Aviation Noise Impact Management through Novel Approaches

D2.7 Recommendations for the use of tools and metrics to allow environmental performance interdependencies to be quantified and illustrated

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[1] Use one of the following codes: R=Document, report (excluding the periodic and final reports)
DEM=Demonstrator, pilot, prototype, plan designs
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1. Executive Summary

The work presented in D2.7 was challenging, starting with the title: Recommendations for the use of tools and metrics to allow environmental performance interdependencies to be quantified and illustrated.

In order to recommend tools and metrics to assess noise and emissions trade-offs, the team was supposed to rely on the information provided by ST2.3.1 on Balanced Approach and ST2.3.2 on Footprints. Unfortunately, the input from both sub-tasks was limited, and thus, the research needed a more ambitious approach.

Consequently, an academic study was performed in order to assess the State of the Art of noise and emissions interdependencies, followed by a review of the airports involved in tackling interdependencies (or mentioning the concept), as part of the 12 airports examined in ST2.3.1. When realising information on tools and metrics is still scarce, and additional gaps were identified on *what, how and when* to use interdependencies within the airport context, an additional tactic was adopted: to conduct an airport case-study at Catania airport, in order to prove the interdependencies concept can be implemented and thus, developing a methodology to be tested in further work as part of ANIMA and beyond. This work will be continued as a 'learning by doing' exercise, included in T2.5.

The structure of the report, composed of 7 Chapters and three large annexes, follows a classical line:

- Chapter 2 on *background information* explains the significance of considering interdependencies, the sub-task objectives and underlines the expected challenges. Information on the team involved is also provided (NLR, MMU, ANOTEC). An important part of this chapter was to identify the research questions which guided the entire work conducted in ST2.3.3.
- Chapter 3 explains the *mix-methodology* approach to data collection strategies, and the methods used to analyse the information obtained via different channels. The approach to Catania case-study is explained in details.
- Chapter 4 presents some *results and current practice* based on an airport review (ST2.3.1), identifying only 5 airports (Heathrow, Barcelona, Schiphol, Helsinki and Vienna) that are considering interdependencies. The Heathrow case-study is the most elaborate one, but, in general, the interdependencies are assessed for changes in operations. The review of metrics and tools is further explored, mentioning information from the Academic study and from the airport survey in ST2.3.1. Additional information is presented in Annex B. The chapter also identifies the gaps in information and suggest an *ANIMA toolkit* to gather relevant information for policy makers and end-users, on regulations, metrics, tools, publications, data-bases etc.

The review of pressure from competing environmental agendas explains the different approaches to noise and emissions trade-offs, while illustrating the stakeholders' conflicting interest.

- Chapter 5 presents *two approaches to Catania airport case-study*, underlying the data sources and their analysis. The ANOTEC approach is to develop a methodology using the SONDEO & SONDEO/EM toolchain (developed in WP4), while the NLR one is to investigate the potential for a trade-off between noise and emissions of four departure procedures.
- Chapter 6 on *discussion,* investigates gaps and barriers to implement interdependencies, exploring the two studies conducted by ANOTEC and NLR, as well as underlying lesson learned and the need for further work.
- The final Chapter, 7, suggest further work as part of ANIMA project and beyond, on noise and emissions interdependencies and their impact.

Two important outcomes can be identified as part of research conducted in T2.3.3 and described in D2.7: the need to develop the ANIMA toolkit to inform policy makers and end-users, and the link to T2.5 on airport exemplification case-study, to validate some findings on trade-offs developed within the airport context and contribute to the development of the WP4 toolchain.

In conclusion, ST2.3.3/D2.7, while challenging at the beginning, is meeting the scope described in the sub-task requirements, and, additionally, is contributing to the interdependencies knowledge-base.

2. Background information (introduction)

2.1. The significance of considering interdependencies

Decisions related to reducing the environmental impact at airports, mainly related to noise and emissions, are usually based on changes in operations. These are often made on the basis of a wide range of strategic, economic, operational and impact-related information. *Considering interdependencies or trade-offs* of the proposed action(s) and/or alternatives is important when using results to inform decision making, or conducting an environmental assessment, to avoid, where possible, any unintended consequences.

Interdependencies and/or Trade-offs?

In general terms, "interdependency" is used to refer to a situation where a change in Factor A results in a change in Factor B (and vice versa), whereas the term "trade-off" is used to describe interdependency where an improvement in Factor A results in a detrimental change in Factor B3. For instance, the introduction of a new departure procedure will reduce noise, but will increase emissions by burning more fuel.

There are different types of 'trade-offs' depending on the type of change and the actions involved. For instance, strategic trade-offs will appear before the planned course of action is adopted: the trade-offs between doing 'nothing' and adopting a different course of action needs to be considered, usually, as a strategic approach. Once the decision is taken and implemented, there may still exist tactical trade-offs[4], during the actual operational practice of the new methods or procedures. The implementation of Continuous Descent Approach (CDA) is such an example: while the new procedure was fully endorsed at the strategic level (e.g. airport management reaction to public protest against noise), it may be ignored by pilots for a given tactical instance, due to other dominant demands, like airport capacity constraints (at a given time).

The application of noise/emissions interdependencies at the airport due to changes in operations (mainly related to flight operations), reflects the current direction of aviation-related environmental analyses, as illustrated in several ICAO circulars[5] and technical reports[6]. This is in line with ANIMA rapid growing airports.

2.2. WP2 Objective on interdependencies and associated work

Though noise is by far the most addressed environmental aspect in the ANIMA project, a specific objective of WP2 is to also understand, and consider

3 Sustainable Aviation, 2017; www.sustainableaviation.co.uk

4 https://www.feverbee.com/strategy/strategic-trade-offs-in-setting-objectives/

5 https://www.icao.int/environmental-protection/pages/caep-operational-interdependencytask.aspx

6 https://www.eurocontrol.int/environment-modelling-tools

interdependencies, and see how airports address competing environmental issues, or competing key performance areas (KPA), using proper metrics and designated tools.

Having in mind that *interdependencies* are one of the four objectives of WP2, meeting its 'challenging' requirements is not a simple task. Several ANIMA partners consider the need to do extra work, outside of ST2.3.3 (D2.7, the current report), particularly that, in the last task (T2.5 on Airport Exemplification Case Studies) research conclusion(s) is expected to underline information on a Best Practice Portal, which requires, also, input on interdependencies. According to the definition adopted in this report, the airports need to assess the benefits (e.g. noise reduction) vs disbenefits (e.g. more fuel burn/carbon), when operational changes are adopted. Yet, the approach could be for trading less emissions with (more) noise. Therefore, answers need to be provided on when to conduct a trial on interdependencies and how to do it, what actors to engage, what results to expect, etc. This information should be distilled further in the last task T2.5 on airport exemplification case-study.

2.3. Sub-Task 2.3.3 Objectives and Challenges

ST2.3.3 Objectives

According to the Grant agreement, ST2.3.3 should consider interdependencies, in particular trade-offs, between aircraft noise and emissions (WP2 task, as described in previous section). Therefore, aspects as airport capacity, third party risk, safety, are not, or only limitedly considered in this report. In the case of the current report (D2.7), we are considering interdependencies associated to change(s) at the local airport level, thus global interdependencies are out of scope.

ST2.3.3 Challenges

A large part of data required by this sub-task should come from evidence collected in ST2.3.1 (Balanced Approach to Noise Management) and ST2.3.2 (Noise Footprints), the expectation being to review the use of metrics and tools to quantify the environmental performance characteristics. The extent to which airports are under pressure to deliver on a suite of potentially competing environment agendas will also be reviewed, but, with few practical examples, due to limited data.

2.4. Partners involved and associated work

The partners involved in delivering the work associated to ST2.3.3 for a period of 15MM (M3-M18) are NLR (lead), MMU and ANOTEC.

The work identified to convey the expected results, has involved the following parts:

- Literature review, with focus on an academic study to understand the challenges of noise vs emissions (MMU)
- Airport review with regard to interdependencies (as requested by sub-task description) (NLR)
- Catania Airport case-study, to complement the missing data from ST2.3.1 and understand better the benefits and challenges associated with noise & emissions trade-offs; to develop a methodology aiming to improve policy makers knowledge on interdependencies, via a *learning by doing exercise* (ALL).

Considering from the start the challenges around lack of data (i.e. only a limited number of European airports were involved in ST2.3.1), the focus was on exploring the 'what do we know so far' and 'how to increase the understanding of interdependencies' benefits, by initiating a case-study and engaging stakeholders in validating the methodology approach.

This approach explains the involvement of Catania airport.

2.5. The identified research questions & anticipated outcome

Based on the task requirements, the partners involved in conducting the research have considered several research questions, which involved informal discussions with ANIMA airports partners and their stakeholders. Particular reference will be given to the outcomes of ST2.3.1 & ST2.3.2

In the end, four research questions were formulated, as illustrated below:

1) Can ANIMA research contribute to a better understanding and added knowledge to the concept of interdependencies? Are there additional metrics and tools to help the implementation process?
2) What are the barriers in implementing the existing knowledge on interdependencies (models, tools), to be able to use them as an instrument to inform policy makers before taking an action of change in operations? Are they related to lack of proper tools, not clear scope or decision making in place?
3) How can an airport case-study contribute to a better understanding of noise and carbon emissions trade-off?
4) What would be the recommendation(s) for future research in ANIMA and beyond?

The anticipated outcome

The expected outcome needs to add to the current knowledge, while identifying existing challenges and barriers to implement interdependencies.

2.6. The ST2.3.3 Scope and its limitation

The expected insufficient recorded data on noise and emissions trade-offs from the airport survey (ST2.3.1) lead to the decision to undertake a literature review (mainly an academic study) and organise an airport case-study (using real data) to define a methodology on approaching trade-offs and exploring tools and metrics which can better quantify the environmental benefits (noise and/vs emissions) at airport level.

Some illustrative examples are presented in ST2.3.1, with reference to operational improvements (Heathrow) – airspace changes, introduction of regimes to accommodate new technologies and techniques such as PBN and CDAs. The assessment of the benefits vs disbenefits of different interventions will need to use *effective metrics and proper tools to better model the potential consequences.*

Limits in Scope

This sub-task (ST2.3.3) was difficult to be conducted due to **limited information on interdependencies** reported from ST2.3.1 and ST2.3.2, on existing examples recorded at airport level, lacking interventions illustrating changes in operations.

Consequently, following the incomplete information and, at the suggestion of the WP2 Lead, the partners involved (NLR, MMU, ANOTEC) agreed to include an airport case-study to 'learn by doing' the limits and barriers in understanding interdependencies. The only airport willing to contribute with airport data was Catania airport. The involvement of this case-study came in M14, so quite late in the process. However, considering that interdependencies is one of the fourth objectives of WP2, the partners (ANOTEC, MMU) agreed to continue the work on this case-study as part of future work in T2.5 *Airport Exemplification Case Studies*, hoping for some valuable outcomes to be used in the Best Practice Portal (WP5), and better formulate areas of further research.

It is worth adding that, the way the subtask was formulated leads to interpretation of the usefulness (need) of a thorough literature review as *state of the art* on noise and emissions trade-offs. Thus, the understanding of interdependencies is covered by an academic study. Therefore, the scope is limited in terms of providing tools and metrics used.

Consequently, the Catania case-study was considered for several reasons:

- To supplement the lack of data in ST2.3.1 and ST2.3.2.
- To understand better the *need* to conduct noise and emissions trade-offs associated to an intervention, traffic growth, environmental challenges, etc through real data and consultation with decision makers.
- To explore the ANIMA added knowledge to the interdependencies state of the art, investigating (a few) noise abatement procedures.
- To try and develop a methodology on *how and when* to use interdependencies.
- To clarify what is the research outcome (lesson learned) from WP2 that can be used in WP4 (SONDEO & SONDEO/EM).

- To identify possible best practices that may be later included in the Best Practice Portal (WP5).

D2.7 is dealing only with tools that cover *airport noise and emissions*, and thus, it does not include global inventory tools. This is not a limitation, it is a clarification based on the task description.

2.7. Future work and added value

The Catania case-study will continue in T2.5 (Airport Exemplification Case Studies) as explained earlier. The work conducted in ST2.3.3 explored the **strategic trade-offs** while in T2.5, the focus will be on the **tactical trade-offs**, enriching the understanding of 'why', 'when', and ''how' to use noise and (carbon) emissions trade-offs.

Further work will identify barriers to the implementation of accepted best practices and tools (SONDEO, SONDEO/EM & FRIDA), testing them via further engagement with Catania and, possible, other airports involved in T2.5.

What is new?

The work undertaken in ST2.3.3 and presented in D2.7, illustrates a largely *qualitative* view of the interdependencies, as their quantitative character is dependent on specifics at a level of detail beyond the initial scope of the task. However, the Catania airport case-study tackles the quantitative aspects, but only partially in this report (see Results Chapter), the continuation being part of the further work to be conducted in the last task of ANIMA WP2 (T2.5).

The current report (D2.7) illustrates the fact that relatively few airports understand the benefits or see the need of conducting an interdependencies trial associated to an intervention, and even fewer are recording the results after implementing a new change/operational procedure.

Additionally, the work of this task addresses, indirectly, the *airport environmental capacity* (development within the environmental limits) - a great challenge to the continued growth of several European airports, ANIMA partners included (Iasi, Cluj, Catania a/p).

3. Methodology

3.1. Airport survey (current practices)

ST2.3.3 is focussed on establishing a robust understanding of the range of environmental tools and metrics currently used by airports, which could be applied to explore interdependency relationships.

This subtask is not expected to undertake basic research or engage in directly seeking information from the airport community. For this ST2.3.3 is specifically dependent upon ST2.3.1 and ST2.3.2.

The approach was to make a list of questions which describe ST2.3.3 data requirements. To this end ST2.3.3 interacted with the above mentioned subtasks on:

- Evidence of the importance of interdependencies to the development and implementation of Balanced Approach (BA) interventions
- Examples of metrics and tools used to assess interdependencies
- How interdependency assessment outcomes informed decision-making
- Stakeholder pressure to consider interdependencies
- Reaching consensus on environmental outcomes – how decisions are made in the light of potentially competing priorities

The list was communicated to ST2.3.1[7] and ST2.3.2[8] partners and ensured their data collection strategies are appropriately constructed to gather information for ST2.3.3 as well.

Further approach of the partners involved in ST2.3.3 was to:

- Stay informed about what to expect from ST2.3.1 airport survey and expand on sources of information if needed, same approach being undertaken in relation to information on tools metrics, expected from ST2.3.2.
- Analyse the received airport data from ST2.3.1 and ST2.3.2.

3.2. Academic study

The academic study provides a systematic literature review and briefly tackles policy review which supplements the airport survey by ST2.3.1. The study details the importance attached to interdependencies at specific airports informed by their political/social context. The study also addresses the noise & emissions

[7] Using a case study approach ST2.3.1 will perform a comprehensive assessment of the balanced-approach implementation by Airports within Member States and will gather information on: reduction of noise at source; land-use planning and management policies; noise abatement operational procedures; operating restrictions on aircraft.

[8] ST2.3.2 will review a wide range of noise metrics and modelling tools to monitor noise, inform noise reduction strategies and communicate with key stakeholders including communities who live around airports.

trade-offs that potentially could be made by airport operators, independently of whether airport actually do so, and are equipped with the applicable tools.

A summary of the results of the (literature review and) academic study is presented in Chapter 4 "Results- Current practices". The academic study text is presented in Annex A. The approach to conduct the academic study was to:

- Select subjects relevant to the interdependency/trade-off topic
- Collect (archived) peer reviewed academic literature
- Discuss with experts in the field (mainly airports decision makers), to provide recommendations for further research.

3.3. Catania Airport case study

The methodology on Catania case-study involved two meetings with the airport stakeholders (including their CEO), to understand their environmental policy and the objective(s) related to monitoring and displaying data on noise and air quality, as well as willingness to get involved in ANIMA research. Important information was about their approach to operational change(s) and decision making process during intervention(s). The concept of interdependencies was introduced at the first meeting between Catania airport and ANIMA partners, based on the airport willingness to take part in research conducted in the ANIMA project. Catania airport was involved in ST2.3.1 as well, following an invitation from TSC (ST2.3.1 lead) in October 2018.

The Catania case-study imported **a mix methodology**, gathering:

- quantitative data: airport operations & flight data
- qualitative data: gathering expert opinions following the engagement with the airport stakeholders, the provider of the noise monitoring system, interviewing professionals in the field (IATA & Eurocontrol) on 'how to approach' the interdependencies.

The data examined aimed to:

- develop arguments for a potentially useful noise and emissions trade-off exercise for the airport, based on the available data.
- perform the trade-off analysis.
- present the result of the trade-off study in an easy to understand way to facilitate, as much as possible, decision-making process for policymakers, and communication process with community.

The results of the Catania Airport case-study are presented in Chapter 5 and Annex C. This provides an example for a potential trade-off between noise and emissions for a typical European airport, with focus on developing a methodology: *how to do it*, aiming at obtaining better results in T2.5. Another aim is to update an existing tool, SONDEO, to be further used in conducting research on noise and emissions interdependency.

4. Results – current practices

4.1. Interdependencies in the airport context

Interdependencies between noise and emissions in the aviation sector are multifaceted and should be considered in operational decision-making. These interdependencies are well documented in literature (see Annex A). Information on aircraft operations associated with noise and emissions trade-offs and associated interdependencies can be found in Annex B.2.

Stakeholders involved

It is important to realise that aircraft operations involve many stakeholders: airlines, authorities/regulators, ANSP's, the airports, residents, associations. Each of these stakeholders weigh operational and environmental aspects differently, while the ones involved in designing the interventions are airlines, ANSPs and airports.

Annex B.1 and B.6 provides more detailed information on stakeholders and decision making involved in the airport operations.

Operational procedures

The academic study and the airport survey results (outcome of ST2.3.1) show that interdependencies between noise and emissions often involve operational procedures in the Landing and Take-off (LTO) phases. Most of these deal with departure procedures, where noise versus emissions trade-off is better illustrated, though also a change in approach procedure was mentioned.

Figure 1 provides a schematically overview of departure and arrival (approach) procedures. Though the figure is on noise mitigation opportunities, it should be emphasized that emissions also play a role here, being linked to aircraft operation.

For departures, (changes in) the following operational procedures are relevant:

- Reduced, or flexible thrust
- Noise Abatement Departure Procedures

For arrivals, (changes in) the following procedures are relevant:

- Continuous Descent Operation (CDO)
- Low power/low drag
- Reduced landing flap

The effect on noise and emissions of the above procedures are further elaborated in the airport survey results (section 4.3) and in Annex A and B.

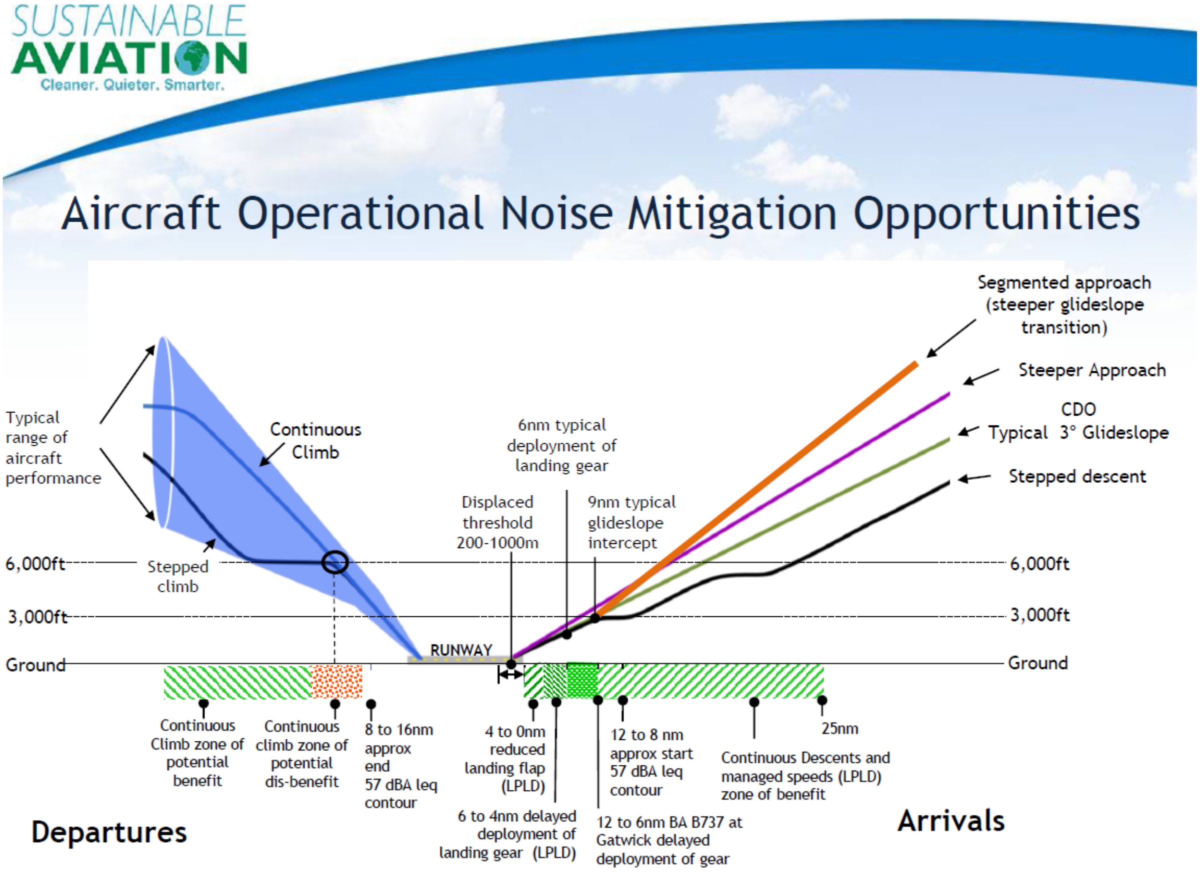


Figure 1: Overview of different departure and approach procedures (Source: Sustainable Aviation, 2017)

More detailed information on noise and emissions interdependencies in airport departure, arrival and ground operations, is provided in Annex B.2.

4.2. Academic study

The academic study undertook a detailed assessment of archived peer reviewed academic literature to present a snapshot of current knowledge and understanding of the interdependencies between aircraft noise and exhaust emissions, and subsequent impact on communities.

This sub-chapter presents a copy of the conclusions of the study. The full text of the academic study is included as Annex A, where a review is provided on possible interdependencies or trade-offs between aircraft noise and exhaust emissions associated with operational procedures in the LTO.

Findings

The study primarily confirms the view that noise and emissions are frequently considered independently and not in a holistic way. Indeed, it appears only a few academic studies have sought to quantify the trade-offs though a number have provided a qualitative/hypothetical assessment. This reflects the approach of regulators who also set independent standards for noise and emissions. This approach and the increasingly stringent noise and emission standards have been successful in reducing the overall environmental impact of aviation. Given the regulatory separation, it is of little surprise, therefore, that the recent peer review and accessible industry literature contains little evidence of a comprehensive noise/emission trade-off analysis.

Generally published studies which have examined the effect of changes to how aircraft operate in and around airports have focused on savings CO_2 or NO_x. Only recently particulate matter (PM) has been factored into the equation primarily through the application of FOA3[9] rather than the actual emission of nvPM (mass and number). There is also little evidence that existing work has considered the formation of secondary PM which could be an order of magnitude larger than the primary emission. This may have profound implications when considering operations with low thrust setting (taxi).

The existing literature is also relatively silent on examining any trade-offs or interdependencies between the impact of noise and emissions. Arguably, it is the impact of aircraft noise and emissions which is important and should be factored in to future trade-off/interdependency analysis. Though, it is recognised that this is not a simple or straightforward task and may go beyond the capability of many airports.

The study does not tackle, in detail, the airport interventions recorded in their technical reports.

4.3. Airport survey

ST2.3.1 provided documents on 12 airport case studies related to the implementation of Balanced Approach. The review presented, in general, a broad description of the cases without explicitly pointing out the information on interdependency/trade-off, metrics and tools. ST2.3.3 made an effort to retrieve this information from the documents. Besides the information from ST2.3.1 a table on noise metrics used in the case studies adds to the information presented in ST2.3.1 (see Annex B.4).

4.3.1. Description of airport case studies tackling interdependencies/trade-offs

The survey results show that only 5 out of 12 airports considered trade-offs/interdependencies: Heathrow, Barcelona, Helsinki, Schiphol and Vienna. These *five case studies* and the interventions are addressed in Annex B.2.

Only Heathrow clearly mentioned a trade-off was made in relation to a change in operational procedure (*steeper departure; see Annex B.3 & ANIMA, D2.5)*.

[9] Methodology to estimate particulate matter emissions from certified commercial aircraft engines. Wayson et al., 2009

Barcelona, Helsinki, Schiphol and Vienna reported and/or showed awareness of interdependencies (noise, fuel burn and/or emissions) in relation to a change in operational procedure.

The other airports (for a list of airports surveyed, see Table B.6) mentioned the availability of airport noise and/or air quality data. The indicated table shows a review of metrics used by the 12 airports surveyed in T2.3.1.

However, several of those case-studies were not reported as interdependencies in relation to an operational choice or intervention, and this aspect will be further explored in T2.5.

For instance, in the Kiev airport case, it was mentioned that all certified airports in Ukraine have noise maps (Noise Protection Zones) and *local air pollution* maps (Sanitary Protection Zones). These maps are obligatorily included in certification procedures of the airports. It is not clear, in the case of an intervention, how the relation between those zones will be considered.

In general the airports of which interdependencies are reported are the larger airports. If there is an interdependency issue, then noise (airport & community interest) and fuel (airline interest) are the two main issues, followed by local air quality related emissions and climate related emissions.

It should be noticed, that the number of reported airport surveys (cases) is not large enough to draw any conclusions on the level of maturity in understanding trade-offs.

4.3.2. Review of metrics and tools

Preliminary overview of available data on noise and/or emissions

Various types of information are required for the development of environmental studies and/or assessments, including trajectories, flight plans, aircraft engine specifications, aircraft performance data, as well as statistical data regarding the number of the population living in the proximity of airports.

Almost all necessary and relevant data regarding interdependency studies can be grouped in three categories (figure 2: Flight Information, Noise, Emissions), that characterise the main focus and use of a **metric**, method, **model, tool** etc.

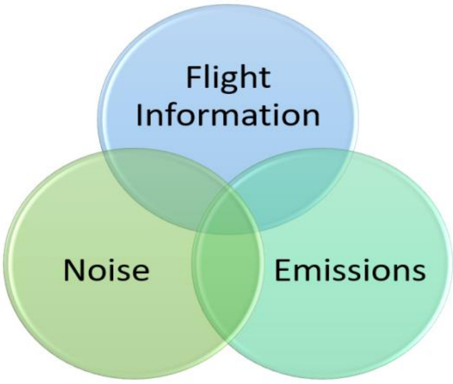


Figure 2: The link between flight operations, noise and emissions showing interdependencies

Figure 3 may facilitate the set-up of an **ANIMA toolkit** to investigate the knowledge on *what & how* related to noise & emissions interdependencies. Focusing on metrics and tools used to assess trade-offs is one priority which will be further examined in T2.5 on airport exemplification case-study. The proposed toolkit will be further tested as part of Best Practice Portal, one of the T2.5 products (outcome).

Figure 3: ANIMA proposed toolkit to assess noise and emissions trade-offs , showing the topics considered as information source

Additionally, following the information provided by ST2.3.1 and D2.5, Table 1 (Source: ANIMA D2.5- updated) presents an updated table on tools used in assessing noise, emissions and trade-offs.

Category of Tools	Tool	Reference to Case Studies
Noise Modelling/ Mapping	BaseOPS software pack (including NoiseMap suite)	(Cluj Airport Case Study, Iasi Airport Case Study)
	IMMI	-
	IsoBella Model	(Boryspil Airport Case Study)
	Predictor-LimA	-
	SoundPLAN	-
Noise Monitoring/Management	ANOMS	(Heathrow Airport Case Study)
	CadnaA	(Iasi Airport Case Study)
	NoiseDesk	-
	Virtual Community Noise Simulator (VCNS)	(Stockholm Arlanda Airport Case Study)
	WebTrak	(Barcelona Airport Case Study, Heathrow Airport Case Study)
	WebTrak MyNeighbourhood	(Heathrow Airport Case Study)
	xPlane	(Heathrow Airport Case Study)
Noise Forums	Airport and Region Forum (Forum Flughafen und Region, FFR)	(Frankfurt Airport Case Study)
	Heathrow Community Noise Forum (HCNF)	Sharing noise information (Heathrow Airport Case Study)
	Vienna Dialogue Forum	(Vienna Airport Case Study)
Noise Publications	A Quieter Heathrow	(Heathrow Airport Case Study)
	Heathrow 2.0	(Heathrow Airport Case Study)
	Noise Management Plan (NMP)	(Stockholm Arlanda Airport Case Study)
	Noise Exposure Plan (PEB)	(ACNUSA Case Study)
	Noise Disturbance Plan (PGS)	(ACNUSA Case Study)
	Sustainability Reports	(Ljubljana Airport Case Study)
	Teddington Community Noise Information Report	Noise data communication (Heathrow Airport Case Study)
Interdependency Tools	AEDT (Aviation Environmental Design Tool)[1]	-
	IMPACT[2]	-
	EDS (Environmental Design Space)[1]	-
	APMT (Aviation environmental Portfolio Management Tool)[1]	-

Table 1 Tools used in airport operations

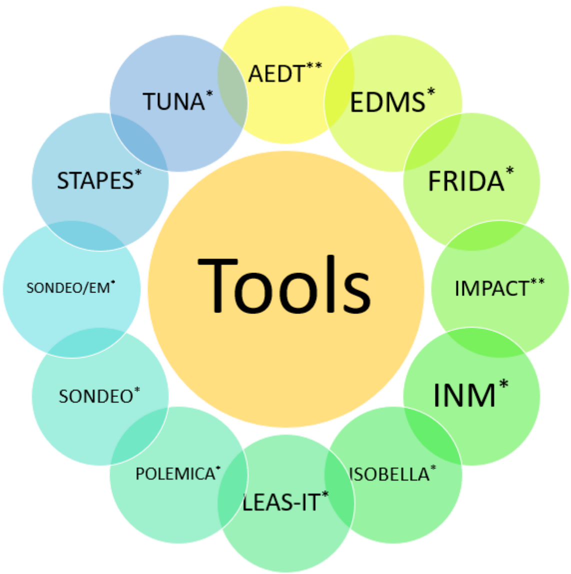
[1] Source: Federal Aviation Administration (https://www.faa.gov)
[2] Source: EUROCONTROL (https://www.eurocontrol.int)

It is important to underline that, in general, the airports are using tools for noise or for emissions, when assessing interdependencies. This shows the lack of a common tool (or tool suite) to assess noise and emissions trade-offs.

Thus, regarding the use of tools the airport survey in ST2.3.1 did provide some information on noise related tools (e.g. INM in Heathrow and Helsinki) but it did not provide any information on the use of specific trade-off/interdependency tools.

Additional information on metrics is provided in Annex B.4. Section 6.3.4 addresses the toolset development in ANIMA WP4, SONDEO & SONDEO/EM.

To have a better picture on what tools are used for noise or/and emissions, the illustration below was designed in support of gathering the information known so far by the ANIMA team involved in conducting research associated to ST2.3.3.



- AEDT— Aviation Environmental Design Tool (Federal Aviation Administration)
- EDMS— Emissions and Dispersion Modelling System (Federal Aviation Administration)
- FRIDA (University Roma Tre)
- IMPACT (EUROCONTROL)
- INM— Integrated Noise Model (Federal Aviation Administration)
- ISOBELLA (National Aviation University, Ukraine)
- LEAS-iT (Royal Netherlands Aerospace Centre)
- POLEMICA (National Aviation University, Ukraine)
- SONDEO (ANOTEC Engineering)
- SONDEO/EM (ANOTEC Engineering)
  STAPES— System for Airport Noise Exposure Studies (EUROCONTROL)
  TUNA (Royal Netherlands Aerospace Centre

*Used for noise OR emissions
**Used for noise AND emissions

Figure 4: A review of Tools used for noise or/and emissions, screening existing knowledge

4.3.3. Review of pressure from competing environmental agendas

To review the extent to which airports are under pressure to deliver on a suite of potentially competing environment agendas when an intervention (change in operations) is considered, interdependencies and/or trade-offs between noise and emissions need to be assessed, as explained in Chapter 2.

The Heathrow case clearly shows that interdependency assessment outcomes informed decision-making. In the Barcelona, Helsinki and Schiphol case interdependencies were considered but based on the provided evidence this had no effect on the decision to change operation. For instance, for Schiphol Airport fuel savings were used for decision making while the effect on noise contours was beneficial too. Hence, both were overall positive and therefore the decision was to recommend the Noise Abatment Departure Procedure #2 (NADP2) to all airlines.

Only in the Heathrow case it is clear that the interests of multiple stakeholders were included in the decision process and that not all community requests were fulfilled. In the Schiphol case fuel reduction was the main driver for the change in procedure. In the Helsinki case environmental pressure was not playing a significant role in the decision making process: close to the airport noise management is prioritized over the CO_2 emissions. More information is presented in Annex B.3.

5. Catania airport case study

5.1. Background

Catania Airport was chosen to perform the case-study on interdependencies, due to their management approach to research, willingness to provide airport data, and showing interest in being part of the ANIMA airport family. The significance of engaging with a mid-sized European airport, located in Sicily, is adding value to end-users' involvement in the EC projects.

Information on Catania airport location, size and its development in passenger and cargo volume is presented in Annex C.1. Additionally, the same Annex provides background information on the airport:

- Environmental Policy
- Noise monitoring network
- Air Quality Monitoring Network
- The relevance of the Environmental Totem
- Operational Procedures

The airport is willing to get involved in a case-study aiming to assess noise and emissions interdependencies, the main objective being to identify pathways to better assess the environmental benefits due to changes in operations.

5.2. Case study objectives

The Catania case-study has several objectives, in line with ST2.3.3:

- To conduct research using real airport data, engaging the provider & end-user in understanding the role of interdependencies.
- To contribute with additional information to the initial data collected by ST2.3.1 & ST2.3.2
- To involve ANIMA partners tools (SONDEO & SONDEO/EM and FRIDA) in conducting research on interdependencies, thus contributing with knowledge to ANIMA/WP4 and to the T2.5 on airport exemplification case-studies.
- To explore a 'learning-by-doing' exercise, thus identifying challenges & limitations of the noise & emissions trade-offs concept.
- To contribute to the Best Practice Portal by providing a structured information on interdependencies state of the art, using ANIMA Toolkit

Both ANOTEC and NLR performed separate case studies for Catania airport, with different objectives:

- ANOTEC analysis aimed at providing insight in the day-to-day variations in noise and emissions that occur while operating a single city-pair by a single operator. For example, the same airline/Alitalia operates Catania-Rome destinations on a daily basis.

- The NLR analysis of the Catania data was to investigate the potential for a trade-off between noise and emissions of four departure procedures.

5.3. The ANOTEC case- study

In order to determine interdependencies between noise and emissions in an efficient and consistent manner, it is convenient to calculate both environmental aspects with models that can use the same input data and that provide results in a compatible format.

