QUIET DRONES 2022

SECOND INTERNATIONAL SYMPOSIUM ON NOISE FROM UASs/UAVs and eVTOLs

PROGRAMME BOOK

JUNE 27-29, 2022

An e-Symposium from Paris

INCE*EUROPE*

CidB
Centre d'information sur le Bruit

ORGANISATION

This Symposium is organised by INCE/Europe in association with CidB with the support of:

ARC (Airport Region Council (Belgium)

ARPAS (the UK Drone Association)

DGAC (the French Directorate-General for Civil Aviation)

DLR (Deutsch Zentrum für Luft-und Raumfahrt)

I-INCE (International Institute of Noise Control Engineering)

The French Ministry for the Ecological Transition

NLR (Royal Netherlands Aerospace Center)

ONERA (the French Aerospace Lab)

TU Delft (University of Technology of the Netherlands)

VKI (the Von Karman Institute Belgium)

COMMITTEES

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Dick Bowdler (Director INCE/Europe) – Co-Chair

Laurent Droin (Director CidB)

Geoff Leventhall (Director INCE/Europe)

Philippe Strauss (Technical Journalist CidB)

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Lucille Lamotte: MicrodB (France)

Antonio J. Torija Martinez: Acoustic Research Centre, University of Salford (UK)

Andy McKenzie: Hayes McKenzie Partnership (UK)

Tiziano Pagliaroli: Universita Niccolo Cusano (Italy)

Christophe Schram: Von Karman Institute (Belgium)

Mirjam Snellen: (TU Delft) - (The Netherlands)

Serguei Timushev: Moscow Aviation Institute – NRU (Russia)

Michael Wieland: UAV DACH e.V. (Germany

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VIRTUAL EXHIBITION

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27 – 29 June 2022

QUIET DRONES 2022

AN E-SYMPOSIUM FROM PARIS

CONTENTS

- Full Papers are available online for registered delegates
- Proceedings of the Symposium can be purchased after the Symposium takes place and will contain the Programme Book and the Full Papers

WELCOME

Quiet Drones 2020, the first International Symposium devoted to all aspects of noise and acoustics from drones and eVTOLs was held online mid-October 2020 and despite the pandemic, turned out to be a huge success in terms of attendance and delegate networking. Extensive discussions between 170 delegates from 22 countries confirmed that, after safety, security and privacy, noise was becoming a fourth hurdle that could impede the widespread deployment of drones and eVTOLs.

Quiet Drones 2022, the second Symposium, will again be held as an online meeting on 27, 28 and 29 June.

It will present methods under development for establishing measurement standards on noise from drones and eVTOLs, as well as new metrics to characterize the impact of their noise on people and environment.

It will explain about recent advances in the study of noise generation and control at its source as well as propagation in different flying conditions and environments. It will also present acoustic tools for the detection and identification of drones as well as drone audition methods for search and rescue.

And it will discuss public acceptance of the noise of delivery drones as well as of air taxis in European cities and the rest of the world.

This Symposium will last 3 days and will be live for about 8 hours a day with

- 4 invited keynote presentations describing international activities of exchange working groups, collaborative projects, workshops, and symposia dedicated to noise,
- over 35 papers coming from 16 countries presented in 8 structured sessions,
- several panel-discussions organized on hot topics

We wish you all a fruitful symposium.

Jean Tourret / Dick Bowdler

QUIET DRONES

Second International e-Symposium on Noise from UASs, UAVs and eVTOLs

27 – 29 June 2022

PROGRAMME

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SECOND INTERNATIONAL SYMPOSIUM ON NOISE FROM UASs, UAVs and eVTOLS

June 27-29 2022 - A fully remote event

TECHNICAL PROGRAMME SCHEDULE

Updated 21 June 2022

Registration, general information: **www.quietdrones.org**

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AN E-SYMPOSIUM FROM PARIS

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PROGRAMME AT A GLANCE

The programme for the symposium will consist of eight technical sessions at which authors will make presentations. At the end of sessions #1 to #8 there will be a discussion centred around the session topic at which authors will be encouraged to take part. Four keynote presentations are also scheduled, as well as two panel discussions and two, more informal, conversations.

We are keen that delegates from all time zones will be able to view all sessions. For this reason, sessions will be recorded and published for offline viewing as soon as they are finished.

Please note that all times listed below are expressed in Central European Summer Time (CEST).

Monday June 27

09:00 – Welcome to participants
10:00 – Session # 1 **– Propeller and motor noise modelling**
12:00 – Panel discussion #1 **- Managing Community Noise from Drone Delivery**

13:45 – Welcome to new participants and tribute to late George Maling
14:15 – Keynote #1 **– Advancing Aerial Mobility: A national blueprint**
14:45 – Keynote #2 **- A Summary of the 2020 e-Workshop: Aerial Mobility - Noise Issues and Technology held at the US National Academy of Engineering**
15:30 – Session #2 **- Acoustic Detection and Identification of Drones**
17:15 – Conversation #1 **- Come and meet the other delegates**

Tuesday June 28

09:00 – Session #3 **– Drone audition for search and rescue - Drones as first responders**
10:45 – Session #4 **– Propeller and motor noise experiments**

14:00 – Keynote #3 **– Activities of the NASA Urban Air Mobility Noise Working Group (UNWG)**
15:00 – Session #5 **– Assessing Noise and its Impact on People and Environment**
17:00 – Conversation #2 **– Come and meet the other delegates**

Wednesday June 29

09:00 – Session #6 **– Measurements of noise produced by drones and related standards**
11:15 – Session #7 **– Noise prediction in different environments and flying conditions**

14:00 – Keynote #4 **– Public acceptance and noise considerations in urban air mobility research – Intermediate results of DLR's HorizonUAM project.**
14:45 – Session #8 **– Public Acceptance of Drones and eVTOLs in the light of noise**
16:30 – Panel discussion #2 **– Air taxis integration in cities in the light of mobility and noise.**

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MONDAY JUNE 27

09:00 — **Welcome to participants**

Informal conversations between delegates and last information for the organisation

10:00 — **SESSION #1 – Propeller and motor noise modelling**

Co-chairs: Christophe Schram (VKI, BELGIUM)
Franck Cléro (ONERA, FRANCE)

Aeroacoustic investigation of co-rotating rotors	Edoardo Grande Delft University of Technology	THE NETHERLANDS
Computational aeroacoustics of the urban air mobility using APAC method	Yuhong Li The Hong Kong University of Science and Technology	CHINA
Numerical study of the aeroacoustics of shrouded propellers for Urban AirMobility vehicles	Sinforiano Cantos The Hong Kong University of Science and Technology	CHINA
Turbulence ingestion noise from multi-rotor UAVs	Ryan McKay (Dotterel Technologies)	NEW ZEALAND
Application of Acoustic-Vortex Decomposition for Numerical Simulation of Drone Prop. Noise	Sergei Timushev Moscow Aviation Institute - National Research University	RUSSIA

Break

12:00 — **PANEL DISCUSSION #1: Managing Community Noise from Drone Delivery**

Organized by: Marion Burgess (UNSW, AUSTRALIA)
Eddie Duncan (RSG, USA)

This panel discussion will start with 2 short overview presentations (3-4 minutes) from the organisers: Eddie Duncan somewhat focussing on the US and Marion Burgess on the Asia Pacific. Before opening the general discussion, some panellists from both the operators and from the government agencies will be invited to comment on their experiences with the management of community reactions to the noise from drone deliveries, minimising annoyance and challenges in the regulatory framework. These will include Jesse Suskin from Wing Australia; Zac Kennedy from Swoop Australia; Kevin Houston from Manna Ireland; Ed Weston from CAA UK; Severine Charmant from DGAC-DTA France. The session will then be opened for a general discussion with other operators, government authorities and researchers sharing their experiences and their views on the future for drone deliveries in regard to noise matters.

