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Trail Bike Exhaust Noise: Are road-legal trail bikes louder than competition bikes?

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ABSTRACT

This paper describes recent research into noise emissions from trail bikes. A review of relevant noise control regulations is provided, covering the operation of trail bikes across Australia, and including regulations specific to the State of Victoria. Initial investigations comprised stationary noise testing a selection of typical bike and exhaust configurations, conducted under controlled conditions and according to standardised test procedures applicable to each regulatory framework. Results from these initial measurements indicated substantial variance between noise levels obtained according to different test procedures, even where the relevant noise limit is identical. The results also clearly demonstrated the influence of engine speed during testing, not only for obtaining repeatable results, but also for meaningful comparison of noise levels obtained for the different regulatory procedures. Following stationary noise testing, a selection of bikes and exhausts were subjected to measurements of noise during ride-bys conducted on a forest road, typical of riding conditions in Victorian State Forests. Results from the ride-by measurements revealed substantial increases in noise between stationary test results and ride-by levels. Influences of after-market exhausts were also studied, and revealed significant increases to the overall noise level and tonal characteristics of noise emitted. This research was commissioned by the Victorian Department of Sustainability and Environment, and completed by AECOM with assistance from the Environment Protection Authority Victoria.

INTRODUCTION

Sales and usage of trail bikes have been increasing significantly over recent years, with growth in national sales for off-road motorcycles peaking in the first half of 2007 at over 12% on the previous year [1]. In 2008, close to 50,000 off-road motorcycles were sold in Australia [2], slightly ahead of total road bike sales for the same year. Increasing numbers of trail bikes has highlighted the impacts of use, and in particular increasing noise impacts of trail bikes ridden on forest tracks and public recreational areas.

The scope of this research was to:

- Review current noise regulations, including requirements for road registered and off-road competition bikes
- Conduct stationary noise testing for a variety of trail bikes and exhaust configurations
- Conduct field measurements with a selection of trail bikes and exhaust configurations.

REGULATORY CONTEXT

Legally acceptable noise emissions from trail bikes – as for all motor vehicles – are regulated in Australia by a number of official bodies, under both state and federal levels of government. As a signatory to international agreements on harmonisation of motor vehicle regulations, legislation enacted in Australia also shares commonality with a number of international regulations and test procedures.

International agreements

Australia is a signatory to the 'Agreement concerning the Adoption of Uniform Technical Prescriptions' of 1958 (the '1958 Agreement'). This agreement also marked the establishment of the 'World Forum for Harmonization of Vehicle Regulations (WP.29)', administered by the United Nations Economic Commission for Europe (UNECE). This forum is the peak international body for managing and updating motor vehicle regulations for approval and publication by UNECE.

Regulations published by UNECE may be adopted or incorporated into local legislation by member nations, as locally appropriate. This process of adopting common standards is intended to enable manufacturers to obtain regulatory approval in just one country, which can then be recognised by other member nations.

Standardised motorcycle classification

UNECE has defined an internationally recognised classification system for motor vehicles. This scheme places off-road motorcycles, including trail bikes into the broader category of 'L_3' motor vehicles, that is:

> A two-wheeled vehicle with an engine cylinder capacity in the case of a thermic engine exceeding 50 cm^3 or whatever the means of propulsion a maximum design speed exceeding 50 km/h. [3]

Official Australian classifications follow the UNECE Vehicle Categories in general terms, defining 'LC Class' vehicles as being:

> A 2-wheeled motor vehicle with an engine cylinder capacity exceeding 50 ml or a 'Maximum Motor Cycle Speed' exceeding 50 km/h. [4]

Standardised moving vehicle noise test

Generally, international motor vehicle noise regulations and test procedures include two distinct testing scenarios. The first test quantifies noise emitted by a moving vehicle, under full-throttle acceleration. This test is the primary test used in the approval procedure for new vehicles, with a simple pass/fail outcome. Actual noise test data is not generally published with certification.

Requirements for the standard test area, entry speed, gear ratio, and microphone positions are all detailed in the relevant technical requirements of the regulation and/or referenced standards. For the purposes of defining noise limits, motor cycles are typically sub-categorised according to engine capacity. The UNECE divides motorcycles into three sub-categories (Table 1), each with applicable limits for noise emission.