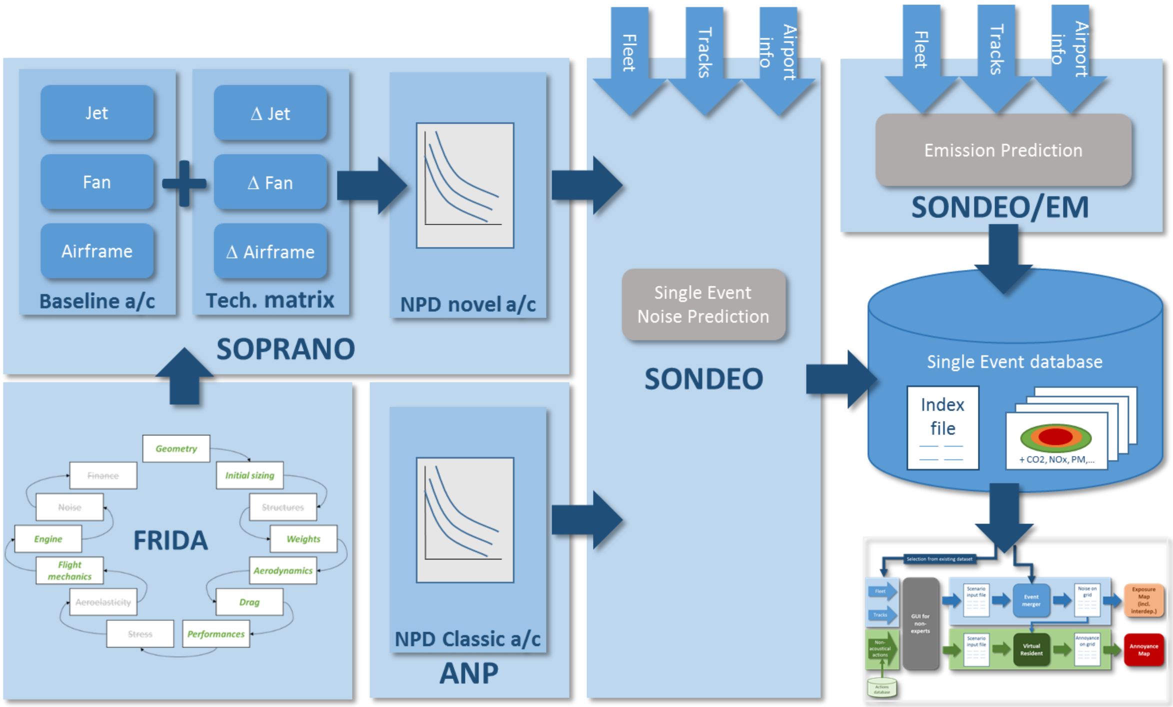


Figure 5 Airport noise and emissions models, integrated in the ANIMA WP4 tool chain (Source: ANOTEC, Feb. 2019)

Figure 5 shows the **WP4 tool chain** which is meant to perform calculations involving noise and emissions. This tool suite was initially proposed to be involved in the Catania airport case-study. However, after assessing options the team decided that SONDEO and SONDEO/EM[10] (both by ANOTEC) were to be used in the Catania case study, since ANOTEC – a partner in ST2.3.3 - was also willing to refine data input for the toolchain used in WP4 and since no ANIMA budget was allocated for the application of FRIDA in ST2.3.3.

[10] **SONDEO** is an airport noise modelling tool that calculates the noise contours for single events in accordance with ECAC Doc 29 and the corresponding ANP database. **SONDEO/EM** is a model that calculates the emissions generated by aircraft operating at an airport. Additional information on both models and data type needed as input is provided in Annex B.4 and in Annex C.2.

5.3.1. Data analysis

To calculate noise and emissions the SONDEO and SONDEO/EM models used data of actual flight operations (incl. trajectories). To this end, an initial and an updated dataset were provided by the airport. A description of the datasets is presented in Annex C.2.

Initial dataset

Figure 6 provides an overview of some flight trajectories contained in the initial dataset.

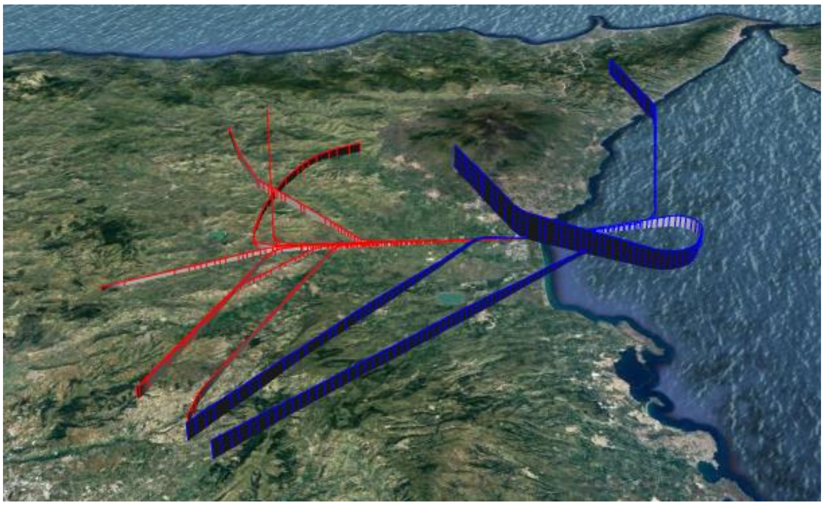


Figure 6: Catania Airport basic flight procedures
blue: departures, red: arrivals (Source: Catania airport)

When preparing the input from the initial dataset for the noise and emissions toolchain, several issues were encountered as presented extensively in Annex C.2. Figure 7 provides an illustration of some of the data problems (too low altitude, misalignment with runway and no track data on runway).

Figure 7. ANOTEC illustration of data problems with the departure profile (Source: ANOTEC, February 2019)

Discussing these issues with the airport, it appeared difficult to resolve them at short notice. In order to avoid a delay in the delivery of the study results, it was decided to start the interdependencies study, acknowledging that the results would not be representative, but considering that in this way at least the methodology could be tested.

After processing the initial dataset with SONDEO and SONDEO/EM the main results were presented in a so-called single-event database (see table C.3 in annex) for each individual operation. These results include noise (LAMAX65 in km2, SEL70 in km2) and emission levels (NOx in kg, CO2 in kg).

It can also be observed that, due to the too low altitude, the noise contours (see Figure C.10) are indeed much longer than may be expected.

Based on the single event emissions various assessments can be made:

- Total CO_2 / NO_x for each aircraft type, per destination, per airline etc
- What-if studies ➔ example: replacement of CFM56 by LEAP

To demonstrate the capabilities of the tool chain, the latter assessment has been worked out in more detail. For the operations with A320 and A321, the standard CFM56 engines were replaced by LEAP engines and the corresponding emissions were calculated for the same flight profiles.

Figure C.11 shows the results of this exercise. It can clearly be seen that both CO_2 and NO_x are significantly reduced thanks to the introduction of the LEAP engine. Here it should be noted that these calculations are based on the wrong trajectory data, and absolute values are therefore not correct.

Summarizing, noise and emissions were calculated both, but with different models. This illustrates there are still limitations in current tools to address both noise and emissions in an integrated way and to assess interdependencies (see also 4.3.2 Review of metric and tools).

Further step: updated dataset

For a full and representative interdependencies study it is necessary to work with correct trajectory information, especially with correct altitude. Since improving the monitoring system at the airport would take more time than that available, it was decided to acquire some data with an interim solution, to be included in the present report. To this end an ADS-B receiver of ANOTEC was installed at Catania airport, with data stored in a local PC, following the ST2.3.3 meeting on 21/02/19 at Catania airport. A first check of the data confirmed that the altitude in the initial dataset was wrong. As can be seen in figure 8, the glide slope in approach according to the initial dataset was around 1.7°, whereas the ANOTEC receiver shows a 3° slope, which is as expected, considering the ILS installed at Catania.

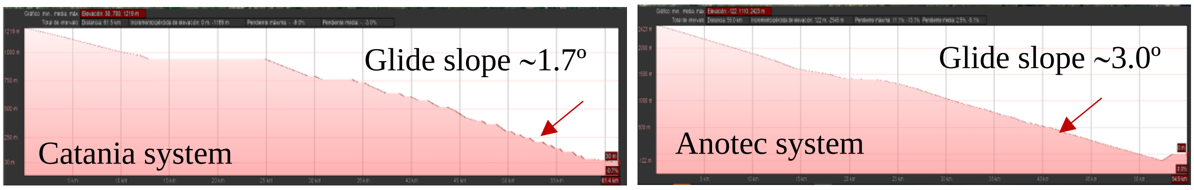


Figure 8: Differences in glide slope

A new single event database was then created, based on the updated dataset (see Table C.4). Both noise contours calculated for the updated dataset shows shapes that appears more realistic as shown by figure 9 (Figure C.13 in the annex).

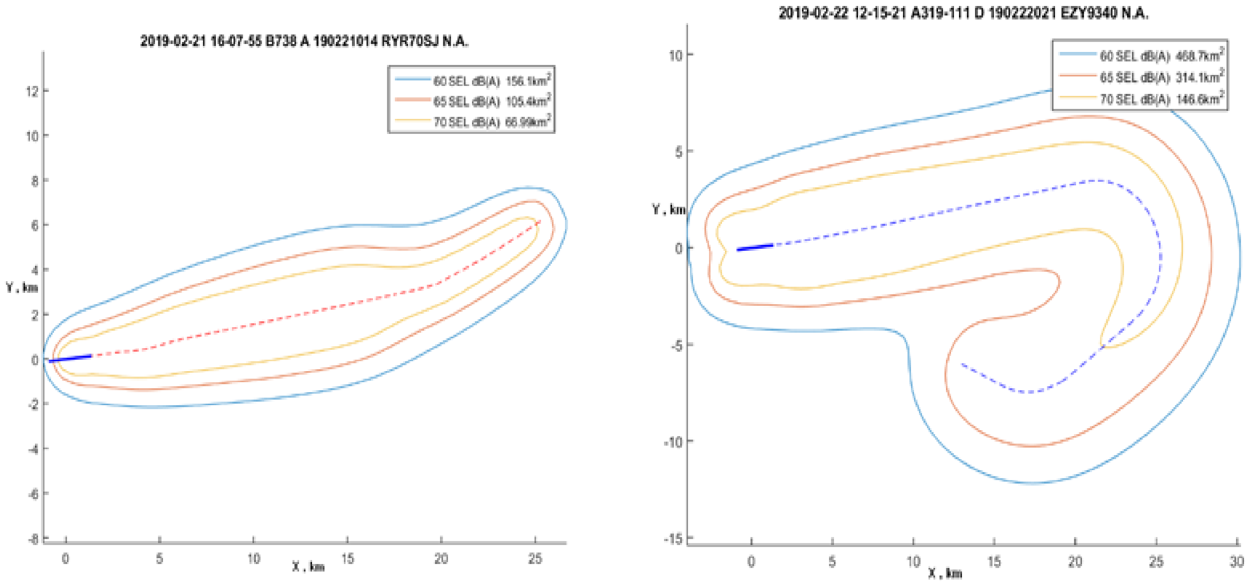


Figure 9: Noise contours, calculated for the updated dataset from the ANOTEC receiver for two different aircraft (B738, A319)

5.3.2. ANOTEC further work

Based on the results described further in 5.3 and in Annex C.2, it can be concluded that the methodology developed for the interdependencies study, based on a simultaneous application of compatible models, is valid and gives useful results, that needs further to be tested to validate SONDEO & SONDEO/EM as part of a toolchain to assess interdependencies.

With resulting single event database various assessments can be made.

Clear scenarios / cases will be designed and executed during T2.5 on Airport exemplification case-study: Catania airport. The team involved has selected for single event: the Catania-Rome flight, departure, morning, using flight data provided for a week.

5.4. NLR study

As explained earlier, NLR objective was different, aiming to investigate the potential for a *trade-off between noise and emissions,* exploring four departure procedures. The purpose of the **NLR analysis was to demonstrate trade-off potential.**

Though the data used is specific to Catania Airport, the analyses are intended to be also valuable (examples) for other airports.

The methodology adopted

The NLR study aims to investigate the trade-off between metrics for noise and emissions. Regarding the impact of different flight procedures, it is important to know the difference between emissions and air quality. The NLR analysis looks at emissions and not at the impact of the emissions (air quality). This is important to emphasize, as for example, emissions of NO_x above 1000 feet will have little impact on ground level – so a change in operational measures may have little impact on local or regional air quality (though PM and UFP may be different – but the science is not mature yet).

Note: The entire NLR study can be found at Annex C.3.

5.4.1. Data analysis

Data received

Two datasets were provided by Catania Airport/ANOTEC as explained earlier. The first received dataset did contain inconsistencies, as described in section 5.3.

Traffic

To illustrate the case study, NLR chose a typical day of traffic at Catania airport for two temperatures (a colder day and a warmer day), while varying NADP procedures. The traffic was then represented by taking the most common take-off runway and the three most commonly observed aircraft at Catania (mid-sized jets) that make up approximately 90% of all flights. More detailed information on selecting case study traffic can be found in Annex C.3.

Approach

The study approach and data analysis was described in the following three sub-sections:

- **Profiles**: Calculate flight profiles (speed, altitude, thrust as function of distance) for four different ANP procedures, and compare these to the average profile in the Catania dataset
- **Methodology**: Describe the applied methodology for assessing noise and emissions
- **Results**: Present and discuss the noise and emissions results. The impact of procedure choice on noise and emissions is investigated and presented as *trade-off*. The idea is to provide the airport with an example of a choice

between possible procedures which – of course – is up to the airport to trade-off applying the airport weights to the different aspects considered.

Profiles

As a first step in the analysis the aircraft speed was approximated from the location and time parameters present in the Catania Airport dataset. Aircraft speed and altitude were plotted as function of distance and these "departure profiles" were then compared with departure profiles calculated using ECAC Doc29 and aircraft performance data from the international Aircraft Noise and Performance (ANP) Database. Four types of Doc29 profiles were considered (1x NADP1 and 3x NADP2). The NADP profiles were calculated for different de-ratings. As an example, four profiles for a specific aircraft type are shown in Figure 10.

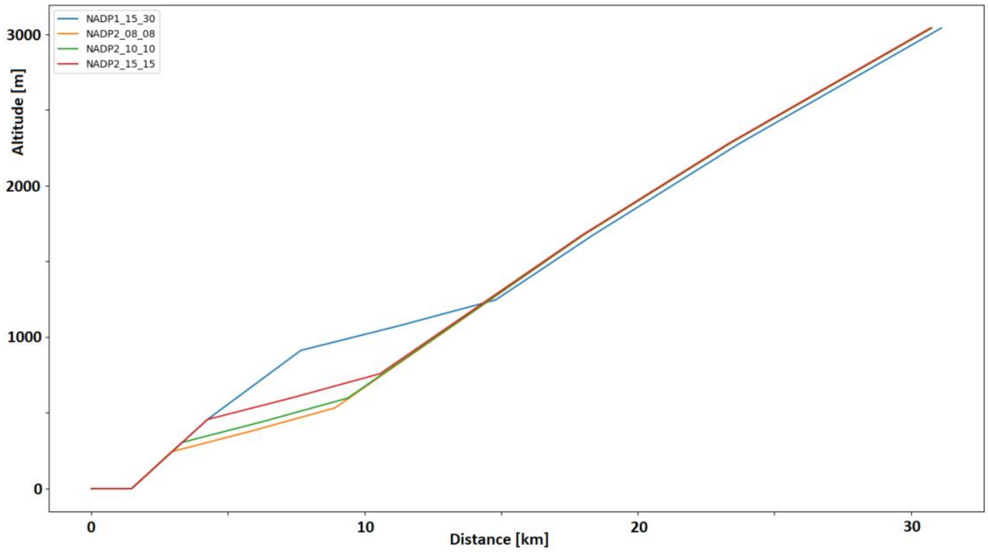


Figure 10: Examples of four NADP procedures (NLR, March 2019)

The chosen NADP profiles have different cutback and acceleration altitudes, and therefore the *NADP profiles show different altitudes and speeds at the same time instance and distance from airports*. The latter is clearly shown in figure 10 for altitude as a function of distance flown.

The profiles were calculated for ISA+20 temperature, since this temperature represents the temperature around Catania airport in, for instance, August. However, profiles were also calculated for ISA temperature. The effect of temperature on calculated profile is presented in Figure 11.

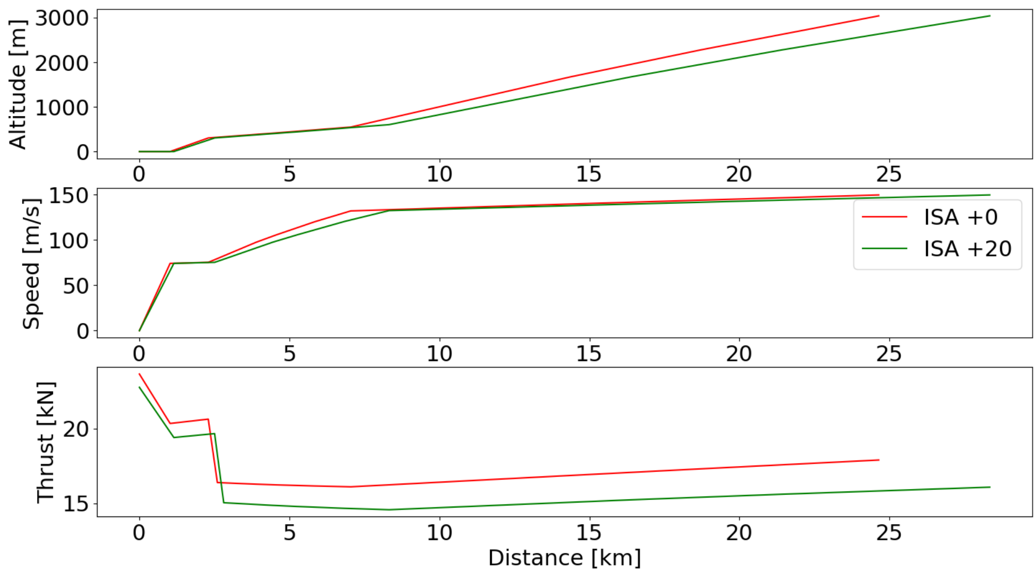


Figure 11: Effect of temperature on aircraft performance shown by comparing a NADP2_10(_10) profile for two different temperatures

Comparison of the calculated profiles with the Catania profiles showed that the NADP2_10(_10) profile[11] appeared to be most similar to Catania profiles. The de-ratings that fitted the Catania flights best were 85% for standard LTO take-off thrust setting and 100% for standard LTO climb-out thrust setting.

In the presentation of the results hereafter the NADP2_10(_10) procedure was therefore used as reference for the comparison with the three other procedures NADP1_15(_30), NADP2_08(_08) and NADP2_15(_15).

Methodology

a) Noise modelling

Noise modelling has been calculated using INM software, version 7d. The fixed point profiles and noise tables have been adjusted for temperature and relative humidity.

Noise emission metrics are based on LAeq contour at 55 dB level. In addition to size of contour, the shape represented by the aspect ratio is calculated, defined as maximum width divided by maximum length. Defined in such a way, a larger aspect ratio represents a larger impact on the population of Catania, because most houses are situated lateral to the runway. On examination of the traffic at Catania, it was found that the number of flights at Catania is about a factor 10 smaller than a typical larger airport. Thus, *a 45 dB contour at Catania*

[11] For profilename coding see Annex C.3.

corresponds to 55 dB contour at an airport with tenfold traffic. Therefore, the metrics calculated for a 45 dB contour are also included (see annex C.3).

b) Emission modelling

CO_2 and NO_x emissions were calculated along the flight paths for each of the considered profiles. The calculated emissions depend on number of *operating engines on the aircraft (aircraft type), engine type, engine thrust setting, engine operating time and other parameters* like installation effects, aircraft speed, aircraft altitude, atmospheric temperature and humidity. A more detailed description of the calculations is provided in Annex C.3.

Results

The results of the Catania case-study are presented in Annex C.3 and discussed in Chapter 6.

6. Discussion

The focus of this Chapter is to assess the current knowledge and explore a niche to contribute to the current understanding of aviation noise and emissions trade-offs. The information and data gathered for *discussion* is based on the academic study, the airport review on balanced approach presented in Chapter 4, and the work conducted by ANOTEC and NLR at Catania airport, illustrated in Chapter 5.

6.1. ANIMA contribution to understanding interdependencies

The Academic Study

The trade-offs or interdependencies between noise and emissions associated with new operational procedures are well documented in industry reports and academic literature. Sustainable Aviation report, for example, provides an extensive overview regarding the impact on noise, CO_2 and NO_x emissions in Departure, Arrival and Ground phase of flights. A number of other academic studies have described noise and emissions trade-offs in detail.

Literature review also shows that a large variety of noise metrics exist, well exceeding that of emission metrics. However, only a few tools exist that can calculate both noise and/or emissions (SONDEO, IMPACT, AEDT, ISOBELLA/POLEMICA, TUNA/LEAS-IT) in a consistent and integrated manner (see Annex B).

Additionally, there appears to be little in the literature which considers the trade-off between the *impact* of aircraft noise alongside the impact of exhaust emissions which arguably is as important, and perhaps more crucial, than focusing on primary emissions. Clearly, this will be important for ANIMA to acknowledge and set out a pathway for it to be addressed in the future.

The Airport Survey

The airport review presented in Chapter 4 and Annex B shows a limited number of airports considering interdependencies, as part of their attempt to assess the change in operations, or evaluate an intervention.

The airport survey data extracted from D2.5 led to the conclusion of a lack of, or mis-understanding of the interdependencies concept and the associated benefits to policy/decision makers. There was no mentioning of dedicated interdependency tools.

Considering Heathrow airport is the only illustrative case-study with its *DET09 Steeper Departure Trial,* the questions remains: why is there such little evidence of airports using interdependencies?

The information extracted from the Academic Study and the knowledge pulled out from ST2.3.1/D2.5 and ST2.3.2/D2.6 contributed to identifying the gaps related to this topic: *there is not enough information, and little evidence to* *validate the benefits of interdependencies*. Additionally, the existing information is dissipated in many places: scientific articles, technical reports, environmental reviews, etc.

Thus, the design of **the ANIMA toolkit**, described in Chapter 4, Figure 3, will come to fill this gap and help airports and their stakeholders understand the need to consider interdependencies when assessing the benefits of an intervention. Usually, it is important to conduct this assessment before the changes in operation take place, to understand the assistance of noise and emissions trade-offs.

The ANIMA toolkit

The ANIMA toolkit (figure 3) shows how ANIMA research can contribute to a better understanding of the interdependencies concept, adding knowledge to some of the existing barriers in using noise and emissions trade-offs (i.e. appropriate tools). This toolkit, composed of 7 pillars (see below), aims also to be an **interdependencies knowledge-based toolkit** (framework), targeting to provide information to end-users. The fragmented information on interdependencies metrics and tools mainly, but also, the lack of clear regulations and gaps in existing databases, obtained through the academic case-study and the airport survey, has justified the additional work on the airport case-study, but, mainly, it has identified the **need for an ANIMA toolkit (framework)** that – at least - raises awareness and consideration of interdependencies**.**

Gathering the information under the same framework will facilitate the understanding of the usefulness of using interdependencies, while examples of methodologies, tools and metrics will facilitate the adoption of this concept.

Rationale for the toolkit was sketched as part of this task, but it will be actually developed and tested during the T2.5 on *Airport exemplification case-study*. The toolkit aims to be an integrated set of information and practicalities that are used to understand and apply interdependencies.

ANIMA Toolkit narrative

The toolkit has 7 pillars providing information on: *regulations, publications, models, metrics, tools, methods and databases,* all related to aviation noise and emissions interdependencies.

Thus, information on regulations, methodologies, metrics and tools will be gathered from literature review and existing airport practice. Examples of publications on relevant trade-offs illustrated in journals and technical reports, will add to this information, while a database built with statistics and evidence-base will contribute to a better understanding on *why, what, how and when* to use noise and emissions trade-offs.

This proposed toolkit will be *tested, developed and validated* as part of the activities in T2.5. The five airports mentioned in the airport survey will be the first to test the usefulness of such a toolkit. From the information captured in D2.5 on Balanced Approach, proper tools to assess interdependencies were not well known. Figure 4 shows 10 tools working on noise *or* emissions, but only two, the IMPACT and the AEDT tools are assessing *both* noise and emissions. The ANIMA toolkit will also contribute to the Best Practice Portal, one of the WP2 expected outcomes with a long lasting impact in the airport and community (joint) activities.

Gaps and Barriers to implementing interdependencies

One important question was repeatedly asked regarding ST2.3.3 research: *what are the barriers in implementing interdependencies?* An honest answer was needed, as several airports that introduced changes in operations, did not record clear involvement in assessing trade-offs: e.g. Innsbruck mentioned curved approaches, but did not recorded the associated interdependencies.

The idea was to describe interdependencies as a powerful 'information package', which will be used as an instrument to inform policy makers before taking an action of change in operation. Thus, the debate amongst the ANIMA researchers was about: lacking proper tools, not clear cope with, or missing decision making in place.

The information from ST2.3.1 showed a different approach from the airport stakeholders when implementing the Balanced Approach, particularly when assessing the new operational noise abatement procedures (NAP): while the airports opted for noise reduction, the airlines & ANSPs were focussing on fuel saving, which results in emissions reduction. The first conclusion drawn from this work was around *the need to design a consolidated case of any intervention*, and involve actively all stakeholders who may benefit or will be impacted by that intervention. Special attention to this aspect will be given to Barcelona, Vienna, Schiphol and Helsinki airport, due to existing initial information. The airport survey on BA seems to confirm that communities around the airports are not happy with changes in operations, due to lack of information on expected impact. This opens a credible opportunity to involve noise and emissions trade-offs in further research.

Founded on the airport survey outcome, combined with the academic study results, and adding the Catania case study, a relevant question remains: why *these interdependencies and trade-offs are currently not in focus and whether this will change in the foreseeable future? How can ANIMA contribute to added knowledge?*

It is beyond the scope of this limited study to provide a final answer to this question, but some queries have been formulated to address the lack in focus. The answers represent the outcome of informal discussions with colleagues from FINAVIA, ACI-Europe, Zagreb airport, who are members of the ANIMA Impact Expert Committee. The objective of those discussions was to test the need for an

ANIMA toolkit, knowing the requirement in the airport strategy to assess noise & emissions at the same time.

Q1: To what extent are airports under pressure to deliver on a suite of potentially competing environmental agendas – currently and, possibly, in the future?

Apparently the current pressure is not such that interdependencies are high on the agenda of airports. However, aviation in Europe is forecast to grow by 2.3% per annum. The outcome of ST2.3.1 shows that several airports which are part of '*starting the journey'* category in implementing the Balanced Approach will experience rapid growth in the next 5-10 years and they need to be able to manage this growth within environmental limits. This, combined with a growing level of attention (and resistance) for local impacts related to noise and emissions, and adding the ongoing discussion about global climate change impact, may well lead to *more focus on interdependencies* in the foreseeable future.

Q2: Is sufficient knowledge/understanding regarding interdependencies available at airports?

The outcome of the work conducted in T2.3.3 shows this knowledge is not sufficiently available, or it does not get sufficient attention at (smaller) European airports. This aspect will be further developed and debated during T2.5, where dissemination of existing knowledge will be conducted, and recommendations on best practices, including tools and metrics will be addressed.

Q3: Are current tools for interdependency studies adequate and available to airports?

The airport survey did not provide any significant response to interdependency tooling. Assessment of tools for noise and emissions is given in table 1 on *Tools used in airport operations,* which shows that, in general, the airports are using tools for noise **or** for emissions, when assessing interdependencies. This shows the *lack of a common tool* (or tool suite) to assess noise and emissions trade-offs. Only two of the mentioned tools are used for both noise and emissions: AEDT & IMPACT (Figure 4), but the limited use of those tools needs further exploration.

Given the above, the role of ANIMA is obvious: since developing adequate interdependency tooling (tool suite) in WP4, it is recommended to approach the previously interviewed airports to specifically ask for tools and metrics used and, if applicable, to discuss the need for a tool that combines noise and emission aspects. Given the ambition of the **ANIMA toolkit**, it is recommended to conduct additional literature search on trials, uses and experiences with those tools, as part of further work.

Q4: What role does the regulatory approach play on the environmental guidelines, standards and limits related to interdependency and trade-off studies?

Currently, regulations address *noise and emissions separately*. This approach and the increasingly stringent noise and emission standards have been successful in reducing the overall environmental impact of aviation. The current regulatory approach may be a barrier in considering the interdependencies. Several good practices on *why, what, how* and *when* to use interdependencies may help the understanding of the usefulness of using the trade-off approach when an intervention is designed.

The pillar on *Regulations* of the **ANIMA Toolkit** will further address these questions, contributing to the Best Practices Portal knowledge base. The user will much easier find the information being looked for, without being overwhelmed by all the data available.

6.2. Airport case study contribution to understanding trade-offs

The importance of a case-study in conducting research

The motivation to include the Catania airport case-study in conducting research in ST2.3.3, is firstly explained in Chapter 2, mentioning the limits in achieving the task requirements, due to lack of data to draw relevant conclusions and extract pertinent key messages. Case-studies have benefits, as they reduce bias and are comprehensive. However, they also have challenges, as often findings can't be generalized.

6.2.1. Catania case-study

The Team involved

Sub-Chapters 5.2 & 5.3 illustrate the setting up of a joint team, ANIMA & Catania Airport. ANIMA partners being engaged to gain a more detailed, unbiased understanding of interdependencies and the airport since it is interested in research and to learn from experts and other airports how to mitigate the environmental challenges.

Study expectations

It is anticipated that the approach chosen in the Catania case-study meets the ST2.3.3 description of work: it will review tool(s) to quantify environmental performance characteristics and (show) how this (i.e. knowledge) has/can be used to inform trade-offs between environmental attributes (e.g. noise vs carbon emissions).

The Catania Airport case-study gives the possibility to add information on understanding interdependencies, while using real data and ANIMA partners' tools (SONDEO & SONDEO/EM). The study was designed to improve the understanding of noise and emission trade-offs, and to support further refinement of the capability of ANOTEC tool suit, SONDEO & SONDEO/EM.

The idea is to 'learn-by-doing' and have the feed-back of an important stakeholder (the airport) on existing barriers in seizing the role of interdependencies in designing noise & emissions (environmental) mitigation strategies.

The Research Approach

Decisions relating to operational changes are often made on the basis of a wide range of *strategic, economic, operational and impact-related information*. Catania case represents the last two: *operational and impact-related approach*.

Thus, in this case, a tactical trade-off was considered, the driver being the *process of assessing noise vs emissions*[12]. The role of the SONDEO tool suit being to support the evaluation of operational aviation impact. The effects of trade-offs quantitatively depend on:

- the objective being pursued and the priorities selected;
- the type of technology and design features involved in reducing noise and emissions (sources, means used, and components affected); and
- the type of engine, the type of aircraft and the phase in which they are applied.

The scope of the study was limited to *noise abatement departure procedures* that can be operated with aircraft currently in service. This decision was taken by both NLR & ANOTEC, considering that trade-offs between noise and emissions are better illustrated in this operation phase.

Methodology: The Role of the Research Questions

Catania case-study is answering, partly, to the research questions identified (see Chapter 2.5) to meet the ST2.3.3 objectives, as illustrated below:

Q1: Catania airport case-study will contribute to a better understanding of interdependencies, by involving local stakeholders in designing the trials, formulating a process associated to an intervention (i.e. change in operations), and quantifying noise and/or emissions. SONDEO & SONDEO/EM are the tools involved in implementation of the interdependencies process (designed methodology).

Q2: Catania airport case-study may clarify some of the barriers in implementing interdependencies, by:

- formulating the intervention and informing the relevant stakeholder(s)
- developing scenarios related to changes in operations

[12] The ICAO Guidance on the Balanced Approach to Noise Management states: *it should be noted that noise mitigation actions might have an influence on some emissions that are considered for their global effects such as CO_2.*

- conducting the trial & using noise & emissions related tools (SONDEO & SONDEO/EM)
- validating the benefits vs the disbenefits through the involvement of experts in the field and airport policy makers.

Q3: The added value of the *learning-by-doing* exercise

The research team was involved in designing this case study, identifying its objectives after consultation with the airport management and understanding their priorities in limiting the environmental impact.

Comments on the outcome

Both ANOTEC and NLR intended to perform separate case studies for Catania airport (see Chapter 5), using in-house tools. However, with different objectives:

- ANOTEC analysis was aimed at providing insight in the day-to-day *variations in noise and emissions* that occur while operating a single city-pair by a single operator.
- The objective of the NLR analysis was to investigate the *potential for a trade-off* between noise and emissions of four departure procedures.

6.2.2. The ANOTEC Approach

The ANOTEC case-study approach is to *calculate both environmental aspects* with models that can use the same input data and that provide results in a compatible format. The involvement of the WP4 tool chain: SONDEO & SONDEO/EM is meant to perform calculations for typical traffic at Catania airport.

The importance of accurate data is better observed in Figure C.10, which presents the noise contours of some operations. It can be observed that, due to the too low altitude, the noise contours are indeed much longer than may be expected. Also some misalignments between trajectory and runway can be found.

A temporary solution made it possible to obtain a correct data for the updated dataset, with which the full process could be validated. With this dataset (see chapter 5.3.1) a new single event database was then created, which gives better information on noise contours. Figure C.13 gives some noise contours, calculated for the updated dataset. The updated data set was important to demonstrate the capabilities of the tool chain.

Annex C also illustrates the emission assessments. The corresponding emissions were calculated for the initial flight profiles.

The work of ANOTEC in D2.7 report illustrates **the type of data and input needed for SONDEO & SONDEO/EM** models, aiming at developing a methodology to tackle noise and emissions trade-offs, which will be validated as part of further work at Catania airport. Noise and emissions calculations are in progress, and research is now part of T2.5 (see 6.2.4 Future Work on Catania airport).

6.2.3. The NLR Study

The purpose of the *NLR analysis was to* ***demonstrate the trade-off potential***. In this study the choice of metrics was also of importance. Since the datasets contained sufficient information for its purpose, the NLR study was performed with concluding remarks, and there is no need for continuation in T2.5.

To illustrate the case study, NLR chose a typical day of traffic at Catania airport for two temperatures (a colder day and a warmer day), while varying NADP starting procedures. The NLR analysis looked at ***noise, CO2 and NOx emissions*** though the impact of the NOx emissions on air quality was considered to be relative small in this case. Though the data used is specific to Catania Airport, the analyses are intended to be also valuable (examples) for other airports.

The study approach and data analysis involved three parts:

- profiles: involving four different ANP procedures.
- methodology: describing the practice adopted to assess noise and emissions.
- results: showing the impact of procedure choice on noise and emissions, presented as trade-off.

Since accurate information on aircraft engine types for Catania airport was not available, and since the **purpose of the current analysis is to demonstrate trade-off potential,** not to be as accurate as possible. Only the emissions of the three most common aircraft at Catania airport were calculated by matching these aircraft to typical engines used for the same aircraft types at Schiphol Airport. The effect of temperature on calculated profile is presented in figure 11, in which a NADP2 profile for two different temperatures is compared.

The study considers only LAeq (thus neglecting Lden penalties for evening and night flights).

NLR added value to the understanding of Trade-offs/interdependencies

The added value of the NLR study was not only in the methodology approach to demonstrate the trade-off potential, but also in the tactic adopted for *noise and emissions modelling*.

