AUTOMOTIVE NOISE – THE INDIAN SCENE IN 2004

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Abstract

Automobiles and two wheelers have been manufactured in India since sixties, but the real thrust in the indigenous effort came in 1990 when the process of liberalization and reforms started earnestly. The story of the automotive noise control is similar. Research and development work in acoustics of ducts and mufflers has been going on at the Indian Institute of Science since late sixties. However, public consciousness of noise pollution in general, and automobile noise in particular, developed during the last decade. This came about primarily because of global competition. National Committee for Noise Pollution Control was set up in 1997 to advise the Central Pollution Control Board, executive wing of the Ministry of Environment and Forests. Advice of the committee has resulted in several gazette notifications limiting the pass-by noise of two wheelers, three wheelers, passenger cars, multi-utility vehicles, buses and trucks/lorries. Type testing and the conformance of production testing is carried out by the Automotive Research Association of India, among others. Research and development work is carried out at the Indian Institute of Science, several Indian Institutes of Technology, etc. Several of the major automobile manufactures have their in-house design and development departments. Department of Science and Technology of the Government of India has set up a Facility for Research in Technical Acoustics (FRITA) at I.I.Sc. in order to offer consultancy in noise control as well as on designing for quietness to industry, apart from carrying out post-graduate teaching and research. This keynote or plenary paper gives an overview of the current automotive noise scene in India.

Introduction

Noise of automobiles is a primary component of the environmental noise pollution, particularly in the cities. In India, where people have rather noisy socio-religious habits, a man in the street would not lose his sleep over automotive noise. However, the scene is changing fast. Vehicles have been produced in India for over fifty years. However their production and use was limited because of socialist policies of the Government which considered an automobile a luxury and therefore imposed heavy excise duty on passenger cars. Gasoline was made excessively costly in order to subsidize diesel, the assumption being that diesel would not be used to power passenger cars. The other, and more compelling, reason has been the fact that India produces only a small part of its petroleum and natural gas requirements. The rest is made up by export from the OPEC countries. This policy discouraged the automobile manufacturers to invest in research and development for improving the design so as to quieten their vehicles. In any case, there were no limits on pass-by noise until 1992. People in general had leant to accept the noise as an inevitable concomitant of all machines, and automobiles were no exception.

In 1990 the Government of India made a conscious change in its policy. It took definite steps towards liberalization and privatization (reforms). It rationalized the tax structure (excise duty, sales tax as well as income tax), reduced subsidies, and encouraged the people to work, compete, earn and spend. This gave a tremendous boost to the manufacture and use of a variety of automobiles. However, with an explosion in the population of automobiles on the road since 1990, consciousness of the menace of noise from two wheelers, three wheelers, passenger cars as well as trucks or lorries, has been spreading.

Fortunately, however, the globalization has forced the automobile manufacturers in India to quieten their products. Otherwise, they would not be able to sell their vehicles abroad (particularly in the developed countries). In fact, they ran the risk of being elbowed out by international players in the Indian market too. The public too has become increasingly conscious about noise pollution, as well as air pollution from the vehicular traffic. Public interest litigations have forced the Government to formulate realistic legislations to control noise from automobiles, portable gensets, stationary diesel gensets (India is short of power), horns, etc. Honking is quiet a habit with many drivers. This is in part owing to lack of lane discipline, pedestrians not sticking to the footpath, there being no separate pathway for bicycles, etc., and partly due to the tendency of some drivers to force their way through the traffic by means of intimidative honking. Therefore, the Indian Government has had to legislate on limiting the use of air horns, particularly within the municipal limits.

In this paper, we review the current noise limits, the development work being carried out by the automobile manufacturers as in-house projects, the design consultancy provided by academicians specializing in technical acoustics, and the direct and indirect support of the Government to the premier institutes of technology and science through generous funding of the sponsored research.