Table 1. Standard categories and noise limits

Category	Engine Cylinder Capacity	Limit dB(A)
First category	cc ≤ 80cm^3	75
Second category	80cm^3 < cc ≤ 175cm^3	77
Third category	cc > 175cm^3	80

Source: UNECE R41-03 [5]

The trail bikes considered in this study all have an engine capacity of 249 cm^3 or greater and fall into the 'Third Category', having a ride-by limit under UNECE Regulation 41-03 of 80 dBA, measurable at 7.5 m from the track centreline.

Standardised stationary vehicle noise test

The second (stationary) test is intended to be used as a reference for simplified in-service testing and as a method to check for significant deterioration or modification from the original equipment:

> The two values measured shall be recorded in a test report. The test on the vehicle when stationary may usefully be taken as a reference value by technical services wishing to use this method to check vehicles in service. [6]

This secondary test requires a stationary vehicle, with measurement to be conducted at a distance of 0.5 m from the exhaust tailpipe. The engine speed for testing is dictated by the applicable technical standard, for which ISO 5130:2007 is generally referenced.

Summary of international regulations

Motor vehicle regulations as applied in different regions frequently differ from the standardised procedures set out by the UNECE (Table 2).

Variations from UNECE standardisation that should be noted:

- Microphone placement for moving vehicle test is standardised at 7.5 m for all regions *except* in the USA, where 15 m applies.
- Noise limits are applicable to L_3 motorcycles with engine capacity greater than 175cm^3 (as defined by UNECE), *except* in the USA where the quoted limit applies to off highway motorcycles with engine capacity greater than 170 cm^3; and New Zealand where the quoted limit applies to motorcycles with engine capacity of more than 125 cm^3.

Table 2. International noise emission regulations for new L_3 class motorcycles with engine capacity >175 cm^3

Region	Regulation	Noise Limits	
		Moving	Stationary
Europe	97/24/EC, Chapter 9, Annex III	80 dBA	'Reference Level'
United States of America	US EPA-CFR 40, Chapter 1, Part 205	82 dBA	No National Limit
New Zealand	Land Transport Rule 32017/2 - Vehicle Equipment Amendment 2007	86 dBA	100 dB
Australia	ADR 83/00	80 dBA	'Signature Level'

Australian new vehicle certification

New vehicles sold in Australia are required under the 'Motor Vehicle Standards Act 1989' to comply with applicable 'Australian Design Rules' (ADR's). The ADR that governs vehicle noise emissions is 'Vehicle Standard (Australian Design Rule 83/00 – External Noise) 2005'. With the introduction of this rule in 2005, Australia adopted UNECE regulations for motor vehicle noise emission, including UNECE R41-03 covering motorcycles.

To meet certification requirements in Australia under ADR 83/00, new motorcycles are expected to meet the drive-by noise limit according to technical requirements of UNECE R41-03. Vehicles that pass this test, are then assessed with the Stationary Vehicle Noise Test of UNECE R41-03 to obtain a Signature Noise Test Value. Signature Noise Test Values, along with the relevant engine test speed, are published in spreadsheet format by the Department of Infrastructure, Transport, Regional Development and Local Government. Compliance stickers, detailing engine test speed and Signature Noise Level, are required to be fixed to all motorcycles certified for on-road use (Figure 1).

Figure 1. Detail of a noise compliance sticker affixed to motorcycle chassis

National in-service requirements

Compliance testing of noise from in-service vehicles is enforced according to the National Stationary Exhaust Noise Test Procedures for In-Service Motor Vehicles (NSENTP) [7], as referred to in Roadworthiness Guidelines issued under Australian Vehicle Standard Rules 1999 Rules 148 – 153). The NSENTP incorporate elements of 'ISO 5130 Acoustics – Measurement of Sound Pressure Levels Emitted by Stationary Road Vehicles'.

It should be noted that Australian Vehicle Standards Rules apply a 5 dB(A) tolerance above the signature level for *in-service* vehicles:

> The stationary noise level of a motor vehicle that is certified to ADR 83/00 must not exceed, by more than 5 dB(A), the noise level that is established for the motor vehicle when it is certified. [8]

State environmental noise policies

The Environment Protection Authority Victoria (EPA) also controls vehicle noise emissions through the Environment Protection Regulations. These regulations prescribe general noise limits for motorcycles, according to type and date of manufacture (Table 3).