Break

MONDAY JUNE 27

13:45 **Welcome to new participants and tribute to late George Maling**

14:15 **Keynote #1 - Advancing Aerial Mobility: A National Blueprint**

Nicholas Lappos (Lockheed Martin, USA)

Chaired by: Gregg Flemming (Director of Volpe's Center for Policy, Planning, and Environment - US Department of Transportation, USA)

Break

14:45 **Keynote #2 - A Summary of the 2020 e-Workshop: Aerial Mobility - Noise Issues and Technology held at the US National Academy of Engineering**

Robert D. Hellweg (Hellweg Acoustics, USA)

Chaired by: Jean Tourret (President INCE/Europe, FRANCE)

Break

15:30 **SESSION #2 - Acoustic Detection and Identification of Drones**

Co-chairs: Lucille Pinel- Lamotte (MicrodB, FRANCE)
Martin Blass (Joanneum Research, AUSTRIA)

Towards mobile microphone array-based UAV tracking	Martin Blass Joanneum Research	AUSTRIA
UAV acoustic localization in a maritime environment: from first results to improvements perspectives	Mathis Bonotto Gipsa-Lab	FRANCE
Identification of deterministic components of propeller noise	Han Wu The Hong Kong University of Science and Technology	CHINA
Comparison of different processing for DOA estimation of an Unmanned Aerial Vehicle with few sensors	Nathan Itare Le Mans University	FRANCE
Deeplomatics: A deep-learning based multimodal approach for aerial drone detection and localization	Eric Bavu LMSSC, CNAM Paris	FRANCE

Break

17:15 **Conversation #1: Come and meet the other delegates**

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TUESDAY JUNE 28

09:00 SESSION #3 - Drone audition for search and rescue - Drones as first responders

Co-chairs: Antoine Deleforge (INRIA, FRANCE)
Shaun Edlin (Dotterel Technologies, NEW ZEALAND)
Michael Kingan (Auckland University, NEW ZEALAND)

Improvement of Rotor Noise Reduction for Unmanned Aerial Vehicle Audition by Rotor Noise PSD Informed Beamformer Design	Yameizhen Li Acoustics Research Center, University of Auckland	NEW ZEALAND
Autonomous Kiteplane System for Drone Audition	Makoto Kumon Kumamoto University	JAPAN
Sound source localization and enhancement from a flying micro aerial vehicle	Lin Wang Queen Mary University of London	UK
Optimization of Microphone Array Placement for Sound Source Localization Using Drones with Microphone Arrays	Taiki Yamada Tokyo Institute of Technology	JAPAN

Break

10:45 SESSION #4 - Propeller and motor noise experiments

Co-chairs: Tiziano Pagliaroli (Unicusano, ITALY)
Hélène Parisot-Dupuis (ISAE -SUPAERO, FRANCE)

Experimental analysis on pitch angle effect on a small-scale propeller to quiet drones' flight	Paolo Candeloro Unicusano	ITALY
Investigation on lightweight double-leaf cylindrical microperforated-panel structures for motor noise reduction of UAVs	Gianyujie Qian Hohai University	CHINA
Experimental investigation on the noise related to rotors interaction	Tiziano Pagliaroli Unicusano	ITALY

Break

TUESDAY JUNE 28

14:00 Keynote #3: Activities of the NASA Urban Air Mobility Noise Working Group (UNWG)

Stephen A. Rizzi (NASA Langley Research Center, USA)

Chair: Patricia Davies (I-INCE V-President Technical Activities, USA)

Break

15:00 SESSION #5 - Assessing Noise and its Impact on People and Environment

Co-chairs: Antonio J. Torija (University of Salford, UK)
Roalt Aalmoes (NLR, THE NETHERLANDS)

Estimation of noise exposure due to drone operations	Carlos Ramos-Romero Acoustics Research Centre, University of Salford	UK
Noise impact on humans – calculation methods and results for some conceivable applications	Stefan Becker BeSB GmbH Berlin Schalltechnisches Büro	GERMANY
Recent NASA research into the psychoacoustics of Urban Air Mobility (UAM) vehicles	Andrew Christian NASA	USA
Experimental investigations and psychoacoustic analysis of a DJI Phantom 3 quadcopter	Erica Gallo Von Karman Institute for Fluid Dynamics	BELGIUM

Break

17:00 Conversation #2: Come and meet the other delegates

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WEDNESDAY JUNE 29

09:00 SESSION #6
Measurements of noise produced by drones and related standards

Co-chairs: Xin Zhang (The Hong Kong University of Science and Technology, CHINA)
Jean-Claude Guilpin (DGAC-DTA, FRANCE)

Accurate measurement of Drone Noise on the ground	Per Rasmussen GRAS Sound & Vibration	DENMARK
Measurement of sound emission characteristics of quadcopter drones under cruise condition	Gert Herold Technische Universität Berlin	GERMANY
Estimating Unmanned Aircraft Takeoff Noise Using Hover Measurement Data	Christopher Cutler-Wood US DOT Volpe Center	USA
Acoustic evaluation of multi-rotor drones in anechoic and semi-anechoic chamber	Zhida Ma The Hong Kong University of Science and Technology	CHINA
Development of the standardized noise measurement procedures for unmanned aircraft system	Siyang Zhong The Hong Kong University of Science and Technology	CHINA
Development of a comprehensive drone performance evaluation platform	Alex McGinn Trinity College Dublin	IRELAND
Noise measurements procedures for eVTOLs	Thierry Cabannes DGAC-DTA	FRANCE

Break

11:15 SESSION #7
Noise prediction in different environments and flying conditions

Co-chairs: Julien Caillet (Airbus Helicopters, FRANCE)
Ignacio Gonzalez-Martino (Dassault Systèmes, FRANCE)

A virtual flight simulation platform for community drone noise assessment	Qichen Tan The Hong Kong University of Science and Technology	CHINA
Numerical aerodynamics and aeroacoustics predictions of a drone under real urban environments	Rémy Atassi Dassault Systèmes	FRANCE
Numerical Investigation of Noise Emissions from a Cargo eVTOL UAV	Michael Schmähl TU München	GERMANY

Break

WEDNESDAY JUNE 29

14:00 **Keynote #4:**
Public acceptance and noise considerations in urban air mobility research – Intermediate results of DLR's HorizonUAM project.

Bianca I. Schuchardt (DLR-FL, GERMANY)

Chair: Fabrice Cuzieux (ONERA, FRANCE)

14:45 **SESSION #8**
Public Acceptance of Drones and eVTOLs in the light of noise

Co-chairs: Bianca I. Schuchardt (DLR-FL, GERMANY)
Fabrice Cuzieux (ONERA, FRANCE)

Drones disruptions: Exploring the social and cultural implications of drone noise	Anna Jackman University of Reading	UK
Airport regions authorities dealing with drones	Sergi Alegre Calero Airport Regions Council	BELGIUM
A greenery-based solution for low-noise delivery hub for unmanned aerial transport	Claudio Pasquali Università degli Studi Roma Tre	ITALY

Break

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WEDNESDAY JUNE 29

16:30 **Panel Discussion #2:**
Air taxis integration in cities in the light of mobility and noise

Moderators: Sergi Alegre Calero (Airport Regions Council, BELGIUM)
Patricia Davies (I-INCE V-President Technical Activities, Purdue Univ. USA)

Topics addressed:

- information on UAM projects in European Cities.
- noise performances of eVTOLs prototypes to be integrated in those projects
- acoustic requirements and solutions for vertiports and other infrastructures
- specific situation of European cities in terms of acceptance.

Panelists:

- Vassilis Agouridas (Airbus), leader of UAM Initiative Cities Community
- Cristina Barrado (Polytechnic University of Catalonia), involved in the CORUS-XUAM project
- Kathryn Bulanowski (European Federation of Passengers), involved in AURORA project
- Julien Caillet (Airbus Helicopters), Acoustic Expert – ETGV
- Jean-Claude Guilpin (DGAC-DTA), Head of aircraft environmental performance department
- Dominique Lazarski (President of the European Union Against Aircraft Nuisances)

Closing session

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OTHER INFORMATION

Special issue of the Acoustique & Techniques Journal on the subject of drone noise

More information: https://www.bruit.fr/acoustique-techniques/vient-de-paraitre-double-numero-d-acoustique-techniques-n-96-97

