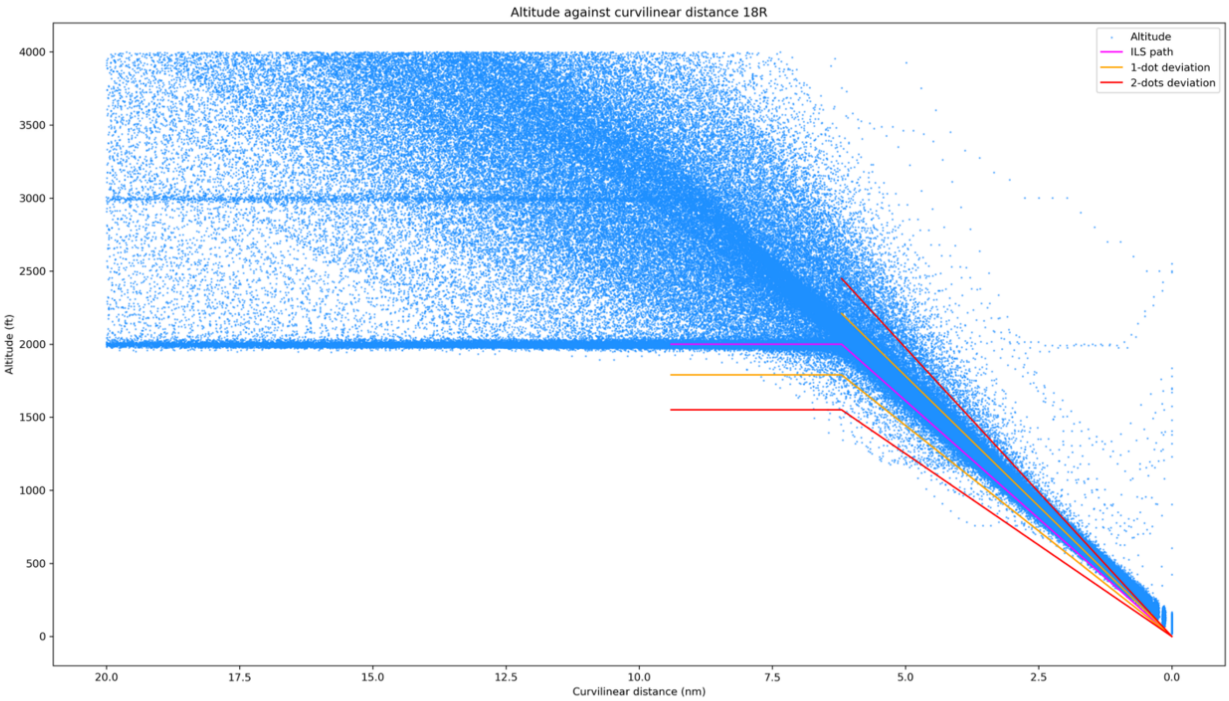


Figure 31 - Altitude profiles for identified atypical approaches runway 18R

Results showed three distinct features in the altitude profile of atypical approaches:

- Majority of atypical approaches altitude profile is above the designed ILS approach path.
- A distinct number of approaches maintain 2,000 ft until the FAF (6.2 nm).
- The deviation from the approach path is greater on 18R compared to 18C due to more observations exceeding two dots being present.

Next, an example of an approach trajectory identified as atypical on runway 18C is shown in Figure 32.

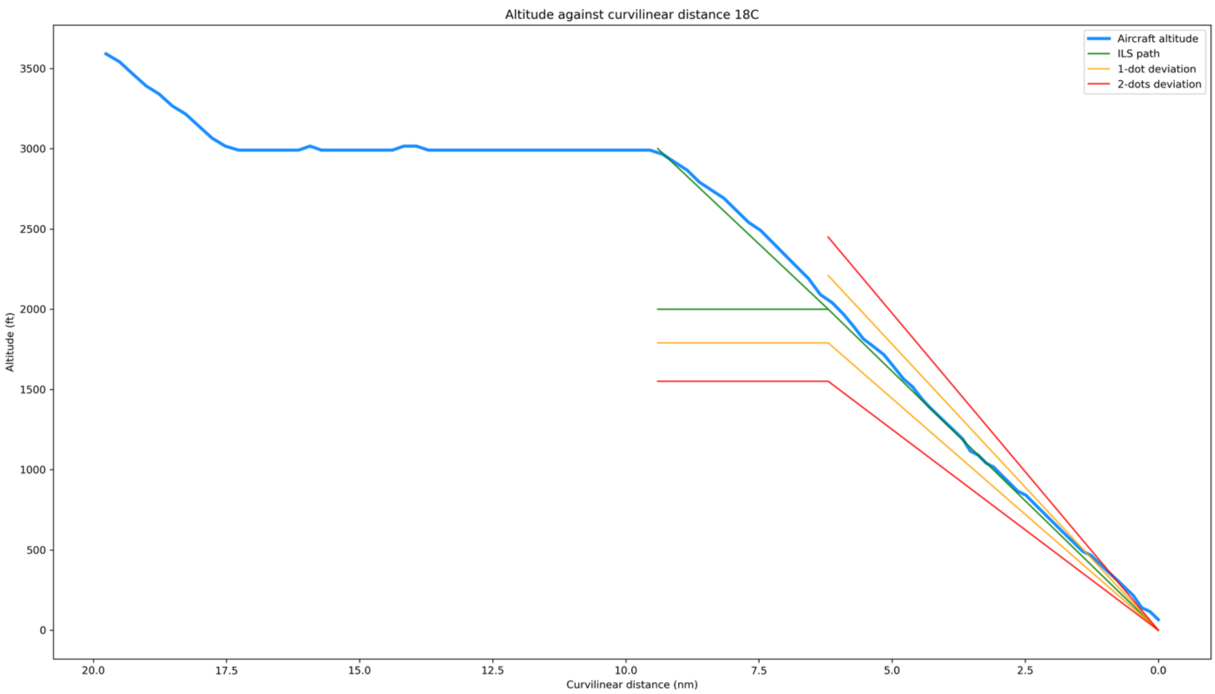


Figure 32 - Altitude profile for an example atypical approach for runway 18C

The example trajectory showing an approach path closely to the designed path denoted by the green line. However, this suggests that the trajectory had higher levels of speed that caused the approach to be identified as atypical. Next, an example trajectory of an atypical approach is shown in Figure 33.

