EUROPEAN COMMUNITY

COMPETITIVE AND SUSTAINABLE
GROWTH PROGRAMME

SOURDINE II

D4.2-1
Safety assessment of Sourdine II procedures
(Top-level document)

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Sourdine II Consortium:

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EUROCONTROL	*European Organisation for the safety of Air Navigation*	*INT*
ISDEFE	*Ingenieria de Sistemas para la Defensa de España S.A.*	*ESP*
INECO	*Ingenieria y Economia del Transporte*	*ESP*
SICTA	*Sistemi Innovativi per il Controllo del Traffico Aereo*	*IT*

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Executive summary

The Sourdine II project aims to define new approach and departure procedures for noise reduction around airports. Four approach and two departure procedures were defined in [S II D3.1-2]. In the Sourdine II documents D4.2-1, D4.2-2 and D4.2-3 these procedures are analysed with respect to safety.

The current document, D4.2-1, is the top-level document of the safety work for Sourdine II. It contains the overall approach, the main results and the conclusions. The document is supported by documents in which the safety assessments are described. The safety assessment of approach procedure II-A is described in the documents constituting D4.2-2. The safety assessments for approach procedure V and departure procedure 2 are described in D4.2-3. The full deliverable structure is:

D4.2-1 Safety assessment of Sourdine II procedures (Top-level document).
D4.2-2 Safety assessment of approach procedure II-A on Schiphol airport.
- a Main document
- b Argumentation-based analysis
- c Simulation-based analysis
- d Collection of expert interviews

D4.2-3 Safety assessment of approach procedure V and departure procedure 2 on Barajas airport.

Set-up of the study

Because complete detailed safety analysis would be a very elaborate and demanding effort, part only of the four approach and two departure procedures have been identified to fall within the scope of detailed evaluation. Therefore, a further selection of these procedures has been made. To accomplish such a selection, an initial high-level safety evaluation of all six procedures has first been done. It is noted that these procedure definitions do not include an embedding of the procedure in an operation.

Based on the initial high-level safety evaluation and on inputs not related to safety the Sourdine II management made a selection of three procedures for safety assessment. For each of these three procedures an operation has been defined on a specific airport including also specific human roles and technical systems. For each of these operations, a safety assessment has been performed, documented in D4.2-2 and D4.2-3 and summarised in the current document.

Initial high-level safety evaluation and selection for safety assessment

The initial high-level safety evaluation identified the following main safety issues for the four approach procedures:

II. <u>Basic CDA with 2° initial Flight Path Angle</u>;

- A possible excess speed at glide slope intercept possibly leading to an unstabilised approach.

III. <u>Basic CDA with 2° initial FPA and increased final glideslope</u>;

- A possible excess speed at glide slope intercept possibly leading to unstabilised approach; more severe than for procedure 2 due to the fact that the excess speed is more difficult to control on a steep final segment;
- The steep final glideslope is a non-standard operation and potentially leads to higher workload. This operation requirs special analysis in relation to acceptance and to obstacle clearance surfaces.

IV. CDA with constant speed, variable FPA segment at landing configuration;

- A possible steep intermediate approach segment resulting to glideslope interception from above, with the potential consequences of a glideslope undershoot and an unstabilised approach;
- Potential flight path control problems, which could lead to an increased workload and an unstabilised approach in case the path is too shallow;

V. CDA with constant speed, variable FPA segment at intermediate configuration;

- The same issues as for procedure IV, though both less severe.

The main safety issues related to each of the two departure procedures are:

2. Sourdine optimised close-in procedure;
   - Speed control problems at low powersetting at OEI climb thrust
3. Sourdine optimised distant procedure;
   - The same issue as for procedure 2, but less severe.

Because procedure II is expected to cause a limited capacity decrease, a variant of procedure II was defined by Sourdine II operational designers, called procedure II-A. In procedure II-A, speed constraints are imposed on the 2 degree flight path angle segment. The procedures selected for safety assessment were: approach procedure II-A, approach procedure V, and departure procedure 2.

Safety assessment of approach procedure II-A on Schiphol airport

A safety assessment has been performed for an operation considering Sourdine II approach procedure II-A in the context of Schiphol airport. The risk has been assessed with respect to risk criteria that combine the [ESARR 4] severity classification with the well-known frequency classification of JAA; the risk is classified per conflict scenario to be NEGLIGIBLE, TOLERABLE, or UNACCEPTABLE.

Five conflict scenarios have been identified that describe in which way an accident or incident could occur:

1 Conflict between two aircraft merging onto one route

2 Conflict between two aircraft on the same route

3 Conflict between two aircraft established on their respective localizers

4 Conflict between two aircraft (one for 18R and one for 18C) of which at least one is turning to intercept its localizer, the other aircraft may also be turning in or already be established on its own localizer.

5 An approaching aircraft encounters the wake vortex of another aircraft in approach.

The risks of conflict scenarios 1 and 3 are classified as TOLERABLE, and the risks of conflict scenarios 2, 4 and 5 are classified as being either TOLERABLE or UNACCEPTABLE.

The uncertainty in the latter results is related to the use of data retrieved from experts, who assess a future operation by extrapolating their experiences with the current operation; to details of the operational description that remain to be specified; and to the scarceness of statistical data on model parameter values.

When considering to which extent the identified (possibly) UNACCEPTABLE risks are generic for the vertical flight profile considered, irrespective of the Schiphol implementation considered, the following conclusions hold:

- The possibly UNACCEPTABLE risk for conflict scenarios 2 and 5, related to longitudinal separation problems caused by an insufficient initial separation at the IAF and by a reduced ability to provide separation in case of 34 aircraft per hour, may be generic for the vertical flight profile considered.
- The possibly UNACCEPTABLE risk for conflict scenario 4, caused by aircraft overshooting the ILS while turning in for parallel approach, while vertical separation of 1000ft has not been guaranteed, is not generic for the vertical profile. However, when considering a generic implementation of this profile on parallel runways, it is very well possible that the risk is possibly UNACCEPTABLE, depending of course on the distance between the runways, the staggering between the runways, and the exact implementation of the procedure.

Since the operation has risks that are classified as (possibly) UNACCEPTABLE, the operation should be improved before implementation. Safety bottlenecks have been identified that could serve as a starting point for the operational concept designers for the identification of risk mitigating measures. It is considered most logical to do a new cycle of the safety assessment once the operation has been improved; then also for conflict scenarios 2 and 5 a simulation-based approach may be used.

Safety assessment of approach procedure V on Barajas airport

The outcome of the safety assessment for approach procedure V on Barajas airport has revealed a series of safety significant issues, which are recommended for further analysis. A distinction is made between those related to the inherent characteristics of the Sourdine II approach procedure V and those for which the particular parallel runway set-up is the determining factor when performing simultaneous and independent CDAs to both runways.

1. *Sourdine II approach procedure V issues:*
   - Non-adherences to CDA speed descent profiles may cause aircraft to breach longitudinal separation (e.g. catch up aircraft ahead or be caught up by trailing aircraft). As a potential result, the probability of wake vortex encounters is likely to also increase. The risk of wake vortex encounter has been classified as possibly unacceptable without further mitigation.
2. *Parallel runway CDA safety issues*
   - Non-adherences to vertical CDA profiles may breach the 1000ft vertical separation that by design, should be maintained at all times between aircraft established on the parallel localisers prior to reaching the area parallel to the NTZ.
   - Separation between aircraft established on the parallel localisers is based on 1000ft vertical separation at all times prior to reaching the area parallel to the NTZ. As a consequence, small-excursion overshoots followed by rapid localiser interceptions would only be associated with an erosion of safety margins whereas wide-excursion overshooting developing into wrong localiser interception or adjacent sector non-authorised incursion would pose a safety critical issue.

The qualitative safety assessment has shown that the Sourdine II approach procedure V adapted to the future Barajas Airport parallel runway configuration exhibits some safety significant issues that are in need of a more detailed and quantitative analysis. It is recommended that decision support tools such as an Arrival Manager (AMAN) and safety-net additional functionality to monitor potential longitudinal breaches of separation for localiser-established consecutive aircraft are considered in future safety assessments.

Safety assessment of departure procedure 2 on Barajas airport

The Sourdine II departure procedure 2 aims at reducing the noise impact around the SID footprint closest to the runway, causing the aircraft to operate at reduced performance with OEI (One Engine Inoperable) power settings. Hence, the main procedure risks will be associated with airport obstacle limiting surface infringements that may lead to loss of separation with obstacles and/or ground. The main emphasis of the high level assessment was placed on whether the procedure-induced departure from the aircraft optimal climbing performance could erode safety margins.

The safety assessment has shown that the most significant risks associated with the Sourdine II departure procedure 2 are due to either engine loss or sudden adverse meteorological conditions that could impair the aircraft airworthiness. However, it is deemed that aircraft could recover from these situations despite flying at reduced power settings and therefore, the procedure does not degrade safety margins. The conducted high level assessment has concluded with all identified risks associated with the departure procedure having been preliminarily classified as acceptable.

Table of Contents

1. Introduction

1.1. Background

With the continuing growth of air traffic as well as the ever increasing level of urbanisation around most airports in Western Europe, the impact of aircraft noise and emissions on the quality of life for the surrounding communities has become a serious issue to be dealt with. Many European airports already face the conflicting problems of increasing their airport capacity to meet the amount of traffic, and the increasing pressure from the general public to reduce environmental impact, particularly noise and emissions, of the increased traffic volume. This has already resulted in specific local constraints to the operation of aircraft, not only around major airports such as Schiphol, Gatwick or Frankfurt, but also more regional airports are already experiencing the pressure to impose constraints to aircraft movements. Therefore, reduced nuisance to the community is a serious issue for the airline transport industry if the projected sustained growth is to be pursued.

A possible solution to noise reduction around an airport is the definition of new approach and departures procedures. By modifying or optimising the operations and traffic flow of aircraft around the airport, it should be possible to achieve noise reduction. In workpackage 3 of the Sourdine II project, many new noise abatement procedures were defined [S II D3.1-1]. All these procedures were assessed with respect to their noise impact, by executing very accurate single event simulations for the A320 and the A340 aircraft [S II D5.3]. Based on these simulations, apart of a baseline approach procedure and a baseline departure procedure, four approach procedures and two departure procedures were selected for further evaluation [S II D3.1-2].

The four approach procedures are Continuous Descent Approach (CDA) procedures. Each of these features either a fixed three-dimensional flight path, or a vertical flight path that is flown with a constant speed. Furthermore the configuration in which the procedure is flown varies; also one of the procedures includes a steeper final approach path. The departure procedures considered are optimised versions of the noise abatement procedures NADP1 and NADP2 of ICAO. One of these aims to decrease the noise level closely to the runway (‘optimised close-in’), the other further away from the runway (‘optimised distant’). All six procedures are flown with P-RNAV (Precision Area Navigation).

1.2. Objective

Obviously, new procedures can only be actually implemented if they have been shown to be sufficiently safe. The objective of this document is to present and summarise the safety analyses performed for the six noise abatement procedures defined in [S II D3.1-2]. This document contains the overall approach, the main results and the conclusions. For details, reference is made to the documents D4.2-2 and D4.2-3.

The document presents an inventory of the main risks of each procedure of the four approach and two departure procedures developed. This evaluation is performed on a rather high level. Out of these six procedures, three procedures are selected for further safety analysis. This selection is not based on the initial high-level safety evaluation only; it takes also other aspects into account. Therefore, this selection is made by the Sourdine II management. For each of these three procedures an operation on a specific airport has been defined, including specific human roles and technical systems. Detailed safety assessments are performed for these operations; these are documented in D4.2-2 and D4.2-3. The assessments give an overview of the risks associated with the operation and show which parts of the operation are most safety critical, such that feedback can be given to the operational concept designers.

1.3. Relations with other documents

The current document, D4.2-1, is the top-level document of the safety work for Sourdine II. It contains the overall approach, the main results and the conclusions. The document is supported by documents in which the safety assessments are described. The safety assessment of approach procedure II-A is described in the documents constituting D4.2-2. The safety assessments for approach procedure V and departure procedure 2 are described in D4.2-3. The full deliverable structure is:

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D4.2-3 Safety assessment of approach procedure V and departure procedure 2 on Barajas airport.

The references of the other documents are [S II D4.2-2a], [S II D4.2-2b], [S II D4.2-2c], [S II D4.2-2d], and [S II D4.2-3]. The interrelations between all these documents are as represented in the following figure:

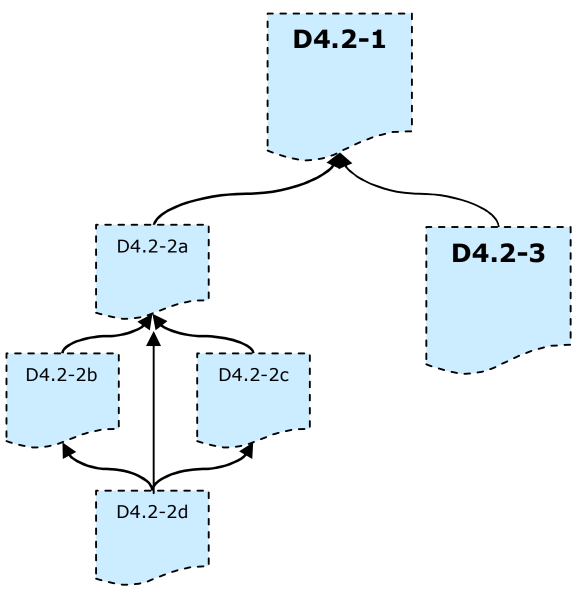

Figure 1: Overview of the relations between the current document D4.2-1 and the other Sourdine II D4.2 deliverables, upon which D4.2-1 is based.

