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urban air mobility aircraft – as well as specialised aircraft. The review will consider the community noise impacts of each type of operation and determine considerations for potential noise regulations. It will also look at developments overseas and at industry innovation to reduce noise impacts through better aircraft design and operations. Submissions on the issues have now closed; almost 100 comments were received.

The number of drones can only increase as new business applications continue to be developed. Meanwhile ever more people are tempted to buy one for personal use. New legislation came into force in the UK on 30 November to regulate use. Anyone responsible for a drone or unmanned aircraft (including model aircraft) weighing between 250g and 20kg now needs to register as an operator at a cost of £9 per year. Operators also need to pass an online education test, which is free and needs to be renewed every three years.

Researchers in a number of countries have been looking into the implications – including the potential for annoyance – now that use of drones is becoming embedded into many areas of business as well as leisure.

Torija's presentation drew attention to some of the work that has been taking place in the UK and elsewhere to look into the growth and acceptability of drones.

Innovation foundation Nesta published a report last year, *Flying High: shaping the future of drones in UK cities*. The *Flying High* project aims to position the UK as a global leader in shaping drone systems that place people's needs first. The ongoing project, which started in December 2017, is run by Nesta Challenges in partnership with Innovate UK. It is described as a collaborative engagement with cities, technologists and researchers, regulators, government, public services and citizens to shape the future of urban drone use in the UK to meet local needs.

The first phase comprised a nine-month research and engagement process, working with five city-regions across the UK – Bradford, London, Preston, Southampton and the West Midlands. This involved developing visions for the future of drones and assessing the technical feasibility and economic and social impact of urban drone applications. The outputs were summarised in the *Flying High* report. The planned next phase will be to design a series of innovation challenges and develop test beds to pioneer drone systems that deliver benefits for cities and citizens.

"There are competing views of the future of drones in UK cities, and the country at large," said Nesta executive director Tris Dyson in the introduction to the report. "Utopian visions of smart cities, congestion solved, services streamlined. Dystopian visions of surveillance, nuisance and noise. And for many, not much vision at all: an uncertain future, seldom thought of in any depth."

The report warns: "Increased drone use could have an adverse environmental impact and this will need to be assessed when considering higher levels of deployment, particularly the impact on noise, visual and light pollution, climate change and air quality, effect on wildlife and life cycle of the drone technology."

The report points out that legislation proposed by European Union Aviation Safety Agency (EASA) includes restrictions on the noise permissible by drones of different classes.

Although drones are much quieter than helicopters, they also operate closer to the ground and may be used in larger numbers; Nesta sees noise caused by drones as a factor in any policy decision related to the increased uptake of drones. One approach to this would be technical noise-limitation standards in the UK, it suggests.

The impact of noise depends on many factors including what the drone sounds like, what kinds of manoeuvres it makes and the context in which it is operating, the report says.

A section of the report points out that London hospitals may find it useful to have urgent medical supplies delivered by drone. "Because there will be regular deliveries, the noise could be particularly annoying for people who live or work under the flight paths. However, since the[re] will already be quite a lot of background noise from the city, the drones may not cause much additional annoyance; different noise levels could be regulated for at different times. As a relatively small multi-rotor drone, noise levels produced by the drone would, in any case, not be particularly high."

The impact of the noise could be reduced through the choice of route, for example, having the drone fly via the river rather than overland and making sure the take-off and landing points are as far from patient accommodation as possible. Although hospitals have high levels of sound insulation, understanding of the effect of possible local drone operations on patient well-being is limited, says the report.

Uber Elevate's focus is on-demand urban air transport – in other words, flying taxis. Even in 2016 it was aware of the importance of noise in terms of making the use acceptable. "For urban air transportation to thrive, the vehicles must be acceptable to communities, and vehicle noise plays a significant role. The objective is to achieve low enough noise levels that the vehicles can effectively blend into background noise; ultimately we believe VTOLs [vertical-takeoff-and-landing air vehicles] should be one-half as loud as a medium-sized truck passing a house. That said, a more sophisticated measure of 'noise' is required in order to properly characterise the impact of vehicle sound on a community. Electric propulsion will be critical for this objective, as well: it enables ultra-quiet designs, both in terms of engine noise and propulsor thrust noise."

As Torija points out, drones are quieter than conventional aircraft – but are operating at relatively low altitudes over populated areas that have not normally been exposed to aircraft noise. Nor does their noise resemble that of contemporary transport vehicles.