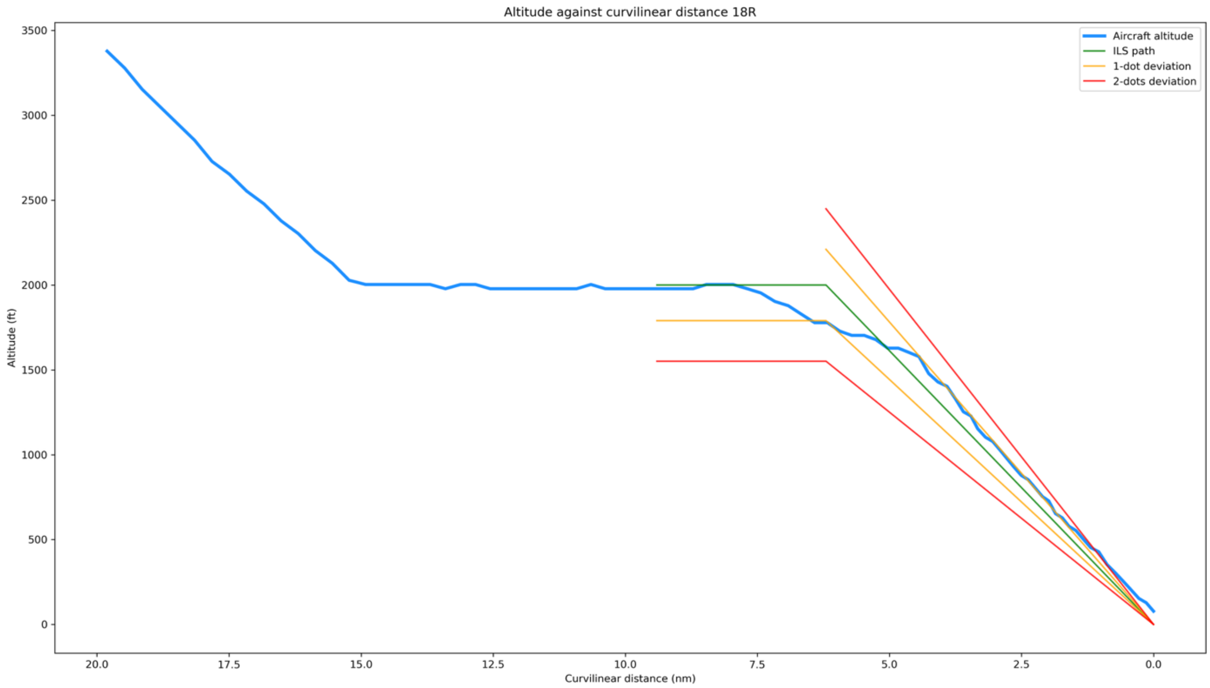


Figure 33 - Altitude profile for an example atypical approach for runway 18R

The example trajectory showing an approach path deviating from the designed path denoted by the green line. With deviations present exceeding 1-dot at different instances in the approach, which corresponds to an identifying criterion of a non-stabilised approach.

Next, atypical approach occurrence in landings and go-around occurrences is explained.

4.1.2 Analysing atypicality for landings and go-arounds

By applying the energy analysis model to the historical surveillance data, the following results have been obtained as shown in Table 2.

	Count	Ratio per 1,000
Total number approaches analysed	312,100	-
No. landings analysed	311,563	-
No. landings atypical	6,307	20.2
No. go-arounds analysed	537	-
No. go-arounds atypical	26	48.4

Table 2 - Overview atypicality results

The results show that 20.2 flights per 1,000 flights that proceed to land are atypical. This is approximately 2.5 times higher in go-around and account for approximately 5% of go-arounds (48.4 of 1,000). This underscores that go-arounds are significantly more prone to deviations compared to approaches that proceed to land.

Next, number of atypical approaches will be explained when comparing approaches for both runway 18C and 18R.

4.1.3 Analysing atypicality for runways 18C and 18R

Results of comparing atypicality occurrence for both runway 18C and 18R are shown in Table 3.

	Count	Ratio per 1,000
No. landings analysed – 18C	75,714	-
No. landings atypical – 18C	2,847	37.6
No. landings analysed – 18R	235,849	-
No. landings atypical – 18R	3,460	14.6
No. go-arounds analysed – 18C	77	-
No. go-arounds atypical – 18C	4	51.9
No. go-arounds analysed – 18R	460	-
No. go-arounds atypical – 18R	22	47.8

Table 3 - Overview atypicality runways results

Results show that atypicality occurs more often on runway 18C compared to 18R for approaches that proceed to land. With the ratio of atypical approaches per 1,000 landings being 2.5 times higher on 18C compared to 18R. Potentially due to higher levels of vectoring on runway 18C compared to 18R. Or because of less track miles (distance) in the approach procedure for 18C compared to 18R. Leading to same amount of energy needing to be 'lost' in a shorter distance. For the number of go-around occurrences, the number of atypical approaches is also higher for 18C compared to 18R. Having quantified the occurrence levels of atypicality, further analysis has been done to compare atypicality occurrence based on aircraft type.

4.1.4 Analysing atypicality in widebody and narrowbody aircraft

For this analysis, aircraft types have been split into two categories: widebody and narrowbody. Results in Table 4 show that atypicality occurs approximately eight times more often in narrowbody aircraft types compared to widebody aircraft types.

	Count	Ratio per 1,000
No. widebody aircraft approaches analysed	64,017	-
No. widebody approaches atypical	186	2.9
No. narrowbody aircraft approaches analysed	248,083	-
No. narrowbody approaches atypical	6,147	24.8

Table 4 - Atypicality comparison widebody and narrowbody results

The result may stem from factors including aircraft mass and vectoring. Higher mass aircraft, such as the widebody aircraft, have higher approach speeds (Vapp). As a result, widebodies have less energy to lose to reach their respective approach speed (Vapp). Secondly, narrowbodies agility can be used to vector them between incoming heavier widebody traffic. Reducing their available distance to manage speed and configuration changes, leaving them more susceptible to atypical approaches.

Next, atypicality has been analysed to identify if deviation from procedures vary when comparing day and night procedures.

4.1.5 Analysing atypicality in day and night procedures

The day and night procedure comparison includes both go-around occurrences and landings. Nighttime, as established by LVNL (n.d.), referring to landings occurring between 21:30 and 04:30 UTC. Results of this comparison are shown in Table 5 below.

	Count	Ratio per 1,000
No. day approaches analysed	293,607	-
No. day approaches atypical	6,207	21.1
No. night approaches analysed	18,493	-
No. night approaches atypical	306	16.5

Table 5 - Atypicality comparison daytime against nighttime results

The comparison revealing that atypicality occurs less often approaches conducted at nighttime compared to approaches conducted daytime. This may stem from the fact that less traffic is present throughout the nighttime. This allowing for night approaches to follow the planned approach profiles, stemming from aircraft navigation equipment, without external interference for traffic separation reasons.

