PROJECT FINAL REPORT

Accompanying Document &
Publishable Summary Report of Technical Achievements

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Introducing Remarks

This accompanying document is the collection of the work package summaries, giving the project activities and technical achievements in more detail and in first hand from the work package leaders.

Its aim is to explain with deeper technical information and give additional understanding by including diagrams, tables and figures.

This document is understood to be "add-on" to the official final project report of COSMA, its content is declared by the authors to be publishable.

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Content

Work Package 1: Specifications, Assessment and Exploitation

1. Task 1.1 – Specifications and Exploitation

Powerplant and aircraft definitions **(D1.5)** have been provided to define the configurations to be used in the current and future scenarios involving current aircraft technology. 3 aircraft of different size (i.e. number of passengers) and Range (with maximum passengers) have been proposed as representative of the annoyance caused by a typical airport operations. The considered aircraft are powered by conventional turbofans and have the following main characteristics:

- Aircraft 1 (short range, bi-engine):
  - o Passenger seating: 150 in a two-class configuration (12 first, 138 Yankee).
  - o Range: 3200 NM with maximum passengers.
- Aircraft 2 (long range, bi-engine):
  - o Passenger seating: 293 in a two-class configuration (30 business, 263 Yankee) and 253 in a three-class configuration (12 first, 36 business, 205 Yankee).
  - o Range: 7250 NM with maximum passengers.
- Aircraft 3 (long range, quad-engine):
  - o Passenger seating: 525 in a three-class configuration.
  - o Range: 8200 NM with maximum passengers.

A "Sound Files Specifications" document **(D1.1)** has been established to support the WP3 activity aimed at producing the various sound files needed to assess the WP5 scenarios by means of the WP2 Lab Tests. As a result, D1.1 provided:

- An overview of the sound files needed to accommodate the 5 scenarios developed by WP5 and to be tested in WP2.
- A list of the aircraft noise samples to be used by WP3 in building up the sound files for the Lab Tests the sounds to be provided for finalizing the Sound Machine (SM) features.

Final recommendations were made **(D1.13)** to favour further exploitation of COSMA achievements. They include the organization of legacy archives covering key COSMA results and core data as well as proposals for a dedicated annoyance workshop to be co-located with Internoise 2013 and supported by X-Noise

2. Task 1.2 - Literature review
The literature review activity involved 2 deliverables:

- **D1.3&1.4**.part 1: List of moderator variables affecting annoyance around airports - based on literature study
- **D1.3&1.4**.part 2: Variables affecting annoyance around airports - critical review based on literature and expert opinion

The first report lists and ranks moderator variables affecting annoyance and sleep disturbance around airports based on a detailed summary of the available literature. Moderator variables are defined as non-acoustic factors that change observed relationships between the input (ie noise) and the output (ie reported annoyance). Two additional chapters are included; the first based on practical examples from the Schiphol CROS field studies indicating gaps in knowledge and a the second showing suggestions of possible use for the WP4 virtual resident.

The second report builds upon and extends the literature review covered by part 1. The relationship between aircraft noise exposure and community response is complex and can be influenced by a wide range of different moderator variables with different effects in different situations. Currently accepted exposure-response relationships are subject to a wide range of different kinds of uncertainty in practical applications. Many but not all of these uncertainties can, in theory, be resolved by future research. Each variable included in any study must be clearly defined to avoid ambiguity, particularly of cause and effect.

Detailed findings from literature review (part 1 & 2) are as follows:
- Guski's conclusion that overall variance can be divided into sound level, moderators, and random factors stands.
- considering moderators and effect modifiers separately, as is suggested by some authors, would not be helpful for COSMA
- demographic variables are included in surveys because they are easy to measure and are widely believed to be good predictors of complaints and community action, although they mostly have small or negligible effects on annoyance and are not useful for policy. Some demographic variables are included in COSMA to check representativeness of samples.
- situational variables have strong effects on annoyance but can be difficult to measure (i.e. when are you normally not at home?) and are less useful for policy.
- acoustic variables other than LAeq have strong effects on annoyance, but could be difficult or impossible to deal with by policy makers. It would not be possible to include independent variation of all acoustic variables of interest in any feasible experimental design, but COSMA should nevertheless measure as many of them as possible.
- attitudinal variables have strong effects on annoyance but can be difficult to define or measure
  - e.g. noise sensitivity is difficult to define precisely and could mean different things in different contexts.
  - e.g. fear of airplane crashes can be important but is difficult to measure without introducing bias.
  - cause and effect can be impossible to unravel
  However, some attitudinal variables, if properly understood, could be of considerable value for policy.

In view of providing recommendations to WP2, the literature review and associated technical discussion confirmed the preliminary view that;
- The research to provide a conclusive list of moderators has not been done.
- Different moderators can be more or less important in different situations.

The selection of questionnaire items for the WP2 telephone interview study took the findings of WP1 literature review into account. It was recommended that the WP2 telephone interview survey should include open questions to discover which moderator variables would be mentioned spontaneously, rather than reading out extensive lists which might introduce bias anyway.

3. Task 1.3 - ANIKBEM

The activity related to the Aviation Noise Impact Knowledge Base and Exchange Mechanism (ANIKBEM) was given time to better formulate the concept and associated issues. A specification document (**D1.2**) was first produced to provide preliminary requirements from the systems aspects.

In anticipation of further steps in concept formulation, a preliminary analysis of wider aspects and potential issues was also carried out.This has lead to emphasize the need for clarification on two key aspects:
1. What information / tools the COSMA consortium would be willing to involve in the exchange mechanism and at what conditions
2. What the "wider world" would be willing or be in position to exchange

This has lead to complement the set of specifications trough several successive steps:

1. Requirements for an Aviation Noise Impact Knowledge Base and associated Exchange Mechanism **(D1.7)**, which include considerations on Storage, Information Extraction, Categorization and Mutual interest model

2. Knowledge Base and Exchange Mechanism Design **(D1.9)**. The Design phase addressed the four key elements described above. A group of experts acting as custodians will provide advice in the task of populating the knowledge base. A typical categorization, in the form of folders and subfolders, has been developed to initiate the ANIKBEM process. As a key facilitating feature supporting the Mutual Interest Model, this should permit in particular access to the specific data supporting a given study and allow to augment the core data base by means of additional experiments conducted in a manner consistent with the relevant protocols. The Mutual Interest Model (MIM) has been considered along its two-dimensional requirements:
   - Make sure information provided by third parties is relevant and brings added-value
   - Make sure the initial content of the knowledge base provides enough incentive to inititiate the process

   On the first aspect, it was decided to use the filter of the Professional Registration Expertise Questionnaire implemented on the X-Noise website to identify the credentials of researchers providing information to include in the knowledge base. The cusdodian group will then be in position to support inclusion of the new information in the base as well as grant access to the requesting researcher (through dedicated username & password provided by the system in return). The questionnaire, accessible through the X-NOISE Secure Site data base system allows to attach documents to it. Once a given person / organisation is registered, this will remain the normal way to post documents in the ANIKBEM, so that the custodian group filter system remains effective.

   The second aspect has involved a consortium consultation on the key results from the COSMA project to make available in order to initiate and validate the MIM. Key COSMA results (also called Legacy information) were identified in D1.13 (Exploitation Policy). A subset of these key results has been selected to support the ANIKBEM demonstrator.

3. Software: Knowledge Base and Exchange Mechanism Demonstrator **(D1.10).** The ANIKBEM demonstrator has been implemented in practice using support from the COSMA Public Website as well as the X-NOISE Public and Secure Websites, thanks to the features described in the previous section. The demonstrator will be maintained and further developed by X-NOISE after the end of the COSMA project.

4. Task 1.4 – Dissemination: Public Website and Final Workshop

The dedicated COSMA Public Website **(D1.6)** is accessible at:http://fp7-cosma.eu/

The site is hosted by the server of the Laboratory of Acoustics of BME and it can be accessed via the broadband university network. The maintenance cost of the domain (fp7-cosma.eu) has a very low rate which ensures that the site will be also maintained after the end date of the project.

As can be seen below, the Project (Main) page describes the project generally, gives the basic information of the project and describes the workplan. The periodic project publishable reports are available, summarizing the most recent achievements. The Consortium page lists the partners of the project. All partners have a short general description, a sort description of the role in COSMA and an URL. Workpackages pages present each workpackage's activity in detail.