A paper written in 2016 by staff from NASA's Langley Research Center looked at measured noise from small unmanned aerial vehicles. It looked at both flyover and hover noise of multicopters as well as the flyover noise of a model aeroplane. The spectra for all vehicles are dominated by tones at harmonics of the blade passage frequency – or frequencies, in the case of the multicopters, it found. Spectrograms showing the variation of acoustic energy with time illustrate the unsteadiness of the noise signatures of these vehicles, particularly for the smallest vehicle, the quadcopter. "Although the blade passage frequencies (BPFs) for the multiple rotors on the multicopters are relatively uniform in a hover condition, the BPFs become separated in forward flight as the rotors are driven at different speeds to maintain the vehicle attitude needed for forward motion. Maximum A-weighted sound pressure levels of the vehicles, adjusted to a 15m altitude flyover, ranged from 63dBA for the quadcopter to 68dBA for the hexcopter and 72 dBA for the model airplane. Effective Perceived Noise Levels (EPNL) of flyovers ranged from 76 EPNdB for a 5m altitude flyover of the quadcopter, to 71EPNdB for a 22m altitude flyover of the hexcopter. The extent to which these metrics quantify human annoyance of small vehicles such as these flying in a community is an open question."

Another paper from the same NASA research centre sought to answer that question. Andrew Christian and Randolph Cabell's research published in 2017 discussed their initial investigation into the psychoacoustic properties of small unmanned aerial system (sUAS) noise. This showed differences in response compared to conventional vehicles. "Initial analysis of the data from this test indicates that there may be a systematic difference between the annoyance response generated by the noise of the sUAS and the road vehicles included in this study," they said. "It is unknown as of now whether this difference can be accounted for by other factors, or whether it is being generated by qualitative differences between the sound of road vehicles and sUAS. This result casts doubt on the idea that sUAS operators can expect their operations to be greeted with minimal noise-based opposition as long as the sound of their systems are 'no louder than' conventional package delivery solutions."

It has been suggested that new metrics are needed and that particular operational characteristics needs to be taken into account. Torija pointed out that work for NASA has found that none of the

Sound sensing discussed

Lis Stedman catches up with an IoA conference held in London on use of technology by way of sensors to monitor noise in cities

The IoA Measurement and Instrumentation Group's recent 'Sound sensing in smart cities' event, looking at future technologies and smart solutions, produced a range of forward-looking presentations.

Kicking off the day, Dan Pope of RSK Acoustics took a look at the topic of "A little electronic Milky Way of sound – the IoT and the future sound of cities". The title references a late work by German electronic music composer Roland Kayn.

Pope focused on the noise problems that arise from 24-hour cities, outlining development possibilities with better options include ensuring industry is outside residential areas, and having well-linked, bike-friendly cities with quiet areas and quieter vehicles, as well as rail and/or mass transit systems.

Regarding a proposed 24-point "evolving toolkit" of city soundscape design options, he noted that some examples are already being well tested, such as zoning and buffer areas. He looked at other toolkit ideas such as the "soundmark", the idea of this being to identify existing sounds unique to a place or identifiers of its character, for which he suggested consideration of protecting these with policy. Cities could also consider incorporating new soundmarks into their design, he suggested.

Another interesting proposal is that where a soundscape of value has been lost due to development, its restoration could be considered. Pope suggested that where densification is planned, standards should be put in place to prevent an increase in noise complaints, improving building regulations and controlling neighbourhood noise, and use of smart city technology like gunshot detector ShotSpotter.

He also highlighted the use of flexible and shift working to encourage work patterns that help reduce traffic congestion during peak hours, though he noted that this needs to be balanced against causing disturbance during rest hours.

Preventing factors that price some tenants out of certain areas has the knock-on effect of reducing commuting, thereby reducing transportation noise, he added. Areas of

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transportation noise metrics that are available are able to account appropriately for the particular acoustic features of drone noise signatures.

He presented some of the research into drone noise that he has been involved in. One of the areas of research has been to determine an annoyance penalty/bonus for small drones in order to inform dose-response analyses. This involved taking a range of sounds – eight from aircraft, four from rotorcraft, eight from road vehicles and 12 from quadcopters – and asking for groups of them to be ranked in order of preference. Preliminary results from experiments involving 30 people listening to small drones compared to road and air vehicles at a normalised sound level showed lower preference ratings for the quadcopters.

The research Torija is involved in is seen as a first step towards development of metrics able to predict the annoyance accurately. Initial results suggest that key aspects are tonality and a loudness-sharpness interaction relating to high-frequency noise, he said.

