WHEEL SQUEAL IN RAIL TRANSIT SYSTEMS

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One of the most prevalent noise by-products of rail transit is wheel squeal. Due to high sound pressure levels (SPL) and pure tones, wheel squeal is increasingly of concern. It results in discomfort to passengers and unacceptably noisy environments for neighbouring land uses. Most environmental noise guidelines do not address this noise source. When it is addressed, the need to mitigate is tempered by the role of transit as a public convenience and essential service, and the limited success of mitigation techniques.

CHARACTERISTICS

Wheel squeal is often characterized by sound level peaks 20-25 dBA (or more) higher than the normal (rolling) sound from wheel rail interaction. Measurements of subway and streetcar wheel squeal conducted on Toronto Transit Commission (TTC) vehicles indicate that subway cars generate higher frequencies than that produced by streetcars. Typical plots of SPL (dB) in each ⅓ octave band are shown in Figures 1 and 2 before and during wheel squeal.

The spectral characteristics of wheel squeal vary from vehicle to vehicle and are affected by environmental factors such as temperature and humidity as well as physical plant related factors. Therefore, wheel squeal may be present for a given vehicle on one day and be absent or modified on others. This variability can complicate field study of the phenomenon.

CAUSES AND FACTORS

On straight track, wheel rotation is a pure rolling motion. On a short radius curve sliding motion occurs between the wheel and track surfaces resulting in the wheel vibrating at its natural frequencies which are often in the audible range.

Sliding speed affects the squeal noise produced. Studies of a simple cantilever on disk type sliding apparatus indicate squeal associated with the fundamental vibration mode varies little at higher speeds. At lower speeds, squeal associated with stick-slip phenomenon occurs and frequency decreases with sliding speed. Chatter noise occurs at very low speeds.

Any factor associated with the natural frequency of the wheel vibration and the frictional rail/wheel contact will affect squeal. Thus, wheel stiffness determined by the wheel material, shape, and damping are important. Lubrication, humidity and temperature also affect the stick-slip phenomenon associated with squeal. Contact forces affect rail and wheel vibration and hence wheel squeal.

However, the interaction of all these factors has not been studied extensively. In many cases where wheel squeal has been eliminated, the underlying reasons are not known. For example, recent renovations to a streetcar line prompted by maintenance requirements, drastically reduced the incidence of wheel squeal. It is unclear whether rail bed changes, new rails (profile or material), or a combination of both, were responsible.

MITIGATION TECHNIQUES

Mitigation techniques can be grouped into three categories: On Board, Structural and Wayside Treatments. To date, a universally applicable, consistently effective method, which addresses durability, operational safety and environmental concerns, has not been found. Some of the approaches used are:

On Board Treatment

Ring Dampers: In some cases squealing noise has been eliminated by fitting to the perimeter of the wheel disk, a damping ring consisting of an elastomer and a thin plate of steel.

Composite Wheel: A layer of elastomer is used between the metal wheel centre and the steel rim which carries the steel tire. Again, this technique has been successful on some systems and has failed on others. For some applications, the effectiveness is limited by the stiffness required for the proper operation of the wheel assembly, e.g. to negotiate track switches and curves.

Lubrication Blocks: Lubrication blocks apply solid lubricant to the wheel (throat and back-of-flange). Lubricants are not applied to the rail head for safety reasons. Success depends on matching the appropriate lubricant to temperature. A temperature insensitive lubricant has been difficult to find, resulting in inconsistent performance from season to season.

Structural Treatments

Rail: Rail segments have been replaced with a material that creates a solid lubricant effect. Success has been limited. Longevity is a concern.

Lubrication Systems: Grease, oil, and water lubricants have been tried. Grease and oil have safety and environmental concerns and are temperature sensitive. Water is effective but has limited seasonal use unless applied with anti-freeze which has environmental concerns.

Increased Radius: Some studies have shown wheel squeal is unlikely to occur on curves with a radius greater than 100 times the truck wheel base. For many urban transit applications e.g. streetcar loops, this could not be implemented due to space restrictions. In practice, loop radii of close to 200 m would be needed.

