Work Order T0218 Roadside Vehicle Noise Measurement – Phase 3 Part B

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Executive summary

The Atkins Jacobs Joint Venture has undertaken research for the Department for Transport into technologies that could be used to improve enforcement against excessively noisy road vehicles. These vehicles lead to annoyance and complaints from members of the public throughout the UK due to 'excessive noise' that is attributed to modified or defective exhaust systems and the use of aftermarket products. The scope of the Phase 3 Part B research was focussed on identifying and reviewing the current noise camera marketplace, and then testing suitable products in a controlled environment to determine their suitability for UK roads as an enforcement tool.

Considerable progress has been made in the development of noise camera technologies since Phase 2 of this project, with several products in their later stages of development alongside novel emerging technologies undergoing prototype testing. A review of the 2022 noise camera marketplace identified ten noise camera systems that were actively being developed that could be used for detecting excessively noisy vehicles, including two systems that were identified during Phase 1. The eight 'new' noise camera systems included three products that were being trialled in France (Bruitparif, MicrodB and ACOEM), a product currently used in parts of London (24 Acoustics), a system developed for research purposes in the Netherlands (NEMO), a system being developed for smart cities in Switzerland (Securaxis), a prototype in Taiwan similar to the one tested in Phase 2, and an emerging technology that does not use microphones (General Noise). Of the ten technologies, four were considered sufficiently developed and potentially suitable for UK roads. Two of the products were selected for testing, which were:

- MicrodB, whose noise camera includes a microphone array; and
- 24 Acoustics, whose noise camera provides a single microphone solution.

The two noise cameras were tested in a controlled environment at UTAC Millbrook during April 2022. The testing aimed to identify strengths and limitations of both systems in simple and complex traffic scenarios, and situations that may generate false positives or limit enforcement from taking place. The testing was undertaken with a car and a motorcycle that were both fitted with aftermarket 'sports' exhausts to generate excess noise. The car was also engine mapped to produce 'pops and bangs' to see if these could be detected by the noise cameras.

The results of the testing found that MicrodB's array-based system was able to automatically assign noise levels to vehicles in a traffic stream and when vehicles pass each other in opposite directions. However, the system did not register noise emissions occurring outside of its detection zone, such as pops and bangs generated by an engine mapped vehicle. The single microphone system from 24 Acoustics was also able to assign noise levels to vehicles in convoys and two-way traffic (referred to in this report as contraflow) scenarios but required a higher level of manual review to do this. However, as its detection zone was larger, a manual reviewer was able to assign noise levels to noise events further away from the system's location.

A key constraint of both systems was that they currently do not incorporate an automatic number plate reader (ANPR) and are reliant on manual review to obtain the vehicle's registration mark. Further development is required to incorporate this to improve automation and efficiency. The use of wide-angled or multi-camera context video and synchronised audio greatly aids the manual review and would be required for the evidence package for traffic enforcement. Further work is also required in terms of evidence package generation and encryption of systems when deployed.

The testing outcomes were used to devise a list of enforceable scenarios based on the current capabilities of the tested noise cameras. Enforceable scenarios include single vehicle passes (including acceleration), traffic streams, contraflows and overtaking manoeuvres. Higher levels of manual review are likely to be required to enforce scenarios where the drivers of stationary vehicles rev their engines or of moving vehicles sounding their horn while passing the noise camera. Noise cameras are likely to offer a better opportunity to tackle antisocial noise from vehicles if located in areas where drivers accelerate unnecessarily harshly compared to locations where the speed is likely to be fixed.

1. Introduction

1.1. Background

According to the World Health Organisation, noise pollution is one of the top environmental risks affecting physical and mental health and wellbeing [1]. Vehicle noise is a significant cause of noise pollution, particularly in urban environments. Excessively noisy road vehicles, which have often been modified, also lead to significant annoyance and complaints from members of the public throughout the UK. The police and local authorities have powers to take action against excessively noisy road vehicles however it is difficult to collect sufficient evidence for meaningful enforcement action. The current approach does not sufficiently discourage vehicle modification.

The Department for Transport (DfT) is seeking to address this issue and has commissioned a number of research studies over the years investigating excessively noisy vehicles and ways of reducing the problem. The most recent study was Phases 1 and 2 of DfT's Roadside Vehicle Noise Measurement project, which identified automated noise cameras as a potential technological solution to the problem [2] [3]. A prototype noise camera comprising a microphone, video camera, speed radar and Automatic Number Plate Reader (ANPR) was developed and tested during 2019 to establish proof of concept. Since the completion of the Phase 2 study, interest in noise cameras as an enforcement tool has grown and a number of noise camera products have been tested or deployed in the UK [4], Europe [5] [6] [7], Taiwan [8] and the United States [9]. Limited information is publicly available on the performance of these products, their suitability for deployment on UK roads and which types of excessively noisy vehicle scenarios they are best equipped to address.

Lessons from the UK and abroad during the development and proliferation of speed and red light cameras over the past two decades can be used to fast-track the design of acoustic detection systems so they are compliant with existing legislation and the requirements of the justice system.

The Atkins Jacobs Joint Venture (AJJV) has been commissioned by the DfT through the Highways England SPaTS2 framework to undertake research into excessively noisy vehicles and technologies that could be used to improve enforcement against them. The contract was awarded to the AJJV during December 2021.

1.2. Project Definition

The primary aim of this project is to improve enforcement against excessively noisy vehicles and in doing so, allow disturbance in affected areas to be reduced. Improvements to enforcement through the provision of enforcement technologies able to detect and identify excessively noisy vehicles would collect a robust evidential trail to support the police and local authorities in successfully taking enforcement action against offenders (such as fines, vehicle defect rectification notices). Visible and publicised enforcement action is likely to improve public awareness of the issue and simultaneously deter drivers from generating excessive noise through certain driving styles or vehicle modification.

Phase 3 of the project comprises three distinct tranches of work with the following objectives;

- Part A – Defining excessive noise
    - To investigate the advantages and disadvantages of using a single noise threshold or a set of noise thresholds for a range of vehicle types
    - To investigate the effect of exhaust and silencer modifications on vehicle noise emissions and how these may acoustically characterise excessively noisy vehicles
    - To provide noise threshold recommendations, with associated tolerances, to be applied in real world driving environments that could be used by an automated system or a handheld device such as a sound level meter
- Part B – Identifying, testing and recommending appropriate technology

    - To identify and review the latest available noise camera products to determine their suitability for UK roads and as an enforcement tool
    - To test the performance of suitable noise camera products in controlled conditions
    - To develop a universal installation and deployment guide for any noise camera product that could be used by the police and local authorities
- Part C – Roadside trials
    - To further test the performance of suitable noise camera products in real world driving environments, particularly in urban environments
    - To finalise the universal installation and deployment guide developed in Part B based experience from the roadside trials

Parts A and B have been undertaken in parallel and are reported separately. Progression to Part C is wholly dependent on the successful outcomes of Part A and B.

This report discusses the research undertaken from the Part B scope of work, identifying the strengths and benefits of current noise camera systems and whether the technology is suitably developed for roadside trials in Part C. The universal installation and deployment guide has been issued as a separate deliverable. The structure of the report is as follows:

- Chapter 2 – Part B Methodology
- Chapter 3 – Technology Review and Selection
- Chapter 4 – Trial Methodology
- Chapter 5 – Results
- Chapter 6 – Discussion
- Chapter 7 – Recommendations
- Chapter 8 – Conclusions

A glossary of technical terms used in this report is available in Appendix A.

2. Part B Methodology

To meet the objectives for Part B outlined in Chapter 1, the scope of work has been split into two core tasks. The approach used for each of these tasks is described in the subsections below.

2.1. Review and appraisal of current noise camera technologies

A review of the noise cameras that are currently available or under development was undertaken. The noise camera suppliers were contacted to obtain product specifications and information on how the products detect vehicles and attribute pass-by sound levels to them.

Based on the review, a functional specification for a noise camera was developed against which the identified noise cameras were screened and scored for further consideration in the project. The screening criteria defined requirements for the sound measurement, vehicle detection and evidence capture elements of the camera, as well as its hardware and software specifications, ability to withstand a range of environmental and meteorological conditions, and ease and logistics of repairing the technology. Data post-processing times and cost were also considered, which encompasses the levels of automation provided by the technology and human assistance required to process the data and to arrive at a decision to take and implement enforcement action. Since the vehicle detection and evidence capture components are well defined in DfT's existing enforcement standards (for example the "Certification of Approved Devices" published in February 2008 [10]) and present a low risk to the project, these were not examined further during this project.

Following the initial screening of noise camera products, potentially suitable noise products were shortlisted for further consideration. At this stage, the AJJV engaged in more detailed discussions with the products' suppliers to further understand their capabilities and suitability for meeting the project's needs. After these discussions, the shortlisted items were ranked and the preferred products selected for testing in a controlled environment.

2.2. Off-road track trial and evaluation of noise camera performance

Having developed the functional specification (also called the success criteria), a trial methodology was developed with UTAC Millbrook, the test facility hosts. The key objectives of the trial were:

- To test the performance of suitable noise camera products in controlled conditions;
- To undertake a set of common tests to characterise the test configuration and establish ground truth data for the camera specific tests. The ground truth data provides factual information through direct observation and measurement independent of the noise camera technologies tested;
- To measure vehicle noise emissions from vehicles fitted with aftermarket products, different driving styles (aggressive, progressive) and complex traffic scenarios, and to understand how these variables impact the performance of noise cameras; and
- To identify false positives and limitations of noise camera systems for enforcement.

The methodology incorporated a series of objective measurements to allow the identified noise camera to be characterised and assessed. The test method defined a number of scenario types using a fixed selection of vehicles to allow for repeatability between tests. The main test vehicles comprised a car and motorcycle that were fitted with aftermarket products to produce acoustic features that may disturb people in a real world setting and which may be considered excessively noisy.

The testing included controls for driving style (i.e. aggressive vs progressive) and incorporated some test runs using different driving styles, including acceleration, cruising, and wide-open throttle acceleration. False positives tests were carried out to determine to what degree sound from other vehicle types can be screened out, such as buses and emergency services vehicles with sirens activated. Night-time testing was undertaken to establish how low lighting levels affect the product's ability to identify vehicles.

Following completion of the trials, the noise camera outputs were compared against ground truth data to establish the ability of the technology to detect individual vehicles and attribute sound levels to them across the test scenarios. The variability in measured sound levels between the noise camera and ground truth was also assessed.

3. Technology review and selection

3.1. Introduction

The AJJV undertook a review of potentially available noise cameras in the marketplace to allow the selection of a candidate noise camera to test under controlled conditions.

During Phase 1 of this project in 2019 [2], four potential noise camera systems and three other systems with potential for future development were identified. At that time none of these systems were suitable for use in the UK and Phase 2 of the project in 2020 developed and tested a prototype noise camera to establish proof of concept [3].

The marketplace was reviewed at the beginning of this phase of the project to establish if there had been any further development of the systems reported in Phases 1 and 2 of this project and to discover if any new systems have been developed. The identified products were appraised, with those that could be suitable testing on UK roads shortlisted for further consideration.

3.2. Product identification and review

3.2.1. Products identified in Phase 1 and Phase 2

The technologies identified in Phases 1 and 2 are shown in Table 3-1 below, with a short summary of the 2022 situation for each.

Table 3-1 Phase 1 and 2 Product Review

System	2019/2020 Details	2022 Situation	Shortlist
Australia Truck Noise	Limited information available in 2019. Focussed on truck braking noise.	No further review taken.	No
Edmonton, Canada	System to display noise levels on roadside screen.	No published reports available. No further review taken.	No
Abu Dhabi	No technical information available in 2019.	No technical information available in 2022 and no evidence of system in use. No further review taken.	No
Noivelcam	Prototype product developed.	Further development work has been undertaken on this product, but not ready for testing or consideration for Phase 3.	No
Akut	Potential technology identified.	Product development in progress for excessively noisy vehicles, but not in the timeframe for Phase 3.	No
Boomerang	Potential technology identified.	No evidence of system development for excessively noisy vehicles. No further review taken.	No
ShotSpotter	Potential technology identified.	No evidence of system development for excessively noisy vehicles. No further review taken.	No
Smart Video Sensing	Prototype developed and used for Phase 2 trials.	No further product development undertaken since Phase 2 trials.	No

The review of the products identified in Phases 1 and 2 of the project shows that further development work is taking place on the Noivelcam and Akut systems, but this has not progressed to the stage where either system could be considered for Phase 3.

3.2.2. Review of 2022 marketplace

Since the publication of the Phase 1 and 2 reports there has been development of a range of noise camera style products and the marketplace was reviewed to identify details of these products and other potential technologies. The marketplace review was completed in two steps:

1. Desktop review to identify details of potential systems.
2. Using relevant industry contacts to identify other systems.

The first step resulted in the identification of eight potential products, which were reviewed so that the most promising of these systems could be short-listed to identify products for the Phase 3 trials.

The second step identified nine industry contacts, mostly from the sound level meter manufacturer/distributor marketplace to identify if they knew of their sound level meter products being used in noise cameras or prototype/development activities leading towards noise cameras. Six contacts responded back, one of which identified that their sound level meter was used in one of the products identified in the first step. No further products or technologies were identified.

The summary of all products identified in the 2022 marketplace review is reported in Table 3-2.

Table 3-2 2022 Marketplace Product Review

System	Details	Shortlist
24 Acoustics	Single microphone system currently in use for enforcement in the Royal Borough of Kensington and Chelsea.	Yes
Bruitparif	A noise camera using a microphone array that has been developed and tested in roadside environments in France.	Yes
MicrodB	An array-based noise camera that has been developed and tested in roadside environments in France.	Yes
ACOEM	An array-based noise camera that has been developed and tested in roadside environments in France.	Yes
Securaxis	A system developed in Switzerland that uses two microphones to detect excessively noisy vehicles using audio profiles.	Yes
NEMO	A noise camera using two microphones that is being developed as part of a European research project to detect excessively noisy road vehicles and trains.	Yes
General Noise	Emerging technology using RADAR/LIDAR instead of microphones. Development is in progress, but is not at the right stage to be considered for Phase 3 trials. Could be considered a disruptive technology.	No
Taiwan camera	Details not available. Appears to be similar to the Phase 2 prototype camera. Not pursued further.	No
National Traffic Safety and Environment Laboratory	A system under development in Japan that uses 31 microphones to and AI to identify vehicles that are fitted with an illegal replacement exhaust muffler.	No

The 2022 marketplace review shows six candidate systems with the potential to be used in the Phase 3 trials, and an emerging disruptive technology that does not use microphones that has future potential.

Contact was made with the developers of each of the six systems taken forward to the shortlist to seek further information about each system.

3.3. Product information

This section gives an overview of the six cameras taken forward to the shortlisting stage.

3.3.1. 24 Acoustics

24 Acoustics provided an in-depth specification of their noise camera product, which has been tested in ‘real-world’ trials and is used for enforcement in parts of London. This noise camera is a fully integrated system and includes Class 1 noise monitoring technology with high quality audio recording and playback capabilities. It has 1/3 octave spectral resolution and functionalities are currently being developed to allow for certain extraneous noise sources to be identified and omitted from further evidential analysis (for example, emergency vehicle sirens) using frequency analysis.

The monitoring capabilities are supported by an encrypted online evidential management system that includes a noise data trace synchronised with video and audio playback. Vehicle number plates can be identified manually from the video file, with vehicle identification retrieved through an application programming interface (API) to an appropriate DVLA database. The noise camera output data can also include close up images and metadata, such as timestamps, maximum recorded noise level and other acoustical parameters, meteorological data, and the rolling background average noise level.

The noise camera records an exceedance of a preset noise threshold. Each time the threshold level is exceeded, the evidence and information collected by the noise camera is uploaded to a secure web portal. The noise camera is not configured to automatically take enforcement action when a noise exceedance takes place. The decision to enforce (such as issuing fines) is taken after the noise camera data is reviewed manually to determine if an offence has occurred.

Figure 3-1 Noise cameras from 24 Acoustics (left) and Bruitparif (right)

3.3.2. Bruitparif

Bruitparif [11] is a French non-profit environmental organisation responsible for monitoring the environmental noise in the Paris agglomeration. They have developed a range of noise detection products and they have recently moved to developing the noise camera ‘Hydra’ which is being tested in France during 2022. Hydra, as shown in Figure 3-1, comprises:

- Two small microphone arrays aligned vertically, one array above the other. Each microphone array is one of Bruitparif’s ‘Medusa’ units, which comprises four Class 2 microphones and calculates sound levels and the direction of the noise being measured.
- Two ANPR cameras able to detect number plates of vehicles in both directions and in up to 4 lanes.
- One wide-angle fisheye camera with 0 lux capabilities, to provide high quality video.

Hydra combines AI technology with the data collected from the Medusa units to provide a higher level of precision about detected events. The system can detect noise from individual vehicles when there are multiple vehicles passing near the camera, and detect the use of horns automatically.

The AI technology helps integrate all data together including compensating for distance from the microphone. The technology can also detect type of vehicle and uses different noise thresholds for these types. The noise camera outputs for enforcement include:

- A video sequence with synchronised audio
- 180° fisheye image of the whole scene with the offending vehicle and sound source plotted
- Close-up image from ANPR cameras
- Close-up images of the front and rear number plates

3.3.3. MicrodB

MicrodB [12] is based in Lyon, France offering a range of microphone arrays. They have developed the dBFlash product, a system to automatically detect and enforce against excessively noisy road vehicles. The system is a prototype which has been fully developed to operate automatically in roadside trials, with the following detection procedure:

1. Video monitoring: Automatic detection of vehicles travelling in both directions
2. Noise measurement and images of the vehicle detected in the control area
3. Measurement of ambient noise level
4. Isolation and quantification of the vehicle noise level in the control area
5. Confirmation that a single vehicle and low background noise has been detected
6. Images taken for plate recognition,
7. Communicating the evidence of enforcement with secure transmission

Their product has been in development since June 2021 with various track and roadside trials taking place in France since then. Their system is able to detect and discard situations where there is uncertainty in the detection, and is shown in Figure 3-2.

Figure 3-2 Noise cameras from MicrodB (left) and ACOEM (right)

3.3.4. ACOEM

Within the French ACOEM Group, the company 01dB has been set up to cover noise monitoring. The ACOEM 'Noise Radar' solution uses CUBE, a 4G smart noise monitoring terminal that conforms to IEC 61672 Class 1. The Noise Radar uses four microphones arranged in an array, covering a frequency range of 6.3Hz to 20kHz and is able to carry out 1/3 octave band frequency analysis. The system includes a fisheye camera, a third party ANPR, meteorological sensors and can collect audio recordings of the noisy vehicle. Alternative video and ANPR products can be integrated to meet the requirements of different enforcement jurisdictions.

Noise Radar has been trialled in France and is being developed further to monitor multiple lanes in the same direction and reduce false positives. The supplier has indicated that the system would need to be installed at least 10m from a reflective wall and without parking bays beneath the system.