Another aspect of research that Torija is working on is the effect of a hovering unmanned aerial vehicle on the perception of urban soundscapes. One of the objectives is to investigate how ambient road traffic noise affects the annoyance caused by the drones. The work involves varying sound pressure levels and types of setting – such as by a road, urban zones and green areas. The team is also investigating audio-visual effects on drone noise annoyance, using 3D audio and virtual reality. His work suggests that the operation of drone fleets through corridors along busy roads might significantly mitigate the increase of community noise impact caused.

Of course, what causes annoyance now might change over time, driven both by alterations in ambient noise levels and in attitudes to drones if more are buzzing by people's homes at all hours.

Work carried out for NASA has said that noise from urban air mobility (UAM) could pose a more notable barrier in future as electric (ground-based) vehicles become more mainstream, potentially causing a reduction in overall ambient noise and hence making UAM more noticeable. In the near term, adverse energy and environmental impacts (particularly, noise) could affect community acceptance.

NASA-commissioned market studies indicate that, by 2030, the USA could have as many as 500 million flights a year for package delivery services and 750 million flights a year for air metro services. It has worked with the FAA, other government agencies, academia, airspace operators and vehicle developers to identify the technical and bureaucratic barriers that must be overcome. These include significant legal, regulatory, infrastructure and weather constraints, along with concerns about public perception related to noise, pollution and safety, it said.

Community acceptance of UAM operations is seen as a challenge. "While demonstrating safe and reliable operations is critically important, it is equally important that vehicle operations don't create unacceptable community noise impacts, and that they fit into the urban land and skyscape," said NASA. "The concept of urban air mobility involves multiple aircraft safely operating within a city.

NASA won't have a direct hand in providing design input for these vehicles, but we can provide technical leadership in areas that require the UAM community to work together, such as the safety, operational integration, and community noise challenges. For example, we and our industry partners can conduct joint flight tests to generate data that drive analyses to support the creation of industry standards, FAA rules and procedures, and even city ordinances."

NASA's Aeronautics Research Mission Directorate (ARMD) is running a series of activities called the 'Grand Challenge' to promote public confidence in advanced air mobility systems and help organisations and companies learn what it really takes to operate air vehicles safely in an urban environment. It covers a range of areas, including noise. One of the objectives is to collect initial assessments of passenger and community perspectives on vehicle ground noise, cabin noise and on-board ride quality.

NASA's interest goes beyond the smaller surveying and delivery drones to what would be, in effect, flying cars. A recent NASA podcast on the topic said that UAM will start with a mix of onboard and remotely piloted vehicles and progress toward autonomous operations. "Car-like adoption is intriguing, but making this all work is one of the most complex tasks ever taken on by an engineering team. As an example, at peak times in the US there are roughly about 10,000 flights in the air flying all over the country, but with the advent of UAM, we could see 10,000 flights over just one metropolitan area."

Noise will be a very big factor with these aircraft because they will be flown "maybe not from your driveway, but somewhere not too far from your house, much closer than what we're used to with typical aviation", it said. It will be essential to understand noise sources and ways that they can be reduced. "There's a lot of research that NASA is currently doing and will probably continue to do to help feed the industry there and help push new ideas forward to help aircraft get more quiet, and help them get more efficient, hopefully, at the same time."

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high population density should have good public transport links, reliance on cars should be reduced and rail, tram or bus infrastructure built. He noted that it is important to consider end-to-end journeys and provide effective interchanges between transport modes for longer journeys.

He also gave examples of positive sound, such as sound art and sound walks, coining the phrase the "playable city". Pope criticised the END concept of "tranquillity", saying it is "ill defined, and member states have been left to interpret as they wish". A more certain way to improve the soundscape and reduce health impacts is to put policy in place to control noise at source and protect the population, wildlife and tranquil spaces, he suggested.

Richard Barham of Acoustic Sensor Networks took the topic of "standards for smart cities", from a noise measurement perspective, starting with the benefits of standardisation. He noted that the largest wave of urbanisation ever experienced is putting immense strain on services, and that smart city technology aims to harness technology and data to meet these challenges head on. "The rise of smart city thinking is an ideal use-case for standardisation", he observed. BSI has pioneered this approach, and ISO has a tranche of Smart City technical committees and related standards.

Barham highlighted several standards including ISO TC43 on standardisation in the field of acoustics and IEC TC 29, on electroacoustics standardisation, which includes specification and calibration of noise measuring instrumentation and audiometric equipment. IEC TC 29 strategic goals include addressing innovative developments such as miniaturisation, MEMS sensors calibration of digital microphones, and wireless communication within the measurement chain.

Within TC 29 is a standard being prepared on modular instrumentation, which Barham noted had an "extremely challenging remit due to the unconstrained variety of options and configurations to contend with". This is currently at the "brain-storming" phase, and is considering aspects of application requirements, modularity and connectivity, calibration and traceability, and environmental influences.