The study reveals the trade-offs as *a function of a parameter that can be manipulated*. Interestingly, trade-offs between noise metrics and emissions can be observed, as well as trade-offs within noise or within emission metrics. *Thus, a trade-off can be observed between aspect ratio and noise area for the 55 dB noise contours.* Additionally, Table C.5 illustrates the results on noise, CO2 and NOx, using the four selected procedures, depending what is important/of value to Catania Airport.

While this study was performed for a medium-sized airport, care must be taken to generalise these trade-off trends to larger airports. The noise metrics would therefore need to be calculated for contour levels that are scaled appropriately (e.g. 10 dB per tenfold increase in number of flights).

In summary, the above presented data indicates that trade-offs between and within noise and emission metrics can be found when using normalized or ranked metrics. However, due to a small number of flights involved in this exercise (75), a clear conclusion can't be drawn. However, the scope of the study to show the noise and emissions trade-off potential was reached.

The study outcome also shows that a more advanced cost-function is required to determine *which procedure is best to reduce the emissions*.

One important outcome of this trade-off exercise is the role of the airport (or other stakeholder) on decision making regarding how to value the different environmental aspects (noise, air quality emissions, climate change).

In general terms, the airports will aim to reduce both noise and emissions, so the results of a trade-off exercise adapted to the airport priorities (noise vs emissions), is very much needed.

6.2.4. Future Work on Catania Airport and toolset development

The ANOTEC approach in T2.5 to assess interdependencies will be the *comparison of noise and emissions of the same operation* (e.g. the same daily flight between Catania and Rome) during a longer period of time based on an extensive dataset acquired from the improved airport monitoring system.

To support this kind of study the actual thrust during this operation will be calculated by a WP4 tool chain that includes the FRIDA module, developed by Roma Tre University (UR3)[13].

Toolset Development

In ANIMA WP4, ANOTEC has implemented both SONDEO and SONDEO/EM as part of the Noise Management Toolchain. The integration of FRIDA with SONDEO and SONDEO/EM is under development in WP4 and once validated, can be used to support the work in Task 2.5.

In ANIMA Task 4.1.2 ANOTEC and MMU will perform a first validation of the SONDEO/EM tool. The tool chain capability may help the process of assessing the noise & emissions trade-offs in an airport context, using ANIMA partners tools. In order to support the availability of a robust interdependencies capability, it is considered of interest to extend this verification & validation process to some of the other model suites that are available to the ANIMA partners.

[13] FRIDA is an inverse flight mechanics model that estimates the thrust using the aerodynamic characteristics of the aircraft to match the actually flown trajectory.

7. Recommendations

7.1. Concluding remarks

Aviation decision-makers and stakeholders are seeking *policies*, technologies, and *operational procedures* that balance environmental and economic interests.

Existing environmental challenges may limit the airport growth and different conclusions may be drawn about the same policy options, depending on whether benefits and *interdependencies are estimated* in terms of noise and emissions (air quality and climate change). These conclusions are sensitive to a variety of uncertainties, starting with proper information and access to suitable modelling techniques, and ending with using adequate metrics. Unfortunately, the information on interdependencies assessment and impact is presented fragmented in different articles and technical reports, illustrating the airports' experience with tradeoffs. A platform gathering together knowledge in *regulations, tools, databases, metrics, publications* may prove useful to advise different stakeholders and policy makers. Such instrument may be the proposed ANIMA knowledge-base toolkit.

The D2.7 report on Recommendations *for the use of tools and metrics to allow environmental performance interdependencies to be quantified and illustrated* proved to be a very challenging piece of work, due to limited information extracted from ST2.3.1 on the Implementation of Balanced Approach at European airports and ST2.3.2 on Footprints.

The main conclusion of D2.7 is the lack in focus and/or reporting regarding interdependencies from the airports side, though some of them have acknowledged the need of better understanding the concept through illustrative examples.

7.2. Further work on interdependencies within ANIMA project

Based on the report outcome, this chapter will formulate recommendations for further work within the ANIMA project and suggestions for research beyond ANIMA.

Further effort will focus on identified gaps in *understanding* the concept of noise and emissions interdependencies and associated benefits. Exploring existing barriers in applying this concept in the airport context will lead to additional research needs.

Likewise, the initial work conducted on Catania airport needs further exploration, to validate the initial findings. While the NLR study has finished with clear conclusions of existing potential for assessing trade-offs, the ANOTEC study requests the validation of *the type of data and input for SONDEO & SONDEO/EM* models. The work will be conducted in T2.5 on airport exemplification case-study.

The approach to solve the initial identified gaps in background information has developed around three pathways:

- to conduct an *academic study*, in order to assess the State of the Art of noise and emissions interdependencies
- to *review* the airports involved in conducting interdependencies (or mentioning the concept), as part of the 12 airports surveyed in ST2.3.1
- to conduct an *airport case-study* at Catania airport, in order to prove the concept can be implemented and to develop a methodology to be tested in further work.

As described in Chapter 3 Methodology, the answer to the ST2.3.3 task description is produced by identifying *current practice and understanding the need* for using trade-offs in interventions (mainly changes in operations).

The recommendations for further work in ANIMA will involve topics around:

1) Developing the ANIMA Toolkit

One important outcome of the ANIMA project is the *Best Practice Portal* which will illustrate the identified (best) practices involved in the implementation of the ICAO Balanced Approach (BA) at airport level. There is no mentioning in the Grant Agreement on best practice associated to interdependencies. However, noise & emissions trade-offs is the result of implementing new operational procedures, which is one pillar of BA. Thus, understanding better interdependencies may contribute to overcome the barriers identified to implementing Balanced Approach.

Additionally, one important objective of WP2 is to *consider interdependencies; in particular, trade-offs between aircraft noise and emissions.* Thus further work on this topic within the ANIMA project is required and fully justified.

The specific work will involve each of the 7 pillars, and will include gathering information and testing its usefulness through direct engagement with airports as part of T2.5. The initial airports to test the ANIMA toolkit will be those involved in T2.3.3: Heathrow, Barcelona, Schiphol, Helsinki and Vienna. However, any other airport involved in T2.5 may join this effort.

Further discussion on the ANIMA Toolkit will take place during a workshop on healthy & wealthy airports, scheduled to take place by early summer 2020. A special session dedicated to interdependencies (suggested by Zagreb airport) will contribute to the validation of the initial findings of the proposed ANIMA toolkit-an interdependencies knowledge-base framework.

2) Validation of ANOTEC findings and contributing to the refinement of the WP4 tool chain

This work will involve additional data from Catania airport, or other airport willing to provide flight operation data, to develop and refine the proposed Noise Management Toolchain in WP4. This tool-suit involves SONDEO and SONDEO/EM and the expected work at Catania airport will help the refinement of the emissions side, in particular. Further work on validation will be conducted within a joint effort of WP2/T2.5 & WP4/T4.1.2, focussing also on appropriate metrics, tools and scenario building.

3) Providing information to the research priorities in WP3

The work associated to T2.3.3 may be further developed to provide input in WP3. Thus, the use of auralisation and visualisation tools, to engage the airport community, may test the usefulness of including noise & emissions trade-offs, considering the task is testing *the impact of the virtual simulation on the habituation or on the understanding of the environment* (T3.2.3) .

Linking knowledge on interdependencies to the quality of life indicators (noise impact vs emissions impact) may help the airports improving communication with communities (T3.1).

Expected outcome

It is expected that, by the end of the ANIMA project, the team involved in conducting research on interdependencies will be able to provide advice on how to deal with interdependencies in the broadest meaning of the word. Tools for calculating and presenting noise and emissions trade-offs will be developed in WP4, the idea of SONDEO & SONDEO/EM being to use the same tool suit when assessing noise and emissions.

Work beyond Anima: interdependencies' impact on health

The academic study sets out an argument that the impact of emissions on local air quality and subsequent possible health outcomes of residents in communities neighbouring airports is of importance. Clearly, this will be important for ANIMA to acknowledge and set out a pathway for it to be addressed in the future.

Considering the research conducted in ANIMA ST2.1.1 was on assessing the *noise impact on health*, conducting research on interdependencies impact on health will be just a further step. The outcomes of the academic study may be used to design further research on health impact and quality of life.

In **conclusion**, the general recommendation of D2.7 is *to continue work on interdependencies*, aiming at finding the right message to inform policy makers on the usefulness to consider interdependencies when designing new interventions, including new operational procedures, developing the airport strategy related to the environmental capacity, setting up new policies.

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9. Annex A Academic study

9.1. Annex A Executive Summary

The primary assumption of ANIMA is that communities living around airports are the key stakeholders with respect to understanding, minimising, managing and mitigating the impact associated with aircraft noise and exhaust emissions. This therefore requires an understanding and appreciation of non-acoustical factors and air quality issues that go beyond the traditional aircraft noise vs emissions debate. However, an objective of ANIMA is to also consider such interdependencies and seek out insights in to how airports or airlines address these potentially competing issues.

This Annex provides a first step in this process and undertakes a detailed review of archived peer reviewed academic literature to present a snap shot of current knowledge and understanding of the interdependencies between aircraft noise and exhaust emissions and subsequent impact on communities. It is clear from the literature that the focus of academic, and perhaps also industry, studies has been overwhelmingly one dimensional. A wide range of studies have considered aircraft noise and related these to operational factors and impact on community annoyance and health. By way of contrast, there have been a relatively smaller number of studies that have considered aircraft exhaust emissions and impact on air quality in and around airports. Only relatively recently have these studies started to embrace the impact of aircraft emissions on the health outcomes of residents who live around airports. Therefore, it is perhaps unsurprising that a holistic approach which considers any interdependencies between aircraft noise and exhaust emissions and subsequent impact on communities have a very limited coverage in the literature. This clearly reflects the regulatory approach which generally considers noise and emissions separately.

The academic study does not seek to offer further insight in to the impact of aircraft noise on communities as this is the prime focus of the ANIMA project. However, it does set out an overview of aircraft exhaust emissions during the LTO cycle and identifies the role that changes to operational procedures can make to the quantitative and qualitative make up of engine exhaust. It also sets out an argument that the impact of emissions on local air quality and subsequent possible health outcomes of residents in communities neighbouring airports is of importance. Until quite recently, the main pollutant of concern for Airports, industry and regulators was NOx (NO_2) given its known health impacts and the need to meet air quality standards. However, within the literature there is increasingly attention being focussed on particulate matter (PM) and specifically ultrafine particles (UFP). This also reflects an increasing number of air quality studies that are seeking to better understand and offer insights into the role of aircraft exhaust emission on the concentration and size of PM in and around airports. In addition, the proposed CAEP/11 standards for LTO nvPM mass and number, the first standards of their kind, will be agreed at CAEP/11 in February 2019. It will also be proposed that the Smoke Number (SN) regulation can be retired (for engines greater than 26kN) and that a maximum concentration limit for nvPM mass agreed. Consequently, it is likely that industry and stakeholders will see nvPM (and possibly total PM) as being a key pollutant of concern particularly in the context of local impacts. As such ANIMA should consider including nvPM within its interdependencies and trade off analysis.

9.2. Annex A.1 Introduction and purpose

The key assumption of ANIMA is that communities living around airports are: i) the main stakeholders associated aircraft noise as they are directly impacted by this problem; and ii) that mitigating and managing the impact of aviation noise requires non-acoustical factors to be taken into account.

A specific objective of ANIMA is to also understand and consider interdependencies and how airports or airlines address competing environmental issues. However, by understanding and valuing the unique position of communities whose lives are affected by aircraft operations, such interdependencies should focus upon environmental issues which have local importance and impact on health outcomes and quality of life. These are primarily aircraft noise and gaseous and particulate emissions from aircraft engine exhaust[14].

Aviation in Europe is forecast to grow by 2.3% per annum[15]. Such growth whilst significantly contributing to wealth creation and offering greater global connectivity also has the potential to impact of European citizen lives and wellbeing through exposure to aircraft noise and exhaust emissions. By 2050 the number of commercial flights landing and taking off in Europe is forecast to be 18.6-26.1 million per annum which is 2-2.7 times the number of 2012[16]. Much of this growth is likely to be accommodated by existing large hub airports, however where aircraft operators are faced with capacity constraints they will grow their business where capacity is available. In doing so, new communities may be exposed to an enhanced level of aircraft noise and exhaust emissions.

The challenge for the regulators and industry is how to minimise, manage and mitigate its future impacts on communities living close to airports and ensure compliance with existing environmental guidelines, standards and limits.

Conventionally, the Committee on Aviation Environmental Protection (CAEP) within ICAO has addressed aircraft noise and emissions impacts independently of each other through measures such as engine NO_x emissions certification

[14] Fuel efficiency and carbon emissions are globally important as part of the climate change debate and have to be factored into the interdependencies equation, but at a local level emissions and noise are the predominant issues of concern for communities impacted by aircraft operations in and around airports.

[15] IATA(2017). Air Passenger Forecast

[16] Eurocontrol Challenges for Growth 2013. Available at: www.eurocontrol.int/sites/default/files/content/documents/official-documents/reports/201307-challenges-of-growth-summary-report.pdf

standards or aircraft noise certification standards[17]. This separation of issues is not isolated to ICAO but is also embedded across many stakeholders and industry bodies. For example, ACARE Flightpath 2050[18] goals also separate aircraft noise and emissions. To a large extent this is a logical and reasonable approach - as the objective is to reduce the environmental burden of aviation across the twin environmental issues of noise and emissions. Although, by not adopting a holistic approach industry and regulators could be criticized by not considering interdependencies. OEMs would, perhaps, argue that in the real world, manufacturers have a heightened awareness of understanding of the issues and seek to minimise or adopt as far as possible a reasonable balance.

On the whole, aircraft noise (and impacts) is the most widely reported environmental issue to be addressed by European airports and described in the recent academic literature (for example during 2016-2018 approximately 500 articles were published detailing studies of aircraft noise in and around airports and annoyance, compared with approximately 40 articles which detail studies focused on the impact of aircraft exhaust emissions on air quality in and around airports)[19].

This focus on noise is reflected in the historic response of the regulators. Since 2001 the International Civil Aviation Organisation (ICAO) has required Member States to adopt a 'balanced approach' to aircraft noise management[20,21]. This consists of identifying the noise problem at an airport and then analysing the various measures available to reduce noise through the exploration of four principal elements with the goal of addressing noise problems on an individual airport basis and to identify the noise related measures that achieve maximum environmental benefit in the most cost-effective way. The four elements are:

- Reduction at source (e g quieter aircraft).
- Land-use planning and management.
- Noise abatement operational procedures.
- Operating restrictions.

These principles also underpin The European Community adopted Regulation (EU) No 598/2014 on the procedures concerning the introduction of noise-related operating restrictions[22].

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[19] SCOPUS. Key words: i) *aircraft* and *noise* limited to *airport* and *annoyance*; and ii) *aircraft* and *exhaust* and *emissions* limited to *airport* or air *quality*.

[20] ICAO (2008). Guidance on the balanced approach to aircraft noise management. 2nd edition (Doc 9829)

[21] Scatolini, F. et al (2016). Easing the concept "Balanced Approach" to airports with densely busy surroundings – The case of Congonhas Airport. *Applied Acoustics* 105. 75-82.

[22] See for example: www.easa.europa.eu/easa-and-you/environment/policy-support-and-research/balanced-approach-regulation

Concern regarding air quality in and around airports has been recognised by *The Advisory Council for Aviation Research and Innovation in Europe (ACARE)* who identify within Action Area 3.5[23] the need for airport development to be sustainable, stating *"assessment of air quality impact at or near airports must be based on accurate measures or prediction of air vehicle emissions combined with sound atmospheric transport models*". These challenges, which are further elaborated within Flightpath 2050[18], amplify the societal and industrial requirement for an enhanced qualitative and quantitative understanding of aircraft engine emissions, physicochemical interactions, and dispersion, with specific reference to pollutants that may have significant health impacts.

However, there is no analogous policy instrument or regulations related to the reduction of emissions from aircraft which embraces the principles of the balanced approach. Nonetheless, a number of academic and industry studies[24,25,26] have shown the potential of changes to aircraft operational procedures to lead to a marginal reduce in emissions (including circulars issued by ICAO)[27].

This brief Annex provides an overview of aircraft engine exhaust emissions in and around airports. It is structured to provide the ANIMA community with an overview of aircraft emissions and impact on local air quality and includes; i) operational procedures for emission reduction; ii) trade-offs and interdependencies between noise and emissions; iii) technological developments and implication for emissions.

9.3. Annex A.2 Airport air quality and health

Health impacts from aviation emissions have been quantified at various scales from national to global[28,29,30,31]. Estimates for premature mortalities attributable

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[23] ACARE Strategic Research and Innovation Agenda, Volume 1. Available at www.acare4europe.org/sria

[24] Koudis, G. S. et al., (2017). Airport emissions reductions from reduced thrust takeoff. *Transport Research Part D*: 52.15-28

[25] Koudis, G.S. et al., (2017). The impact of aircraft takeoff thrust setting on NOx emissions. *Journal of Air Transport Mnagement*: 65: 191-197.

[26] Flughafen Zurich (2010). Sensitivity of Aircraft Operational Improvements. LAQ modelling of landing and take-off cycles. Available at: https://www.zurich-airport.com/~/media/flughafenzh/dokumente/das_unternehmen/laerm_politik_und_umwelt/luft/2010_zrh_laq modelling_sensitivities.pdf

[27] ICAO circular 303 -AN/176.

[28] Yim, S.H.L. (2015). Global, regional and local health impacts of civil aviation emissions. *Environ. Res. Lett*. 10. 034001

[29] Morita, H. et al (2014) Global health impacts of future aviation emissions under alternative control scenarios. *Environ. Sci. Technol*. 48(24): 14659-14667.

[30] Penn, S.L. et al. (2017). Modelling variability in air pollution health damages from individual airport emissions. *Environmental Research*. 156. 791-800.

[31] Levy, J.I. et al (2012). Current and future particulate matter related mortality risks in the United States from aviation emissions during landing and take-off. *Risk Analysis* 32 (2). 237-249

to aviation have been estimated as 8,000 associated with cruise emissions[32] and a total of about 5000 people who live within 20 km of airports are estimated to die prematurely each year due to long-term exposure to aviation-attributable $PM_{2.5}$ and O_3[28,33].

There is a developing consensus of understanding about the possible health effects of aircraft engine emitted pollutants, other than NO_x (as NO_2), this is driving airport operators needs for a quantitative and qualitative understanding of aircraft engine emissions of PM (specifically UFP), VOC and SVOC. Scientists and regulators have an increasingly informed understanding of the complex nature of Particulate Matter (PM) in ambient air, in terms of particle size and chemical composition from different sources both natural and anthropogenic. What is less certain, is how PM species and precursors evolve and interact within the atmosphere, and which characteristics of the PM are most harmful to public health. Within this context, it is considered that Ultra Fine Particles (UFP), defined as particles of aerodynamic diameter less than 100 nm, may have greater toxicity on an equal mass basis than currently regulated larger particles ($PM_{2.5}$/PM_{10})[34] because their vast numbers and small diameters provide a high surface area which is a potentially important toxicological interface[35]. These UFP's are relevant to civil aviation, and recent studies have shown that aircraft engines emit primary aerosol as non-volatile Particulate Matter (nvPM)[36,37,38,39] as well as secondary aerosol precursor gases such as organic gases and sulphates[40] that nucleate within the exhaust plume within this size range. The contribution of UFP from aircraft operations to the emissions inventory in and around airports is therefore largely unknown, and could be significant[41].

[32] Barrett, S.H. (2010). Global mortality attributable to aircraft cruise emissions. *Environ. Sci. Technol*. 44 (19) 7736-7742.

[33] Harrrison, R. et al. (2015). Civil Aviation, air pollution and human health. *Environ. Res Lett*. 10: 041001

[34] Air quality in Europe – 2017 report, (p 58), European Environment Agency

[35] RIVM, (2016). Explorative study into health risks of UFPs from aviation around Schiphol airport and proposal for follow-up

[36] Kinsey, J.S. et al (2011). Chemical characterisation of the fine particle emissions from commercial aircraft engines during the aircraft particle emissions experiment (APEX) 1 to 3. *Environ. Sci. Technol*. 45. 3415-3421.

[37] Hudda, N. et al (2014). Emissions from an International airport increase particle number concentrations 4 fold at 10km downwind. *Environ. Sci. Technol*. 48. 6628-6635.

[38] Hudda, N and Fruin, S.A. (2016). International Airport Impacts to air quality: size and related properties of large increases in ultrafine particle number concentrations. *Environ. Sci. Technol*. 50. 3362-3370.

[39] Winther, M. et al. (2014) Emissions of NOx, particle mass and particle numbers from aircraft main engines, APU's and handling equipment at Copenhagen Airport. *Atmospheric Environment*. 100. 218-229.

[40] Kilic, D. et al. (2018). Identification of secondary aerosol precursors emitted by an aircraft turbofan. *Atmos. Chem. Phys*. 18, 7379-7391

[41] Jannsen N. et al., Verkenning gezondheidsrisico's ultrafijnstof luchtvaart rond Schiphol en voorstel vervolgonderzoek. RIVM Briefrapport 2016-0050

9.4. Annex A.3 Pollutants of concern for airports – a change of focus?

NO_x has historically been viewed as the primary aircraft exhaust emission of concern though it is the concentration of NO_2 at receptors that is associated with adverse health effects, not NO_x. There have been many studies on estimating the NO_x burden on an airport and relating these to health based NO_2 standards[42,43]. In the more recent academic literature (2016-18) emissions of PM (and secondary formation) has been identified as important pollutant that has the potential to impact on the health of airport workers and adjacent communities (see above). A number of airports across Europe share this concern and it is reasonable to speculate that PM is likely to occupy a more dominant space in the operator agenda. This is evidenced by the recent focus placed on understanding the spatial and temporal concentration of ultra-fine particles (UFP) in and around airports[44,45]. A number of airports across Europe have put in place detailed measurement studies in an attempt to quantify the issue. In addition, a number of academic based studies[46,47,48,49,50,51,52] have also provided additional insight into the magnitude and impact of aircraft PM emissions.

9.5. Annex A.4 PM Emission Index

Given the increased importance that is focused on PM as a major pollutant of concern for the airport community it is important to appreciate: i) there is not a direct emissions Index (EI) for PM; and ii) the significant effort by ICAO and aviation stakeholders to develop a robust approach in estimating emissions.

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[42] Herndon, S.C. et al. (2004) No and NO2 emission ratios measured from in use commercial aircraft during taxi and take-off. *Environ. Sci. Technol*. 38. 6078-6084.

[43] Carslaw, D.C. et al. (2006) Detecting and quantifying aircraft and other on-airport contributions to ambient nitrogen oxides in the vicinity of a large international airport. *Atmos. Environ*. 40. 5424-5434

[44] ACI (2018) Ultrafine particles at airports – current understanding of ultrafine particle emissions and concentrations at airports in 2018

[45] ACI (2012) Ultrafine particles at Airports – discussion and assessment of ultrafine particles (UFP) in aviation and airports in 2012. http://dit.cph.dk/wp-content/uploads/2015/06/ACI-study-on-ultrafine-particles-at-airports.pdf

[46] Maisol, M. et al. (2017). Sources of sub-micrometer particles near a major international airport. *Atmos. Chem. Phys.* 17, 12379-12403

[47] Hudda, N. et al. (2016). Aviation emissions impact ambient ultrafine particle concentrations in the greater Boston area. *Environ. Sci. Technol*. 50. 8514-8521.

[48] Hudda, N. et al. (2018) Aviation-related impacts on ultrafine particle number concentrations outside and inside residences near an airport. *Environ. Sci. Technol.* 52, 1765-1772

[49] Woody, M.C. and Arunachalan, S. (2013). Secondary organic aerosol produced from aircraft emissions at the Atlanta Airport: An advanced diagnostic investigation using process analysis. *Atmospheric Environment*. 79 101-109.

[50] Masiol, M. et al. (2016). Source apportionment of wide range particle size spectra and black carbon collected at the airport of Venice (Italy). *Atmospheric Environment* 139, 56-74.

[51] Riley, E.A. et al. (2016) Ultrafine particle size as a tracer for aircraft turbine emissions. *Atmospheric Environment*. 139, 20-29

[52] Ren, J. et al. (2016). A study of ambient fine particles at Tianjin International Airport, China. *Science of the Total Environment*. 556, 126-135

To address the lack of an EI a simple methodology (FOA3)[53,54] was established in 2007 to estimate aircraft PM mass emissions based on Smoke Number. However, more recently in conjunction with the findings of the SAMPLE and A-PRIDE studies, a new regulatory framework for the sampling and measurement of nvPM mass and number emissions was agreed and adopted by ICAO (CAEP/10, Annex 16 Vol II)[55]. Since adoption of the nvPM methodology, numerous independent OEM tests and collaborative 'parallel' measurements with an EU, North American and Swiss reference systems, have populated an ICAO database for aircraft engine nvPM mass and number emissions. This is currently being used to develop a nvPM mass and number CAEP/11 regulatory standard[56]. In the future engine emissions will be regulated for both nvPM mass and number, and if scientifically established for local air quality assurance, a measure of total PM, including secondary PM evolved in the exhaust plume from gas precursors or condensed vPM may also be required. As an interim step a revised methodology for estimating nvPM has been developed known as Smoke Correlation for Particle Emissions – CAEP11 (SCOPE11). This new methodology revises the PM EI and predicts ~32% higher BC mass emissions than FOA3[57].

It should also be noted that emissions from APU (e.g. NO_x and PM) are not currently regulated by ICAO, but may contribute noticeably to air quality issues particularly on and around the apron[58].

9.6. Annex A.5 -Emissions or air quality the importance of understanding the difference

The process used to estimate gaseous emissions (SO_2, NO_x, CO) and non-volatile PM within the exhaust of aircraft engines is well understood within the aviation community and across stakeholders. A comprehensive description is detailed in the ICAO Doc 9889[54] and more recently elsewhere[59]. However, airports do not have to comply with standards based on emissions, though a number of airports have adopted a NO_x charging scheme based on a cost per kilogram of NO_x

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[53] Wayson, R. et al. (2009). Methodology to estimate particulate matte remissions from certified aircraft engines. *Journal of the Air and Waste Management Association*. 59. 91-100

[54] ICAO Doc 9889. Airport Air Quality Manual. (2011)

[55] The latest version of Annex 16, Vol II is the 4th edition, published in July 2017

[56] The CAEP10 nvPM standard regulates the LTO nvPM maximum mass concentration and requires reporting of LTO EIs for nvPM mass and number. The future CAEP11 nvPM standard will regulate engine nvPM emissions over the LTO cycle for mass and number

[57] Agarwal, A. et al (2019) The SCOPE11 method for estimating aircraft black carbon mass and particle number emissions. Submitted to: *Environ. Sci. Technol*. (in review)

[58] Masiol, M. and Harrison, R.M. (2014). Aircraft engine exhaust emissions and other airport related contributions to ambient air pollutant: A review. *Atmospheric Environment*. 95. 409-455.

[59] Zaporozhets, O. and Synylo, K. (2017). Improvements on aircraft engine emission and emission inventory assessment inside the airport area. *Energy*. 140 (2) 1350-1357

emitted per landing and take-off cycle[60,61] in order to incentivise airlines to use aircraft which meet CAEP6 standard[62].

Given the primacy of NO_2 and PM for European airports (O_3 is important in the US) primary and secondary emissions (NO_x, NO_2, VOC, PM etc) have to be modelled to account for any chemical transformation and dispersion to estimate the concentration of regulated pollutants (NO_2, $PM_{2.5}$/PM_{10}) to ensure compliance with health-based standards.

NO_2: Aircraft NOx emissions are made up primary NO_2 and NO but conventionally termed NO_x. To calculate the concentration of NO_2 at a receptor requires a detailed understanding of i) the magnitude of NO and primary NO_2 emissions; ii) concentrations of oxidants (principally NO_2 and O_3) in the air; iii) the magnitude of incoming solar radiation and; iv) travel time.

PM: It is widely recognised that the current International Civil Aviation Organization (ICAO) regulatory requirement for the measurement of gases, nvPM and Smoke Number at engine exit, may not be sufficient to accurately predict total PM formed in the exhaust of an aircraft engine.

Aircraft engines emit volatile precursors of PM and non-volatile PM in form of soot or black carbon with diameter below 100 nm (UFP) and volatile material. In the process of dilution of the exhaust with ambient air, the particles are coated by volatile species and new volatile particles are created from a range of gaseous sulfates and organic precursors[63,64]. Superimposed on these processes is the overall physical dynamics of the exhaust flow. While there is an increasing amount of measurement data and theoretical estimates of the mass and number emission of nvPM, major gaps exist in understanding and modelling the subsequent aging processes and formation of particles from volatile and semi-volatile PM. For the exhaust dynamics, major uncertainties exist in describing the effects of exit turbulence, buoyancy and wingtip-vortex interactions[65] as a function of meteorological conditions, LTO segment, and aircraft size. These processes can have strong impact on the resulting pollutant concentration in and around an airport.

Airports have to comply within the EU include the Ambient Air Quality Directives[66] and the National Emission Ceilings Directive[67], which includes a new

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[60] CAA (2017). Environmental charging- review of impact of noise and NOx landing charges. Update 2017. CAP 1576.

[61] Boeing (2015). Airport noise and emission regulations. www.boeing.com/commercial/noise/

[62] www.icao.int/environmental-protection/Pages/technology-standards.aspx

[63] See e.g. Kärcher, B. et al., (2000), Journal of Geophysical Research. 105/D24:29,379-29,386

[64] Timko, M.T. et al., (2013): *Environ. Sci. Technol.* 37:3513-3520

[65] See e.g. Unterstrasser, S. et al., (2014): Atmospheric Chemistry and Physics 14: 2713-2733

[66] Ambient Air Quality Directives. (2004, 2008). Available at: ec.europa.eu/

[67] National Emissions Ceiling Directive NECD (2016). Available at: eur-lex.europa.eu

emission reduction commitment for fine particulate matter (PM2.5). Many European airports are located in or close to air quality management zones/agglomerations where statutory bodies are required to adopt measures to improve air quality and meet EU ambient air quality directives (specifically NO_2 and PM_{10}/$PM_{2.5}$). For many airports this requires the development of a detailed emissions inventory of airport activity (aircraft, landside traffic, airside traffic, boiler plan etc). This is then layered on to other local and regional sources to produce the input data for detailed dispersion modelling. After accounting for background concentrations, the impact of aircraft emissions to receptors can be readily estimated. For example, at Heathrow it is estimated that the contribution of all emission sources at the airport to NO_x pollutant levels is about 30% at the boundary and significantly less at distances less than 1km away[68].

There is a clear analogy between the impact associated with aircraft noise and exhaust emissions. With aircraft noise there are also complex relationships between noise, the annoyance response and non-acoustical factors (for example fear and individual noise sensitivity). Whilst for gaseous or PM pollutants there are also complex relationships between the magnitude of the emission release, atmospheric transformation and exposure. A simple noise vs emissions approach to assessing trade-offs or interdependencies is perhaps a simplistic approach which disregards actual impact and down plays the importance for the industry and stakeholders.

9.7. Annex A.6 CO2 – an important driver for airlines

In October 2016, the International Civil Aviation Organization (ICAO) agreed on a Resolution for a global market-based measure to address CO_2 emissions from international aviation from 2021[69].

The Carbon Offsetting and Reduction Scheme for International Aviation, or CORSIA, aims to stabilise CO_2 emissions at 2020 levels by requiring airlines to offset the growth of their emissions after 2020.

Airlines will be required to:

- monitor emissions on all international routes;
- offset emissions from routes included in the scheme by purchasing eligible emission units generated by projects that reduce emissions in other sectors (e.g. renewable energy).

During the period 2021-2035, and based on expected participation, the scheme is estimated to offset around 80% of the emissions above 2020 levels.

[68] Carslaw, D. C. et al. (2006). Detecting and quantifying aircraft and other on-airport contributions to ambient nitrogen oxides in the vicinity of a large international airport. *Atmos. Env*. (40). 5424-5434

[69] ICAO (2018). Annex 16 Vol IV Carbon offsetting and reductions scheme for international aviation (CORSIA).

Emissions of CO_2 from aircraft engines are directly related to fuel burn and can be estimated relatively easily[70]. Fuel efficiency is important for airlines in terms of economic savings and environmental (global) impacts. It is estimated that the annual average RTK fuel efficiency from 2009-2014 stands at 2.4% compared to the 1.5% industry target[71]. This trend in fuel efficiency is likely to increase in the short term as CORSIA and the rising cost of fuel drive the industry to reduce costs including the a wider uptake of fuel efficient aircraft including Boeing 787-9 and Airbus A350-900 and A320neo. In addition, airlines routinely employ a variety of operational measures to gain fuel savings including reduced thrust/de-rated take-offs, CDA, reduced engine taxi etc. A number of academic studies have described these in detail[72,73,74,75,76,77,78,79].

9.8. Annex A.7 Interdependencies/trade-offs between emissions and noise within the LTO

The potential for trades-offs between noise and emissions have been qualitatively summarised elsewhere[80]. The academic peer reviewed literature provides details of possible or potential trade-offs or interdependencies associated with some aircraft operations in the LTO, but there appears to be limited recent peer reviewed and archived studies that provide a detailed analysis of the array of the trade-offs or interdependencies between noise and emissions. Likewise, those studies which have isolated one operational procedure (such as CDO or reduced thrust take-off) have not taken into account the full suite of emissions. Most studies focus on the trade-off or interdependency between CO_2 (fuel) or NO_x with noise but do not consider other primary

[70] Ashok, A. et al. (2014). Quantifying the air quality CO_2 trade-off potential for airports. *Atmos. Env*. (99). 546-555.

[71] IATA (2018). Economic performance of the airline industry – semi-annual report. www.iata.org/publications/economics/Reports/Industry-Econ-Performance/IATA-Economic-Performance-of-the-Industry-mid-year-2018-report-final-v1.pdf

[72] Clarke, J.P. (2013). Optimised profile descent arrivals at Los Angeles International Airport. *Journal of Aircraft* 50 (2) 360-369

[73] Nikoleris, T. et al. (2011) Detailed estimation of fuel consumption and emissions during aircraft taxi operations at Dallas/Fort Worth International Airport. *Transportation Research Part D*. 16, 302-308.

[74] Koudis, G.S. et al. (2017). The impact of aircraft take-off thrust setting on NOx emissions. *Journal of Air Transport Management*. 65, 191-197

[75] Turgut, E. T. et al. (2013). Estimation of vertical and horizontal distribution of take-off and climb NO_x emissions for commercial aircraft. *Energy Conservation and Management*. 76, 121-127.

[76] Solveling, G. et al. (2011). Scheduling of runway operations for reduced environmental impact. *Transportation Research Part D* 16, 110-120.

[77] Ashok, A. et al. (2017). Reducing the air quality and CO_2 climate impacts of taxi and take-off operations at airports. *Transportation Research Part D* 54, 287-303.

[78] Turgut, E. T. and Usanmaz, O. (2012). NO_x, fuel consumption and time effects of flight path angle during descent. *Journal of Aerospace Engineering*. 227(5), 737-750

[79] Hao, L. et al. (2017). Estimating fuel burn impacts of taxi-out delay with implications for gate hold benefits. *Transportation Research Part C* (80) 454-456

[80] Sustainable Aviation (2017) Inter-dependencies between emissions of CO_2, NO_x and noise from aviation. www.sustainableaviation.co.uk/wp-content/uploads/2018/06/FINAL__SA_InterDependencies_2017.pdf

emissions including nvPM or the formation of secondary pollutants which potentially have health related impacts. Equally, there appears to be little in the literature which considers the trade-off between the impact of aircraft noise alongside the impact of exhaust emissions which arguably is as important, and perhaps more crucial, than focusing on primary emissions. Clearly, this will be important for ANIMA to acknowledge and set out a pathway for it to be addressed in the future.