3.3.5. Securaxis

Securaxis [13] is based in Switzerland and specialises in technologies used for measurement and monitoring sound in cities. The Securaxis noise camera is capable of measuring noise omni-directionally in the range of 20Hz to 20kHz with 1/3 octave analysis. The default noise equipment is to IEC 61672 Class 2, however there is an option for Class 1 equipment.

The Securaxis solution currently does not rely on a camera, instead it captures noise profiles. The system uses artificial intelligence to learn the sound profiles of various sound sources such that those sources can be identified when they are present. The system has not been specifically designed with enforcement in mind. Securaxis has indicated that another version of their system with a third party ANPR will be available towards the end of 2022.

3.3.6. NEMO

The NEMO project [14] has received funding from the European Union's Horizon 2020 research and innovation programme to develop new remote sensing technology to measure noise and air emissions from individual road vehicles and trains in real time. The noise aspects of the research are led by two consultancies based in the Netherlands (M+P and Müller-BBM), who have been developing a noise camera system. The system is being tested in the city of Rotterdam in the Netherlands, and further tests are being arranged in Italy and Spain. The NEMO project synchronises the results at a particular installation site together, sending them to a data hub for further processing and analysis.

NEMO is a prototype autonomous system to measure noise from road and rail vehicles under actual driving conditions. Their system is aiming to identify individual road vehicles within a live traffic stream. The system will be able to distinguish between engine noise and tyre-road noise. The system aims to automatically detect vehicles emitting more noise than the levels set at type approval. Further development is focussing on detecting and eliminating false positives and triggers from emergency vehicles.

3.4. Product appraisal and selection

3.4.1. Scoring

To allow the suitability of these products to be assessed for the Phase 3 work, a questionnaire was sent to each of the product developers to identify the level of product development and suitability for the Phase 3 work.

The questionnaire was split into two parts, the first part considered the acquisitional aspects of the camera and the second part looked at the non-acquisitional aspects, with specifics in nine areas as shown in Table 3-3.

Table 3-3 Camera questionnaire

Part	Aspect	Details
Acquisitional	Acoustic	Specification and characteristics of the microphone(s) and subsequent analysis and capture of the acoustic signal.
Acquisitional	Video	Specification and details of the video signal
Acquisitional	Automatic Number Plate Reader (ANPR)	Specification and details of number plate capture
Acquisitional	Meteorological	Details of meteorological data captured by the camera
Non-acquisitional	Evidence management	Details of the contents and encryption of the evidence pack created by the camera
Non-acquisitional	Power	Details of power supply details, power consumption and maintenance requirements
Non-acquisitional	Physical	Environmental limitations, mounting arrangements and GPS information
Non-acquisitional	Cost and Availability	Details of any territorial restrictions and indicative costs
Non-acquisitional	Reliability	Details of the performance of the camera in terms of availability and mean time between failures.

Some of the items in the questionnaire were given a minimum performance specification whereas other items were sought for information. Overall, there were 38 specific details captured in the questionnaire. The completed questionnaires were scored to give an overall score for each product.

A weighted average score was calculated for each of the acquisitional and non-acquisitional capabilities. The acoustic, video, ANPR and evidence management aspects were considered to be most important, and the average score for these capabilities was weighted to influence in the overall score.

In addition to scoring the noise cameras on the specifics of the questionnaire, a set of more general questions were also considered and scored by the AJJV based on the information available for each camera:

- Does the product feel like it is ready to be installed?
- Does the product feel like it would be reliable?
- Does the product integrate its data together?
- Is all data processing carried at/in the product?
- Could this product be easily installed?
- Would this product be resistant to tampering?
- Would this product work well in the dark?
- Would this product work well in UK weather conditions?
- Would this product need minimal maintenance?

The overall score for each noise camera was calculated from the scores assigned to the general questions above and the sum of the weighted averages for its acquisitional and non-acquisitional capabilities. The maximum scores and weighting applied are detailed in Appendix B.

3.4.2. Product selection

The capabilities of the six shortlisted noise camera systems are summarised in Table 3-4. All of the products had been tested in real-world conditions in a roadside environment before February 2022.

Table 3-4 Summary of noise camera capabilities

Product supplier	System features					Notes
	Array	Video / image	ANPR	Weather sensor	For enforcement	
24 Acoustics	×	✓	×	Optional	✓	One microphone, screens out some false positives. Currently used in the UK for enforcement, evidence review is labour intensive.
MicrodB	✓	✓	×	✓	✓	Automatically detects vehicles in both directions, some known false positives.
Bruitparif	✓	✓	✓	✓	✓	Uses vehicle tracking and AI, screens out some false positives.
NEMO	×	✓	✓	✓	×	Two microphones for noise measurements, created for research project. Not yet a ‘product’ - installation could be difficult in urban areas.
Securaxis	×	✓	×	✓	×	Two microphones, created for remote sensing.
ACOEM	✓	✓	✓	✓	✓	Uncertainty in evidential management capabilities

Product supplier	System features					Notes
	Array	Video / image	ANPR	Weather sensor	For enforcement	
						and ANPR performance from the data provided.

All of the products considered are prototype cameras at various stages of development. The 24 Acoustics noise camera is the most developed product and has been used for enforcement in the UK. The MicrodB, Bruitparif and ACOEM noise cameras are developed into standalone products which have undergone a range of roadside trials. The NEMO noise camera is not developed yet to a point where it could be considered for this project. The Securaxis noise camera is primarily designed for monitoring and would need additional features for enforcement to take place.

To ensure that the scoring and assessment of the noise cameras was fair and consistent, the scores were moderated by the AJJV's technical experts taking into account the merits and potential shortcomings of each product. The availability of the product for testing during Part B was also considered. From this process, it was concluded that the NEMO and Securaxis noise cameras were not sufficiently developed for participation in the Part B trials. The remaining four products were ranked based on the scoring, availability for the trials and ability to further our understanding of noise camera technologies. The final outcomes of the scoring and ranking are shown in Table 3-5, with further information available in Appendix B.

Table 3-5 Final Ranking

Camera	Rank	Justification	Outcome
24 Acoustics	1	Single microphone solution currently used for enforcement in the UK. Post-processing not automated.	Candidate for Part B and Part C trials.
Bruitparif	2	Has vehicle tracking, assigns noise levels to vehicles in real-time.	Candidate for Part C trial (unavailable for Part B).
MicrodB	3	Complete system with 52 micro-electromechanical systems (MEMs) microphones. Development needed for multiple passing vehicles.	Candidate for Part B and Part C trials.
ACOEM	4	Complete system, can integrate any ANPR. Development needed for multiple passing vehicles.	Candidate for Part B and Part C trials.

As the Bruitparif camera was not available for the timing of the Part B trials, the 24 Acoustics and the MicrodB cameras were both recommended to be taken forward to the Part B trials. This recommendation was taken forward and the Part B trials were conducted with both the 24 Acoustics and MicrodB noise cameras.

One of the key shortfalls of the elements of the cameras being considered is a lack of integrated automatic number plate recognition (ANPR), and it is recognised that may be a key factor in determining selection for Part C trials.

4. Trial methodology

4.1. Track specifications and layout

The track trials were undertaken at the UTAC Millbrook Proving Ground facility located in Bedford, which has a specialised external track designed for undertaking noise measurements of vehicle pass-bys for type approval. The site geometry, sound absorption characteristics and asphalt road surfacing are compliant to ISO 10844:2021 [15], the track specification standard for type approval testing. The track comprises a straight section with return loops at each end, with the noise surface positioned centrally in the straight section for a total length of 26m. The ambient sound pressure level in absence of vehicles is 36 dB(A) during meteorological conditions suitable for noise measurement (dry conditions with wind speeds below 5 m/s). An overview of the test track and layout during the testing is provided in Figure 4-1, adapted from UTAC Millbrook track brochure [16].

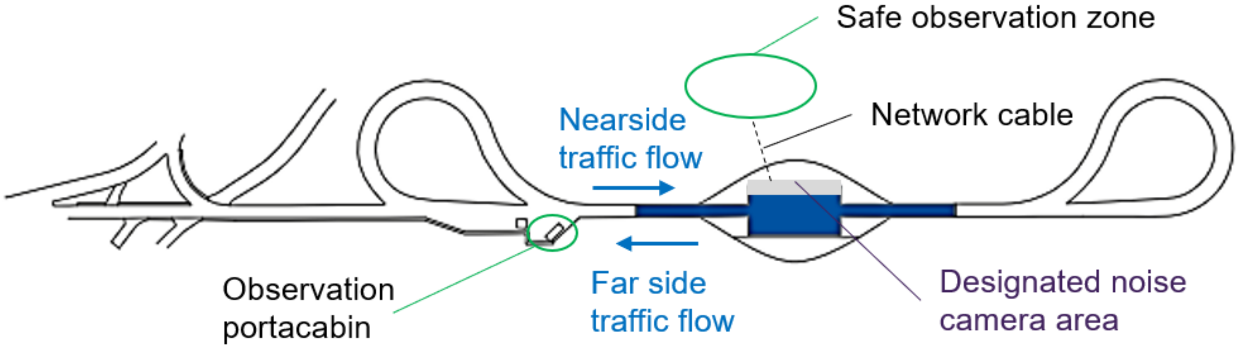

Figure 4-1 Overview of test track

Three sets of acoustic measurement equipment were positioned within the designated area on the test track, which comprised the following:

- "**Millbrook" system:** Two microphones, one either side of the test lane at 7.5m from the centre of the test lane in accordance with type approval testing standards. The microphone height was 1.2m above ground level.
- **"AJJV" system:** Single microphone positioned in proximity to the nearside Millbrook microphone to allow verification of noise levels and provide a 'ground truth'. It was also positioned at 7.5m from the centre of the test lane and at 1.2m above ground level. The AJJV system was to Class 1 of BS EN 61672 [17], and field calibrated during the trials with a calibrator of Class 1 of BS EN 60942 [18].
- **Noise camera systems:** Positioned on telescopic masts either side of the Millbrook nearside microphone in accordance with suppliers' specifications and requirements. The systems were positioned as close together as practically possible and approximately equidistant from ground level to ensure they captured the same event simultaneously, minimising the need to repeat tests, whilst not compromising the quality of data being recorded or system performance.

In addition to the acoustic measurement equipment, two weather stations were sited at the back of the designated area to collect meteorological data during the testing. One of the weather stations directly interfaced with the Millbrook system to simultaneously assign meteorological data to each test run. During periods of inclement weather, namely precipitation other than very light rain, testing stopped and sensitive acoustic instrumentation was removed temporarily from the test track until the weather conditions improved. Testing resumed when the test track was dry and safe enough for testing to continue.

A pair of light barriers were positioned at the entrance to and exit from the test area at a known distance apart. When the light beam between each pair of light barriers is broken by the test vehicle, the average speed of the test vehicle is calculated based on the distance between the light barriers and the time taken for the test vehicle to pass through each pair of light barriers.

Figure 4-2 provides information on the site and equipment setup.

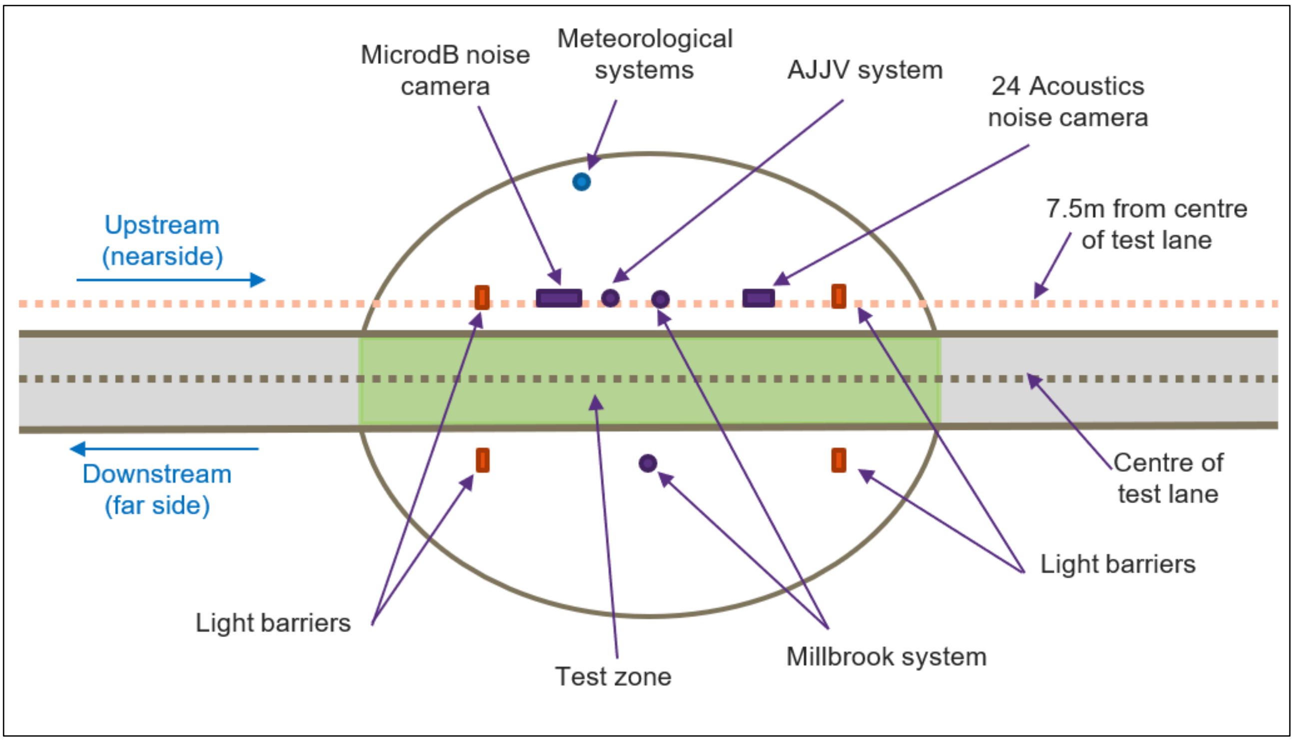

Figure 4-2 Representation of noise camera positioning – plan view

4.2. Test Vehicles

The testing focussed on testing a car and a motorcycle in either a standard condition (referred to as 'stock') or with aftermarket products fitted. The two test vehicles were a 1200cc BMW K1200s motorbike (referred to as Vehicle C) and a 2006 Ford Focus ST (referred to as Vehicle E). The same two test vehicles were assessed in the Part A scope of work.

The test vehicles were occasionally supported by other vehicles (standard vehicle(s), bus, patrol vehicle) as dictated by the objectives of the test. All vehicles were sourced by UTAC Millbrook and were checked prior to any testing to ensure they operated and functioned correctly.

The two test vehicles were fitted with aftermarket products to reflect real world scenarios where excessively noisy vehicles have been modified to generate excess noise. Both of the test vehicles were fitted with alternative exhaust systems branded as 'sports exhausts' to increase noise levels. The product fitted to the motorbike was a slip-on carbon fibre finish sports exhaust with its noise silencer 'bung' removed. The product was marked legal for road use with the silencer 'bung' fitted. The product fitted to the car was a non-resonator 'cat back system'[1] sports exhaust with no markings shown to denote whether it was road legal.

The car was also engine tuned (remapped) which allowed for the following three settings to be selected:

- Standard (as delivered from the factory),

[1] A 'cat back system' has a larger diameter than a manufacturer installed exhaust and has a more efficient mid-pipe and tail pipe due to improved exhaust flow from less-restrictive silencers. This results in a more 'aggressive' exhaust sound.

- De-cat[2] tuned performance enhancement, and
- De-cat tuned to create 'pops, bangs and crackles'.

The majority of the testing for Vehicle E utilised the de-cat tuned with the 'pops, bangs and crackles' mapping, which has been abbreviated to 'pops and bangs' for the purposes of reporting. The variation in noise emissions from the different engine maps is further explored in Part A [19].

All vehicles were driven by experienced professional drivers provided by UTAC Millbrook, following a prescribed method. This introduced controls related to the variability in driving style between individuals and this ensured that the results from the testing were repeatable and reproducible.

4.3. Test scenarios

4.3.1. Noise camera set-up

Several tests were designed to simulate common traffic scenarios that a noise camera would face in real world conditions in order to investigate their performance. The tests comprised:

- Simple scenarios where vehicles were operated without any additional acoustic contributions from other sound sources
- Complex traffic scenarios involving additional vehicles, such as overtaking, convoys and contraflows
- Aggressive and progressive driving styles
- False positive tests, such as excess noise from car horns or emergency services sirens.

Each noise camera had a 'detection zone' on the straight section of track, where excessively noisy vehicles would be detected in an enforcement scenario. A conceptual diagram of the detection zone is shown in Figure 4-3.

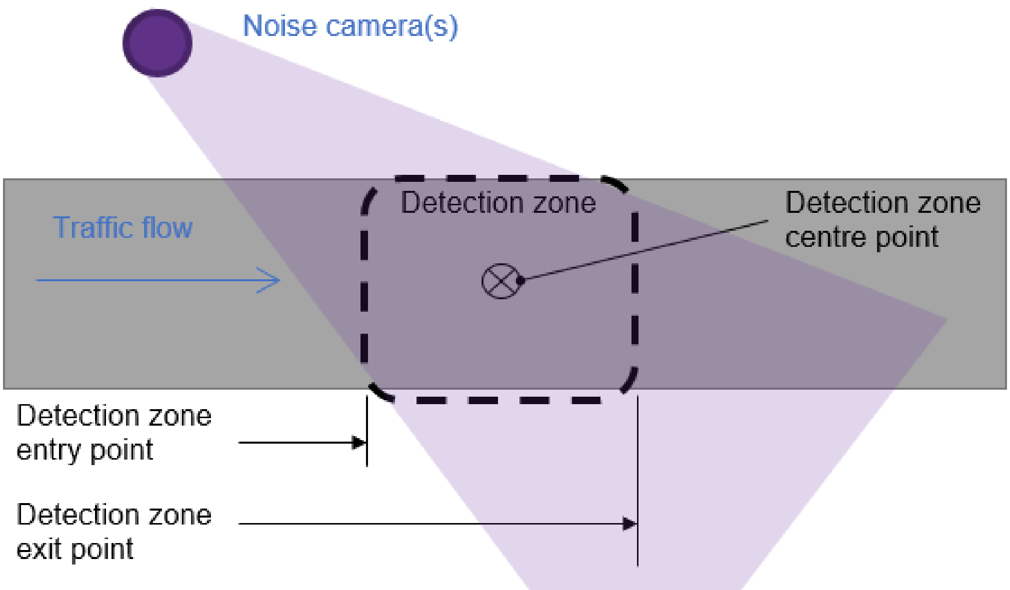

Figure 4-3 Detection zone parameters

The detection zones were set-up in accordance with the manufacturer specification for each product. The size and position of the detection zone was different for each noise camera as they

[2] De-cat refers to the removal of the catalytic converter. This has the effect of increasing the maximum available power (marginally) and making the vehicle louder as the catalytic converter has a small silencing effect. The de-cat tuning modifies the performance of the engine to optimise the engine performance where the catalytic converter has been removed.

were offset from the test lane and each product had different requirements. Although the detection zones overlapped, additional test runs were undertaken for some tests to ensure that both products were tested fairly.