Table 3. EPA Victoria general noise limits for motorcycles

Vehicle Type	Noise Level
Motorcycle, other than a new recreational motorcycle, manufactured before 1 March 1985	100 dBA
Motorcycle, other than a new recreational motorcycle, manufactured on or after 1 March 1985	94 dBA
New recreational motorcycle, manufactured on or after 1 January 1994	94 dBA

Source: EPA Victoria [9]

Noise levels for off road racing motorcycle are specified separately, according to the relevant competition category (Table 4).

Table 4. EPA Victoria limits (off-road racing motorcycles)

Category of Use	Noise Level
Motocross	102 dBA
Speedway (All track Racing)	102 dBA
Trial	94 dBA
Any Other Competition Event	96 dBA

Source: EPA Victoria [10]

It should be noted that the current Regulation does not provide direct reference to ADR83/00 or the Australian Vehicle Standards Rules, but rather applies fixed limits, according to vehicle type and category of use.

By comparison, the State of New South Wales has recently amended Environmental Protection regulations to explicitly reference ADR 83/00. Under the amended requirements in NSW, bikes certified to ADR 83/00 must meet the prescribed level (Signature Level) plus 5 dBA – in line with national in-service requirements.

Recreational Registration (Victoria)

In Victoria, trail bike owners have the option (not offered in other states or territories) of full vehicle registration (as per other vehicle classes), or the less expensive option of Recreational Registration.

Registration under this scheme, which is available to any two-wheeled motorcycle, including motorcycles such as Motocross bikes and mini-bikes which do not comply with ADR standards, requires that “recreation motorcycles must have a silencing device which restricts the noise level to 94 dBA or less” [11].

Other conditions imposed include being only permitted on roads outside of built up areas (except for freeways or arterial roads).

Fédération de Internationale Motorcyclisme (FIM)

FIM Technical Rules (2009) for Motocross, Enduro and Track Racing events include requirements for noise emission levels to be tested at specific engine speeds based on engine specifications.

Determination of engine test speed under 2009 FIM rules [12]:

$$N = \frac{30,000 \times cm}{l}$$

Where: N = prescribed RPM of engine
cm = fixed mean piston speed (in ms^{-1})
l = stroke in mm

Applying this formula, a typical 250cc capacity four-stroke bike would be tested at around 7222 rpm. Sound Level Meters with ‘Slow’ response are required (i.e. 1 second time integration); and meter readings are required to be rounded down to the nearest whole integer.

Note that for the 2010 race season, FIM propose to introduce a new motorcycle noise emission testing regime, consisting of measurement at 2 metres from the tailpipe, at full throttle, and with revised noise emission limits of 115 dBA for Motocross bikes (112 dBA for Enduro bikes).

Motorcycling Australia (MA)

MA rules for motorsport competition require stationary noise readings conducted with sound level meters on Slow time response (i.e. 1 second time integration), and that meter readings be rounded down to the nearest whole integer. Further, 1 dB is deducted from readings taken using a Type I sound level meter, and 2 dB deducted from readings using a Type II sound level meter.

The noise level limit is 94 dBA for Enduro bikes (including both four-stroke and two-stroke engines). Motocross bikes have limit of either 94 dBA (four-stroke engines), or 96 dBA (two-stroke engines). The engine speeds for testing noise emission are set according to engine capacity (Table 5).

Table 5. MA specified engine speeds for testing of noise (Motocross, Supercross and Enduro)

Engine Capacity	RPM
Up to 85cc	8000
85cc to 125cc	7000
126cc to 250cc	5000
251cc to 500cc	4500
Over 500cc	4000

Source: MA 2009 Manual of Motorsport [13]

STATIONARY NOISE MEASUREMENTS

Stationary noise testing was carried out by EPA staff at the EPA’s Vehicle Testing Station. Measurements were made for each bike at four different engine speeds, according to each of the regulatory procedures being followed.