As described above, there are a number of studies which have considered fuel burn and emissions across the whole of the LTO. These studies illustrate the importance of accessing data from FDR in order to estimate emissions as the operational values are generally found to differ from the ICAO databank values in a statistically significant manner.

For completeness this report briefly summarises the main aircraft manoeuvres or operational procedures associated with trade-offs or interdependencies and which are widely reported in industry and academic literature.

Arrival

CDO: When an aircraft follows a Continuous Descent Operation (or Continuous descent approach) procedure it stays higher for longer, descending continuously and avoids extended level segments of flight prior to intercepting the 3-degree glide path. Consequently, a continuous descent also requires significantly less engine thrust than required for level flight. Details of CDO/CDA have been discussed widely and the noise and emission impacts described in regulator, industry and academic literature[81,82,83,72]. There are both fuel (and CO_2) and NO_x savings associated with CDO/CDA[72,78]. However, NO_x emissions savings within the LTO cycle are relatively minimal and will not contribute greatly to improved air quality.

Low power/Low drag: Low power/low drag is the collective term used for describing the lowest noise configuration for a given speed and/or altitude during the approach. If pilots select more flap than is required for a given speed it will typically lead to more airframe noise, increase fuel burn due to higher engine power to compensate for the increased drag and thus lead to higher noise – typically in the order of 1 dB. The deployment of the landing gear also significantly increases aircraft drag and airframe noise, and necessitates an increase in engine power to maintain the flight path. This can lead to increased noise in the order of 5 dB[84,85]. Procedures to optimise flap and landing gear

[81] Wubben, F.J.M and Busink, J.J. (2000). Environmental benefits of continuous descent approaches at Schiphol Airport compared with conventional approach procedures. NLR-TP-2000-275

[82] ICAO Doc 9931

[83] Eurocontrol (2011) Continuous Descent – a guide to implementing continuous descent. www.eurocontrol.int/sites/default/files/publication/files/2011-cd-brochure-web.pdf

[84] CAA (2017). Review of aircraft noise controls (CAP1554).

[85] ECAC.CEAC Doc29

deployment would have an impact on noise and fuel (CO_2) and gaseous emissions. However, as with CDO procedures emission reductions within the LTO would be minimal and have limited impact on local air quality.

Reduced landing flap: Reduced landing flap requires an aircraft on approach to be flown at higher speeds. This is likely to increases the touchdown speed, which in some circumstances may lead to an increased use of reverse thrust to slow the aircraft. However, overall it can reduce fuel burn and engine emissions (NO_x). Noise reductions could be in the order of 0.5-1.5 dB.

Take-Off procedures

Reduced or flexible thrust: Most operators prefer to reduce the level of take-off thrust as much as possible to reduce engine maintenance, minimise operational costs and reduce noise close to an airport. This common practice is referred to as using *reduced* or *flexible* thrust. The take-off phase is an important generator of emissions. For example, at Heathrow the take-off roll is estimated to produce 60% of total ground level NO_x emissions and 50% of black carbon. Consequently, for airport operators, airlines and regulators this is a phase of aircraft operations that provides a major opportunity to reduce emissions. Recent work using FDR data from an airline operating at Heathrow indicate that using reduced thrust take-off reduces fuel consumption, NO_x and black carbon BC emissions by 1.0–23.2%, 10.7–47.7%, and 49.0–71.7% respectively relative to 100% thrust take-off [24]. Consequently, when appropriate and subject to safety and other operational conditions the use of reduced thrust take-off offers emissions savings, however this may reduce the height of cutback and at least beyond the cutback point create more noise at ground level.

Taxi in/out procedures

A number of recent studies have sought to model aircraft LTO emissions and quantify the benefits of adopting reduced pollutant- emitting operations, primarily during taxiing activities[86]. Through optimising operations including pushback, gate location and taxiway orientation fuel consumption reductions of between 19 and 31% were identified. However, as with other phases of operation the robust estimation of fuel burn and pollutant emissions is highly dependent upon the availability of data from FDR rather than reliance on ICAO databank assumptions for TIM and EI. Studies have shown that using FDR[87] to determine taxi fuel consumption illustrates lower engine thrust and the importance of the number of accelerations events (stop/start). In general fuel

[86] Zurich Airport (2017). Taxi emissions at Zurich Airport – calculation, analysis and opportunities. www.zurich-airport.com/~/media/flughafenzh/dokumente/das_unternehmen/laerm_politik_und_umwelt/taxi_study_zurichai report_20171207.pdf

[87] Khadilkar, H. and Balakrishan, H. (2012) Estimation of aircraft taxi fuel burn using flight data recorder archives. *Transportation Research Part D* 17 (7) 532-537.

flow fuel flow estimates using the ICAO method over predicted fuel burn by up to 35% compared to the FDRs. However, variations to taxi procedures will have marginal benefits for the overall noise contour of an airport.

Reduced engine taxi: Taxi operations with less than all engines operating is often known as single engine operation. Though for four engine aircraft the two inner engines may be turned on or off sooner or later. Single taxi operations are used by many airlines and at numerous airports. However, there appear to be few academic studies which seek quantify the fuel savings and impact on pollutant emissions from the use of reduced engine taxi procedures and which seek to quantify impact on PM emissions and secondary formation. However, industry is taking a lead and an analysis at Zurich Airport[86] provides a comprehensive analysis of the fuel savings and impact on pollutant emissions including NO_x and nvPM. Recent work which could have a significant bearing on the understanding of aircraft emissions on air quality in and around airports highlights the importance of secondary aerosols[88]. A reduction in engine idling thrust from circa 7% to 3% could lead to an increase in the formation of secondary organic aerosols by 30%.

9.9. Annex A.8 Future technological developments impacting on emissions

This section of the report provides a brief overview of likely technological developments which will have an impact upon emissions and will potentially factor in future trade-off/interdependency analysis. The emission reduction derived from step changes in technology and the availability of alternative drop-in fuels will deliver significant emission and subsequently impact benefits leading to improved air quality in and around airports.

The ACARE flight path 2050 targets are... "procedures available allow a 75% reduction in CO_2 emissions per passenger kilometer and a 90% reduction in NO_x emissions. The perceived noise emission of flying aircraft is reduced by 65%. These are relative to the capabilities of typical new aircraft in 2000". In addition, aircraft are expected to be emission free during taxi and the Europe will be a centre of excellence for sustainable fuel.

Aircraft engine emission improvements are created primarily through step change and through incremental technology insertions. WP6 will unpick the technological roadmap further and examine possible emission reductions. For the purposes of WP2 this brief introduction highlights that future developments will most likely be significantly more important than any marginal gains made through addressing trade-offs or interdependencies.

[88] The dominant source of airport aerosol is aircraft engine exhaust and is classified as either directly emitted primary aerosol or secondary aerosol. Primary aerosol from aircraft engines and contains mainly black carbon whereas secondary aerosol is formed by the oxidation of emitted precursor gases.

Engine: Technological developments to reduce emissions have historically been focussed on NO_x production. Specifically, OEMs have adopted two main strategies in combustor architecture design to address NOx production. These approaches are the Lean combustor and the Rich Burn-Quick Quench-Lean Burn (RQL) combustor. Lean combustor designs burn at a low fuel-air ratio to drive NO_x production down. The Lean technique allows for combustion at a lower temperature and the staging of piloted chambers and nozzles to adapt to each LTO cycle and reduce residence time.

RQL combustor designs begin by burning fuel in a rich environment, where the free O2 and N2 particles are scarce compared to fuel. Following that, bypass air is quickly mixed to quench the fuel-air ratio and shortcut the transition to a final lean combustion, essentially avoiding combustion at the stoichiometric ratio.

However, when a CAEP12 nvPM (mass and number) stringency limit is agreed then OEMs will be seeking to manage the interdependencies between NO_x, PM and VOC. With both Lean and RQL technology emissions of nvPM and VOC may increase or decrease (there may also be a trade-off between nvPM and VPM) across some operational procedures within the LTO. This may be an issue for OEMs particularly if the formation of secondary aerosols in the plume is considered.

Alternative drop in fuel: The connectivity between fuel chemistry and combustion exhaust emissions has long been established in sectors such as automotive. In recent years, the introduction of alternative into the aviation sector (ASTM D7566; DefStan 91-91) has similarly led to a growing body of evidence to suggest that the wider benefits of these engineered fuels can be realised in commercial operations. Furthermore, these benefits are not limited to the headline reduction in fossil CO_2 of up to 60%:

Classes of predominantly paraffinic fuels have been shown to greatly reduce the emission of nvPM, particularly in the idle and lower thrust range. Moreover, the near zero levels of fuel sulphur inevitably lead to significant reductions in emissions of vPM. Hence the potential to reduce the proportion of total PM from aircraft sources has been established, and the possible transference of these emission reductions to improvements in local air quality is credible.

In contrast, current research suggests that the perturbation in the acoustic signature from aircraft using alternative fuels is small to negligible, and any reduction in the emission of noise is unlikely to be discerned within impacted communities.

9.10. Annex A.9 Conclusion

This review has provided an overview of possible interdependencies or trade-offs between aircraft noise and exhaust emissions associated with operational procedures in the LTO. The study primarily confirms the view that noise and emissions are frequently considered independently and not in a holistic way.

Indeed, it appears only a few academic studies have sought to quantify the trade-offs though a number have provided a qualitative/hypothetical assessment. This reflects the approach of regulators who also set independent standards for noise and emissions. This approach and the increasingly stringent noise and emission standards have been successful in reducing the overall environmental impact of aviation. Given the regulatory separation it is of little surprise, therefore, that the recent peer review and accessible industry literature contains little evidence of a comprehensive noise/emission trade-off analysis.

Generally published studies which have examined the effect of changes to how aircraft operate in and around airports have focused on savings to CO_2 or NO_x. Only recently has PM been factored into the equation primarily through the application of FOA3 rather than the actual emission of nvPM (mass and number). There is also little evidence that existing work has considered the formation of secondary PM which could be an order of magnitude larger than the primary emission. This may have profound implications when considering operations with low thrust setting (taxi).

The existing literature is also relatively silent on examining any trade-offs or interdependencies between the impact of noise and emissions. Arguably, it is the impact of aircraft noise and emissions which is important and should be factored in to future trade-off/interdependency analysis. Though it is recognised that this is not a simple or straight forward task and may beyond the capability of many airports.

9.11. Annex A.10 Recommendations

The following recommendations have been set out to help guide the development of D2.3.3.

1. Scope11 methodology should be used to estimate the concentration of PM as a key in any trade-off or interdependency analysis.
2. Keep a watching brief on the development of new insights into primary emission of PM and precursors.
3. Consider how to factor environmental impact (nuisance vs air quality) into future analysis of interdependencies.
4. Consider how to layer into the interdependency debate health impacts. How do health outcomes differ between exposure to noise and emissions?
5. Obtain a better understanding of the potential emission benefits that may be derived from new technology and fuel formulation.

10. Annex B Airport review – operations – metrics and tools

10.1. Annex B.1 Stakeholders & Collaborative Environmental Management (CEM)

Stakeholders

In aircraft operations near airports one might observe that different stakeholders weigh operational and environmental aspects differently:

- For communities around airports limiting or decreasing the impact of both noise and exhaust emissions related to air quality (NOx and PM) is important.
- For airlines operational costs/revenues and sustainability goals are both on the agenda. Less fuel burn means economic savings and less CO2 emissions.
- For authorities/regulators it is important that airport and airline operations are safe, that impact on health and the environment is within the imposed limit values and that the airport contributes to the national, regional or local economy.
- For ANSP's a safe, efficient air operation is leading.
- The airport wishes to have a balanced operation in accommodating the airlines (air transport (growth)) and the needs of the community around the airports, working together with regulators and ANSP's, and - last but not least - serving their own interests in being a viable, responsible and responsive 'entity'.

Collaborative Environmental Management (CEM)

To find common solutions to the environmental challenges related to operations at and around airports, Eurocontrol[89] has developed the Collaborative Environmental Management (CEM) concept.

CEM promotes a collaborative approach between all the actors at an airport, so that they can find collective 'environment' solutions that take account of all the interdependencies between them and so that they can realise the maximum potential for the sustainable growth of the airport. CEM also helps the airport to have a robust and transparent dialogue with external stakeholders.[90]

The noise and emissions trade-offs topic is a good example to test the viability of this concept.

[89] CEM- Collaborative Environmental Management: https://www.eurocontrol.int/collaborative-environmental-management-cem

[90] https://www.eurocontrol.int/news/collaborative-approach-environmental-management

10.2. Annex B.2 Operations

Aircraft operations associated with trade-offs or interdependencies are well documented in industry and academic literature. As example Sustainable Aviation[91] provides a detailed overview of the Operational Inter-Dependencies regarding the noise, CO_2 and NOx (LAQ) impact in Departure, Arrival and Ground phase of flights (see tables B.1, B.2 and B.3).

Technique	Noise Impact	CO2 Impact	NOX (LAQ) Impact	Comments
Increasing take-off power	Reduces under flight-path, but footprint area can be increased	Slightly altered Note 1	NOX increases with power	Note 2. Adverse impact on engine maintenance costs
Reducing take-off flap setting	Reduces noise if lift-to-drag ratio improved - dependent on aircraft & runway characteristics	May be slightly reduced	Slightly changed, dependant on aircraft & runway characteristics	Note 2. Possible implications for tail strike under certain conditions
Reduce acceleration altitude	Noise increased close to airport, reduced further out	Reduced	Note 3	Note 4. Actual differences depend upon the difference in selected acceleration altitude versus standard airline practice.
Delayed flap retraction in the climb	Noise reduced close to airport, slight increase further out	Increased	Note 3	Note 4.
Increased cut-back altitude	Noise increased at some parts close to airport, reduced further out	Slightly reduced or increased, depending on flap retraction schedule.	Note 3	Note 4.
Reduce power, retract flaps, then accelerate	Reduced noise under flight-path, after normal acceleration point.	Increased	Note 3	Note 4. Aircraft in high-drag configuration with low power set may concern regulators.
Increase *VR*, *V2* and climb speeds	Noise slightly increased close to airport, reduced further out	Minimal change	May increase or decrease depending on take-off thrust setting method	Not applicable to some aircraft types and some operators. Depends upon take-off performance limitations
Increasing climb power settings	Noise increases after cutback closer to the airport, reduces further out	Slightly reduced	Note 3	Note 4. Adverse impact on engine maintenance costs
Novel Power Management (Managed Noise)	Reduced at specific points identified as sensitive for noise.	Dependant on procedure, aircraft and airport requirements.	Note 3	Note 4.Currently only feasible with latest aircraft such as A380, A350, B787

Table B.1 Departure (Sustainable Aviation 2017 Update, Appendix B)

[91] https://www.sustainableaviation.co.uk/wp-content/uploads/2018/06/FINAL__SA_InterDependencies_2017.pdf

Note 1: Although fuel flow is greater at the higher power setting, the time at that setting will be shorter, resulting in slight differences in overall fuel-burn that can be either positive or negative and will not be the same for all aircraft.

Note 2: Legal constraint: Noise Abatement Departure Procedures (*NADP*s) are not allowed below 800 ft (PANS-OPS/EU-OPS).

Note 3: Changes in NO_x emissions above 1000ft *aal* have negligible impact on local ground-level NO_x concentrations [ICAO, 2008].

Note 4: Will have an impact on flight path and speeds, so will need to keep ATC advised, and may affect adherence to Noise Preferential Routes with low level turns.

Generally speaking Table B.1 shows that for a number of Departure techniques noise level may decrease and emissions may increase and also that noise may both decrease and increase depending on the area considered near the airport.

Technique	Noise Impact	CO2 Impact	NOX (LAQ) Impact	Comments
Continuous Descent Operations (CDO)	Reduced	Reduced	Little or no difference	Note 5, Note 6 Procedures need to be set up. Greatest benefit will occur when initiated at higher altitudes with more advanced navigation equipment, though might impact airspace capacity.
Low Power/Low Drag (LPLD)	Reduced closer to the runway *threshold*	Reduced.	Slight reduction	Note 6, Note 7, Note 8 *ICAO*-stabilised approach criteria may also act as a constraint.
Steep Approach	Reduced overall, though there may be some changes in the geographical distribution of noise, due to different flap and landing-gear extension points	Reduced.	Note 9.	Note 7, Note 8 Legal constraint: Steep approach cannot be implemented solely for noise abatement purposes. [ICAO]. *LVP* considerations may also limit application.
Curved Approach	Reduced, though dependant on the distribution of local populations	Dependent on difference in track miles.	No difference below 1,000 ft *aal*	Note 5, Note 7 Procedures need to be set up, and more advanced navigation equipment will be required.
Displaced or Inset Threshold (Note 10)	Note 9	No difference	Note 9.	Note 6, Note 8

Table B.2 Arrival (Sustainable Aviation 2017 Update, Appendix C)

Note 5: Reductions arising from these techniques are achievable above the ILS capture altitude. Below ILS capture, there is no noise or emissions benefit relative to standard approach.

Note 6: Safety considerations might preclude reductions in flap setting if runway is short or wet/contaminated.

Note 7: May require specialist aircraft and/or ground equipment to be installed, as well as additional training for aircrews

Note 8: May result in increased use of reverse thrust, potentially eroding some of the benefits of the technique.

Note 9: Slight reduction in area impact, since low-level noise/emissions take place closer to (or within) the airport boundary

Note 10: Moving the threshold along the runway so that it is further within the airport boundary

Technique	Noise Impact	CO2 Impact	NOX (LAQ) Impact	Comments
Taxi-Out with engine(s) not operating	Reduced, though may be masked by higher power from operating engine(s) Note 11	Reduced	Reduced	Safety issues may limit the extent of deployment – i.e. not suitable for all flights in all conditions. Operational requirements may mean that the APU has to be running which will reduce the benefits. Use may in some cases conflict with airport efficiency considerations.
Taxi-in with engine(s) shut down	Reduced, though may be masked by higher power from operating engine(s) Note 11	Reduced	Reduced	Safety issues may limit the extent of deployment – i.e. not suitable for all flights in all conditions. Operational requirements may mean that the APU has to be running which will reduce the benefits.
E-Taxiing	Reduced Note 11	Reduced	Reduced	Trade-off between on-ground fuel-burn saving and in-air fuel-burn penalty due to system weight – best suited to short-to-medium range flights.
Towed taxiing	Reduced Note 11	Reduced	Reduced, though the type and/or technology standard of the aircraft tug will determine the extent of the reduction	Nose wheel leg strength, and taxiway congestion may be an issue at some airports – some aircraft may need specialist tugs. Instances of *FOD* will be reduced.

Table B.3 On Ground (Sustainable Aviation 2017 Update, Appendix D)

Note 11: In most cases, changes in noise levels beyond airport boundary are expected to be minimal, being masked by higher noise levels from aircraft in flight (arriving/departing)

The presented Arrival and Ground techniques almost always lead to win-win situations for noise and emissions. For take-off there are significant trade-offs possible. For descent and approach, operational choices can result in environmental benefits without any trade-offs.

10.3. Annex B.3 Airport case studies with interdependencies and trade-offs

Description of the airport case studies tackling interdependencies/trade-offs

The information presented in this sub-chapter is extracted from D2.5, which summarises the work conducted in ST2.3.1 (Balanced Approach implementation), as required by the description of ST2.3.3 on interdependencies.

10.3.1. Annex B.3.1 Heathrow

In 2017 London Heathrow Airport (LHR) served just under 476,000 annual aircraft movements, carrying approximately 78m passengers. Located 21km west of central London, the airport employs over 76,000 people - half of whom live in the surrounding five London Boroughs. The airport is operated by Heathrow Airport Holdings Ltd (HAHL) a consortium comprising 7 organizations. In July 2015, the airport was recommended by the Airports Commission that the airport be granted a third runway, so as to improve its operating capacity, and in June 2018 the UK cabinet signed off plans that had been approved by the Government's economic sub-committee. This highly contentious runway has the potential to add an additional 222,000 aircraft movements to the airport.

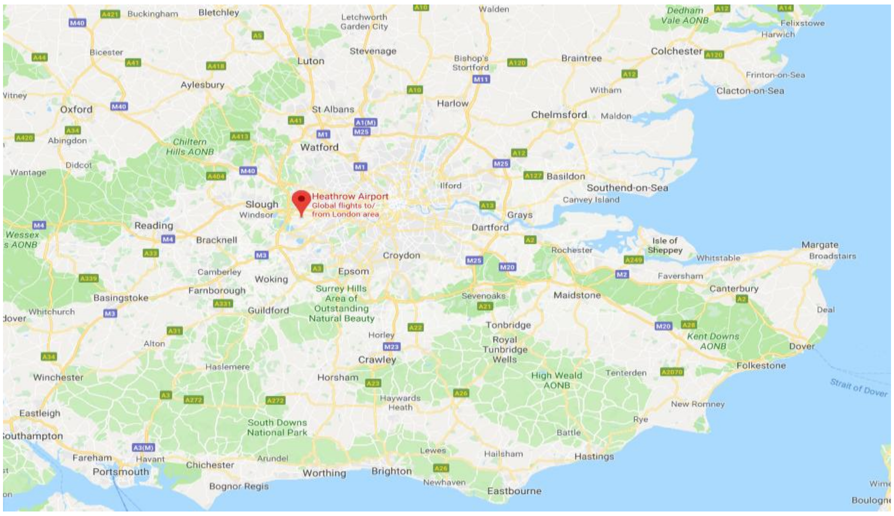


Figure B.1 Heathrow Airport geographical position

The continued development of Heathrow's approach to noise is visualized in figure B.2 below, taken from the airports 2018 document "Our Approach to Noise[92]".

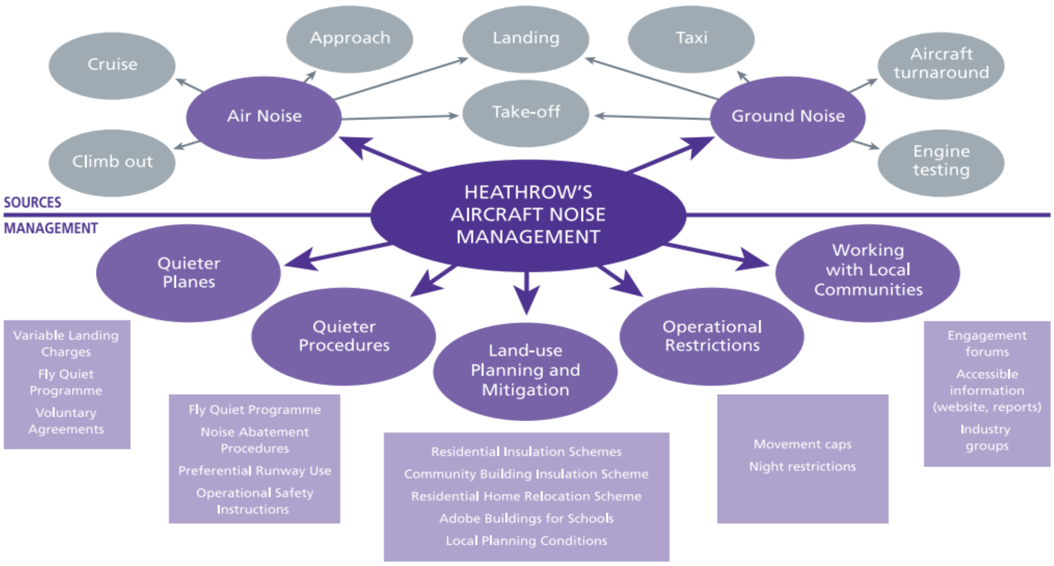


Figure B.2 Heathrow Airport's approach to noise management

92 https://www.heathrowconsultation.com/wp-content/uploads/2018/01/6746-Expansion-Noise-v11-KL.pdf

Heathrow airport has moved over time from noise monitoring to working to actively reduce noise impact, first through the implementation of noise related landing charges in the 1970s, but by the turn of the century including night flight restrictions, revised departure noise limits, voluntary daytime noise insulation schemes, flight track_improvements, and the 'pioneering' of the continuous descent approach.

Hence, the airport had been effectively engaging in the 4 Balanced Approach elements prior to its official implementation into EU legislation in 2002, as well as working closely with communities for many years. The airport Noise Action Plans also refer to ***the concept of interdependencies***, which refer to carbon emissions and air quality implications of the airport's operations. The reports state that operational controls need to be balanced. For example, they give the example of reducing thrust to lessen NOx emissions has the impact of increasing noise lightly for those under the same flightpath. *The airport has also been in a number of studies to help* ***investigate interdependencies in detail, and to quantify the most appropriate balance of these issues in specific situations***.

The airport also operates a 'Fly Quiet and Green Programme' which benchmarks aircraft in terms of noisiness. Results are published quarterly in a league table that enables good performing airlines and those who have been improved to be identified. For noise, airlines are ranked against 'noise quota per seat', Chapter certification, early or late movements (between 23:30 and 04:30), continuous descent approach violations, and compliance of flying 'noise preferential routes'.

Operational Procedures

Heathrow airspace is managed with the aim of reducing noise impact (considering interdependencies such as safety, carbon emissions and air quality), doing so by working with local communities to identify potential changes and their impacts. This includes a focus on providing respite to communities from early morning arrivals and on some departure routes. Heathrow defines three broad categories that aim to make operations 'quieter':

- Making individual aircraft quieter (i.e. by changing thrust settings during take-off and approach).
- Making aircraft higher (i.e. when flying over communities).
- Managing aircraft routes differently (to avoid populated areas).

The airport works with the UK Civil Aviation Authority, NATS and airlines to explore and employ smarter operating procedures that fulfil these objectives, with measures reported by the airport including:

- Aircraft are required to be at a height of not less than 1000 ft aal (above aerodrome level) at 6.5 km from the start of roll, as measured along the departure track of that aircraft.
- There are noise limits applied at fixed noise monitors for departing aircraft and fines are enforced for breaches.

- Aircraft departing from Heathrow are required to follow specific paths called **noise preferential routes (NPRs)** up to an altitude of 4000 ft.
- **4% minimum climb gradient** between 1000 and 4000 ft.
- Westerly preference on departures to reduce the number of aircraft flying over London.
- ***Continuous Descent Approaches to reduce noise emissions*** for communities under arriving aircraft en-route to the final approach.
- Limiting use of reverse thrust at night by arrivals.
- Runway alternation/rotation: During westerly operations, wherever practicable the arrival runway is alternated according to a published schedule.
- Joining point rules: Between given times for aircraft approaching specific runways and using the Instrument Landing System (ILS) the aircraft shall not descend on the glide path below a given altitude before being established on the localizer, nor thereafter fly below the glide path.
- Slightly steeper approaches of 3.2 degrees compared to the standard 3 degrees.

Thus, the approach to operation at Heathrow airport gives several indications of tackling interdependencies. One such example is the Steeper departure Trial:

Case Study (Operational Procedures): Heathrow DET09 Steeper Departure Trial

The intention of introducing this case study is to investigate the processes that underpin best practice at London Heathrow. In so doing providing context surrounding the actions undertaken, and decisions made in reducing noise impact. To recap the process described in the methodology, this process takes the airport from an initial awareness of a noise problem or requirement for change, through to the design of interventions, the selection of an appropriate intervention option, and its subsequent implementation, and post-implementation evaluation.

Aircraft leaving Heathrow are required to be at an altitude of at least 1000ft, 6.5Km after the start of their take-off roll (UK AIP EGLL AD 2.21). From this point, they are required to maintain a gradient of at least 4% until reaching 4000ft AAL. This is not part of the standard Instrument Flight Procedure (IFD), rather it is something implemented by the airport for noise abatement purposes to ensure that noise is progressively reduced along the ground (see figure B.3).

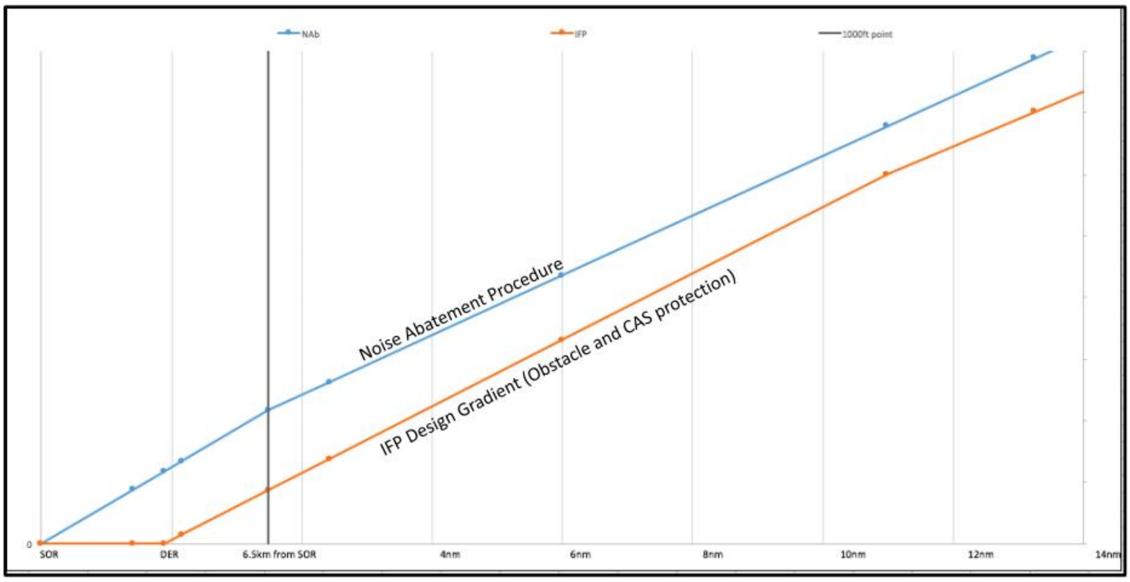


Figure B.3 Illustrating how the airport's noise abatement procedure results in aircraft being higher than they would be following the IFP design gradient

Although this gradient has existed for many decades, technology to monitor compliance has only recently existed, with Heathrow only collecting and reporting data since January 2017, as part of the airports regular flight performance reporting. The overall compliance rate in 2017 was 99.8%, with the majority of compliance failures being due to A380 operations.

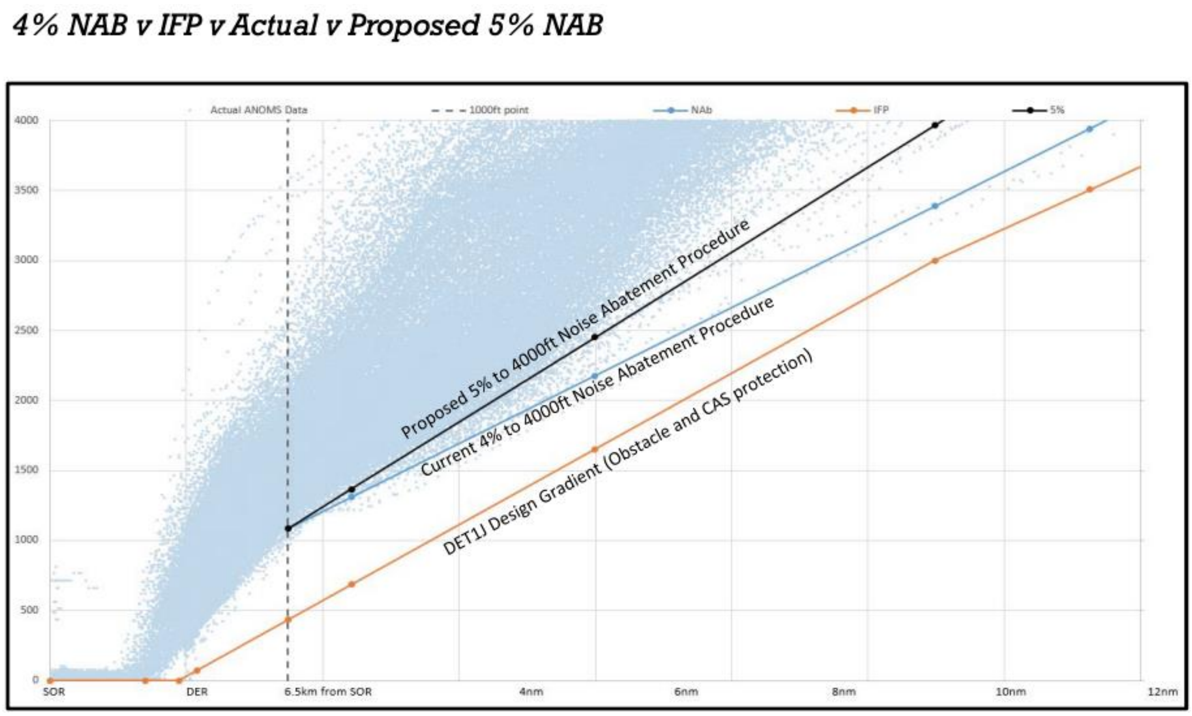


Figure B.4 Illustrating the results of the analysis, showing how the vast majority of flights were well in exceedance of the 4% and 5% departure gradients.

The report was based data collected from noise monitoring terminals in the area, and for the wider geographical area, on the Heathrow INM model. The airport uses the INM model as its primary tool for noise modelling, however, they acknowledged that modelling is complementary to monitoring and should not be used exclusively. For this reason, data was also assessed from the airports existing noise monitors in the area.

In terms of **interdependencies,** the CAA made it clear that any changes made to the departure profile would not be allowed to result in an increase in emissions below 1000ft (hence another reason why the 5% departure profile was selected – steeper profiles would not have been in compliance with this). Safety was also a concern as it is the main priority underpinning all operations at Heathrow. A joint risk assessment was held with airlines and NATS to determine any other operational impacts. This determined that a steeper departure would have affected the flow of aircraft leaving the airport as steeper climbing results in slower speeds. Moreover, aircraft that would not be able to meet steeper profiles would need accounting for and would also cause significant logistical issues. Steeper climbs also meant that aircraft would reach 600ft more quickly (the restriction altitude for Heathrow SIDs). The airport had to consider how this would interact with other airports' routes and how that is affecting continuous climb operations.

Rather than go immediately ahead with implementing the new departure gradient as part of their SID, Heathrow decided to first trial the new procedure. This decision was made based on an **awareness that changes to a flight path would have implications in terms of interdependencies** – namely, fuel burn, emissions, safety, and changes to the distribution of noise along the ground based on the fact that changes to operational procedures do not reduce noise, but rather move it into different places. The suspicion here would be that whilst a steeper departure profile would reduce noise exposure in the Teddington community, it would increase noise closer to the runway, and along the side lines of the flight path. This is clear evidence of a high-level of knowledge about noise distribution and the consideration of interdependencies in the noise management process.