1.4. Structure of the document

The structure of the current document, D4.2-1, is the following:

- In Section 2 the overall set-up of the safety study is explained;
- In Section 3 the safety assessment methodology used is introduced, and it is described how this methodology is used;
- In Section 4 the six procedures are evaluated (high-level) on safety;

- In Section 5 those procedures are selected for which a safety assessment is done;
- In Section 6 the safety assessment of approach procedure II-A on Schiphol airport is described;
- In Section 7 the safety assessment of approach procedure V on Barajas airport is described;
- In Section 8 the safety assessment of departure procedure 2 on Barajas airport is described;
- In Section 9 the conclusions are presented.

1.5. Glossary

ALARP	As Low As Reasonably Practicable
ATC	Air Traffic Control
ATM	Air Traffic Management
CDA	Continuous Descent Approach
CS	Conflict Scenario
DCPN	Dynamically Coloured Petri Net
ESARR	EUROCONTROL Safety Regulatory Requirements
FMS	Flight Management System
FPA	Flight Path Angle
ft	feet
IAF	Initial Approach Fix
IAS	Indicated Air Speed
ICAO	International Civil Aviation Organisation
ILS	Instrument Landing System
JAA	Joint Aviation Authorities
JAR	Joint Aviation Requirements
kts	knots
LNAV	Lateral Navigation
NM	Nautical Mile
NTZ	No Transgression Zone
OEI	One Engine Inoperative
PANS-OPS	Procedures for Air Navigation Services and OPerationS
P-RNAV	Precision Area Navigation (RNP-1 compliant)
RNAV	Area Navigation
RNP	Required Navigation Performance
SID	Standard Instrument Departure
Sourdine	Study of Optimisation procedURes for Decreasing the Impact of NoisE
SRC	Safety Regulation Commission

TMA	Terminal Manoeuvring Area
TOGA	Take-off Go Around
TOPAZ	Traffic Organization and Perturbation AnalyZer
WP	WorkPackage
WPT	Waypoint

1.6. References

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2. Organisation of the safety study

In workpackage 3 of the Sourdine II project, many new noise abatement procedures were defined, as reported in [S II D3.1-1]. In workpackage 5, all these procedures were assessed with respect to their noise impact, by executing very accurate single event simulations for the A320 and the A340 aircraft [S II D5.3]. Based on these simulations, apart from a baseline approach procedure and a baseline departure procedure, four approach procedures and two departure procedures were selected to assess them with respect to:

- capacity;
- safety;
- emissions;
- airport noise (assessment of noise footprints/contours for realistic fleet mixes for the following airports: Paris (Charles de Gaulle) / Madrid (Barajas) / Naples (Capodichino) / Amsterdam (Schiphol);
- cost-benefit aspects; and
- acceptance of end-users (pilots and air-traffic controllers).

Because complete detailed safety analysis as well as detailed assessment of the “acceptance to end-users” by Real Time Simulations on a cockpit simulator and ATC simulator, would be a very elaborate and demanding effort, part only of the four approach and two departure procedures have been identified to fall within the scope of detailed evaluation. Therefore, a further selection of these procedures has to be made for the detailed assessment with respect to the two parameters safety and acceptance to end-users.

The safety methodology on which the safety assessments executed are based is described in Section 3. In Section 3.10 it is described for each of the safety assessments to which extent the general methodology description was followed.

To support the selection process, an initial high-level safety evaluation of all six procedures has first been done. This is documented in Section 4 of the current document for the procedures as they have been defined in [S II D3.1-2]. For a short summary of the procedures, the reader is referred to the beginning of Sections 4.1 (approach) and 4.2 (departure). It is noted that these procedure definitions do not include an embedding of the procedure in an operation, including a description of the technical systems, humans, and exact procedures and their interactions, and the specific operational context of such an operation. It was decided that for the initial high-level safety evaluation of these procedures no operational context was needed.

Section 5 describes the further selection for the scope based on all information then available: the initial high-level safety evaluation, single event noise simulations, some draft results of capacity assessments, prototyping sessions on a cockpit simulator and an ATC simulator, and information gathered in meetings with the expert panel. The following aspects are taken into account in the further selection: safety, capacity impact, cost-benefit, acceptability for pilot and air-traffic controller, availability of new avionics functions, etc. As these criteria do not only involve safety, this further selection has been made by the Sourdine II management. The aim is to select those procedures that look, with the limited information available, the most promising procedures for implementation.

For the ‘most promising’ procedures selected for the scope of the safety assessments this way, an operation is defined on either Schiphol airport (Amsterdam) or Barajas airport (Madrid) by operational concept developers. This means that the human roles, technical systems, and procedures of the operation are described, as is the operational context, and the interactions between these elements. Next, for each of those operations a safety assessment is performed; these are described in Sections 6 to 8.

It is noted that previously it was the idea first to assess all procedures qualitatively (as part of WP4) and next assess one of these procedures quantitatively (as part of WP6). However, it has been chosen to assess each of the selected operations only once. Within such an assessment it is considered which parts of the operation are assessed using an argumentation-based and which using a simulation-based way of working. Here, ‘simulation-based’ refers to the usage of Monte Carlo simulations; often using these simulations a more detailed risk assessment can be done. This is a quantitative approach. ‘Argumentation-based’ refers to safety assessment in which argumentations are built to support why the risk is of a certain class. This resembles much to qualitative approaches; however quantitative frequency classes can be used, and the argumentations can have a quantitative character. In Section 3 more details about the simulation-based and argumentation-based way of working are given.

3. Safety assessment methodology

This section gives a description of the TOPAZ safety assessment methodology used. First, in Section 3.1 to 3.9 this method is described in a general way. In Section 3.10 it is described how this methodology is used, as some variations have been made. The description given is as of the methodology description presented in [TOPAZ]. An overview of the steps in a cycle of safety assessment is given in Figure 2.

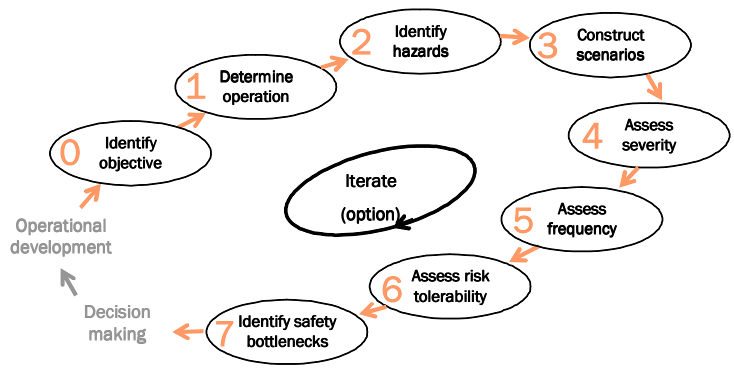

Figure 2: Overview of the steps in a TOPAZ safety assessment cycle.

In step 0 the objective of the study is determined, as well as the safety context, the scope and the level of detail of the assessment. The actual safety assessment starts by determining the operation that is assessed (step 1). Next, hazards associated with the operation are identified (step 2), and clustered into conflict scenarios (step 3). Using severity and frequency assessments (steps 4 and 5), the risk associated with each conflict scenario is classified (step 6). For each conflict scenario with a (possibly) UNACCEPTABLE risk, safety bottlenecks are identified (step 7), which can help operational concept developers to find improvements for the operation. Should such an improvement be made, a new cycle of the safety assessment should be performed to investigate whether all risks have decreased to an acceptable level.

3.1. Step 0: Identify objective

Before starting the actual safety assessment, the objective, scope and level of detail of the assessment are set. This should be done in close co-operation with the customer. Also, the safety context must be made clear, such that the assessment is performed in line with the safety management framework of the customer.

Objective
Generally, the objective of the safety assessment is to obtain a first indication how safe the developed operation is, in order to decide about implementation of the operation, or redevelopment.

Safety context
An important issue for the safety context is the choice of safety criteria with respect to which the assessment is performed. Example criteria are the risk classifications of EUROCONTROL ([ESARR 4])

or JAA ([JAR AMJ 25-1309]). These criteria imply severity classifications and frequency classifications, which can be combined using a risk classification scheme.

Scope
The scope of the assessment concerns for instance the boundaries of the operation under consideration. These can be physical boundaries as well as boundaries of the procedures or technical systems under consideration.

Furthermore, it must be decided whether an absolute or relative safety assessment is to be performed. Also, it must be decided which risks are to be considered. Options can be to consider all internal risks of the operation, such as aircraft - aircraft conflicts or wake vortex encounter conflicts, or to consider only certain conflict types.

Level of detail
The assessment can be performed with varying level of detail. It is possible to assess the severity and the frequency of the conflicts purely qualitatively, but one can also choose to use advanced modelling techniques to obtain a quantitative estimate of the frequency. It is also an option to use first an approach with limited level of detail, such that a good overview is retrieved which risks are mainly of importance and such that the areas with highest risk can be identified, and next deepen the analysis of those areas by a more quantitative approach.

In the current assessment two approaches with varying level of detail are used: an ‘argumentation-based‘ approach and an ‘simulation-based’ approach. The simulation-based approach heavily depends on advanced mathematical modelling using inputs from statistics and experts, and Monte Carlo simulation of these models. The argumentation-based method relies on structuring of inputs retrieved from experts and statistics into argumentations. Here, the mathematics used are simple.

The simulation-based method can be used to gain detailed insight in the accident risk of a conflict scenario, including an unbiased risk estimate with a 95% credibility bracket. The argumentation-based method is used to retrieve estimations in terms of orders of magnitude for the frequency of each severity class for a conflict scenario.

In Section 3.6 some more details about the differences between these approaches are given, and some criteria for deciding which approach to use in which case are introduced.

3.2. Step 1: Determine operation

Important aspects that need to be covered in the operational concept description are:

- The *objective* of the operation;
- The *operational context* of the operation, describing e.g. the geometry of the airport or the air route structure, the timeframe, and the traffic characteristics;
- The roles and responsibilities of the *humans* involved in the operation, especially air traffic controllers and pilots;
- The operational *procedures*, both from an ATC and from a pilot point of view; and
- The *technical systems* used in the operation. These systems are usually divided according to communication, navigation and surveillance functions. Questions like how the systems serve the human, what is their performance, and how are they used need to be answered.

The operational context of the operation should be described in generic terms if possible in order to promote universality of application. On the other hand, the description should provide all the necessary assumptions used in the safety assessment.

Note that it is no part of the safety assessment to develop the operation; this is a task outside the scope of the assessment, which definitely should be performed by operational concept designers. Step 1 just serves for the safety assessors to obtain a complete and concise overview of the operation, and to freeze this description at least through the cycle of the safety assessment. It is impossible to assess an operation that is changing in the meantime; therefore changing viewpoints with respect to the operation during the production of the assessment are not taken into account.

To patch up holes and inconsistencies in the description of the operation, it may be necessary to have them repaired by the concept developers, and also to make some *assumptions*.

Main input to step 1 is a description of the operation from concept developers, while the output is a sufficiently complete, structured, consistent and concise description of the operational concept.

3.3. Step 2: Identify hazards

In the TOPAZ safety assessment methodology, a hazard is a non-nominal event or situation with possibly harmful effects. Such a non-nominal event or situation may evolve into danger, or may hamper the resolution of the danger, possibly in combination with other hazards or under certain conditions. Goal of step 2 of the methodology is to identify as many hazards as possible, while these hazards should also be as diverse as possible. The hazards should be within the scope of the assessment, and thus within the boundaries of the operation and the relevant conflict types, as has been determined in step 0.

[De Jong] gives guidelines how ‘functionally unimaginable’ hazards can be identified using brainstorm sessions. Necessary participants in these sessions are an air traffic controller, a pilot, a moderator, somebody taking notes, and preferably an expert on the operational concept. The participants should all have a sufficient level of understanding of the operation under consideration. The moderator should prepare by identifying some hazards to trigger the brainstorm when necessary, and by making an initial list of general conflict types that should at least be covered.

It is important that the brainstorming sessions are only used to identify hazards, and not to analyse them, as seemingly unimportant hazards may turn out important in the later steps and they may trigger the invention of more relevant ones. Hazards are usually described as they were recorded from the brainstorm session.

As secondary means to identify hazards, previous studies on similar subjects and NLR’s ATM Hazard Database [TOPAZ hazard database] are consulted to check for completeness. Furthermore, during the progress of the study additional hazards may be identified.