In total, 37 motorcycle and exhaust combinations were tested. Of these, 3 Motocross bikes (with a total of 12 exhaust combinations) were not certified to ADR 83/00, and so no Signature Noise Level was recorded. The default noise test limit set down in NSENTP for non-ADR bikes or any bike without a Stationary Noise Test Information sticker is 94 dB(A) at 3000 rpm (4-stroke) and 3750 rpm (2-stroke).

Of the bikes that had certification to ADR 83/00:

- 7 were fitted with unmodified exhausts, as supplied by original equipment manufacturer (OEM)
- 4 had modified OEM exhausts (e.g. removal of insert)
- 11 were fitted with a third-party after-market exhaust

- 3 were fitted with an after-market exhaust from the bike manufacturer

NSENTP results (Signature Noise Levels)

Three of the unmodified bikes (i.e. original OEM specification) exceeded their relevant Signature Noise Level, however only one bike exceeded the 5 dB tolerance allowed for in-service vehicles (another was at the allowable 5 dB tolerance).

It was clearly observed that the fitting of after-market exhausts and/or modified exhausts generally increased stationary noise levels, however this did not automatically put them over the Signature Noise Level or 5 dB tolerance.

It was observed during the measurements that testing at the specified engine speed for NSENTP often required engine speeds close to idle. This made testing difficult from a practical perspective to obtain a stable engine speed, and highlighted that the required NSENTP testing is not intended to be representative of noise emissions from a vehicle under power or at high engine speeds.

Figure 2. Simultaneous sound level meter and tachometer readings for stationary measurements

MA and FIM test results

For each motorcycle / exhaust combination, stationary noise levels were also measured according to methods prescribed by Motorcycling Australia (MA) and the Fédération Internationale de Motorcyclisme (FIM). These alternative methods – used for organised competition events – are conducted in the same general manner as the NSENTP test, but at higher engine speeds and with the sound level meter on slow time-weighting.

Failure rates for compliance tests

Both the MA and FIM methods clearly produce higher noise levels than the NSENTP method, as could be expected with higher engine speeds specified for the MA and FIM test procedures. The FIM method generally requires higher engine speeds than MA procedure, however the same 94 dBA limit currently applies. This difference accounts for the much lower pass rate for the FIM test (only 3 bike configurations passed, all of which measured on 94 dB).

Of the three formal test procedures, the following failure rates were observed:

- NSENTP: 32 % failure rate (8 of 25 bike configurations)
- NSENTP performed at default engine speed: 33% failure rate (3 of 12 bike configurations)
- MA: 59 % failure rate (22 of 37 bike configurations)
- FIM: 89 % failure rate (32 of 36 bike configurations)

It is important to note the above failure rates imply that a significant number of the bike configurations tested would pass compliance testing for in-service use on Australian roads, but fail noise tests applicable for entry into off-road competition events.

Engine speed at maximum power

Bringing engine revs up to rated Engine Speed at Maximum Power (ESMP) – or to twice the engine speed specified in NSENTP – provided a more stable speed for many bikes. The engine speed at ESMP was generally closest to the engine speed specified in the FIM procedure. This resulted also in noise levels measured at ESMP, being closest to the levels measured according to the FIM procedure.

RIDE-BY NOISE MEASUREMENTS

Summary by bike and exhaust type

Of the 37 motorcycle / exhaust combinations tested during the stationary noise measurements phase, a selection of nine were used for the field measurements of ride-by noise.

The test procedure used was adapted from the procedure contained in UNECE R41-03 (Annex 3, Section 1), and adopted by ADR 83/00 for new motorcycle approvals. The procedure was generally adhered to, with the exception of the following test site elements which were modified specifically for the purposes of this study:

- Test site not level
- Track surface not compliant with track surface specifications contained in Annex 4 of UNECE R41-03

A moderately inclined track with lightly compacted gravel surface was selected to obtain ride-by noise measurements of bikes accelerating uphill (Figure 3). This condition was considered representative of real world riding in most forests, and expected to provide valuable insight into typical maximum noise emission levels.

Figure 3. The test-zone for ride-by measurements

Microphones were placed at 7.5 m either side of the track centreline (at 1.2 m above ground). One of these microphones was connected to a Sound Level Meter capable of recording digital audio files of each pass-by (in addition to displaying the usual sound level parameters).