Next an analysis will be done per inbound approach stack towards Amsterdam airport.

4.1.6 Analysing atypicality per stack

An analysis has been done to establish if atypicality occurrence varies per stack. Given go-around approaches do not include stack information, the following results are based on approaches that proceed to land only. Results shown in Table 6 reveal that atypicality is highest for the ARTIP stack.

	Count	Ratio per 1,000
No. approaches via RIVER analysed	84,552	-
No. atypical approaches via RIVER	1,239	14.7
No. approaches via SUGOL analysed	102,276	-
No. atypical approaches via SUGOL	1,834	17.9
No. approaches via ARTIP analysed	124,735	-
No. atypical approaches via ARTIP	3,234	25.9

Table 6 - Atypicality stack analysis results

This observation of atypicality occurrence being highest for the inbound stack ARTIP may stem from the fact that the track miles are shorter for ARTIP compared to the others. Especially to runway 18C.

Next, results on quantification of occurrence for criteria identifying NSA's are explained.

4.1.7 Atypicality & Non-Stabilised Approaches

Results of criteria on vertical speed requirements, as outlined in Chapter 3.2.1, are shown in Table 7.

	Landings count	Ratio per 1,000	Go-arounds count	Ratio per 1,000
No. landings analysed	311,563	-	-	-
No. go-around analysed	-	-	537	-
Vertical speed >1,000 ft/min (6.2 – 3 nm)	123,323	395.8	267	497.2
Of which atypical	4,929	40.0	21	78.7

Vertical speed >1,000 ft/min (5 – 3 nm)	81,442	261.4	235	437.6
Of which atypical	3,228	39.6	19	80.9
Vertical speed >1,000 ft/min (4 – 3 nm)	19,588	62.8	142	264.4
Of which atypical	968	49.4	12	84.5
Vertical speed > 50% of target	2	0.0	0	0.0
Of which atypical	1	500.0	0	0.0

Table 7 - Non-Stabilised Approach criteria analysis results – Vertical speed

Results showed that non-stabilisation for vertical speed occurs more often with go-around occurrences compared to approaches that proceed to land. As well as vertical speeds in the last mile before the stabilisation point being the strongest indicator for atypicality for both landings and go-around occurrences. With vertical speed exceeding 1,000 ft/min occurring between 4 and 3 nm from the runway threshold being the strongest indicator for atypicality. As if 1,000 approaches proceeding to land were taken, which have a vertical speed exceeding 1,000 ft/min in this segment, 49.4 of them would be identified as atypical.

Next, identifying NSA criterion on bank angle are quantified and explained.

Results of the non-stabilisation criteria on bank angle are shown in Table 8.

	Landings count	**Ratio per 1,000**	**Go-arounds count**	**Ratio per 1,000**
No. landings analysed	311,563	-	-	-
No. go-around analysed	-	-	537	-
Bank angle > 30 degrees	773	2.5	11	20.5
Of which atypical	197	254.9	4	363.6

Table 8 - Non-Stabilised Approach criteria analysis results - Bank angle

Results showed that bank angle exceeding 30-degrees occur more often with go-around occurrences, as compared per ratio of 1,000 occurrences. If 1,000 landings were taken where the bank angle exceeds 30-degrees, 254.9 of them would have been identified as atypical. Next, identifying NSA criterion on vertical ILS approach path deviation are quantified and explained.

Results of the non-stabilisation criteria on vertical ILS path deviation are shown in Table 9.

	Landings count	**Ratio per 1,000**	**Go-arounds count**	**Ratio per 1,000**
No. landings analysed	311,563	-	-	-
No. go-around analysed	-	-	537	-
Vertical ILS deviation > 1 dot reference	15,658	50.3	312	581.0
Of which atypical	1,229	78.5	20	64.1
Vertical ILS deviation > 2 dot reference	1,368	4.4	256	476.7
Of which atypical	538	393.2	19	71.2

Table 9 - Non-Stabilised Approach criteria analysis results - Vertical ILS path deviation

Results showed vertical ILS path deviation occurs more often for go-around occurrences compared to flights that proceed to land. With a higher than two-dot deviation being the strongest indicator for atypicality.

Results of non-stabilisation criteria on horizontal ILS path deviation are shown in Table 10.

	Landings count	Ratio per 1,000	Go-arounds count	Ratio per 1,000
No. landings analysed	311,563	-	-	-
No. go-around analysed	-	-	537	-
Horizontal ILS deviation > 1 dot (6.2 – 3 nm)	167	0.5	2	3.7
Of which atypical	54	323.4	2	1,000.0
Horizontal ILS deviation > 1 dot (5 - 3 nm)	129	0.4	2	3.7
Of which atypical	44	341.1	2	1,000.0
Horizontal ILS deviation > 1 dot (4 - 3 nm)	119	0.4	1	1.9
Of which atypical	42	352.9	1	1,000.0
Horizontal ILS deviation > 2 dots (6.2 - 3 nm)	37	0.1	1	1.9
Of which atypical	34	918.9	1	1,000.0
Horizontal ILS deviation > 2 dots (5 - 3 nm)	37	0.1	1	1.9
Of which atypical	34	918.9	1	1,000.0
Horizontal ILS deviation > 2 dots (4 – 3 nm)	37	0.1	1	1.9
Of which atypical	34	918.9	1	1,000.0

Table 10 - Non-Stabilised Approach criteria analysis results - Horizontal ILS path deviation

Results showed horizontal deviation occurs more frequently in go-around occurrences compared to flights that proceed to land, when comparing ratios expressed per 1,000 occurrences. With horizontal deviation greater than 2-dots being the strongest indicator for atypicality.

Results of the final stabilisation criteria on KIAS trend deviation with KIAS variations greater than the tolerated +10/-5 from the trend is not detected in any of the approaches.

Of all the individual stabilisation criteria, the proportion of atypical approaches for each has been visualised as shown in Figure 34.