4.3.2. Custom tests

A series of four 'custom tests' were undertaken to simulate typical driving in the following simple and complex scenarios:

- A single stationary vehicle idling and revving, to represent a simplified scenario of an inconsiderate driver revving their engine whilst stationary (e.g. waiting at traffic lights)
- Constant speed pass-bys of a single vehicle, to represent simple conditions on a low-trafficked road
- Constant speed pass-bys of a 'convoy' of vehicles travelling in the same direction, to represent the more complex situation of a typical traffic stream
- Constant speed pass-bys of two vehicles travelling in opposite directions, to represent the more complex situation of bidirectional roads or situations with contraflow conditions.

The methodology for each of these tests is summarised in Table 4-1. All test combinations were repeated five times with tolerances of ± 3 mph of target speed for constant speed tests.

Table 4-1 Track trials tests information

Test name	Description	Test method	Variants
Test 1	Single stationary vehicle tests	The test vehicle is stationary in the detection zone and is revved to 80% of the red-line speed or to the point that the governor activates. The duration of the revving is 5 seconds, starting from the time that the required rev condition has been met and finishes when the throttle is released completely in one quick action at the end of the test duration.	Vehicle type
Test 2	Single vehicle pass-bys	Each test vehicle passes through the detection zone at a constant speed without any other vehicles present.	Vehicle type, 20 mph, 40 mph
Test 3	Convoy passes	The test vehicle is centrally located within a 3-vehicle platoon (car, test vehicle, car) and passes the noise camera at a constant speed. A platoon comprising two motorcycles and the test vehicle was not possible as insufficient motorcycle qualified drivers were available. All vehicles travel in the same direction similar to the pass-by tests but as a platoon. Headways were 1.5 seconds to 2 seconds. All vehicles travel with suitable gearing and revs for the target speed.	Vehicle type, 20 mph, 30 mph, 40 mph
Test 4	Contraflow passes	The test vehicle passes the noise camera at a constant speed while a standard car travelling in the opposing direction passes through the detection zone simultaneously. All vehicles travel with suitable gearing for the target speed. Tolerance for contraflowing vehicles passing the manufacturer's nominated detection zone centre point within the test area to be: $T\ (\text{seconds}) = \dfrac{30}{\text{nominal pass speed (mph)}}$	Vehicle combinations, 20 mph, 30 mph, 40 mph

4.3.3. Other tests

A series of 'other tests' were undertaken to identify potential false positives, situations and driving styles that could affect the performance of the noise cameras. The methodology for each of these tests is summarised in Table 4-2. All test combinations were repeated 5 times with tolerances of ± 3 mph of target speed for constant speed tests.

Table 4-2 False positive and limitations testing

Test name	Description	Test method	Variants
Test OT1	Idling bus near noise camera	Constant speed pass-by of the test vehicle with a bus stationed opposite the noise camera with its engine running.	Vehicle type, 20 mph, 30 mph, 40mph
Test OT2	Convoy passes, both noisy vehicles	Constant speed pass-bys where both test vehicles travel through the detection zone in a traffic stream. The headway between the vehicles is 1.5 seconds to 2 seconds.	Vehicle order, 20 mph, 30 mph, 40 mph
Test OT3	Siren tests	The test vehicle and a vehicle fitted with an active siren pass the noise camera(s) at a constant speed. The test vehicle is in front of the siren vehicle with a headway of 1.5 seconds to 2 seconds.	Vehicle type, 20 mph, 30 mph, 40 mph
Test OT4	Coasting past the noise camera	The test vehicle accelerates hard to reach 30 mph at a point 10m upstream of the detection zone entry point, then coasts through the detection zone until it passes the detection zone exit point. The test imitates a 'camera surfing' driving style that can occur at speed cameras.	Vehicle type, engine map
Test OT5	Type approval tests	Full and partial type approval tests carried out for Part A of the project – test methodology and results are reported separately [19].	Vehicle type, vehicle speed
Test OT6	Overtaking	The overtaking vehicle approaches the test zone maintaining a constant position with respect to the target vehicle. Upon passing the nominated point, the overtaking vehicle accelerates hard through the remainder of the detection zone.	20 mph, 30 mph, 40 mph, car overtaking motorcycle, motorcycle overtaking car
Test OT7	Hard acceleration	The test vehicle is stationary and idling 10m upstream of the detection zone entry point, without any other vehicles nearby. The test vehicle then accelerates hard to the detection zone exit point.	Vehicle type
Test OT8	Horn tests	Constant speed pass-by of the test vehicle in stock condition with the horn activated as it passes through the detection zone	Vehicle type, 20 mph, 30 mph, 40 mph
Test OT9	Single vehicle pass-bys, wet road	Detection zone wetted with water such that the surface is visibly wet and spray is	Vehicle type, 20 mph,

Test name	Description	Test method	Variants
		generated. Constant speed pass-bys of the test vehicle through the detection zone.	30 mph, 40 mph
Test OT10	Image quality and number plate legibility	The main objective of the test was to examine the image generation components of the systems (camera and video) during the daytime and night-time. The night-time data was obtained from constant speed pass-bys of the test vehicle at 30 mph.	Number plate fonts, lit and unlit street lighting
Test OT11	Stationary test within idling traffic	Test vehicle positioned centrally in a stationary 3 vehicle platoon at the test area. The test vehicle is revved to 80% of the redline speed or until the governor engages for 2 seconds and the throttle released quickly. All other vehicles in the platoon are idling.	Vehicle type
Test OT12	Single vehicle pass-bys, 60mph	Constant speed pass-by of test vehicle at 60mph.	Vehicle type
Test OT13	As loud as possible	Test vehicle operated to run as loud and as quiet as possible during a single vehicle pass-by at constant speed.	Vehicle type

4.4. Data collection and management

4.4.1. Sound measurement

The AJJV and Millbrook acoustic systems measured the equivalent continuous sound pressure level ($L_{Aeq,T}$) and maximum sound pressure level (L_{AFmax}) from each test run. Spectral data in 1/3 octave band frequencies were also collected. Further information on the instrumentation used in provided in Appendix C.

4.4.2. Noise cameras

The data outputs from the noise cameras comprised measured sound levels from each system and images of the detected vehicles. The MicrodB noise camera provided additional acoustic information produced by its array. The 24 Acoustics noise camera provided additional contextual information from its video cameras.

4.4.3. Speed check device

The test vehicles were equipped with a GPS sensor which transmitted a speed signal to the control room at UTAC Millbrook. This information was used to record the speeds of the target vehicles as the tests were undertaken, in addition to data generated from the light gates.

4.4.4. Video recording device

An independent video recording device was used as part of the trial to record footage of the testing. The recording device was positioned to capture vehicles passing through the test area and the noise cameras.

4.4.5. Meteorological sensor

Meteorological data was collected from two weather stations at UTAC Millbrook for each test, comprising a permanent system at UTAC Millbrook and a portable system supplied by the AJJV.

The data collected included air pressure, humidity, air temperature, road surface temperature, wind speed and direction.

4.4.6. Data management

The Part B testing was undertaken in two separate weeks with a step back period between the two weeks of testing. The step back period allowed for initial validation and review of data and identification of any necessary changes to the proposed tests.

The test engineers undertook checks periodically to ensure the necessary data was being captured by the sound measurement devices. The AJJV and Millbrook data were backed up after each day of testing. Data collected from the noise cameras were issued to the AJJV after each week of testing.

4.5. Programme

The Part B testing was programmed to take place over a ten day period from Monday 4 April to Friday 8 April 2022 and Monday 25 April to Friday 29 April 2022. The availability of both noise camera systems placed a constraint on the testing programme as the only time when both systems were available for simultaneous testing was the second week of the trial. The test programme was therefore developed to prioritise the most important or complicated tests for dates when both systems were present. This means that a full dataset was collected for one of the noise camera products and limited or partial data collection was achieved with the other. Table 4-3 summarises the availability of the noise camera systems during the testing.

Table 4-3 Programme and data sources

Week	Period	Sound Measurement Data Source			
		Millbrook	AJJV	MicrodB	24 Acoustics
1	Monday 4th April to Friday 8th April 2022	✓	✓	✓	
2	Monday 25th April to Friday 29th April 2022	✓	✓	✓	✓

5. Results

5.1. Overview of the data collected

As described in Chapter 4, 16 sets of tests were performed during April 2022 to examine how the two noise camera systems detect and attribute sound levels to potentially excessively noisy vehicles. Additional testing was undertaken of the test vehicles in support of the Part A scope of work (OT5), which considered how the aftermarket products and engine mapping affected the noise emissions of the test vehicles. Further information on vehicular noise emissions of the test vehicles is available in the Part A report [19].

Table 5-1 summarises the testing undertaken for Part B and the data acquired from each noise camera and Millbrook during the trial. Further information relating to data sources shown as collecting a partial dataset is available in Appendix D.

Table 5-1 Track trials test information

Test name	Description	Date/s	MicrodB	24 Acoustics	Millbrook
Test 1	Single vehicle stationary tests	04/04/2022, 07/04/2022, 29/04/2022	✓	✓	✓
Test 2	Single vehicle pass-bys	05/04/2022, 25/04/2022, 26/04/2022	✓	✓	✓
Test 3	Convoy passes	26/04/2022	✓	✓	✓
Test 4	Contraflow passes	27/04/2022	✓	✓	✓
Test OT1	Idling bus near noise camera	05/04/2022, 06/04/2022	✓	×	✓
Test OT2	Convoy passes, both noisy vehicles	26/04/2022	✓	✓	✓
Test OT3	Siren tests	04/04/2022, 29/04/2022	✓	✓	✓
Test OT4	Coasting past the noise camera	07/04/2022	✓	×	✓
Test OT6	Overtaking	26/04/2022	✓	✓	✓
Test OT7	Hard acceleration	27/04/2022, 29/04/2022	✓	✓	✓
Test OT8	Horn tests	04/04/2022, 29/04/2022	✓	✓	✓
Test OT9	Single vehicle pass-bys, wet road	25/04/2022	✓	✓	✓
Test OT10	Image quality and number plate legibility	26/04/2022	✓	✓	✓
Test OT11	Stationary test within idling traffic	26/04/2022	✓	✓	✓

Test name	Description	Date/s	MicrodB	24 Acoustics	Millbrook
Test OT12	Single vehicle pass-bys, 60mph	26/04/2022	✓	✓	✓
Test OT13	As loud as possible	27/04/2022	✓	✓	✓
Legend					
✓	Full dataset				
✓	Partial dataset				
×	No data				

5.2. Test scenarios

The outcomes from each of the test scenarios and their variants are reported in the subsections below. The noise levels presented are the average maximum noise levels (L_{AFmax}) from each measurement system derived from each of the repeat test runs, for example, five single vehicle pass-bys at 20mph for Vehicle C.

5.2.1. Test 1: Single vehicle stationary tests

5.2.1.1. Data Review

Single vehicle stationary vehicle tests were undertaken for both test vehicles in two rounds of testing. The results of the first round of stationary tests are shown in Table 5-2.

Table 5-2 Measured noise levels from the first round of stationary tests

Test vehicle	Exhaust	Engine map	Source	Measured noise level (dB L_{AFmax})
Vehicle C (motorbike)	Aftermarket	Stock	AJJV	94
			Millbrook	94
			MicrodB	95
			24 Acoustics	Not Present
Vehicle E (car)	Stock	Stock	AJJV	80
			Millbrook	81
			MicrodB	78
			24 Acoustics	Not Present
Vehicle E (car)	Aftermarket	Stock	AJJV	88
			Millbrook	89
			MicrodB	80
			24 Acoustics	Not Present
Vehicle E (car)	Aftermarket	Pops and Bangs	AJJV	109
			Millbrook	108
			MicrodB	86
			24 Acoustics	Not Present

A 22 – 23 dB L_{AFmax} difference in noise level is noted between AJJV / Millbrook and MicrodB data sources when the pops and bangs mapping was utilised on Vehicle E. Due to the short data capture window of the MicrodB noise camera, the noise from the pops and bangs was not captured. The pops and bangs noise were noted to be extremely loud during these tests.

The results show a good correlation between data sources for Vehicle E with a stock exhaust and engine map, however a difference 8 – 9 dB L_{AFmax} is noted between AJJV / Millbrook and MicrodB data sources for Vehicle E with stock engine mapping and an aftermarket exhaust. Vehicles fitted with an aftermarket exhaust provided a greater contribution of noise emissions from the exhaust, which emits noise more directionally compared to that from the engine, which emits noise more equally. As the AJJV and Millbrook microphones were located at ground level (1.2m), more noise was incident upon the microphones from the aftermarket vehicle exhaust compared to the MicrodB microphone array, which was mounted at height (4m above ground level).

The second round of stationary tests was undertaken with the 24 Acoustics camera present to investigate this phenomenon further. The additional tests included two different vehicle orientations as described below and shown indicatively in Figure 5-1:

- Upstream, where the test vehicle is parked underneath the 24 Acoustics noise camera with its exhaust facing the MicrodB noise camera; and

- Downstream, where the test vehicle is parked underneath the MicrodB noise camera with its exhaust facing the 24 Acoustics noise camera.

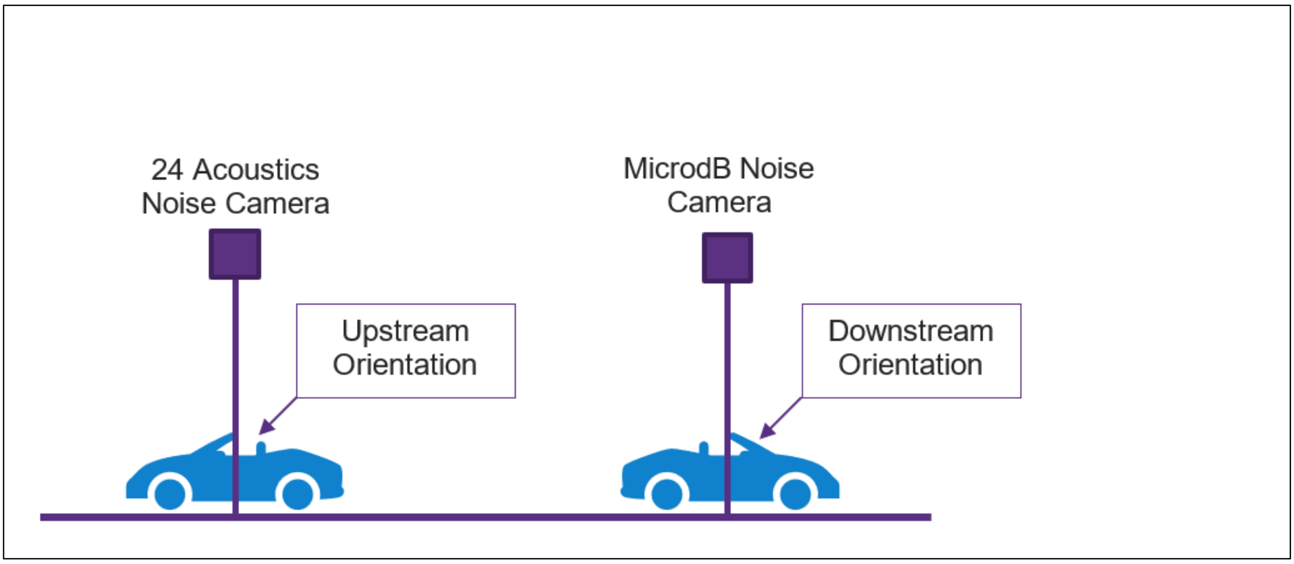

Figure 5-1 Vehicle orientations for the second round of stationary tests

Table 5-3 Measured noise levels from the second round of stationary tests considering upstream and downstream configurations

Orientation	Vehicle	Exhaust	Engine map	Source	Measured noise level (dB L_{AFmax})
Upstream, exhaust facing MicrodB	Vehicle C (motorbike)	Stock	Stock	AJJV	88
				Millbrook	88
				MicrodB	No data (1)
				24 Acoustics	89
Downstream, exhaust facing 24 Acoustics	Vehicle C (motorbike)	Stock	Stock	AJJV	87
				Millbrook	86
				MicrodB	89

Orientation	Vehicle	Exhaust	Engine map	Source	Measured noise level (dB L_{AFmax})
				24 Acoustics	88
Upstream, exhaust facing MicrodB	Vehicle E (car)	Aftermarket	Stock	AJJV	92
				Millbrook	No data (2)
				MicrodB	82
				24 Acoustics	84
Downstream, exhaust facing 24 Acoustics	Vehicle E (car)	Aftermarket	Stock	AJJV	90
				Millbrook	93
				MicrodB	No data (1)
				24 Acoustics	89

(1) No data captured due to data stability issues
(2) No data captured due to equipment malfunction

The results shown in Table 5-3 demonstrate a greater difference in noise level between data sources located at ground level (AJJV / Millbrook) and the noise cameras (i.e. located at height) for Vehicle E when an aftermarket vehicle exhaust is fitted.

It is noted that the MicrodB noise camera measured 2 dB L_{AFmax} lower than the 24 Acoustics noise camera for Vehicle E despite the vehicle exhaust being directed towards the MicrodB noise camera. It is understood this is due to the directivity of the microphone array resulting in the noise from the exhaust being measured with partial grazing incidence, as the vehicle was located outside of the noise camera's detection zone during the test.

The aftermarket vehicle exhausts also caused an increase of noise in the lower frequencies for both vehicle types, as shown in Figure 5-2.