For all bikes tested, measured ride-by noise levels exceeded both the Stationary Noise Levels measured at 0.5 m, and the ADR 83/00 moving vehicle noise limit applied for vehicle approval. Unmodified bikes were on average 14 dB louder on these ride-by measurements than the 80 dBA approval level required for certification to ADR83/00. Bikes with after-market or modified exhausts were an average 20 dB above the 80 dBA approval level.

For the nine bike / exhaust combinations tested in the field, a relatively weak correlation exists between stationary noise levels measured to NSENTP, and the noise levels measured for in-field ride-bys.

Figure 4. Full throttle acceleration through the test zone

Frequency spectra of ride-by noise

Clear tonal components in the exhaust noise were observed at around 50–80 Hz and 125–200 Hz, with a smaller peak around 250–315 Hz. The frequency of these peaks are generally attributable to the engine speed and firing interval of the engine cylinder, as modified by the attenuation and resonant characteristics of the exhaust system.

The only two-stroke bike tested contained equivalent tonal peaks, but centred in the 160 Hz, 315 Hz and 500 Hz third-octave bands, reflecting the characteristic higher-frequency sound of a two-stroke motorcycle engine.

Influence of aftermarket and modified exhausts

The stationary noise tests revealed a general trend of increased noise levels from modified or after-market exhaust systems. This pattern is repeated in the ride-by measurements. In particular, of the nine bikes measured in the field, two bikes were measured with different exhausts fitted, or with modification of tailpipe inserts (Figure5).

Figure 5. Detail of an aftermarket exhaust, fitted with an interchangeable tailpipe insert

Analysis of the spectral noise emissions from these bikes reveals the noise level with frequency and illustrates tonal differences in the sound quality for each bike/exhaust configuration. The tonal shift to higher frequencies for OEM exhausts appears to indicate that the maximum noise level for these two bikes in OEM configuration, is not reached until the bike is at a slightly higher engine speed than when fitted with the after-market systems.

OTHER POSSIBLE INFLUENCES

Selected Gear

Ride-by's were measured for all bikes in both 2^{nd} and 3^{rd} gear. Very little difference was observed between ride-bys in 2nd and 3rd gear. On average, ride-by's in 2^{nd} gear were just 0.6 dB louder than in 3^{rd} gear on the same bike.

The largest difference observed between 2^{nd} and 3^{rd} gear ride-by's was for the Yamaha WR-250F with OEM exhaust which recorded an average ride-by noise level 3.4 dB louder in 2^{nd} gear than in 3^{rd}. Interestingly, when fitted with an after-market exhaust (GYTR) the average ride-by noise emission was louder in 3^{rd} gear than 2^{nd}, albeit by a mere 0.3 dB.

Gradient

It was expected that some increase in noise levels would result from running the ride-by measurements on an uphill incline. However the actual influence of varying gradient was not investigated directly in this research. It is not clear if the substantially higher noise levels observed (compared to the ADR 83/00 approval limit) are due only to the introduction of a moderate gradient, even the bikes with OEM specification exhausts averaged 14 dB above the 80 dB approval limit.

Another study [14] has concluded that the effect of gradient for cars and motorcycles to be approximately 0.45 dB per % road gradient. Based on this relationship and the estimated gradient of the test area, noise levels for OEM bikes would have been expected to be less than 4 dB above the 80 dBA approval limit for ADR 83/00.

The 14 dB difference observed for OEM bikes, and 20 dB difference for non-OEM bikes is not fully accounted in existing models predicting noise level for increased gradient, and so suggests either that gradient may have a much larger influence than previously thought, or that there are other factors influencing noise emission which have not been fully quantified.

Track Surface

The noise contribution from the interaction of tyres and track surface was itself observed to be negligible in the presence of engine / exhaust noise for all the bikes when under acceleration.

Figure 6. Applying full throttle at entry to test zone

It seems reasonable that the gravelled surface could have contributed to some wheel slip, resulting in slight increases of engine speed and higher noise emissions when under wide open throttle. However, wheel slip was not excessive during the wide open throttle ride-bys for any of the bikes. In fact, it was observed that the majority of bikes obtained sufficient traction on the gravelled surface that front wheel lift was generally the limiting factor in applying wide open throttle (Figure 6).