He summed up the challenges for the noise measurement community as developing instrumentation and networks capable of addressing the range of wider Smart City applications where benefits can be realised, encouraging cross-sector solutions, and raising awareness of the needs and benefits of noise considerations to create the demand for the new capabilities – a break away from legislation-driven demand for noise measurement.

Paul McDonald of Sonitus Systems looked at sound level monitors and Smart City tools, and where acoustics fits into the mix of options. Touching on the road to market access, he highlighted the role of telecoms companies and tech giants like Microsoft and Google, and downstream vendors and integrators, with end users that might not necessarily be customers.

In terms of which technologies and sensors are "good enough", he identified Class 1 and 2 sensors, MEMS, and weatherproof, heated, and calibrated solutions covering both regulated (planning, noise mapping) and unregulated (soundscapes, policy) aspects.

He also looked at uses of such equipment, citing some early and well-known examples, like noise fines for motorbikes in Paris, traffic noise radar in Switzerland, gunshot detection in the US, noise mapping in Dublin, and quiet delivery trucks in Sweden.

McDonald also looked more deeply at potential applications and uses, which for cities could be in planning, environment and transport, with a question of what extra revenue could be generated from business. Communicating messages means getting the right information to the right people, he noted, in forms easy to access and understand, leading to better decisions.

Urban environmental monitoring involves identifying hotspots for action and allowing citizens to find the cleanest, quietest places in the city, and monitoring city-wide parameters with real-time ratings for noise and air quality (he noted that this is already being used by Dublin City Council). Here, 10 years of monitoring has produced over nine million readings through three rounds of noise policy, with seven areas of the city being protected.

McDonald also looked at smart stadia, with the potential to measure the loudest crowd roar, and the potential for instrumented seating sending live readings to Intel gateways, tracking social media and combining this with match analysis. Again, this is being used in Dublin, at Gaelic games stadium Croke Park.

In the US, sensors are being used to triangulate the sound of a shot being fired and can pinpoint it to within 10 feet. This system is currently in use in over 100 cities, with a detection rate of 90% and response time of under 60 seconds, plus $44 million in revenue generated.

Dr Andreas Herweg, manager at Sound Perception & Assessment, looked at tools for data collection in soundscape applications, and began by emphasising the role of context in soundscapes, influencing the way we perceive our environment and providing the frame of reference for experiencing it.

Despite the increasing significance of soundscape research, he noted that the comparability of study results is low, and several publications do not apply the general axioms of soundscape concepts. There is, he added, a need for a common understanding and harmonisation of methods and tools.

Herweg discussed the data collection tools of ISO/TS 12913-2, the acoustics-soundscape standard, including the requirement to perform a soundwalk and/or a questionnaire and/or a guided interview, in addition to binaural measurements.

The standard defines a soundwalk as a "method that implies a walk in an area with a focus on listening to the acoustic environment", and there are various different data collection methods. Binaural acoustic measurements record sound as if a human listener is present in the original sound field, maintaining all spatial information, he explained.

He outlined the various tools used for soundscape data collection, including webcams and GPS, as well as software such as sound measurement and analysis solution ArtemiS, and talked through an example soundscape study. Such studies also collect information on those undertaking the soundwalks, such as age, sex, and whether there is any hearing impairment, he observed. Focusing in on particular areas, the level and loudness of the soundscape can be captured both through measurements and opinion via the questionnaire.

Herweg noted that the soundscape approach provides a standardised way of collecting relevant additional data, allowing a more accurate description of the location under scrutiny. He noted that "the standard does provide several valuable tools but leaves a lot of decisions to the person executing the measurement".

Doing a soundwalk with a selection of participants is the opposite of automated data collection, especially if a full interview is undertaken, he added. Questionnaires can be filled in digitally, for example on smartphones, and it is possible to discuss solutions on how to collect data from random people, and match those with sensor data.

Professor Mark Plumbley of the University of Surrey looked at the topic of AI for sound, a future technology for smart cities, discussing the many new directions being taken by machine listening, including security (detection of glass breaking or shouting); "legacy IoT" (monitoring of sound-emitting devices); assisted living (sounds of activity and assistance calls); medical (the sounds of hearts and lungs), and traffic (autonomous driving).

In terms of "why AI" for sound, he noted the significant invisible value of sound, including the UK acoustics industry annual output of £4.6 billion, urban road estimated social costs of £7-10 billion, and the value of the international sound recognition technology market, estimated at £1.2 billion by 2021.

The university has investigated various interesting developments, like CHiME-