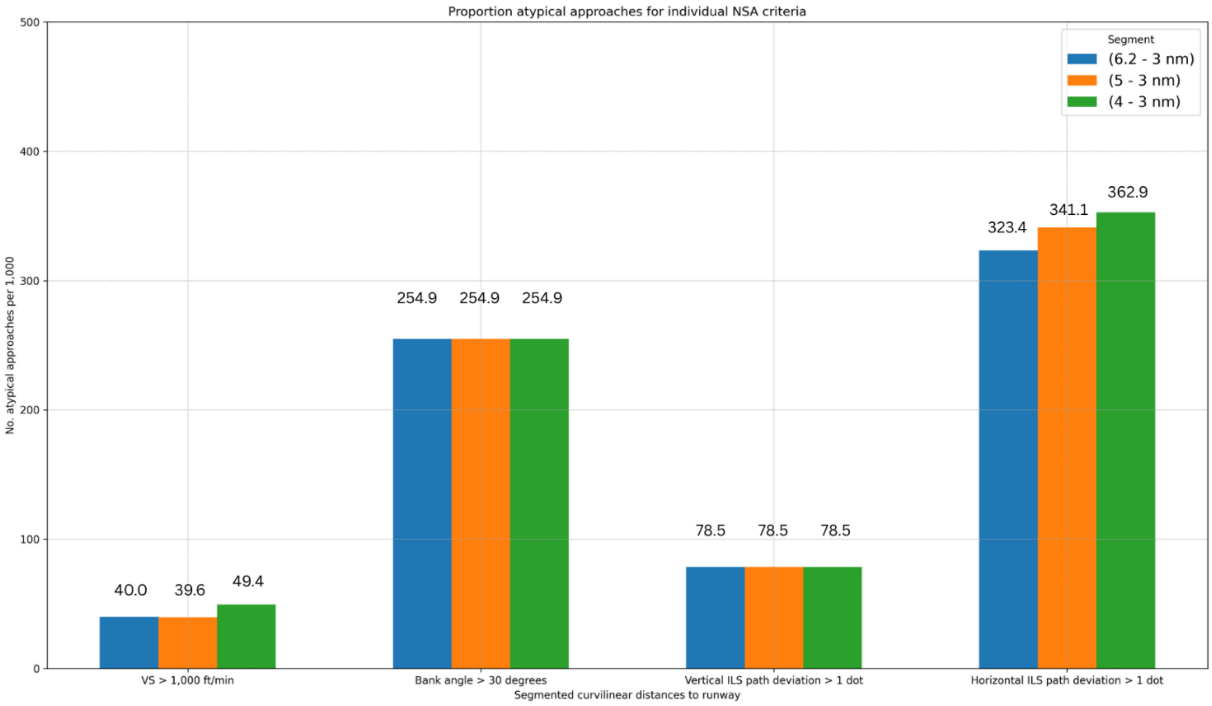


Figure 34 - Proportion atypical approaches in identifying NSA criteria

Next, results on quantification of occurrence for criteria identifying Non-Compliant Approaches are explained.

4.1.8 Atypicality & Non-Compliant Approaches

An analysis on the non-compliance criteria of Glide Intercept From Above (GIFA) has been done to quantify occurrence as shown in Table 11.

	Landings count	Ratio per 1,000	Go-arounds count	Ratio per 1,000
No. landings analysed	311,563	-	-	-
No. go-around analysed	-	-	537	-
GIFA (Glide Angle >3.00°)	65,970	211.7	69	128.5
Of which atypical	2,872	43.5	7	101.4
GIFA – short (Glide Angle >3.00°)	115,795	371.7	105	195.5
Of which atypical	4,344	37.5	10	95.2
GIFA (Glide Angle >3.36°)	2,280	7.3	21	39.1
Of which atypical	569	249.6	5	238.1
GIFA – short (Glide Angle >3.36°)	3,566	11.4	28	52.1
Of which atypical	851	238.6	7	250.0
GIFA (Glide Angle >3.72°)	478	1.5	11	20.5
Of which atypical	229	479.1	4	363.6
GIFA – short (Glide Angle >3.72°)	907	2.9	20	37.2
Of which atypical	407	448.7	5	250.0

Table 11 - Non-Compliant Approach criteria analysis results – Glide Intercept From Above

This revealed that one and two dot deviation occur more frequently in go-around occurrences compared to landings. Along GIFA for two dots being the strongest indicator for atypicality. As if 1,000 landings were taken where GIFA is present with a glide angle exceeding two dots (3.36-degrees), 479.1 of the approaches would be atypical. For go-arounds this would be 363.6 out of a 1,000.

Next, speed adaption compliance has been analysed as shown in Table 12. With non-adaption referring to approaches where the empirical KIAS is higher than the approach design criteria for the FAF, and lower than the requirement for 4 nm from runway threshold.

	Landings count	Ratio per 1,000	Go-arounds count	Ratio per 1,000
No. landings analysed	311,563	-	-	-
No. go-around analysed	-	-	537	-
Non-Adapted KIAS – FAF (180 kts)	68,054	218.4	106	197.4
Of which atypical	4,946	72.7	9	84.9
Non-Adapted KIAS – FAF (182.5 kts)	41,230	132.3	63	117.3
Of which atypical	4,544	110.2	7	111.1
Non-Adapted KIAS – FAF (185 kts)	26,806	86.0	34	63.3
Of which atypical	4,082	152.3	7	205.9
Non-Adapted KIAS – 4 nm from runway	94,680	303.9	181	337.1
Of which atypical	1,071	11.3	8	44.2

Table 12- Non-Compliant Approach criteria analysis results - Speed adaption

Results showed non-adaption at the FAF being occurring more often for flights that proceed to land compared to go-around occurrences. Also showing non-adaption at the FAF with a speed higher than 185 knots being the strongest indicator for atypicality for both landings and go-around occurrences. Non-adaption at 4 nm from the runway threshold occurring more often, as a ratio per 1,000, for go-around occurrences compared to landings.

Results of interception angle compliance show no non-compliance for both 45 and 30-degrees interception angles.

Of all the individual stabilisation criteria, the proportion of atypical approaches for each has been visualised as shown in Figure 35.