QUIET DRONES 2022

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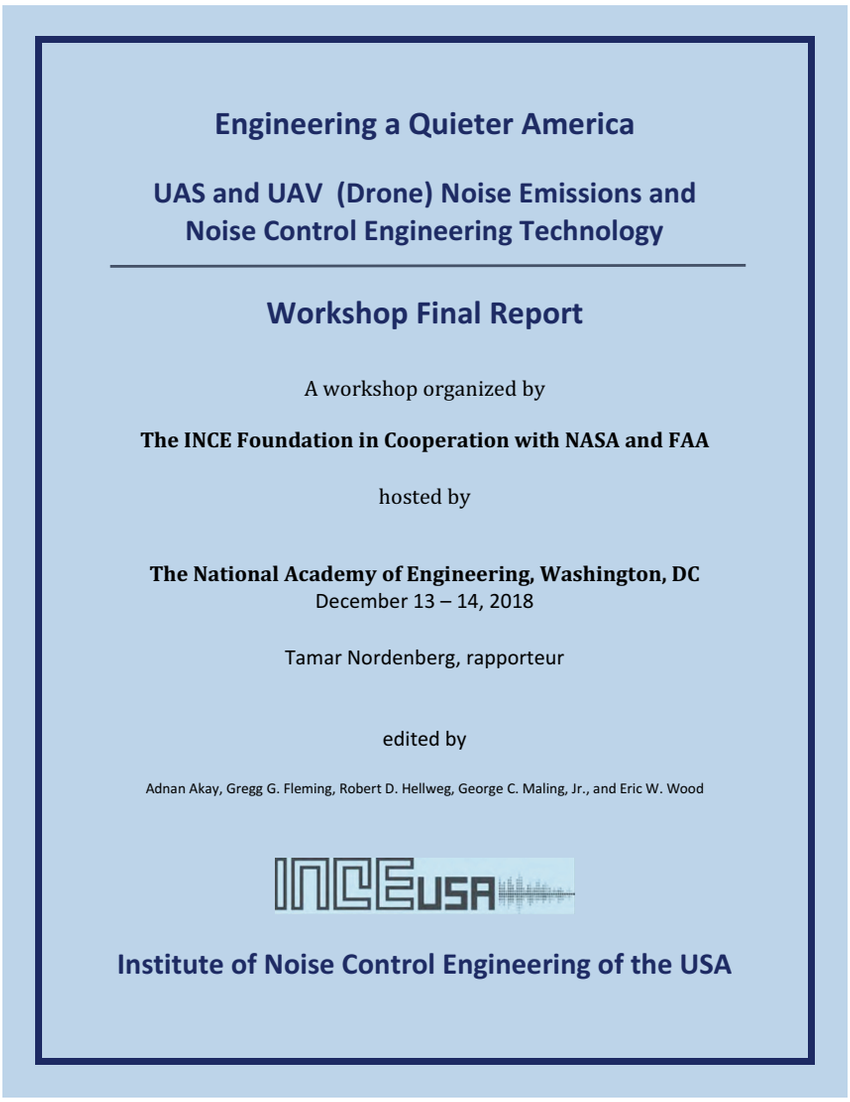
2018 Workshop

"UAS and UAV (Drone) Noise Emissions and Noise Control Engineering Technology",
NAE hosted Workshop Final Report, December 13 – 14, 2018,
INCE/USA 2020

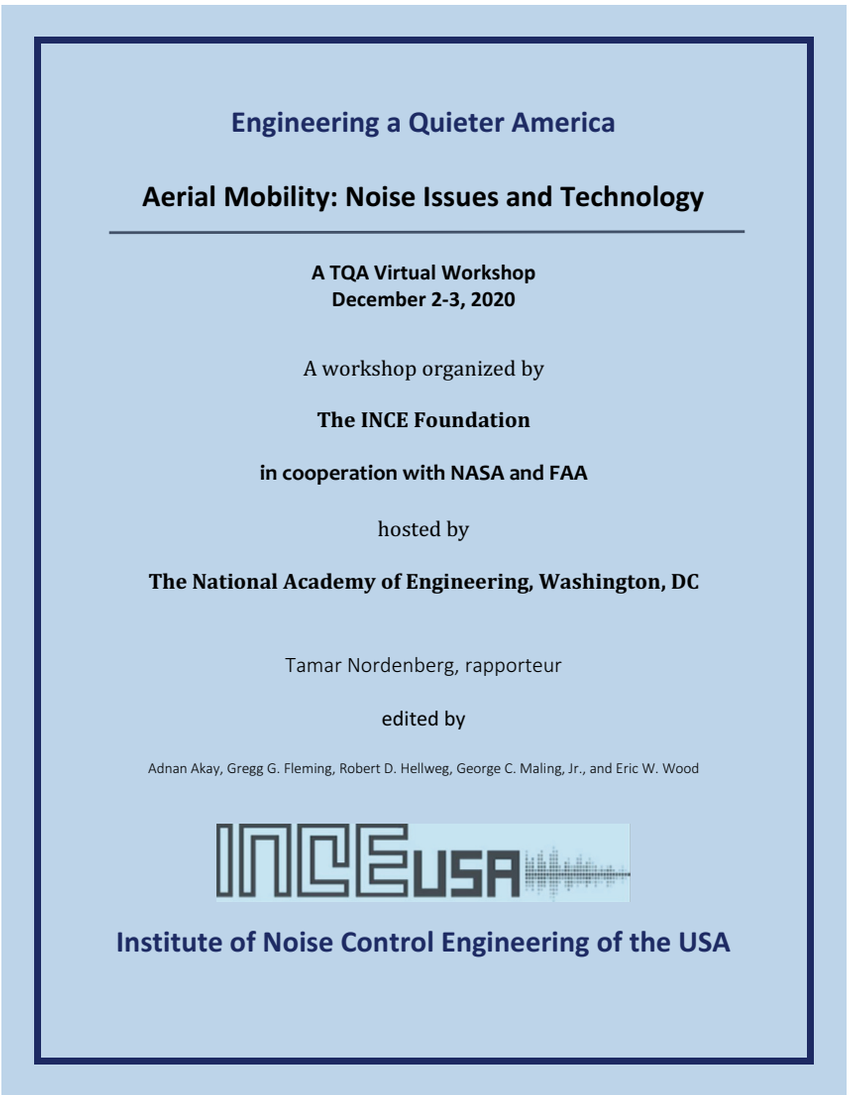
https://www.inceusa.org/publications/technology-for-a-quieter-america



2020 Workshop

"Aerial Mobility: Noise Issues and Technology", NAE hosted Workshop Report, December 2 – 3, 2020, INCE/USA 2021

https://www.inceusa.org/publications/technical-reports/



NCEJ

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NCEJ
Noise Control Engineering Journal

An International Publication

Special issue to come on

Unmanned Aerial Vehicles (UAVs) and Advanced Aerial Mobility Vehicles (AAMs)

Editors:

Dr. Judith (Judy) Rochat
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The Noise Control Engineering Journal (NCEJ) is the international journal for the Institute of Noise Control Engineering of the USA. The journal reaches noise control professionals around the world, covering over 50 national noise control societies and institutes. NCEJ accepts both technical papers and case studies, and all submissions are peer-reviewed.

NCEJ is organizing a special issue on Unmanned Aerial Vehicles (UAVs) and Advanced Aerial Mobility Vehicles (AAMs). We are currently developing papers based on Noise-Con 2022 and Quiet Drone 2022 submittals, as well as others outside these venues. **We encourage additional participation, and papers can be submitted for review/consideration: deadline is August 15, 2022**. We are seeking a broad range of topics in relation to UAVs and AAMs, including, but not limited to:

- Community considerations, including perception and detection
- Operational considerations
- Measurements/metrics
- Predictions
- Noise certification considerations
- Environmental policy

To submit a paper for review/consideration, please go to: https://www.inceusa.org/publications/noise-control-engineering-journal/.

If you have any questions, please contact Judy or Jean for further information. If you cannot meet the deadline for submittal but would like to participate, please let us know – it may be possible to include your paper depending on where we are in the review process with the other papers.

Drone Noise: A New Public Health Challenge

INT. JOURNAL OF ENVIRONMENTAL RESEARCH AND PUBLIC HEALTH

(Open Access MDPI Journal)

Special Issue published on

Drone Noise: A New Public Health Challenge

Guest Editor: Antonio Torija Martinez

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https://www.mdpi.com/journal/ijerph/special_issues/drone_noise

Special Issue Information

This special issue offered a platform for researchers to publish their latest research on drone noise.

Published Papers (5 papers)

- A Psychoacoustic Approach to Building Knowledge about Human Response to Noise of Unmanned Aerial Vehicles. https://doi.org/10.3390/ijerph18020682
- Drone Noise Emission Characteristics and Noise Effects on Humans—A Systematic Review. https://doi.org/10.3390/ijerph18115940
- Quantification of the Psychoacoustic Effect of Noise from Small Unmanned Aerial Vehicles. https://doi.org/10.3390/ijerph18178893
- Comparative UAV Noise-Impact Assessments through Survey and Noise Measurements. https://doi.org/10.3390/ijerph18126202
- Assessment of Sound Source Tracking Using Multiple Drones Equipped with Multiple Microphone Arrays. https://doi.org/10.3390/ijerph18179039

Special Issue "2nd Edition of Drone Noise: Emission, Modelling and Community Noise Impact"

https://www.mdpi.com/journal/ijerph/special_issues/2nd_edition_drone_noise

After the successful Special Issue “Drone Noise: A New Public Health Challenge”, this Special Issue seeks research papers on several key topics of drone noise. We encourage the submission of manuscripts that focus on, but are not limited to, the following topics:

- Drone noise at the source, including vehicle classification and certification;
- Drone noise measurement, including procedures and metrics;
- Novel approaches for drone noise modelling, including noise mapping and auralisation;
- Management of drone noise, including operating procedures and noise annoyance;
- Effects of drone noise on human health and well-being;
- Effects of drone noise on wildlife.