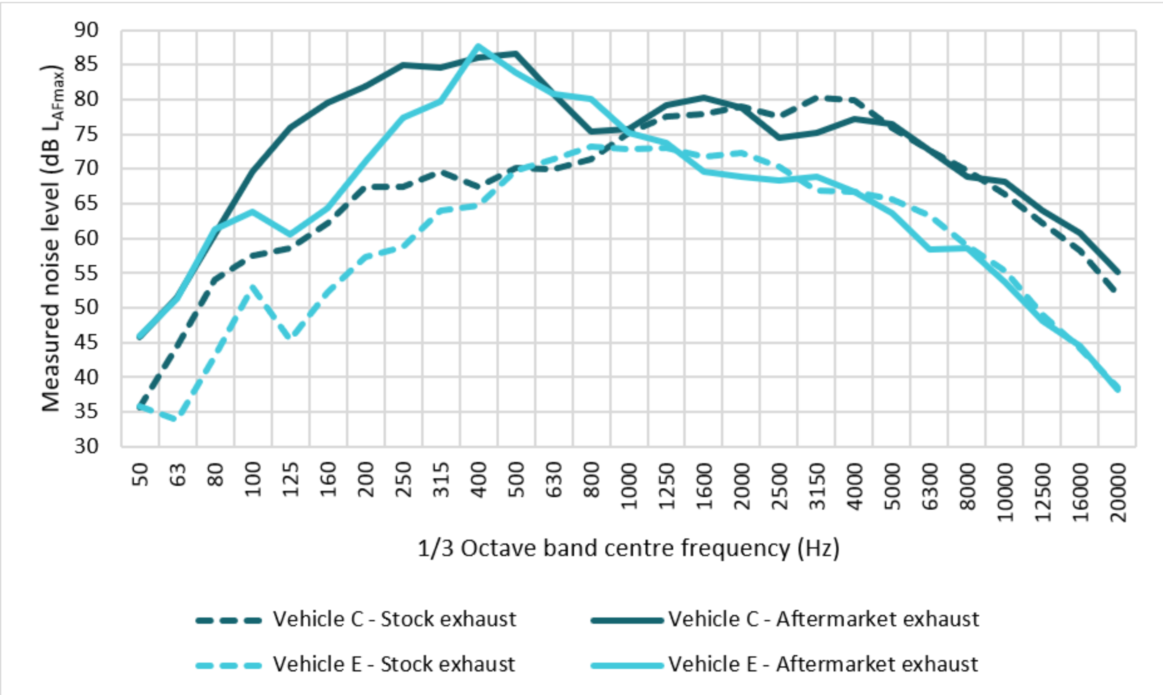

Figure 5-2 Frequency profile of Vehicles C and E with stock engine maps when stationary and revved (Test 1)

The increased low frequency noise is a characteristic of vehicles fitted with aftermarket products which is understood to result in increased annoyance.

5.2.1.2. Enforceability

It is deemed that noise from a single stationary vehicle is enforceable subject to the review of a suitable enforcement data pack.

5.2.2. Test 2 and OT12: Single vehicle pass-bys

5.2.2.1. Data review

Single vehicle pass-by tests were undertaken for both test vehicles, as shown in Table 5-4.

Table 5-4 Single vehicle pass-by tests

Vehicle	Exhaust	Engine map	Source	Measured pass-by noise level (dB L_{AFmax}) at test speed		
				20 mph	40 mph	60 mph
Vehicle C (motorbike)	Aftermarket	Stock	AJJV	80	80	84
			Millbrook	81	81	86
			MicrodB	78	No data	87
			24 Acoustics	79	82	85
Vehicle E (car)	Aftermarket	Pops and Bangs	AJJV	63	71	86
			Millbrook	64	72	85
			MicrodB	58	68	77
			24 Acoustics	65	74	86
Vehicle E (car)	Stock	Performance	AJJV	60	69	N/A
			Millbrook	61	71	N/A
			MicrodB	60	68	N/A
			24 Acoustics	Not Present	Not Present	N/A

A good correlation (difference of ≤ 3 dB L_{AFmax}) across all datasets is noted for Vehicle C and Vehicle E with Performance mapping. A difference of 3 – 9 dB L_{AFmax} is noted between AJJV / Millbrook / 24 Acoustics and MicrodB datasets when Pops and Bang mapping is utilised on Vehicle E.

The pops and bangs caused by the engine mapping often occurred approximately 10 – 30m downstream of the noise cameras when the driver lifted off the accelerator. As the MicrodB noise camera detection zone (i.e. zone and time period where noise is measured by the noise camera) is ±5m either side of the centre of the microphone array, the noise from the pops and bangs was often not measured by the MicrodB noise camera.

The performance mapping of Vehicle E subjectively did not result in a noticeable increase in noise compared to stock conditions.

5.2.2.2. Enforceability

It is deemed that single vehicle pass-bys are enforceable subject to the review of a suitable enforcement data pack.

5.2.3. Test 3 and Test OT2: Convoy passes

5.2.3.1. Data Review

Convoy pass tests with a 1.5 to 2 second headway between vehicles were undertaken for both test vehicles when fitted with aftermarket products, as shown in Table 5-5.

Table 5-5 Convoy pass tests using the test formation standard car, test vehicle, standard car

Vehicle	Exhaust	Engine map	Source	Measured pass-by noise level (dB L_{AFmax}) at test speed		
				20 mph	30 mph	40 mph
Vehicle C (motorbike)	Aftermarket	Stock	AJJV	80	80	81
			Millbrook	81	81	82
			MicrodB, Standard Car 1	71	64	68
			MicrodB, Test Vehicle	79	80	78
			MicrodB, Standard Car 2	71	64	66
			24 Acoustics	80	81	81
Vehicle E (car)	Aftermarket	Pops and Bangs	AJJV	64	70	76
			Millbrook	65	70	77
			MicrodB, Standard Car 1	58	64	68
			MicrodB, Test Vehicle	58	64	70
			MicrodB, Standard Car 2	58	64	67
			24 Acoustics	64	69	77

Table 5-5 demonstrates the ability of the MicrodB noise camera to provide independent noise levels for each vehicle within the convoy, whereas the 24 Acoustics noise camera provides an overall noise maximum for the whole convoy. Manual review of video footage, audio recording and noise data trace is required to identify which vehicle within the convoy is noisy.

The results show a good correlation between data sources for the tests undertaken with Vehicle C, however, a difference of 5 – 7 dB L_{AFmax} is noted between AJJV / Millbrook / 24 Acoustics and MicrodB datasets for tests undertaken with Vehicle E. This is because the MicrodB noise camera did not capture the increased noise level caused by the pops and bangs engine mapping that occurred outside of its detection zone.

Additional tests were undertaken with Vehicles C and E travelling in a convoy, as shown in Table 5-6.

Table 5-6 Convoy tests with Vehicles C and E following each other (OT12)

Vehicle	Exhaust	Engine map	Speed (mph)	Source	Measured noise level (dB L_{AFmax})
Vehicle E following Vehicle C	Aftermarket Aftermarket	Pops and Bangs Stock	20	AJJV	80
				Millbrook	81
				MicrodB, Vehicle C	77

Vehicle	Exhaust	Engine map	Speed (mph)	Source	Measured noise level (dB L_{AFmax})
				MicrodB, Vehicle E	60
				24 Acoustics	80
Vehicle E following Vehicle C	Aftermarket Aftermarket	Pops and Bangs Stock	30	AJJV	81
				Millbrook	82
				MicrodB, Vehicle C	82
				MicrodB, Vehicle E	67
				24 Acoustics	82
Vehicle E following Vehicle C	Aftermarket Aftermarket	Pops and Bangs Stock	40	AJJV	80
				Millbrook	81
				MicrodB, Vehicle C	81
				MicrodB, Vehicle E	70
				24 Acoustics	82
Vehicle C following Vehicle E	Aftermarket Aftermarket	Stock Pops and Bangs	20	AJJV	81
				Millbrook	81
				MicrodB, Vehicle C	80
				MicrodB, Vehicle E	60
				24 Acoustics	81
Vehicle C following Vehicle E	Aftermarket Aftermarket	Stock Pops and Bangs	30	AJJV	81
				Millbrook	81
				MicrodB, Vehicle C	82
				MicrodB, Vehicle E	65
				24 Acoustics	82
Vehicle C following Vehicle E	Aftermarket Aftermarket	Stock Pops and Bangs	40	AJJV	81
				Millbrook	81
				MicrodB, Vehicle C	84
				MicrodB, Vehicle E	70
				24 Acoustics	82

A good correlation is noted across all datasets throughout the tests with more variability between AJJV / Millbrook / 24 Acoustics and MicrodB datasets due Vehicle E to pops and bangs. This is due to noise from Vehicle C dominating the overall convoy noise level measured by AJJV / Millbrook / 24 Acoustics.

Comparison is made between the individual vehicle noise levels measured by the MicrodB noise camera during the convoy tests and those measured during the standard single vehicle pass-by tests (see Section 5.2.3) in Table 5-7.

Table 5-7 Comparison of MicrodB convoy and single vehicle pass-by noise levels

Test	Vehicle	Speed (mph)	Measured noise level (dB L_{AFmax})
Single Vehicle	Vehicle C (motorbike), Aftermarket Exhaust	20	78
Convoy			77
Single Vehicle	Vehicle C (motorbike), Aftermarket Exhaust	40	No data
Convoy			81
Single Vehicle	Vehicle E (car), Aftermarket Exhaust, Pops and Bangs Map	20	58
Convoy			60
Single Vehicle	Vehicle E (car), Aftermarket Exhaust, Pops and Bangs Map	40	68
Convoy			70

Table 5-7 demonstrates repeatability of the measured single pass-by vehicle noise level when the same vehicle is measured as part of a convoy with a 1.5 to 2 second headway between vehicles.

5.2.3.2. Enforceability

Convoy pass-by events are deemed to be enforceable with a varying degree of manual review required to identify the noisy vehicle within the convoy, depending on the noise camera technology.

As the MicrodB camera technology can automatically identify and exclude instances where multiple vehicles are within the detection zone and close together, the overall dataset required for manual review for enforcement is reduced. The 24 Acoustics system requires an increased degree of manual review as such instances of multiple vehicles within the detection zone need to be identified manually, thus increasing the size of the overall dataset.

It should be noted that tests were limited to a 1.5 to 2 second headway. Shorter headway times may be less enforceable.

5.2.4. Test 4: Contraflow passes

5.2.4.1. Data Review

Contraflow pass tests were undertaken for both test vehicles when fitted with aftermarket products, as shown in Table 5-8.

Table 5-8 Contraflow pass tests

Vehicle	Exhaust	Engine map	Source	Measured pass-by noise level (dB L_{AFmax}) at test speed		
				20 mph	30 mph	40 mph
Vehicle C (motorbike)	Aftermarket	Stock	AJJV	81	79	81
			Millbrook	81	80	81
			MicrodB, Test Vehicle	76	78	81
			MicrodB, Standard Vehicle	56	62	66
			24 Acoustics	81	81	81

Vehicle	Exhaust	Engine map	Source	Measured pass-by noise level (dB L_{AFmax}) at test speed		
				20 mph	30 mph	40 mph
Vehicle E (car)	Aftermarket	Pops and Bangs	AJJV	64	70	74
			Millbrook	65	70	75
			MicrodB, Test Vehicle	56	64	70
			MicrodB, Standard Vehicle	59	61	68
			24 Acoustics	65	70	75

Similar to the convoy pass tests, Table 5-8 demonstrates the ability of the MicrodB camera to provide independent noise levels for each vehicle whereas the 24 Acoustics camera provides an overall noise maximum for the whole contraflow event.

The MicrodB noise camera also automatically excluded any contraflow events which occurred where the two vehicles were both within the noise cameras ±5m detection zone, as the system is not able to automatically differentiate the separate vehicle noise levels. A total of 6 out of the 30 contraflow tests captured by the MicrodB noise camera were automatically rejected.

A difference of 5 dB L_{AFmax} is noted between AJJV / Millbrook / 24 Acoustics and MicrodB results for Vehicle C travelling at 20mph. This could be due to reflected noise from the standard vehicle which was travelling in contraflow.

A difference of 4 – 9 dB L_{AFmax} is noted between AJJV / Millbrook / 24 Acoustics and MicrodB datasets for tests undertaken with Vehicle E as the MicrodB noise camera did not capture increased noise level caused by the pops and bangs engine mapping.

5.2.4.2. Enforceability

Due to the narrow detection zone of the MicrodB noise camera, individual vehicle noise levels within a contraflow can be measured, providing multiple vehicles are not within the detection zone at the same time. This allows contraflow events to be enforced. When multiple vehicles are within the detection zone, it is possible for these cases to be automatically discarded to reduce the amount of data which requires manual review.

Due to the wider detection zone of the 24 Acoustics noise camera, manual review of the dataset is required to identify individual vehicle noise levels within a contraflow. This does not compromise the overall enforceability, but does require more manual review in order for enforcement to occur.

5.2.5. Test OT1: Idling bus near noise camera

5.2.5.1. Data Review

To investigate the influence of high background noise levels near to noise cameras, single vehicle pass-by tests were undertaken with a bus parked opposite side of the test track to the noise camera whilst idling, as shown in Table 5-9.

Table 5-9 Idling bus near noise camera

Vehicle	Exhaust	Engine map	Source	Measured pass-by noise level (dB L_{AFmax}) at test speed		
				20 mph	30 mph	40 mph
	Aftermarket	Stock	AJJV	80	80	80

Vehicle	Exhaust	Engine map	Source	Measured pass-by noise level (dB L_{AFmax}) at test speed		
				20 mph	30 mph	40 mph
Vehicle C (motorbike)			Millbrook	83	84	83
			MicrodB	75	80	80
			24 Acoustics	Not Present	Not Present	Not Present
Vehicle E (car)	Aftermarket	Stock	AJJV	73	76	76
			Millbrook	80	80	80
			MicrodB	Processing Rejected	70	71
			24 Acoustics	Not Present	Not Present	Not Present
Vehicle E (car)	Aftermarket	Pops and Bangs	AJJV	72	72	74
			Millbrook	75	77	77
			MicrodB	Processing rejected	Processin g rejected	70
			24 Acoustics	Not Present	Not Present	Not Present

The MicrodB noise camera automatically discounts triggers which occur when a high background noise level is noted before the trigger event. The noise level of the idling bus in isolation was typically measured as 67 dB L_{AFmax} by the AJJV microphone. All runs conducted with Vehicle C were sufficiently above the idling bus noise level for the noise camera to calculate a vehicle noise level. Of the 29 captured runs for Vehicle E, 23 were automatically rejected due to high background noise from the idling bus.

Noise levels measured by AJJV / Millbrook were consistent across all tests and demonstrate that the idling bus noise was dominant at the respective microphone locations.

Comparison is made between the single vehicle pass-by tests (see Table 5-4) and those passing the idling bus near noise camera tests as measured by the MicrodB noise camera in Table 5-10.

Table 5-10 Idling bus near noise camera and single vehicle pass-by comparison

Vehicle	Exhaust	Engine map	Speed (mph)	Single vehicle pass-by noise level (dB L_{AFmax})		
				With idling bus dB	Without idling bus	Difference
Vehicle C (motorbike)	Aftermarket	Stock	20	75	78	-3
Vehicle E (car)	Aftermarket	Pops and Bangs	40	70	68	2

For the two tests where comparative measurements are available, noise levels measured with the idling bus opposite the noise camera were within 3 dB L_{AFmax} of those measured during the single vehicle pass-by tests, showing a good correlation.

Additional tests were conducted with the bus parked directly adjacent to the noise camera to obscure the line of sight between the noisy vehicle and the camera. Tests were undertaken for Vehicle C at 20 and 30mph. The data captured during these tests was limited, as the MicrodB noise camera had to be manually triggered (one run at 20mph and two runs at 30mph) due to the noisy vehicle being obscured from view. The results are summarised in Table 5-11 and are compared to the results obtained with the bus parked on the opposite side of the test track:

Table 5-11 Idling bus near noise camera, location comparison

Vehicle	Exhaust	Engine map	Speed (mph)	Single vehicle pass-by noise level (dB L_{AFmax})		
				With bus located opposite	With bus located adjacent	Difference
Vehicle C (motorbike)	Aftermarket	Stock	20	75	61	- 14
Vehicle C (motorbike)	Aftermarket	Stock	30	80	61	- 19

Table 5-11 demonstrates that when a large stationary vehicle (i.e. a bus) is parked direct adjacent to a noise camera so that the line of sight between the noisy vehicle and noise camera is blocked, the resultant noise level greatly reduced.

5.2.5.2. Enforceability

It is possible to mitigate the influence of high background noise levels on the enforcement process via automatic exclusion of noise triggers which occurred whilst background noise levels were high. This will assist in the reduction of false-positives and/or edge cases which require manual review.

Noise camera systems which do not identify periods of high background noise before an event trigger (such as the 24 Acoustics system) are at a greater risk of false enforcement due to extraneous noise increasing the noise level of the passing vehicle. The ability to mitigate this, as per the MicrodB system, demonstrates that enforceability is not compromised if analysis of the background noise is provided by the noise camera.

Should the line of sight be obscured by a large stationary vehicle, the resultant noise levels measured from the noisy vehicle are greatly reduced.

5.2.6. Test OT3: Siren tests

5.2.6.1. Data Review

Vehicle pass-by tests were undertaken with an emergency vehicle with the siren active following the test vehicle. An approximate 1.5 to 2 second headway was maintained between the test vehicle and emergency vehicle. The measured noise levels are shown in Table 5-12.

Table 5-12 Siren tests

Vehicle	Exhaust	Engine map	Source	Measured pass-by noise level (dB L_{AFmax}) at test speed		
				20 mph	30 mph	40 mph
Vehicle C (motorbike)	Stock	Stock	AJJV	94	94	95
			Millbrook	96	95	96
			MicrodB, Test Vehicle	69	71	73
			MicrodB, Siren	97	98	98

Vehicle	Exhaust	Engine map	Source	Measured pass-by noise level (dB L_{AFmax}) at test speed		
				20 mph	30 mph	40 mph
			24 Acoustics	98	96	98
Vehicle E (car)	Aftermarket	Pops and Bangs	AJJV	94	91	91
			Millbrook	96	95	94
			MicrodB, Test Vehicle	58	66	69
			MicrodB, Siren	94	90	96
			24 Acoustics	Not present	Not present	Not present

Similar to the convoy and contraflow pass tests, Table 5-12 demonstrates the ability of the MicrodB camera to provide noise levels for each vehicle within the convoy whereas the 24 Acoustics camera provides an overall noise maximum for the test vehicle and siren vehicle pass-by event.

A good correlation is shown between all datasets for the siren noise event. It is noted that the AJJV / Millbrook results were typically 1 – 4 dB L_{AFmax} lower than the MicrodB / 24 Acoustics. This is due to the siren being mounted on the roof of the vehicle and therefore some acoustic shadowing of the siren noise was provided by the vehicle for the lower microphones, whereas the noise cameras had direct line of sight and were at closer to the siren.

The isolated noise level of the test vehicle as measured by the MicrodB noise camera shows an increase of noise with speed, however the siren noise levels remains consistent throughout all speeds. This is expected as the siren noise dominates any tyre / road, engine or exhaust noise associated with the emergency siren vehicle.

5.2.6.2. Enforceability

Sirens have the potential to cause false-positive triggers and therefore will require additional processing and / or manual review to reject associated enforcement. Automated rejection of enforcement due to sirens may be possible through frequency analysis, however due to the varied tonalities of sirens used between vehicles and within different regions across the country, accounting for all siren noise eventualities may be challenging.

Comparison between the siren noise level and single vehicle pass-by spectra at 40mph are shown in Figure 5-3.