3.4. Step 3: Construct scenarios

When the list of hazards is as complete as reasonably practicable, it is processed to deal with duplicate, overlapping and verbosely described hazards. The output of this process is a list of *events*. Each event is a group of similar hazards, and for each event a concise and unambiguous hazard description is given.

To cope with the complexity of the various possible causes and results of the conflicts to be considered, *clusters* of events are formed. A cluster is a group of events that may cause, or that may result from, the same more general hazardous situation. A cluster of events could for instance be the set of ‘events causing a missed approach to deviate from the normal path’.

Each cluster that is formed plays a role in one or more *conflict scenarios*. A conflict scenario is a bundle of event and state sequences, centred on a general kind of conflict (such as for instance ‘conflict between two aircraft merging onto one route’ or ‘aircraft encounters wake vortex of parallel departure’). Accordingly, in such a conflict scenario all ways in which this conflict type can occur, and in which way it can end, are bundled.

A conflict scenario is represented by the various sequences of events in combination with certain states that may lead to and result from the conflict. Often, a conflict is caused by a hazard in combination with a state. The conflict scenarios should be constructed in such a way, that all relevant ways in which a hazard can play a role in a conflict are taken into account. Together, the conflict scenarios should cover all relevant ways in which an incident or accident can happen.

Each of the identified hazards can be of the following types:

- a root hazard, which may cause a conflict; or
- a resolution hazard, which may complicate the resolution of a conflict.

Usually, clusters of root hazards and clusters of resolution hazards play a role in the conflict scenarios.

3.5. Step 4: Assess severity

For each of the identified conflict scenarios it is determined which of the severity classes, as defined in step 0, are applicable. The severity classification of [ESARR 4], for instance, distinguishes between SIGNIFICANT INCIDENT, MAJOR INCIDENT, SERIOUS INCIDENT, and ACCIDENT severity.

Usually, safety experts assess which of the classes are applicable for a conflict scenario, by consultation of and review by operational experts.

If a conflict occurs, then the consequences and the severity of its consequences depend strongly on many factors, such as the conditions under which the conflict occurs, the geometry of the conflict, and on whether (timely) resolution of the conflict takes place. Therefore, often a range of severity classes applies to a conflict scenario. Depending on the scope and level of detail of the assessment as chosen in step 0, it can be chosen to imply all of the applicable severity classes in the assessment. In that case, the spectrum of all possible conflict scenario outcomes should be divided into ‘bands’ of reasonably determined severity that moreover have a clear operational interpretation. The choice and the structuring of the events in a conflict scenario (step 3) are then updated such that each applicable severity category is linked to the occurrence of specific event sequences.

3.6. Step 5: Assess frequency

Next, for each possible severity outcome of each conflict scenario the frequency of occurrence is assessed. Within TOPAZ, one can opt for an argumentation-based approach, or use a, more quantitative, simulation-based approach. These are outlined next, and then it is explained how conflict scenarios can be allocated to these approaches.

Argumentation-based approach

A main source of data for the frequency assessments using an argumentation-based approach is formed by interviews with operational experts, who are familiar with the local ATM systems and procedures in, or (in case of a newly developed concept of operation) similar to those in the operation under consideration. The interviews aim to get insight in the expert’s opinion on safety issues concerning the operation, and more specifically, to identify frequencies of root hazards and conditional probabilities of the possible outcomes of the conflict scenarios. Assessing root frequencies uses answers of questions like: ‘*How often have you experienced this hazard? Will the hazard become more or less probable in the operation under consideration*?’ For assessing conditional probabilities of the possible outcomes of the conflict scenarios use is made of the following type of questions: ‘*Suppose the pilots do not detect and resolve the conflict. What is the probability that your actions as a controller would prevent a collision*?’

Each interview is evaluated by a team of safety analysts. Often, it is necessary to make an interpretation of the answers given by the experts, and accordingly, results obtained for one subject are generalised to other subjects where possible. Some qualitative expressions are to be translated in quantitative assessments, as the applicable safety criteria are expressed in numbers. Additionally, statistical databases can be used, as for instance NLR’s Air Safety Database [Air safety database]; also, information from real-time experiments can be used, as for Sourdine II from [S II D6.3 v0.2].

The frequency is usually assessed using frequency classes, which have a qualitative interpretation. For instance, PROBABLE, REMOTE, EXTREMELY REMOTE, and EXTREMELY IMPROBABLE.

Complicating factors in assessing the frequency of a conflict ending in a given severity at once can be that there is often little or no experience with the new operation, and that the situation may involve several variables. This holds especially for the more severe outcomes of the conflict, since these situations occur rarely, and accordingly less information is at hands about the behaviour of air traffic controllers and pilots in such situations.

As a result, there will be uncertainty in the frequency estimates. This uncertainty should be dealt with carefully; one of the following approaches can be chosen:

- ranges can be identified, which contain the true value with a given confidence; or
- one can stay on the safe side by using conservative frequency estimates.

For more details on the argumentation-based approach, we refer to [QSA method].

Simulation-based approach

For a simulation-based approach, the following activities are executed:

1. Develop a stochastic dynamical model of the accident risk for the conflict scenario within the operation. The stochastic dynamical model takes the form of a Dynamically Coloured Petri Net (DCPN), which models the hazards identified, and which uses an advanced human performance modelling.
2. Perform Monte Carlo simulations and mathematical analysis techniques to assess the accident risk based on this stochastic dynamical model.
3. Perform a Bias and Uncertainty assessment; i.e., first identify all assumptions adopted, such as numerical approximation assumptions, model structure assumptions, non-coverage of hazards assumptions, parameter-value assumptions; next, evaluate the effect of all adopted assumptions on the accident risk. The effect of each assumption can be as follows:
   - Bias: due to the adoption of the assumption, the model-based risk is systematically higher or lower than expected for the real operation,
   - Uncertainty: due to the adoption of the assumption, there is uncertainty in the model-based accident risk.
4. Combine the results of steps 2 and 3, leading to an estimation of accident risk for the real operation (i.e. the model-based accident risk, compensated for all assumptions adopted), and a 95% credibility interval for this accident risk.

For more technical details on DCPN, we refer to [Everdij & Blom, 2003]. For details on the development of DCPN and the Monte Carlo simulations, we refer to [Blom et al., 2001] and [Blom et al., 2003b]. For more details on human performance modelling, we refer to [Blom et al., 2003a]. For the Bias and Uncertainty assessment we refer to the methods described in [Everdij & Blom, 2002] and [Stroeve et al., 2003].

Allocation of approaches to conflict scenarios

For the risk assessment of each conflict scenario, a simulation-based approach and/or an argumentation-based approach can be adopted. Criteria that support the allocation of conflict scenarios to the approaches are:

- A simulation-based approach can give more detail into the risk than an argumentation-based approach. Therefore a simulation-based approach may be chosen for conflict scenarios that are expected to be more safety critical, more typical for the operation under consideration, or in another sense more important.

- The simulation-based approach is more effective in tackling risk estimation in which the exact flight paths play an important role.
- Applying the simulation-based approach needs the development of a detailed mathematical model, which is relatively labour extensive if a model is not available yet.
- For conflict scenarios for which an argumentation-based approach suffices to show that the risk related to it is acceptable, it is generally not efficient to apply a simulation-based approach. The same holds for conflict scenarios for which an argumentation-based approach suffices to show that the risk related to it is unacceptable.

3.7. Step 6: Assess risk tolerability

Next, for each conflict scenario the associated risk is classified. This is done by combining the severity and frequency assessments.

For instance, it could be derived that conditions with the following combinations of severity and frequency are allowed:

- SIGNIFICANT INCIDENT severity may be PROBABLE.
- MAJOR INCIDENT severity must be no more frequent than REMOTE.
- SERIOUS INCIDENT severity must be no more frequent than EXTREMELY REMOTE.
- ACCIDENT severity must be EXTREMELY IMPROBABLE.

To assess the risk associated with each conflict scenario, the classified severity outcomes can be combined with the corresponding frequency outcomes in a risk matrix. In such matrix, the combinations of severity and frequency listed above are classified as TOLERABLE*.* Conflict scenarios with a higher level of severity and/or a higher frequency of occurrence are classified as implying UNACCEPTABLE risk; the risk of remaining conflict scenarios are classified as NEGLIGIBLE. An example of the result is shown in the following table:

Table 1: Example risk tolerability diagram containing the tolerability assessment results for a particular conflict scenario

Severity Frequency	ACCIDENT	SERIOUS INCIDENT	MAJOR INCIDENT	SIGNIFICANT INCIDENT
PROBABLE	UNACCEPTABLE	UNACCEPTABLE	UNACCEPTABLE	TOLERABLE
REMOTE	UNACCEPTABLE	UNACCEPTABLE	TOLERABLE	NEGLIGIBLE
EXTREMELY REMOTE	UNACCEPTABLE	TOLERABLE	NEGLIGIBLE	NEGLIGIBLE
EXTREMELY IMPROBABLE	TOLERABLE	NEGLIGIBLE	NEGLIGIBLE	NEGLIGIBLE

In this example, the frequency for the SIGNIFICANT INCIDENT class and for the MAJOR INCIDENT class have been assessed rather precisely; for the other two classes there is still some uncertainty. Conflict scenarios that are analysed using a simulation-based approach often allow a more precise risk tolerability representation.

3.8. Step 7: Identify safety bottlenecks

From the risk tolerability assessment, it may follow that some conflict scenarios have a risk that is UNACCEPTABLE, or that some conflict scenarios have a risk that is possibly (i.e. in case of uncertainty in the frequency classifications) UNACCEPTABLE. For these conflict scenarios so-called safety bottlenecks are identified. These are hazards or conditions that cause the conflict scenario to have a risk that is (possibly) UNACCEPTABLE. Knowledge about these bottlenecks can be used to support further development of the operation.

A systematic way to search safety bottlenecks for a conflict scenario with (possibly) UNACCEPTABLE risk is the following: For hazards playing a role in the conflict scenario, see what would happen to the risk of the conflict scenario if this hazard would occur with zero probability. If the risk is then no longer UNACCEPTABLE, the hazard apparently plays a large role in causing the large risk of the conflict scenario, and it is called a safety bottleneck.

In principle, other aspects of the operation, such as meteorological conditions may also play an important role in high risks. A similar way of working can be adopted to check these for safety bottlenecks: Re-assess the risk for an alternative for the condition; if the risk is then no longer UNACCEPTABLE, the condition is a safety bottleneck.

The identification of safety bottlenecks is important as it gives operational concept designers clues to finding potential risk mitigating measures for the operation.

3.9. Optional iteration of the assessment

The above steps constitute the TOPAZ safety assessment methodology. Following the assessment, decision-makers can consider whether the operation as assessed will be implemented as such, or that the operation will be adapted or redeveloped, or that the operation will not be implemented at all. If there still exists too much uncertainty on the risk level, it may also be decided to deepen the assessment.

Risks classified as NEGLIGIBLE usually do not form an objection to implement the operation as assessed. Risks that are classified as UNACCEPTABLE are considered to identify aspects of the operation that need some adaptation or further development. Finally, for risks classified as TOLERABLE, the ALARP principle is assumed to hold, which states that the operation could be implemented as long as the risk is kept As Low As Reasonably Practicable, i.e. anything technically and commercially possible will be done to minimise the risk.

In case adaptation or redevelopment of the operation takes place, a new safety assessment should be performed that adopts the same wide view as the first cycle, not limiting to the adapted operational details. The reason for this is that adaptations of the air traffic operation may improve safety in one respect, but may cause safety problems in another part of the operation.

3.10. Usage of the methodology

The safety evaluation documented in Section 4 and the selection of procedures for further research documented in Section 5 can be seen as part of the scope definition for the three safety assessments. In Sections 6, 7, 8 of this document these safety assessments are described.

The safety methodology on which these safety assessments are based has been described in Sections 3.1 to 3.9. In the following it is described to which extent the general methodology description was followed in the assessments of Sections 6, 7, and 8:

- The safety assessment described in Section 6 did not deviate from the methodology as described.
- For the safety assessment described in Section 7 and Section 8 some differences are:
  - Steps 2 and 3: no clustering of individual hazards into conflict scenarios has been applied; instead ‘scenario-like’ hazards were identified.
  - Steps 4, 5 and 6: the frequency assessment was not performed for every possible severity outcome. Instead, the worst case credible severity of the outcome of the hazard was selected and assessed on frequency.
  - Step 5: the frequency assessment was done purely qualitatively.

4. Initial high-level safety evaluation of six procedures

In this section an initial high-level safety evaluation is done for the four approach procedures and two take-off procedures introduced in Section 1. These procedures are compared with a baseline approach or take-off procedure that is currently in standard use. In this safety evaluation the potential safety impacts of conducting these procedures are described as compared to the current standard operating procedures. The six procedures and two baseline (approach and take-off) procedures are briefly summarised; for a more complete description of these procedures one is referred to [S II D3.1]. Subsequently the main safety issues that are related to conducting these procedures are addressed. The safety evaluation performed feeds the selection of procedures for further research in Section 5; together these activities can be seen as part of the scope definition of the safety assessments executed in Sections 6, 7, and 8.