Dr. Antonio J. Torija Martinez
Prof. Dr. Charlotte Clark
Guest Editors

INCEEUROPE

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Drone Fusion

Call for papers: Aerocoustics of drones

Call for Papers **Deadline for submissions: 15 December 2022**

Fluids Journal

(MDPI)

Specific issue on

Aeroacoustics of Drones

Guest Editor: Tiziano Pagliaroli

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https://www.mdpi.com/journal/fluids/special_issues/aeroacoustics_drones

Special Issue Information

The European Union has a defined service-orientated architecture for air traffic management of drones in urban areas, called U-space. One of the main obstacles to the massive use of drones in our cities is the generated noise and its impact on health. For these reasons, the topic of noise generated by drones has become dominant in the aeroacoustics scientific community, which is responding with colossal efforts.

This Special Issue will present the state of the art of the aeroacoustics of small-scale rotors and propellers for drone propulsion. Manuscripts are invited covering the full range of noise simulation, from low- to high-fidelity methods, experimental techniques, novel strategies for data post-processing, and methods for noise mitigation. In particular, manuscripts concerning noise and noise sources associated with single propellers, propellers in twin and contra-rotating configuration, wing–propeller or fuselage–propeller interaction, and complete drones are welcome.

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BOOKLET of ABSTRACTS

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ABSTRACTS FOR KEYNOTE LECTURES

A Summary of the 2020 e-Workshop: Aerial Mobility - Noise Issues and Technology.

Robert D. Hellweg, Jr., Hellweg Acoustics: Hellweg@HellwegAcoustics.com

Adnan Akay, Bilkent University: akay@cmu.edu

Gregg Fleming, United States Department of Transportation – Volpe National Transportation Systems Center: Gregg.Fleming@dot.gov

George C. Maling, Jr., Managing Director Emeritus INCE-USA: georgemaling.nae@gmail.com

Eric W. Wood, Acentech Inc.: ewood@acentech.com

The U.S. National Academy of Engineering (NAE) hosted an e-workshop “Aerial Mobility:

Noise Issues and Technology” on December 2-3, 2020 attended by 71 individuals. The purpose of the December 2020 workshop was to examine several facets of the increasing interest in air or aerial mobility vehicles, which are often referred as “urban air mobility” (UAM). The workshop was organized by the INCE Foundation in cooperation with the U.S. National Aeronautics and Space Administration (NASA) and the U.S. Federal Aviation Administration (FAA). The workshop had 22 presentations from representatives of world-wide air mobility vehicle manufacturers and users, U.S. government agencies, universities, consultants and professional societies. There were presentations on a wide-range of topics, including a summary of the 2020 Quiet Drones eSymposium, regulatory issues and standards, community acceptance, modelling, the design of air mobility vehicles, psychoacoustics, noise reduction strategies, measurement techniques, and legal issues. The 2020 workshop report includes a summary of each presentation and images of selected slides, and the report is available on the INCE/USA web page at https://www.inceusa.org/publications/technical-reports/.

Advancing Aerial Mobility: A National Blueprint

Nick Lappos, Chair Committee on "Enhancing Air Mobility—A National Blueprint"

In 2018, the National Aeronautics and Space Administration (NASA) asked the National Academies of Sciences, Engineering, and Medicine to undertake a study to evaluate the potential benefits and challenges associated with advanced aerial mobility, an emerging technological development that can be simultaneously transformative and disruptive for the nation's aviation infrastructure and industry. Although the statement of task referred to "urban air mobility," while this study was under way the aviation community—and NASA itself— increasingly used the term "advanced aerial mobility," of which "urban air mobility" is considered a subset (albeit the most challenging one). The committee therefore chose to use advanced aerial mobility to capture the broader range of opportunities and operations that are being discussed. The National Academies formed a committee that met three times between spring and fall 2019. This is a dynamic subject that was changing as the committee was finalizing its report and even during the report's review. Nevertheless, the committee sought to provide findings and recommendations that will help NASA and others in the aviation community foster an environment in which the nation can maintain its leadership in developing, deploying, and embracing new technology that opens up new opportunities. Whether through drone delivery of goods in urban environments, linking rural areas to population centers through passenger and cargo aviation, or an entirely new method of passenger travel within a metropolis and its surrounding areas, advanced aerial mobility can make aviation a part of daily life. Such benefits do not come without challenges. This committee also sought to ensure that the foreseen problems that will inevitably arise from such cutting-edge technologies can be mitigated during development and that the unforeseen problems are discovered through processes established to safely test vehicles and methods of operation. By addressing these problems proactively in collaboration with other federal agencies, NASA can facilitate the integration of advanced aerial mobility into the national airspace infrastructure safely and with minimal negative impact on general aviation and the publicat- large. It is the goal of this committee that this report reflects both the forward-thinking optimism and the caution that such a transformative technology merits.

Activities of the NASA Urban Air Mobility Noise Working Group (UNWG)

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The NASA-led Urban Air Mobility Noise Working Group was established in 2018 following an exploratory meeting of stakeholders from traditional and emerging aviation sectors across industry, government agencies, academia, and community groups. Its mission is to create and support a diverse community of acoustics experts to identify, discuss, and address noise issues associated with UAM vehicles and their operations. The UNWG is comprised of four subgroups including Tools and Technologies, Ground and Flight Testing, Human Response and Metrics, and Regulation and Policy. In 2020, NASA published the white paper entitled “Urban Air Mobility Noise: Current Practice, Gaps, and Recommendations,” that presents a set of high-level goals and makes recommendations to address gaps in the current practice. This presentation is about recent activities of each of the subgroups to address those recommendations, including work towards establishment of an aeroacoustic test database for model validation, development of a set of measurement guidelines to quantify vehicle acoustic emission, a remotely administered human response study for quantifying annoyance to UAM operations, and status on noise standard, regulation, policy, and community engagement developments.

Public acceptance and noise considerations in urban air mobility research – Intermediate results of DLR's HorizonUAM project

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The project "HorizonUAM – Urban Air Mobility Research at the German Aerospace Center (DLR)" pools existing competencies of ten institutes within DLR. The project combines the research about urban air mobility (UAM) vehicles or air taxis, the corresponding infrastructure, the operation of UAM services, as well as the public acceptance of future urban air transportation. The analysis of flight guidance concepts and the sequencing of air taxis at vertidromes is a central part of the project. Selected concepts for flight guidance, communication and navigation technology are demonstrated with drones in a scaled urban scenario.

The HorizonUAM project has started in 2020 and will run until mid-2023. Among the highlights of the first half of the research project are first vehicle fleet pre-designs including cabin interior design and the installation of a mixed reality UAM cabin simulator. A rating method for the design of starting and landing areas, so called vertidromes, has been established and a first capacity analysis was conducted for vertidrome integration at the airport of Hamburg, Germany. Furthermore, a virtual reality study on the acceptance of drones and air taxis flying over pedestrians in an urban setting has been completed with 47 subjects. An online survey among UAM stakeholders from unmanned aviation associations, research and industry confirmed the assumptions on the use cases defined within HorizonUAM: airport shuttle, sub-urban commuter, intra-city, inter-city and megacity.

This keynote gives an overview of the research covered in the HorizonUAM project with special focus on the topics of public acceptance and noise.

QUIET DRONES

Second International e-Symposium on Noise from UASs, UAVs and eVTOLs

27 – 29 June 2022

SUBMITTED ABSTRACTS

Airport regions authorities dealing with drones

Sergi Alegre Calero (Airport Regions Council).

Drones noise impact is one of the most important challenges of their massive use. On the other hand, drones explotation will be linked with aviation activities at airports. Therefore, Airport Regions Council, the European association of public administrations of cities and regions with an airport in their territory is working since so time ago, to promote the proper conditions of the use of drones in order to avoid/minimize/manage the noise impact to the citizens in order to have a peaceful development of this sector. As the administrations/citizens that have dealt more with air noise, we understand that our collaboration can be key in this matter.