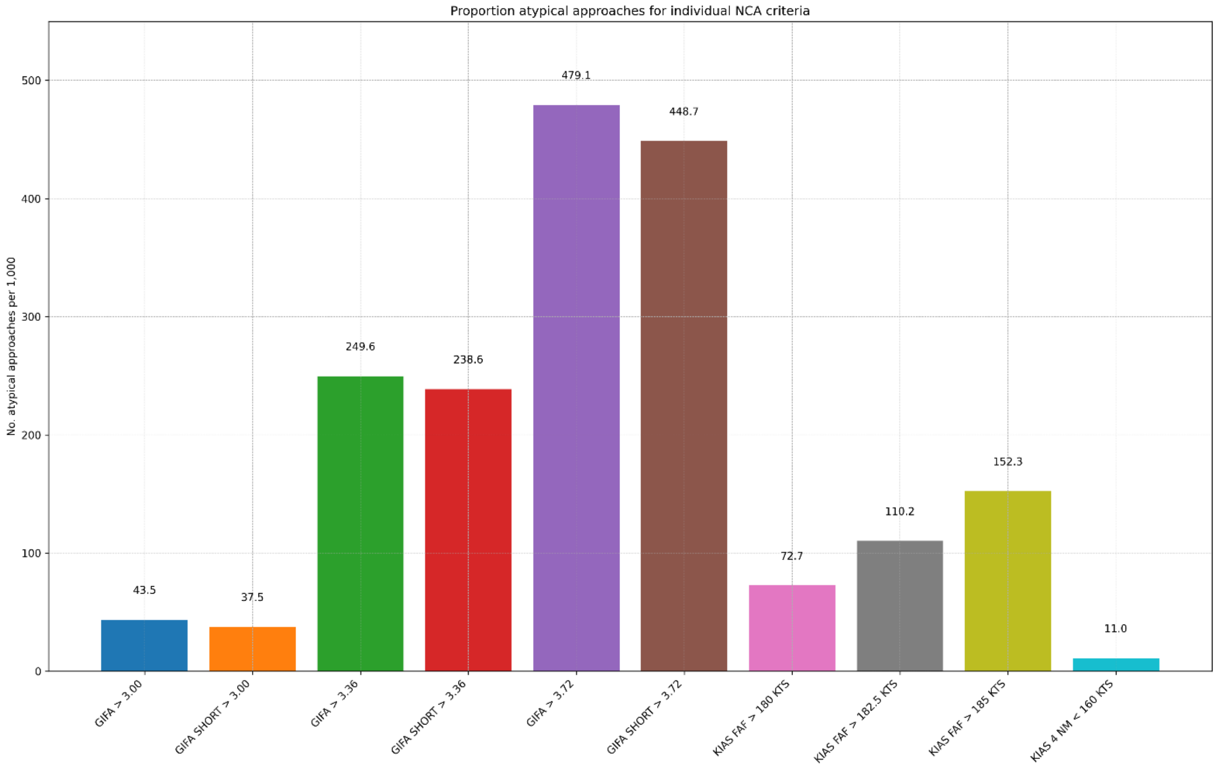


Figure 35 - Proportion atypical approaches in identifying NCA criteria

Next, results of the statistical testing will be outlined and explained.

4.2 Statistical testing relation atypicality

Results in Chapter 4.1 have shown that the proportion of atypical occurrences is higher in go-around occurrences compared to landings as shown in Table 13.

	Atypical occurrences per 1,000	Proportion
Landings	20.2	0.0202
Go-Around occurrences	48.4	0.0484

Table 13 - Proportions atypicality in landings and go-arounds

Where the proportion refers to the share of occurrences. E.g. a proportion of 0.202 equates to 2.02% or 20.2 per 1,000 occurrences.

For the stabilisation criteria, the following proportions have been established for approaches that proceed to land as shown in Table 14. For results where the total occurrence count is zero or fewer than 30, these have been marked as ‘–‘, as a minimum sample size of 30 is required for z-test to be able to be used (Mendenhall et al., 2008).

	Atypical occurrences per 1,000	Proportion
Vertical speed > 1,000 ft/min	40.0	0.0400
Vertical speed > 50% of target	-	-

Bank angle > 30-degrees	254.9	0.2549
Vertical ILS path deviation > 1 dot	78.5	0.0785
Horizontal ILS path deviation > 1 dot	323.4	0.3234
KIAS trend deviation > (+10/-5)	-	-

Table 14 - Proportions atypicality for identifying individual stabilisation criteria

For the results of the non-compliance, the following proportions have been established as shown in Table 15.

	Atypical occurrences per 1,000	Proportion
Intercept angle > 30-degrees	-	-
Intercept angle > 45-degrees	-	-
Non-Adapted KIAS at FAF	72.7	0.0727
Non-Adapted KIAS at 4 nm	11.3	0.0113
GIFA	43.5	0.0435
GIFA-short	37.5	0.0375

Table 15 - Proportions atypicality for identifying individual compliance criteria

Based on these results, statistical testing will be conducted to determine if a correlation exists between the specified criteria and atypicality. The analysis aims to identify which of the criteria are associated with higher levels of atypicality. Therefore, only criteria with a higher proportion of atypical occurrences than all landings are considered. Consequently, the speed adaption requirement at 4 nm from the runway is excluded from the statistical testing. Results of the statistical testing shown in Table 16.

Criteria	Critical z-value	Obtained z-value	Conclusion
Go-Around occurrences	1.645	2.920	Reject the null hypothesis: There is sufficient evidence to support the alternative hypothesis.
Vertical Speed > 1,000 ft / minute		64.484	
Bank Angle > 30-degrees		14.971	
Vertical ILS deviation > 1 dot		17.121	
Horizontal ILS deviation > 1 dot		7.688	
GIFA		47.984	
GIFA short		52.834	
Non-Adapted KIAS at FAF		110.071	

Table 16 - Results from statistical testing

Results revealed a significantly greater proportion of atypical approaches during go-arounds compared to landings, indicating a strong association between atypical approaches and go-arounds. Additionally, across the defined identifying criteria for NSA and NCA, atypical approaches were also found to have significantly higher rates, strengthening the case for using these criteria as predictors of atypical approaches.

5 Conclusion

Historical approach and landing accidents showed two types of deviation from nominal procedures: atypical altitude and atypical energy. Introduced by Delahaye et al. (2018), energy trajectories have been used in this thesis to analyse these deviations. Energy trajectories relating to capturing altitude through potential energy and capturing energy resulting from motion through kinetic energy and combining them into a singular variable – total specific energy.

The definition given for atypical approaches has been tailored to establish clear boundaries for the approach phase studied, directly answering the first sub-objective. The approach phase starting at the Final Approach Fix (FAF), an approach waypoint set a 6.2 nm from the runway, until the stabilisation point, a reference point 3 nm from the runway, has been studied. In this approach phase, a linear decrease in total energy is expected from an ideal nominal approach due to linear deceleration established by Tremaud (2000) and a linear decrease in altitude. The following definition has been given to atypical approaches used in this thesis:

An atypical approach occurs if an approach trajectory's cumulative total specific energy loss exceeds the 20 knots per nautical mile threshold in the approach phase from the final approach fix to the 3 nautical mile stabilisation point.

Three years of surveillance data has been analysed, spanning from May 2022 until April 2025 including 312,100 approaches. With the given definition of atypical approaches, 20.2 of 1,000 landings have been identified to be atypical, directly relating to the main objective aiming to quantify atypical approaches occurrence. Results further showed that atypicality occurs approximately 2.5 times more often in go-arounds (48.4 of 1,000) and compared to landings and account for approximately 5% of go-arounds, directly relating to the main objective to identify if atypical approaches occur more often in go-arounds.

Specifically, atypicality is found to be higher for landings on runway 18C (37.6 of 1,000) compared to landings on 18R (14.6 of 1,000). Approaches via the inbound stack ARTIP also found to have higher levels of atypicality.