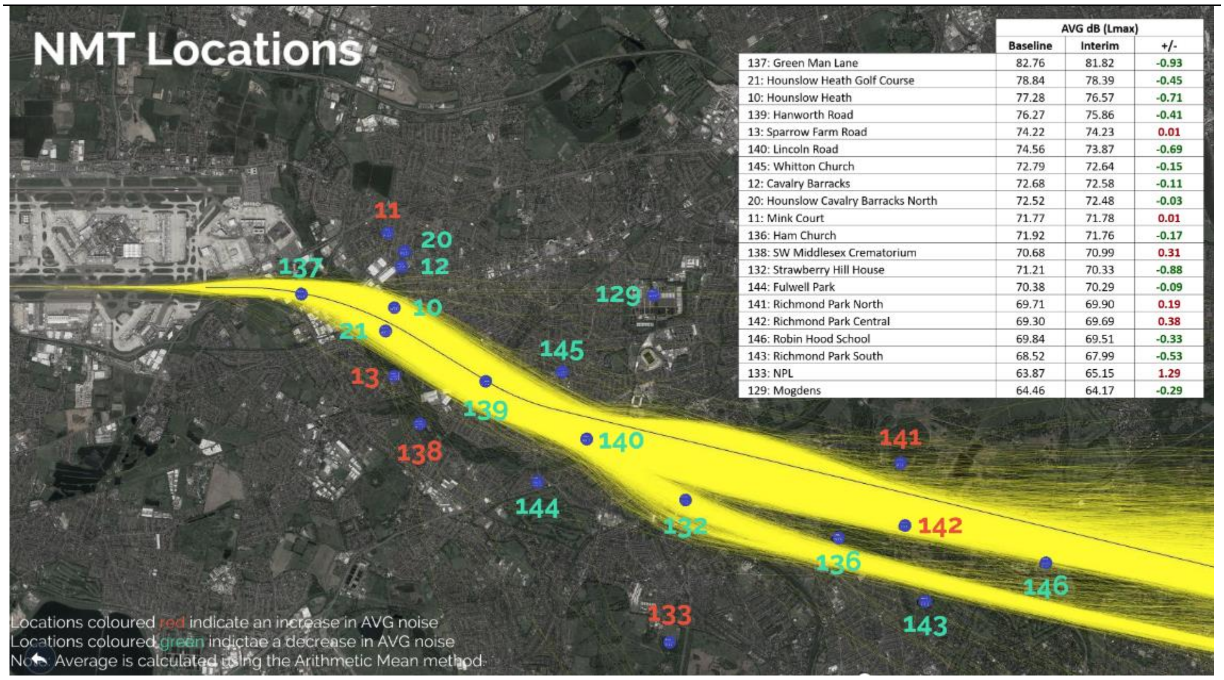


Figure B.5 Location of Noise Monitoring Terminals and differences in AVG dB (max) between the baseline period and interim trial results

Following the above described processes, modelling and regulatory procedures have ensured a safe and successful trial. Success was determined through the array of class-one microphones and monitoring stations deployed around the airport and the subsequent analysis of collected data.

In conclusion, being the first such study of its kind in the world, the Detling Steeper Departure Trails can be seen as a leading example of an operational procedure intervention, a good example to assess interdependencies between noise and (carbon) emissions.

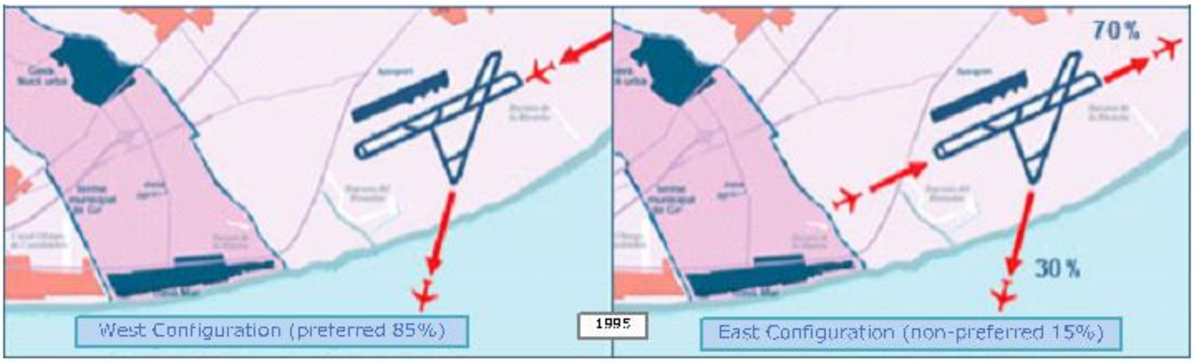
10.3.2. Annex B.3.2 Barcelona

In 2018 Barcelona airport saw the record figure of 50,172,457 passengers, 6.1% more than the previous year, as well as 335,651 operations and 172,940 tonnes of cargo. The airport is open 24 hours a day and can handle 90 operations/hour (78 slots/hour currently). The airport can process 55 million passengers/year (Terminal T1: 33 million pax + Terminal T2: 22 million pax). A new Masterplan is needed for this airport in these moments, new challenges for all stakeholders.

It is the 7th busiest airport in Europe and 17th in the world. Located in "El Prat de Llobregat", 15 km southwest of central Barcelona, the airport is the main driver of the Catalonian economy.

The airport is operated by AENA, the world's leading airport operator by number of passengers. AENA is a state-owned company that manages general interest airports (46) and two heliports in Spain. Through its subsidiary company Aena Internacional it also participates in the management of 17 airports abroad.

The airport implemented a basic operations configuration based on landings on runway 25 and take-offs on runway 20, which made it possible to increase the capacity of the airfield progressively from 38 operations per hour to 50.

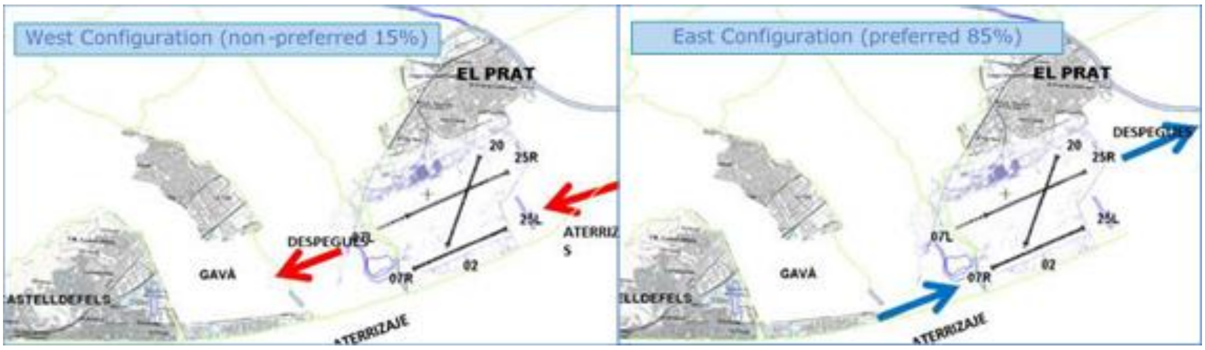


From 1995, Barcelona-El Prat Airport was consolidated as one of the top 15 airports in Europe and one of the top 50 in the world.

In 1999, the Ministry of Public Works approved the Master Plan for Barcelona-El Prat Airport, formally implementing the Barcelona Plan, the third great transformation operation of the airfield was inaugurated in September 2004 and brought the third runway, parallel to the main runway, into service.

This new infrastructure is equipped with the maximum category runway lighting facilities (ILS Category II/III systems in each departure point). This enables its use in both directions and in foggy conditions. Runway 07L-25R has also been lengthened to 3,743 meters and widened to 60 meters.

The construction and introduction of the third runway in September 2004 and the extension to the primary runway were decisive steps to increase the airport's capacity to reach 90 operations per hour.



The whole project of the new Master Plan was approved, and got an **Environmental Impact Statement** as the result of a complex and participatory process in 2002 (lengthy discussions with the territory to preserve certain sites of Community Importance).

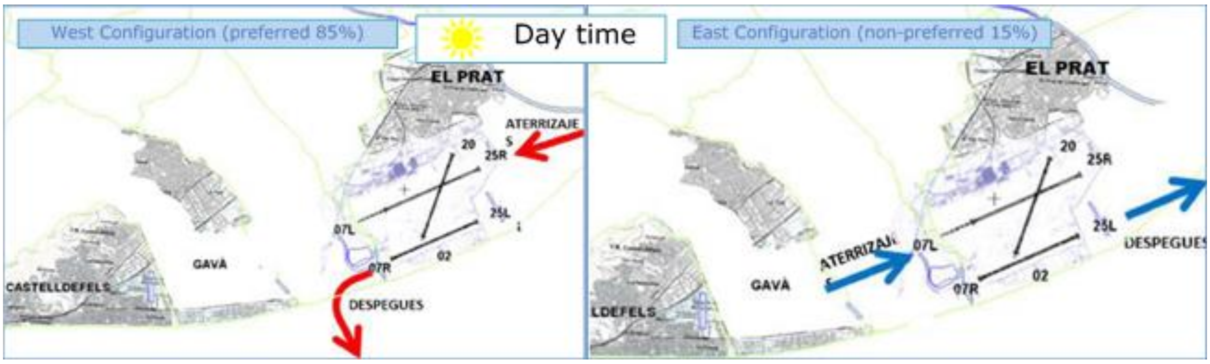
Barcelona Operational Procedure Case: Switching the role of each runway during the day (the ones that would be used for take offs, should be used for landings and vice versa), and new flight configuration during the night.

Barcelona airport was an infrastructure close to the sea and therefore didn’t use to have significant noise problems. The planes could take off or land using tracks over the sea or over the industrial area of Barcelona to the East. Only Western areas like Castelldefels that had experience with airport noise were used to and were aware of the problem.

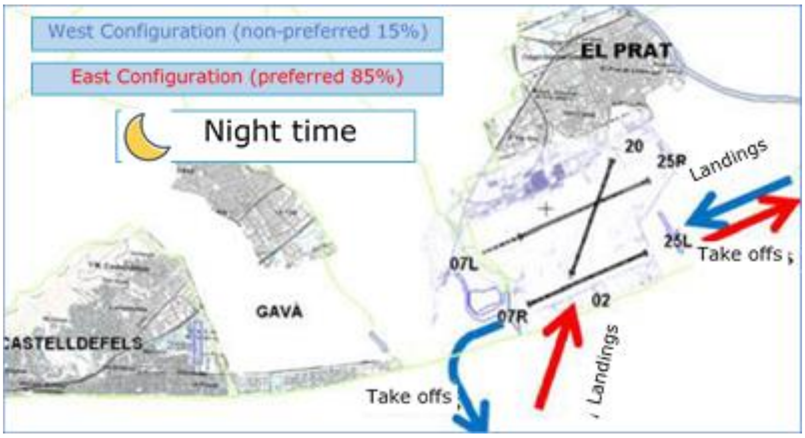
The main problem was the noise impact due to a non-preferred operation configuration. There were people really affected by "normal" airport noise in less frequent flight paths (non-preferred configurations). There are non-preferred tracks of use of each airport but still within “normal” operation. Most airports operate with a preferred configuration for take offs and landings (usual tracks and runway ends for departures and landings most of the time throughout a year). Depending on the orientation and intensity of the wind, it is sometimes necessary to change to an alternative configuration (normally this alternative configuration involves switching the roles of the runways, in other words the ones used for take offs are used for landings and vice versa) in which aircrafts use tracks that are not as common but perfectly well-known and "normal".

The Solution

Switching the role of each runway during the day: The longest runway should be used for departures, and the shortest for landings (for safety reasons). The GTTR studied switching the role using the shortest for take-off and the longest for landings and some take-offs that required more length for take-off (depending of the kind of aircraft).



Night configuration change: Avoided the demolition of the previous cross runway (02-20) and used it during night periods and East configuration with less capacity. Permanently limited the night capacity in Barcelona airport for the West configuration during the night.



When speaking about operational measures, **technical/constructive studies** (radio interference, new runway exit, new access to apron, and so on), **operational studies** (air traffic controller point of view), **capacity studies** (in the air and on the ground) and **environmental/sustainability studies** are required. The technicians had to assess cost/benefit of each option from all perspectives (safety, sustainability, capacity, budget, time frame…).

In this case, from an environmental/sustainability point of view there were:

1. Emissions study: It was a taxi time study associated with capacity ground studies for each option. There was an optimization of it.
2. Noise study: There were three new options to be evaluated against a reference option. Then the study had for each option and for the reference:
    - Daily indicators (Lday, Levening, and Lnight) with people and areas affected (from 75dB till 40dB). It is worth mentioning that all the calculations were done for each configuration (West and East) and

with different fleets, tracks, % of use, and so on, per each period of time (night/day/evening).
- Number of overflights in different points of populated areas and an average of SEL and LAmax in those points. Moreover, the hardest part of the work was taking some working hypotheses and repeat all the calculations for the future horizons 2010 and 2025 like for example:

Operational procedures

Noise abatement flight procedures

- Continuous Descent Operations (CDO), referred to in the past as Continuous Descent Arrival or Approach (CDA); during night hours (between 23:00-07:00), arrival procedures in continuous descent (CDA) are authorized for noise abatement reasons. This procedure avoids the stage flight segments that occur during a conventional landing and has a lower noise impact as well as reduction of fuel and emissions.
- Noise Abatement Departure Procedures (NADP); Published in the AIP and must be followed by all aircrafts, except for safety reasons or air traffic control (ATC) instructions:
    - Take off (RWY 25L): in order to avoid excessive noises at the runway center line extension, the initial turn prescribed in the standard instrument departure (SID) shall begin no later than reaching 500 ft. altitude.
    - Aircraft must follow the nominal trajectory of SID until they have reached 6000 ft., unless they are over the sea, above 3500 ft, in ascent and moving away from the coastline or at more than three nautical miles from the coast and in parallel to it.
- Modified approach angles, staggered, or displaced landing thresholds; some heads of runway have a displaced threshold to allow an increase of the altitude of the flights over the surrounding areas of the airport.
- Low power/low drag approach profiles; According to each aircraft manual for SIDs 25R
- Minimum use of reverse thrust after landing: Reverse use restrictions during night time hours.

The airport has clear opportunities to investigate interdependencies, topic to be developed in T2.5 on airport exemplification case-studies.

10.3.3. Annex B.3.3 Helsinki

Helsinki airport was originally built for the Summer Olympics in 1952. Meanwhile, approximately 1500 companies operate at the airport providing 25000 jobs. Helsinki airport became the largest airport in Finland and the fourth busiest airport in the Nordic countries. About 90% of Finland's international air traffic passes through Helsinki Airport. In 2018 approximately 21 million passengers were handled, including almost 18 million international passengers and 3 million domestic passengers. On average, the airport handles around 350 departures a day. Two terminals include a total of 29 gates with jet bridges and 80 remote aircraft parking stands.

The airport makes use of three runways. An overview of the three runways is shown in figure B.6.

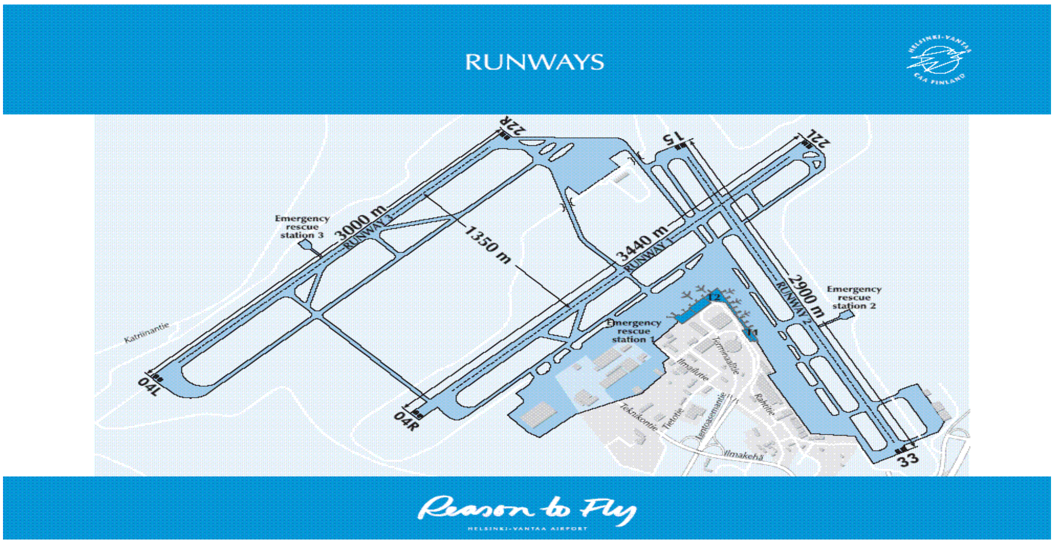


Figure B.6 Map showing the three runways used at Helsinki Airport

Review of NAPs and previous Balanced Approach interventions

In 2015 Finnish Transport Safety Agency, as the competent authority in accordance with the Directive 2002/30/EC, decided on noise-related operating restrictions at Helsinki Airport. Operating restrictions had been requested by an application submitted on the basis of the environmental permit requirement. In its decision Finnish Transport Safety Agency rejected to impose any noise-related operating restrictions at Helsinki Airport as it could not find any ground for them for the time being. The process involved establishment of the noise management objective for the airport and none of the proposed operational restrictions was found necessary for achieving the objective.

Previous BA interventions include **CDO implementation and continuous monitoring of the performance,** NADP1 implementation for runway 22L departures, departure route design minimizing the noise impact to residential areas and noise level restrictions on certain departure routes. In 2017 effective noise abatement strategies for high-weight aircraft were applied in the same way as for low-weight aircrafts. The regulations are in line with the International Civil Aviation Organization's (ICAO) recommendations (Chapter 14).

The departure tracks have been fine-tuned according to the geography and location of suburbs. This has been stepwise implemented during the past 15 years and is meanwhile well optimized. Finavia maintains effective cooperation with Vantaa's local government, which has led to a consensus forming on route-planning and runway use. The runway usage preference principle includes approximately 20 different combinations. The primarily preferred runway for landings is runway 2 (15) from the northwest.

Identification of any trends and overarching processes and internal systems that underpin BA implementation

A noise area forecast has been included in the Helsinki Region Land-Use Masterplan defining housing restrictions to noise areas. **CEM working arrangement** promotes active co-operation of the major airlines and ANSP to find operationally feasible solutions to **further improve arrival and departure procedures supporting the noise and emissions management**. Noise charges and other economic incentives were implemented to encourage avoiding night time operations and supporting the use of quieter aircraft types.

Introduction to the intervention

Implementing an increased amount of departures at the runway RWY-22L was complex and brought several concerns. One concern was that using the runway RWY-22L more intensively causes that more air traffic will fly over noise sensitive residential areas. Therefore the **noise level based departure procedure** (by ICAO) Noise Abatement Departure Procedure (**NADP1**) was introduced to prevent more intensive noise exposure for the residents. This implies that the airplanes climb higher with constant speed before acceleration is applied. This means that airplanes are flying slower but with higher altitude. The result is a lower noise level due to a higher flight altitude. The altitude difference between NADP1 and Finavia's ("Baseline") regular procedure is schematically sketched in figure B.7.

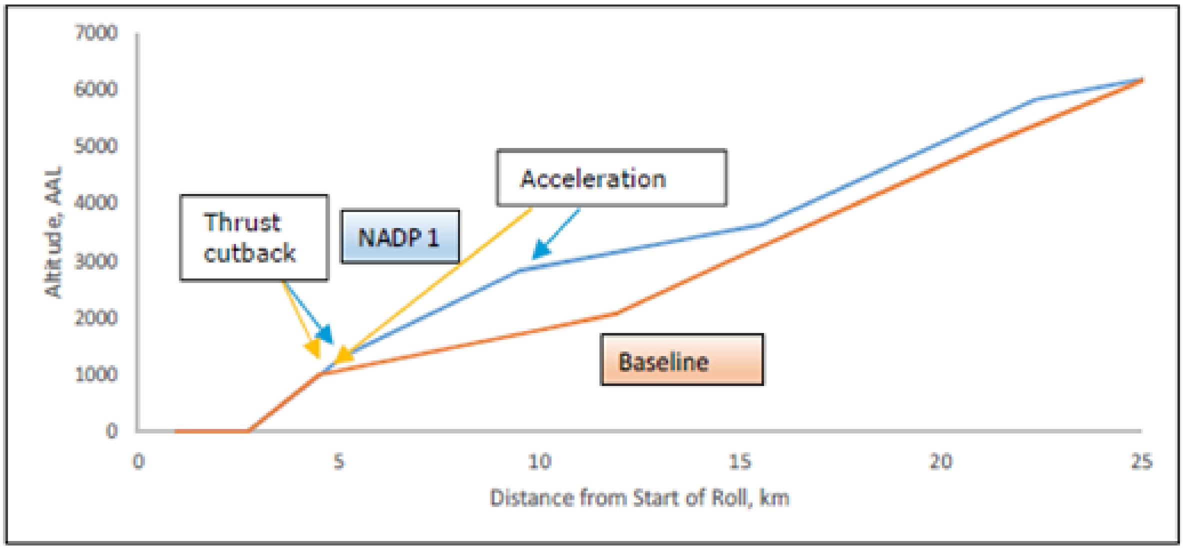


Figure B.7 The NADP1 procedure enabled a reduction of the noise level due to higher flight altitude and longer noise attenuation distances

Exploration the processes behind the case

a. Identification of the 'need'

The departure demand at Helsinki Airport increased during the last years. It was foreseen that the usage of the primary departure runway RWY-22R would reach its limits especially during the afternoon peak hours between 4 pm and 6 pm. Figure B.8 shows the most typical runway configurations at Helsinki Airport.

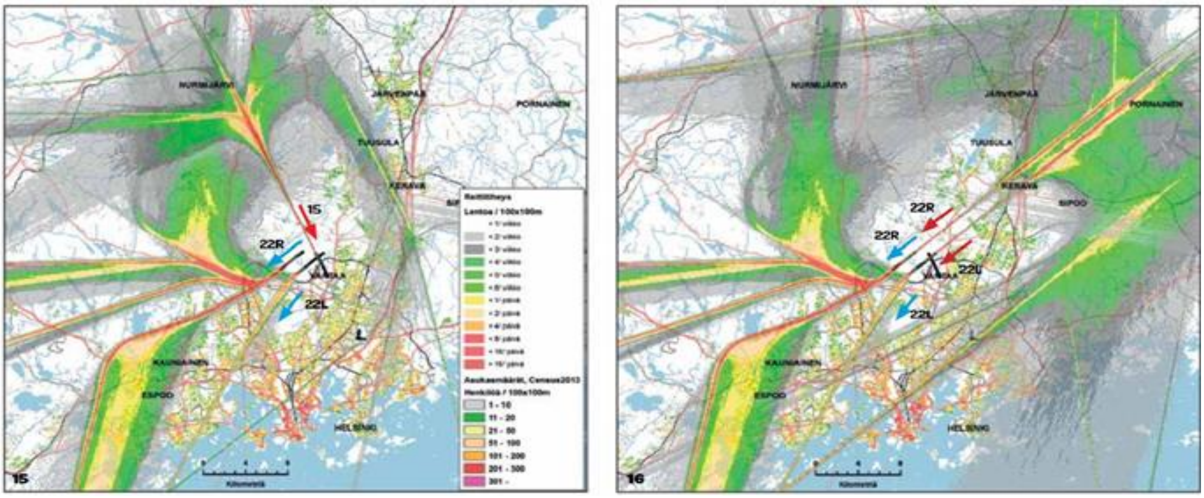


Figure B.8 Typical runway configurations at Helsinki Airport

An additional departure runway was required to handle the increased capacity of aircraft departures. One possible solution to increase the departure capacity was to use runway RWY-22L more intensively within the already implemented noise restrictions. Until April 2018 only one exit point (DOBAN) was used for the traffic to the south. Increased airplane traffic from RWY 22L that fulfilled the security requirements was enabled by splitting the DOBAN exit point into two separate exit points (KOIVU and VALOX), as shown in figure B.9.

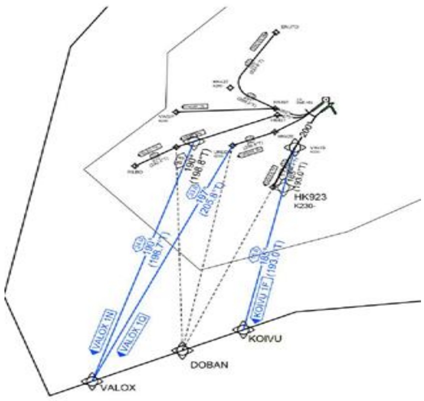


Figure B.9 Splitting the DOBAN exit point into the two separate exit points VALOX and KOIVU

b. The design of options

There was only one option to increase the flight capacity and that was using the runway RWY-22L. The NADP1 departure procedure was chosen at it appeared as the best solution for the populated areas.

c. c. The selection of the intervention

It was expected that the runway RWY 22L would be used more intensively in the future due to the increased air traffic demands. The Integrated Noise Model (INM) was used to calculate the estimated noise abatement for the usage of runway RWY 22L. A flight profile was created for the changed departure procedure. The **estimated noise levels for departures** using runway RWY 22L were compared with the estimated noise levels for the NADP1 departure procedure. A reduction in maximum noise levels (Lmax) was expected based on the calculations. Measurements proved that the application of the NADP1 departure procedure resulted in a reduction of the Lmax levels of approximately 3 dB. Summing up, the results for decision making **were less noise exposure and emissions,** less taxi time and air times.

Implementation

The airspace was changed by replacing the exit point DOBAN with two new exit points KOIVU and VALOX. In the same context, the Standard Instrument Departure (SID) route was adjusted to better avoid certain residential areas. The traffic flows are further managed by Estonian Air Navigation Service Provider (ANSP) by using the Route Availability Document (RAD). The airspace changes were planned and implemented in cooperation between ANS Finland (Finnish ANSP), EANS (Estonian ANSP) and Finavia. The RAD was updated by Estonian ANSP as the traffic flows towards south proceed to Estonian airspace after leaving the Terminal Maneuvering Area (TMA). The gradual traffic increase from RWY 22L was enabled by splitting the DOBAN exit point to KOIVU and VALOX points, as shown in figure B.9.

Post-Implementation evaluation

A post-implementation evaluation was not as such carried out. The comparison of multiple track flight departure profiles between Finavia’s regular used departure procedure and NADP1 in practice is shown in figure B.10. For NADP1, the aircraft is required to climb with constant speed to a higher altitude before acceleration (green circle) as compared to Finavia’s regular procedure (red circle). Reduced noise levels were enabled because the attenuation distance is longer for an aircraft flying at higher altitude.

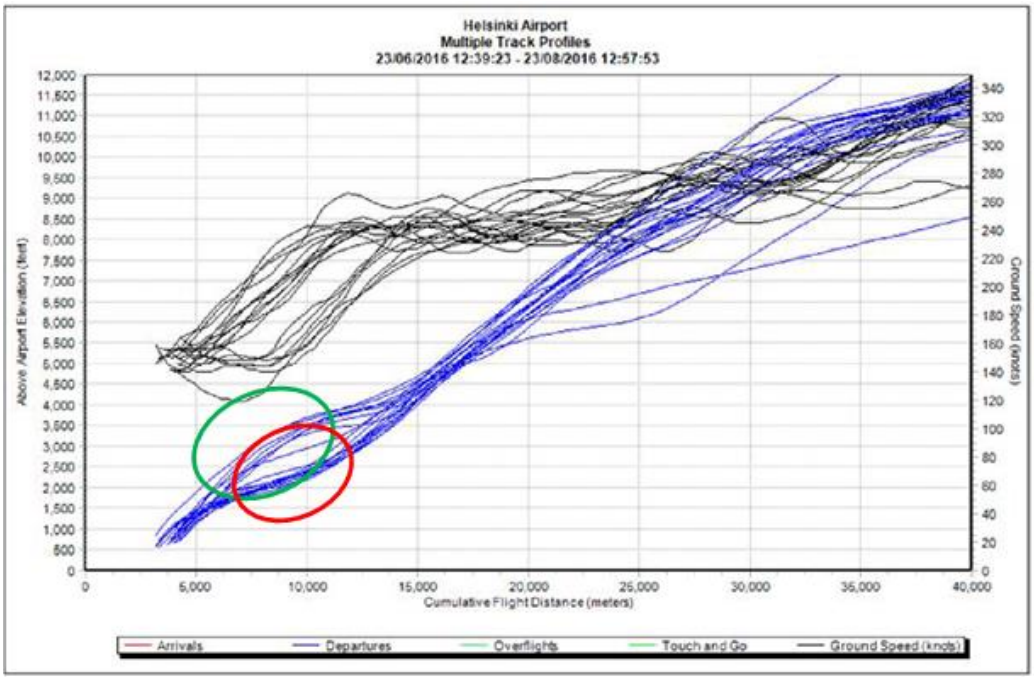


Figure B.10 Departure profile comparison between commonly used departure procedure and NADP1

Summary (of the whole airport case)

Departures were split up between RWY-22L and RWY-22R. This lead to fuel, time and emission savings, due to shorter taxi and flight route distances. The safety and capacity situation at Helsinki Airport was improved due to the divided traffic flow. The noise exposure was reduced by **applying the NADP1 departure procedure**. The greatest difficulty was the actual implementation of the changed operational procedure. The avionics data houses did not recognize the changes at the time that the implementation became applicable. The consequence was that the implementation of cockpit charts took extra time and effort. Finavia implemented a note into their flight preparation software to specify departures from the RWY 22L runway. The overall perception of the benefit of the intervention was positive and for the airport and the airlines worth the effort. There was only a small number of noise related complaints from the nearby residential community. The increased number of flight operations has not significantly increased the annoyance of air traffic noise.

In conclusion, the Helsinki case-study is a good opportunity to **assess noise and emissions interdependencies, considering the change in operations**: departures were split up between RWY-22L and RWY-22R. The willingness of the Airport management to engage further with interdependencies will be explored further in T2.5 on airport exemplification case-study.

10.3.4. Annex B.3.4 Schiphol

Amsterdam Schiphol Airport is the main international airport of the Netherlands and located 9 kilometers southwest of Amsterdam. With 71 million passengers in 2018 travelled from, to or via Amsterdam Airport Schiphol it is the third busiest airport of Europe in terms of passenger volume. Schiphol Airport ranks as the world’s fifth busiest airport in terms of international passenger traffic and the world's sixteenth busiest for cargo tonnage. The Schiphol Airport passengers increased by 4% in 2018 as a result of an increased number of aircraft movements. The terminal infrastructure consists of one-terminal concept that includes three large departure halls serving local airlines and as a European hub. Schiphol Airport has six runways, covering a total area of 2.79 ha land. The runway use at Schiphol Airport is shown in figure B.11. The red colored flight tracks indicate departures while the blue colored flight tracks indicate take-offs. Schiphol is mainly approached from the North Sea and Flevoland, which is an artificial, low populated island.

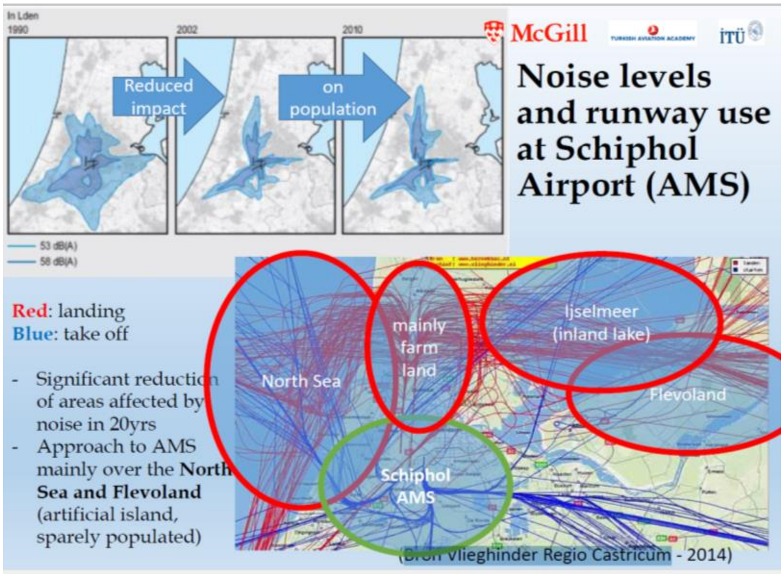


Figure B.11 Runway use at Schiphol Airport indicating flight tracks for departures (red color) and landings (blue color)

Interdependencies and the Balanced Approach

In the Aeronautical Information Publication (AIP) Netherlands are details of regulations, procedures and other information pertinent to flying aircraft described. Currently **applied noise and emissions restrictions** at Amsterdam Schiphol Airport (AMS) are included in EHAM AD 2.21 under noise abatement procedures. The AIP Netherlands includes departure and arrival procedures that have proved to be highly efficient in respect of noise abatement in the vicinity of Schiphol Airport. Deviations from the procedures are permitted for safety reasons. The noise *abatement procedures* are included in table B.4.

Procedure	Explanation

Take-off and climb procedure	National abatement take-off and climb procedure NADP2 recommended for all jet aircrafts departures. If for operational reasons compliance with the recommended procedure is not possible, NADP1 may be used.
Minimum noise routing	Standard instrument departure routes aiming avoid residential areas as much as possible.
Reduced flaps	Reduced flaps landing procedure is recommended
ILS available	Minimum flaps setting with landing gear retracted
Non precision approach and visual approach	Following descent path using a minimum flap setting with landing gear retracted not lower than 5.2% (3.0 degrees), selecting gear down after passing 2000 ft AMSL and postponing minimum certified landing flap setting until passing 1200 ft AMSL.
Use of runways	a) As landing runway: 06, 18R, 36R, 18C, 36C, 27. b) As departure runway: 36L, 24, 36C, 18L, 18C, 09

Table B.4 Noise abatement procedures applied in the vicinity of Schiphol

Further noise restrictions include engine run-up, controlled APU (ground power units), operating quota in effect and a preferential runway system.

Introduction to the case study optimization of start procedures

Noise abatement operational procedures are applied to provide noise relief to communities around airports from both arriving and departing aircraft. Two specific noise abatement departure procedures (NADP's) were developed to mitigate air traffic noise. The ***NADP-1 departure procedure*** is most effective in confining the noise impact within a small area around the airport. NADP-2 has a distant cross-over point to become quieter than **NADP-1 and is most effective to reduce fuel consumption.**

The differences between NADP1 and NADP2 with respect to the ground and flight speed and the lateral noise exposure is illustrated in figure B.12 below. The noise exposure is shorter due to a higher ground speed when NADP2 is used compared to NADP1 (see point 1 in figure B.12). For the NADP2 departure procedure the flight altitude is lower, which results in a reduction of the lateral noise exposure (see point 2 in figure B.12).