4.1. Initial high-level safety evaluation of the approach procedures

The following approach procedures are considered:

I. Baseline approach procedure; descend to 3000 ft with constant speed, and at this altitude fly a level segment while changing to the intermediate configuration, until the glideslope is intercepted. At glideslope intercept the gear is extended and the aircraft is configured for the final approach configuration.

II. Basic CDA with 2° initial Flight Path Angle (FPA); characteristic for this procedure is that from 7000 ft to the glidepath interception point a constant 2° flight path angle is flown while the aircraft decelerates (with idle power) to the intermediate configuration.

III. Basic CDA with 2° initial FPA and increased final glideslope; this procedure is similar to the previous, except that the final approach path is steeper (4° in stead of 3°).

IV. CDA with constant speed, variable FPA segment at landing configuration; characteristic for this procedure is that the FPA during the descent from 7000 ft to 2000 ft is not constant. Before 7000 ft the aircraft decelerates with idle thrust while configuring to the landing configuration and subsequently the aircraft descends further to 2000 ft, where the glideslope is intercepted.

V. CDA with constant speed, variable FPA segment at intermediate configuration; this procedure is similar to the previous procedure (IV), except that the aircraft is first configured to the intermediate configuration, then intercepts the glideslope at 3000 ft, where the aircraft is further configured to the final approach configuration.

Main operational differences

A principal difference between the baseline and the introduced CDA procedures is that all CDA procedures try to avoid the level segment before the glideslope intercept as a way to reduce the noise burden on the ground. The inevitable consequence is that the glideslope is not intercepted from a level segment but from a descending segment. For procedures II and III this descending segment will have a fixed descend angle of 2°, and therefore there will be a rather shallow intercept angle with the glideslope. Although non-standard, most autopilot and flight director systems will be able to accommodate such an intercept.

The shallow intercept may lead to an increase in pilot workload because some additional thrust corrections may be required to compensate for gear extension (for some aircraft types the additional drag of gear extension is approximately equivalent to a change in flight path angle of 3° without significant thrust changes).

For procedures IV and V the difference with the baseline may be somewhat more noticeable, because the intercept with the glideslope may occur from a steeper (than 2°) descend path. It may even be possible that the glideslope is intercepted with a significant intercept angle from above.

The safety concerns are considered in the following.

Flight path or speed control on the intermediate approach segment

When comparing the procedures II & III with IV & V, an essential difference is that in the first two procedures the flight path angle is the controlled variable (path on elevator), while in the latter two procedures the airspeed is the controlled variable (speed on elevator).

Path on elevator (procedures II and III)

The consequence of having the flight path angle as controlled variable in the first two procedures is that there is only limited control over airspeed. This means that airspeed will change according to a pre-planned schedule, depending on aircraft performance characteristics. The only way to control airspeed is by adjusting (i.e., advancing or delaying) the required configuration changes. In real circumstances, resulting from the fact that the planned conditions may (or will) deviate from the planned conditions, the speed schedule cannot be expected to develop as planned. The final consequence from this is that the aircraft will be not delivered at the glideslope intercept point at the planned airspeed. In case that speed bleed-off will be higher than anticipated this will require early application of engine thrust, in order to prevent under-speed conditions. It is noted that this will reduce the anticipated reductions in noise production; significant safety implications are not expected.

In case the speed bleed-off will be less than anticipated, the aircraft will arrive at glideslope intercept with excess speed, that has to be reduced while the aircraft is configuring for the final approach configuration. This may lead to an increased workload and potentially to situations of unstabilised approach. It should however be noted that the proposed CDA procedures all have a final approach segment extending to 3000 ft. This means that there is a relatively long (about 9 NM) final approach segment length, which in general will provide sufficient time for the pilot to stabilise the aircraft.

Speed on elevator (procedures IV and V)

For the last two procedures (IV and V), airspeed instead of flight path is the controlled variable. Therefore the resulting (vertical) flight path will depend on the pre-planned schedule and the associated aircraft performance characteristics. Here also it has to be assumed that planning will not be perfect and therefore the actual flight path will deviate from the planned flight path. This means that the vertical flight path will either be too steep or too shallow. In the first case the minimum descent altitude will be reached before the glideslope is intercepted. This will result into a level flight segment before intercepting the glideslope, requiring associated power changes, and thus partly negating the anticipated noise reduction, but not having any significant implications on safety.

In case the resulting flight path angle is too shallow, this may result in late (i.e. low altitude) intercept of the glideslope. This may lead to an unstabilised approach and it may significantly add to the pilot's workload.

Glideslope intercept

As already discussed, the shallow glideslope intercept angle in procedures II and III is non-standard and may lead to some increase in pilot workload. A more significant issue exists however for procedures IV and V, namely that the resulting flight path angle before intercepting the glideslope may become steeper than the glidepath angle itself (i.e. steeper than 3°). Especially for procedure IV, in which the aircraft is configured for the final approach configuration before intercepting the glideslope, this 'interception from above' can be expected.

It should be emphasised here that intercepting the glideslope from above is a non-standard procedure that may increase pilot workload significantly. Moreover, it is known that current technology autopilot and flight director control laws are not optimized for glidepath intercept from above. This may lead to situations of significantly undershooting the glidepath, or in worst case not capturing the glidepath at all. The safety implications of this behaviour are obvious; serious reductions in the margins to the obstacle clearance surfaces may be caused. It is noted that possible solutions to this potential problem that imply introducing a level segment before intercepting the glidepath would again reduce the noise benefits of the proposed procedure.

Steep approach

An additional safety concern for procedure III is that the final approach path is steeper than the standard 3° (i.e. 4°). In itself, this constitutes not a major safety concern from an aircraft handling point of view. In general, aircraft are certified up to an approach angle of 4.5° without requiring further proof or demonstration (above 4.5° special steep approach certification is required). Nevertheless it is a deviation from standard operating practices, and therefore would require special pilot training in order to get familiarised with the non-standard visual reference and flare characteristics.

In addition, it is stated in the ICAO PANS-OPS document [PANS-OPS V1]: *"Glide path angles above 3.5° should be used in approach procedure design only for obstacle clearance purposes and must not be used as a means to introduce noise abatement procedures. Such procedures are non-standard and require a special approval"*.

This means that any approach procedure using a glideslope in excess of 3.5° for noise abatement purposes would require a special safety case, addressing (also from [PANS-OPS V1]):

a) an appropriate adjustment of the obstacle assessment surfaces; and

b) an appropriate increase in the height loss/altimeter margin.

The height loss/ altimeter margin should be verified by certification or flight trials. The effects of the following issues should then be covered: a minimum drag configuration, wind shear, control laws, handling characteristics, a minimum power setting for anti-icing, modification of GPWS, the use of flight director/autopilot, the engine spin-up time and an increase of the landing speed V_{at} for handling considerations.

Summary

In the following the main safety issues concerning the defined CDA procedures are summarised:

II. Basic CDA with 2° initial Flight Path Angle;

- A possible excess speed at glide slope intercept possibly leading to an unstabilised approach.

III. Basic CDA with 2° initial FPA and increased final glideslope;

- A possible excess speed at glide slope intercept possibly leading to unstabilised approach; more severe than for procedure 2 due to the fact that the excess speed is more difficult to control on a steep final segment;
- The steep final glideslope is a non-standard operation and potentially leads to higher workload. This operation requirs special analysis in relation to acceptance and to obstacle clearance surfaces.

IV. CDA with constant speed, variable FPA segment at landing configuration;

- A possible steep intermediate approach segment resulting to glideslope interception from above, with the potential consequences of a glideslope undershoot and an unstabilised approach;
- Potential flight path control problems, which could lead to an increased workload and an unstabilised approach in case the path is too shallow;

V. CDA with constant speed, variable FPA segment at intermediate configuration;

- The same issues as for procedure IV, though both less severe.

4.2. Initial high-level safety analysis of the departure procedures

The following departure procedures are considered:

1. Baseline take-off procedure; this procedure concerns the standard (ICAO-A) take-off procedure, comprising a climb out at V_2 + 10 with take-off power until 1500 ft, then reduce to climb thrust, and at 3000 ft retract flaps and accelerate to 250 kts while climbing further to 15000 ft.
2. Sourdine optimised close-in procedure; this procedure is almost similar to the close-in take-off climb procedure described as NADP 1 in [PANS-OPS, Vol. 2]: Climb out at V_2 + (10 to 20) kts with take-off power, and reduce at 800ft. From 800ft the prescribed power setting is used that provides the minimum one engine inoperative (OEI) climb gradient in case an engine failure occurs, and from 3000 ft to 5000 ft a steeper climb gradient is flown by selecting climb power, while maintaining speed. Finally when passing 5000 ft the aircraft is cleaned up and accelerated to 250 kts.
3. Sourdine optimised distant procedure; this procedure is almost similar to the distant take-off climb procedure described as NADP 2 in [PANS-OPS, Vol. 2]. When comparing the procedure to procedure 2, the main difference is that after reaching 800 ft first the aircraft is cleaned up and accelerated to the zero-flap speed V_{zf}. After reaching that speed thrust is reduced to the prescribed power setting providing the minimum one engine inoperative climb gradient in case an engine failure occurs.

Main operational differences

As indicated the defined departure procedures do not differ significantly from the noise abatement procedures as provided by ICAO [PANS-OPS, Vol. 2]; they can be considered as ‘optimised’ versions of those. The optimised procedures however extend to 5000 ft, whereas the ICAO procedures prescribe a smooth transition to en-route climb speed above 3000 ft. A second difference is that [PANS-OPS, Vol. 2] only mentions “reduced power, while maintaining positive climb” during the second climb segment, while the optimised procedures prescribe a reduction to the OEI climb gradient. thrust. This means that if, after the thrust-cut-back, an engine failure occurs, the required climb performance is obtained without changing the engine setting.

Directly after the thrust cut-back, the procedures 2 and 3 prescribe the thrust setting and the speed (at fixed configuration). As a consequence, the flight path angle will be the resulting parameter.

Effect of the number of engines

For the Sourdine departures, the thrust cut-back of 2-engined aircraft will be very close to the ICAO-A procedure. For 4-engined aircraft, the thrust cut-back will be large as compared to ICAO-A procedure.

However, in case an engine failure occurs, the prescribed minimum climb performance is still not violated during “ standard” weather operations. However, due to severe atmospheric disturbances (turbulence, windshear) an undershoot in the flight path angle may occur, which would infringe on the margins to the obstacle clearance surfaces.

Engine failure during climbing at the OEI climb thrust

When engine failure occurs, the minimum required climb performance is still met. However, due to the low powersetting after thrust cut-back, it may take additional time, especially for today’s high by-pass ratio engines, to increase climb performance.

Speed control during climb out

In particular, departure procedure 2 envisions to keep airspeed constant at V_2 + (10 to 20) kts at a low powersetting until 3000 ft is reached. This procedure will leave the aircraft relatively vulnerable to speed disturbances for a significant period of time. In case the airspeed would drop below lower values, speed control will be hampered by relatively sluggish engine response at low powersetting. In addition, due to flying with a low climb gradient, it is not preferred to accelerate speed recovery by using the speed on elevator technique (i.e. trading altitude for speed). For that reason speed control may prove difficult for departure procedure 2.

For procedure 3 this problem seems less severe because after reaching 800 ft the aircraft is first accelerated to V_{zf} and flaps and slats are retracted before the OEI climb gradient is maintained. This leaves the aircraft less vulnerable to speed disturbances closely to the ground.

Summary

In the following the main safety issues concerning the defined departure procedures are summarised:

2. Sourdine optimised close-in procedure;
   - Speed control problems at low powersetting at OEI climb thrust
3. Sourdine optimised distant procedure;
   - The same issue as for procedure 2, but less severe.

5. Selection of procedures for safety assessment

As discussed in Section 2, a selection of the four approach and two departure procedures introduced has to be made for detailed safety assessment and also for detailed assessment with respect to acceptance to end-users. The initial high-level safety evaluation of all these four plus two procedures of Section 4 serves as input to this selection process, as does the high-level assessment of acceptance to controllers and pilots of references [S II D6.1] and [S II D6.2]. Furthermore, all other information currently available is used as input: single event noise simulations, some draft results of capacity assessments, prototyping sessions on a cockpit simulator and an ATC simulator, and information gathered in meetings with the expert panel.

The following aspects are taken into account in the further selection: safety, capacity impact, cost-benefit, acceptability for pilot and air-traffic controller, availability of new avionics functions, etc. The aim is to select those procedures that look, with the limited information available, the most promising procedures for implementation. This way, the scope of the safety assessments of Sections 6, 7, and 8 is determined.

5.1. Selection of approach procedures

For the approach procedures, the following observations apply:

<u>Procedure I: Baseline approach procedure:</u> This is the baseline arrival procedure.