Atypicality has also found to be approximately 8 times more frequent in narrowbody aircraft (24.8 of 1,000) compared to widebody aircraft (2.9 of 1,000).

Comparing nighttime against daytime approach procedures has found atypicality to be higher for landings throughout the day (21.1 of 1,000) compared to those at during nighttime (16.5 of 1,000).

Previous studies identified two types of approaches deviating from the nominal: Non-Stabilised Approaches (NSA) and Non-Compliant Approaches (NCA). The thesis objectives related to determine if atypical approaches coincide more often with NCA/ NSA, including establishing criteria that can be used in identifying NSA's/ NCA's. After establishing criteria used to be able to detect these NSA's and NCA's, individual criteria of each have been analysed.

Results show that for NSA's the following identifying criteria have a significant correlation with atypicality:

- Horizontal approach path deviation exceeding 1 dot (323.4 of 1,000 being atypical)
- Bank angle exceeding 30 degrees (254.9 of 1,000 being atypical).
- Vertical approach path deviation exceeding 1 dot (78.5 of 1,000 being atypical).
- Vertical speed exceeding 1,000 ft/min (70.0 of 1,000 being atypical).

For identifying criteria of NCA, the following have been identified to have a significant correlation with atypicality:

- Approaches non-compliant with the indicated airspeed requirement (Non-Adapted) at the FAF (72.7 of 1,000 being atypical).
- A Glide Intercepted From Above (GIFA) for the approach path (43.5 of 1,000 being atypical).

However, this applied methodology in this thesis also has some limits. Firstly, the methodology analyses the energy change of the entire approach phase from the FAF to the 3 nm stabilisation point. It does not allow to identify, at a given distance, how much the approach trajectory deviated from the nominal.

Secondly, the method used to identify the approach path intercept angle is a static method. It is fixed at determining the intercept angle at the FAF. Therefore, it does not allow to analyse the approach path intercept angles for approaches that intercept the approach path before the FAF.

Lastly, the methodology used is a distance-based method and not time-based. Time based would allow to analyse how much more time an approach identified as atypical would require to lose energy to be within nominal margins.

5.1 Recommendations

This thesis aimed to define and quantify atypical approach occurrence. Given the results and methods used in this thesis. the following recommendations can be made:

- This thesis scope is limited to runways 18C and 18R at Schiphol airport. It is recommended to analyse approaches on all other runways at Schiphol airport for atypicality.
- It is recommended to include atypicality as a Key Performance Indicator (KPI) for analysing approaches. The KPI can be incorporated in the criteria used to design approach procedures and analyse the effect of the phenomena with changes in procedures.
- It is recommended to introduce a dynamic method to analyse the interception angle for approaches joining the approach path. Allowing for analysis of intercept angles not directly on the FAF.
- It is recommended to conduct a time-based analysis to identify atypicality. With the goal to identify how much extra time an aircraft would need to lose energy to be within nominal margins.
- Identifying commonalities to why aircraft got into a situation that led to an atypical approach.

5.2 Future work

From these, the following recommendations for future research include:

- To evaluate insights into atypical approaches for common factors that lead to atypical approach occurrence.
- To establish a method used to dynamically identify the approach intercept angle, beyond or before the FAF, with the approach path.

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Appendix I - Reflection

Conclude writing this thesis, I reflect upon the last couple of months in this dissertation writing process. Initially, it was a challenging start given the few reference papers on this topic. From initially getting to grips with the factors that identifies an atypical approach, through correlating it with the go-around, non-stabilised approaches and non-compliant approaches. It has been a challenging but rewarding experience. Given the interest of many on this topic and the expertise of those around me helped me throughout establish the idea’s, methods to obtain the results in this dissertation.

Especially, I want to thank my supervisor Koos for granting me this incredible opportunity, and his support throughout the dissertation process. Our weekly catch-up meetings and sparring sessions helped me refine my research but also provide clarity. Sharpening the focus on the area’s requiring most attention.

Additionally, I also want to express my appreciation to my university supervisor, Alejandro, for his continued efforts to my academic journey in this dissertation. Aiding me in structuring my thoughts and methods effectively. As well as pushing me to enhance the clarity and readability of my dissertation.

Also, I want to thank those internally at LVNL who’s expertise helped me in the process of defining the methods used in this thesis. Too many names to list them all but I want to give a special thanks to Bart, Evert, Jan, Mithun and Ferdinand. Each contributing in their own unique way, from helping me connect the ideas in this thesis to the challenges LVNL currently faces, to helping me with Python. But also, to help me write queries to download data from the database. I appreciate everyone’s contribution throughout.

Lastly, I want to thank the airline pilots who have helped me throughout the last couple of months. Their invaluable guidance has helped me grasp the key factors that define non-stabilized approaches, as well as the intricate complexities of operations at Schiphol. Their expertise was instrumental in interpreting the data analysis results and justifying the primary operational reasons behind them

Now reflecting back, I am also happy to see the progress I made myself in Python programming skills throughout the last months. Initially, I was not too sure how Python intense the topic would be. And in honesty it was more than I initially expected, but it has been a fun challenge. I have enhanced my Python skills in many ways, especially when it comes to code-efficiency required for large datasets. For this learning process I am very grateful and would be keen to apply the skills I learnt further in my career.

In conclusion, this thesis dissertation paper has been a challenging but rewarding experience. I am happy with the progress I made in both Python and my academic writing skills. I look forward to applying what I have learnt in my future endeavours and want to once again thank everyone who has contributed to it in their own unique way. Baie dankie!

