Sound Engineering For Aircraft
Content

• SEFA basic features
  • Partnership
  • SEFA objectives
  • Starting conditions
• Main achievements
  • Methods and results of psychometric tests
  • Aircraft target sound design
  • Development of a virtual aircraft tool
  • Developments of a virtual listener tool
  • Aircraft sound quality design criteria
• Conclusions
Title: Sound Engineering For Aircraft
Acronym: SEFA
Contract Nr.: AST-CT-2003-502865
Total Costs: 5.9 M€
EU Contribution: 3.9 M€
Starting Date: 01/02/2004
Duration: 36 months + 5months
Web-site: https://cms.x-noise.net/sefa/Portal/ (internal)

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SEFA partnership

- Dornier GmbH → EADS
- Snecma Moteurs
- Deutsches Zentrum für Luft- und Raumfahrt
- SASS acoustic research & design GmbH
- Metravib RDS
- Office National d'Etudes et de Recherches Aérospatiales
- Institut of Sound and Vibration Research University of Southampton
- Royal Institute of Technology
- Alenia Aeronautica S.p.A.
- Forschungsgesellschaft für Arbeitsschutz und Arbeitsphysiologie
- Budapest University of Technology and Economics
- Dipartimento di Ingegneria Mecc. e Ind. Università degli Studi Roma Tre
- Instituto Superior Técnico
- EADS Deutschland GmbH, CRC
- Université de Cergy Pontoise
- Institut National de Recherche sur les Transports et leur Sécurité
- Leuven Measurement Systems International N.V.
- C.R.F. Società Consortile per Azioni
- Institut für Technische und Angewandte Physik GmbH
- Universita' di Napoli "Federico II" DPA
Sound Engineering for Aircraft

... is the first approach applying sound engineering methods to control exterior aircraft noise.

Objectives

WP4
Expert Panel

WP5
WP2

WP3

WP6

Identification of least preferred characteristics of aircraft noise
Definition of preferred aircraft sounds
Development of design criteria for preferred aircraft sounds

Listening tests..........Target sound design..........Design criteria
Starting conditions

• Mathematics and statistics well known
• Never before applied to subjects listening to aircraft flyover sounds

WP5 virtual listener

• Large competence in tool development
• No methods for aircraft source noise synthesis

WP4 virtual a/c tool

• Large competence and experience in noise effects
• Limited experience for flyover sound quality listening tests in the laboratory

WP2 psychometric tests

• Strong experience from automotive applications
• Limited experience for flyover sound design
• No suited flyover recordings available

WP3 sound design

WP6 design criteria
WP2 achievements / Psychometric tests

Methods development for psychometric listening tests
- Development of test procedures for Semantic Differential as well as a Paired Comparison tests including
  - General questionnaire (personal data as age, gender, housing, occupation etc.)
  - Noise Sensitivity questionnaire NoiSeQ (individual noise sensitivity of each subject)
  - Mood questionnaire (current mood of a subject)
  - Audiometric pre-screening (hearing ability of a subject)
- Translation of the questionnaires into 7 languages and integration of one common software tool for a standardized procedure in 8 different laboratories
- Definition of common hardware for testing
- Pilot studies provided information on
  - subjects’ physical and mental fatigue during listening (max. 35 comparisons/session)
  - the importance of pre-training with sound examples

Methods validation
- Paired Comparison and Semantic Differential both are adequate methods to describe human perceptional space towards current aircraft sounds
- The laboratory standardization with common software and instructions was very successful
- Cultural effects, age, gender, noise sensitivity and the status of being an airport resident have no relevance on the judgment on aircraft sounds
WP2 achievements / Psychometric tests

Test series with matrix of current, recorded sounds
- For the subjects differences among the aircraft sounds were detectable, but the differences were small. Convincing dependences to psychoacoustic and clear standards for target sound design could not be derived exclusively.

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FT = future target configurations
T = take-off
A = approach
**WP2 achievements / Psychometric tests**

**Test series focusing on sound modifications of a/c #12 and #22**
- Check the influence of buzz-saw-tones (±5dB), fan tones (±5dB), broadband noise below 315Hz (±4dB), broadband noise above 315Hz (±4dB) and overall level (±3dB) vs. the original sound.

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**WP2 achievements / Psychometric tests**

**Test series applying combined sound modifications**

- Check the combined influence of buzz-saw, fan, propeller and turbine tones and jet noise for a/c’s #5, #8, #13, #11

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Ref.:
-4dB 0dB -8dB 0dB 0dB -4dB 0dB -8dB
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WP2 achievements / Psychometric tests

Test series applying combined sound modifications

• The scaling results were aircraft specific, i.e. effects were different in kind and order of magnitude depending on the perceptual frame of reference. The frame of reference is influenced by e.g. the sound features of the reference sound and the context in which subjects are asked to judge them.