Automotive Noise Limits

The central Pollution Control Board (CPCB) is the executive wing of the Ministry of Environment and

Forests (MoEF) of the Government of India, and is responsible for the monitoring and control of air pollution, water pollution and noise pollution, among other duties. It is advised by a standing National Committee for Noise Pollution Control (NCNPC). Set up in 1997, this committee has been chaired by the author. Among its membership, there are a few experts from academic institutes, a few members from the pollution control boards of states (provinces), a couple of senior officers of the CPCB and MoEF. The Member–Secretary of NCNPC is the executive secretary of CPCB, and communicates the recommendation of the Committee to the Ministry which in turn issues notifications to be published in the Gazette of India for the public to comment upon. The Committee revises its recommendations accordingly, and then advises the Ministry to issue the final notification, and that becomes the Law, and is binding on all concerned.

Table 1 gives the present pass-by limits of automobile noise applicable at present and Table 2 the ones that will become applicable from April 2005. The measurement of pass-by noise (see Fig. 1) has to be as per the Indian Standard IS: 3028–1998, which follows closely ISO 362 [1]. Enforcement of these limits for new vehicles is done through the Automotive Research Association of India (ARAI) which carries out the type testing as well as the Conformance of Production (COP) testing.

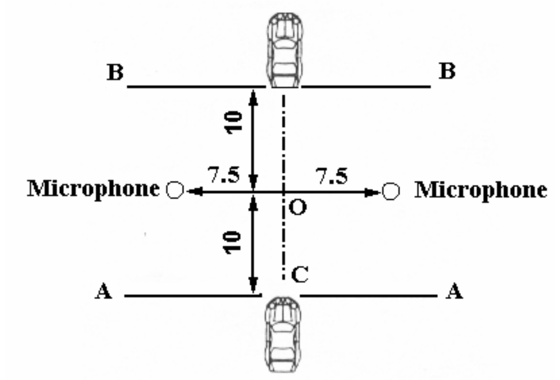


Fig. 1. Microphone positions for measurements IS: 3028-1998

The NCNPC is trying to evolve the stationary vehicle noise limits in order to test the in-use vehicles (see Fig. 2). It would involve measurement of full speed idle exhaust noise of new vehicles (by ARAI), and then fixing the permissible limits a little higher (by 5 dB, say). All measurements and limits refer to the A–weighed sound pressure levels (L_{pA}), as is indeed the practice all over the world.

Table 1. Noise limits for vehicle applicable at manufacturing stage from the year 2003

Sl. No.	Type of vehicle	Noise limits dB (A)
	Two wheelers	
1.	Displacement upto 80 cm^3	75
2.	Displacement more than 80 cm^3 but upto 175 cm^3	77
3.	Displacement more than 175 cm^3	80
	Three wheelers	
4.	Displacement upto 175 cm^3	77
5.	Displacement more than 175 cm^3	80
6.	Passenger Car	75
	Passenger or Commercial Vehicles	
7.	Gross vehicle weight upto 4 tonnes	80
8.	Gross vehicle weight more than 4 tonnes but upto 12 tonnes	83
9.	Gross vehicle weight more than 12 tonnes	85