<u>Procedure II: Basic CDA with 2° initial FPA:</u> In this procedure a fixed 2-degree flight path angle from 7000ft up to the ILS intercept at 3000ft is applied. This is a very realistic and probably operationally feasible procedure, both from pilot and ATC perspective. All civil aircraft types are able to decelerate in a clean configuration during this 2-degree flight path. However, when the fixed flight path angle is combined with idle thrust, different aircraft types will show different speed profiles. This will cause a capacity decrease of the airport.

It is noted that it could be chosen to add speed constraints to the procedure definition, and to allow for (low) non-idle thrust settings. Then the speed profiles of the different aircraft types can be harmonised (to a large extent) and the capacity restrictions may be very limited.

The main safety issue identified for procedure II is that a possible excess speed at glideslope intercept might lead to an unstabilised approach.

<u>Procedure III: Basic CDA with 2° initial FPA and increased final glideslope:</u> The difference between arrival procedure II and III is the steeper flight path angle on the ILS (3° for procedure II, 4° for procedure III). This has a major impact on aircraft operations since this increased flight path angle requires a new certification process for the autoland system. This is not foreseen for the existing fleet of aircraft from a cost-benefit point of view. Therefore the introduction of an increased glideslope as the standard operating procedure will require a renewal of the fleet or its avionics and will take at least 20 years.

This procedure has the same main safety issue as procedure II, though more severe. Another safety issue is the 4° glideslope angle, which requires special analysis. At least it could increase the workload in the cockpit.

Also for this procedure one could introduce speed constraints. The effect of these constraints would be about the same as indicated for procedure II.

Procedure IV: CDA with constant speed, variable FPA segment at landing configuration: In this procedure a large part, between 7000 ft up to ILS intercept, is flown with idle thrust in landing configuration. During the RTS prototyping sessions in both the flight simulator (see reference [S II D6.2]) and the ATC simulator (see reference [S II D6.1]) several issues were raised concerning the flyability and controllability:

There is no control available once the descent from 7000ft is initiated: engines are on idle, in numerous aircraft types no speedbrakes are available in landing configuration.

- From the moment of glideslope intercept, high thrust settings are required to maintain the 3 degrees path. Normally the landing configuration is reached significantly later.
- Aircraft were not designed to fly for these long times with the required flaps settings: aircraft structure fatigue might lead to higher maintenance costs, auto-pilot control laws might reach their limit.
- The steep descent will be uncomfortable for passengers.
- The steep descent towards the glideslope might trigger the ground proximity warning system (for field surrounded by terrain, but possibly also for flat areas due to the high sink rate), especially in lower visibility conditions pilot might cancel the approach.

An important aspect for ATC is the unpredictability of the CDA Initiation Point (CIP); when will the pilot start its descent along this variable flight path? Although the speed profile is fixed the early speed reduction and the speed variations (Final Approach Speed is aircraft specific and can easily vary 30kts over different aircraft types) hence can result in a substantial loss of runway capacity.

Main safety issues identified are related to a possible glideslope intercept from above and to potential flight path control problems.

Procedure V: CDA with constant speed, variable FPA segment at landing configuration: This is the same type of procedure as procedure IV. Procedure V also uses a variable flight path, which is now the resultant of a thrust idle descent in an intermediate flap configuration from 7000 ft up to ILS intercept. This configuration directly solves many of the above raised issues of procedure IV. Especially the flyability is improved considerably:

- pilots have control over the aircraft in case of ending up too high (speed brakes are available, earlier adding drag by earlier flap selections on the glideslope etc.

For this procedure the same ATC aspects as mentioned for procedure IV are of interest (unpredictability of CIP, early speed reduction and speed variations). Although variations in intermediate flap speed occur between the different aircraft types, the speed levels are much higher in a long range of the approach procedure, yielding less capacity reduction than for procedure IV.

Main safety issues identified for this procedure are the same as for procedure IV, however less severe.

Conclusion

Procedure II and III both are procedures with a fixed, prescribed flight path angle (at idle thrust), resulting in different speeds for different types of aircraft. Procedure IV and V are defined with a fixed speed at idle thrust, resulting in a different flight path angle for different type of aircraft. For completeness it is considered to evaluate at least one procedure of each type of procedures.

As procedure II looks much more promising with respect to the flyability aspects, procedure II is preferred over procedure III. Because procedure II is expected to cause a limited capacity decrease, a variant of procedure II is defined (called procedure II-A). In procedure II-A, speed constraints are imposed on the 2 degree flight path angle segment.

The impact of these speed constraints, i.e., the difference between procedure II and II-A, will be analysed in the FTS for the Schiphol situation, as well as during the RTS in the flight deck simulator and the ATC simulator. The detailed safety analysis will be limited to the II-A variant.

From the other two set of arrival procedures (IV and V), procedure V is advantageous on all main aspects (flyability, safety, aircraft loads, passenger comfort, and capacity). Therefore procedure V is preferred over procedure IV.

Based on the considerations above, for safety assessment the following Sourdine II approach procedures have been selected: procedures II-A and V.

The safety assessment for approach procedure II-A on Schiphol airport is documented in [S II D4.2-2a], and the safety assessment for procedure V on Barajas airport is documented in [S II D4.2-3]. The safety assessments are summarised in Sections 6 and 7.

5.2. Selection of departure procedures

For the departure procedures, the following observations apply:

Procedure 1: Baseline take-off procedure: This is the baseline departure procedure.

Procedure 2: Sourdine optimised close-in procedure: This is the close-in departure procedure, for which the noise relief is located relatively closely to the runway. This procedure resembles the well-known ICAO-A and NADP1 procedures.

Main safety issues identified for this procedure are that speed control problems can occur at the low powersetting at OEI climb thrust.

Procedure 3: Sourdine optimised distant procedure: This is a distant procedure, for which the noise relief is located further away from the runway. This procedure is more in line with the ICAO-B and NADP2 procedures. While noise relief closely to the runway can only be realised by changing the vertical path, noise relief further away from the runway can often be realised by changing the lateral path.

The main safety issue identified for this procedure is the same as for procedure 2, though less severe.

Conclusion

Both departure procedures (procedures 2 and 3) use low energy profiles (aircraft stay relatively low) and require gradual thrust restoration (probably automatic). While noise relief closely to the runway can only be realised by choosing for such a low energy profile, noise relief further away from the runway can often be realised by changing the lateral path. Therefore procedure 3 is considered to be of less interest than procedure 2. Procedure 3 may be somewhat more promising from a safety point of view, but in the end procedure 2 is judged to be more promising.

Based on the considerations above, for safety assessment the following Sourdine II procedure has been selected: Departure procedure 2. The safety assessment for departure procedure 2 on Barajas airport is documented in [S II D4.2-3], and is summarised in Section 8.

6. Safety assessment of approach procedure II-A on Schiphol airport

6.1. Introduction

In Section 4.1 approach procedure II was introduced. Characteristic for this procedure is that from 7000 ft to the glidepath interception point a constant 2° flight path angle is flown, while the aircraft decelerates (with idle power) to the intermediate configuration. In Section 5.1 a variant of this approach procedure II was defined, called approach procedure II-A. In this procedure II-A speed constraints are imposed on the 2° flight path angle segment. Also in Section 5.1, this approach procedure II-A was selected for safety assessment.

This safety assessment is performed for a specific operation featuring procedure II-A applied to Schiphol airport, including the humans, further procedures and systems playing a role in it. The safety assessment is described in the following documents:

<u>Safety assessment of approach procedure II-A on Schiphol airport</u>

[S II D4.2-2a]	Main document
[S II D4.2-2b]	Argumentation-based analysis
[S II D4.2-2c]	Simulation-based analysis
[S II D4.2-2d]	Collection of expert interviews

Document [S II D4.2-2a] is the main document of this safety assessment. Documents [S II D4.2-2b] and [S II D4.2-2c] contain the more detailed safety analysis. In [S II D4.2-2d] all the supporting expert interviews are collected. Below, the safety assessment is summarised.

The risks associated with the operation have been assessed using the safety assessment methodology TOPAZ, described in Section 3. This methodology combines an argumentation-based approach with a simulation-based approach. The assessment performed is an absolute assessment of all the risks of the operation as described in this document, but restricted to the scope adopted in [S II D4.2-2a].

6.2. The operation

Approach procedure II-A can be considered as a Continuous Descent Approach (CDA) procedure, as it features a fixed three-dimensional flight path that does not include a horizontal segment before glide path intercept. It is however not a classical CDA with idle thrust; some speed constraints are in force, and thrust has to be applied when required. This way it is aimed to reduce noise hindrance, while maintaining capacity. The procedure is flown using P-RNAV (Precision Area Navigation).

In [S II D6.6 v0.2] a concept of operation has been developed for approach procedure II-A on Schiphol airport Amsterdam. Apart from the procedure the operation consists of humans, technical systems, more procedures, the operational context, and the interactions between these elements. The route structure associated with the considered approach procedure, applied to the situation of Schiphol airport, is provided in the figure below.

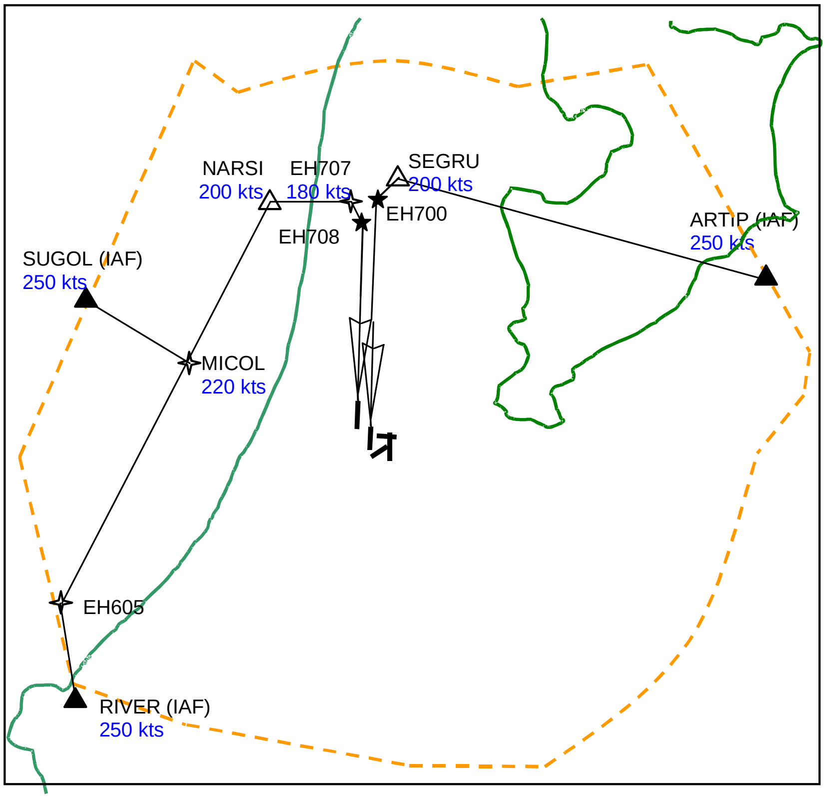

Figure 3: Arrival route structure on Schiphol airport considered, with speed constraints indicated.

6.3. Conflict scenarios

In various brainstorming sessions with operational experts, hazards have been identified that could occur in the considered operation. These hazards were structured into five conflict scenarios that describe the ways in which the hazards can lead to or worsen a conflict situation, and some sub scenarios:

1 Conflict between two aircraft merging onto one route

- a At MICOL
- b At NARSI (after a direct-to from SUGOL)
- c At EH708 (after an extended downwind)

2 Conflict between two aircraft on the same route

- a Two aircraft on the same route before the CDA (from ARTIP, SUGOL or RIVER)
- b Two aircraft on the same CDA (from ARTIP or the one from RIVER/SUGOL)
- c Two aircraft on the extended downwind
- d Two aircraft on the same ILS

3 Conflict between two aircraft established on their respective localizers (one for 18R and one for 18C)

4 Conflict between two aircraft (one for 18R and one for 18C) of which at least one is turning to intercept its localizer, the other aircraft may also be turning in or already be established on its own localizer. Here several situations can be taken into account: One or both aircraft can make a turn towards the wrong ILS or to a wrong waypoint, or may make an overshoot. In addition, one or both aircraft may have come from the extended downwind or not.

5 An approaching aircraft encounters the wake vortex of another aircraft in approach.

   a An aircraft flies into the wake vortex of an aircraft of the traffic flow that it is to be merged with

   b An aircraft flies into the wake vortex of the preceding aircraft in the same approach flow

   c On the parallel approach an aircraft flies into the wake vortex of the aircraft flying on the parallel lane

   d While turning in for parallel approaches an aircraft flies into the wake vortex of the aircraft turning in on the parallel lane

6.4. Risk assessment results

The risks have been assessed using risk criteria that combine the [ESARR 4] severity classification with the well-known frequency classification of JAA. This is done since a suitable approach of applying the overall ESARR 4 maximum allowed frequency to a conflict scenario is not (yet) available. The risk of each conflict scenario is classified as either UNACCEPTABLE (above a maximum tolerable probability), TOLERABLE or NEGLIGIBLE.