Links have been established with the X-NOISE public website (www.xnoise.eu) which features a description of the project objectives and partnership, along with other EU projects involved in aviation noise research. The list of publications related to COSMA activities is also accessible at this address and the project public summary reports further disseminated through this channel.

The final Dissemination Event (**D1.12)** was organized March 14, 2013 in Brussels, attended by some 40 participants, including external experts and researchers. Two sessions were dedicated to presentations showcasing achievements COSMA from WP3and WP5, then WP2 and WP4. A third session involved presentation of the ANIKBEM concept followed by an open discussion. The workshop was concluded by the EC.

5. Experts Panel

The Experts Panel attended the Kickoff meeting and performed project assessment at the occasion of the 18 Month and Final Meetings.

Three members of the Panel (Ken Hume, Samir Gerges and Patrick Boussard) attended the 18-Month meeting and provided on-site comments at the end, emphasizing the complexity and ambition of the COSMA work programme, also stressing the links with SEFA, and the progress achieved in keeping up with a rigorous approach since then. Such continuity has also favoured close partners collaboration, considered as a key factor of success in this project. Three members (Ken Hume, Samir Gerges and Peter Hullah) also represented the Experts Panel at the Final Meeting and Dissemination Workshop, providing comments on the project achievements as well exploitation aspects in view of future research efforts.

Two deliverables (**D1.8** and **D1.11**) were issued summarizing the experts views and recommendations at mid-term and at project end.

Work Package 2: Annoyance Examinations

The COSMA annoyance studies were organised in WP2. Part of them were telephone and field studies at three different European airports, which were supported by the extensive literature study done in WP1. In parallel an extended analysis of original data of the Frankfurt Noise Annoyance Study 2005 *FRA-S* has been made at the beginning of the project in order to identify the important acoustical and non-acoustical factors for the prediction of both long-term and short-term (hourly) aircraft noise annoyance which could be on the one hand considered in the methodology for the telephone and field studies as well as served as a first database input for the Virtual Resident model development in WP4.

One possible way to reduce annoyance around airports besides reducing the SPL is to improve the sound quality of future single aircraft fly-overs. An Interactive Sound Synthesis Machine (SSM) was developed in WP3 with which WP2 subjects had the possibility to create their own preferred sounds for different aircraft by using faders, assigned to attenuate or amplify several distinct acoustical parameters like buzz saw, tonal components, airframe noise, etc.. Technical constraints of future noise reduction potentials were considered, the overall-loudness always remained constant. In order to analyse their potential to reduce annoyance around airports in future airport scenarios, provided by WP5, i.a. these improved aircraft sounds, so-called *target sounds*, were examined in three comprehensive laboratory studies in a living-room atmosphere.

Telephone and field studies:

Several studies around airports in the past found out that not more than one third of the variance in the annoyance judgments could be explained by acoustical features. A broad number of non-acoustical factors which might vary from airport to airport became more and more important. This suggests that there is no one exposure-response curve for annoyance that fits for all airports.

The extensive telephone and field study examinations in WP2 were carried out around three European airports: London-Heathrow as a main hub, Cologne/Bonn as an airport with many movements in the night and Stockholm-Arlanda as a main Scandinavian hub in a non-densely populated area. Aim of the 1.200 telephone interviews with more than 40 questions at each airport (scopes: residential area, noise annoyance, coping measures, attitudes, demographic data) was to map the status quo of current aircraft noise annoyance situation as well as to provide information about the most important non-acoustical variables explaining the variance in the annoyance judgments. Furthermore, the results of the telephone interviews served as the basis to identify the areas where the field study subjects were recruited. In the field study at every airport 50 subjects were examined for six days whereas for four days and nights the outer sound pressure level was continuously measured, damping parameters were determined and the acute annoyance during daytime quantified by means of brief hourly questionnaires using a netbook. Comprehensive opening and conclusion questionnaires were applied as well as sound quality judgment sessions at the subjects' residence.

In these extensive acoustic datasets the single aircraft events had to be identified by means of flight schedules and flight route maps and more than 40 acoustic parameters have been calculated. This work has been done by WP4. The results of these acoustical data were used for the final statistical analysis of WP2 field data:

The main aims of the field studies were:

- the determination of acoustic indicators that predict best acute annoyance.
- the determination of non-acoustical variables that influence long-term annoyance overall and at night.

Acoustic predictors of noise annoyance

The acoustic stress that causes annoyance is a complex variable, where not only the sound pressure level but the temporal and spectral composition plays a decisive role. Noise stress is usually indicated by a single number but this number can be composed and calculated by differently weighted acoustic parameters. For the present study noise stress during the day and for each hour was expressed by a battery of overall 33 indicators. There are 27 that base on outdoor measurements and 6 person-related indicators that consider the actual stay of the participants i.e. the changes between indoor and outdoor stays. Considerable differences between the three airports could be demonstrated. The most important variable that determines hourly annoyance at the airports Cologne/Bonn and Stockholm obviously seems to be the total number of aircraft as well as the number of aircraft above 55, 60, 65 and 70 dB(A) (NAT55, NAT60, NAT65, NAT70) and the time an aircraft is perceived. The correlation coefficients are much higher at Stockholm than at Cologne/Bonn, most likely due to the low background noise as indicated by the highly significant correlation between annoyance and the signal to noise ratio in Stockholm only. Cologne/Bonn is the only airport where hourly annoyance correlates significantly with the equivalent noise level in the expected direction. The correlation coefficients determined for London Heathrow were throughout less than 0.2, which might be due to the influence of other noise sources in the very noisy neighbourhood around that airport.

Time of day

The analysis of the most annoying times of the day (Figure 1, Table 1), gained from the opening questionnaire, revealed that annoyance overall and at night is higher in those persons who feel particularly annoyed on weekdays and on weekend days in the early morning (06:00 to 07:00) and/or in the evening (20:00 to 24:00). For weekend days annoyance from 13:00 to 14:00 was again decisive for the evaluation of long-term annoyance.

It was, however, disadvantageous that the participants revealed a very low annoyance rate during the four days where the participants rated hourly the degree of annoyance from 7:00 to 22:00. Eighty per cent of the answers indicated that the participants were 'not at all' or 'slightly' annoyed. This rather low rate prevented e.g. the statistical analysis of activity-related annoyance.

Table 1. Significant odds ratios of moderator variables: time of day.

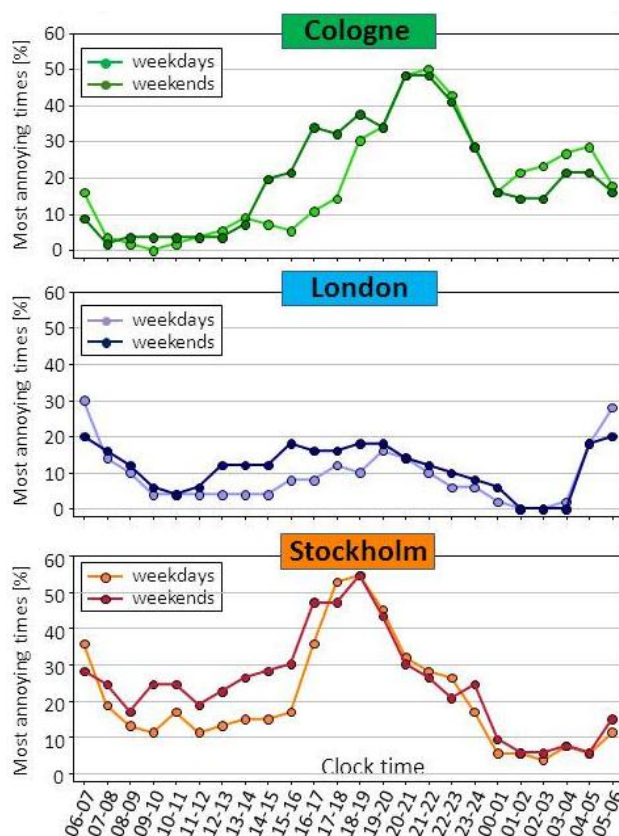|	Annoyance overall (24 h)		Annoyance at night	
	Clock time	All airports	Clock time	All airports
Weekdays	06-07	**8.18**	06-07	**4.10**
	23-24	**4.58**	22-23	**5.58**
Weekend	06-07	**9.59**	06-07	**4.80**
	20-21	**3.83**	22-23	**8.02**
	13-14	**4.94**		

Figure 1. Most annoying clock times rated for long-term aircraft noise annoyance

Summary of non-acoustic variables that enhance annoyance:
Long-term annoyance is determined by a huge number of non-acoustical factors. The following lists can just give a rough survey of the most important non-acoustical factors for the long-term annoyance and for annoyance at night resulted from the analysis of the extended datasets gained in the field studies.