Numerical aerodynamics and aeroacoustics predictions of a drone under real urban environments

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For the purpose of studying noise impact of drones in communities and public acceptance, we aim to conduct several analysis using Very-Large Eddy Simulations (VLES), which is a mathematical model for turbulence used in computational fluid dynamics (CFD). CFD Lattice- Boltzmann unsteady simulations coupled with Ffowcs- Williams Hawkings integration method are used to predict both UAV aerodynamics and radiated acoustics.

The present study starts with a particular interest on urban flows. As a matter of fact, this first part of the study aims to predict and to understand all behavioral patterns of airflows in a specific urban area. Experimental data from wind-tunnel campaigns are used to assess and validate the numerical predictions in terms of airflows.

Then, the second part of this study is dedicated to the analysis of the performance and the aeroacoustics of a generic isolated eVTOL in real flight conditions.

Finally, the third and last part of this study carries on with the demonstration of the flight of this same drone in the urban environments we studied in the first part. With the experimental validation of our numerical model of a specific urban flow, we will have an accurate computational model to study the influence of the flight of a generic drone on the environment it flies in.

The complete study performed will allow to accurately assess the noise generated by the flight of a generic drone in a specific urban area, and the airflow interaction between the evolving field where the drone flies and the drone itself.

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Deeplomatics: A deep-learning based multimodal approach for aerial drone detection and localization

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Protection against illicit drone intrusions is a matter of great concern. The relative stealthy nature of UAVs makes their detection difficult. To address this issue, the Deeplomatics project provides a multimodal and modular approach, which combines the advantages of different systems, while adapting to various topologies of the areas to be secured. The originality lies in the fact that acoustic and optronic devices feed independent AI to simultaneously localize and identify the targets using both spatial audio and visual signatures.

Several microphone arrays are deployed on the area to be protected. Within its coverage area (about 15 hectares), each microphone array simultaneously localizes and identifies flying drones using a deep learning approach based on the BeamLearning network. Each array is attached to a local AI which processes spatial audio measurements in realtime (40 estimations per second), independently to the other units of the surveillance network.

A data fusion system refines the estimates provided by each of the AI-enhanced microphone arrays. This detected position is shared in real-time with an optronic system. Once this system has hooked its target, a Deep Learning tracking algorithm is used to allow an autonomous visual tracking and identification. The optronic system is composed of various cameras (visible, thermal, and active imaging) mounted on a servo-turret. The active imaging system can capture scenes up to 1 km, and only captures objects within a given distance, which naturally excludes foreground and background from the image, and enhances the capabilities of computer vision.

The Deeplomatics project combines benefits from acoustics and optronics to ensure real-time localization and identification of drones, with a high precision (less than 7° of absolute 3D error, more than 90 % detection accuracy). The modular approach also allows to consider in the long term the addition of new capture systems such as electromagnetic radars.

Experimental investigation and psychoacoustic analysis of a DJI Phantom 3 quadcopter

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Drones, and in particular multicopters, are already present in our environment, i.e. for parcel delivery, medical support or industrial inspections, and are seeing their application range increasing fast. Yet, their social acceptance is pending upon their noise emissions and resulting annoyance. In this work we have measured the noise emitted by a DJI Phantom 3 quadcopter in hovering, flyover and transition flight conditions, in a view to rank those three manoeuvres in terms of annoyance. The data have then been processed to examine their time-frequency content and sound quality metrics, used to finally obtain a psychoacoustic annoyance factor. The ranking reveals that the most annoying manoeuvres are not necessarily those with the largest Sound Pressure Level spectra, but that loudness and sharpness correlate well with annoyance.

Noise impact on humans – calculation methods and results for conceivable applications

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As part of a study for the German Environment Agency, it has been investigated among other things, whether it is possible to apply ISO 9613-2 or the German aircraft noise assessment method DIN 45684-1 for to calculate noise immissions resulting from the use of drones.

In principle, plausible results can be obtained with both calculation methods. However, both methods have their own limitations. Neither method is suitable for universal use. The German standard organisation DIN has therefore started a new project for to develop a new standard, which is more adopted to drone flights.

All drone sounds of multicopter design studied so far have a pronounced tonality. This makes the operation of drones easily audible and therefore more annoying than other sounds. If the evaluation is based on the noise limits of the German TA Lärm **Error! Reference source not found.,** a surcharge of 6 dB must be taken into account.

The results calculated for 3 conceivable applications can be summarized as follows: Overflights of residential houses at a height of 100 m above ground will only exceed the noise limits of the German TA Lärm Error! Reference source not found. if a large number (> 100) of overflights take place. If a certain minimum distance to residential properties is provided, drone operations tend to be rather uncritical. On the other hand, if drone operations take place in a short distance to a residential property, only a short time of operation is needed for to exceed the noise limits.

Towards mobile microphone array based UAV tracking

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The emergence of new technologies for UAVs and their commercial availability offer great opportunities in supporting humans in a wide variety of tasks. However, when used as a means of attack, single UAVs or swarms may create a potential asymmetric threat situation, which cannot be satisfactorily countered with existing sensor technology. Currently, multimodal approaches are being investigated in which UAVs can be detected, localized, and tracked using a composite of different sensors. In the development of such multi-sensor solutions, the acoustic domain has emerged as an indispensable element. However, existing systems relying on acoustic sensors primarily focus on stationary operation and detection of a single UAV. In this work, we present approaches for the development of a mobile acoustic sensor system that can detect and track multiple drones based on the direction of sound incidence. In contrast to the majority of solutions existing in the literature, where the focus lies on either detection or localization, we propose joint estimation of UAV sound presence and incidence. We evaluate our proposed system on a dataset acquired in the course of a measurement campaign conducted at a military camp near Bure, Switzerland, for a stationary as well as for a mobile scenario, where a microphone array was mounted on the roof of a vehicle.

UAV acoustic localization in a maritime environment: from first results to improvements perspectives

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Thanks to their high maneuverability and low cost, UAVs are increasingly used on military operation fields to threaten valuable assets. To assess this threat, numerous counter UAV systems have been developed, based on different physical modalities like radar, optics, or radio- frequency. However, in this fast evolving domain, recent studies tend to show that each modality taken separately is not self-sufficient to work in all the possible scenarios.

As the targeted UAVs are mostly quadcopters that emit significant noise due to their propellers, the acoustic modality has been naturally studied. It has the advantage to work at night or in foggy weather, to deal with autonomous targets, and also to identify them through their acoustic signature. Nevertheless, acoustic localization directly depends on the power of the ambient noise in which the sensor is buried, from very low into rural areas to very high into dense urban ones. If the rural and urban areas have already been studied, data and studies are lacking in a major military field: the maritime environment.

This paper aims at filling this gap thanks to recordings that have been made on a coastal area, in windy conditions, with a strong backwash. Acoustic signals are first thoroughly analyzed to understand the contribution of UAV and ambient noise. Then, a validated localization method based on MUSIC method is tested against this complex scenario to evaluate its performances. The pipeline limitations are explained, and improvement perspectives are proposed to increase the initial results.

An Aeroacoustic Experimental Analysis on Pitch Angle Effect on a small- scale Propeller to Quiet Drones Flight

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The aim of the present study is to investigate the pitch angle effect on the rotor noise generated by small scale rotor for mini drone propulsion. The experimental tests were performed on a two bladed propeller within an anechoic chamber. The rotor was instrumented with an embedded load cell in order to measure thrust and torque. The study consists also in near-field pressure measurements executed by means of a single microphone mounted on a rotating automatic support. Main goal of the present study is to investigate the noise signature of a propeller in hover at different rotational velocities and different pitch angles.

Drone noise is addressed as a central issue for the scientific community due to the very fast growth of the UAV market for both civil and military applications in the last few years. A lowering of their acoustic impact is essential for the market of these vehicles in the future. Since, the interest on this topic involve both academic and industrial point-of-view. Noise of such vehicles is a very challenging task for scientific community. This aspect justifies the presented work, in fact a simple approach aimed at reducing the number of variables in the optimization process is reported.

For the experimental tests the chord-based Reynolds number ranged from 20.000 to 50.000 and the tip Mach number was about 0.025. Such conditions gave rise to complex phenomena as a laminar separation bubble and the transition from laminar to turbulent boundary layer, that is proved to be the counter part of a complex noise signature. The results in the Fourier domain reveals that the main noise component is the broadband one despite the tonal noise is still relevant and can't be neglected. To investigate both the noise component singularly a POD-based decomposition strategy has been performed with very promising results.