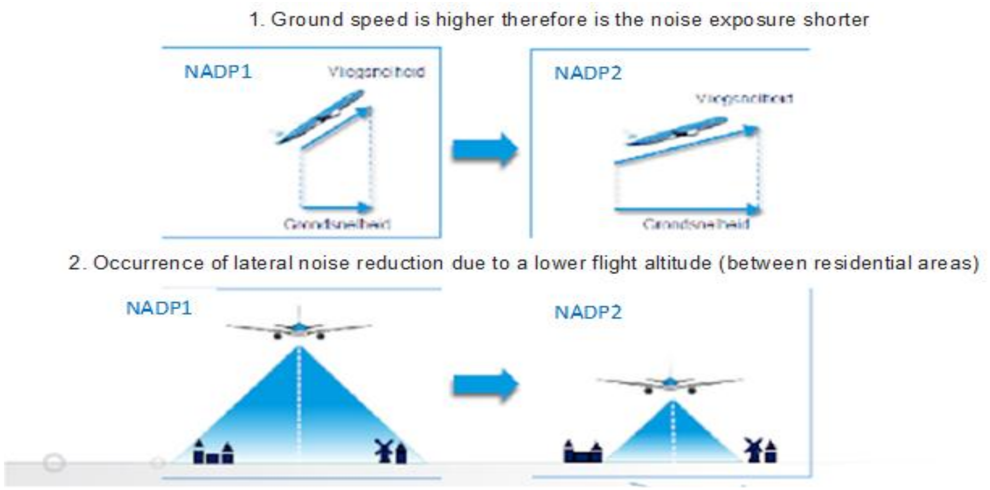


Figure B.12 Comparison of the ground speed and the lateral noise exposure between NADP1 and NADP2

The NADP2 departure procedure leads to a reduction in noise exposure due to a shorter fly over event and a smaller lateral area of exposure, compared to NADP1. The noise abatement departure procedure included a choice between thrust cutback altitude and acceleration altitude

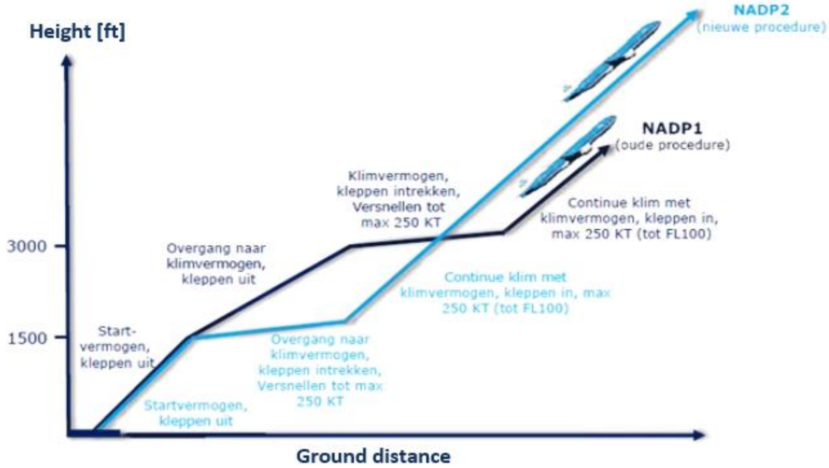


Figure B.13 Illustration of the climb heights between NADP1 and NADP2

The NADP2 procedure starts with a steeper climb where the acceleration required for flaps and slats retraction starts at 1500 ft.

The selection of the intervention

Operations based results, meaning **fuel savings, were used for decision making**. The effect within the noise contours was beneficial too. Hence, both were overall positive and therefore the decision was to recommend this procedure to all airlines. The noise effects were assessed based on the legal criteria for Lden and the locally established dose response relationship. Adopting the departure procedures from NADP1 to NADP2 was for Schiphol more a change in an operational procedure than a decision. That is the reason why the communities were informed ahead of time before the departure procedures were changed but they were not directly involved in the decision making process.

Actual noise and fuel consumption measurements

The noise monitoring system (NOMOS) of the Amsterdam Airport Schiphol was used to determine real, measured sound levels of the alternative NADP2 departure procedure. NOMOS consists of a network with more than 25 noise monitoring terminals located in residential areas around Schiphol Airport. Not all 25 measurement terminals were required. The tested runway and route combination together with the relevant NOMOS measurement stations.

In practice is it very difficult to test two departure procedures under the exact same conditions. An experiment was carried out to determine the isolated effect of the NADP2 departure procedure. A number of pairwise comparisons of acoustic measurements between an experimental group of airplanes and multiple test groups were applied.

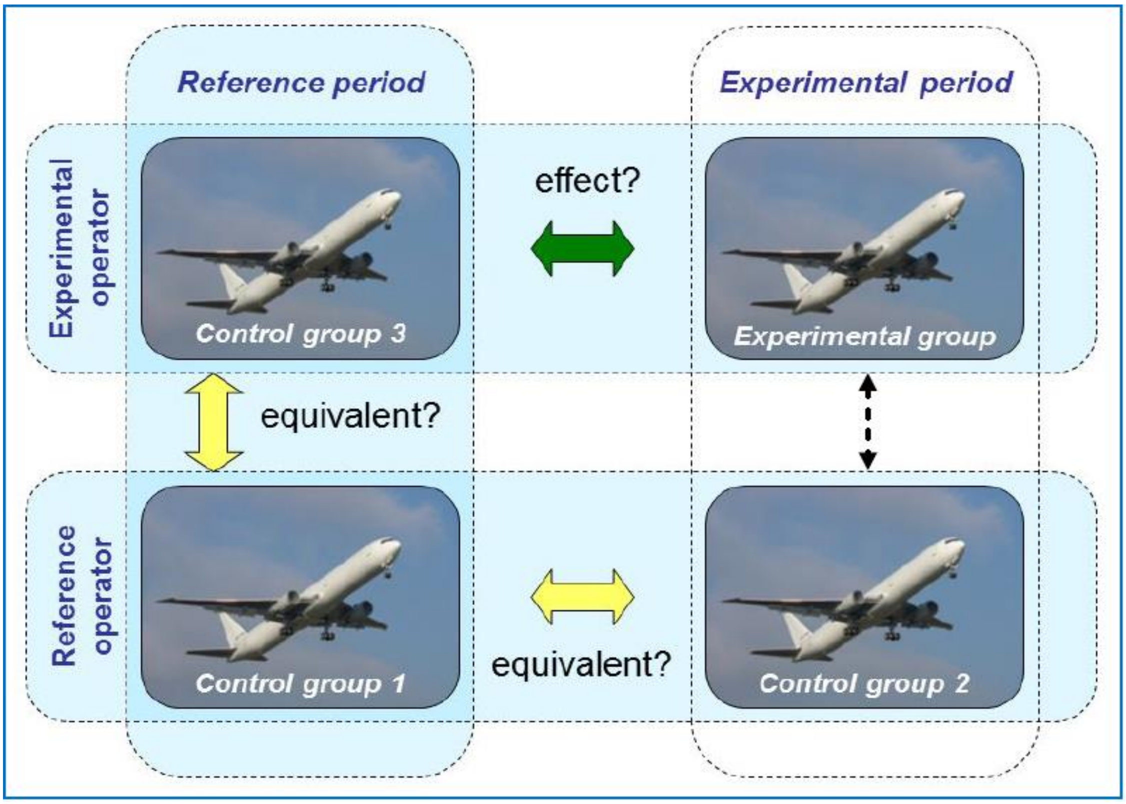


Figure B.14 Schematic presentation of the experimental design

The measurements from the experimental group were compared with three control groups. The likelihood of any difference in noise levels between the experimental group and the control groups was tested using hypothesis testing. The scheme of the experimental design is shown in figure B.14. The relevant comparisons between the experimental and the control group are indicated by green and yellow arrows. The applied pairwise comparisons can provide a qualitative judgment about the likelihood of the effects of the alternative NADP2 departure procedure. However, the influence from external and airline dependent factors cannot completely be eliminated.

Interdependencies

In terms of operational procedures the **priority was fuel consumption**. If changing the departure procedure would have been framed as noise mitigation measure the whole project would have been treated differently and we would have been less independent. The question is at what point is it smart and necessary to involve the local community? Are interdependencies really a matter that the local communities should decide about? It is due to the high amount of critics very important to be careful about how a message is presented and who it is presented to. Schiphol Airport tries to balance everybody’s interests in the best possible way, which also applies to for this project.

The benefits assessments for NADP's procedures are complex and may require detailed modelling in order to be well understood. **The results confirmed the expected fuel reduction for the NADP2 procedure.**

10.3.5. Annex B.3.5 Vienna

Vienna Airport is the largest airport in Austria. It acts as a hub for Austrian Airlines, and in 2018 served a total of approximately 27m people (representing annual growth of 10.84%), and over 240,000 aircraft movements. The airport has two run ways (29/11 and 16/34) that are able to operate with no restrictions in terms of aircraft size.

Located 17km west of central Vienna, the airport is surrounded by mostly rural areas but there are a number conurbations in the proximity of the airport, particularly Essling and Groß-Enzersdorf to the North, which are particularly relevant for the below described case study. It is the largest Airport in Austria acting both as a hub for Austrian Airlines and Eurowings, but also as a base for several low-cost carriers.

The airport has three terminals, and two runways which enable the airport to serve large aircraft up to the Airbus A380. Traffic at the airport is forecast to increase, with current capacity expected to be reached in approximately 2025.

In anticipation of growth, the 1998 Master Plan to 2015 detailed a number of expansion projects at the airport. Significantly this included plans for a third runway to help increase airport capacity and to meet demand under the rationale that such growth has significant local socio-economic benefits

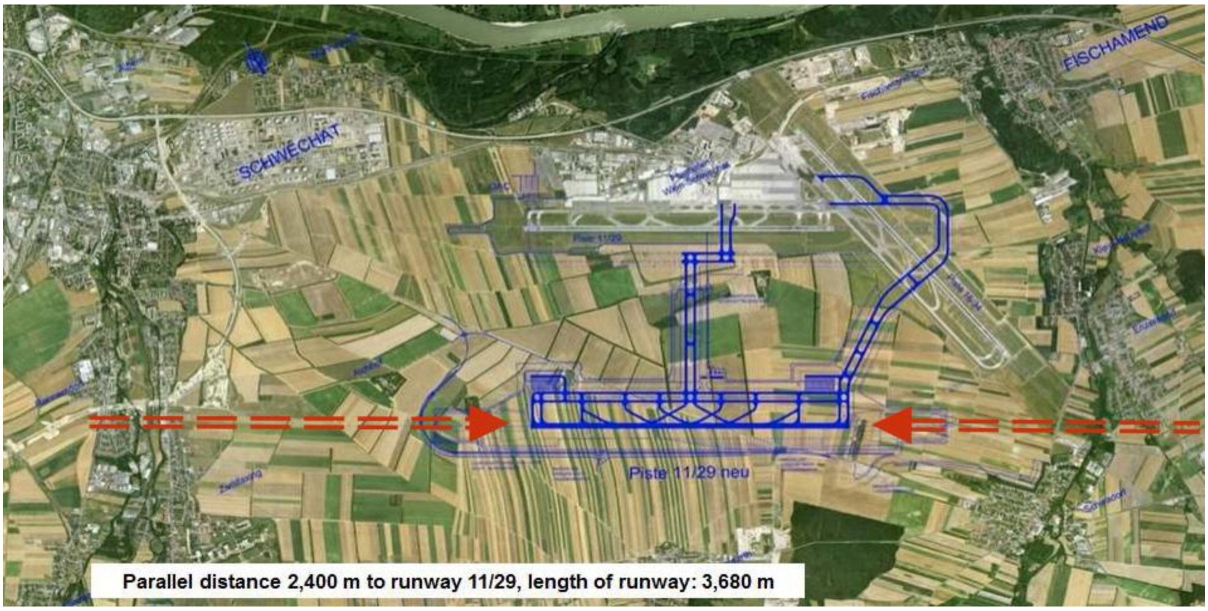


Figure B.15 Proposed location of the third runway

There is no law in Austria regarding airport noise, however noise is a very important issue for Vienna Airport, with the **airport having a considerable noise footprint that includes over two million people**. Noise has been of concern to the airport since the construction of its second runway in 1972 with opposition to aircraft noise reaching a critical point when the airport announced plans for a Third runway - of which local communities were not consulted. This led to significant conflict with the airport and objections to the runway being given approval.

Today, changes regarding **noise-induced operational restrictions** require the involvement of the Dialogue Forum and its many members, and can only be implemented after an established procedure has been followed. Existing balanced approach measures implemented by the airport are listed in table B.5. The airport **follows a number of operational procedures** designed to minimize noise (and emissions) impact, and these are particularly influenced by the Dialogue Forum. In terms of restrictions these are typically imposed by the responsible administration and not by the airport, however discussions in the Dialogue Forum lead to restrictions in the number of flight movements during night that went beyond legal compliance.

In terms of **operational procedures**, several other agreements were made, notably **minimum noise routes** to avoid overflying communities, and improved flight track procedures, developed through cooperation between the ATC Autrocontrol and airlines. Such procedures are regularly reviewed by the Dialogue Forum, with any changes made to SIDs investigated with the airports flight track monitoring system (FANMOS), and results used for further negotiation.

TABLE B.5 Overview of Balanced Approach in Vienna Airport

Operational Procedures	Land-Use Planning	Operating Restrictions
Noise mitigating descent and ascent techniques based on RNP	In the course of the mediation process, the Flughafen Wien AG (Airport Vienna AG) and the neighbouring communities agreed contractually on the abandonment of building land/ housing area in areas, based on the predicted aircraft noise zone of a three runway system, with a L_{den} of 54 or 55, respectively.	Night flight restrictions for single runway directions/ departure routes between 21:00h-07:00h
CDO and CCO when possible	Areas subjected to more than 54dB day and 45 dB night properties can receive between 50%-100% of insulation costs for windows and doors.	Limitation of the number of flight movements during core night time of 4.700/a since 2010. In case of the commencement of a possible 3rd runway: 3.000/a.
Curved Approach on RWY 16 (testing phase)	Noise absorption measures.	Limitation of APU operating time of max. 30 minutes before take-off/ after landing.
RF-Turns after take-off from RWY 16	Winter gardens constructed in highly noise exposed residences.	
Variable parking positions for engine test runs dependent on the wind		

The Curved Approach- a change in operation

As previously stated, one of the outcomes from the mediation process of the third runway was that it would only take landings arriving on a curved approach. Unlike a standard landing procedure where aircraft follow a long, straight-line landing, the curved approach is a satellite-controlled landing method that sees aircraft swivel in just before the runway and start their approach. The curved approach is a relatively new operational procedure available to the industry. In the case of Austria it had been previously applied at Innsbruck Airport.

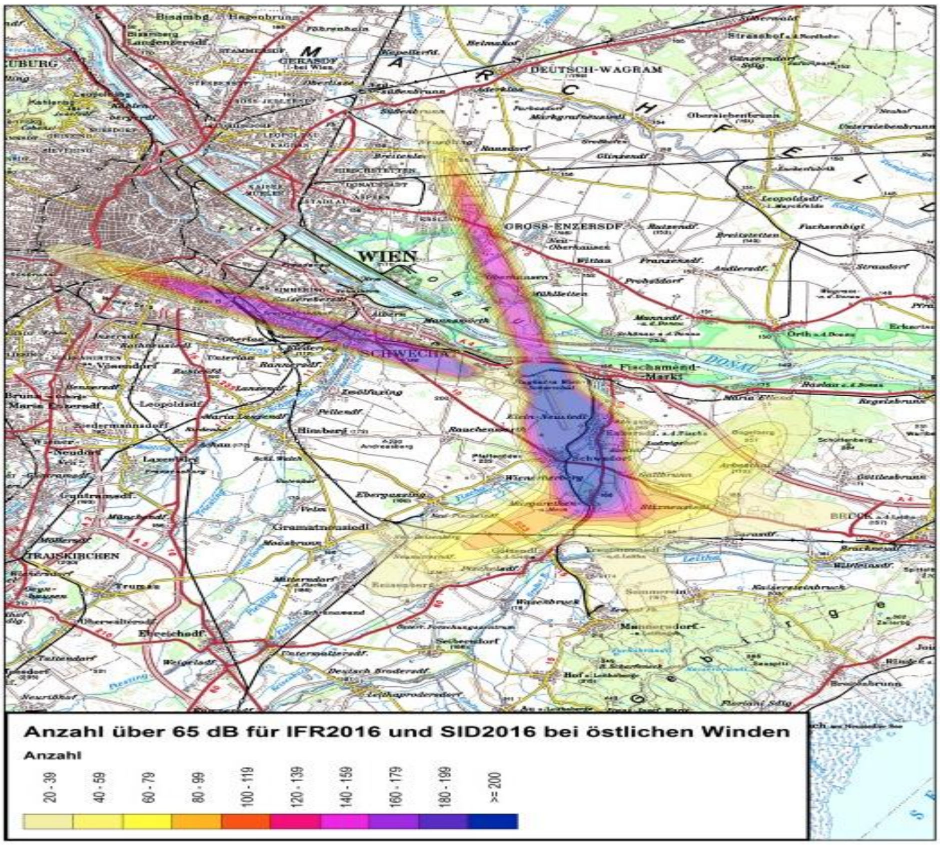


Figure B.16 Proposed curved approach

By including this procedure in the mediation contract, the concept of a curved approach gained much exposure and communities began to enquire if such an approach could be used elsewhere to help avoid overflying currently exposed populations. The call for this operational change was raised to the Dialogue Forum, and it was here that the multi-stakeholder background of the forum in which proposals were reviewed by all communities played a key role

The Dialogue Forum created a Curved approach Working Group in order to find an outcome that would be best suited for all communities. A key consideration of the group is to not transfer the burdens of noise onto others. Thus proposed flight paths were assessed on their ability to fly over uninhabited areas with the aim of noise delivering newly exposed populations.

Through discussions in the Dialogue Forum it was decided (in association with Austro Control) to commence trials to assess the impact of aircraft flying on the curved approach. **Air quality and carbon emissions where not assessed as a priority in these trials as <u>noise</u> is the primary area of concern for communities**.

The airport is considering differential landing charges for those who are not able to fly the curved approach in order to help with the transition to improved technology.

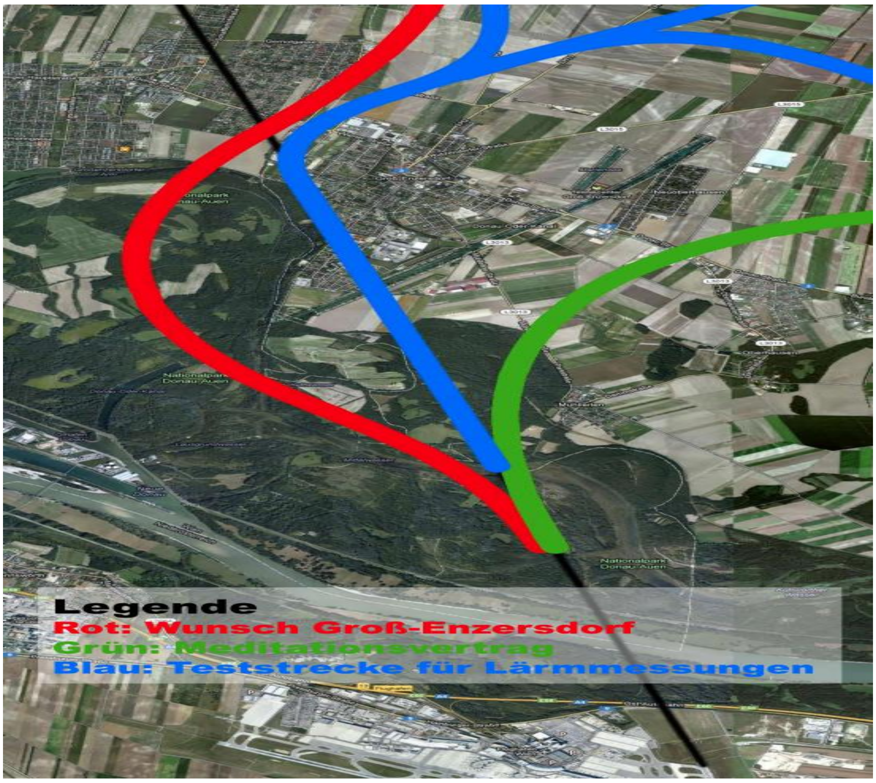


Figure B.17 Options for the proposed curved approach

Noise monitoring terminals were placed along the new flight path and placed symmetrically to assess noise distribution on the ground with one noise monitor placed directly under the flight track and one to either side. Measurements were taken for over 2.5 years – with the time frame determined by obtaining an adequate sample. This required such a long trial as there are significant restrictions on how many aircraft are actually able to use the curved approach. Firstly, the aircraft must have the technical prerequisites to do so. Secondly, pilots must have obtained the appropriate level of training in order to fly this special kind of route. Thirdly the aircraft must be flying from an appropriate direction and with the appropriate winds.

The case study on curved approach needs to explore further the aspect of noise and emissions interdependencies. The T2.5 may be a good opportunity to engage with Innsbruck airport on this topic.

10.4. Annex B.4 Review of metrics and tools

The review of the airport survey data from ST2.3.1 and the below table extracted from ANIMA D2.5 showed that noise metrics were mentioned in all studies. For completeness, table B.6 shows acoustic metrics for all airports of the survey.

The metrics related to emissions are generally expressed in kg or grams. As an illustration: *an **emission intensity** (also **carbon intensity**, C.I.) is the **emission** rate of a given pollutant relative to the **intensity** of a specific activity, or an industrial production process; for example grams of **carbon** dioxide released per megajoule of energy produced*
(https://fmlink.com/articles/greenhouse-gas-emission-metrics/)

Airport Case Study	Acoustic Metrics		
	Single Event (at defined receiver points)	Time Averaged (at defined receiver points)	Spatial Averaging and Aggregation
ACNUSA	LAmax – Number above event profiles over time periods and by aircraft groups	Laeq, Lden, Lday, evening, night. For arrival, departures and total movements	Lden contours for noise exposure plan
Arlanda	None listed	Lden/Lnight	Lden noise contour maps
Barcelona	Lmax events from noise monitoring stations in 5dB bands for town councils	Lday, evening, night. Plus averaged indicators for monitoring stations	Lday, evening, night noise contours
Catania	None listed	Lden /Lnight	Lden and Lnight contours
Cluj	$L_{E,A}$ sound exposure level; $L_{p,AS,max}$ or $L_{p,A,eq,1s,max}$ maximum sound pressure levels	Lden / Lnight	Lden and Lnight contours
Frankfurt	Continuous SPL, L_{Amax_events} from noise monitoring stations	Measured data for every : $Leq_{Aircraft}$,Leq_{total}, $L_{DEN\_Aircraft}$, L_{DEN_total}, L_{DEN}, Maximum level distribution, L_{night}	Contour maps calculation Leq_{Day}, Leq_{Day}, $Leq_{Night50}$+6x68
Heathrow	Single event noise profile	Leq for specific location	LAeq dB noise contours
Helsinki	LAmax used to identify changes to the routes	None listed	None listed
Iasi	$L_{E,A}$ sound exposure level; $L_{p,AS,max}$ or $L_{p,A,eq,1s,max}$ maximum sound pressure levels	Lden / Lnight	Lden and Lnight contours
Kiev	LAmax	LAeq day, evening and night	LAeq day, evening and night contours
Ljubljana	EPNL for loudest aircraft	Lday, Levening, Lnight and Lden	Lden and Lnight contours
Schiphol	Lmax used to record measurements from monitoring stations	Lden	Grid analysis of contours
Vienna	LAmax profiles	Leq	N65 contours (As per mediation contract).

Table B.6 Noise information matrix – airport case study use of different noise indicators by type

Emission metrics

The burning of fuel in the aircraft engine (and APU) results in engine exhaust emissions. Regarding these emissions there are different gasses and particles to consider. For this study CO2, NOx and PM emissions are most relevant (see chapter 5). However, other gasses like HC, CO, H2O may be of importance too in airport case studies. The mass of gasses exiting the engine exhaust is expressed in kg, g or ton. PM (PM10, PM2.5) is also expressed in these units but ultrafines are often expressed in number and size distribution. Airport emissions may be calculated in different ways depending on the intended use of the data. A common way is to calculate emissions for the so called Landing and Take-Off (LTO) cycle. This cycle is used in engine certification, but can also be used for emission inventories at airports in which case the so called time-in-modes may be adapted to the specific airport. Another option is to calculate emissions from ground level up to – for instance - 300m[93] when considering local air quality and the impact of emissions on the community.

Figure B.18 shows an example of how emissions may be presented when considering the introduction/change of a procedure.

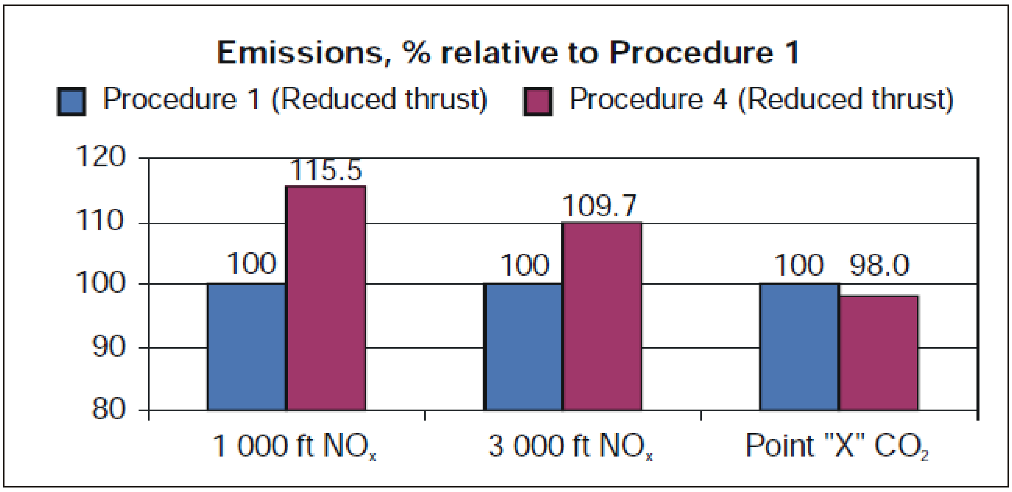


Figure B.18 Example of comparison between the emissions of two departure procedures[94]

Noise metrics

A variety of noise metrics is available from literature. The various metrics found can be classified according to table B.7.

[93] Above 300m emissions have little impact on local air quality.

[94] Source : ICAO Circular 317 « Effects of PANS-OPS Noise Abatement Departure Procedures on Noise and Gaseous Emissions »

Type	Single-event	Multi-event
Instantaneous	LA, LC, LZ, PNL, PNLT	**-**
Maximum levels	LA_{max}, LC_{max}, LZ_{max}, PNLTM	**-**
Integrated	LA_{eq}, LC_{eq}, LZ_{eq}, EPNL, SEL_A, SEL_C, SEL_Z	**Lden, Lnight, DNL, $LA_{eq,1h,ac}$, $LC_{eq,1h,ac}$, $LZ_{eq,1h,ac}$, $LA_{eq,1h}$ Flight Noise Level**
Contour related	-	**Contour Area Contour aspect ratio**
Time related	Time Above Threshold Time Audible	**Time Above Threshold, Percentiles, Time Audible, Noise Free Interval**
Nº events related	-	**Number Above Threshold Nº audible events**
Population related	**-**	**Person Events Index Average Individual Exposure**

Table B.7 Classification of metrics

Each of these metrics has their application domain. For environmental studies usually A-weighted metrics are used. When comparing e.g. different departure procedures, a single-event noise level as a function of distance might be a good metric (see e.g. figure B.19).

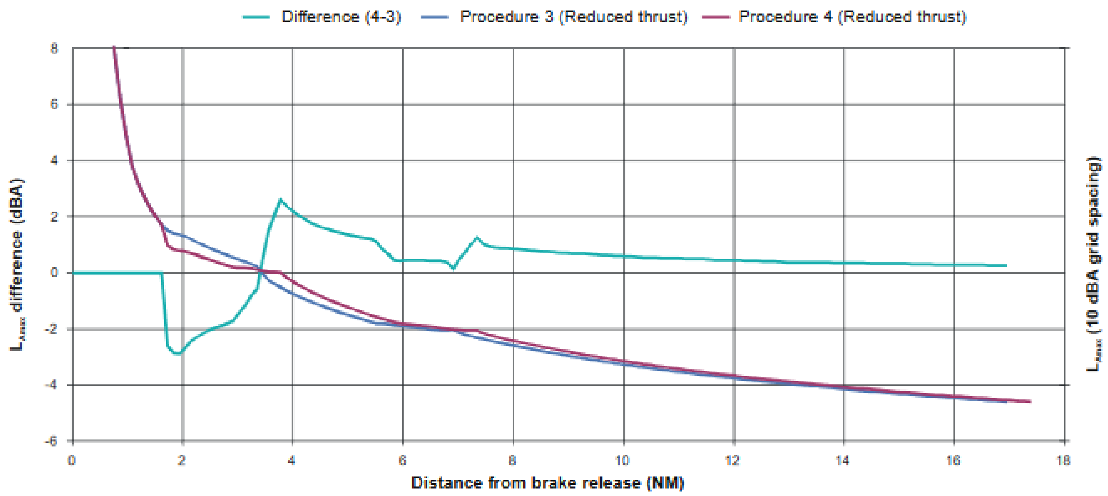


Figure B.19 Example of comparison between the noise of two departure procedures[95]

Tools

In essence airports often use their own tools/contracts out to specialists who use single issue tools – e.g. noise modelling and air quality modelling. But these may make various assumptions which could be in conflict.

The airport survey did show that the noise tool (INM) was used in the Heathrow and Helsinki cases. However, review of the received documentation did not show the use of a tool that could calculate both noise and emissions.

[95] Source : ICAO Circular 317 « Effects of PANS-OPS Noise Abatement Departure Procedures on Noise and Gaseous Emissions

Organisation	Tool for		Notes
	Noise	Emissions	
ANOTEC	SONDEO	SONDEO/EM	Batch capability
EUROCONTROL	IMPACT/STAPES	IMPACT	Batch capability Incl. LAQ
FAA	AEDT/INM	AEDT/EDMS	Incl. LAQ
NAU (Kiev)	ISOBELLA	POLEMICA	Incl. LAQ
NLR	TUNA	LEAS-IT	Incl. LAQ
University Roma Tre	-	FRIDA	

Table B.8 Identified noise and emissions tool suites

In a study under a contract from DG-MOVE[96] several ANIMA partners (NLR, DLR, ANOTEC) reviewed the existing models for aviation environmental impact assessments. Whereas many organisations have developed stand-alone tools for noise **or** emissions calculations, only a few have available tools that can handle noise **and** emissions in a consistent and integrated manner, e.g. by using the same input data environment. Table B.8 provides the list of tool suites that were identified in this study.

Tool description:

SONDEO

Developed by ANOTEC, the SONDEO model can estimate noise contours surrounding an airport, as well as the number of people exposed within that contour. The noise contour module (NCM) calculates noise contours for a variety of noise metrics according to ECAC Document 29 (4th edition). The population module is capable of overlaying the noise contours from NCM on population maps, so as to determine the number of people exposed to certain levels of noise. From the total number of people exposed, the percentage of highly annoyed people may be derived. The EM module has been added to SONDEO in order to estimate emissions for the same traffic and route scenario as used for noise. Emissions are calculated based on the fuel flow and emission indices of the ICAO Aircraft Engine Emissions Databank for turbofan and turbojet engines, the FOI database for turboprops and the FOCA database for piston engines. Both the ICAO LTO (TiM) and Boeing FFM2 methods have been implemented to calculate fuel burn, CO2, CO, HC and NO_X emissions. PM emissions can be calculated based on the First Order Approximation v3.0 (FOA3). SONDEO can be executed for a single airport or for a batch of airports to facilitate regional/global assessments.

IMPACT

Within the context of the SESAR Research and Innovation programme, EUROCONTROL has developed IMPACT, an integrated aircraft noise and

[96] Design of a Publicly Accessible Aviation Tool Suite Report ; Deliverable D1 in the framework of Service contract No. MOVE/C2/SER/2014-269/SI2.706115 for the development of a Public European Model Suite for Aviation – Jan.2016

emissions modelling platform that supports both aircraft noise and fuel burn/emissions assessments[97].

AEDT (INM & EDMS)

In the United States the Aviation Environmental Design Tool (AEDT) [98] is used to model aircraft performance in space and time to estimate fuel consumption, emissions, noise, and air quality consequences. Such computations can take place on a range of levels, from a single flight at an airport to scenarios at the regional, national, and global levels.

ISOBELLA/POLEMICA

The **IsoBella** model has been designed in National Aviation University (NAU), Kyiv, Ukraine, for calculation of noise levels/indices at specific points and/or noise contours (for a number of types of level/indices) for airport flight scenarios under consideration. IsoBella is fully compliant with the airport noise contour modelling methodology described in ICAO Document 9911 and meets the ECAC requirements from Doc 29 3rd Edition.

POLEMICA

POLEMICA (Pollution and Emission Calculations) is a modelling system for the calculation of airport-related pollutant emissions and air pollution in the lower atmosphere. The tool was developed by the National Aviation University (NAU), Kiev and is currently under the evaluation by ICAO/CAEP/MDG (Modelling & Database Group).

Main purpose of the PolEmiCa is to provide the dispersion (Pollution) and inventory (Emission) calculations for the aircraft engine emission during the landing and take-off (LTO) cycle of the aircraft movements inside airport area. Besides LTO stages of flight it includes the aircraft emission from aircraft engine start-up procedures, APU and GSE also. Current version of the PolEmiCa combines the calculation for the main stationary sources of the emission and road vehicles inside airport area with character matters for aircraft engine emission: CO, HC, NOx, SOx, PM and fuel vapours (HC).

TUNA/LEAS-iT

TUNA (by NLR) is a model which assists parties to calculate noise contours in accordance with ECAC Doc 29, hence supporting airport management, local authorities and residents in evaluating development plans, traffic scenarios and different flight procedures. While TUNA is a stand-alone model it can share its input with NLR's LEAS-iT (emissions) and TRIPAC/GEVERS (third party risk) models. Model outputs are Noise grid and or contours in metrics like LDEN,

[97] https://www.eurocontrol.int/sites/default/files/service/files/2014-IMPACT-factsheet.pdf
[98] https://aedt.faa.gov/

LNIGHT, LAMAX, SEL, etc., as well as the number of houses or number of residents within the noise contours. Required as inputs are scenarios like number of aircraft movements per year specified by aircraft type, flight phase (take-off/landing), runway, and flight procedure (flightpath).

LEAS-iT

LEAS-iT Local Emissions (around) AirportS inventory Tool is an advanced tool capable of analysing and assessing the various aircraft emissions, in space and time, at and around the wider vicinity of airports. The emissions are based on the airport and runway layouts and are sensitive to operational procedures and routes, traffic, and aircraft performance and emissions properties. Both airborne and ground operations can be modelled. LEAS-iT can handle different types of fuel e.g. Jet-A1, Avgas. The model's outputs are detailed air traffic fuel use and emissions (amongst others: CO_2, H_2O, NO_x, PM_{10}, lead, unburnt hydrocarbons) in 3D-grid and hourly dimensions, both ground and airborne operations.

10.5. Annex B.5 Review of pressure from competing environmental agendas

In the case of Heathrow a stepwise process has taken place in which the community request was partially fulfilled. The community wanted a steeper profile, however this was informed by incorrect information on what other airports were doing and what was operationally feasible. Heathrow did the maximum slope they thought was possible. It is good practice as it was a community request that was acted on by the airport – the airport just couldn't go to the same distance as the communities wanted due to interdependencies (safety / emissions). In the Helsinki case the community was not directly involved in the decision-making process. Also in the Schiphol case the community was not directly involved in the decision making of the project but it was informed well ahead of time. In Vienna stakeholders - including the community - were consulted with regards to change in operations.

10.6. Annex B.6 Decision making process

Interdependencies between noise and emissions in the aviation sector are multifaceted and should be considered in aircraft/engine design decisions, operational decisions and regulatory decisions.

Examples of each type of these decisions are:

- When comparing open rotor and the turbofan designs fuel burn and noise characteristics must be carefully evaluated
- When introducing a (change in) flight procedure noise levels - depending on the specific area considered - may decrease or increase in communities around the airport.
- Regulatory noise limitations may have the potential to increase emissions.

Having the required knowledge in making the best decision is not an easy task.