Noise levels relative to ambient environment

Average background noise levels measured throughout the day were 30 dBL_{A90}.

The average trail bike noise level measured at 7.5 m was 98 dBA, resulting in an average difference between ambient background noise and noise from trail bikes of 68 dB. The loudest trail bike measured was 103 dBA; 72 dB above background.

No correction was needed to compensate for background noise levels under the ADR 83/00 procedures for moving vehicle noise tests (which specify corrections to be made if background noise is measured to be within 16 dB of the sound levels produced by the motorcycle under test).

SUMMARY

The current research study has generated noise level data for a range of trail bikes and exhaust systems. A number of conclusions have been drawn from stationary noise level measurements; plus noise measurements of trail bikes under wide-open throttle on a moderate uphill incline in the field.

Stationary noise measurements

- When tested against the NSENTP method used for enforcing roadworthiness compliance, 32 % of measured bike /exhaust combinations failed. When tested against motorsport competition rules, increased failure rates were observed of 59 % against MA regulations and 89 % against 2009 FIM regulations.
- Failure rates for assessment against the relevant noise limits imply that a significant number of trail bikes would pass compliance testing for in-service use on Australian roads, but fail noise tests applicable for entry into off-road competition events.
- Testing against the NSENTP revealed that many bikes are difficult to test reliably at the specified engine speeds which are often barely above idle. The NSENTP method would appear to be inappropriate for many common trail bikes.
- FIM test procedure requires testing at higher engine speeds than the MA procedure, resulting in higher noise levels and higher failure rate (both procedures impose the same noise limit of 94 dBA for the majority of bikes).
- Testing at higher engine speeds makes maintaining a stable speed easier for testing, and produces more consistent measurements.

Ride-by noise measurements

- All bike/exhaust configurations tested in the field exceeded the ADR 83/00 moving vehicle noise limit. The modifications made to the standard ADR 83/00 moving vehicle test for this study do not appear capable of explaining the substantially higher noise levels observed.
- Stationary Noise testing under NSENTP provides only a weak correlation with the ADR 83/00 moving vehicle noise test, as adapted for in-field testing in this study.
- Noise emission spectra clearly illustrate the variations in noise emission levels for the same bike when fitted with different exhaust systems.
- Substantial variation was observed for measured in-field noise emissions when compared against the ADR 83/00 approval limit that the bikes should have met in order to receive certification.
- The adaptation of the moving vehicle test to real-world conditions confirms that the standard moving vehicle noise tests – explicitly designed to be representative of urban riding conditions – does not appear to be representative of noise emissions for real world off-road riding conditions.

FUTURE WORK

This study has assessed the results from the ADR 83/00 moving vehicle test, adapted to ‘real-world’ off-road riding conditions. It has not directly investigated the original moving vehicle test methodology, and test data from certification testing does not appear to be available or to have been widely published. A useful extension of this study would be to source original moving vehicle test data from the certification process, or to replicate the official moving vehicle test with trail bikes ridden on a level, asphaltic test track.

Further investigation of the influences of varying terrain on noise emission, to correlate terrain conditions with noise emissions at source would be useful. Based on the work completed in this study, it is likely that this could be achieved in the field by the test rider carrying a backpack mounted Sound Level Meter, time-synced with a logging GPS unit. Alternatively, measurements on a dynamometer may also yield useful data.

Other potential influences that could warrant further investigation include varied track surfaces, such as the effect of gravelled surfaces on wheel slip and resulting engine speed during acceleration.

The scope of this study was limited to a survey and investigation of current test procedures (as at 2009). However, there are currently at least two significant proposals under discussion concerning introduction of new testing procedures for noise emission from motorcycles. The following draft procedures are expected to be especially worth future comparison:

- Proposal currently before UNECE WP29 for Additional Sound Emission Provisions (ASEP) to apply to Regulation 41 (i.e. a proposed ‘04’ series of amendments). The current proposal is based on proposed amendments to ISO 362.1.
- New FIM test procedure, implemented in 2010 for the noise testing at competition events. This includes a stationary test with wide open throttle, and measurement at 2 metres. New noise limits are 112 dBA for Enduro events and 115 dBA for Motocross events.

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