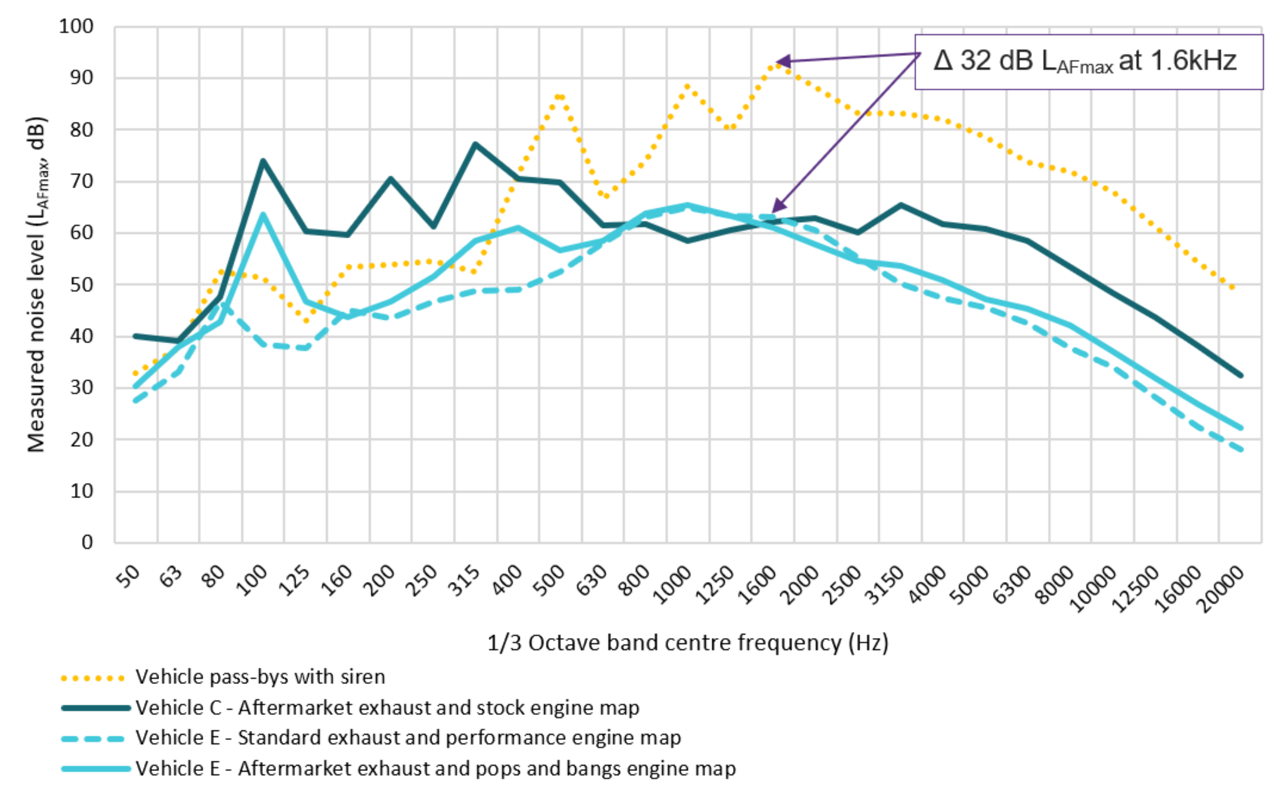

Figure 5-3 Siren and single vehicle pass-by (40mph) spectra

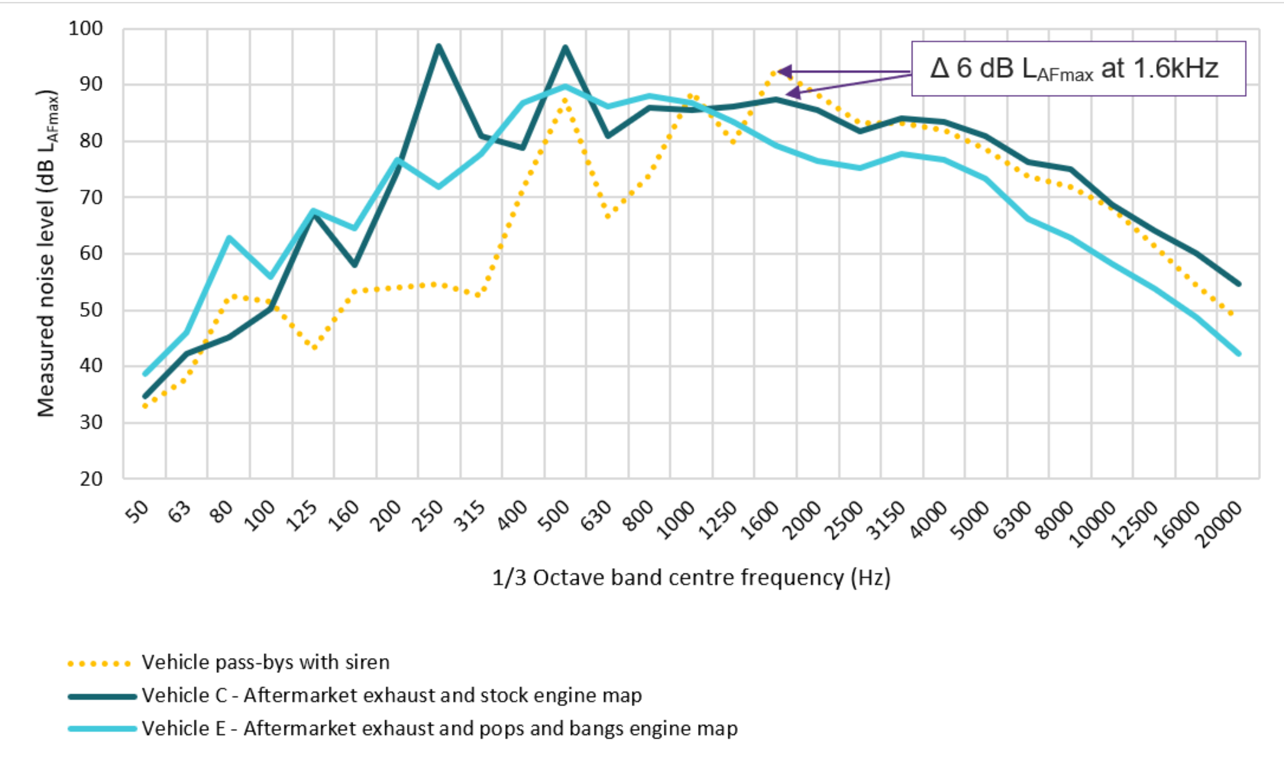

Figure 5-4 Siren and as loud as possible acceleration, spectra

Figure 5-3 indicates that it may be possible to use high-frequency (e.g. at 1.6kHz) analysis to identify and disregard false-positives caused by sirens, however the difference in the noisy vehicle and siren spectra reduced for louder noise events, such as hard acceleration (see section 5.2.9) is less, as shown in Figure 5-4.

Whilst it may be possible to identify emergency vehicle sirens through frequency analysis as shown in Figure 5-4, automatic rejection of the noise event may result in some true-positive edge cases being discounted, as shown in Figure 5-4. It may be possible to use a frequency analysis flag to identify potential emergency vehicle sirens for manual review.

Emergency vehicles could alternately be identified and excluded from enforcement via manual review of the video footage or through number plate identification.

5.2.7. Test OT4: Coasting past the noise camera

5.2.7.1. Data Review

'Camera surfing' in the context of speed cameras is the practice of reducing speed whilst passing the speed camera. This practice can be analogous for noise cameras whereby drivers reduce speed and/or change into a higher gear or coast whilst passing a noise camera in order to reduce noise levels. This practice was created during the tests as shown in Table 5-13 whereby the test vehicle approached the camera at 30 mph, reduced speed, then accelerated away from the camera from the edge of the test zone (see Figure 4-2):

Table 5-13 Camera surfing

Vehicle	Exhaust	Engine map	Source	Measured noise level (dB L_{AFmax})
Vehicle C (motorbike)	Stock	Stock	AJJV	83
			Millbrook	84
			MicrodB	75
			24 Acoustics	Not present
Vehicle E (car)	Aftermarket	Stock	AJJV	70
			Millbrook	72
			MicrodB	65
			24 Acoustics	Not Present
Vehicle E (car)	Aftermarket	Pops and Bangs	AJJV	68
			Millbrook	71
			MicrodB	65
			24 Acoustics	Not Present

Noise levels measured by the MicrodB noise camera are noted to be 3 – 9 dB L_{AFmax} lower than the AJJV / Millbrook systems as the system does not measure noises level outside of the ±5m detection zone, whereby further upstream of the noise cameras, the vehicle was accelerating.

5.2.7.2. Enforceability

Camera surfing can momentarily reduce vehicle noise levels when a vehicle is near to a noise camera. Depending on the noise camera technology, camera surfing may reduce the number of enforceable scenarios; i.e. noise cameras which utilise a narrow data capture window will measure more of the reduced vehicle noise level as the vehicle 'surfs' / coasts by the camera compared to a camera with a longer data capture window, which will capture higher noise levels if the vehicle accelerates away from the noise camera.

5.2.8. Test OT6: Overtaking

5.2.8.1. Data Review

Overtaking tests were undertaken for both test vehicles, as shown in Table 5-14. Note that the speed indicated in Table 5-14 refers to the speed of the vehicle which was overtaken.

Table 5-14 Overtaking tests

Vehicle	Exhaust	Engine map	Source	Measured pass-by noise level (dB L_{AFmax}) at test speed		
				20 mph	30 mph	40 mph
Vehicle C (motorbike)	Aftermarket	Stock	AJJV	95	93	94
			Millbrook	97	98	98
			MicrodB	93	No data (1)	97
			24 Acoustics	97	99	96
Vehicle E (car)	Aftermarket	Pops and Bangs	AJJV	92	96	92
			Millbrook	94	96	94
			MicrodB	92	92	88
			24 Acoustics	92	99	91

(1) No data captured due to data stability issues

A good correlation is noted between all datasets with some increased variation (up to 6 dB L_{AFmax}) noted between AJJV / Millbrook / 24 Acoustics and MicrodB results as the MicrodB noise camera did not capture increased noise levels caused by the pops and bangs engine mapping. The pops and bangs were noted to be loud during these tests due to the higher engine revs used as part of the overtaking manoeuvre.

Higher noise levels (≥ 13 dB L_{AFmax}) are noted for the overtake tests compared to fixed speed tests (single vehicle pass-by, convoy, contraflow etc.) due to the hard acceleration and increased engine revs associated with the overtake manoeuvre.

The MicrodB noise camera excluded any overtake events whereby both vehicles were within the ±5m detection zone, as the system is not able to automatically differentiate the separate vehicle noise levels. A total of 8 out of 22 overtake tests captured by the MicrodB noise camera were automatically rejected.

A still image capture from the site video recording showing Vehicle E overtaking Vehicle C is shown in Figure 5-5:

Figure 5-5 Overtake manoeuvre, still image capture

5.2.8.2. Enforceability

Overtake events are deemed to be enforceable with a varying degree of manual review required to identify the noisy vehicle which is overtaking, depending on the noise camera technology. It is possible for edge cases to be automatically discarded to reduce the amount of data which requires manual review.

When a noisy vehicle is overtaking, the noisy vehicle may be more easily identified and therefore more enforceable due to the increased noise associated with the overtake manoeuvre. Tests were not undertaken where a standard vehicle overtook a noisy vehicle.

5.2.9. Test OT7 and OT13: Hard acceleration / as loud as possible

5.2.9.1. Data Review

The measured noise levels from the hard acceleration tests are shown in Table 5-15.

Table 5-15 Hard acceleration tests

Vehicle	Exhaust	Engine map	Source	Measured noise level (dB L_{AFmax})
Vehicle C (motorbike)	Stock	Stock	AJJV	90
			Millbrook	92
			MicrodB	93
			24 Acoustics	93
Vehicle C (motorbike)	Aftermarket	Stock	AJJV	95
			Millbrook	97
			MicrodB	94
			24 Acoustics	97
Vehicle E (car)	Aftermarket	Pops and Bangs	AJJV	98
			Millbrook	99
			MicrodB	93
			24 Acoustics	98

A good correlation is noted between AJJV, Millbrook and 24 Acoustics datasets. The MicrodB noise camera measured lower noise levels as the system does not measure noises level outside of the ±5m detection zone, whereby further upstream of the noise cameras, the vehicle was still accelerating and therefore creating more noise. Noise from the pops and bangs was also not captured by the MicrodB noise camera due to the narrow data capture window. The pops and bangs were noted to be loud during these tests due to the higher engine revs used during hard acceleration.

The measured noise levels of Vehicle C in stock conditions under hard acceleration are noted to be 3 – 9 dB L_{AFmax} higher than during a constant speed 60mph pass-by when fitted with an aftermarket exhaust. This is an indication that vehicles without aftermarket products can generate noise levels which could be considered excessively noisy when they are accelerated hard.

To supplement the hard acceleration test, similar tests were undertaken with an attempt to make the vehicles as loud as possible. This involved the vehicle accelerating past the noise cameras whilst maintaining high engine revs immediately adjacent to the noise cameras. The resultant measured noise levels are shown in Table 5-16.

Table 5-16 As loud as possible tests

Vehicle	Exhaust	Engine map	Source	Measured noise level (dB L_{AFmax})
Vehicle C (motorbike)	Aftermarket	Stock	AJJV	98
			Millbrook	100
			MicrodB	103
			24 Acoustics	100
Vehicle E (car)	Aftermarket	Pops and Bangs	AJJV	98
			Millbrook	96
			MicrodB	92
			24 Acoustics	99

A good correlation is noted between all datasets with some increased variation (up to 7 dB L_{AFmax}) noted between AJJV / Millbrook / 24 Acoustics and MicrodB results as the MicrodB noise camera did not capture increased noise level caused by the pops and bangs engine mapping.

5.2.9.2. Enforceability

Noise produced during the hard acceleration / as loud as possible tests were some of the highest measured throughout the tests and demonstrate that the manner in which vehicles are driven has a large influence (e.g. increase of ≥ 10 dB dB L_{AFmax} compared to a 60mph single vehicle pass-by) on the resultant noise level. Hard acceleration noise events will likely be one of the most enforceable noise events due to the high noise levels produced.

There is potential for vehicles without aftermarket products to generate noise levels which could be considered excessively noisy when they are accelerated hard. For example, Vehicle C in stock conditions produced a level of 93 dB L_{Amax} which is only 2 dB below the 95 dB L_{Amax} threshold suggested within Part A. The noise cameras tested suitably captured such noise events, however context will need to be considered via a video stream to determine if the driving style was justified or if it was undertaken purposely to create noise.

The video stream captured by the 24 Acoustics system provides simultaneous video from two angles (upstream and downstream) and provides much better overall context compared to the still images provided by the MicrodB system. The multi-camera video stream gives a wide view of the road and should provide context to determine whether the increased noise due to the driving style was justified.

5.2.10. Test OT8: Horn tests

5.2.10.1. Data Review

Single vehicle pass-by tests were undertaken with the horn of the vehicle being sounded. Tests were undertaken for both vehicles in stock conditions, as shown in Table 5-17.

Table 5-17 Horn tests

Vehicle	Exhaust	Engine map	Source	Measured pass-by noise level (dB L_{AFmax}) at test speed		
				20 mph	30 mph	40 mph
Vehicle C (motorbike)	Stock	Stock	AJJV	90	89	89
			Millbrook	93	92	92
			MicrodB	94	94	92
			24 Acoustics	95	95	94
Vehicle E (car)	Stock	Stock	AJJV	89	90	89
			Millbrook	92	92	91
			MicrodB	88	89	88
			24 Acoustics	Not present	Not present	Not present

The measured noise levels are similar for each vehicle respectively at all speeds tested demonstrating that the noise due to the horn is dominant. This would still be the case if the vehicles were tested with aftermarket products as these were shown to generate single vehicle pass-by noise levels of up to 87 dB L_{AFmax} (see Table 5-4). This demonstrates that it is possible for drivers to mask the noise level of their vehicle by sounding the horn.

5.2.10.2. Enforceability

To enforce against drivers who purposely sound the vehicle horn to obscure the measured noise level captured by the camera, a context video will be required as part of the evidence package. The angle of view of the video(s) will need to be such that it can be confirmed beyond reasonable doubt that the horn was sounded without valid reason other than to obscure the noise camera data.

Similarly, the context video will be required to discount potential enforcement against drivers who used their horn with a valid reason.

As per section 5.2.9.2, the video stream captured by the 24 Acoustics provides a good overall context to determine whether horns were sounded with a valid reason (e.g. warning of vehicle presence, altering other drivers of a hazard etc.).

5.2.11. Test OT9: Single vehicle pass-bys in wet conditions

5.2.11.1. Data Review

In order to investigate the influence of wet weather on the functionality of noise cameras, single vehicle pass-by tests were undertaken for both test vehicles when fitted with aftermarket products whilst the track was wet, as shown in Table 5-18.

Table 5-18 Single vehicle pass-by tests on a wet road surface

Vehicle	Exhaust	Engine map	Source	Measured pass-by noise level (dB L_{AFmax}) at test speed		
				20 mph	30 mph	40 mph
Vehicle C (motorbike)	Aftermarket	Stock	AJJV	79	81	81
			Millbrook	81	82	79
			MicrodB	No data (1)	81	81
			24 Acoustics	79	82	82
Vehicle E (car)	Aftermarket	Stock	AJJV	69	74	78
			Millbrook	70	76	79
			MicrodB	69	74	78
			24 Acoustics	69	74	77

(1) No data captured due to data stability issues

A good correlation is noted across all datasets. Comparison is made between the dry and wet track single vehicle pass-by test in Table 5-19.

Table 5-19 Comparison of single vehicle pass-by tests on wet and dry road surfaces

Vehicle	Exhaust	Engine map	Speed (mph)	Source	Measured pass-by noise level (dB, L_{AFmax})		
					Dry track	Wet track	Difference
Vehicle C (motorbike)	Aftermarket	Stock	20	AJJV	80	79	-1
				Millbrook	81	81	0
				MicrodB	78	No data	-
				24 Acoustics	78	79	+1
Vehicle C (motorbike)	Aftermarket	Stock	40	AJJV	80	81	+1
				Millbrook	81	79	-2
				MicrodB	No data	81	-
				24 Acoustics	82	82	+1
Vehicle E (car)in	Aftermarket	Pops and Bangs (dry), Stock (wet)	20	AJJV	63	69	+6
				Millbrook	64	70	+6
				MicrodB	58	69	+10
				24 Acoustics	65	69	+4
Vehicle E (car)	Aftermarket	Pops and Bangs (dry), Stock (wet)	40	AJJV	71	78	+7
				Millbrook	72	79	+7
				MicrodB	68	78	+10
				24 Acoustics	74	77	+3

The wet track had a minimal influence (up to 2 dB L_{AFmax}) on the noise level of Vehicle C. It should be noted that 2 dB L_{AFmax} is within the typical variability of measurements. Also, as Vehicle C is noisier than Vehicle E in general, the influence of the noise from the wet track will be less.

5.2.11.2. Enforceability

Single vehicle pass-bys during wet weather are deemed to be enforceable as both noise cameras were able to track vehicles during wet conditions. Vehicles noise emissions were higher in wet conditions, which may lead to additional exceedances being triggered that would be excluded during manual review.