Conflict scenarios 1, 2, 3, and 5 have been analysed using an argumentation-based approach. In this approach for each of these conflict scenarios the severity and the frequency have been assessed using argumentations built on inputs retrieved mainly from operational experts' judgement, information from the real-time experiments [S II D6.3 v0.2], and knowledge from other studies. Based on these severity and frequency assessments, and the adopted risk criteria, an evaluation of the acceptability of the risk of each conflict scenario was given.

The risk of conflict scenario 4 has been assessed using a simulation-based approach. Here, only accident risk has been considered, thus no incident risk. This approach relies to a large extent on Monte Carlo simulations using an advanced stochastic model. The approach uses four steps:

1. Development of mathematical model
2. Model-based accident risk assessment
3. Bias and uncertainty assessment
4. Combination of results of step 2 and 3.

The bias and uncertainty assessment (step 3) judges all model assumptions adopted during the model-based accident risk assessment (steps 1 and 2), and assesses the factor by which model-based accident risk should be multiplied to compensate for the effect of these model assumptions. The result of step 4 is an expected accident risk value and a 95% uncertainty area for realistic accident risk.

The results of the risk assessment are that the risks of conflict scenarios 1 and 3 are assessed to be TOLERABLE, and that the risks of conflict scenarios 2, 4 and 5 are either TOLERABLE or UNACCEPTABLE. For the risk of conflict scenario 4, the expected accident risk value is in the TOLERABLE region, and large part of the 95% uncertainty area is in the TOLERABLE region with a small part in the

UNACCEPTABLE region. It could be decided to qualify this as tolerable; however, more important is that the current detailed risk assessment would require better founded risk criteria.

Uncertainty in the assessment results

For all conflict scenarios, some uncertainty ranges in the risk assessment results were found. In particular, for some conflict scenarios it could not be ruled out that the risk is in more than one acceptability region (UNACCEPTABLE, TOLERABLE, and NEGLIGIBLE). The reason for this is the uncertainty in the risk assessment, which is related to the following issues:

- A certain level of uncertainty is inherent to the method chosen, which depends on the structured use of operational experts' judgements, who assess a future operation extrapolating their experiences with the current operation;
- The details of the operational description remain to be specified; and
- Statistical data on model parameter values is scarce.

6.5. Potential safety bottlenecks

The possibility of UNACCEPTABLE risk could not be ruled out in the conflict scenarios 2, 4 and 5. Potential safety bottlenecks for these conflict scenarios are discussed next.

For conflict scenario 2 the following conclusions hold:

- The risk is possibly UNACCEPTABLE for both the approach procedure to runway 18C and the one to runway 18R. The reason for the risk being possibly UNACCEPTABLE is that longitudinal separation problems can occur caused by an insufficient initial separation at the IAF and by a reduced ability to provide separation in case of 34 aircraft per hour, may be generic for the vertical flight profile considered; this could ultimately lead to danger of collision.
- The possibly UNACCEPTABLE risk for conflict scenarios 2 and 5, related to.
- The reduced ability of the controllers to maintain separation when assuming 34 aircraft per hour is related to:
  - The aircraft have trouble flying both a vertical profile and prescribed speed, also because changing circumstances (e.g., wind predictions change differ from actual wind) are not taken into account;
  - The controllers become more reactive, and should not vector anymore, and speed instructions have only limited efficacy, also because controllers do not know the exact performance and reaction of the aircraft;
  - The declared capacity of 34 aircraft per hour (a lower capacity would give more space); and
  - The non-optimal timing of the traffic entering the TMA.

For conflict scenario 4 the following conclusions hold:

- The biggest contributor to accident risk is the situation in which an aircraft for runway 18R does not turn in for ILS, while an aircraft for runway 18C turns in for ILS 18C.
- Main reason why an aircraft would not turn in for an ILS localizer course is that an incorrect ILS localizer frequency is selected and that this remains undetected. Hence, this issue can be regarded as a safety bottleneck. The selection error can be made by both the crew and the system; in the latter case a wrong input of the runway or ILS identifier or a database error can be the cause.

- A related safety bottleneck is that, as it was assumed, the autopilot automatically drops LNAV once the localizer interception mode is engaged. This means that in case the correct localizer frequency has not been selected the aircraft does not follow the defined route but crosses the extended centreline.
- Finally, an important safety bottleneck is that in this concept of operation (in contrast with current Schiphol operations), there is not 1000ft vertical separation between two aircraft turning in for their respective ILSs for runways 18R and 18C. Indeed, if there would be 1000 ft vertical separation between the two flows of traffic, the situation in which one aircraft does not intercept its ILS (i.e. the safety bottleneck mentioned above) would not necessarily lead to loss of separation anymore, hence the weight of the biggest contributor to risk as identified above would be reduced.

It is noted that these latter safety bottlenecks are not directly related to flying a CDA. The choice taken by the operation designers to implement two CDAs with completely identical vertical paths on the parallel runways however does cause that the aircraft cannot turn in for final approach with 1000ft vertical separation. Furthermore it is noted that an important assumption taken was that the NTZ stretches from the runway to beyond the ILS interception points; this is not in accordance with current ICAO regulations.

For conflict scenario 5 the following conclusions hold:

- As for conflict scenario 2, the risk is possibly UNACCEPTABLE for both the approach procedure to runway 18C and the one to runway 18R, and this is related to a reduced ability to provide separation further on the route; causes for this have already been mentioned. Here however this could ultimately lead to danger of a wake vortex encounter.
- Conflict scenario 5 considers wake vortex encounters and thus also more directly wake vortex related hazards could be seen as safety bottlenecks. However, it is judged that the relevant safety bottlenecks are the common causes that cause the high risk of both conflict scenarios 2 and 5. Accordingly, no more directly wake vortex related safety bottlenecks have been identified.

6.6. Concluding remarks

The Sourdine II operation for approach procedure II-A on Schiphol airport has risks that are classified as (possibly) UNACCEPTABLE. Therefore, the operation should be improved before implementation. The identified safety bottlenecks could serve as a starting point for the operational concept designers for the identification of risk mitigating measures. It is considered most logical to do a new cycle of the safety assessment once the operation has been improved; then also for conflict scenarios 2 and 5 a simulation-based approach may be used. It is recommended to study how better founded risk criteria can be derived for the type of detailed risk assessments performed in this document.

When considering to which extent the identified (possibly) UNACCEPTABLE risks are generic for the vertical flight profile considered, irrespective of the Schiphol implementation considered, the following conclusions hold:

- The possibly UNACCEPTABLE risk for conflict scenarios 2 and 5, related to longitudinal separation problems caused by an insufficient initial separation at the IAF and by a reduced ability to provide separation in case of 34 aircraft per hour, may be generic for the vertical flight profile considered.
- The possibly UNACCEPTABLE risk for conflict scenario 4, caused by aircraft overshooting the ILS while turning in for parallel approach, while vertical separation of 1000ft has not been guaranteed, is not generic for the vertical profile. However, when considering a generic implementation of this profile on parallel runways, it is very well possible that the risk is possibly UNACCEPTABLE, depending of course on the distance between the runways, the staggering between the runways, and the exact implementation of the procedure.

When comparing the risk of the operation studied with the risk of the resembling operation on Schiphol airport considered in the Approve study, no conclusive statement can made on which of the two operations is safer. Both operations show some (possibly) UNACCEPTABLE risks.

- The causes of the (possibly) Unacceptable risk in the Approve study are related to aspects of the operation not part of the Sourdine II operation: In Approve only part of the traffic is P-RNAV equipped and follows the RNAV route, the rest of the traffic is radar vectored along the routes; in Approve there is a turn in the route just for a merging point, and in Approve aircraft are expected to fly straight ahead, off-route, in case no timely approach clearance is derived.

The causes of the (possibly) UNACCEPTABLE risk in the Sourdine II study are related to some aspects of the operation not part of the Approve operation and some aspects out of scope in the Approve study. Turning in for final approach without vertical separation is not part of the Approve operation, and longitudinal problems along the route are hardly considered in Approve.

7. Safety assessment of approach procedure V on Barajas airport

7.1. Introduction

This section describes the safety assessment carried out by AENA (Aeropuertos Españoles y Navegación Aérea) considering the extrapolation of the Sourdine II procedure V (introduced in Section 4.1, CDA with constant speed, variable FPA segment at intermediate configuration) to Barajas airport, considering the most probable parallel runway scenario in 2015. The full safety assessment can be found in [S II D4.2-3].

From a pure operational point of view, some hypotheses have been considered when performing the assessment, before considering the safety perspective. Prior to the safety assessment, a modification to approach procedure V was required to overcome a significant constraint when extrapolating the vertical profiles described in Sourdine II to the future Barajas scenario. The Barajas parallel runways approach operations will be based on vertical separation and a clear incompatibility would arise if "pure" CDA to both approaches was to be applied as the runway heads are not sufficiently staggered in distance to ensure a 1000ft vertical separation while performing independent continuous descent approaches. The adopted solution following extensive consultations with operational experts has been to modify, prior to carrying out the safety assessment, the Sourdine II procedure:

- Apply a pure Sourdine II procedure V for approaches to runway 33L, starting at 8000 feet.
- Apply Sourdine II procedure V with a horizontal level flight leg in the intermediate approach for the approaches to runway 33R.

The hazard identification has been carried out through brainstorming sessions with operational personnel and further analysis with safety experts. The information captured during the sessions was processed and as a result, twenty-two identified hazards were grouped into categories based on the phase of flight within the approach stage: TMA transition, approach intermediate – localiser intercept, approach intermediate – localizer establish, approach final and TMA overall.

The main purpose for the argumentation-based safety assessment has been to evaluate the Sourdine II noise abatement approach procedure V safety implications when introduced into a real airport approach scenario. Only hazards directly related to the Sourdine II noise abatement approach procedure or whose consequences would be made worse by its implementation have been considered. Thus, the present safety assessment needs to be considered within its intended scope and cannot be understood to cover, either partially or totally, any safety aspect of the future Barajas Airport operations.

7.2. Safety assessment methodology and criteria considerations

The argumentation-based safety assessments for Sourdine II procedures adapted for Barajas Airport (circa 2015) have been carried out following a methodology consistent with ESARR 4 [ESARR 4] requirements. Expert sessions with the participation of pilots, ATC officers and safety personnel familiar with the Barajas Airport future parallel runway planned operations have been held to introduce the concept of operations and to identify the hazards that the Sourdine II procedure would pose to ATM operations. Subsequently, the identified hazards have been assigned a severity and an estimated occurrence frequency in order to determine their risk tolerability. No attempt has been made to numerically quantify the frequency occurrence.

With regards to severity classification, the ESARR 4 scheme has been employed to classify the identified hazards. Unfortunately, the risk classification scheme (or matrix) provided by ESARR 4 is still under development and an alternative scheme must have been selected to complete the risk analysis. The risk classification scheme selected corresponds to ED-78A "Guidelines For Approval Of The Provision And Use Of Air Traffic Services Supported By Data Communications" [ED-78A].

The safety assessment methodology employed using ESARR 4 and ED-78A necessarily needs of some assumptions to be made. The ED-78A guideline hazard classification is somewhat different to ESARR 4 severity classification scheme, as identified in SRCs Assessment of EUROCAE ED78A as a means of compliance with ESARR 4 [SRC Doc 20]. A comparison between both schemes can be found in [S II D4.2-3]. However, with regards to ESARR 4 hazard identification, risk assessment and mitigation processes, ED-78A is found in agreement with ESARR 4 in terms of an assessment of the effects they may have on the safety of aircraft, as well as an assessment of the severity of those effects once Annex E is taken into account. For the purposes of this safety assessment, the differences between severity classification schemes are not deemed significant in order to obtain a preliminary assessment of risk tolerability regardless of their acceptability. Should a more in-depth noise abtement procedure safety analysis be developed based on the present assessment, it is recommended to analyse the classification scheme differences in detail before reaching any judgements on risk tolerability.

7.3. The operations

The operation under study corresponds to the Sourdine II approach procedure V (CDA with idle thrust) extrapolated to Barajas in an anticipated 2015 scenario, with two sets of parallel runways. The study focuses on the most commonly used North Configuration at Barajas, 33L and 33R for approaches and 36L and 36R for departures as displayed in Figure 4

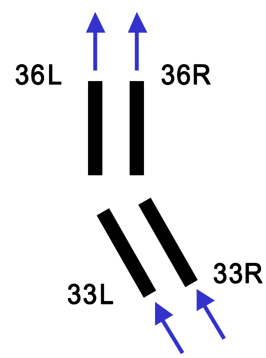

Figure 4: Barajas airport parallel runway north configuration

The scenario under consideration presents the following characteristics:

- Two sets of parallel runways.
- The arrivals and the departures are segregated.
- The distance between the runways enables independent departures as well as independent arrivals procedures. There are some dependencies between arrivals to runway 33R and departures from 36L due to the missed approach procedures from the 33R (in North configuration).