A numerical study of the aeroacoustics of shrouded propellers for urban air mobility vehicles

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The aerodynamic performance and noise generation of a ducted propeller were studied with numerical simulations for different incoming flow conditions. Steady simulations were performed to efficiently evaluate the aerodynamic performance of the ducted propeller over wide operating conditions. For noise performance, delayed detached eddy simulations were performed for the near-field turbulent flow fields. The far-field directivities were calculated from integral solutions of the Ffowcs-Williams and Hawkings equation. The present results reveal that, in addition to the propeller, the duct can also generate thrust. When the axial flow speed increases, the thrust generated by the duct decreases rapidly. The spectra and directivity of the aerodynamic noise are compared, showing that the noise is reduced with the flow speed.

Recent NASA research into the psychoacoustics of Urban Air Mobility (UAM) vehicles

Andrew Christian

NASA maintains multiple psychoacoustic laboratories across the United States. One focus of research in these facilities is to investigate the human reaction to the noise of notional UAM vehicles. This effort will look for answers to several questions: What does a “good” UAM sound like? What might be the impact on existing urban soundscapes? What will people think when there are an [economically viable] number of these machines operating? Although this effort is ongoing, a number of advances have already been made: A psychoacoustic test to guide UAM sound design has been recently completed. Several algorithms to assess the audibility of a UAM vehicle in an existing background soundscape have been put forward. A technical memorandum detailing best practices for recording and reproduction of background sounds for UAM psychoacoustic research has been published (TM 20210017504). Flexible data analysis methods that could be agile to changes in perception that occur when large numbers of vehicles are flying have been developed by extending existing metrics. This presentation gives an overview of this completed and continuing research.

Estimating Unmanned Aircraft Takeoff Noise Using Hover Measurement Data

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The Volpe Center, in support of FAA, has collected acoustic data from multiple unmanned aircraft over the last few years in a series of measurement campaigns. With this expanding dataset, it is now possible to estimate the noise produced by various types of flight operations and test the validity of those methods. Of particular interest in the context of environmental analyses is the noise produced during takeoff operations. This paper describes the process of using hover noise measurement data including directivity patterns to estimate the noise generated during takeoff procedures for an unmanned aircraft and presents a comparative analysis of the results and actual measurements.

Aeroacoustic investigation of co-rotating rotors

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Aerodynamic performance and acoustic far-field of a small-scale, co-axial co-rotating rotor in hover are investigated by means of Lattice-Boltzmann Very-Large-Eddy simulations. The study focuses on the effect of the phase angle between the two corotating propellers. Co-rotating rotors are further compared with two single isolated rotors. The study demonstrates that increasing the azimuthal separation between the two co-rotating rotors, is beneficial for thrust production and noise reduction in the propeller plane because of destructive interference.

Measurement of sound emission characteristics of quadcopter drones under cruise condition

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Quadcopter drones have distinctive sound emission characteristics, which also depend on their mode of operation. While determining these characteristics is of interest in different contexts, this proves particularly challenging when the mode of operation involves movement of the drone.

In this contribution, a method for characterizing the in-flight sound radiation in terms of sound power and directivity is applied to three different drone configurations flying at different speeds. Based on microphone array measurements, the trajectory of the drone during its flight through the array is reconstructed. The estimated flight path is then used to de-dopplerize the measured signals and determine the directivity based on the timedependent relative angle of radiation from the drone to the microphones.

The exemplary evaluations include the calculation of sound power spectra and directivity factors. Current limitations of the method are highlighted and ways to overcome them are discussed.

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Comparison of different processing for DOA estimation of an Unmanned Aerial Vehicle with few sensors

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During the last years, many methods have been developed and studied in the field of source localization. A particular area of interest is the tracking of UAVs (Unmanned Aerial Vehicles) because of the numerous threats that can appear near sensitive sites. Delay and Sum Beamforming (DSB) is one of the methods that can be very useful to face this challenge. Indeed, this technique has a good robustness to noise which makes it an interesting tool. Recently, some processes have been studied to enhance the performance of DSB by taking into account the signature of UAVs. Signals obtained from a microphone antenna can be filtered according to the signature of an UAV before beamforming. Beamforming can also be performed from the measured signals, then the harmonic signature can be considered using the time-frequency representation of the focused signal. A pitch tracking algorithm can provide the fundamental frequency of the signals for consideration of the UAV's signature. Another interesting approach is the Steered Response Power (SRP) which can perform well in noisy environment. The use of generalized cross correlation with different spectral weightings provides a wide range of options. This study aims at comparing the performance of beamforming with timefrequency representation and SRP-PHAT on an experimental measurement with a UAV in flight.

Drone disruptions: Exploring the social and political implications of growing drone noise in UK skies

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We are in the midst of a global turn to the drone. While domestic drones are the subject of increasing scrutiny – most often along lines of surveillance and privacy, security, and safety, the issue of drone noise and its impacts remains comparatively under-studied. Exploring the drone as it enters and is poised to punctuate UK airspace, this report reflects on the diversity of actors (human and nonhuman), spaces (urban and rural), and understandings (commercial, regulatory, public) of the issue and impacts of drone noise. In so doing, it centrally argues that drone noise is multiple; it is at once contextual (i.e. dependent on both the geographical location, type of land use, and type of drone operation), subjective (i.e. varying by person as well as community), and shifting (i.e. not a static issue). In developing this discussion, it at once demonstrates the value of engaging with interdisciplinary drone scholarship, and aims to raise questions of the political, social, and cultural dimensions of drone noise more widely.

Swoop Aero: Making access to the skies seamless

Zachary Kennedy (Swoop Aero)

Globally, the commercial drone ecosystem has moved on from the pioneer phase and is approaching the end of the early adoption phase. This transitionary period serves as a catalyst for the advancement of the global regulatory environment, specifically in major and high resource environments such as Europe, the United States and Oceania, and thus, marks an exciting opportunity for market leaders to expand their value, reach and impact.

However, many enabling areas of legislation have not kept pace with this exponential growth and pose a significant operational risk to widespread adoption despite substantial improvements in sustainability, scalability, and cost-effectiveness of drone logistics.

The more recent push by operators for significant operational latitude (LUCs, Part 135 Certifications etc.) means that regulators can no longer create bespoke approvals or exemptions to allow operations.

It is critical for the longevity of the emerging aviation technologies sector to develop fitfor- purpose frameworks that address community expectations, are flexible enough to support commercial operations, and have the appropriate legal authority to avoid a patchwork of laws and regulations at different levels.

Autonomous Kiteplane System for Drone Audition

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This paper presents an autonomous auditory drone system for a kiteplane. Since it has a large delta-shaped main wing, it is capable of flying stably and slowly. This capability is effective for observation tasks such as monitoring and surveillance. The developed system integrates the autonomous flight control and the robot audition functions so that the system can improve the performance of sound source localization from the sky by exploiting the silent glide mode. Alternating Drive-and-Glide Flight Navigation (AltDGFNavi) proposed by the authors controls a kiteplane by driving or gliding alternately. The glide mode reduces ego-noise such as rotor and airflow noise drastically. The kiteplane has a newly designed microphone array consisting of three microphone arrays by taking the nonholonomic flight characteristics of the kiteplane into account. On this auditory kiteplane as a platform, AltDGFNavi is designed in detail and evaluated by test flights. This paper reports the design and implementation of AltDGFNavi and its evaluation in terms of sound source localization. The results of flight tests with AltDGFNavi demonstrate the effectiveness of the developed system.

Improvement of Rotor Noise Reduction for Unmanned Aerial Vehicle Audition by Rotor Noise PSD Informed Beamformer Design

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Unmanned aerial vehicles (UAV) are popular in many areas including search and rescue and filming industries. UAVs are widely used for the convenience in collecting visual information, while using them for the audio recording remains a challenge due to the high levels of rotor noises (a.k.a. ego noise). Previous studies demonstrated an existing speech enhancement algorithm using beamforming and Wiener filter to be effective for reducing rotor noise for UAV audition. The algorithm was later improved by incorporating the rotor noise's power spectral density (PSD) estimated by non-acoustic information. To further improve the rotor noise reduction performance, this paper proposes an alternative design of the MVDR beamformer using a PSD informed spatial noise co-variance matrix estimation. The method separately estimates the magnitude and phase components of the matrix. The magnitude component is calculated from the rotor noise PSD estimated by the previous study, whereas the phase component is calculated by the time delay of arrival due to the relative positions between the microphone array and the rotors. The proposed method was evaluated under low (3000 - 3500 rpm) and high rotor speed (3500 - 4000 rpm) conditions. The proposed method achieved an average improvement in signal to rotor noise ratio (SRNR) of around 23 dB under the low rotor speed condition and approximately 26 dB under the high rotor speed condition. These are significant improvements compared to the existing method performing the average SRNR improvement of around 15 dB and 20 dB under the low and high rotor speed conditions, respectively.