Turntables: Turntables have been proposed as an alternative to short radius loops. Problems with this method include potentially higher maintenance costs, restricted access at terminals, and level grade requirements.

Wayside Treatments

Wayside treatments are primarily limited to noise barriers. Effectiveness is limited by gaps for vehicle access in many cases.

ENVIRONMENTAL NOISE IMPACT

The potential environmental noise impact of wheel squeal can be significant. Typical A-weighted time histories of two streetcar passbys are shown in Figures 3a and 3b. The plots shown are for passbys made at the same location for two different vehicles (but same model), one exhibiting wheel squeal, the other with wheel squeal absent. Based on typical transit headways, the estimated daytime (0700-2300 hrs), nighttime (2300-0700 hrs) and 24 hour transit attributable L_{eq} for these passbys, with and without wheel squeal at this location, are:

	L_{eqDay}	$L_{eqNight}$	L_{eq24}
Wheel Squeal Present:	65 dBA	61 dBA	64 dBA
Wheel Squeal Absent:	58 dBA	54 dBA	57 dBA

The wheel squeal contribution to environmental noise is significant and in this case results in exceedences of most generally accepted environmental noise guidelines.

CURRENT RESEARCH

The above discussion highlights the need for further research into causes and mitigation of wheel squeal. The US Transportation Research Board has recently commissioned a study on Wheel/Rail Noise Control including wheel squeal. Hopefully, this will provide some further insight to an often overlooked problem. Research is needed within Canada. This will require a collective effort on the part of transit agencies, industry and universities.