Overall annoyance (24h):

For all three airports the stepwise selection of variables identified the following factors with a significant higher risk of being highly annoyed:
- being most annoyed at weekdays between 6:00 – 7:00 and 23:00 – 24:00
- being most annoyed at weekends between 6:00 – 7:00, 20:00 – 21:00 and 23:00 – 24:00
- being disturbed at mental work and relaxing indoors
- being disturbed at relaxing outdoors
- being disturbed at falling asleep, at sleep in the 2nd half, having a reduced sleep quality
- using coping strategies
- being less satisfied with noise insulation
- thinking that aircraft noise is bad for health for the individual and for the residents in general
- not agreeing with the opinion that the airport is important for the economic system
- thinking to get used to aircraft noise in the future
- being noise sensitive
- not having influence over results of airport decision processes
- not feeling fairly treated concerning aircraft noise

Annoyance at night:

For all three airports the stepwise selection of variables identified the following factors
with a significant higher risk of being highly annoyed at night:
- being most annoyed at weekdays between 22:00 – 23:00 and 3:00 – 4:00
- being most annoyed at weekends between 22:00 – 23:00 and 6:00 – 7:00
- being disturbed at relaxing indoors or outdoors
- being disturbed at falling asleep, at sleep in the 2nd half, having a reduced sleep quality
- having shorter occupancy
- using coping strategies
- being less satisfied with noise insulation
- thinking individually and globally that aircraft noise is bad for health
- not agreeing with the opinion that the airport is important for the economic system
- thinking to get used to aircraft noise in the future
- being noise sensitive
- not feeling fairly treated concerning aircraft noise.

Based on the Odds ratios for the non-acoustical factors the influences on annoyance can be
summarized as in Figure 2. It shows that disturbances at night and resulting annoyance at night,
disturbances of relaxation, negative attitudes against the airport, particularly the fear that air traffic is
a health hazard and the necessity to apply coping measures enhance annoyance. In contrast,
satisfaction with the area the respondents live in, the conviction that they get used to aircraft noise in
the future and the feeling to be fairly treated by the airport authorities reduce the chance to be
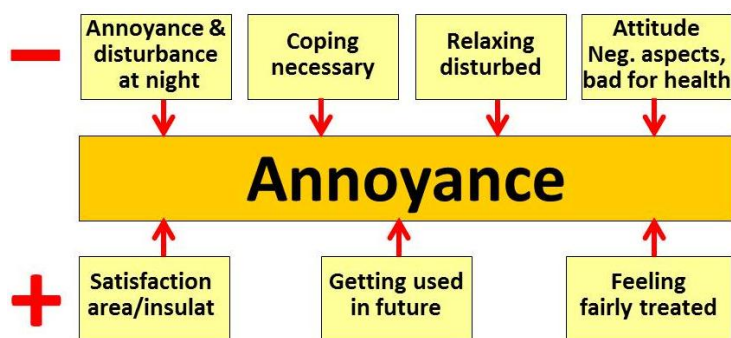annoyed by aircraft noise.

Figure 2. Summary of non-acoustical factors influencing long-term annoyance

The current EU exposure-response curve for highly-annoyed residents around airports bases on a
meta-analysis of studies accomplished before 1990. Aircraft noise has explicitly changed since those
times, the aircraft became significantly quieter but their number considerably increased which
altogether results in similar equivalent sound pressure levels. As several newer studies already
indicated, although it was not the purpose of COSMA to develop new exposure-response curves, the
example given in Figure 3 for Cologne/Bonn airport also confirms that the EU curve has to be
updated. Apart from the acoustics, this time also the non-acoustical factors have to be considered in
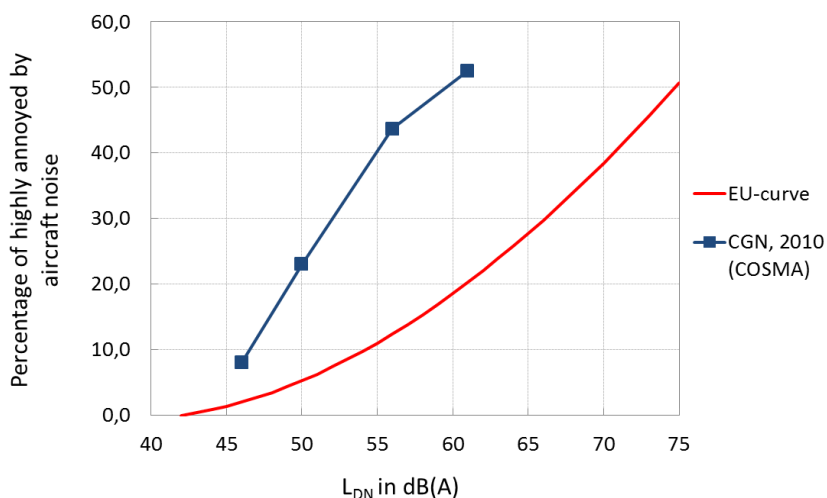order to be able to describe annoyance around airports.

Figure 3. Exposure-response relationship for the percentage of highly annoyed residents around Cologne/Bonn Airport (Telephone study) plotted against the generalized EU-curve.

Laboratory studies:

Objectives and the general design of the laboratory studies

Laboratory studies are required for the evaluation of optimised/improved future airport noise scenarios vs. current airport scenarios as they allow the variation of the acoustic stimuli (number of sound events – noise levels – sound quality etc.) while keeping constant other environmental factors. Participants, placed under laboratory conditions close to the real world situations (from noise exposure and host conditions points of view) are exposed to air traffic sounds reproducing different sound situations. During this time, they perform various "like at home" activities as well as a cognitive performance task.

The evaluation and the comparison of these scenarios were carried out on the basis of the following criteria:

- short term effects: overall annoyance - activity disturbance - cognitive performances
- perception of single overflights (sound quality);

Experimental protocol

The protocol was applied to four comparisons, involving 288 participants: 72 per comparison and 96 per laboratory.

Table 2: Experimental protocol

	Activities and Tasks	**min**	**Noise exposure**
	Demographic questionnaire Training Stroop test	15	Background noise

Experiment (1st run)	Sound scenario 1 or 2 Reading magazines / Memory task/ Stroop test	45	Aircraft & back.
	Short term annoyance questionnaire	5	Background
	Memory task / Stroop test Free time	30	Background
Experiment (2nd run)	Sound scenario 2 or 1 Reading /Memory task / Stroop task	45	Aircraft & back.
	Short term annoyance questionnaire	5	Background
Assessment of single overflight	Listening to 5, 8 or 10 aircraft overflights questionnaire	20	Aircraft & back.
	Concluding questionnaire	10	Background

The role of the number of aircraft

The first and the second comparisons focused on the number of aircraft sound events respectively at takeoff and landing. The baseline sequence is composed with 22 events (5 different types of aircraft) and is compared to 11 aircraft (2 different types of aircraft among the 5 of the baseline sequence). All sequences were supposed to transport the same number of passengers (about 4000 passengers).

For these two comparisons with about the same equivalent sound level (± 1 dB(A)), and the same peak levels, the number of aircraft had a significant influence on global annoyance ($p<0.001$ for take offs and $p<0.006$ for landings), which can be summarized by higher scores of annoyance for 22 aircraft than for 11 aircraft. There was an interaction between the sequences and the order of the listening. At the time, the annoyance is rated in the median of the scale whatever the number of aircraft, but the difference between the 22 and the 11 event sequences was clearly noticed at the second listening.
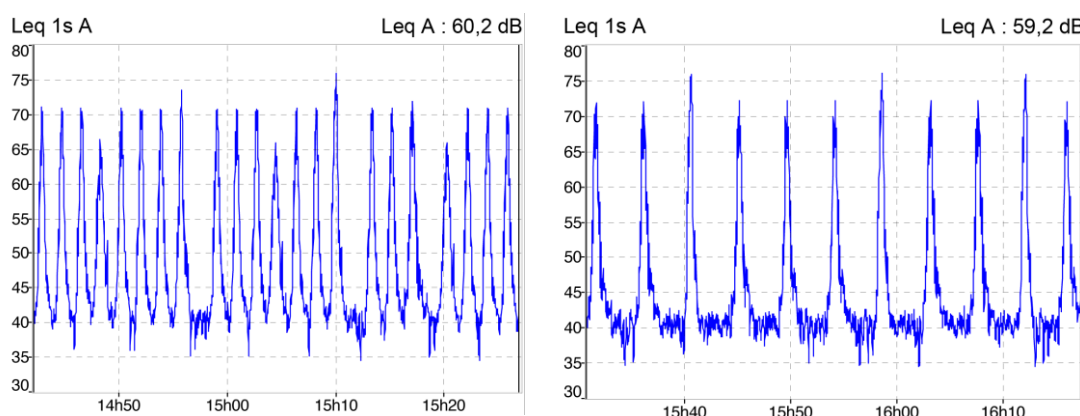

Figure 4: Example of the sound level evolutions for the 22 and 11 events at take off (first comparison).