Tyre / road noise would increase further during multiple vehicle convoy and contraflow passes in front of noise cameras in wet weather. Such events may be more difficult to enforce due to contamination of the vehicle noise level by the increased tyre / road noise or spray.

5.2.12. Test OT11: Stationary test within idling traffic

5.2.12.1. Data Review

Stationary tests were undertaken with the test vehicle revving in-between two idling standard cars, as shown in Table 5-20.

Table 5-20 Stationary tests with two idling vehicles

Vehicle	Exhaust	Engine map	Source	Measured noise level (dB L_{AFmax})
Vehicle C (motorbike)	Aftermarket	Stock	AJJV	89
			Millbrook	91
			MicrodB	92
			24 Acoustics	89
Vehicle E (car)	Aftermarket	Pops and Bangs	AJJV	95
			Millbrook	94
			MicrodB	No data (1)
			24 Acoustics	88

(1) No data captured due to data stability issues

Pops and bangs noise events were noted to be loud during these tests. A good correlation is noted across the dataset for Vehicle C, however a difference of 6 – 7 dB L_{AFmax} is noted between AJJV / Millbrook and MicrodB and 24 Acoustics results for Vehicle E.

The 6 – 7 dB L_{AFmax} difference between AJJV / Millbrook and 24 Acoustics results is likely due to the orientation of the vehicle such that the exhaust of Vehicle E was facing away from the 24 Acoustics noise camera.

The MicrodB noise camera had to be manually triggered for stationary tests. Only one run was captured for Vehicle C and no runs were captured for Vehicle E.

5.2.12.2. Enforceability

To enforce against noisy vehicles within stationary traffic, review of a context video and audio will likely be required. The 24 Acoustics video and audio package provides clear context of the test undertaken. Enforcement against Vehicle C is clear as it is possible to see the driver's wrist move (operating the throttle on a motorbike) at the same time as the noisy vehicle is heard, however for Vehicle E, it is not clear which vehicle within the stationary traffic emitted the noise.

5.2.13. Test OT10: Image quality and number plate legibility

5.2.13.1. Data Review

Each noise camera system has the ability to capture images of vehicles within their respective detection zones. The MicrodB noise camera provides a still image of the top and rear of the vehicle, whereas the 24 Acoustics noise camera provides a video feed on an online portal that can be manually paused and zoomed by a reviewer to read number plates.

Figure 5-6 Image from a paused and zoomed video feed from 24 Acoustics noise camera

Figure 5-7 Image from MicrodB noise camera showing and rear of the vehicle

As neither of the systems currently have an integrated ANPR, the ability to distinguish the alphanumeric characters from a number plate image is considered vital for enforcement to take place. The image quality of both systems was generally adequate for number plates to be read during the daytime, however, the images from the MicrodB noise camera tended to be pixelated. The ability of the 24 Acoustics system to zoom into the video feed ensured a good image quality and that number plates could be manually read.

Some vehicle pass-bys were undertaken during the daytime with number plates fitted to the test vehicles. These number plates were either tinted or used non-standard fonts with irregular character spacing or italicised or 3D characters, and are shown in Appendix E. All these non-standard number plates could be read clearly manually from the 24 Acoustics samples (see Figure 5-8).

Figure 5-8 Daytime image collected by the 24 Acoustics noise camera showing a number plate with non-standard character spacing

From the MicrodB samples, these non-road legal number plates looked blurred from the images. The blurriness varied between different number plate designs, with the tinted ones being slightly more readable than others (see Figure 5-9).

Figure 5-9 Daytime images from the MicrodB system – tinted number plate (left), italics number plates (right)

The image quality performance at night-time follows a similar pattern to that of the daytime tests with 24 Acoustics being superior. From the 24 Acoustics samples, the number plates could be read in all cases (see Figure 5-10). As a result of the camera operating in ‘night-mode’, it was not possible to tell the colours of the vehicles. This means the verification of vehicles by colour using the DVLA database will not be possible. However, considering that the paused images of the video feed were of good quality and the number plates were in clear focus, it is anticipated that such verification will not be required.

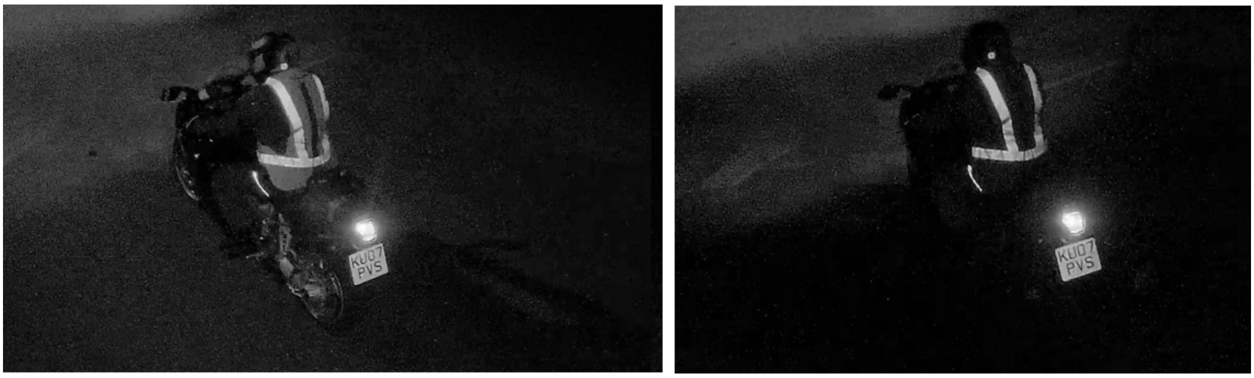

Figure 5-10 Images from the 24 Acoustics noise camera in night-time under lit (left) and unlit conditions (right)

In the case of MicrodB, the video camera only operated sufficiently to trigger the system but not to capture the number plates effectively. The saved images were of little use as the number plates could not be read (see Figure 5-11).

Figure 5-11 Images from the MicrodB system in night-time under lit (left) and unlit conditions (right)

5.2.13.2. Enforceability

Currently, both systems tested require manual review of video and/or images to read the vehicle number plates. The legibility of the number plates varied between the two noise camera technologies and in some cases, enforcement would not be possible due to unreadable number plates. In both cases, the two noise cameras use a standard video camera. The manual review of images to read number plates is labour intensive and costly, which may deter the police or local authorities from taking enforcement action.

Systems which automatically identify the number plate of vehicles (i.e. an ANPR system) would reduce the amount of time for manual review needed when enforcing. Purpose designed ANPR cameras use a variety of techniques (including infra-red illumination and dynamic exposure and gain adjustment) to ensure a non-blurred plate capture is achieved. The ability of the noise camera system to enforce at night will depend on the ability of the ANPR system to read number plates during the night, however the quality of the video capture may limit the enforceability if the details of the make and colour of the vehicle cannot be identified.

6. Discussion

6.1. General performance of the noise cameras

Comments on the general performance of the noise cameras are shown in Table 6-1 with commentary on the MicrodB array-based noise camera and the 24 Acoustics single microphone noise camera given in Sections 6.1.1 and 6.1.2 respectively.

Table 6-1 Comments on the general performance of the noise cameras

Factor	MicrodB	24 Acoustics	Comment
Detection of cars and motorcycles	Good	Good	Easily captured by the noise cameras tested. Neither system differentiated between cars and motorcycles.
Ability to read number plates (including different fonts)	Limited but resolvable	Limited but resolvable	Human operator required to read number plates from video/images. Integration of an ANPR could automate this.
Image quality (day and night)	Limited (night) to Good (day) but resolvable	Good	Overall quality is dictated by third-party video camera components which are included as part of the noise camera system. Upgrades may lead to better quality.
Single pass-bys	Good	Good	Easily captured by the noise cameras tested.
Vehicles passing close together in the same lane (1.5-2 second headway)	Good	Manual review of evidence required to identify the noisy vehicle	Good detection capabilities with the possibility to assign individual noise levels per vehicle depending on noise camera technology.
Vehicles passing in opposite directions	Good	Manual review of evidence required to identify the noisy vehicle	Good detection capabilities with the possibility to assign individual noise levels per vehicle depending on noise camera technology. Potential limitation when vehicles pass closest to the camera at the same time.
Presence of other significant sound sources (e.g. idling bus)	Good – Automatically flags instances whereby the background noise level is high	Manual review of evidence required to determine if high noise level is due to other significant sound sources	Cases may be resolvable where noisy vehicle noise level is sufficiently above the background noise level. Edge cases can be automatically discounted and/or flagged.
Restricted view (bus shielding view of road)	Poor	Poor	When the line of sight between the noisy vehicle and noise camera is

Factor	MicrodB	24 Acoustics	Comment
			blocked, the results are adversely affected.
Stationary traffic	Limited	Limited	Identification of the offending vehicle may be difficult.
Wet weather	Good	Good	Noise levels sufficiently captured under wet weather road conditions.
Overtaking	Good	Good	Good detection capabilities with the possibility to disregard and / or flag edge cases for manual review.
Ability to capture noise from vehicle modifications and driving styles (e.g. pops and bangs)	Limited – Due to narrow detection zone, some noise events can be missed	Good	Context video required to identify noise events which occurred further away from the noise camera whilst a non-offending vehicle was nearer.
System stability	Limited but resolvable	Good	Some stability issues noted however system stability was not detrimental to the tests.
Installation	Good	Good	Both noise cameras were installed within the allotted time period during the trials.

6.1.1. MicrodB

The MicrodB noise camera performed well throughout most of the tests. Some missed runs due to data stability of the system were noted, and in some tests all the runs were missed.

The system did not capture noise events due to engine overrun pops and bangs which occurred outside of ±5m detection zone in front of the array. More pops and bangs noise events would have been captured by the system if the tests involved Vehicle E accelerating before entering the test zone rather than within the test zone. Whilst this meant the noise camera missed some potential enforcement triggers, the benefit of the narrow capture window means that the system can assign individual noise levels to vehicles in both convoy and contraflow scenarios. Similarly, the system can automatically reject instances whereby two or more vehicles are within the detection zone thus reducing the number of edge-cases required for manual review.

The microphone array allows the noise camera to detect the location of the noise source within the detection zone and thus assists with the assignment of individual noise levels to vehicles within a convoy and contraflow. Acoustic traces / heat maps can be produced by the system which form part of the enforcement pack for review. The acoustic traces give an indication of the noise source level and location within the detection zone against time.

The system can also reject instances whereby the background noise level is high in comparison to the passing vehicle noise level.

The picture quality of the system is reasonable during the day however is poor in low-light conditions and the system does not store video. The system also cannot be automatically triggered under stationary traffic conditions meaning that excessive vehicle noise due to stationary revving cannot be detected by the system. The power consumption of the system is also high (400W), which may limit the deployment of the unit in certain areas due to inadequate power supply.

6.1.2. 24 Acoustics

The 24 Acoustics noise camera performed well throughout all tests with excellent data stability. No runs were missed throughout the tests. The 24 Acoustics noise camera is expected to have performed equally well for the tests where it was not present.

The data package provided by the system was comprehensive allowing for review of synchronised video, audio and noise data. The system however does not automate any decision making and is reliant on manual review of all trigger exceedances.

The wider detection zone allows noise events, such as pops and bangs from an engine mapped vehicle, which occur after the initial vehicle pass-by (i.e. when the vehicle is not directly underneath the noise camera) to be measured and manually allocated to the noisy vehicle via review of the video, audio and noise data. This is only achievable for vehicles that are clearly visible on the video footage and may not be possible where traffic is stationary.

6.1.3. Correlation with noise levels measured at type approval position

The measured noise levels of the test vehicles from the noise camera technologies were generally within ±3dB of the maximum noise levels measured at the type approval position (the 'Millbrook' position) provided that the maximum noise levels occurred while the vehicle was moving in the detection zone. The scenarios leading to greater variations between the noise cameras and the type approval microphone were:

- Instances where high noise levels were generated outside of MicrodB's detection zone, such as hard acceleration when camera surfing or some instances where pops and bangs were emitted from Vehicle E,
- Instances where pops and bangs were generated from Vehicle E when its exhaust was facing away from the 24 Acoustics noise camera, and
- Situations where large vehicles such as an idling bus restricted the view of the detection zone and increased local ambient noise levels.

The 24 Acoustics system and the type approval microphone tended to correlate better with each other than the MicrodB system as the two systems were acoustically similar. As the 24 Acoustics system has one microphone and the type approval position has two single microphones on opposite sides of the test lane and both captured sound in a omnidirectional manner (from all directions), the systems behaved in a similar way. However, neither the type approval position nor the 24 Acoustics noise camera were able to automatically attribute maximum noise levels to other vehicles in a traffic stream (convoy and contraflow passes) even if they were also excessively noisy (as shown in Table 5-6), which the MicrodB system was able to achieve because of its array-based system.

The array-based MicrodB system uses directional microphones (i.e captures noise primarily from the front) and a narrower detection zone to capture the maximum noise level as the vehicle passes the array. This excludes more data for the approach and departure of the vehicle compared to the omnidirectional systems and is why noise from engine overrun / pops and bangs was not captured by the system, hence the difference in noise level measured by the MicrodB system and type approval positions when pops and bags occurred.

6.1.4. Potential for false positives

The testing undertaken with Vehicle E indicated that false positives may occur when a noisy vehicle emits 'pops and bangs' further away from the noise camera whilst a non-offending vehicle passes through the detection zone. This can result in the noise emissions from the upstream/downstream noisy vehicle being attributed to the vehicle in the detection zone. The same effect can be achieved from other high noise events occurring in proximity to the noise camera, for example, construction noise from nearby roadworks, fireworks, and pedestrians making loud noises to attempt to trigger the noise camera. The potential for this form of false positive was observed across a variety of test types where pops and bangs from Vehicle E occurred further away from the noise cameras, such as the stationary traffic scenarios, single vehicle pass-bys and convoy passes.

The size of the noise camera detection zone influences the potential for false positives due to extraneous noise events. A large detection zone (as utilised by the 24 Acoustics noise camera) has the potential to result in more false positives and longer time periods for manual review. A smaller detection zone (as utilised by the MicrodB noise camera) may record less false positives but would be less able to identify and enforce against these kinds of noise events.

The manual review of a wide-angled context video would allow such false positives to be managed, however, enforcement against vehicles outside of the detection zone or video range is less robust and open to legal challenges. The technology requires further development and automation to overcome this issue. Exclusion of 'pop and bang' noise or other instantaneous noise events from automatic enforcement may be possible using analysis of the noise onset time, where noise events that do not show the typical increase and decrease of noise level as a vehicle pass the camera are excluded. However such processing is not currently possible by either noise camera tested.

6.2. Potentially enforceable traffic scenarios

Table 6-2 summarises the potential enforceability of the test scenarios if they were they to occur in an enforcement context based on the outcomes of the trial. The test scenarios were considered to be potentially enforceable if the data collected from the noise camera provided enough information to detect and identify the excessively noisy vehicle, regardless of the degree of automation incorporated in the tested technologies to achieve this.

Table 6-2 Potentially enforceable traffic scenarios

Scenario	Potentially Enforceable?	Justification
Single vehicle passes (fixed speed or acceleration)	Yes	Event trigger and assignment of noise to individual vehicles easily achieved. Higher noise levels during acceleration are more enforceable than fixed speed as fixed speed passes have lower noise levels. Drivers may attempt to avoid enforcement by driving past cameras more quietly, which may provide some respite to residents at affected locations.
Vehicle convoys	Yes	Assignment of noise levels to individual vehicles in a convoy is possible (tested to an approximate 1.5-2s headway).
Contraflow	Yes	Assignment of noise levels to individual vehicles in contraflow is possible. Edge cases when two vehicles are simultaneously adjacent the noise camera can be rejected or flagged for manual review.
Overtaking	Yes	Higher noise levels are produced allowing for easier identification of the noisy vehicle when it is overtaking other vehicles. Edge cases when two vehicles are simultaneously adjacent the noise

Scenario	Potentially Enforceable?	Justification
		camera can be automatically rejected or flagged for manual review.
Noise generated whilst vehicle stationary	Yes, but requires in-depth manual review	Enforcement is possible, however it is likely that most cases will require manual review of a context video / audio. This situation would be most challenging when there are multiple vehicles within the view of the camera.
Use of the horn	Yes, but requires in-depth manual review	Review of context video / audio required to determine if use of the horn was justified.
Environments/situations with high noise levels	Yes, but requires in-depth manual review	Enforcement is possible, however it is likely that most cases will require manual review of a context video / audio.
Night-time	Yes, but requires in-depth manual review	Enforcement is possible, however it is likely that most cases will require manual review of a context video / audio. There may be challenges in identifying number plates and verifying that the vehicle is correctly identified.
Restricted view between camera and road	No	With the line of sight restricted, supporting video evidence cannot be gathered and measured noise levels are likely to be lower.

The way vehicles fitted with aftermarket products are driven was found to have an influence on the resultant noise levels, with higher noise levels generated when vehicles were accelerating. Noise cameras are likely offer a better opportunity to tackle antisocial noise from vehicles if located in areas where drivers accelerate unnecessarily compared with locations where their speed is likely to be fixed. However, locating cameras where the road arrangement often requires a driver to accelerate has potential to be perceived to unfairly treat those drivers who need to accelerate for example from a pedestrian crossing, a speed hump or a chicane. It may also be inappropriate to position noise cameras where there is likely to be a special demand for acceleration or high engine loads such as on hills or near junctions on high speed roads.

Table 6-3 summarises situations where cameras may falsely detect excessively noisy vehicles.

Table 6-3 Potential false positive scenarios

Scenario	Potential false positive?	Potential management
Sirens	Yes	Noise levels generated by sirens on emergency vehicles are likely to exceed the threshold for excessively noisy vehicles. Manual review of a context video / audio should support exclusion of these cases

Scenario	Potential false positive?	Potential management
Wet road conditions	Yes	Vehicles that are noisy (but not excessively noisy) may generate levels above the threshold for excessively noisy vehicles when the road surface is wet. Manual review of a context video / audio would be required. Alternatively a suitable weather tolerance would need to be applied to the measured noise level or incorporated into the noise threshold for enforcement.
Excessively noisy events occurring outside the detection zone	Yes	During the trial 'pops and bangs' from the engine-mapped car sometimes occurred after the vehicle left the detection zone of the noise camera. A false positive could occur if a compliant vehicle was in the detection zone at the time the 'pops and bangs' or other types of excessive vehicle noise occurred. Manual review of a context video / audio would be needed to ensure enforcement against the other vehicle does not occur or the noise cameras need to be further developed and calibrated to exclude transient high-noise events unrelated to the vehicle(s) in the detection zone.

This table shows that the use of the products tested may give rise to false positives if used to enforce against excessively noisy vehicles. The data from the noise camera would need to be reviewed to either eliminate or minimise false positives in order to demonstrate that enforcement actions taken are robust.