These decisions may impact more global (en-route) aircraft operation but also more local airport operation. Since the airport is central in the description of work of ST2.3.3 this Annex addresses airport operations and decision-making by the main stakeholders involved in selecting local procedures to achieve noise and/or emissions reduction. Since it is not possible to address all specific cases for each and every EU airport and, furthermore, in most cases the required level of detail[99] of data will be absent to address these cases in detail, this chapter provides a more qualitative approach. This Annex is meant to inform about and to raise awareness of a range of possible measures and its implications on noise, NOx and CO2 emissions.

Regarding emissions historically NOx and CO2 have been important. More recently PM is becoming too (see also Annex A). A significant knowledge gap in environmental studies is the amount of PM actually produced during aircraft operations. The PM emissions are (often) calculated with methods that are based on measurement data with a high degree of uncertainty[100].

This means that PM emissions in airport environmental studies, including the ones on the impact of (a change in) aircraft operations, are also calculated with a high degree of uncertainty, if they are calculated at all. For this reason Annex B addresses the interdependencies and trade-offs between noise, NOx and CO2 emissions as effect of aircraft operation changes and does not address the interdependencies with PM emissions.

[99] For instance, FDR data may be lacking when considering flight procedure changes and their effects.

[100] Annex A provides more information on the latest developments regarding PM (including ultrafines) measurement and modelling.

11. Annex C Catania Airport case study

11.1. Annex C.1 Airport Data

Airport characteristics

Catania–Fontanarossa Airport (Italian: *Aeroporto Internazionale Vincenzo Bellini di Catania-Fontanarossa*) (IATA: CTA, ICAO: LICC), also known as Vincenzo Bellini Airport, is an international airport 2.3 NM (4.3 km; 2.6 mi) southwest[101] of Catania, the second largest city on the Italian island of Sicily.[102]

- Class 4E (ICAO)Surface 217 ha, (parking area 16.6 ha)
- Distance from Urban Centre 4 km

Table C.1 shows airport passenger and cargo[103] development. The table shows a continuous growth in passengers with an increase of +38% flights & +59% passengers in 2018.

Year	n. Flights	Passengers	Goods (t)
2012	53,178	6,246,888	7,512
2013	54,406	6,400,127	6,123
2014	59,926	7,304,012	6,206
2015	54,988	7,105,487	6,220
2016	61,080	7,914,117	6,379
2017	68,170	9,120,913	6,691
2018	73,494	9,933,318	6,418

Table C.1 Catania-Fontanarosssa Airport passenger and cargo development

The Airport has one runway (08-26) with east-west orientation and is located very close to the sea and approximately 5km south of the City of Catania.

For completeness, the urban areas closest to the Airport and its activities are:

- North, the residential areas of Catania;
- West, the village of Librino;
- South-South West, the villages of Fontanarossa and Torregalliera (Industrial areas);
- East, mainly touristic activities/beach.

[101] https://en.wikipedia.org/wiki/Catania%E2%80%93Fontanarossa_Airport

[102] http://www.aeroporto.catania.it/?lang=en

[103] https://assaeroporti.com/wp-content/plugins/multipage_xls_reader/pdf_file/2018.pdf)

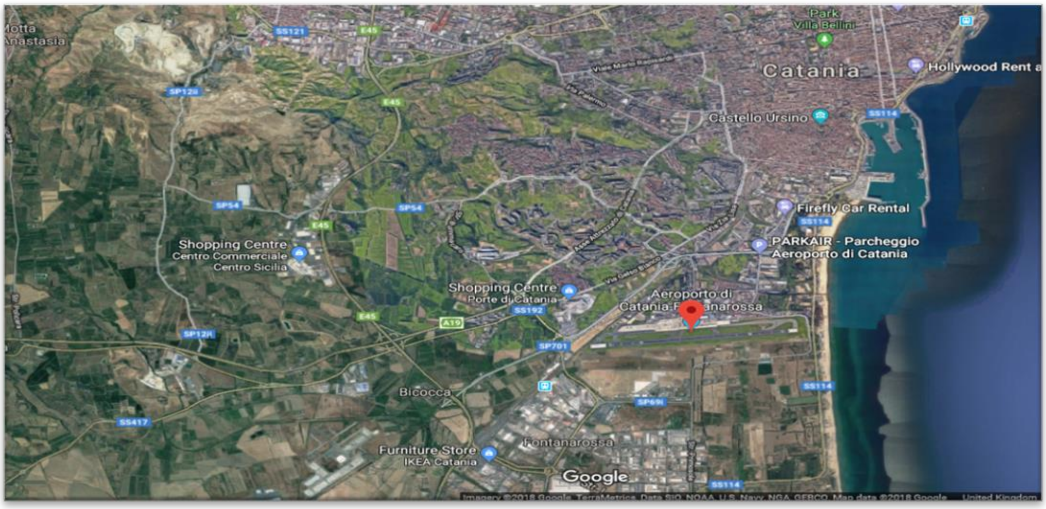


Figure C.1 Catania Airport location (Source: Google maps-Dec 2018)

Figure C.2 The proximity of city centre to runway
(Source: Catania Airport Environmental unit, Dec 2018)

The Environmental Policy

Catania Airport is part of SAC – Societa' Aeroporto Catania, an organisation with an ambitious environmental policy and an environmental impact management system in place. SAC's aim goes beyond merely fulfilling the basic legislative requirements, to constantly look for new ways and means to prevent and mitigate any negative impact on the environment, caused by the airport operations.

Noise policy is the most stringent one, the Airport being located only 4 km from the city center.

Noise monitoring network

SAC is currently monitoring noise levels (at several sites) and has, since 2018 a real-time info point for passengers. Catania Airport is planning to implement a new approach based on ADS-B (GPS data from aircraft) to produce more reliable and real-time paths (Radar is not currently available).

In the wider areas around Catania Airport other noise sources from transport systems are present, such as the rail line west to the Airport, in proximity of the end of track 08, the SP55 road, going in parallel to the rail line and the military heliport "Mario Calderara".

From a legislative point of view, the noise zoning system with noise maps was approved in 2005 by the Commission in charge, (ex Article 5 of D.M. 31/10/1997 in 2005) and the Catania Council acoustic classification plan was approved on the 04/03/2013.

At present, the noise monitoring network at Catania Airport is constituted by a monitoring system of three fixed and one mobile noise monitoring sites, being located within the Airport area, as shown in figure C.3. The whole Airport complies with the ARPA[104];[105] guidelines ("Linee guida per la progettazione e la gestione delle reti di monitoraggio acustico aeroportuale"). Table C.2 illustrates the characteristics of the noise monitoring network.

Figure C.3 Noise monitoring network (fixed sites)

[104] http://www.aeroporto.catania.it/?lang=en

[105] ARPA – Agenzia Regionale per la Protezione dell'Ambiente

ID number	Site name	Location	Coordinates	Related Weather station
P1 - 1301	Testata 26	Inside (B)	37° 27' 58.94" N 15° 4' 56.59" E	SI "Vaisala Weather Transmitter WXT533"
P2 - 1302	Testata 08	Inside (A)	37° 27' 47.28" N 15° 2' 59.00" E	SI "Vaisala Weather Transmitter WXT533"
P3 - 1303	Pista lato sud	External	37° 27' 43.77" N 15° 3' 54.25" E	NO
P4 - 1304	Mobile	N.D.	N.D.	NO

Table C.2 Noise monitoring network characteristics

Noise Maps

Noise maps have been generated in 2017 using specific software, Integrated Noise Model (INM).

Figure C.4 Noise Maps, Lden, 2017

Range (dB)	Exposed Population	
	LDEN	LNIGHT
55-59	1378	619
60-64	399	330
65-69	268	215
70-74	126	59
>75	61	39

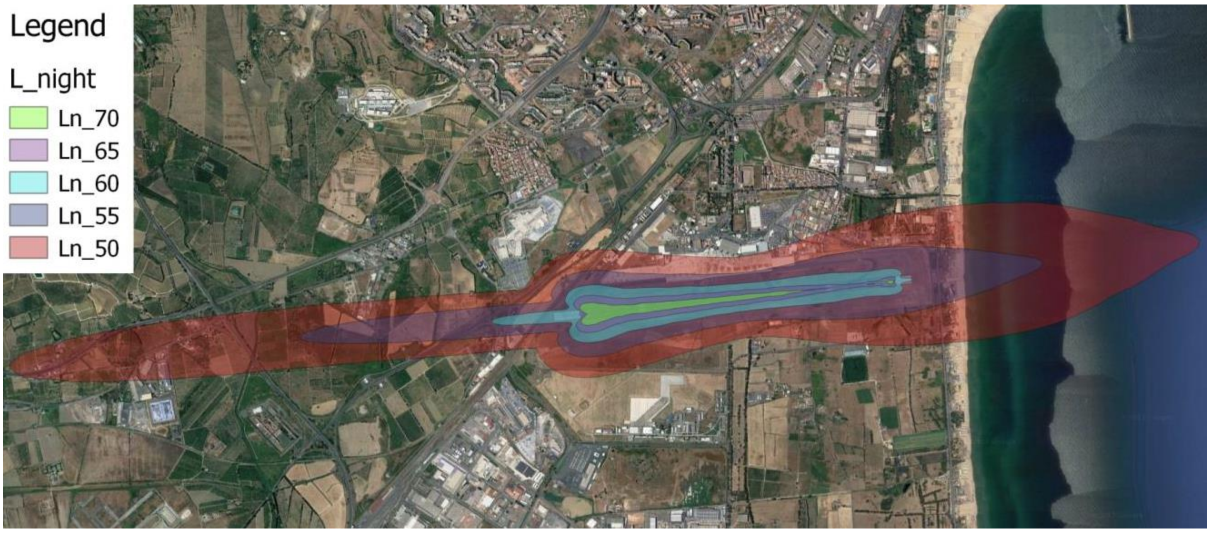


Figure C.5 Noise Maps, L_night, 2017

Air Quality Monitoring Network

Catania Airport has also a good coverage of Air Quality monitoring. Monitoring stations are in line with the Italian Environmental Agency and can be static or mobile, but in both cases are based on cabins equipped with different pollution sensors.

The location of the stations has been designed and selected with great attention and all of them are within the airport premises. This makes possible the analysis of correlations between measured levels and sources of emissions in the surrounding areas. Most of the stations have been located in proximity of the *primary landing and taking off* routes, projected to maximise the relevance of the data collected to support the environmental impact analysis. Similarly, some stations have been located in front of the terminal, in the urban area, to assess the contribution to airport pollution levels due to road traffic (road).

Some example of the stations type is provided in figure C.6 below where both versions, static and mobile are represented. Also, the figure below provides the map of the location of the two monitoring stations.

Figure C.6 Air Quality monitoring systems and a partial mapping (Source: Catania Airport, March 2019)

The relevance of the Environmental Totem: recently, an environmental totem, part of the SARA platform has been installed inside the airport terminal, displaying to passengers, on a large screen, the environmental information (noise and air quality), monitored in real-time.

This was the start of ANIMA & Airport cooperation: existing data and willingness to take part in research.

The screen particularly shows the following information:

- Position of flights in real-time, as the aircraft taxi on apron area, or fly in the vicinity of the airport;
- Real-time information on noise level monitored by the network during the take-off and landing procedures;
- Trend of noise level over the previous 5 minutes;

- Level of atmospheric pollution in the previous hour (see above pollutants);
- Trend of atmospheric pollution over the previous 24 hours;
- Weather conditions in real-time.

Operational Procedures

Information on the airport (noise abatement) *operational procedures* is essential when conducting research on interdependencies. Below, some *departure procedures* are presented, as both ANOTEC and NLR have selected departure procedure to conduct their research, based on the fact that noise & emissions trade-offs are easier to be quantified during departure flights, comparing to the approach.

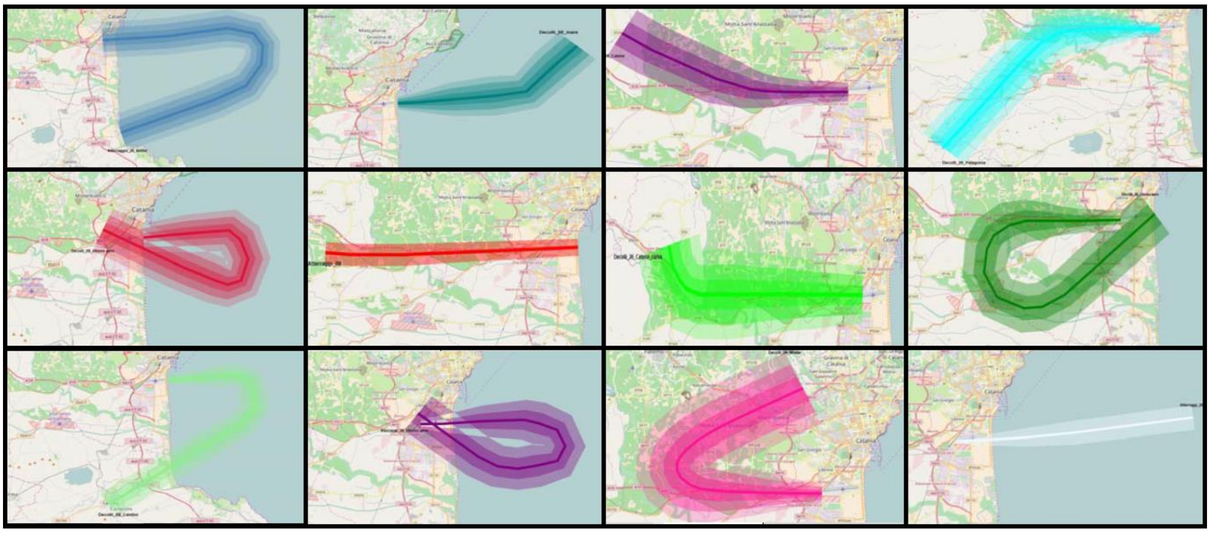


Figure C.7 Standard Instrument Departure Route (SID) (Source: Catania Airport, Dec 2018)

11.2. Annex C.2 ANOTEC case-study

Note: tools, results and discussions on ANOTEC case-study are presented together in Annex C.2, for a better understanding of work involved.

Tools

In order to determine interdependencies between noise and emissions in an efficient and consistent manner, it is convenient to calculate both environmental aspects with models that can use the same input data and that provide results in a compatible format. To this end the SONDEO and SONDEO/EM models are used here, since both have been integrated in the tool chain, developed in ANIMA WP4 (Figure 5-Chapter 5; Figure C.8 below).

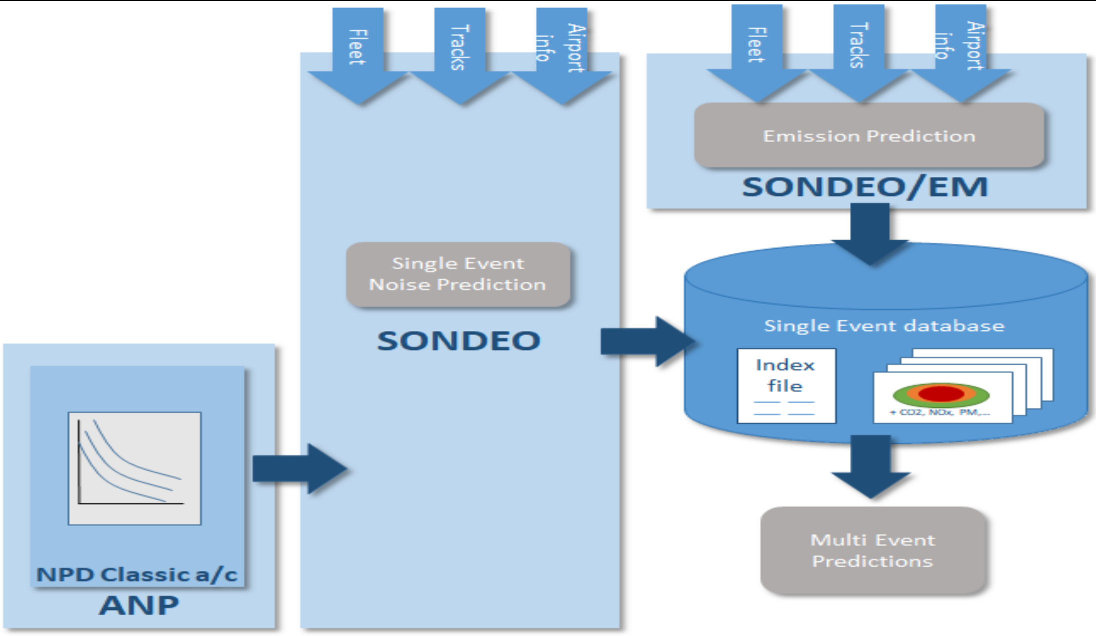


Figure C.8 Airport noise and emissions models, integrated in the ANIMA WP4 tool chain

SONDEO is an airport noise modelling tool that calculates the noise contours for single events in accordance with ECAC Doc 29 and the corresponding ANP database. These single events are stored in a database, and for a given scenario (typically a specific fleet/track combination), the relevant single event results are merged to simulate the total noise around the airport, representative for that specific scenario. For this, SONDEO basically needs the following input:

- Fleet (operations)
- Flight Tracks
- Airport information (runway data etc)

SONDEO/EM is a model that calculates the emissions generated by aircraft operating at an airport. Several methods are incorporated (ICAO LTO, Boeing Fuel Flow Method 2, FOA), with which the main emissions can be obtained (CO2, NOx, PM, …). As with the noise model, SONDEO/EM calculates the emissions for each single event and stores the results in the single event database, together with the noise data. For a specific scenario the total emissions are then calculated by combining the results of the corresponding single events. For this, SONDEO/EM uses the same input as that used by SONDEO.

Application of the tools to the Catania case

Both the SONDEO and SONDEO/EM models were used to determine the noise and emissions for the Catania case study, based on data of actual flight operations (incl. trajectories).

To this end, a first dataset was provided by the airport, corresponding to the first week of August 2018. This data was based on the monitoring system installed at the airport, and contained:

- Flight trajectories (4D)
- Aircraft type
- Route
- Peer airport
- Time of day
- Daily noise metrics
- Daily average pollution values for some pollutants

Results based on initial dataset

Figure C.9 provides an overview of some flight trajectories contained in the initial dataset.

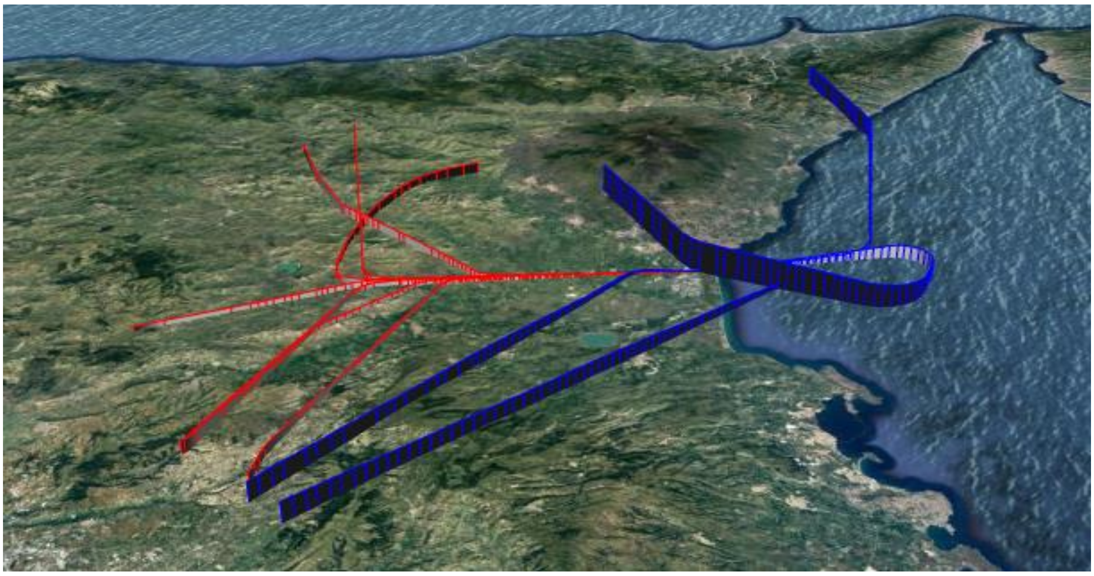


Figure C.9 Catania Airport basic flight procedures (blue: departures, red: arrivals) (Source: Catania airport)

However, when preparing the input for the noise and emissions toolchain, several issues with this dataset were encountered:

- The altitude as provided by the monitoring system appeared much lower than expected. When matching the ANP standard profiles to find the best fit, this would result in a much too low profile (corresponding to the highest aircraft weight), resulting in unrealistically big noise contours.
- The destination is not available in 80% of the operations. This information is required to estimate the aircraft range and hence weight, so it has to be obtained from other sources.
- Horizontal trajectory (track) data is given in a local coordinate system, not compatible with the standard WGS84 or UTM system, resulting in a misalignment with the runway
- There is no trajectory data near or on the runway, probably due to a shadow zone of the track antenna (ADS-B). This requires processing to split between e.g. landing and taxi

When discussing these issues with the airport, it appeared difficult to resolve them at short notice. In order to avoid a delay in the delivery of the study results, it was decided to start the interdependencies study, acknowledging that the results would not be representative, but considering that in this way at least the methodology could be tested.

Both SONDEO and SONDEO/EM were executed for the initial dataset provided by the airport. Table C.3 provides the main results of these calculations, as entries in the single event database.

ID	Date	Time	Flight	Airline	ACFT	A/D	Org/Dest	Org/Dest2	AC_ANP	PROFILE	STG	km2LAMAX65	km2SEL70	ENGUSED	BADAENG	KGNOX	KGCO2
1	02/08/2018	0:21:47	MAC393	MALTA CHARTER	A320	A	N.A.	GMMN	A320-211	STANDARD	1	14.8	66.0	CFM56-5-A1	CFM56-5B	1.393	659.5
2	02/08/2018	0:28:00	AMC648	AIR MALTA	A320	A	N.A.	LMML	A320-211	STANDARD	1	14.8	65.9	CFM56-5-A1	CFM56-5B	1.393	659.5
3	02/08/2018	0:39:48	MSA792	AIRMERCI	B733	A	LIPO	LIPO	737300	STANDARD	1	16.6	45.6	CFM56-3-B1	CFM56-3-B1	0.887	522.5
4	02/08/2018	1:20:50	MAC394	MALTA CHARTER	A320	D	N.A.	GMMN	A320-211	ICAO_B	5	32.7	136.5	CFM56-5-A1	CFM56-5B	12.604	1633.4
5	02/08/2018	2:55:54	AMC649	AIR MALTA	A320	D	N.A.	LMML	A320-211	ICAO_B	5	32.4	135.5	CFM56-5-A1	CFM56-5B	12.604	1633.4
6	02/08/2018	4:06:03	AZA1722	ALITALIA	A320	D	N.A.	LIRF	A320-211	ICAO_A	5	33.3	145.8	CFM56-5-A1	CFM56-5B	13.303	1773.1
7	02/08/2018	4:30:05	EWG3NV	EUROWINGS	B738	A	N.A.	EDDN	737800	STANDARD	1	21.4	73.2	CFM56-7B2	CFM56-7B2	1.552	667.3
11	02/08/2018	4:32:12	RYR4851	RYANAIR	B738	D	LIRF	LIRF	737800	ICAO_B	4	52.1	484.4	CFM56-7B2	CFM56-7B2	10.966	1404.5
9	02/08/2018	4:32:52	AZA5CM	ALITALIA	A319	D	LIML	LIML	A319-131	ICAO_A	4	19.8	112.1	V2522-A5	V2522-A5	10.850	1457.8
8	02/08/2018	4:40:12	N.A.		A320	A	N.A.		A320-211	STANDARD	1	-1	-1	CFM56-5-A1	CFM56-5B	1.393	659.5
10	02/08/2018	4:50:02	AMC184	AIR MALTA	A320	A	N.A.	EGMC	A320-211	STANDARD	1	-1	-1	CFM56-5-A1	CFM56-5B	1.393	659.5
13	02/08/2018	4:52:46	EZY17DM	EASY	A319	D	N.A.	LIMC	A319-131	ICAO_B	4	-1	-1	V2522-A5	V2522-A5	9.986	1292.4
14	02/08/2018	4:58:38	AZA1367	ALITALIA	A320	D	LIPE	LIPE	A320-211	ICAO_B	5	32.1	134.6	CFM56-5-A1	CFM56-5B	12.604	1633.4
15	02/08/2018	5:05:03	AZA5LW	ALITALIA	A321	D	LIRF	LIRF	A320-211	ICAO_B	5	32.3	134.5	CFM56-5-A1	CFM56-5B	12.604	1633.4
18	02/08/2018	5:38:00	AMC641	AIR MALTA	A320	D	LMML	LMML	A320-211	ICAO_B	5	32.2	136.2	CFM56-5-A1	CFM56-5B	12.604	1633.4
19	02/08/2018	5:42:26	AMC184	AIR MALTA	A320	D	N.A.	EGMC	A320-211	ICAO_A	5	-1	-1	CFM56-5-A1	CFM56-5B	13.303	1773.1
21	02/08/2018	5:49:44	AZA1700	ALITALIA	A319	D	LIPZ	LIPZ	A319-131	ICAO_A	5	27.1	114.5	V2522-A5	V2522-A5	12.478	1656.7
17	02/08/2018	5:50:21	N.A.		B738	A	LIPE	LIPE	737800	STANDARD	1	21.3	72.0	CFM56-7B2	CFM56-7B2	1.552	667.3
23	02/08/2018	5:59:20	EWG4189	EUROWINGS	B738	D	N.A.	EDDN	737800	ICAO_A	6	-1	-1	CFM56-7B2	CFM56-7B2	12.804	1670.9
20	02/08/2018	5:59:43	EZS52YJ		A319	A	N.A.	LSGG	A319-131	STANDARD	1	-1	-1	V2522-A5	V2522-A5	1.018	548.0
25	02/08/2018	6:09:47	CFG4YW	CONDOR	A320	A	N.A.	GCLA	A320-211	STANDARD	1	-1	-1	CFM56-5-A1	CFM56-5B	1.393	659.5
28	02/08/2018	6:09:48	RYR358E	RYANAIR	B738	D	N.A.	LIRF	737800	ICAO_B	6	-1	-1	CFM56-7B2	CFM56-7B2	12.333	1586.8
22	02/08/2018	6:12:06	AZA1761	ALITALIA	A320	A	N.A.	LIRF	A320-211	STANDARD	1	-1	-1	CFM56-5-A1	CFM56-5B	1.393	659.5
26	02/08/2018	6:20:20	RYR55NN	RYANAIR	B738	A	N.A.	LIME	737800	STANDARD	1	-1	-1	CFM56-7B2	CFM56-7B2	1.552	667.3
27	02/08/2018	6:27:00	N.A.		B738	A	N.A.		737800	STANDARD	1	-1	-1	CFM56-7B2	CFM56-7B2	1.552	667.3
30	02/08/2018	6:42:59	RYR318Q	RYANAIR	B738	D	N.A.	LIPE	737800	ICAO_A	6	-1	-1	CFM56-7B2	CFM56-7B2	12.804	1670.9
32	02/08/2018	6:57:53	EDW398	EDELWEISS	A320	A	LSZH	LSZH	A320-211	STANDARD	1	14.0	65.9	CFM56-5-A1	CFM56-5B	1.393	659.5
33	02/08/2018	7:02:24	RYR61UQ	RYANAIR	B738	A	EPRZ	EPRZ	737800	STANDARD	1	21.3	71.0	CFM56-7B2	CFM56-7B2	1.552	667.3
35	02/08/2018	7:10:46	AZA1744	ALITALIA	A320	D	LIRF	LIRF	A320-211	ICAO_B	5	32.0	135.9	CFM56-5-A1	CFM56-5B	12.604	1633.4

Table C.3 Single event database based on initial dataset

Figure C.10 presents the noise contours of some operations. It can be observed that, due to the too low altitude, the noise contours are indeed much longer than may be expected. Also some misalignments between trajectory and runway can be found.

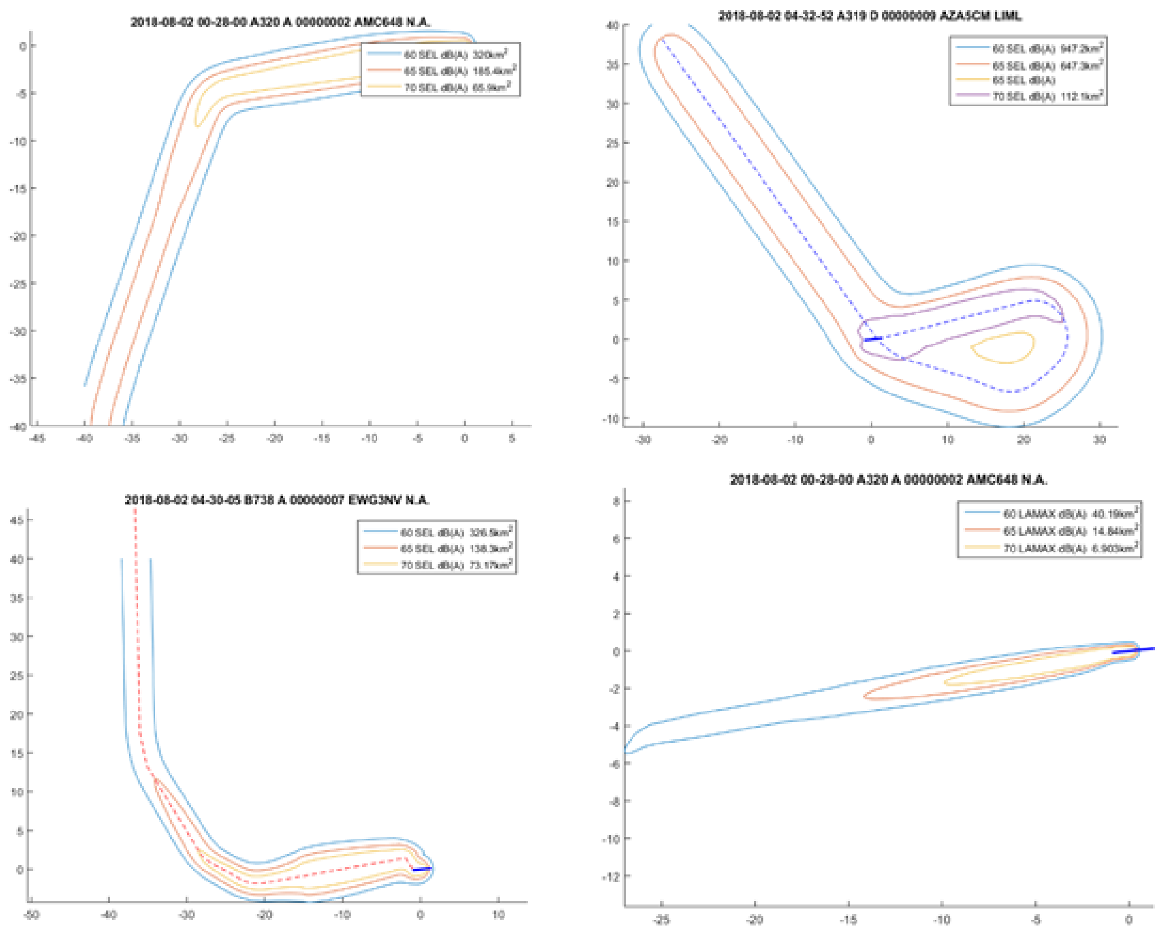


Figure C.10 Noise contours based on trajectories from initial dataset

Based on the single event emissions various assessments can be made:

- Total CO2 / NOx for each aircraft type, per destination, per airline, etc..
- What-if studies ➔ example: replacement of CFM56 by LEAP

To demonstrate the capabilities of the tool chain, the latter assessment has been worked out in more detail. For the operations with A320 and A321, the standard CFM56 engines were replaced by LEAP engines and the corresponding emissions were calculated for the same flight profiles.

Figure C.11 shows the results of this exercise. It can clearly be seen that both CO2 and NOx are significantly reduced thanks to the introduction of the LEAP engine. Here it should be noted that these calculations are based on the wrong trajectory data, and absolute values are therefore not correct.

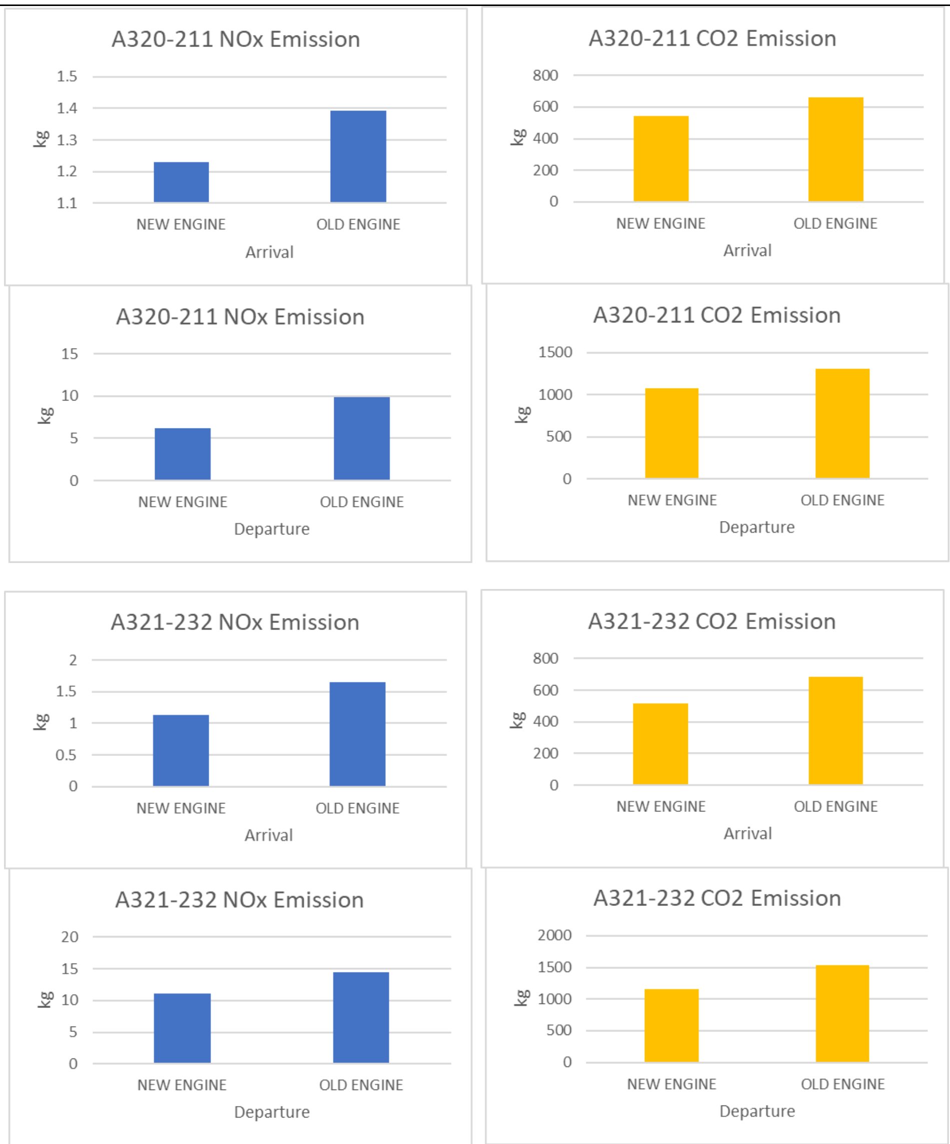


Figure C.11 Effect on emissions of re-engining A320 and A321 with LEAP engines

Updated dataset

For a full and representative interdependencies study it is necessary to work with correct trajectory information, especially with correct altitude. Since improving the monitoring system at the airport would take more time than that available, it was decided to acquire some data with an interim solution. To this end an ADS-B receiver of ANOTEC was installed at Catania airport, with data stored in a local PC. A first check of the data confirmed that the altitude in the initial dataset was wrong. As can be seen in Figure C.12, the glide slope in approach according to the initial dataset was around 1.7º, whereas the ANOTEC receiver shows a 3º slope, which is as expected, considering the ILS installed at Catania.