Computational aeroacoustics of an urban air mobility vehicle using the acoustic preserved artificial compressibility method

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This work investigates the turbulent flow of an urban air mobility (UAM) vehicle and its far-field acoustic feature. The vehicle is equipped with six propellers, which can generate a total thrust of about 5000 N. Each propeller has a radius of 1 m. The near-field flows are simulated using the acoustic wave preserved artificial compressibility (APAC) method, and the turbulence is modelled through the delayed detached eddy simulations (DDES). The far-field noise is computed by an on-body integral solution of the Ffowcs Williams and Hawkings (FW-H) equations. Results show strong fluctuations in the thrust signal for the vehicle under hovering conditions, which are caused by the interaction between each propeller and its support structure. Such interaction also produces unsteady loadings acting on blade surfaces, leading to considerable tonal noise at the blade passing frequency and its harmonics. The noise directivity is also explored, and the spectra at various observers exhibit visible patterns that are likely attributed to the interference between noise from individual propellers. Additionally, the propeller wake interacts with the vehicle fuselage, changing its propagation direction and causing pressure fluctuations on the fuselage, which can also contribute to noise emissions.

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Acoustic measurement of multi-rotor drones in anechoic and hemi- anechoic chambers

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The rapidly widening applications of drones can cause significant noise pollution issues. There exist needs for drone noise measurements in controllable test facilities. In this paper, we present the outcome of in-flight noise measurements of a quad-rotor drone in an anechoic chamber that can be set up as either a full anechoic configuration or a hemianechoic configuration. Flight conditions including hover, cruise, vertical climb and descent were tested. The noise was measured by two linear microphone arrays with a total of 15 free-field microphones. The instantaneous position of the drone was recorded by an optical motion capture system. For each working condition of the drone flight, multiple tests were conducted to reduce the statistical errors and uncertainties in the noise measurement. A criterion about the observer distance to ensure the acoustic farfield condition is proposed and justified using the measurement results. Moreover, by adjusting the drone's position and orientation, i.e., the heading angle, the noise directivity patterns on a spherical surface are obtained, showing a discernible correlation with the drone's airframe geometry and rotor configuration. The comparison between the full anechoic and the hemi-anechoic configurations highlighted the need of using nonreflective facilities for drone noise tests.

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Development of a Comprehensive UAV Noise Evaluation Platform

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Drones, Unmanned Aerial Vehicles (UAVs) and or Unmanned Aerial Systems (UAS) are set to become more prevalent in our skies over coming years. This project developed and applied a process and test rig for measuring drone noise under the ISO 3744:2010 standard and European Union Aviation Safety Association (EASA) legislation. In the process it also assessed the practicality of the standard and over-arching regulation. The potential for environmental pollution resulting from the rapid growth and diversification in drone use has begun to attract regulatory attention. An initial review of applicable standards and regulations was carried out and used to develop a process compliant with ISO 3744:2010 for measuring noise emissions from UAVs. A compact and portable test rig was designed based on the approach of a rotating sound source within a fixed microphone configuration, surrounded by a protective cover and acoustic baffles. The rotating noise source consisted of a base plate, turntable and stepper motor and bracket to which a drone could be secured. The test procedure was executed and refined in three different rooms. As all three of these rooms have a hard reflecting plane for a floor as stipulated in ISO 3744:2010, an approach was adopted of first testing a reference sound source (RSS) and then using these results to develop correction factors for the drone measurement. The refined procedure was then applied to a commercially available drone - DJI Inspire 1 - in the most suitable of the tested rooms. Measurements were taken at 10° intervals. The results obtained showed clear directionality in the noise emitted by the drone as well as confirming that the drone's maximum sound power is above the limit set out by the EASA. Overall, the testing process and rig performed well. The ISO Standard was found to be suitable and applicable and this is discussed in more detail. Suggestions are also made for refining the EASA legislation. Further work to refine the design of the drone restraint mechanism and containment strategy and to build a database of drone test results is planned.

Multirotor UAV turbulence ingestion noise

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Turbulence ingestion noise (TIN) is an important noise source for multirotor unmanned aerial vehicles (UAVs). TIN is caused by streamwise elongation of ingested turbulent eddies interacting with a propeller and is particularly problematic for hovering UAVs when the propeller interacts with an elongated eddy over multiple blade passages. This generates quasi-tonal noise centred around a multitude of harmonics of the blade passing frequency (BPF). This paper presents predictions using a model previously presented by the authors of a propeller in an anechoic chamber and of a hovering DJI Mavic UAV. These predictions are compared with experimental measurements. A simplified form of the TIN model which has significantly reduced computational costs is also presented. Predictions from this simplified model are compared to the experimental measurements which show slightly worse agreement than the forementioned model.

Experimental investigation on the noise related to rotors interaction

Tiziano Pagliaroli, Paolo Candeloro (Unicusano), Fabrizio di Gregorio, Giuseppe Ceglia

This paper presents an experimental investigation of the noise radiated by two propellers for the propulsion of medium-size drones, in different flight configurations. Unmanned aerial vehicles are tipically designed with multi-rotor systems in order to guarantee the proper manouvreability and versatility, such properties being key aspects of the commercial spread they have had in recent years. In this configuration, the rotors are located in close promiximity to each other and to the airframe leading to several phenomena related to interaction. In particular, the separation distance between the adjacent rotor seems to have a great influence on the noise emitted by the entire vehicle. Such effect is related to a strong interaction of the vortical structures that shed from the propeller. Since, the aim of the present study is to investigate if novel noise sources occur due to interaction. For this purpose, a innovative experimental setup has been designed. The testbench is composed of two three-bladed propellers at fixed rotor-to-rotor distance, mounted on a specific vertical aluminium support, rotating at four different rotational velocity, within an anechoic chamber. To complete the study also far-field measurements executed by means of a linear microphone array mounted on a rotating support in order to characterize the directivity of the noise source has been performed. In addition, to study the effect of the phase angle between the two rotor a very effective control system has been implemented. Finally, in order to understand the effect on the single noise component a POD-based decomposition has been performed on the pressure time history.

A greenery-based solution for low-noise delivery hub for unmanned aerial transport

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Unmanned Aerial vehicles are nowadays involved in a wide range of applications, such as surveillance, safety control, scientific research, and commercial activities. The logistics industry, in particular, is showing a substantial interest in a partial tran- sition of the last-mile delivery service from ground to air transport. A key point to make this scenario feasible resides in the design of delivery hubs to serve the sur- rounding areas, thus overcoming the logistical difficulties of a door-to-door delivery while respecting the strict regulations in terms of noise. The proposed paper deals with the study and design of an urban hub for package delivery that uses natural ele- ments such as hedges to limit the noise footprint associated with drone operations by exploiting the shielding capabilities of natural barriers. Some constraints driving the design are identified, leading to a tentative conceptual design. The acoustic prop- erty of a sample hedge is evaluated using an equivalent porous medium approach, informed by parameters estimated by image processing of the external surface of the hedge. Eventually, the model is used in coupled BEM-FEM simulations of simplified designs. Preliminary results show encouraging noise reductions in the areas surrounding the hub.

Investigation on lightweight double-leaf cylindrical microperforated-panel structures for motor noise reduction of UAVs

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With the ongoing proliferation of unmanned aerial vehicle (UAVs) which usually operate in close proximity to dense populations, their noise is attracting more and more attention and may become great limiting factor for the public acceptability of their operations in urban areas. Although the noise of an electric powered UAV mainly comes from the motors and propellers, previous studies have paid more attention to propeller noise reduction, while neglecting the role of the motors. For this, on the basis of the authors' prophase work related, a noise reduction technique based on lightweight double-leaf cylindrical microperforated-panel (CDMPP) structures is further developed and explored for noise reduction of UAV motors in this paper. Firstly, the theoretical methods for calculating the transmission loss of an CDMPP based on equivalent circuit model are provided. And based on this model, the difference between metallic and non-metallic CDMPP is discussed. Then a case study is performed to evaluate the noise reduction performance and the heat dissipation performance of the proposed CDMPPs for a DC motor of UAVs at different rotating speeds. Results show that our CDMPP is of potential to insulate motor noise at frequency range from 1 kHz to 8 kHz without leading to significant temperature increase.

Estimation of noise exposure due to drone operations.