6.3. Technological constraints

6.3.1. Exhaust directivity

The single vehicle stationary tests (Test 1) identified that the height of a microphone can cause variation in measured vehicle noise levels due to the directional nature of sound emitted from exhausts. For a given source-to-microphone distance, microphones mounted closer to the ground may measure increased noise levels compared to a noise camera located at greater heights. This will need to be considered for prospective noise cameras technologies (e.g. handheld devices) that are mounted closer to the ground.

6.3.2. Restricted line of sight

Should the line of sight between the noise camera and road be obscured (as tested with a stationary bus), the resultant noise levels measured of the noisy vehicle are greatly reduced and supporting video evidence may be affected. This may pose limitations on the prospective positioning of noise cameras near to bus routes or delivery zones.

The influence of this factor on the operation of the camera could be minimised by setting up the detection zone of the camera to avoid areas with restricted line of sight.

6.3.3. Use of horn

The noise level produced by a vehicle horn can be greater than the noise emission of a vehicle fitted with aftermarket products under some driving conditions, such as during fixed speed pass-bys. It is therefore possible for drivers to mask the noise level of their vehicle by sounding their horn. There are currently no automatic identifiers or processing of horns provided by either noise camera tested. However, inappropriate sounding of horns could be considered a driving style that is excessively noisy when supported by contextual video evidence and can be enforced using Rule

112 of the Highway Code [20] and the Road Vehicle (Construction and Use) Regulations 1986 [21].

6.3.4. ANPR

Neither system tested utilised ANPR technology, therefore manual review of video and/or images would be required to identify the vehicle number plates when using these cameras. This constraint increases the amount of manual review required for enforcement but is resolvable through the integration of a suitable ANPR, as has been achieved by other noise camera products.

6.3.5. Night-time performance

During the testing, one of the noise cameras had more difficulty identifying the detected vehicles in low light conditions whereas the other noise camera had a ‘night mode’ setting to improve this. Issues around vehicle identification at night or low light conditions are resolvable through specification of the video, image capture and ANPR components. A robust link between the vehicle detected by the microphones, ANPR and vehicle shown in the low light conditions context video will need to be established in the evidence pack.

6.3.6. Meteorological monitoring

Wet road surfaces can result in a large increase in noise during single vehicle pass-bys. Tyre / road noise would increase further during multiple vehicle convoy and contraflow passes in front of noise cameras in wet weather, which may result in additional exceedances of a fixed noise level for enforcement. In these cases, manual review would be required and tolerances for wet weather applied or incorporated into the noise threshold for enforcement. For noise cameras that collect frequency data, an approach for reducing wet weather false positives could be to focus the data collection on noise emissions below 1.25 kHz as these frequencies were shown to be unaffected by wet road surfaces and are often the frequency components most associated with excessively noisy vehicles. This could involve reducing the sound frequency range for data collection but this would only viable if there are no sources of excessive vehicle noise in the higher frequencies that should be enforced against (such as horns). Alternatively an acoustic signature for the additional high frequency noise from wet weather could automatically flag wet weather and apply a tolerance if necessary.

Noise camera products may include meteorological monitoring through sensors that form part of the noise camera or links to third party weather stations or datasets to enrich the data collected. Neither noise camera tested had meteorological monitoring during the trials. For enforcement, meteorological data is not required as rainfall and wet road surfaces would be evident within from the video clip and audio obtained for the evidence package. For example, the camera lens may have rain drops on it, there may visible and audible surface water spray. Any meteorological data obtained from the noise camera or third parties should be issued separately from the evidence pack where it is required.

6.3.7. Vehicle revved in stationary traffic

To enforce against noisy vehicles within stationary traffic, review of a context video and audio would be required to determine which vehicle or vehicles are excessively noisy. The information within the video and audio files may not permit robust identification of the vehicle generating the excessive noise. Enforcement against motorcycles could be more straightforward as it may be possible to see the driver’s wrist move at the same time as the noisy vehicle is heard. For cars it may be less clear which vehicle emitted the noise.

6.3.8. Detection zone size

The noise cameras were trialled as individual fixed units, collecting vehicle data and noise levels over a limited area akin to a fixed speed camera. It is recognised that using a single noise camera in this way would not necessarily prevent offences from occurring further upstream or downstream of the installation site. Additional noise cameras could be deployed at strategic locations at a hotspot to improve the overall coverage and encourage a behavioural change throughout the area.

The directivity characteristics of the microphone arrays incorporated into a noise camera are important. Where the array has a narrow zone of detection it is more able to identify individual vehicles automatically when multiple vehicles are passing close to the array. This situation also gives rise to the array not detecting noise from vehicles outside the zone of detection, which may be important for directional noise sources like some exhaust pipes or sounds from engine re-mapping. Increasing the size of the detection zone may identify noise from more individual vehicles, but decrease the ability of the camera to separate individual vehicles where multiple vehicles are passing.

Similarly, ‘camera surfing’ through the detection zone can momentarily reduce vehicle noise levels and may reduce the number of enforceable scenarios. Noise cameras using a narrow detection zone would measure more of the reduced vehicle noise level as the vehicle ‘surfs’ or coasts past it compared to a noise camera with a wider detection zone, which would be more likely to capture higher noise levels if the vehicle accelerates away from the noise camera. Although this kind of driving behaviour could evade enforcement from the noise camera, it could still reduce noise levels and be effective at a number of locations, such as the edges of villages where there is a speed limit change.

6.4. Enforcement routes

At present, there is no clear route for the prosecution of vehicles deemed to be excessively noisy although a number of options are available. The current practical implementation of a noise camera has been achieved for local authorities by the use of a Public Spaces Protection Order (PSPO) that prohibits certain activities that, in the opinion of an enforcement officer, cause excessive nuisance [19]. Some police forces have enforced excessively noisy vehicles through the Road Vehicle (Construction and Use) Regulations [21]. A document parallel to “The Certification Of Approved Devices” [10] is required to provide local authorities and the police with a specification against which the procurement of noise cameras can be managed, with guidance on enforcement routes.

7. Knowledge gaps and recommendations

The work undertaken for Part B has uncovered some knowledge gaps based on limitations of the track trial tests, the performance of the tested technologies and the enforcement process. The identified knowledge gaps are discussed in the following subsections along with recommendations for Part C and further research.

7.1. Current knowledge gaps

7.1.1. Proportion of traffic that drive similarly to the track trials

During the track trials, the test vehicles were driven in a controlled environment and it was demonstrated that the noise cameras were able to detect individual vehicles. The vehicles were driven using the same drivers to ensure the repeatability and reproducibility of the test data. Although the tests were designed to safely test some aggressive driving styles (such as the OT13 ‘as loud as possible’ test), it is not known if real drivers of excessively noisy vehicles would drive similarly or if there may be occasions when excessively noisy vehicles are driven less safely (for example vehicles driving closer together than the tested 1.5-2 second headway). This could reduce the ability of the camera to isolate a specific vehicle.

7.1.2. Challenges to prosecution

Drivers have the potential to challenge a prosecution by demonstrating that they did not intend to create an excessive noise or that the noise detected was not from their vehicle. Examples of this may include drivers of vehicles in stock condition who grind gears, motorcyclists who miss a gear, false neutral selection, and screeching fan belts. No data was collected during the trials to determine how these actions would affect noise emissions. The noise level selected for enforcement could be selected to avoid penalising driving behaviours that are not excessively noisy, or such incidents could be screened by the noise camera or enforcement officer.

Not all potential challenges are known, however, the technical challenges are likely to focus on the accuracy and reliability of the noise camera which can be addressed through a type approval or documented calibration and system acceptance testing process for the technology. The data collected from the noise camera and exported in an evidence pack (video clip of a suitable length, ANPR, noise levels and audio) should be sufficient for an enforcement officer to withstand a vexatious challenge linked to driver behaviour. Ignorance is not valid defence when using the Road Vehicle (Construction and Use) Regulations [21] as a basis for enforcement.

7.1.3. Appetite for spending time reviewing data from cameras

Both of the noise cameras tested require a degree of manual intervention prior to enforcement, which could be minimised with further camera development. The appetite of the police or Local Authorities to minimise time reviewing data during enforcement is unknown.

7.1.4. Integration of ANPR

The ability of the noise cameras tested to include automatic number plate recognition is unknown. The expectation is that the technology could be readily integrated into the tested noise cameras as this has been achieved for alternative noise camera products. For any noise camera product, there would need to be sufficient assurance that the number plate captured related to the vehicle producing the noise. This can be achieved with high confidence for vehicles that generate excess noise as they pass the noise camera, but could be more challenging if extraneous noise is generated outside of the product’s detection zone such as when pops and bangs are generated.

7.1.5. Generation and transmission of suitable evidence packs

Further development is needed on both of the trialled noise camera products to automatically generate and transmit suitable evidence packs for enforcement. The ease of this development and the definition of the evidence packs are unknown at this time, however, the evidence pack specifications and data security requirements are expected to be similar to those currently specified in the Certification of Approved Devices [10].

7.1.6. Definition of the penalty and consideration of its power to be a deterrent

Discussion is required to determine what the penalty for excessive noise is. Increased penalties may be considered a larger incentive to prevent excessive noise and obtain benefits, but the penalty would also need to be proportionate with penalties for other offences. Based on current enforcement approaches for excessively noisy vehicles [2], it is assumed that a Fixed Penalty Notice for £50-80 would be issued. A Vehicle Defect Rectification Notice may also be issued if it is clear that the vehicle is fitted with aftermarket products that generate excessive noise. As with all penalties, the deterrent effect is a combination of the scale of penalty and the perceived probability of detection, so a lower penalty would be effective only if there were either very large numbers of noise cameras or mobile/covert noise cameras deployed on our roads giving the potential to be caught at any time.

7.1.7. Scale of engine mapped vehicles emitting ‘pops and bangs’

During testing some of the pops and bangs from the engine-mapped car were not detected as the noise occurred after the vehicle was outside the detection zone. This can be a strength or weakness to noise camera technologies as some products may capture such vehicles but generate false positives when unrelated transient high noise levels occur (such as fireworks), or the opposite situation for other systems.

The proportion of vehicles that are excessively noisy using this type of re-mapping is unknown, meaning that there is limited information on the scale of the problem. This may influence future performance requirements for noise cameras, how they are deployed and data insights considered desirable to support enforcement or noise awareness campaigns.

7.1.8. General level of traffic

The trialled noise cameras have not been tested in situations with multiple lanes of traffic. It is not clear if they would be able to identify excessively noisy vehicles to the same level of confidence in situations where there are multiple lanes of traffic. Although some alternative noise camera products claim to have this functionality, roads with multiple lanes have potential for more than one vehicle in one direction at the same time in the noise camera’s detection zone. This may be resolvable through the deployment of additional noise camera units to focus the detection zone on different sections, for example, different sides of a dual carriageway.

7.2. Usage for enforcement

The path for noise cameras to become approved devices has not yet been decided, but our expectation is that they would be treated in the same way as traffic enforcement cameras used for civil enforcement (e.g. Bus Lane Enforcement). Using this approach, the noise cameras will require type approval from the Secretary of State for Transport, with the approval route through a document substantially similar to “The Certification of Approved Devices” published by the DfT [10] to permit the enforcement of civil traffic offences under the Traffic Management Act 2004. In use, the system will be used by an appointed Civil Enforcement Officer.

From an analysis of the results of the Part B trials, it is clear that a good proportion of noisy vehicle contexts can be enforced by noise cameras. It is possible that a number of the test scenarios will require a detailed investigation at review, and it is likely that a proportion of these will be found to be inconclusive or unenforceable for a number of possible reasons (multiple vehicles in zone, extraneous noise, interference from emergency vehicle). However, this does not detract from the fact that enforcement is taking place. This will have a deterrent effect even if not all contraventions detected are actionable. The goal with this type of enforcement should not be to take action against every case but to take enough action that the individuals carrying out the behaviour will realise that there is a chance of being caught.

7.3. Recommendations for Part C

The aim of Phase 3 Part C is to test the performance of a suitable noise camera product in real world driving environments, particularly in urban environments. A noise camera would be deployed in a typical street scene at four locations and operated in ‘dummy enforcement mode’ to represent the way they would operate in a real enforcement situation.

Based on the current state of the noise camera technologies, the AJJV recommends that the project proceeds to roadside testing in Phase 3 Part C. The research has demonstrated that the noise camera marketplace has expanded and the capabilities of these technologies has significantly improved since Phase 2. Both of the products tested for Phase 3 Part B have been deployed on live carriageways which indicates that the technologies are becoming suitably advanced to cope with real-world conditions.

However, it is recognised none of the deployments to date would meet the requirements for fully automated enforcement and that further development is required. The development required includes:

- Improvement of automation by incorporating an ANPR to tie the evidence to a particular vehicle;
- Generating complete evidence packages for civil enforcement generally in line with the requirements of DfT publication “The Certification of Approved Devices” [10];
- Encrypting and authenticating the evidence package such that it can be transmitted to the enforcement centre.

Once implemented, these developments would reduce the time taken for a human operator to review and confirm whether an offence has taken place and thus improve the efficiency and uptake of the systems overall. They would also provide adequate security to ensure that the evidence captured could be relied on for any legal process that might arise.

As further development is required for noise camera systems to meet their full potential, it is recommended that the scope of the roadside trials for Part C is proportionate to the current capabilities of the technology and focusses on:

- Identifying enforceable scenarios,
- Identifying false positives, and
- Validating the noise thresholds for enforcement proposed in Part A.

The methodology suggested for Part C is described below and is broken down into a number of tasks which are described individually in the following subsections. The main tasks identified in Part C are:

- Site selection and stakeholder engagement
- Noise camera selection and site commissioning
- Trials on live carriageways
- Analysis and reporting

7.3.1. Site selection and stakeholder engagement

The roadside trial sites will be selected through an application process announced by the Secretary of State for Transport during April 2022 [22] [22]. Members of Parliament have been invited to nominate a suitable location in their constituencies where the roadside trial could take place, and to provide technical and contextual information to support the application. The AJJV will review these applications and score them based on the following criteria:

- The scale and type of the excessively noisy vehicle problem at the nominated location and whether the trial could capture excessively noisy vehicles and genuinely bring about a meaningful positive change;

- Willingness of the local authority, local highway authority and police to be proactively involved in the trial and gain experience using the technology;
- Ability for the trial to take place at the nominated location during Summer/Autumn 2022;
- Site locations, conditions and the availability of suitable existing street furniture to install and power the noise camera.

At least two of the installation sites will be in urban areas and the overall selection of installation sites will aim to cover as wide a range of settings as possible (such as urban canyons, open park / agricultural land, wooded, high / low rise accommodation). The selection process for sites will also include situations where traffic conditions are more complex than those considered during the testing described in this report. This will allow some of the knowledge gaps to be reduced and some of the uncertainties around the operation of the camera and potential enforcement to be explored.

As far as practicable, the four trial sites will be selected in different local authority or police areas. This will enable as many local authorities and police forces as possible to improve their awareness of noise cameras and to gain practical experience of using the technology.

If the application process does not identify enough suitable trial sites, the AJJV will review the suitability of locations identified during or after Phase 2 of the project. Options will be explored for undertaking the roadside trial at these locations.

7.3.2. Noise camera selection and site commissioning

One suitable noise camera will be selected for the roadside trials following discussions with the suppliers identified in Chapter 3. The final selection will be influenced by the supplier’s ability and availability to participate in the roadside trials, as well as the potential for the identified product to further our understanding of noise camera technologies.

Once the trial sites are selected, a detailed plan for the installation of the noise camera product will be formed taking into account the noise camera’s installation requirements and the site conditions and constraints. This includes consideration of power supplies, data connections and permits required to install and operate a noise camera. The AJJV will engage with the participating local authorities and police forces throughout the site commissioning process and will work with the noise camera supplier and installation subcontractor (where required) to install the noise camera at the identified sites.

Upon completion of the installation, the project team will subject the noise camera to a series of commissioning tests. This will include observing a number of standard vehicle passes using both the camera (possibly with the noise threshold set artificially low) and simultaneously measuring noise with a calibrated sound level meter. The noise camera performance will be compared to the ground truth data from the calibrated sound level meter and if there is adequate correlation between the noise camera data and the ground truth data, we will proceed to the next phase of roadside testing. The local highways authority and the relevant police force will be invited to attend during both the installation and commissioning testing.

7.3.3. Noise camera testing at selected sites

The next stage, the in-road trial, will be to operate the noise camera in ‘dummy enforcement’ mode to determine its effectiveness as a viable enforcement solution. The noise camera will be deployed for a defined period allowing it to collect data. This data will be collected, together with any ground truth data obtained during monitoring visits. The three steps in a dummy enforcement session shown in Figure 7-1 will be attempted for each set of tests:

Establishing that an offence has taken place

Reviewing the captured data and video records and attempting to satisfy an enforcement officer that, to the balance of probabilities, an offence has taken place and that it is unambiguously possible to identify the offending vehicle.

Preparation of an evidence pack

Using the captured data and video records from the noise camera to prepare example packages of information (evidence packs) which demonstrate that an offence has taken place and that the captured vehicle is an offending vehicle.

Export of a contravention record

Exporting the captured data and video records to example packages that could, in the future, be sent to a member of the public to demonstrate that their vehicle has exceeded the pre-set noise threshold.

Figure 7-1 Dummy enforcement steps

The data collected from the roadside trials will be stored safely and securely in line with GDPR and other data privacy requirements. A Privacy Impact Assessment will be completed prior to the roadside trials taking place, along with site-specific Risk Assessment and Method Statements, to ensure that all potential risks are identified and mitigated appropriately.

7.3.4. Analysis and reporting

The characteristics of those vehicles whose noise output appeared to exceed the triggers levels proposed in Part A [19] for Part C data collection and for enforcement will be examined for each trial site. This will focus on the following:

- Did the system capture those vehicles that were subjectively identified as being excessively noisy;
- The confidence that the correct vehicle was identified;
- Could the possible sources of excessive noise be identified from the video/audio; and
- Were any identified vehicles the result excessive noise from compliant vehicles due to adverse driver behaviour.

Following the completion of the roadside trial phase, the project team will prepare a final project report outlining the methodology and approaches used, key outcomes of the roadside trials including the performance of the noise camera, and a discussion of how the outcomes from the roadside experience may affect recommendations in Part A relating to threshold noise levels for enforcement.

The potential suitability of the noise camera for establishing an evidential trail and carrying out enforcement in real world conditions will also be assessed, taking into account: additional development required, costs of installation, costs of operation and the benefit to communities affected by excessively noisy vehicles. The report will also recommend the next steps required for the possible deployment of noise cameras and outline the legislative and organisational considerations that will have to be addressed before enforcement can be deployed in a real-world context.

7.4. Further work

Opportunities for further research have been identified that are not currently part of the scope for this project but could enhance the understanding of the excessively noisy vehicle problem and the strengths and limitations of noise cameras as an enforcement measure. The current scope of Part C requires testing one noise camera at each of the four selected trial sites. It may be beneficial to undertake limited testing of a second noise camera simultaneously at one of the trial sites to better understand how different products perform in a real-world setting.