• A ranking of modifications leading to specific recommendations was derived.
Generation of a sound data base

- A sample of 238 fly-over AC-sounds (arrival and take-off) was measured at three different airports in Europe (Germany and United Kingdom) using a binaural microphone technique. Fly-over events were documented by standardized photography and by airport fly-movement records.

- From the broad sample a core matrix of 32 sounds representing 23 aircraft (business, regional, short and medium range twin, long range twin, long range quad) was selected for further signal processing.
WP3 achievements / Target sound design

Signal processing

• For synthesis of aircraft sounds new methods were developed based on
  • spectral decomposition
  • non-linear filtering

• Based on original flyover recordings a database of several hundred modified aircraft sounds was generated using both methods

• These modified sounds were partly EPNL equalized and included an objective psychoacoustic analysis.

• Airframe noise predictions and synthesis.
Generation of sound modifications e.g. by modification of broadband noise spectrum over time and/or modification of tonal components.

1. Recorded sound
2. Broadband noise in third octave bands
3. Doppler shifted tones + third octave bands
4. Synthesized sound with interference pattern
WP3 achievements / Target sound design

SASS filtering method

Generation of a set of spectrally derived dynamic steering parameters which are tuned to the tonal components

Generation of dynamically changing filter parameters amplitude, frequency and bandwidth
WP4 achievements / Virtual aircraft tool

Development of a virtual aircraft tool VACD

- Providing realistic, audible flyover sounds for virtual aircraft configurations in order to generate a feedback link from target sounds to aircraft configuration

  - Assembly of noise source data on component level
  - Synthesize the source components on a time-depending flight path
  - Include Doppler effect
  - Include atmospheric absorption effects
  - Include ground reflection effects
  - Include indoor/outdoor propagation effects
  - Generate a tool architecture including a GUI (graphical user interface)
  - Qualification, validation and application
WP4 achievements / Virtual aircraft tool

Development of a virtual aircraft tool VACD

- Assembly of noise source data on component level
- Synthesize the source components on a time-depending flight path
- Include Doppler effect
- Include atmospheric absorption effects
- Include ground reflection effects

VACD graphical user interface
Development of a virtual listener tool VLIS

- Providing the average subjective evaluation of a flyover sound with respect to a preference scaling in order to replace future listening tests
- Assembly of WP2 data for tool development
- Optimization of data reduction procedure and selection of most appropriate descriptors
- Set up of mathematical models
  - Galois-Lattice theory
  - Artificial Neural Network
  - Statistical Regression Analysis
- Qualification, validation and application
Validation of VLIS

- Relevant (psycho-)acoustical parameters have been identified which allow good predictions of subjective response.
- The best performing parameters are the same as those identified by WP2.
- Performance limitations are due to the necessarily limited range of aircraft noise stimuli which could be tested even within the large SEFA test program.

VLIS graphical user interface

VLIS validation vs. test results
Definition of design criteria for optimized target sounds

- Within SEFA results the derived target sounds were aircraft type specific. For this reason global aircraft design guidelines cannot yet be defined.

- Guidelines for airframe and engine design and flight procedures have been derived according to aircraft specific phenomena. For example, for the aircraft #11 reference configuration it turned out that a reduction of the buzz-saw noise components leads to large benefits for the noise effects while it has only minor influence on EPNL. This would lead to the recommendation to adapt the rpm/bypass ratio or to integrate a zero-splice liner.

- A multidisciplinary optimization approach (MDO) has been extended on target sound design based on a sound similarity index implemented as a merit function.
Conclusions

Lessons learned

• The differentiation and scaling of aircraft sounds is a very difficult task for typical listeners. One of the reasons is that full flyover events are continuously changing during a typical 40 sec. duration.

• Effects of specific sound features (e.g. fan tones) are largely depending on the overall sound composition of a flyover event, i.e. a number of other tonal and broadband components.

• Global target sound optimization has more dimensions than anticipated at the beginning of SEFA.

Achievements and results

• Validated methods for sound quality listening tests

• Validated aircraft flyover sound synthesizing methods for target sound design

• Validated tools estimating sound quality effects (VLIS) and the corresponding aircraft configuration

• A number of sound modifications have been identified which have an effect on sound quality additional to the sound level.


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Thank you for your attention!