The memory task which was judged as the most difficult activity is the most disturbed by the aircraft noise. The rating of the global annoyance is similar to this activity disturbance. The global annoyance is also correlated to the reading task which lasts 30 minutes over the 45 minute duration of the listened sequence. Performance scores are not influenced by the noise sequences.

The role of the proposed optimizations: sound quality and new approach procedures

During these comparisons, the baseline sound sequence was composed by 22 aircraft (5 different types of aircraft for sound quality and 3 different types of aircraft for new approach procedure). For these two comparisons, each flyover has been optimized. For the sound quality optimization, the sounds which have been created by the participants to the sound machine tests took place of the original aircraft sounds. For the new approach procedure, each original flyover has been substituted by synthesized sounds with an optimized trajectory.

In both cases, the annoyance is not significantly reduced by the optimisation. This is not to say that there is no influence of the sound quality or of the approach procedure, but the number of subjects is too small here to reveal such a subtle effect, due to the large variance between the participants.

The assessment of single flyovers.

In accordance to the results of the SEFA project, the COSMA laboratory tests confirm that the most annoying factors are the perceived loudness, the spectral balance and the duration of the flyover.
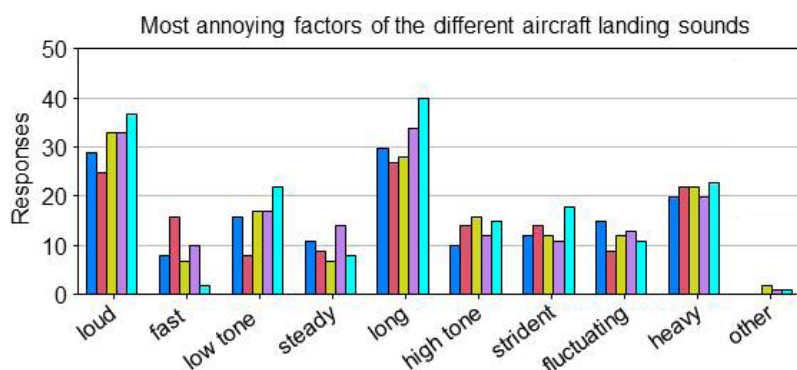

Figure 5: The most annoying factors mentioned by the participants, concerning 5 different aircraft noise at landing.

Reducing some of the annoying factors (for example reducing the high tonal components keeping constant the noise level) does not always lead to a reduced annoyance, due to the fact that some other annoying factors (for example the low broadband noise or the fluctuations) are sometimes perceived as amplified.

Outlook:

The very detailed analysis of the COSMA field and laboratory studies shows that understanding the annoyance due to aircraft noise is a very complex issue. The variance in the annoyance judgment of airport residents can not solely be explained by acoustics, non-acoustic factors become more and more important. There is not one exposure-response curve that can describe the annoyance around all EU airports.

Indeed the ratio of acoustic factors explaining the variance in annoyance judgments becomes smaller. However, reducing the noise at the source will confidently reduce annoyance around all airports. Further small improvements can be achieved by enhancing the sound quality (especially tonal components, buzz saw noise).

Non-acoustical factors as they were identified and ranked in the COSMA studies, on the contrary, might vary from airport to airport and also in time. But they, on the other hand, have the potential for airport managers and politics to clearly reduce annoyance around individual airports shortsight whereas reducing aircraft noise at the source typically needs ten years and more until the more modern aircraft fleet at an airport equipped with the "quieter" technology reached a significant number.

Reducing the annoyance around airports first requires a detailed analysis and description of the problem at the considered airport. Therefore, in the EU it is inevitable to replace the current exposure-response curve by several curves for different kinds of airports respecting the findings of COSMA. An open and trustful communication between airport/politics and residents is one main key point for a successful implementation of annoyance reducing procedures. Future annoyance studies necessarily should tackle this issue.

Work Package 3: Sound Engineering

1. Major outcomes of WP3

The major outcomes of WP3 are:

- A dedicated sound engineering tool was developed allowing a sound quality accurate synthesis and analysis of aircraft flyover noise events in airport communities. The tool is composed of two components:

    - On-line SOUND MACHINE (SM) for interactive sound quality analysis of single aircraft flyovers

    - AIRPORT NOISE CLIMATE SYNTHESIZER (ANCS) producing multiple event sound sequences in real airport scenarios based on source component data and noise propagation models

- Several airport scenarios were synthesized based on WP5 engineering guidelines for aircraft designs and operations

2. SOUND MACHINE

Aircraft sounds are composed of various harmonics (fan tones, turbine tones, buzz-saw, airframe cavity tones, etc.) and broadband noise components (jet noise, airframe noise, combustor noise, fan noise, etc.) with complex inter-relations affecting the sound quality perception.

In the SOUND MACHINE tool, faders are assigned to the individual sound components allowing subjects to change the composition of the sound during playback and compose a more preferable target sound. The tool has an inner algorithm that compensates for the loudness changes introduced by the fader operations. The software is controlled by an external hardware device with a touch screen presenting the most important control elements (faders, start/stop, etc.) to the user.

The fader input sound components were generated for several aircraft types of the AIRBUS fleet (A318, A320, A330, A343, A346) in both take-off and approach conditions. A dedicated sound decomposition algorithm was used to extract the harmonics and broadband noise components from aircraft noise recordings.

The SOUND MACHINE tool was delivered to WP2 for target sound design studies.

3. AIRPORT NOISE CLIMATE SYNTHESIZER

The AIRPORT NOISE CLIMATE SYNTHESIZER (ANCS) tool allows reproducing the noise environment at any location in an airport community with the capability to consider the effect of novel aircraft technologies and noise optimized procedures. ANCS is a powerful sound engineering tool using source component spectra and noise propagation models as a basis for the noise synthesis.

The V-ACD tool, developed in the foregoing project SEFA, was used as a starting base for the tool development. Several new functionalities were implemented:

- An interface was made to the SOPRANO tool, which serves as a data management tool to support and manage any kind of source component models and data

- Source component modification capabilities are provided, allowing impact assessment of technology increments and novel aircraft technologies

- Improved noise propagation models are integrated, covering turbulences, wind effects and complex terrain effects

- Complex airport scenarios can be synthesized including multiple events

- Sound quality post-processing algorithms allow computing noise annoyance maps for airport communities

A 3D sound reproduction system was developed and interfaced to the ANCS tool to enhance the degree of authenticity of the synthesized sounds. The sound system combines a conventional surround setup with four line array speakers mounted above the listener. The sounds are presented within a cube of 4m (length) x 2.1m (width) x 2m (height). Digital sound control is done with Adobe Audition 3.1 in multi-channel mode. The 3D method successfully simulates a spatial sound environment which is more effective than one generated by stereo or mono sound reproduction.

A case study was conducted to test and validate the complete ANCS chain including the modeling of the aircraft noise sources and their propagation to the ground, the synthesis of audio signals and their comparison to noise recordings. The exercise was done for an AIRBUS A320 in take-off and approach. Public domain source prediction models were developed for airframe noise, fan-compressor noise and jet noise. The procedural parameters relevant to the noise prediction models were provided by WP5. Flyover sounds were synthesized for an observer point at 9 km from the runway and compared to noise recordings. The noise signatures of the simulations and measurements show a good correspondance in both time and frequency. The synthesized sounds were judged as realistic in terms of perception, confirming the validity of the tool.