Appendix II – *Basic Operating Manual Airline 1: Stabilisation Criteria*

Stabilized approach operation: The following criteria should be satisfied for all stabilized approach operations: The flight management systems and approach aids should be correctly set and any required radio aids identified before the FAP/FAF. The aeroplane should be flown according to the following criteria from the FAP/FAF: The angle of bank should be less than 30 degrees. The target rate of descent should be that required to maintain the correct vertical path at the planned approach speed. Note: The target rate of descent for the final approach segment (FAS) of a stabilized approach normally does not exceed 1000 fpm. Where a rate of descent of more than 1000 fpm will be required (e.g. due to high ground speed or a steeper-than-normal approach path), this should be briefed in advance. For circling approaches, the two points above apply until the start of the level flight segment and again from the point at which the aircraft begins descent from the level flight segment down to a point of 50 ft above the threshold or the point where the flare manoeuvre is initiated, if higher. During a circling approach, wings should be level on final when the aeroplane reaches 300 ft AFE. Variations in the rate of descent should normally not exceed 50 % of the target rate of descent. An aeroplane is considered stabilized for landing when the following conditions are met: The aeroplane is tracking within an acceptable tolerance of the required lateral path. Note: The requirement for the aeroplane aircraft to be tracking within an acceptable tolerance of the required lateral path does not imply that the aircraft has to be aligned with the runway center line by any particular height. Uncontrolled document after printing and download OM A - BOM 8 OPERATING PROCEDURES 8.4 All Weather Operations Page: 8-97 Date: 03-Oct-2024 Revision no.: 31 The aeroplane is tracking within an acceptable tolerance of the required vertical path. The vertical speed of the aeroplane is within an acceptable tolerance of the required rate of descent. The airspeed of the aeroplane is within an acceptable tolerance of the intended landing speed. Note: Acceptable tolerances for lateral and vertical path, speed and configuration are stated in OM Part B. The aeroplane is in the correct configuration for landing, unless operating procedures require a final configuration change for performance reasons after visual reference is acquired. The thrust/power and trim settings are appropriate. All briefings and checklists have been conducted. The aeroplane should be stabilized for landing before reaching 500 ft above the landing runway threshold elevation. Note: Below 500 ft, flight manoeuvres should be restricted to corrections necessary to maintain the required flight path only. For approach operations where the pilot does not have visual reference with the ground, the aeroplane should additionally be stabilized for landing before reaching 1000 ft above the landing runway threshold elevation except that a later stabilization in airspeed may be acceptable if higher than normal approach speeds are required for operational reasons. Note: Operational reasons for specifying a higher-than-normal approach speed below 1000 ft may include compliance with ATC speed restrictions. If the criteria above are not met at 500 ft or 1000 ft as applicable, a go-around must be initiated. Note: Approach procedures requiring stabilization on final approach below 500 ft height above threshold are authorized provided approach stability requirements according OM Part B are met.

<u>B737 policy at Airline 1</u>

Elements of a Stabilized Approach The following recommendations are consistent with criteria developed by the Flight Safety Foundation. All approaches should be stabilized by 1,000 feet AFE in instrument meteorological conditions (IMC) and by 500 feet AFE in visual meteorological conditions (VMC). An approach is considered stabilized when all of the following criteria are met: • the airplane is on the correct flight path • only small changes in heading and pitch are required to maintain the correct flight path • the airplane should be at approach speed. Deviations of +10 knots to – 5 knots are acceptable if the airspeed is trending toward approach speed • the airplane is in the correct landing configuration • sink rate is no greater than 1,000 fpm; if an approach requires a sink rate greater than 1,000 fpm, a special briefing should be conducted • thrust setting is appropriate for the airplane configuration • all briefings and checklists have been conducted. Specific types of approaches are stabilized if they also fulfill the following: • ILS approaches should be flown within one dot of the glide slope and localizer, or within the expanded localizer scale • Localizer approaches should be flown within one dot of the localizer • VOR approaches should be flown within 2.5 degrees from the inbound track • NDB approaches should be flown within 3 degrees from the inbound track. • during a circling approach, wings should be level on final when the airplane reaches 300 feet AFE. Unique approach procedures or abnormal conditions requiring a deviation from the above elements of a stabilized approach require a special briefing. Note: If an approach becomes unstabilized below 1,000 feet AFE in IMC or below 500 feet AFE in VMC initiate a go-around. These conditions should be maintained throughout the rest of the approach for it to be considered a stabilized approach. If the above criteria cannot be established and maintained until approaching the flare, initiate a go-around. At 100 feet HAT for all visual approaches, the airplane should be positioned so the flight deck is within, and tracking to remain within, the lateral confines of the runway edges extended. July 25, 2024 737 NG Flight Crew Training Manual k Approach and Missed Approach FCTM B737NG 5.5 As the airplane crosses the runway threshold it should be: • stabilized on approach airspeed to within + 10 knots until arresting descent rate at flare • on a stabilized flight path using normal maneuvering • positioned to make a normal landing in the touchdown zone (the first 3,000 feet or first third of the runway, whichever is less). Initiate a go-around if the above criteria cannot be maintained.

<u>A320neo policy at Airline 1</u>

The stabilization height is defined as one of the following: - 1 000 ft above airfield elevation (AAL) without visual reference to the ground, or - 500 ft above airfield elevation (AAL) with visual reference to the ground, or - Any other height defined in OM Part A or OM Part C. In order for the approach to be stabilized, all of the following conditions must be satisfied before, or at the stabilization height: - All briefings and checklists have been completed. - The aircraft is on the correct lateral and vertical flight path - The aircraft is in the desired landing configuration - The thrust is stabilized, usually above idle, and the aircraft is at target speed for approach Note: Without visual reference to the ground, a later speed and thrust stabilization can be acceptable provided that: - The aircraft is in deceleration toward the target approach speed - The flight crew stabilizes speed and thrust as soon as possible and not later than 500 ft AAL. - The flight crew does not detect any excessive flight parameter deviation. If one of the above-mentioned conditions is not satisfied, the flight crew must initiate a go-around, unless they estimate that only small corrections are required to recover stabilized approach conditions. Note: If the predicted tailwind at landing is greater than 10 kt, decelerated approach is not permitted, and the aircraft speed should be stabilized at around VREF + 5 kt in final.

Appendix III – *Stabilisation Criteria Airline 2*

All approach operations shall be flown as stabilised approach operations.
The following criteria must be satisfied for all stabilised approach operations.

- The flight management systems and approach aids must be correctly set and any required radio aids identified before the FAP/FAF.
- The aeroplane must be flown according to the following criteria from the FAP/FAF:
    - The angle of bank must be less than 30 degrees, and
    - The target rate of descent must be that required to maintain the correct vertical path at the planned approach speed. Variations in the rate of descent must normally not exceed 50% of the target rate of descent.

    NOTE:
    The target rate of descent for the final approach segment (FAS) of a stabilised approach normally does not exceed 1000 fpm. Where a rate of descent of more than 1000 fpm will be required (e.g. due to high ground speed or a steeper-than-normal approach path), this must be briefed in advance.
    - For circling approaches, the two points above apply until the start of the level flight segment and again from the point at which the aircraft begins descent from the level flight segment down to a point of 50 ft above the threshold or the point where the flare manoeuvre is initiated, if higher. During a circling approach, wings must be level on final when the aeroplane reaches 300 ft AFE.
- The aeroplane must be stabilised for landing before reaching 500 ft above the landing runway threshold elevation.

NOTE:
Below 500 ft, flight manoeuvres must be restricted to corrections necessary to maintain the required flight path only.

- For approach operations where the pilot does not have visual reference with the ground, the aeroplane must additionally be stabilised for landing before reaching 1000 ft above the landing runway threshold elevation except that a later stabilisation in airspeed may be acceptable if higher than normal approach speeds are required for operational reasons.