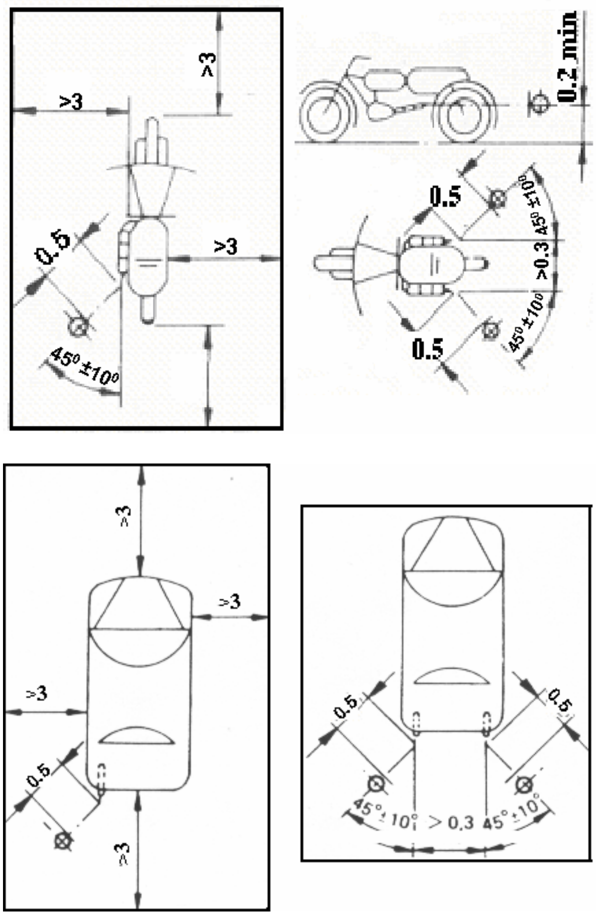


Fig. 2. Test site and microphone positions for measuring exhaust noise

Table 2. Noise limits for vehicles at manufacturing stage applicable on and from 1st April 2005

Sl. No.	Type of vehicle	Noise limits dB (A)
	Two wheelers	
1.	Displacement upto 80 cc	75
2.	Displacement more than 80 cc but upto 175 cc	77
3.	Displacement more than 175 cc	80
	Three wheelers	
4.	Displacement upto 175 cc	77
5.	Displacement more than 175 cc	80
6.	Vehicles used for the carriage of passengers and capable of having not more than nine seats, including the driver's seat	74
	Vehicles used for the carriage of passengers having more than nine seats, including the driver's seat, and a maximum Gross Vehicle Weight (GVW) of more than 3.5 tonnes	
7.	With an engine power less than 150 kW	78
8.	With an engine power of 150 kW or above	80
	Vehicles used for the carriage of passengers having more than nine seats, including the driver's seat \ vehicles used for the carriage of goods	
9.	With a maximum GVW not exceeding 2 tonnes	76
10.	With a maximum GVW greater than 2 tonnes but not exceeding 3.5 tonnes	77
	Vehicles used for the transport of goods with a maximum GVW exceeding 3.5 tonnes	
11.	With an engine power less than 75 kW	77
12.	With an engine power of 75 kW or above but less than 150 kW	78
13.	With an engine power of 150 kW or above	80

Designing for Quietness

Different sources of automobile noise contributing to the pass–by microphone location (see Fig. 1) are:

a. engine exhaust noise
b. engine intake noise
3. cooling fan noise
4. engine body noise
5. mechanical noise
6. structure borne noise

The designer can make appropriate choices in each of these cases in order to arrive at an engine and automobile that would be inherently quieter. He can provide an efficient exhaust muffler as well as intake muffler with limited back pressure, size, weight and cost [2-8].

Temperature–controlled drive for the cooling fan would keep the fan off during most long distance journeys, thereby saving fuel consumption, increasing shaft power and reducing pass–by noise. Same advantages, to a lesser degree though, can be obtained by more efficient design of air passages and heat exchanger or the radiator, because then one would be able to reduce the fan tip speed (for the required cooling) and hence the fan noise. Relatively smaller reduction in the fan noise may be obtained by proper choice of the material, shape and number of blades, shroud, etc [9].

The engine body noise can be reduced at the source by smoothening the combustion process (by reducing the ignition lag, for example), or in the transmission path by altering the structural response to input forces (by means of efficient vibration isolation through impedance mismatch), or at the exterior sheet metal surfaces by damping them or by reducing the radiation efficiency through change of shape [9–11].

Mechanical noise includes piston slap noise, impact excitations of the connecting rod and crankshaft bearings, gear rattle impacts, valve train noise, etc. Piston slap noise may be reduced by reducing bore distortion, modifying the skirt profile, controlling thermal expansion, and use of certain coatings, and piston pin offsets. The lash in valve trains may be eliminated by means of hydraulic valve lifters. Noise of accessories such as oil pumps, alternators, air–conditioned compressors may be reduced by mounted them to the engine so as to avoid resonances of the mounting brackets [9–10].

Impedance mismatches (step changes in stiffness) are incorporated in a structure in order to minimize its response to the suspected force inputs. For example, an engine block could be made very stiff at the location where crankshaft forces would be transmitted through the main bearings, soft between these beings and the oil pan flange, and very stiff at the oil pan flange. Unfortunately, however, this is not very cost effective. A more practical method is to isolate the sheet metal component and design their shape to lower their radiation efficiency. In particular, it helps to lower the stiffness of large covers with large flat surfaces, and stiffen the small components like valve covers, oil pans, etc, and to isolate them from the engine structure by means of soft gaskets and grommets [10].