4. Synthesis of airport noise scenarios

Five airport noise scenarios were synthesized as listed in table 1. The fleet is composed of AIRBUS planes of types A318, A320, A330, A343 and A346.

a) Airport scenario 1

Airport scenario 1 is the reference scenario comprising existing aircraft and standard procedures. Four multiple event sound sequences of 45 minutes each (1 baseline sequence and 3 optimized ones using different optimization criteria) were synthesized for both take-off and approach.

b) Airport scenario 2

Airport scenario 2 was generated by replacing the individual aircraft sounds in reference scenario 1 by their respective target sounds. The target sounds were obtained from the SOUND MACHINE tests in WP2. Four sound sequences with duration of 45 minutes were produced for take-off and approach.

c) Airport scenario 3

Airport scenario 3 was generated according to optimized flight procedures specified by WP5. Four sound sequences of 45 minutes were generated for take-off and approach.

d) Airport scenario 4

Design optimizations were studied in airport scenario 4. Approach and take-off sounds were generated for an aircraft with optimized wing geometry.

e) Airport scenario 5

Novel technologies were investigated in airport scenario 5. Sounds were synthesized for the AIRBUS RFN (Rear Fuselage Nacelle) configuration obtained from the OPENAIR project.

SCENARIO	SEQUENCES	OPTIMIZATION CRITERIA
SCENARIO 1 a/c: current proc: standard	SEQ 1 SEQ 2 SEQ 3 SEQ 4	Baseline EPNL at single point Maximum no. events (small AC) Minimum no. events (large AC)
SCENARIO 2 a/c: target sound proc: standard	SEQ 1 SEQ 2 SEQ 3 SEQ 4	Baseline EPNL at single point Maximum no. events (small AC) Minimum no. events (large AC)
SCENARIO 3 a/c: current proc: optimized	SEQ 1 SEQ 2 SEQ 3 SEQ 4	Baseline EPNL at single point Maximum no. events (small AC) Minimum no. events (large AC)
SCENARIO 4 a/c: design optimization	Single event	Optimization of wing geometry
SCENARIO 5 a/c: novel technologies	Single event	AIRBUS RFN configuration (OPENAIR)

Table 1: Overview of synthesized airport noise scenarios

Work Package 4: Virtual Resident

1. Introduction: Task of the VRes, kinds of input, expected output

The main goal of WP4 was to develop a Virtual Resident (VRes) tool simulating human subjective perception of aircraft noise. As part of the model, the VRes tool is able to predict human response to i) single aircraft sounds, i) hourly aircraft noise exposure as well as iii) the long-term annoyance of airport residents who are regularly exposed to multiple events.

The VRes tool (Figure A) has been developed into a standalone, executable program and has been extensively tested and validated.
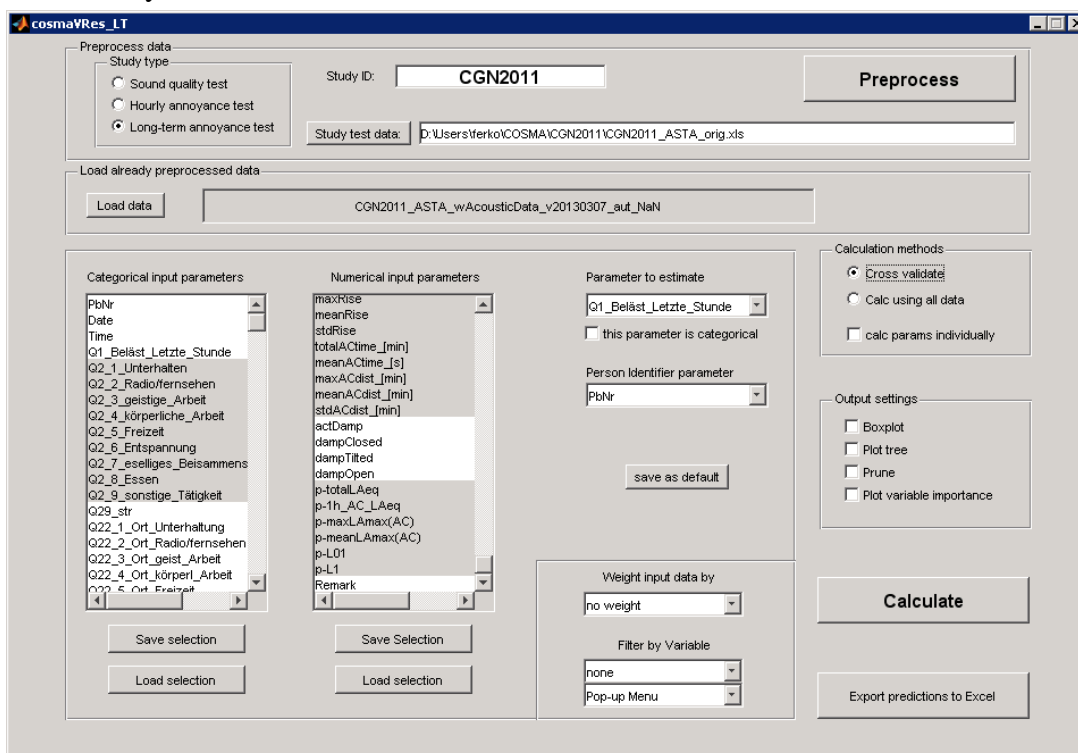
Figure A. The Virtual Resident tool's user interface

The tool has been set up and validated by using COSMA WP2 field study data. Please note that the amount of data doesn't allow that the tool could be used as an universal annoyance prediction tool for different airports. It has been validate to be fully operational and having a reasonable accuracy for this set of data, but extensive analysis of the data revealed that the dataset itself cannot be seen representative for whole airport populations even not for the examined airports (either the dataset is too small or the gathered information is not detailed enough).

The general workflow of the WP2's test-data processing is as follows:
a) Acoustical scenarios, which can be as short as 1 flyover but can be as long as one year, are measured/calculated and human responses are collected to rate these scenarios. Participants taking part in the tests give also non-acoustical information about themselves.

b) The software uses then a certain amount of data to set up a model and uses the remaining to test the model (i.e. by predicting annoyance for the unused data-set and comparing to the actual ratings).

c)

2. The COSMA Virtual Resident software

The tasks of the software can be divided into 2 main parts:

- pre-processing of the data, i.e. bringing various kinds of data to the required input format, extracting/selecting relevant information / reducing the input data set
- running the Virtual Resident's core algorithm on the pre-processed data: parameterising the model (i.e. "teaching" it) and then predicting annoyance (for the model) unknown data

2.1 Pre-processing of the data

In COSMA 3 different kinds of data have been collected during the field studies: long-term annoyance through telephone interviews and computed acoustical data, hourly-annoyance through in-situ SPL-log measurements and hourly based participants' ratings and single fly-over sound preference through in-situ noise recordings and participants' ratings. The core algorithm to be applied on them are the same, so different pre-processing is needed to bring the different kinds of data into the same format. It is of key importance that the input data, which is fed into the core algorithm, is condensed enough, so for tests producing huge amount of data a very strong data reduction is needed.

B) Telephone interviews: long-term annoyance

The input data is already very condensed, in fact from the point of view of acoustics it is not detailed enough. (Note: The main goal of these tests were to find the governing non-acoustical parameters influencing annoyance, not to collect data for calculating dose-response curves for the airports under test.) So for the telephone interview data there is no input data pre-processing necessary. Just data importing is performed.