Additionally, working with a Local Authority or police force who already use noise camera systems for enforcement could add value to the outcomes of the roadside trials for Part C. This would result in gaining a greater understanding of the user experience of those who use the technology for enforcement to determine whether the systems are viable for widespread use, and what changes may be needed to encourage this. It may also be useful for these experienced users of noise cameras to test a different system to further understand the strengths and weaknesses of these systems and threats to their long-term viability.

The application process announced by the Secretary of State for Transport [22] provides an opportunity to create a map identifying the locations where excessively noisy vehicles are disturbing local residents. From this information, the scale of the problem can be better understood as well as the prevalence of different types of excessively noisy vehicle problems (car cruises, popular motorcycle routes, antisocial driving in car parks), which could inform future strategies at national level for managing the issue or enforcement.

The Secretary of State's announcement [22] has started conversations in Local Authorities about how they could use noise cameras as an automated enforcement tool. Further consultation is recommended to better understand the barriers that Local Authorities face that would prevent enforcement from an automated noise camera from occurring.

7.5. Summary of Phase 3B

The outcomes of Phase 3B are summarised in Table 7-1 with reference to the objectives specified for Phase 3B.

Table 7-1 Summary of Phase 3B outcomes

Description	Summary of outcome
To identify and review the latest available noise camera products to determine their suitability for UK roads and as an enforcement tool	• The majority of the technologies identified during Phases 1 and 2 have not been further developed into a noise camera product for excessively noisy road vehicles. The Noivelcam and Akut systems have been further developed for this purpose but would not be ready for trialling within the project's timescales. • A review of the 2022 marketplace identified 8 new noise camera systems, of which 4 were deemed potentially suitable for UK roads and had been trialled on live carriageways based on their current state of development. Development work continues on some of these products. • Many of the noise cameras do not include an ANPR as standard, further development to include a suitable ANPR would be needed for automated enforcement.
To test the performance of suitable noise camera products in controlled conditions	• Two noise camera systems were tested under controlled conditions at UTAC Millbrook during April 2022. • The array-based system was able to automatically assign noise levels to vehicles in a traffic stream and when vehicles pass each other in opposite directions. However, the system did not register noise emissions outside of its detection zone.

	• A single microphone system was also able to assign noise levels to vehicles in convoys and contraflow scenarios but requires a higher level of manual review to do this. However, as its detection zone is larger, a manual reviewer is able to assign noise levels to events further away from the system's location. • The testing outcomes were used to devise a list of enforceable scenarios based on the current capabilities of the tested noise cameras. Enforceable scenarios include single vehicle passes (including acceleration), traffic streams, contraflows and when overtaking manoeuvres are performed. Higher levels of manual review are likely to be required to enforce scenarios where stationary vehicles rev their engines or moving vehicles sound their horn while passing the noise camera. • The testing also identified some scenarios with the potential to generate false positive results, and outline methods for managing this process are given.

8. Conclusion

Considerable progress has been made in the development of noise camera technologies since Phase 2 of this project, with several products in their later stages of development alongside novel emerging technologies undergoing prototype testing.

Two noise cameras were tested in a controlled environment at UTAC Millbrook and were found to have different technological challenges to overcome that are resolvable with further development. Testing under controlled conditions has demonstrated that noise cameras using a microphone array are effective at automatically assigning noise levels to vehicles in a traffic stream and when vehicles pass each other in opposite carriageways and offer the most potential for automated enforcement for this reason. However, the microphone array is focussed on the noise emissions measured within a defined detection zone and excludes excess noise that occurs outside of this target area. This prevents false positives from automatically assigning high noise levels from outside the detection zone to a compliant vehicle passing through the detection zone.

Noise cameras without an array can still be effective at identifying vehicles and assigning sound levels to them but a higher level of data review is required. These technologies benefit from fewer detection zone constraints and can identify excess noise over a greater area with a corresponding increase in manual data review. The use of wide-angled or multi-camera context video and synchronised audio greatly aids the manual review and would be required for the evidence package for civil traffic enforcement. However, the use of an omnidirectional microphone increases the potential for exceedances from unrelated noise sources to be registered, increasing the potential for false positives. The use of screening criteria within the technology to reduce types of false positive events (such as emergency services sirens) would reduce the workload of enforcement operatives reviewing each potential offence.

Both of the tested noise cameras would benefit from the incorporation of an ANPR into their systems to increase automation of the noise camera technology. This would improve efficiency by reducing the review time of a human operator to confirm offences, making the technology more attractive from a user perspective. Existing automated enforcement systems, such as speed cameras, ensure that the review time from an enforcement officer does not need to exceed 2-3 minutes for each potential offence. A similar level of review time would be expected for noise cameras to ensure their long term viability and would require reducing the current average review time by 75% [19]. Further work is also required in terms of evidence package generation and encryption of data for transmission when deployed.

The size of the detection zone is a limitation of any noise camera technology when deployed as a single fixed unit. Deploying a single noise camera in this way would not necessarily detect or prevent offences from occurring further upstream or downstream of the installation site outside of the detection zone. These limitations can be exploited by siting a noise camera at locations where this would not be an issue, such as the edge of a village where there is a speed limit change. Alternatively, a noise camera could be periodically relocated or additional units could be deployed at strategic locations within a hotspot to improve the overall coverage and encourage a behavioural change throughout the area. These options are supported by the police, who have expressed interest in a mobile enforcement solution for excessively noisy vehicles. Mobile noise cameras would provide the police and local authorities with the opportunity to target more locations and to use them to reduce noise from antisocial driving due to car cruises or similar events.

The driving style of vehicles fitted with aftermarket products was found to correlate with higher noise emissions, with higher noise levels are generated during acceleration. Noise cameras are likely to offer a better opportunity to tackle antisocial noise from vehicles if located in areas where drivers accelerate unnecessarily harshly compared to those where the speed is likely to be fixed.

The measured noise levels from the noise camera technologies were generally within ±3dB of the maximum noise levels measured at the type approval position provided that the maximum noise levels occurred while the vehicle was moving in the detection zone. Larger differences were observed when large idling vehicles were present in the detection zone or when the maximum noise level occurred outside of the detection zone. As the type approval microphone position or testing procedure is not designed to assess and distinguish noise from multiple vehicles at the same time, this sometimes resulted in larger differences compared to the array-based noise camera which was better able to distinguish between individual vehicles.

The noise cameras were able to collect data during wet weather conditions and showed large increases in noise levels compared to dry conditions. Meteorological data is not required for enforcement as rainfall and wet road surfaces would be evident within from the video clip and audio obtained for the evidence package. Provided that a tolerance for adverse weather is included in the noise threshold for enforcement, there would be no need for the enforcement officer to exclude data due to weather conditions. For noise cameras that collect frequency data, an approach for reducing wet weather false positives could be to focus on noise emissions below 1.25 kHz as these frequencies were shown to be unaffected by wet road surfaces and are often the frequency components most associated with excessively noisy vehicles. This approach is viable if there are no sources of excessive vehicle noise in the higher frequencies that should be enforced against.

Based on the outcomes of the track trials, a set of scenarios was identified where noise cameras could be potentially suitable for enforcement use. These scenarios include vehicle pass-bys at fixed speed or during acceleration, overtaking, and vehicles passing in the same or opposing directions which were tested with headways of approximately 1.5-2 seconds. The violating vehicle in these scenarios could be automatically determined when using an array-based microphone system, or by manual review for a single microphone. Stationary vehicle scenarios, such as queuing vehicles at traffic lights, are enforceable but only with manual review from an enforcement operative. Improved detection and automation for stationary vehicle scenarios is a key area for future noise camera development that would make the technology more efficient, flexible and desirable.

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Appendix A. Glossary and Abbreviations

Acoustic signature	The spectral profile and acoustic characteristics of a single noise source or collection of noise sources or components forming a system. In the context of this project, the acoustic signature refers to detailed information about the sound produced by a passing vehicle.
Aftermarket exhaust	Replacement exhaust from a third-party company.
AI	Artificial Intelligence.
AJJV	Atkins Jacobs Joint Venture.
ANPR	Automatic Number Plate Reader.
API	Application Programming Interface.
A-weighting	The process by which noise levels are corrected to account for the non-linear frequency response of the human ear. A-weighted sound is often denoted by ‘A’ in noise indices, for example L_{Aeq} and L_{Amax}.
dB, dBA	Decibel, A-weighted decibel.
Contraflow (noise camera test scenario)	Two-way traffic; a bidirectional road with one lane in each direction.
De-cat	De-cat refers to the removal of the catalytic converter. This has the effect of increasing the maximum available power (marginally) and making the vehicle louder as the catalytic converter has a small silencing effect. The de-cat tuning modifies the performance of the engine to optimise the engine performance where the catalytic converter has been removed.
Decibel	The unit of measurement for sound.
Detection zone	The area on the road surface where a noise camera detects a vehicle exceeding the stated noise threshold and records an evidence pack. The detection zone has an entry and exit point dictated by the direction the vehicle is moving in. The centre point is positioned in the middle of the detection zone.
DfT	Department for Transport
Directional microphone	A microphone that receives sound from a certain direction or number of directions.
DVLA	Driver and Vehicle Licencing Agency.
Edge-case	Scenarios and/or results which may be difficult to resolve for enforcement. These are attributed to uncertainty in the outcome due to difficulties in reviewing the evidence manually.
Engine Mapping	The process of tuning an engine via the vehicle’s electronic control unit to achieve a higher engine power output. This can potentially create ‘pops and bangs’.
Evidence package	Encrypted data outputs from the noise camera pertaining to a potential offence that are transmitted securely to an enforcement officer.

False positive	A test that wrongly indicates that a particular condition or attribute is present. In the context of this project, a false positive is a compliant vehicle being identified by a noise camera as excessively noisy.
Fast response	Noise measurement with a 125 ms time constant, meaning that the sound pressure level is sampled every 125 ms. This is sometimes denoted in noise indices by ‘F’, such as L_{AFmax}.
Frequency	Rate at which sound wave crests reach a given point (cycles per second), measured in Hertz (Hz). Low frequency sounds have long wavelengths, resulting in a bass sounds (e.g. engines, thunder). High frequency sounds have short wavelengths and have a higher pitch (e.g. bird song, emergency vehicle siren).
GDPR	General Data Protection Regulation
Ground truth	The independent measurement of an event using calibrated instruments (e.g. a sound level meter).
Hard acceleration	Scenario where the test vehicle accelerates at the maximum rate that will maintain adhesion between the vehicle tyres and the road surface.
Headway	The time (or distance) between the rear of the leading vehicle and the front of the following vehicle.
HGV	Heavy goods vehicle
ISO	International Organization for Standardization.
$L_{Aeq,T}$	The equivalent continuous A-weighted sound pressure level during time period T.
$L_{Amax,T}$	The maximum A-weighted sound pressure level measured during time period T.
MEMs microphone	Micro-electromechanical systems microphone, also known as microphone chips. These are commonly used in smartphones and computers.
Noise	Unwanted sound.
Noise camera	System typically comprising a sound level meter, ANPR and video camera that can be used to identify vehicles producing excessive noise.
Omnidirectional microphone	A microphone that receives sound with equal gain from all directions.
Performance Map	Engine remapping which modifies the amount of fuel injected and the timing of its injection in order to achieve a higher power output.
Pops and bangs	The effect where noise is generated on the vehicle overrun. Normally fuel is stopped when letting off the accelerator but the remapping changes this to continue to inject fuel and change the ignition timing so it is retarded to a point when it sparks the mixture very late in the engine combustion cycle and the igniting of the fuel happening in the exhaust rather than the engine.
PSPO	Public Spaces Protection Order
Repeat measurement, repeat test run	The number of times the test was performed with the noise camera positioned to the nearside of the vehicle
Stock	Unchanged from factory conditions.

Test zone	The extent of the ISO noise surfacing on the straight section of the test track, located within the outer edge of the centre circle.
Type approval	A procedure whereby a manufacturer can obtain certification from a competent authority that their product meets the requirements of a certain European Directive or Regulation.
UK	United Kingdom
Wavelength	The distance between the two peaks (or two troughs) of a sound wave, measured in metres.

Appendix B. Noise Camera Appraisal Scoring

The scoring system used to appraise the noise camera systems is shown in Table B-1 and the moderated scores are shown in Table B-2.

Table B-1 Themes and weighting used to score the noise camera systems

Part	Aspect	Weighting	Maximum score
Acquisitional	Acoustic	3	9
	Video	3	9
	Automatic Number Plate Reader (ANPR)	3	9
	Meteorological	1	3
Non-acquisitional	Evidence management	3	9
	Power	1	3
	Physical (mounting, environmental limitations)	1	6
	Cost and Availability	1	3
	Reliability	1	3
Additional questions	Readiness for installation	1	5
	Reliability	1	5
	Data integration	1	5
	Data processing	1	5
	Ease of installation	1	5
	Resistance to tampering	1	5
	Dark lighting conditions	1	5
	UK weather conditions	1	5
	Maintenance	1	5

Table B-2 Moderated scores

Product	Acquisitional components (max score 30)	Non-acquisitional components (max score 24)	Moderated Additional questions (max score 45)	Score (out of 10)	Rank
24 Acoustics	29.8	21.2	30.5	8.2	1
Bruitparif	25.9	14.0	36.5	7.7	2
MicrodB	25.3	21.2	28.5	7.6	3
ACOEM	19.1	4.0 (due to incomplete responses)	23.5	4.7	4

Appendix C. Instrumentation

C.1. Millbrook system

The instrumentation used by UTAC Millbrook for the track trials is presented in Table C-3.

Table C-3 Millbrook instrumentation and calibration details

Item	Serial number	Date of next laboratory calibration
Millbrook ISO 10844 Noise site	19-0844-24	05 November 2022
Brüel and Kjær PBN Data Acquisition System Ch1	50-6500-BD	24 February 2023
Brüel and Kjær PBN Data Acquisition System Ch6	50-6501-BF	24 February 2023
Brüel and Kjær 4231 Sound Level Calibrator	51-6002-18	07 February 2023
Brüel and Kjær 4189 Microphone	24-6500-01	24 February 2023
PCB Microphone 377B02	118798	24 February 2023
Brüel and Kjær 2250 Sound Level Meter	-	-
Static Tailpipe Exhaust Jig	21-MPG113	14 September 2023
Vaisala WXT536 Weather Station	04-0364-16	01 March 2023
Tyre pressure gauge	34-2252-05	23 September 2022
Longacre Weigh Pads	41-7458-11	26 August 2022
Racelogic Speed Sensor	23-6267-VT	04 February 2023

C.2. AJJV system

The instrumentation used by the AJJV for the track trials is presented in Table C-4.

Table C-4 AJJV instrumentation and calibration details

Item	Serial number	Date of next laboratory calibration
01dB FUSION Frequency Meter	11195	13 November 2022
GRAS 40 CE Microphone	233226	13 November 2022
01dB No22 External Pre-Amplifier	1605094	13 November 2022
01dB FUSION Internal Pre-Amplifier	11195	13 November 2022
01dB CAL21 Associated Calibrator	34565045	22 November 2022

Appendix D. Trial Data Obtained

A detailed description of the test data collected is shown in Table D-1.

Table D-1 Track trials tests information

Test name	Description	Date/s	MicrodB	24 Acoustics	Millbrook
Test 1	Single vehicle stationary tests	04/04/2022, 07/04/2022, 29/04/2022	✓*1	✓*2	✓*3
Test 2	Single vehicle pass-bys	05/04/2022, 25/04/2022, 26/04/2022	✓*4	✓*5	✓
Test 3	Convoy passes	26/04/2022	✓	✓	✓
Test 4	Contraflow passes	27/04/2022	✓	✓	✓
Test OT1	Idling bus near noise camera	05/04/2022, 06/04/2022	✓*6	✗*7	✓
Test OT2	Convoy passes, both noisy vehicles	26/04/2022	✓	✓	✓
Test OT3	Siren tests	04/04/2022, 29/04/2022	✓	✓*8	✓
Test OT4	Coasting past the noise camera	07/04/2022	✓	✗*9	✓
Test OT6	Overtaking	26/04/2022	✓*10	✓	✓
Test OT7	Hard acceleration	27/04/2022, 29/04/2022	✓	✓	✓
Test OT8	Horn tests	04/04/2022, 29/04/2022	✓	✓*11	✓
Test OT9	Single vehicle pass-bys, wet road	25/04/2022	✓*12	✓	✓
Test OT10	Single vehicle pass-by, Night-time	26/04/2022	✓	✓	✓
Test OT11	Stationary test within idling traffic	26/04/2022	✓*13	✓	✓
Test OT12	Single vehicle pass-bys, 60mph	26/04/2022	✓	✓	✓
Test OT13	As loud as possible	27/04/2022	✓	✓	✓
Legend					
✓ (green)	Full dataset				
✓ (amber)	Partial dataset				
✗ (red)	No data				

*1: MicrodB did not capture data for Test 1 ‘downstream’ for Vehicle E (aftermarket exhaust, stock map).

*2: 24 Acoustics did not capture data for Test 1 on 04/04/2022 and 07/04/2022 as they were not present on the track trials.

*3: Millbrook did not capture data for Test 1 ‘upstream’ for Vehicle E (aftermarket exhaust, stock map) E due to logger issues.

*4: MicrodB did not capture data for Test 2 pass-bys at 40mph for Vehicle C (aftermarket exhaust, stock map).

*5: 24 Acoustics did not capture data for Test 2 on 05/04/2022 as they were not present on the track trials.

*6: MicrodB automatically excluded data for Test 3 for the following scenarios: Vehicle E (aftermarket exhaust, stock map) at 20mph, Vehicle E (aftermarket exhaust, pops and bangs map) at 20 and 30mph.

*7: 24 Acoustics did not capture data for Test OT1 on 05/04/2022 and 06/04/2022 as they were not present on the track trials.

*8: 24 Acoustics did not capture data for Test OT3 on 04/04/2022 as they were not present on the track trials.

*9: 24 Acoustics did not capture data for Test OT4 on 07/04/2022 as they were not present on the track trials.

*10: MicrodB did not capture data for Test OT6 for Vehicle C (aftermarket exhaust, stock map) at 30mph.

*11: 24 Acoustics did not capture data for Test OT8 on 04/04/2022 as they were not present on the track trials.

*12: MicrodB did not capture data for Test OT9 for Vehicle C (aftermarket exhaust, stock map) at 20mph.

*13: MicrodB did not capture data for Test OT11 for Vehicle E (aftermarket exhaust, pops and bangs map).

Appendix E. Non-standard number plates

The non-standard number plate variants tested are shown in Table E-1.

Table E-1 Non-standard number plate variants

Number plates	Description
	'3D' raised lettering
	Standard plate with non-standard character spacing
	Standard plate with 40% tint
	Standard plate with italic font

ATKINS Jacobs