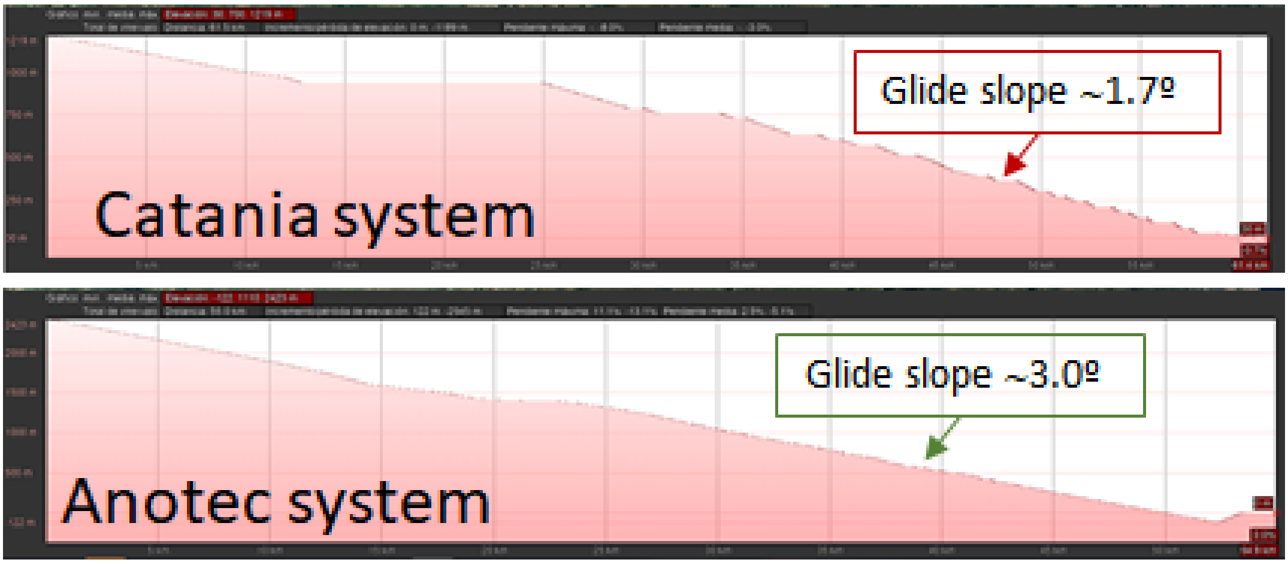


Figure C.12 Check on altitude information provided by Catania and ANOTEC systems

A new single event database was then created, based on the updated dataset (see Table C.4).

ID	Date	Time	Flight	Airline	ACFT	A/D	Org/Dest	AC_ANP	PROFILE	STG	km2LAMAX65	km2SEL70	ENGUSED	BADAENG	KGNOX	KGCO2
190221010	21/02/2019	15:50:30	RYR36YU	RYANAIR	B738	D	BGY	737800	ICAO_B	6	46.711	97.305	CFM56-7B26	CFM56-7B27	12.333	1586.802
190221014	21/02/2019	16:07:55	RYR70SJ	RYANAIR	B738	A	MXP	737800	STANDARD	1	21.595	59.255	CFM56-7B26	CFM56-7B27	1.552	667.321
190221018	21/02/2019	16:29:42	RYR5UD	RYANAIR	B738	D	TRN	737800	ICAO_A	6	58.543	122.585	CFM56-7B26	CFM56-7B27	12.804	1670.904
190221020	21/02/2019	16:42:41	AZA1723	ALITALIA	A319	A	LIN	A319-131	STANDARD	1	12.076	29.511	V2522-A5	V2522-A5	1.018	547.981
190221022	21/02/2019	17:04:43	RYR52HX	RYANAIR	B738	A	BLQ	737800	STANDARD	1	21.115	54.247	CFM56-7B26	CFM56-7B27	1.552	667.321
190221015	21/02/2019	17:13:27	RYR3T	RYANAIR	B738	D	MXP	737800	ICAO_A	6	59.175	123.614	CFM56-7B26	CFM56-7B27	12.804	1670.904
190221013	21/02/2019	17:17:58	RYR8YD	RYANAIR	B738	D	FCO	737800	ICAO_B	5	57.726	135.125	CFM56-7B26	CFM56-7B27	11.912	1530.683
190221019	21/02/2019	17:47:07	RYR664P	RYANAIR	B738	A	TSF	737800	STANDARD	1	21.419	49.515	CFM56-7B26	CFM56-7B27	1.552	667.321
190221023	21/02/2019	18:01:02	RYR11UR	RYANAIR	B738	A	MAD	737800	STANDARD	1	21.537	50.576	CFM56-7B26	CFM56-7B27	1.552	667.321
190221021	21/02/2019	18:11:11	AZA1704	ALITALIA	A319	D	LIN	A319-131	ICAO_A	4	22.407	85.697	V2522-A5	V2522-A5	10.850	1457.823
190221024	21/02/2019	19:07:05	RYR4065	RYANAIR	B738	D	MAD	737800	ICAO_B	2	46.822	121.927	CFM56-7B26	CFM56-7B27	9.524	1213.410
190222003	22/02/2019	09:10:07	AZA5ZB	ALITALIA	A321	A	LIRF	A320-211	STANDARD	1	12.362	25.255	CFM56-5-A1	CFM56-5B	1.393	659.498
190222024	22/02/2019	09:29:07	EZY38AC	EASYJET	A320	A	MXP	A320-211	STANDARD	1	7.041	12.271	CFM56-5-A1	CFM56-5B	1.393	659.498
190222029	22/02/2019	10:38:42	THY2SU	TURKAIR	A321	A	IST	A320-211	STANDARD	1	4.802	7.951	CFM56-5-A1	CFM56-5B	1.393	659.498
190222004	22/02/2019	10:42:46	AZA1710	ALITALIA	A321	D	LIRF	A320-211	ICAO_B	5	31.937	85.362	CFM56-5-A1	CFM56-5B	12.604	1633.429
190222026	22/02/2019	10:53:35	BMS3MZ	BLUEAIR	B738	A	TRN	737800	STANDARD	1	9.642	17.453	CFM56-7B26	CFM56-7B27	1.552	667.321
190222025	22/02/2019	10:56:05	EZY47DN	EASYJET	A320	D	MXP	A320-211	ICAO_A	5	29.610	69.899	CFM56-5-A1	CFM56-5B	13.303	1773.125
190222032	22/02/2019	11:04:22	AZA1746	ALITALIA	A320	A	LIN	A320-211	STANDARD	1	14.877	34.086	CFM56-5-A1	CFM56-5B	1.393	659.498
190222001	22/02/2019	11:21:45	AZA1731	ALITALIA	A321	A	LIRF	A320-211	STANDARD	1	8.401	15.231	CFM56-5-A1	CFM56-5B	1.393	659.498
190222030	22/02/2019	12:00:13	THY5BK	TURKAIR	A321	D	IST	A320-211	ICAO_A	5	33.105	94.120	CFM56-5-A1	CFM56-5B	13.303	1773.125
190222027	22/02/2019	12:03:23	BMS6GT	BLUEAIR	B738	D	TRN	737800	ICAO_B	6	59.679	123.045	CFM56-7B26	CFM56-7B27	12.333	1586.802
190222022	22/02/2019	12:05:16	EZY92JA	EASYJET	A319	A	VCE	A319-131	STANDARD	1	8.189	14.658	V2522-A5	V2522-A5	1.018	547.981
190222033	22/02/2019	12:25:17	AZA1747	ALITALIA	A320	D	LIN	A320-211	ICAO_A	5	33.526	81.362	CFM56-5-A1	CFM56-5B	13.303	1773.125
190222017	22/02/2019	12:33:21	EZY16WD	EASYJET	A320	A	MXP	A320-211	STANDARD	1	12.231	24.298	CFM56-5-A1	CFM56-5B	1.393	659.498
190222034	22/02/2019	13:14:37	RYR4DH	RYANAIR	B738	A	BGY	737800	STANDARD	1	7.924	13.946	CFM56-7B26	CFM56-7B27	1.552	667.321
190222023	22/02/2019	13:50:25	EZY67KY	EASYJET	A319	D	VCE	A319-131	ICAO_A	5	25.596	85.640	V2522-A5	V2522-A5	12.478	1656.707
190222016	22/02/2019	14:13:56	EZY71WU	EASYJET	A319	A	NAP	A319-131	STANDARD	1	11.260	22.791	V2522-A5	V2522-A5	1.018	547.981
190222031	22/02/2019	14:36:33	RYR2537	RYANAIR	B738	A	MLA	737800	STANDARD	1	21.061	67.935	CFM56-7B26	CFM56-7B27	1.552	667.321

Table C.4 Single event database based on updated dataset

Figure C.13 gives some noise contours, calculated for the updated dataset. Both contour shapes and areas appear more realistic. The updated dataset was provided to NLR for further analysis.

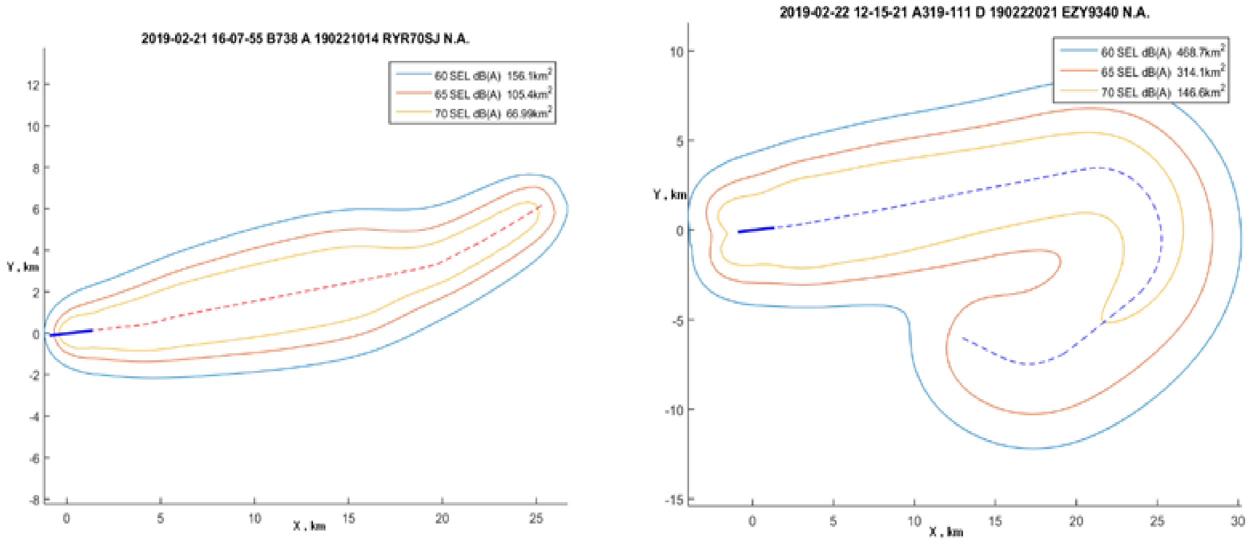


Fig C.13 Noise contours, calculated for the updated dataset

Conclusions

The initial dataset provided by the airport appeared to contain incorrect altitude information. A permanent solution for this takes more time than is available for the delivery of the present document. A temporary solution made it possible to obtain some correct data, with which the full process could be validated.

Based on the results described in this section, it can be concluded that the methodology developed for the interdependencies study, based on a simultaneous application of compatible models, is valid and gives useful results.

11.3. Annex C.3 NLR Approach

Note: the NLR approach is presented together, as results and discussion, to facilitate the understanding of the information flow, the work input and the method undertaken.

As explained in Chapter 5, the NLR objective was different (from the one taken by ANOTEC), aiming to investigate the potential for a *trade-off between noise and emissions* of four departure procedures. The purpose of the **NLR analysis was to demonstrate trade-off potential.**

Regarding the impact of different flight procedures, it is important to know the difference between emissions and air quality. The NLR analysis looks at emissions and not the impact of the emissions (air quality). This is important to emphasize, as for example, emissions of NOx above 1000 feet will have little impact on ground level – so a change in operational measures may have little impact on local or regional Air Quality (though PM and UFP may be different – but the science is not mature yet). Noise versus CO2 emissions is a much more relevant interdependency to look at, in this case.

Though the data used is specific to Catania Airport, the analyses are intended to be also valuable (examples) for other airports.

Data sources

Two datasets were provided by Catania Airport/ANOTEC as explained earlier. The first received dataset did contain inconsistencies, as described in section 5.3.

However, since the datasets contained sufficient information for its purpose, the NLR study was performed with concluding remarks. The following data was used in the NLR study:

- Aircraft type
- Airport of departure
- Airport of destination
- Distance along flight path (including ground roll)
- Time
- Altitude

Data analysis

The study approach and data analysis is described in the following three sub-sections:

- **Profiles**: Calculate flight profiles (speed, altitude, thrust as function of distance) for four different ANP procedures, and compare these to the average profile in the Catania dataset
- **Methodology**: Describe the applied methodology for assessing noise and emissions

Results

Present and discuss the noise and emissions results. The impact of procedure choice on noise and emissions is investigated and presented as *trade-off*. The idea is to provide the airport with an example of a choice between possible procedures which – of course – is up to the airport to trade-off applying the airport weights to the different aspects considered.

Profiles

As a first step in the analysis the aircraft speed was approximated from the location and time parameters present in the Catania Airport dataset. Aircraft speed and altitude were plotted as function of distance and these "departure profiles" were then compared with departure profiles calculated using ECAC Doc29 and aircraft performance data from the international Aircraft Noise and Performance (ANP) Database. This was necessary, since the Catania data did not provide information on thrust setting and knowledge about the thrust setting is necessary to calculate noise and emission levels. Four types of Doc29 profiles were considered (1x NADP1 and 3x NADP2). The NADP profiles were calculated for different de-ratings. As an example, four profiles for a specific aircraft type are shown in figure C.14. The presented profiles include a 85% de-rating on standard LTO settings in the take-off phase, no de-rating in the climb out phase and are calculated for an ISA+20 deg temperature.

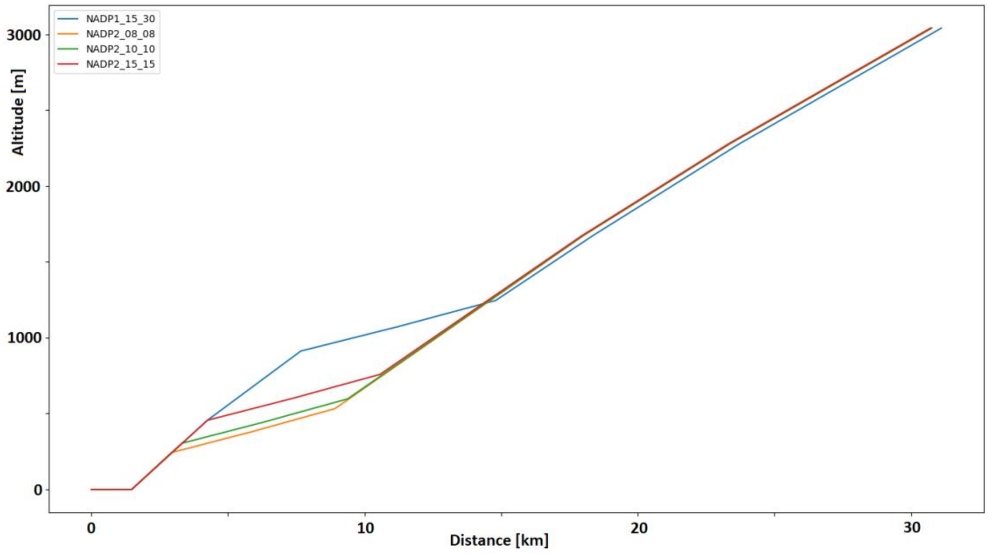


Figure C.14 Examples of four NADP procedures (NLR, March 2019)

The Legend of figure C.14 describes the four profiles generically as NADP1_xx_yy or NADP2_xx_yy where "xx" denotes the cutback altitude[106] of the flight profile (10 = 1000 ft, 15 = 1500 ft etc) and "yy" denotes the acceleration altitude[107] (10 = 1000 ft, 15 = 1500 ft etc).

The chosen NADP profiles have different cutback and acceleration altitudes, and therefore the *NADP profiles show different altitudes and speeds at the same time instance and distance from airports*. The latter is clearly shown in figure C.14 for altitude as a function of distance flown. The four variants were generated by taking one of the example departure procedures from the ANP database and applying modifications to thrust cutback altitudes and acceleration altitudes, in line with NADP1 and NADP2 definitions.

Aircraft departing from Catania airport have an average flight distance which corresponds to a pre assigned weight class. This weight class is class 2 and is used for the analysis of the profiles. This weight class corresponds to flights with a flight distance of 500-1000 nautical miles which is representative for the average of flights departing from this airport.

[106] The cutback altitude is the altitude at which the aircraft engine thrust setting is reduced

[107] The acceleration altitude is the altitude at which the flaps and slats are retracted

Since accurate information on aircraft engine types for Catania airport was not available, and since the **purpose of the current analysis is to demonstrate trade-off potential,** not be as accurate as possible, the analysed aircraft were matched to typical engines used for the same aircraft types at Schiphol Airport.

The profiles were calculated for ISA+20 temperature (International Standard Atmosphere), since this temperature represents the temperature around Catania airport in, for instance, August. However, profiles were also calculated for ISA temperature. The effect of temperature on calculated profile is presented in Figure C.15.

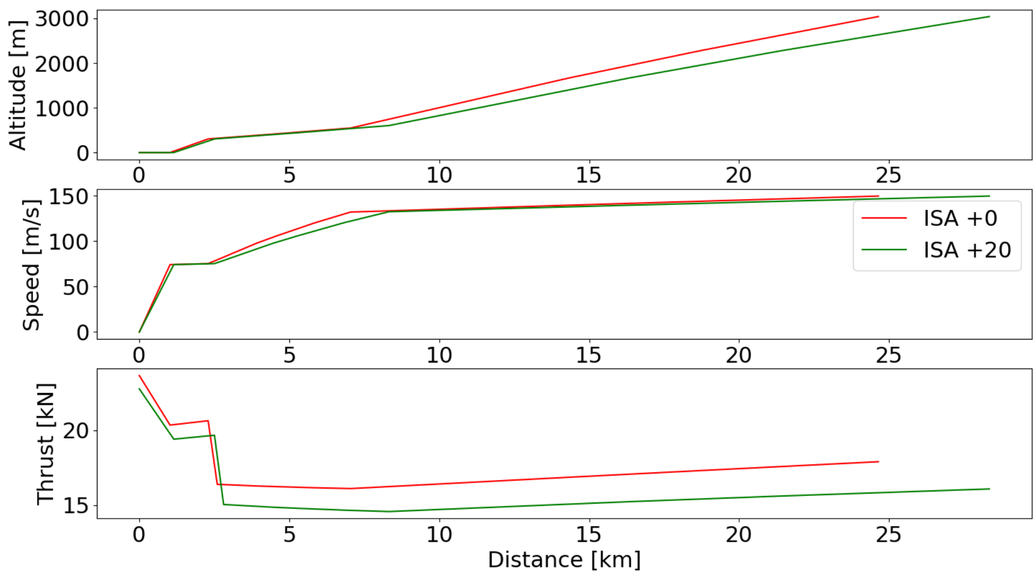


Figure C.15 Effect of temperature on aircraft performance shown by comparing a NADP2_10(-10) profile for two different temperatures

Figure C.15 shows that the higher the atmospheric temperature, the less thrust the engine produces with consequently both a *lower climb rate and a slower speed build-up.*

Comparison of the calculated profiles with the Catania profiles showed that the NADP2_10(_10) profile appeared to be most similar to Catania profiles. The de-ratings that fitted the Catania flights best was 85% for standard LTO take-off thrust setting and 100% for standard LTO climb-out thrust setting.

In the presentation of the results hereafter the NADP2_10(_10) procedure was therefore used as reference for the comparison with the three other procedures NADP1_15(_30), NADP2_08(_08) and NADP2_15(_15).

Methodology

The current study aims to investigate the **trade-off between metrics for noise and emissions**. As a case study NLR chose a typical day of traffic at Catania airport for two temperatures (a colder day and a warmer day), while varying NADP starting procedures.

As a ranking analysis does not critically depend on absolute noise values, the traffic distribution at Catania is approximated for the most common take-off (runway 08 east straight out, 8 knot head-wind) without the contribution of landings or other take-offs. Also we consider only LAeq (thus neglecting Lden penalties for evening and night flights).

The traffic is represented by taking the three most commonly observed aircraft at Catania (mid-sized jets) that make up approximately 90% of all flights. The relative contribution of these aircraft has been modelled (16, 27 and 31.5) with a total of 75 take-offs.

Since temperatures at Catania in summer are rather hot, the effect of a temperature of 35 degrees Celsius is also investigated as compared to a temperature of 15 degrees Celsius. The relative humidity is assumed to be constant (60%).

Noise modelling

Noise modelling has been calculated using INM software, version 7d. The fixed point profiles and noise tables have been adjusted for temperature and relative humidity.

Noise emission metrics are based on LAeq contour at 55 dB level. In addition to size of contour, the shape represented by the aspect ratio is calculated, defined as maximum width divided by maximum length. Defined in such a way, a larger aspect ratio represents a larger impact on the population of Catania, because most houses are situated lateral to the runway. On examination of the traffic at Catania, it was found that the number of flights at Catania is about a factor 10 smaller than a typical larger airport. Thus, a 45 dB contour at Catania corresponds to 55 dB contour at an airport with tenfold traffic. Therefore, the metrics calculated for a 45 dB contour are also included.

Emission modelling

CO2 and NOx emissions were calculated along the flight paths for each of the considered profiles. The calculated emissions depend on number of operating engines on the aircraft (aircraft type), engine type, engine thrust setting, engine operating time and other parameters like installation effects, aircraft speed, aircraft altitude, atmospheric temperature and humidity. As mentioned before, the calculations were done for the three most common aircraft types at Catania airport matched to typical engines for these aircraft types at Schiphol airport. The thrust settings and engine operating times during departure (85% of full thrust) were obtained from the profiles and translated to fuel flow and NOx emissions using ICAO Aircraft Engines Emissions Databank[108]. CO2 emissions were derived from fuel by applying a 3.14 kg CO2/kg fuel conversion factor.

A correction has been added for installation effects correcting the bare engine fuel flow to the installed fuel flow at a given thrust setting. Emissions were also adjusted for the effect of temperature and altitude.

A trapezoidal method was used to integrate the fuel consumption over time to obtain the total fuel within the chosen time frame. (The time frame originates from the time required to obtain a predefined altitude).

The Doc29 profiles consist of data up to an altitude of 3000m. So, in principal the emissions can be calculated from ground level up to a maximum altitude of 3000m. However, CO2 emissions were calculated up to 1500m (5000ft) and NOx emissions up to 300m (1000ft).

The CO2 emissions were calculated up to 1500m because the four considered departure profiles are approximately the same from this point onwards. So for the *comparison of the profiles* the CO2 emissions above this altitude are less relevant, though these emissions at higher altitudes – of course - do also have an impact on climate change.

NOx is modelled up to an altitude of 300m (1000ft) because above this altitude NOx has only a small impact on local air quality. Since the four profiles considered differ only for altitudes above 800 ft the difference in presented NOx emissions for the four profiles will be limited.

Results

Noise contours for Catania departure procedures

The effect of departure procedures on 45 and 55 LAeq contours is shown in Figure C.16 for the reference temperature (T=15, top) and a higher temperature (T=35, bottom). Clearly, the area size is reduced by about 40% at a higher temperature. When comparing top and middle graph, one can deduce that the area reduction due to changes in the flight profile (e.g. a decreased height, speed and thrust with higher temperature) is only modest. The reduction can be attributed to largest extent to a change in atmospheric propagation (e.g. a slight increased absorption) at higher temperatures (compare middle and bottom graph).

Furthermore, at each temperature, a change in shape is evident as a function of procedure. A narrowing and lengthening of contours for NADP2 compared to NADP1 can be observed for the 55 dB contour. This narrowing and lengthening seems in line with previously reported case study results for Schiphol (ANIMA)

[108] https://www.easa.europa.eu/easa-and-you/environment/icao-aircraft-engine-emissions-databank

which showed that compared to NADP1, the NADP2 procedure tends to decrease the noise levels near the airport (attributable to a lower exposure duration and thrust) and increase the noise levels further away (attributable to a less steep ascend). This trend is not observed for the lower 45 dB noise contour.

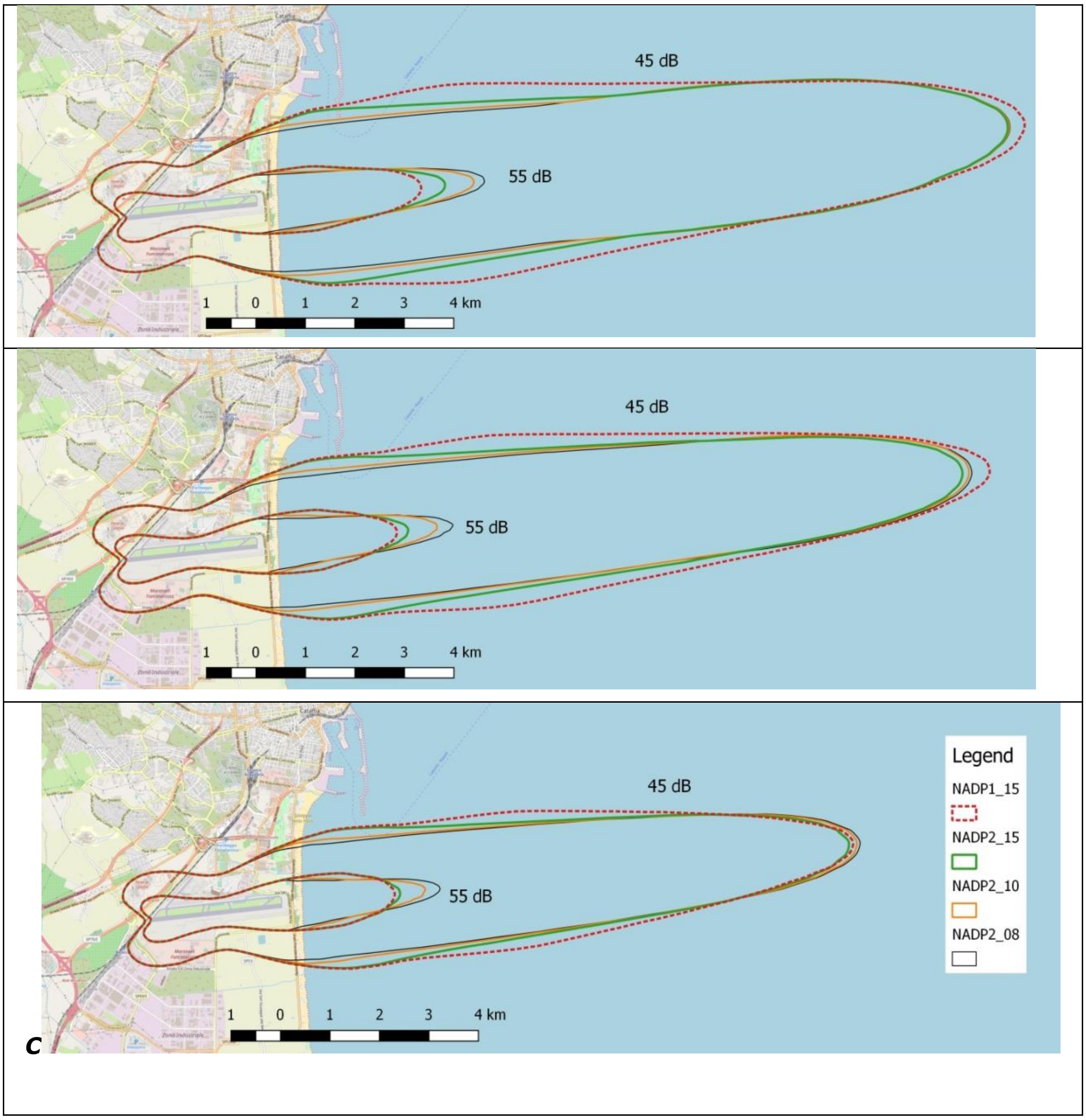


Figure C.16 Effect of start procedure on 45 and 55 dB LAeq contours for T=15 degree (top) and 35 degree (bottom). Middle graph: contours for T=35 degree flight profiles and T=15 degree noise propagation.

Trade-offs/interdependencies

Figure C.17 shows the effects of changing the departure procedures at both temperatures (T=15 and T=35 degree) after normalising the metrics for each temperature with Catania's most common procedure (NADP2_10). Metrics are normalized by dividing aspect ratio, area and emissions values for each considered profile by the corresponding value of the NADP2_10 profile (for the same temperature). Note that by scaling metrics per temperature, a representation is given that does not show the large effects of temperature on noise area (and the effect on NOx emissions), **but does reveal the trade-offs as a function of a parameter that can be manipulated**. Interestingly, trade-offs between noise metrics and emissions can be observed, as well as trade-offs within noise or within emission metrics.

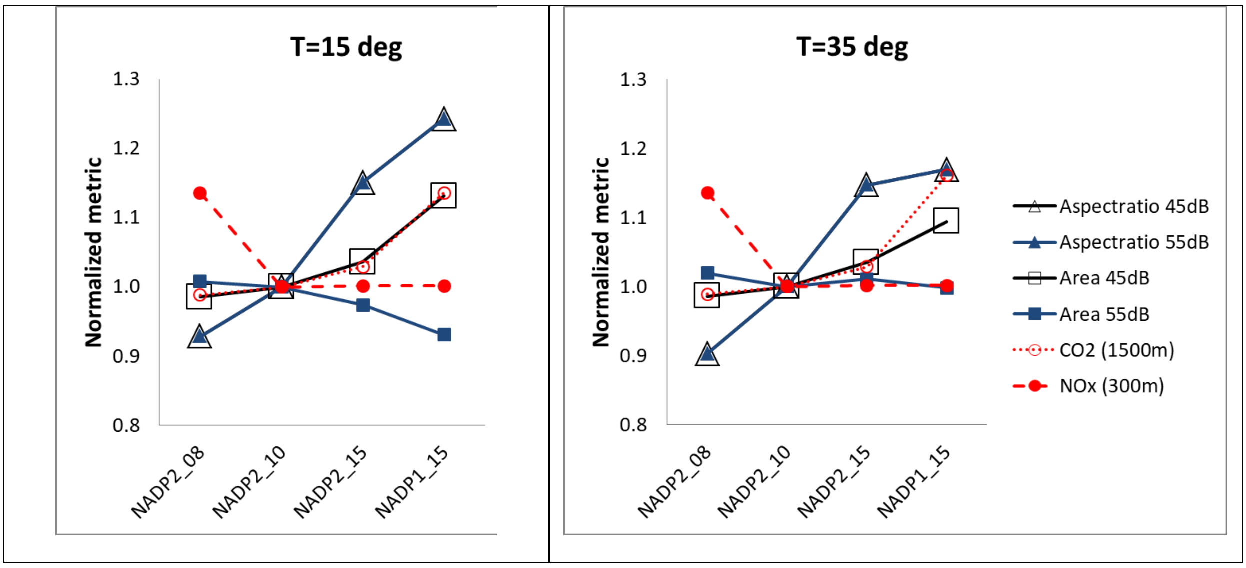


Figure C.17 Trade-off between metrics for noise (aspect ratio and area at 45 and 55 dB LAeq contour levels) and emissions (CO2 and NOx) as a function of NADP procedure.

First of all, the aspect ratio (width vs length) shows an upward trend with increasing NADP2 cutback height and is largest for the NADP1-15 procedure. This upward trend is independent of contour and temperature. In contrast, the trend for area size for T=15 degree is upward for the 45 dB contour, but downward for the 55 dB contours. ***Thus, a trade-off can be observed between aspect ratio and noise area for the 55 dB noise contours***. A trade-off between aspect ratio and 55 dB area metrics is still present at T=30 degree, albeit less pronounced.

Secondly, figure C.17 shows, on the one hand, a downgoing trend for the NOx emissions for both temperatures. This trend is a result of the lower cutback and acceleration altitude for the NADP2-08 profile as compared to the other three profiles, resulting in more flying time below 1000ft and therefore more NOx emissions at lower altitude than the other three profiles. As mentioned before the expected impact of this difference in NOx emissions on local air quality will be small. On the other hand, the CO2 emissions show an upgoing trend since more time is flown with (more) extended flaps up to 1500m altitude. The decreasing trend in NOx emissions and the increasing trend in CO2 emissions also show that a trade-off may be considered to take place between types of emissions.

The same trade-off trends can be observed in Table C.5 after ranking. Note, the noise aspect ratio is the same for 45 and 55 dB (see also fig. C.16). Both scaled and ranked-based analyses indicate that a more advanced weight and cost-function will be necessary to determine which procedure is best to reduce the emissions.

T	Procedure	Noise (aspect ratio)	Noise (Area 45 dB)	Noise (Area 55 dB)	CO2 (kg, 1500m)	NOx (kg, 300m)
15	NADP2-08(-08)	-	-	+	-	+++
	NADP2-10(-10)	0	0	0	0	0
	NADP2-15(-15)	+	+	-	+	++-
	NADP1-15(-30)	++	++	--	++	++-
35	NADP2-08(-08)	-	-	++	-	+++
	NADP2-10(-10)	0	0	0	0	0
	NADP2-15(-15)	+	+	+	+	++-
	NADP1-15(-30)	++	++	-	++	++-

Table C.5 Trade-off table illustrating results

Trade-off table expressing results in for instance: "+, 0, -, ++, ..." (depending what is important/of value to Catania Airport).

Note that care must be taken to generalise these trade-off trends to larger airports. First of all, the noise metric LAeq scales logarithmically with the number of flights. To generalise these trade-off results to airports with more flights, the noise metrics would therefore need to be calculated for contour levels that are scaled appropriately (e.g. 10 dB per tenfold increase in number of flights). Also, the aircraft modelled here are mid-size aircrafts so that trade-off relations may be different if more heavy weight classes are included.

In summary, the above presented data indicates that trade-offs between and within (for) noise and emission metrics can be found when using normalized or ranked metrics. However, due to a small number of flights involved in this exercise, a clear conclusion can't be drawn.

It also shows that a more advanced cost-function is required to determine which procedure is best to reduce the emissions. Since it is up to the airport (and other stakeholders) to decide upon the procedure that would best fit the local evaluation of different environmental aspects, no final choice can be made here regarding the procedure to be chosen. A further discussion with Catania airport will take place during T2.5.

The trade-offs are applicable to higher temperatures as well (ISA+20 degree Celsius). For the noise area metric, the trade-offs depend critically on the chosen contour level.