All the above measures can be used to design an engine and automobile for quietness. A final measure, if necessary, can be the use an acoustic enclosure or a shield which has to be designed with sufficient ventilation, but openings must be sealed to minimize acoustic leakages.

Status of Design and Development

Several major manufacturers of automobiles in India have in–house design departments, test beds, proving grounds, etc. For example, Tata Motors Ltd. Have a full fledged NVH (Noise, vibration and harshness) laboratory in their Engineering Research Centre in Pune, the unofficial automobile capital of India. This laboratory is equipped with a large hemi–anechoic chamber with chassis dynamometer, noise and vibration instrumentation, vibro–acoustic software like SYSNOISE, etc. They have proper proving grounds, crash test facilities, and of course the pass–by noise measurement facilities. They have traditionally been manufacturing trucks and buses, but during the last five years, through entirely indigenous knowhow, they have put into the market a range of passenger cars (INDICA, INDIGO, etc.) that satisfy the European pass–by noise standards as well. Thus they have not only been able to capture a substantial portion of the domestic market but also are exporting these cars to other countries. The author of this article has had the satisfaction of helping them in their efforts to design the engine as well as the body for quietness by making use of some of the principles listed in section above.

Several other major manufacturers like Hindustan Motors, Ashok Leyland, Mahindra & Mahindra, Eicher Motors, etc. started their operations by manufacturing engines and vehicles under licence from internationally established players, but now have established in–house facilities for acoustic testing and are trying to develop quieter engines and vehicles making use of consultancy from the Indian Institute of Science Bangalore, and some of the Indian Institutes of Technology, so as to satisfy the noise limits listed in Table 2.

The Automotive Research Association of India (ARAI), in Pune is funded jointly by the Government of India and the Society of Indian Automobile Manufacturers (SIAM). It has a variety of testing facilities. The most recent addition to this list is the acoustic test centre comprising a hemi–anechoic chamber for testing engines, a pair of reverberation chambers, an impedance tube set up, B & K instruments, LMS instruments, and acoustic softwares like COMET, SYSNOISE, etc. These facilities, designed by the author, are available to the member industries for their development work, and to the Government for statutory Type Testing and the Conformance of Production Testing of new automobiles as also two wheelers and three wheelers. This institute is also represented on the National Committee for Noise Pollution Control, by its Senior Deputy Director. It makes available to the Committee the test statistics and submits proposals to the Committee for arriving at realistic noise limits for different types of vehicles.

Department of Science and Technology of the Government of India under its scheme of Centres of Excellence, has funded the Facility for Research in Technical Acoustics (FRITA) with the Author as its Convener, at the Indian Institute of Science. Since Nov. 1998, its faculty have been offering graduate courses on Fundamentals of Acoustics, Structural Acoustics, Industrial Noise Control, Acoustics of Ducts and Mufflers etc. They have also been arranging short–term courses on noise control and designing for quietness for industries and teachers of undergraduate colleges. They have also been undertaking sponsored research as well as industrial consultancy. Incidentally, FRITA indicates the importance that the Indian Government attaches to the development of quieter technologies, particularly for automobiles.

Recently, a Core Group for Automotive Research and Development (CAR) has been formed by the Principal Scientific Adviser (PSA) to the Government of India for coordinating R & D efforts of the academia and automobile industry. It will get contributions from different ministries, and disburse the same to the researchers, aiming at definite deliverables.

Muffler Acoustics

Probably the most significant contribution to the noise control of automobiles, or to the design of quieter vehicles, has come from the advances in the analysis and design of mufflers. Exhaust noise of reciprocating internal combustion engines is generally controlled by means of reactive mufflers that make use of the impedance mismatch to reduce the resistive part of the acoustic impedance as seen by the source of exhaust noise. Perforated elements have long been known to be acoustically more efficient than the corresponding simple tubular elements [12].