B) Field studies: hourly annoyance

During the hourly annoyance tests of the field studies, SPL-logs have been recorded at participants' home. Making use of actual airport flight schedule data, from the SPL logs aircraft flyovers are identified and then acoustical data is computed for the hours, which have been rated by the participants. For this kind of data requirements to the format of the various input data are exactly specified. The pre-processor reads these files and computes hourly-acoustical data from them. The details pre-processing for this kind of data are as follows:

- Phase 1: flight detection algorithm
STEP 1: Estimation of the background noise level
First a smooth background noise level curve have to be computed so later-on peaks (the possible fly-overs) emerging from the background noise can be identified. This is done by calculating a sliding percentile filter of the SPL-log data, which is then smoothed by an exponential low pass filter. (see Figure B)

STEP 2: Find events by advanced peak-picking with constraints
The SPL-log is smoothed by a Savitzky-Golay filter. The resulting lower order function is used to compute local maxima. The found local maxima is thinned out by adding constraints. The first constraint is that the local maxima must exceed by a certain amount of dBs (L_{constr}) the background noise level. The second constraint is the minimum time gap between two events (T_{min}), which is characteristic for each airport.
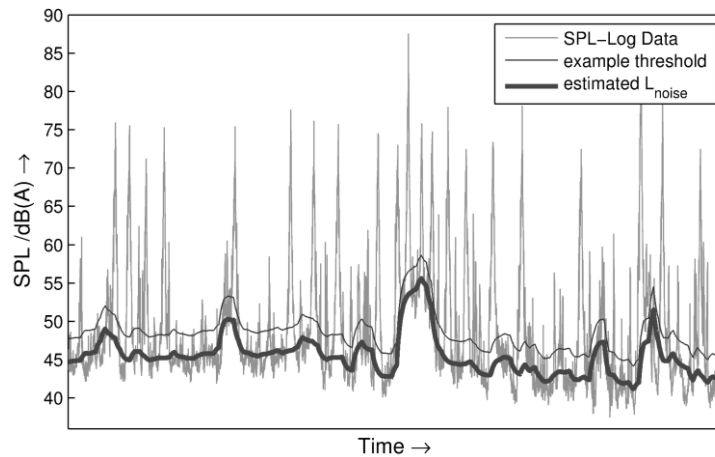

Figure B. Estimation of the background noise level. The erratic thin line is the measured SPL-log data, the thick smooth line is the estimated background noise level and the thin smooth line is the estimation plus an arbitrary bias, i.e. the minimum required level for peaks.

STEP 3: Assign corresponding flight events from the flight schedule if provided
To make the detection more reliable cross correlation between found maxima and flight events in the airport's actual flight schedule is calculated. This allows the determination of the mean approach/departure time lags at participants' site. Finally a nearest neighbour search allow to pair the found peaks in the SPL logs and the entries in the airport's flight schedule.

- Phase 2: acoustical parameter extraction

After identifying the fly-overs in the SPL log, aircraft specific acoustical parameters can be computed: e.g. number of aircraft (with L_{Amax} above a certain level), duration of fly-over events, time influenced by aircraft during the individual hours, aircraft-only L_{Aeq}, Aircraft level ratio to background noise level). Knowing the location of the participants during the analysis hours and the position of the windows (open/closed/tilted) a kinds of personal acoustical levels can be computed, which are approx. the levels what the person was exposed to (ignoring indoor noise sources, i.e. focussing only on the external noises). Together with regular acoustical parameters, the module computes a total of 39 parameters.

C) Field studies: sound quality examinations

During the field studies participants also had to sit in their living rooms quietly (2 times each 1 hour) an listen to passing-by aircraft. After each fly-over they had to rate it. During the tests the noise was recorded. This way an immense amount of measurement data (approx. 30 GB/airport) have been collected together with the participants' ratings (approx. 600/airport). To build models for this kind of data, first from the wave recordings, the flyovers have to be isolated, then for each fly-over (psycho-)acoustical parameters have to be computed. In the VRes tool included pre-processor needs the already isolated fly-overs to be stored as individual wave files. It computes then the (psycho-)acoustical data for the core algorithm by

means of the SAP tool (Sound to Acoustic Parameter converter tool – which have been developed by the SEFA European project).

2.2 Core Algorithm

For the actual data processing two kinds of models have been developed: a Categorical and Regression Tree- and a multi-step Neural Network based model.

A) Categorical and Regression Tree modeling (CART)

Categorical and Regression Tree modeling works by recursively sub-dividing the data into smaller parts. Normally the model is constructed as a binary tree where each node of the tree is a simple yes/no question and the answer guides us to next node until we reach a leaf and the predicted value. An example of a prediction tree model can be seen in Figure C. The nodes closer to the root of the tree contain the questions that will maximize the information about the predicted values at the leaf.
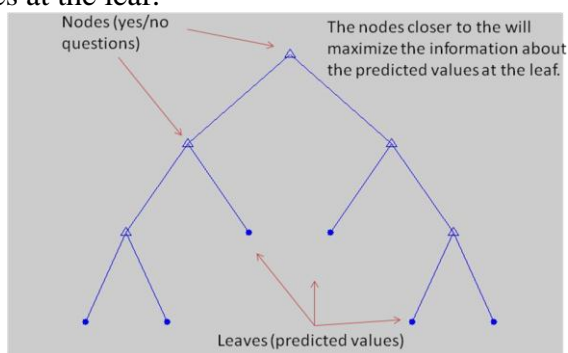
Figure C. Example of a prediction tree modelling

The raw output from a CART analysis is a decision tree, which can be quite large to use for model purposes. Therefore a process called pruning is commonly used to reduce the size of the tree. This procedure can be performed in several steps to reduce important variables that have been discovered and consequently to reveal other parameters that might predict the annoyance.

B) Neural Networks (BME)

The Neural Network based core algorithm uses a function approximation approach to predict annoyance for acoustical events (both short- and long-term). Function approximation means that an unknown mapping from measured parameters onto annoyance is supposed and it is aimed to learned by Radial Basis Function Neural Network. Hence, input parameters are supposed to be of numerical types (categorical descriptors cannot be handled).

The training process of the network (by a data set called *training set*) consists of three steps:

1. Principal Component Analysis is used to reduce the dimensionality of the input space. (By using PCA transformation similar parameters can be merged and parameters having no impact on the explained variance can be neglected.)
2. In order to reduce the uncertainty of human subject's ratings, clustering (i.e. grouping) of the data is used. Clustering algorithms group the data, which are near in the input space (acoustically similar events), and after grouping the center of the cluster and the mean annoyance of their elements is used for model building. (I.e. several points in the input space are "merged" to create a more stable set of input data.)

3. The RBF network is then trained by the clustered data. In the RBF Gaussian basis functions and the same width parameter for all the basis functions are used. The width parameter is calculated by an empirical formula, however it is fine tuned by using the training set.

After training the RBF net, predictions can be computed by feeding unknown data (called *test set*) into the trained model. For each element of the test set (i.e. each acoustical event) the expected annoyance can be predicted by the optimized RBF net. If one has the human ratings (annoyance values) for the test set as well, the performance of the approximator (RBF net) can be determined by different metrics such as correlation or mean squared error.
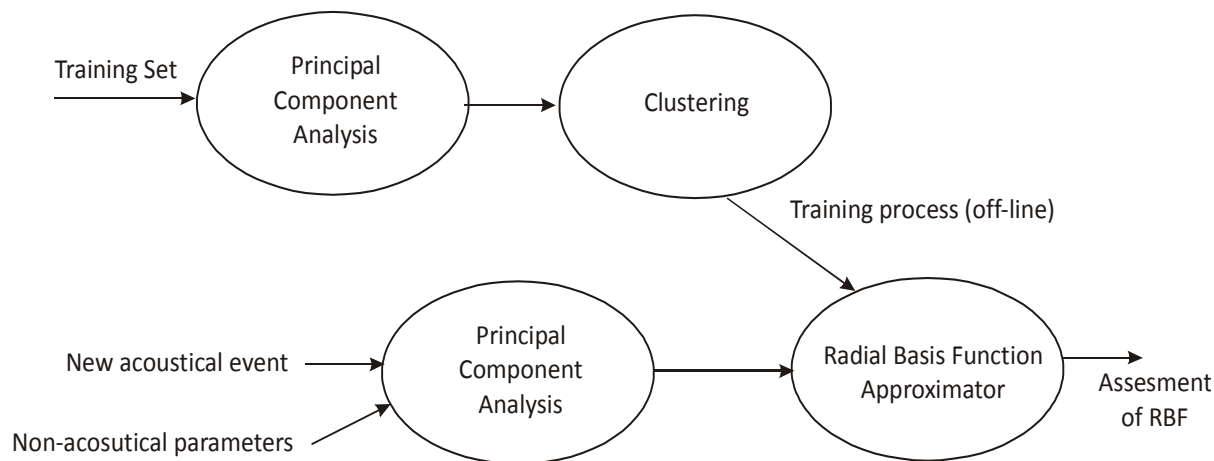
Figure D. The structure of the RBF based Virtual Resident

3. Evaluation of COSMA field study data

A) Performance of prediction models with the VRes tool

After building and fine tuning the Virtual resident tool it has been extensively tested. The accuracy of the models is reasonable, the correlation between predictions and actual ratings is approx. 0.7-0.8 for all three kinds of input data. (Note that for hourly-annoyance and single fly-over tests the data have been grouped so the very high uncertainty in participants' responses is lowered and the models are evaluated by the mean annoyance ratings vs. approximations of groups. The point-by-point correlation for both kinds of tests were approx. 0.3-0.4.)