NOTE:
Operational reasons for specifying a higher-than-normal approach speed below 1000 ft may include compliance with ATC speed restrictions.

An aeroplane is considered stabilised for landing when the following conditions are met:

- The aeroplane is tracking within an acceptable tolerance of the required lateral and vertical path.
    - ILS approaches must be flown within one dot of the glideslope and localizer.
    - Localizer approaches must be flown within one dot of the localizer.
    - Approaches using the FMS as the primary source must be flown within 75 ft (one dot) above or below the vertical profile at any time, or half-scale deflection for LPV approaches.
    - Lateral deviation must not exceed half the RNP value. Brief deviations (e.g. overshoots or undershoots during and immediately after turns) up to a maximum of 1 time the RNP value must be allowable.
    - VOR approaches must be flown within 2.5 degrees from the inbound track.
    - NDB approaches must be flown within 3 degrees from the inbound track.

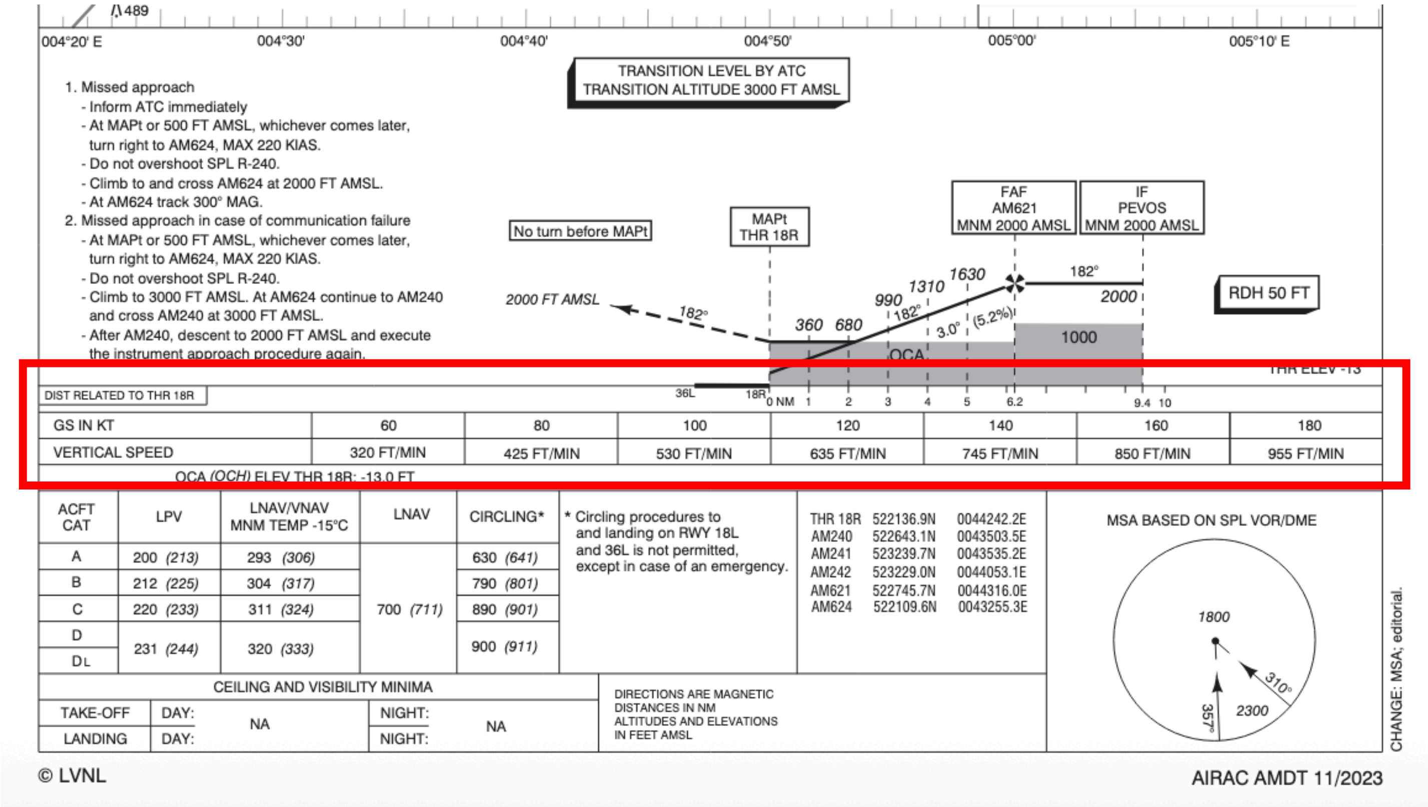
NOTE:
The requirement for the aeroplane to be tracking within an acceptable tolerance of the required lateral path does not imply that the aircraft has to be aligned with the runway centre line by any particular height.

- The vertical speed of the aeroplane is within an acceptable tolerance of the required rate of descent.
- The airspeed of the aeroplane is within an acceptable tolerance of the approach speed (VAP).
- Deviations of +10 to -5 KIAS are acceptable if the airspeed is trending towards VAP.
- The aeroplane is in the correct configuration for landing, unless operating procedures require a final configuration change for performance reasons after visual reference is acquired.
- The thrust/power and trim settings are appropriate.
- All briefings and checklists have been conducted.

If the criteria above are not met at 500 ft or 1000 ft as applicable, a go-around must be initiated.
1000 ft call
A 1000 ft call must be included in the final part of each approach to serve as an awareness call for approach stability.
500 ft call
A 500 ft call must be included in the final part of each approach:
- To protect against subtle incapacitation.
- To serve as an awareness call for the approach stability.
- To confirm the landing clearance.

All flight crew members must be convinced that the landing clearance has been received and acknowledged before landing.

Appendix IV – Vertical speeds



GS IN KT	60	80	100	120	140	160	180
VERTICAL SPEED	320 FT/MIN	425 FT/MIN	530 FT/MIN	635 FT/MIN	745 FT/MIN	850 FT/MIN	955 FT/MIN

ACFT CAT	LPV	LNAV/VNAV MNM TEMP -15°C	LNAV	CIRCLING*
A	200 *(213)*	293 *(306)*	700 *(711)*	630 *(641)*
B	212 *(225)*	304 *(317)*		790 *(801)*
C	220 *(233)*	311 *(324)*		890 *(901)*
D / DL	231 *(244)*	320 *(333)*		900 *(911)*

CEILING AND VISIBILITY MINIMA			
TAKE-OFF	DAY: NA	NIGHT: NA	
LANDING	DAY:	NIGHT:	

AIRAC AMDT 11/2023

Visualisation of groundspeeds against vertical speeds obtained from approach procedures.