During the description of the operation for the Sourdine II approach rocedure V applied to Barajas, the following hypotheses have been considered:

- The runways used for arrivals in North Configuration are 33R and 33L.
- It has been considered only from the IAFs to the missed approach fix, of both runways.
- From a technological point of view:

- Communications: Mainly voice communication. Probably for 2015 there will be more datalink applications but this study is focused on the CDA for Barajas rather than on technological improvements.
- Navigation: RNP1 in TMA and RNP0.3 in final approach (ILS segment). All the aircraft following the procedure will be equipped.
- Surveillance: Mode S. There is an NTZ (No Transgression Zone) with additional equipment (high resolution radar screen).

- Aircraft equipped with new generation FMS, that allows to follow the procedure as it is described in [S II D3-1].
- Fleets: A320 and A340. The rationale for choosing these fleet is data availability.
- Roles:
  - Ground:
    - Directors controllers (one per runway): West for 33L and East for 33R. Only for arrival traffic to each of the runways.
    - Final approach (one per runway): West for 33L and East for 33R; they are in charge of NTZ surveillance. Only for arrival traffic to each of the runways.
  - Air:
    - Pilot flying.
    - Pilot not flying.

When extrapolating the Soudine II procedure V vertical profile to the future Barajas scenarios, there is a pure operational constraint: the current description of the future Barajas operations for approaches to parallel runways are based in vertical separation, so there is a clear incompatibility with applying a pure CDA to both approaches. This constraint was identified previous to undertaking the safety analysis.

The solution adopted following operational expert consultation has been to:

- Apply a pure Sourdine II procedure V for approaches to runway 33L, starting at 8000 feet
- Apply Sourdine II procedure V with a horizontal level flight leg in the intermediate approach for the approaches to runway 33R

There is more population close to the approach area to the runway 33L than to the runway 33R; for that reason was chosen to apply a pure CDA to runway 33L in order to reduce noise where it is more necessary.

The following figures shows the application of this CDA V to Barajas future scenario (horizontal profiles), starting with the baseline and then showing the different possibilities depending on the approach route.

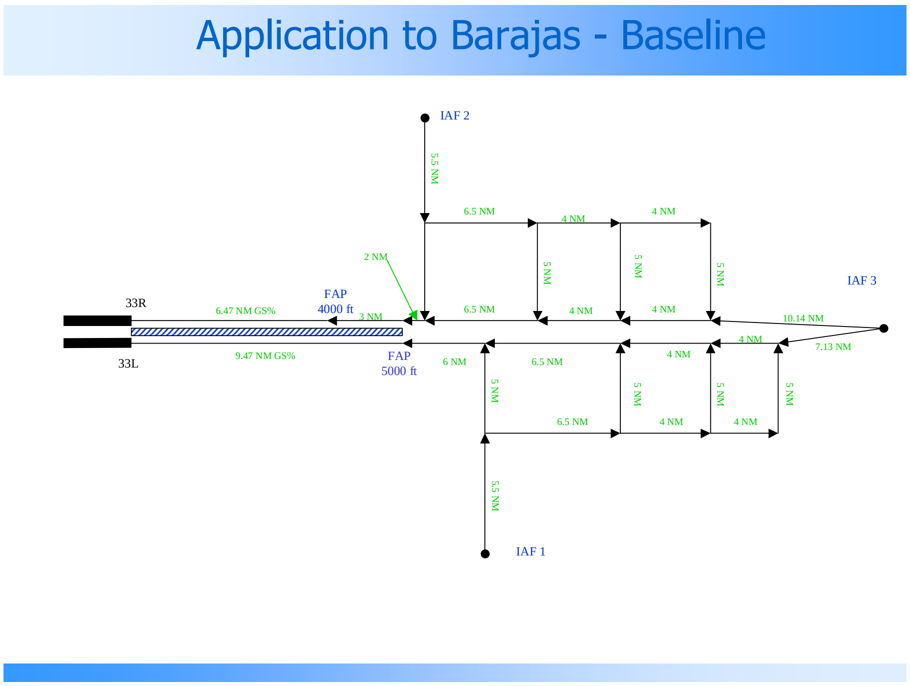

Figure 5: Baseline.

The baseline provides the complete set of procedures that are proposed to be used in the future Barajas airport, considering only the horizontal layout. The baselines shows an arrays approach, that allows to take advantage of the capacity of the runway having possibilities for high and low number of arrivals, depending on the length of the approach. It is used as the starting point to apply the vertical profiles defined in Sourdine II procedure V.

There are three IAFs: the IAF1 for aircraft approaching from the south-west area, the IAF2 used by aircraft approaching form the south-east area and the IAF 3, used to balance East and West traffic when necessary.

All the aircraft have to be aligned with the ILS localiser before reaching the area parallel to the NTZ. When the aircraft reaches the area parallel to the NTZ, there is, at least, 1000 ft of vertical separation between the two parallel approaches. From the Final Approach Point, in both approaches, the aircraft descent according to the glide slope (3º).

7.4. Safety assessment outcome

When trying to extrapolate the vertical profiles described in Sourdine II to the future Barajas scenarios, a significant constraint was found. The future Barajas operations under current consideration for approaches to parallel runways are based in vertical separation. Therefore, a clear incompatibility arises when applying “pure” CDA to both approaches as the runway heads are not sufficiently staggered in distance to ensure a 1000ft vertical separation while performing independent continuous descent approaches to both runways. The adopted solution following extensive consultations with operational experts has been to modify the Sourdine II procedure with a level flight leg in the intermediate approach for approach to runway 33R, due to the lower population density in the runway vicinity. In runway 33L a pure Sourdine II approach procedure V has been applied. This procedure modification was carried out prior to undertaking the safety assessment.

Identified hazards have been grouped as a function of the phase of flight within the approach stage into the following categories (the number of derived risks appear between brackets):

- TMA Transition (4)
- Approach Intermediate – Localiser Intercept (3)
- Approach Intermediate – Localiser Established (11)
- Approach Final (3)
- TMA Overall (1)

The outcome of the safety assessment has revealed a series of safety significant issues, which they are recommended to be analysed further. A distinction is made between those related to the inherent characteristics of the Sourdine II approach procedure V and those for which the particular parallel runway set-up is the determining factor when performing simultaneous and independent CDAs to both runways.

Sourdine II approach procedure V issues:

1. The fact that final approach controllers will only monitor separation rather than issue vectors to implement separation (except in conflict situations) makes that non-adherences to CDA speed descent profiles may cause aircraft to breach longitudinal separation (e.g. catch up aircraft ahead or be caught up by trailing aircraft). As a potential result, the probability of wake vortex encounters is likely to also increase. A simulation exercise for final approach standard separations for different traffic mixes at peak times will be required to determine whether CDAs could be sustained without being detrimental to airport capacity. Mitigation emergency procedures will also be required to manage breaches of separation during the final approach stage prior to the NTZ and the impact of any aborted approaches on departures analysed. The risk of wake vortex encounter has been classified as possibly unacceptable (Risk ID 18) without further mitigation. Additionally while some of the procedure deviation risks have been assessed as acceptable (Risks ID 8 & 9), it must be noted that this tolerability is based on the minimum safety requirement established by ED78-A. The construction of a simulation model is recommended to evaluate the frequency of occurrence in more detail.

Parallel runway CDA safety issues

2. Within the final approach stage once established in the localiser, separation is ensured vertically. Thus, non-adherences to vertical CDA profiles may breach the 1000ft vertical separation that by design, should be maintained at all times between aircraft established on the parallel localisers prior to reaching the area parallel to the NTZ. While the associated risk of such occurrences would be low, it would constitute a significant erosion of safety margins according to current safety standards and any subsequent non-adherence to the horizontal flight profile could rapidly develop into a serious incident with very little reaction time available.

3. Independent CDA-based approaches to parallel runway airport configurations exhibit a safety significant issue related to failed localiser intercepts, commonly known as localiser “overshoots”. In the future Barajas airport configuration, separation between aircraft established on the parallel localisers is based on 1000ft vertical separation at all times prior to reaching the area parallel to the NTZ. As a consequence, small-excursion overshoots followed by rapid localiser interceptions would only be associated with an erosion of safety margins as vertical separation would be maintained with opposing traffic. However, wide-excursion overshooting developing into wrong localiser interception or adjacent sector non-authorised incursion would pose a safety critical issue as while continuously descending vertical separation with other aircraft in the vicinity would rapidly be eroded. The outcome of the safety assessment has showed that there may be UNACCEPTABLE risks associated with localiser-failed interceptions (Risk Ids 5.3 & 6.3). It is also recommended that a simulation model be constructed in order to obtained a more detailed risk quantification and established the most severe incidents likelihood of occurrence.

7.5. Concluding remarks

The qualitative safety assessment shows that the Sourdine II approach procedure V adapted to the future Barajas Airport parallel runway configuration exhibits some safety significant issues that are in need of a more detailed and quantitative analysis. It is recommended that the analysis takes into consideration the inclusion of decision support tools such as an Arrival Manager (AMAN) to manage the arrival sequences on both runways. It is also suggested that a safety-net additional functionality is considered in order to monitor potential longitudinal breaches of separation for localiser-established consecutive aircraft.

8. Safety assessment of departure procedure 2 on Barajas airport

8.1. Introduction

This section describes the safety assessment carried out by AENA (Aeropuertos Españoles y Navegación Aérea) considering the extrapolation of the Sourdine II departure procedure 2 (introduced in Section 4.2, take off power up to 800ft, OEI setting up to 3000ft with steeper climb gradient flown up to 5000ft, cleaning up and accelerating until 250kts) to Barajas airport, considering the most probable parallel runway scenario in 2015. The full safety assessment can be found in [S II D4.2-3].

The hazard identification has been carried out through a brainstorming session with operational personnel and further analysis with safety experts. The information captured during the session was processed and as a result, ten hazards were identified. It must be noted that resource constraints limited the number of operational experts involved in the analysis. For this reason the assessment has been termed as a high level safety assessment. Subsequently and subject to this caveat, all derived risks have been preliminarily considered to be acceptable.

The main purpose for the argumentation-based safety assessment has been to evaluate the Sourdine II departure procedure 2 safety implications when introduced into a real airport approach scenario. Only hazards directly related to the Sourdine II departure procedure or whose consequences would be made worse by its implementation have been considered. Thus, the present safety assessment needs to be considered within its intended scope and cannot be understood to cover, either partially or totally, any safety aspect of the future Barajas Airport operations.

8.2. Safety assessment methodology and criteria considerations

The argumentation-based safety assessments for Sourdine II procedures adapted for Barajas Airport (circa 2015) have been carried out following a methodology consistent with ESARR 4 [ESARR 4] requirements. Expert sessions with the participation of pilots, ATC officers and safety personnel familiar with the Barajas Airport future parallel runway planned operations have been held to introduce the concept of operations and to identify the hazards that the Sourdine II procedure would pose to ATM operations. Subsequently, the identified hazards have been assigned a severity and an estimated occurrence frequency in order to determine their risk tolerability. No attempt has been made to numerically quantify the frequency occurrence.

With regards to severity classification, the ESARR 4 scheme has been employed to classify the identified hazards. Unfortunately, the risk classification scheme (or matrix) provided by ESARR 4 is still under development and an alternative scheme must have been selected to complete the risk analysis. The risk classification scheme selected corresponds to ED-78A “Guidelines For Approval Of The Provision And Use Of Air Traffic Services Supported By Data Communications” [ED-78A]. A more detailed description of additional assumptions made can be found in section 7.2.

8.3. The operations

The operation under study corresponds to the Sourdine II departure procedure 2 (Optimised Close-In) extrapolated to Barajas in an anticipated 2015 scenario, with two sets of parallel runways. The study focuses on the most commonly used North Configuration at Barajas, 33L and 33R for approaches and 36L and 36R for departures (as shown in Figure 4).

The scenario under consideration presents the following characteristics:

- Two sets of parallel runways.

- The arrivals and the departures are segregated.
- The distance between runways enables independent departures as well as independent arrivals procedures. There are some dependencies between arrivals to runway 33R and departures from 36L due to the missed approach procedures from the 33R (in North configuration).

During the description of the operation for the Sourdine II departure procedure 2 applied to Barajas, the following hypotheses have been considered:

- The runways used for departures in North Configuration are 36R and 36L.
- It has been considered only from the threshold to approximately 48 MN since lift-off.
- From a technological point of view:
  - Communications: Mainly voice communication. Probably for 2015 there will be more datalink applications but this study is focused on the CDA for Barajas rather than on technological improvements.
  - Navigation: RNP1 in TMA. All the aircraft following the procedure will be equipped.
  - Surveillance: Radar separation for departure.
- Aircraft equipped with new generation FMS, that allows to follow the procedure as it is described in [S II D3-1].
- Fleets: A340. The rationale for choosing these fleet is data availability.
- Roles:
  - Ground:
    - Departure controllers (one per runway): West for 36L and East for 36R.
  - Air:
    - Pilot flying.
    - Pilot not flying.