Taking into account the high uncertainty of human ratings and the relatively small data set collected in COSMA one can say that the models are fairly good and they are worth to be applied on larger (future) field study data.

An additional outcome of the VRes tool is the possibility to determine parameter importance from the fine-tuned models, i.e. to be able to say, which are the most important parameters, which determine the annoyance. As the results for the collected data cannot be generalised and the data-sets even don't represent fully the examined three airports the extracted parameter importance is not presented here.

B) Exploration of further aspects of the data

Aim of this activity was the prediction of annoyance ratings measured by the *hourly annoyance* of groups of subjects and of individuals considering three different cases:

- Case #1: All three WP2 airport data sets were analysed by applying generic (sample based) *time series* modelling, i.e. selected hours (e.g. 10-11 a.m.) are predicted from the data of all the other data.
- Case #2: Time series modelling is applied to *individual data* (Cologne data only).
- Case #3: Data of *individual subjects* are predicted based on the data of the remaining subjects using again on all three data sets.

Dependent on time the Case #1 generic modelling showed GOF-scores (Goodness Of Fit – is the Pearson's correlation between real and predicted annoyance values.) in the range from $r = 0,27 – 0,75$. The mean GOF – function depicts an inverse U-pattern having maxima in the range from $r = 0,6 – 0,65$. In the early morning hours and in the evening the mean GOF-scores are considerably less than in the time between.

Individual modelling of the Cologne data (Case #2) allowed a separation of "high responder" (GOF: $r <= 0,5$; 34,9 % of the sample) and "low responder" (GOF: $r <= 0,2$; 37,2 % of the sample) participants, i.e. how strongly a participant's rating is determined by acoustics.
ANOVA showed a significantly higher hourly annoyance level over time of the "high responders" as compared to the "low responders" (p=0.004). Differences were most pronounced in the morning and late afternoon. To explain this difference it can be hypothesized that both groups differ in perception and/or motivation related to the aircraft noise to which they are exposed. The interpretation of the GOF score as an indicator of motivation is confirmed by the results of the Case #3 analysis. In this case generic modelling of all individuals was applied to the data of the three airports by predicting the annoyance data of a selected subject using the remaining data. This allowed again to separate subjects having a GOF $>= 0,5$ from those having a GOF $<=0,2$. ANOVA showed a significantly higher hourly annoyance level over time of "GOF $>= 0,5$ subjects" as compared to "GOF $<= 0,2$ subjects" (p<0.001). Differences again were most pronounced in the morning and late afternoon.

As a conclusion it can be stated that motivation (i.e. the non-acoustical parameters of the individuals) plays a crucial role when trying to forecast annoyance by acoustical predictors. If the acoustical environment under study has no real impact on the affective state of the listener a valid prediction is not possible. On the other hand, interestingly, people being not too much influenced by acoustics report generally a lower annoyance – at least for hourly annoyance. Most probably these people are disturbed by other factors of the air transportation as the acoustics of one or the other hour and even if they perhaps report higher long-term annoyance they report low annoyance levels for hourly annoyance tests.

Work Package 5: Optimisation of Airport Noise Scenarios

COSMA's WP5 has dealt with all the aspects more strictly related to the aeronautical engineering domain. In this respect, two main functions can be identified: on one hand, the support to the other work packages in providing all the technical information and data required to accomplish their tasks; on the other hand, the definition of the final engineering recommendations, design directions and operational constraints to eventually achieve a community friendly aviation system, with a level of annoyance as lowest as possible. As a consequence, all the results and foregrounds achieved in WP5 should be contextualized within this framework, in order to properly understand the technological and cultural advancements. In doing this, it must be kept clear in mind that the two mentioned functions have been always carried out in a deeply interconnected fashion, to comply with the basic requirements of a continuous multidisciplinary interaction between the work packages.

The main results achieved in the work package can be summarized as follows:

1. A database of 2D noise optimized procedures, including the noise spectra at specified positions on the ground, as well as a database of sequences of take-off and landing events, optimized with respect to objectives related to the number and/or the type of the aircraft involved. A tool for the generation of the sequences sound files out of a database of recordings or simulations.
2. A large database of multi-objective, multidisciplinary optimizations of 3D procedures, including the complete sets of operational settings of the aircraft, ready to be used in the synthesis of sound files.
3. A database of spectra describing the effect of the low noise technologies on the most energetic aircraft noise sources, as well as a database of directivity filters to take into account the effect of an unconventional engines installation in the synthesis of noise tracks.

All these results are directly related to the mentioned function of support to the other work packages. One of the fundamental needs of WP2 and WP3 was the possibility to have access to a complete, detailed description of the operational procedures, including the time history of all the settings of the aircraft, such as the engines operation point, the high-lift-device setting, and the angle of attack. Indeed, the descriptions of the take-off and landing procedures available in the literature (or through the use of commercial software) are typically limited to the basic features of the aircraft operation, such as the trajectory and the instantaneous speed. Furthermore, they are limited to standard, certified procedures. Figure 1 depicts one example of the set of parameters made available for each procedure analysed.
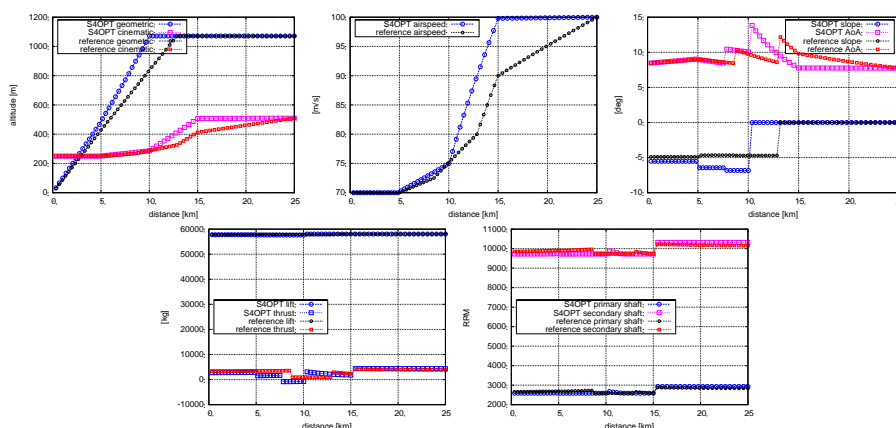

Figure 1 – An optimized procedure, and its detailed operational description.

In order to analyse the effect of complete airport scenarios, a number of sequences of events, ordered in five different technological scenarios, were introduced to help WP2 in the proper definition of the laboratory studies. Using the different scenarios, it has been possible to take into account not only the technologies currently available, but also those expected to be operative in the next two decades. The classification of scenarios and sequences is shown in Figure 2.
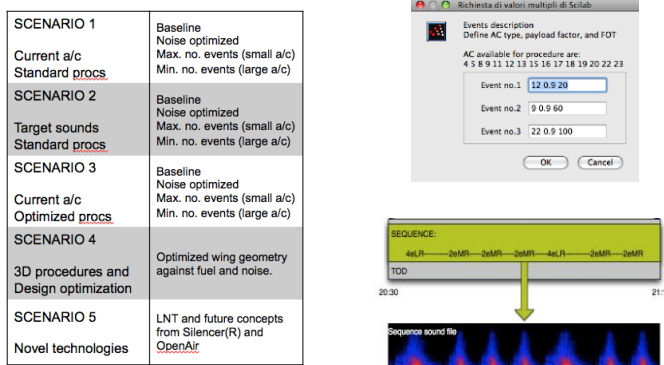

Figure 2 - Scenarios, sequences, the SequenceR tool and the resulting sound track.

Moving to a larger scale to consider the effects of approach and departure procedures on a wider area, the multi-objective optimization of procedures of noise and fuel consumption has been completed using state-of-the-art evolutionary algorithms. The results, in form of optimal Pareto sets (see Figure 3), have been the basis to implement an innovative decision-making approach, which is one of the major foregrounds achieved in WP5 during COSMA (see later).
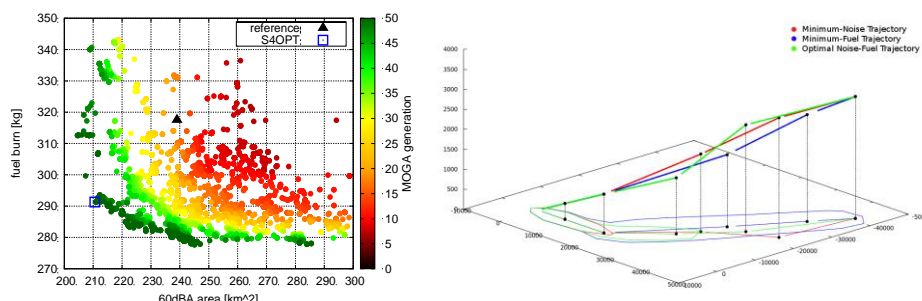

Figure 3 - Pareto set of a multi-objective optimization of an approach, and three selected solutions.