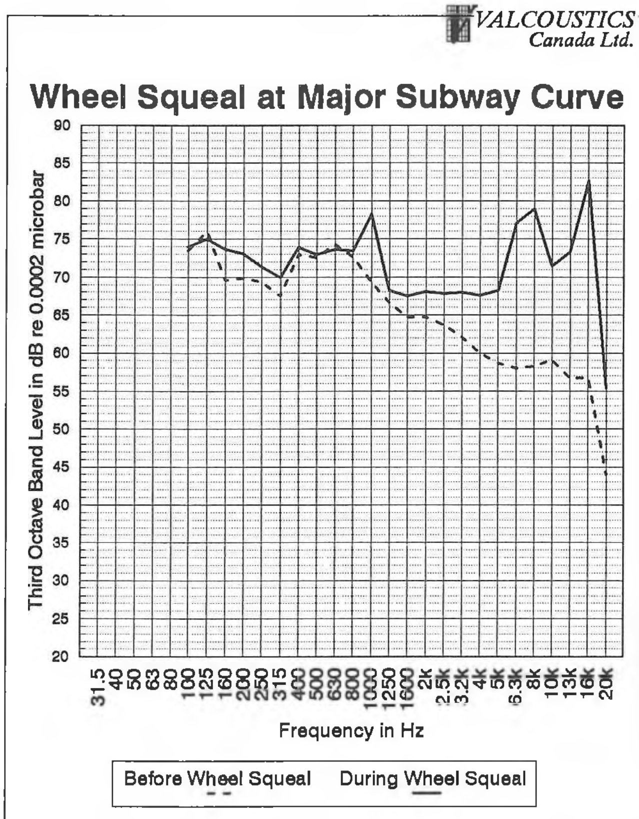

Fig 1: Spectral Comparison of Subway Before & During Wheel Squeal

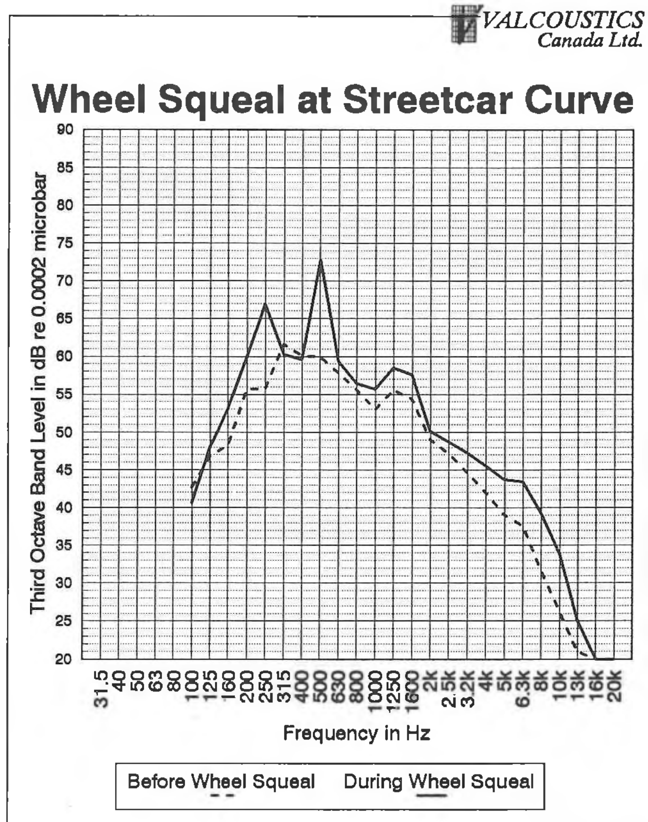

Fig 2: Spectral Comparison of Streetcar Before & During Wheel Squeal

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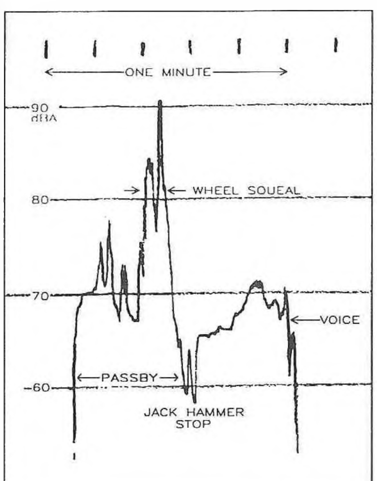

Event Data

SEL: 88 dBA
$L_{max}^{(a)}$: 90 dBA
$L_{MAX}^{(b)}$: 86 dBA

Ambient Data
(12:33 - 13:33)

L_{eq}: 72 dBA	L_{10}: 73 dBA
$L_{99.9}$: 57	L_5: 75
L_{90}: 61	L_1: 82
L_{75}: 65	L_0: 94
L_{50}: 70	

Notes

[a] Largest SPL (dBA) occuring during the homogeneous portion of the event, measured on fast response.

[b] RMS average of the plateau for the event's homogeneous portion (i.e. assumed portion of the event when the vehicle is directly in front of the microphone).

Location: 2nd Floor Deck, Residential Building
Distance to Centre-Line of Rail: 22 m
Other Noise Sources: Jack hammering in background

FIGURE 3a: Typical Streetcar Passby Time History
Wheel Squeal Present

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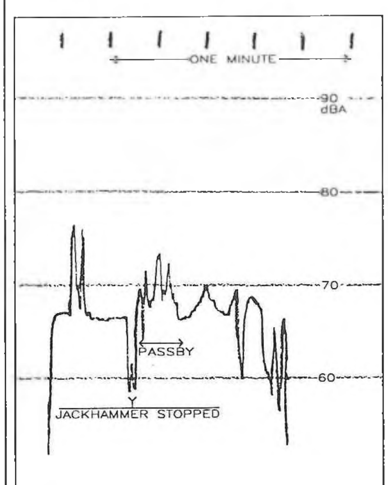

Event Data

SEL: 81 dBA
$L_{max}^{(a)}$: 73 dBA
$L_{MAX}^{(b)}$: 71 dBA

Ambient Data (12:33 - 13:33)

L_{eq}: 72 dBA	L_{10}: 73 dBA
$L_{99.9}$: 57	L_5: 75
L_{90}: 61	L_1: 82
L_{75}: 65	L_0: 94
L_{50}: 70	

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FIGURE 3b: Typical Streetcar Passby Time History
Wheel Squeal Absent