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Drone operations have significantly grown during the last few years and are expected to inundate our skies with innovative aerial transportation projects. If this scenario materialises, drones will become an important source of environmental noise pollution. Although substantial investigation has been carried out to develop our understanding of the sound source generation mechanisms and noise reduction technologies for drones, still there are important questions regarding the requirements for operational procedures and regulatory framework.

An important issue is that drones operate closer to communities, owing to the lower operating altitudes, than conventional aircraft or rotorcraft. In addition, the noise produced is highly tonal and with important high-frequency content which may cause significant impacts on exposed communities, due to adverse effects such sleep disturbance.

This paper presents the results of the estimation of the maximum A-weighted Sound Pressure Level $LA!"\#$ and Sound Exposure Level SEL as received in typical indoor residential environments. To do this, a series of drone sounds recorded during in-situ operations in free field have been filtered to simulate the external to internal transmission loss associated with sound propagation through a typical partition which includes a standard glazing configuration.

This estimation of drone noise exposure indoors is highly relevant to inform operational constraints, such as the optimal distance to minimise noise annoyance and sleep disturbance.

Accurate measurement of Drone Noise on the ground

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Accurate measurement of noise from smaller unmanned aerial vehicles/systems (UAVs/UASs) can be performed in anechoic chambers, but larger types need to be tested in outdoor environments. This will introduce ground reflections that may disturb the measurements if microphones are mounted above the ground. By placing the measurement microphone on a fully reflecting ground board, the influence of the reflection becomes well defined and will result in a simple pressure doubling. By using flush-mounted microphones in the ground board, the frequency range of the system may be extended to cover the full audible range up to 20 kHz.

QUIET DRONES
Second International e-Symposium on
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Numerical Investigation of Noise Emissions from a Cargo eVTOL UAV

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Urban air mobility (UAM) applications such as cargo electric vertical take-off and landing (eVTOL) unmanned aerial vehicles (UAVs) promise additional transportation capacities for congested urban areas. A major drawback facing UAM operations in future is that the new aerial vehicle movements are bound to lead to additional traffic noise emissions affecting urban areas. Minimum noise designs are therefore essential for UAM aircraft. This paper presents a numerically based computational fluid dynamics (CFD)/Ffowcs Williams-Hawkings (FW-H) model of the noise emissions generated by a cargo eVTOL UAV with separate hover and cruise propellers and focuses on the cruise flight. Installation effects play a predominant role in the noise generation of this highly integrated aerial vehicle configuration. The numerical results of the vehicle's base configuration are validated by inflight noise measurement data. The noise results are split into propeller and airframe components. Alternative tail and propeller configurations are simulated to identify noise reduction potentials that stem from the effects of decreased aerodynamic interaction. It is envisaged that these investigations should form the groundwork for future numerical noise optimizations of the before mentioned base configuration, which explicitly consider the effects of aerodynamic interaction on noise emissions. The noise reduction potentials identified in this study support the idea of parallel rotor and airframe optimization.

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Community noise assessment of a delivery drone based on a flight simulation and noise assessment platform

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Drones are promising transport means for the last-mile deliveries in urban communities. However, the low-altitude flights can cause severe noise pollution, requiring rational operational strategies to minimize noise emissions. In this work, the noise emission of delivery drones in an urban community is investigated using a flight simulation and noise assessment platform. Both the tonal and broadband noise components are considered via analytical and semi-analytical prediction methods. The noise propagation in the urban environment is computed by an efficient Gaussian beam tracing method. A systematic study is made for a representative community by considering a drone under different operational conditions. The influence of flight speed and payload on noise emission is studied, and various flight strategies are also explored. This study suggests that the flight simulation and noise assessment platform could be a cost-effective approach for the lownoise path planning of drones in practical urban applications.

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Application of Acoustic-Vortex Decomposition for Numerical Simulation of Drone Propeller Noise

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Over the past ten years, there has been a sharp increase in the use of quadcopters for various purposes. Quadcopters have become extremely popular and are used in areas ranging from monitoring traffic or fire conditions to distributing the Internet or cold drinks. Soon, legislation to limit drone noise is adopted in developed countries in Europe and the United States. In the European Union, in 2020, requirements were developed for the maximum permissible noise levels on the terrain of multi-copter UAVs for two ranges of takeoff weights - up to 900 g and from 900 to 4000 g. Therefore, the noiselessness and efficiency of a propeller propulsion system are critical aspects of modern unmanned aerial vehicles. The development of this area of aviation technology in the context of tightening noise standards is impossible without effective optimization methods that work in conjunction with computer-aided design systems. Such a challenge requires the development of theoretical approaches to the numerical simulation of sound generation mechanisms by propellers of quadcopters and the corresponding software. This article discusses software based on a method for calculating sound generation and noise emission by a drone propeller, taking into account the decomposition of the vortex and acoustic modes in a subsonic isentropic flow. The development of this method makes it possible to consider the influence of flow inhomogeneity and turbulence, rotor interference, sound diffraction by airframe elements, impedance characteristics of the hull coating, and other factors while ensuring accuracy and speed of calculations. For preliminary analyses, software based on a single-processor version of FlowVision 2.5 was used, which implements this method in the time domain for propeller blade passing frequency harmonics. Estimates are made about the influence of the grid on the calculated sound power and the distribution of the oscillation amplitude in the near acoustic field. It is demonstrated that in the plane of rotation of the propeller, the sound field is formed by the quasi-potential of two rotating vortices generating a pressure field with a spiral shape of the wave-fronts. The possibilities of the method are demonstrated in the examples of a separate rotor and quadra, Hexa and Hexa-2 configurations with coaxial propellers in the mode of hovering above the ground. Comparing different designs with the same propeller geometry in terms of emitted sound power and aerodynamic parameters are presented.

Sound source localization and enhancement in 3D space from a flying drone

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The ego-noise generated from rotating motors and propellers as well as the movement of the drone impose significant challenges to drone audition, which aims to sense the acoustic environment with onboard microphones mounted on a flying drone. As a stateof- the-art framework for sound processing on drones, time-frequency spatial filtering (TFS) exploits the time-frequency sparsity of the acoustic signals and their correlation at multiple microphones to localize and enhance a target sound in the presence of strong ego-noise. The original TFS framework was proposed with a 2D coordinate system considering azimuth only in the horizontal plane. We extend the TFS framework to a 3D coordinate system for the microphone array considering both azimuth and elevation. We validate the proposed framework with data from a flying drone, and the proposed algorithm significantly outperforms the baseline SRP-PHAT algorithm.

Identification of deterministic components of propeller noise

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This study focuses on methods of processing the noise data of propulsive propellers commonly found on ubiquitous multi-rotor flying vehicles. The noise signals recorded in experiments typically contain both periodic tonal and random broadband components produced by rotational motion of the propellers, interaction between the propellers and turbulence, and other random factors. Factors such as unsteady rotational speed, manufacturing tolerance and flow disturbance can exist, leading to time-varying characteristics of the noise signals. In this study, we made assessments of methods to identify the deterministic components of the noise signals of propellers. Considering that the different noise patterns within two adjacent periods (due to the rotation) are similar, we applied averaging methods to remove the random components iteratively. A total of three methods were employed in this work: simple averaging, exponentially weighted moving averaging, and Kalman filter averaging. The exponentially weighted moving averaging method uses a constant weight while the weighting parameter based on the Kalman filter approach is iteratively adjusted. The methods are applied to results obtained using computational aeroacoustic simulations and laboratory experiments, demonstrating the capabilities of the methods to remove the random components. Some characteristics of the noise signals are identified.

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Optimization of Microphone Array Placement for Sound Source Localization Using Drones with Microphone Arrays

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Sound source localization techniques have been playing an important role for drones to find sound sources in low visibility conditions. For example, drones will be able to find people calling for help in disaster sites, and existing work has shown that drones can find sound sources by using microphone arrays. Since a single microphone array is generally used for estimating the sound source direction, utilizing multiple microphone arrays is a way to estimate the location of the sound source. Previous studies have proposed methods to estimate the sound source location by triangulation or using the spatial spectrum used in direction estimation. However, either process may degrade the localization results depending on the placement of microphone arrays. This paper investigates the effect of microphone array placement on sound source localization, and we propose a microphone array placement method that is optimal for sound source localization. The proposed method is evaluated through simulation, considering rescue task scenarios using real drone noise. Optimizing microphone array placement can be developed into an action planning problem for drones, which is our future work, allowing them to perform disaster relief tasks efficiently.

INDEX of AUTHORS