The activity in support of the sound engineering and annoyance assessment work packages has been completed with the evaluation of the benefits achievable using low-noise technologies and non-conventional configurations. Also in this case, the specific needs of COSMA required a dedicated approach to the problem. Indeed, the effect of technological advancements have been have been recast in form of spectral and directional filters, to allow the easy use of the simulations in the synthesis of sound. An example of these filters is presented in Figure 4.
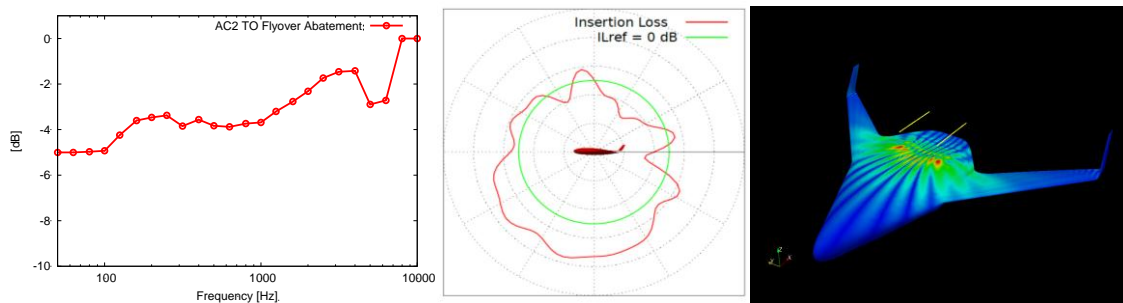
Figure 4 - Advanced technologies spectral and directional filters, to be used in sound synthesis.

On the second front of activity, *i.e.,* the identification of the design criteria and the operational constraints capable to potentially accomplish the recommendations received from WP2, the achievements can be considered as the main foreground produced by WP5. The interactive loop implemented at the beginning of the project (see Figure 5) has revealed to be an effective approach to include annoyance-related considerations in the optimal design process.
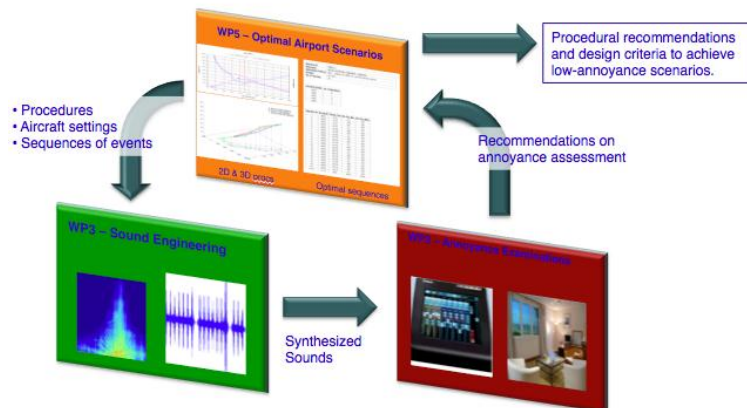

Figure 5 - Work packages interaction loop.

Thanks to the continuous interchange of information, it has been possible to address the final task using two different approaches.

1. The *"annoyance-driven optimization,"* where procedures and design concepts were optimized to minimize the influence of those noise sources which were considered as the more annoying during the Sound Machine tests.
2. An innovative *"decision-making"* approach, aimed at the selection of the least annoying design and procedural solutions along the Pareto front obtained with the multi-objective optimization.

Both the approaches represent a novelty in the aircraft design community, and definitely deserve additional investigation and development to disclose their potential. The preliminary results obtained in COSMA are extremely promising. An example is depicted in Figure 6, where the application of the LNT at take-off is limited to the noise components that are considered as the most annoying by the subjects analysed (see included table). As can be seen, the optimized procedures closest to the ideal points show a substantial difference in terms of noise level. The area bounded by the 60dB isophonic is reduced of about 30%, so the use of the LNT only on a subset of the sources did not affect significantly the benefit in terms of noise level. At the same time, the spectrum of the produced noise has significantly changed, due to the different contribution of the different components, with a substantial reduction only of the most annoying. These statements need to be verified with a second round of Sound Machine tests using the filters provided to take into account the advanced

technologies. Nevertheless, even in absence of this countercheck, the results obtained appear to be coherent and consistent with the interaction scheme adopted.
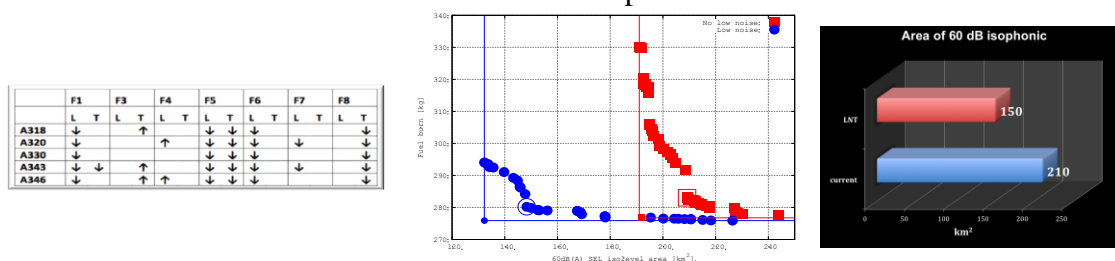

Figure 6 - *Annoyance-driven optimization***. Optimal Pareto sets obtained to minimize the influence of the most annoying noise components (F5 and F8, see table on the left).**

Even more interesting is the possibility to implement a reliable *"decision-making"* algorithm to select the least annoying solutions along the Pareto set, taking advantage of the results achieved in COSMA and of the experience previously matured in the earlier project SEFA (Sound Engineering For Aircraft). Indeed, the consistency of the Sound Machine tests suggests the possibility to automatically generate weakly annoying *target sounds* by simply applying the LNT filters to the most annoying components, and then use these sounds to verify which are the non-dominated solutions corresponding to noise spectra with the best matching with the target (see Figure 7). This approach represents an evolution of the sound-matching based optimization introduced in SEFA for isolated flyovers.
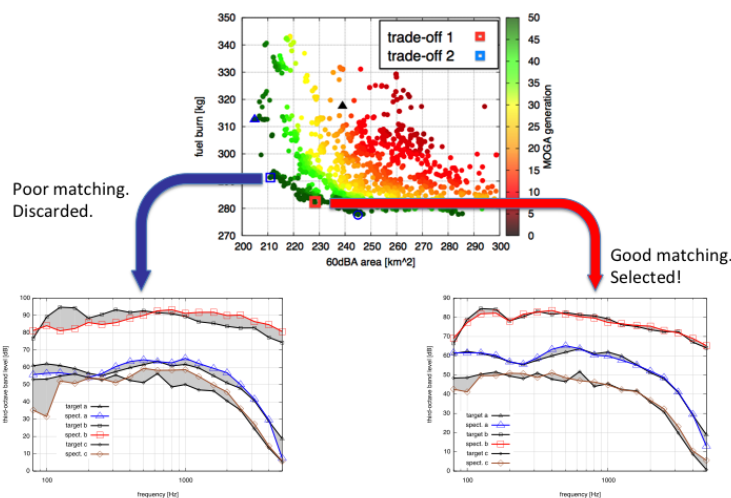

Figure 7 - Target sound matching optimization along the Pareto front.

The main novelty here is that the approach is not applied to all the possible solutions pertaining to the design space, but only on the subset resulting from the previous multi-objective optimization, thus limiting the research only to those solution that are by definition *Pareto optimal*. This procedure represents an innovative approach to the problem, and introduces a reliable, deterministic method to take into account in the design process an extremely complex phenomenology such as the community acceptance. To the aim of a better understanding of the potentiality of the approach, which represents probably the most important foreground of WP5, and to guarantee its further development, it is definitely worth performing additional investigations.