The departure procedure 2 (Optimised Close-In), considering the vertical profile, is described in the following table, from the data provided in the project:

Table 2: Vertical description of Sourdine II departure procedure 2

Condition	Parameter values
0 ft	– TOGA (Take-off Go Around) thrust – Brake release and acceleration to rotation speedRotation and lift-off
	– Retraction of undercarriage – Climb out at speed of V2 + 10-20 kts IAS
1000 ft	– Reduce thrust to OEI climb gradient or max climb (the lowest) – Maintain V2 + 10-20 kts IAS
3000 ft	– If OEI climb gradient thrust was selected, gradually change to thrust to climb thrust

	– Maintain V2 + 10-20 kts IAS
5000 ft	– Accelerate and retract flaps/slats on schedule to clean configuration – Continue acceleration to 250 kts – Climb to 15000 ft

The following figure shows the set of departure procedures that are planned to be used in the future Barajas airport, North configuration.

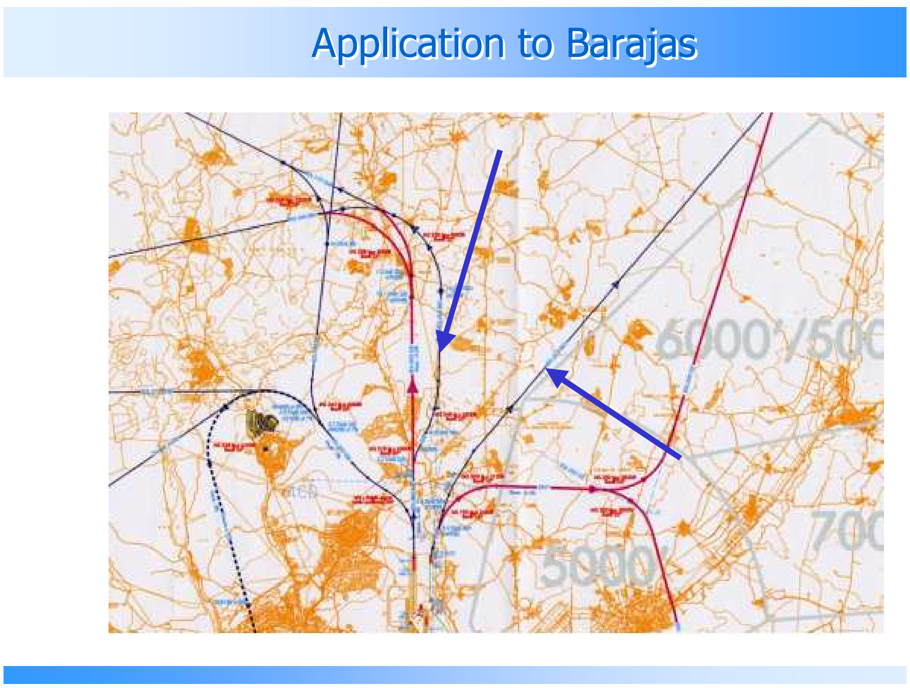

Figure 6: Future departure procedures in Barajas Airport.

8.4. Safety assessment outcome

Ten hazards were identified during the expert session for the Sourdine II departure procedure 2, adapted to the future Barajas airport layout. Given the number of hazards and the characteristics of the procedure, the hazards were not classified into any particular categories. Five of the identified hazards are inherently characteristic of the departure procedure and the remaining five are of a more general nature and are also applicable to departures as well as to arrivals procedures.

The Sourdine II departure procedure 2 aims at reducing the noise impact around the SID footprint at ranges closest to the runway, causing the aircraft to operate at reduced performance with OEI (One Engine Inoperable) power settings. This fact necessarily imposes that the main procedure risks will be associated with airport obstacle limiting surface infringements that may lead to loss of separation with obstacles and/or ground. The main emphasis of the assessment was placed on whether the procedure-induced departure from the aircraft optimal climbing performance could erode safety margins. In particular, the assessment has taken into account whether aircraft flying the Sourdine II departure 2 procedure could easily recover from other failures, even though flying at OEI power settings.

The safety assessment concludes that the most significant risks associated with the Sourdine II departure 2 procedure are due to either engine loss (such as a catastrophic malfunction or malfunction caused by a bird strike) or sudden adverse meteorological conditions (such as windshear or thunderstorm turbulence) that could impair the aircraft airworthiness. However, it is deemed that aircraft could recover from these situations despite flying at reduced power settings and therefore, the procedure does not degrade safety margins. The combination of both hazards (engine loss and adverse meteorological conditions) could have a significant safety impact, however this could be mitigated by restricting the range of meteorological conditions in which the Sourdine II departure 2 procedure may be flown.

8.5. Concluding remarks

The qualitative high level safety assessment shows that the Sourdine II departure procedure 2 adapted to the future Barajas Airport parallel runway configuration exhibits some safety issues. These issues are related to the fact that noise reduction is achieved by operating the aircraft at reduced power settings and associated to any failure that may cause airport obstacle limiting surface infringements that may lead to loss of separation with obstacles and/or ground. The conducted high level assessment has concluded with all identified risks having been preliminarily considered as acceptable. Given the high level nature of the assessment in terms of number of participating experts, it is recommended that further analysis is undertaken to increase the confidence in the resulting risk classification.

9. Conclusion

Safety analyses have been performed for the four approach and two departure noise abatement procedures defined in [S II D3.1-2]. Based on an initial high-level safety evaluation of these four approach and two departure procedures and on inputs not related to safety the Sourdine II management made a selection of three procedures for safety assessment. For each of these three procedures an operation has been defined on a specific airport including also specific human roles and technical systems. The results of these safety assessments consist of an overview of the risks associated with the operations and show which parts of the operations are most safety critical, such that feedback can be given to the operational concept designers.

First the conclusions of the initial high-level safety evaluation of the four approach and two departure procedures are given, next the main conclusions of each of the three safety assessments are presented.

9.1. Conclusions of the initial high-level safety evaluation

The main safety issues related to each of the four approach procedures are:

II. Basic CDA with 2° initial Flight Path Angle;

- A possible excess speed at glide slope intercept possibly leading to an unstabilised approach.

III. Basic CDA with 2° initial FPA and increased final glideslope;

- A possible excess speed at glide slope intercept possibly leading to unstabilised approach; more severe than for procedure 2 due to the fact that the excess speed is more difficult to control on a steep final segment;
- The steep final glideslope is a non-standard operation and potentially leads to higher workload. This operation requirs special analysis in relation to acceptance and to obstacle clearance surfaces.

IV. CDA with constant speed, variable FPA segment at landing configuration;

- A possible steep intermediate approach segment resulting to glideslope interception from above, with the potential consequences of a glideslope undershoot and an unstabilised approach;
- Potential flight path control problems, which could lead to an increased workload and an unstabilised approach in case the path is too shallow;

V. CDA with constant speed, variable FPA segment at intermediate configuration;

- The same issues as for procedure IV, though both less severe.

Because procedure II is expected to cause a limited capacity decrease, a variant of procedure II was defined by Sourdine II operational designers, called procedure II-A. In procedure II-A, speed constraints are imposed on the 2 degree flight path angle segment.

The main safety issues related to each of the two departure procedures are:

1. Sourdine optimised close-in procedure;
   - Speed control problems at low powersetting at OEI climb thrust
2. Sourdine optimised distant procedure;
   - The same issue as for procedure 2, but less severe.

9.2. Main conclusions of the safety assessment of approach procedure II-A on Schiphol airport

This safety assessment has been performed for the operation described in D4.2-2a, in which Sourdine II approach procedure II-A is considered in the context of Schiphol airport. The risk has been assessed with respect to risk criteria that combine the [ESARR 4] severity classification with the well-known frequency classification of JAA.

Five conflict scenarios have been identified that describe in which way an accident or incident could occur. The risks of conflict scenarios 1 and 3 are classified as TOLERABLE, and the risks of conflict scenarios 2, 4 and 5 are classified as being either TOLERABLE or UNACCEPTABLE.

The uncertainty in the latter results is related to the use of data retrieved from experts, who assess a future operation by extrapolating their experiences with the current operation; to details of the operational description that remain to be specified; and to the scarceness of statistical data on model parameter values.

When considering to which extent the identified (possibly) UNACCEPTABLE risks are generic for the vertical flight profile considered, irrespective of the Schiphol implementation considered, the following conclusions hold:

- The possibly UNACCEPTABLE risk for conflict scenarios 2 and 5, related to longitudinal separation problems caused by an insufficient initial separation at the IAF and by a reduced ability to provide separation in case of 34 aircraft per hour, may be generic for the vertical flight profile considered.
- The possibly UNACCEPTABLE risk for conflict scenario 4, caused by aircraft overshooting the ILS while turning in for parallel approach, while vertical separation of 1000ft has not been guaranteed, is not generic for the vertical profile. However, when considering a generic implementation of this profile on parallel runways, it is very well possible that the risk is possibly UNACCEPTABLE, depending of course on the distance between the runways, the staggering between the runways, and the exact implementation of the procedure.

Since the operation has risks that are classified as (possibly) UNACCEPTABLE, the operation should be improved before implementation. Safety bottlenecks have been identified that could serve as a starting point for the operational concept designers for the identification of risk mitigating measures. It is considered most logical to do a new cycle of the safety assessment once the operation has been improved; then also for conflict scenarios 2 and 5 a simulation-based approach may be used.

9.3. Main conclusions of the safety assessment of approach procedure V on Barajas airport

The outcome of the safety assessment for approach procedure V on Barajas airport has revealed a series of safety significant issues, which are recommended for further analysis. A distinction is made between those related to the inherent characteristics of the Sourdine II approach procedure V and those for which the particular parallel runway set-up is the determining factor when performing simultaneous and independent CDAs to both runways.

1. *Sourdine II approach procedure V issues:*
    - The fact that final approach controllers will only monitor separation rather than issue vectors to implement separation (except in conflict situations) makes that non-adherences to CDA speed descent profiles may cause aircraft to breach longitudinal separation (e.g. catch up aircraft ahead or be caught up by trailing aircraft). As a potential result, the probability of wake vortex encounters is likely to also increase. The risk of wake vortex encounter has been classified as possibly unacceptable without further mitigation.

2. *Parallel runway CDA safety issues*

- Within the final approach stage once established in the localiser, separation is ensured vertically. Thus, non-adherences to vertical CDA profiles may breach the 1000ft vertical separation that by design, should be maintained at all times between aircraft established on the parallel localisers prior to reaching the area parallel to the NTZ.
- Independent CDA-based approaches to parallel runway airport configurations exhibit a safety significant issue related to failed localiser intercepts (i.e. "overshoots"). In the future Barajas airport configuration, separation between aircraft established on the parallel localisers is based on 1000ft vertical separation at all times prior to reaching the area parallel to the NTZ. As a consequence, small-excursion overshoots followed by rapid localiser interceptions would only be associated with an erosion of safety margins while wide-excursion overshooting developing into wrong localiser interception or adjacent sector non-authorised incursion would pose a safety critical issue.

The qualitative safety assessment has shown that the Sourdine II approach procedure V adapted to the future Barajas Airport parallel runway configuration exhibits some safety significant issues that are in need of a more detailed and quantitative analysis. It is recommended that decision support tools such as an Arrival Manager (AMAN) and safety-net additional functionality to monitor potential longitudinal breaches of separation for localiser-established consecutive aircraft are considered in relation to future safety assessments.

9.4. Main conclusions of the safety assessment of departure procedure 2 on Barajas airport

It must be noted that resource constraints limited the number of operational experts involved in this particular departure procedure analysis. For this reason the assessment has been termed as a high level safety assessment. The Sourdine II departure procedure 2 aims at reducing the noise impact around the SID footprint at ranges closest to the runway, causing the aircraft to operate at reduced performance with OEI (One Engine Inoperable) power settings. This fact necessarily imposes that the main procedure risks will be associated with airport obstacle limiting surface infringements that may lead to loss of separation with obstacles and/or ground. The main emphasis of the assessment was placed on whether the procedure-induced departure from the aircraft optimal climbing performance could erode safety margins. In particular, the assessment has taken into account whether aircraft flying the SII departure 2 procedure could easily recover from other failures, even though flying at OEI power settings.

The safety assessment has concluded that the most significant risks associated with the Sourdine II departure procedure 2 are due to either engine loss (such as a catastrophic malfunction or malfunction caused by a bird strike) or sudden adverse meteorological conditions (such as windshear or thunderstorm turbulence) that could impair the aircraft airworthiness. However, it is deemed that aircraft could recover from these situations despite flying at reduced power settings and therefore, the procedure does not degrade safety margins. The combination of both hazards (engine loss and adverse meteorological conditions) could have a significant safety impact. However, this could be mitigated by restricting the range of meteorological conditions in which the SII Sourdine departure procedure 2 may be flown.

The conducted high level assessment has concluded with all identified risks having been preliminarily considered as acceptable. Given the high level nature of the assessment in terms of number of participating experts, it is recommended that further analysis is undertaken to increase the confidence in the resulting risk classification.