Transfer matrix representation is ideally suited for analysis of cascaded one-dimensional systems like acoustic filters or mufflers. Performance of a muffler may be obtained readily in terms of the four-pole parameters or transfer matrix of the entire system, which in turn may be computed by means of successive multiplication of the transfer matrices of the constituent elements [2, 7].

Over the last three decades, transfer matrices have been derived for many of the basic elements that constitute automotive mufflers. Some of these are [2, 7]:

Uniform tube with flow and viscous losses (Fig. 4)
Sudden area changes (Fig. 5)
Extended inlet/outlet (Fig. 6)
Conical tube (Fig. 7a)
Exponential tube (Horn) (Fig. 7b)
Flexible hose (Fig. 8)
Two-duct perforated elements (Figs. 9 and 10)
- Concentric tube resonator
- Cross-flow expansion element
- Cross-flow contraction element
- Reverse-flow expansion element
- Reverse-flow contraction element
- Reversal-expansion, two-duct, open end, perforated element

Reversal-contraction, two-duct, open-end perforated element
Perforated extended inlet
Perforated extended outlet
Three-duct perforated elements (Fig. 11)
Cross-flow, three-duct, closed-end element
Reverse-flow, three-duct, closed-end element
Cross-flow, three-duct, open-end element
Reverse-flow, three-duct, open-end element
Three-duct perforated elements with extended perforation (Fig. 12)
Cross-flow, open-end, extended-perforated element
Cross-flow, closed-end, extended-perforated element
Reverse-flow, open-end, extended-peroration element
Three-Pass perforated elements (Fig. 13)
Flush-tube three-pass perforated element chamber
Extended-tube three-pass perforated element chamber
Catalytical converter elements (Fig. 14)
Pallet block catalytic converter element
Capillary-tube monolith catalytic converter element
Acoustically lined circular duct (Fig. 15)
Parallel baffle muffler (multi-pass lined duct) (Fig. 16)
Helmholtz resonator (Fig. 17)
In-line cavity (Fig. 18)
Flexible Bellows (Fig. 19)
Pod silencer (Fig. 20)
Quincke Tube (Fig. 21)
Annular air gap lined duct (Fig. 22)
Micro-perforated Helmholtz Panel Muffler (Fig.23)

Transfer matrices for all these muffler elements are given explicitly in the handbook on Formulas of Acoustics [7]. These have been incorporated in a comprehensive FORTRAN language computer program–TMMP.

While the transfer–matrix based frequency–domain analysis (see Fig. 3) is available for prediction of transmission loss of a given muffler [2], the time domain method of characteristics would be needed for prediction of the muffled as well as the unmuffled exhaust (or intake) noise, and hence the insertion loss of a given (designed) muffler [3]. A hybrid approach could combine the advantages of the time–domain analysis of the engine source (independence from the prior knowledge of source characteristics) and frequency–domain analysis of the muffler (convenience, fastness) [4–7]. The normal method is to synthesize a muffler configuration from the general criteria developed from the frequency–domain analysis [2, 8] and then make use of the hybrid approach for predicting performance of the so–designed muffler for a given engine. The final validation and optimization would still call for the testing on the road.

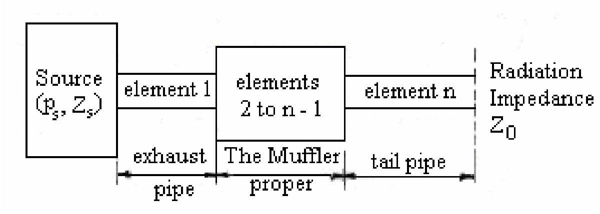


Fig. 3. Schematic of a typical exhaust system

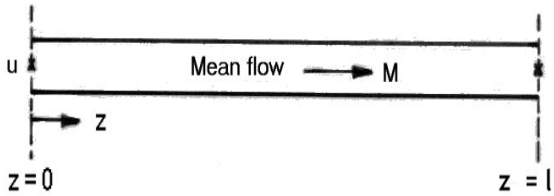


Fig. 4. A uniform tube with moving medium

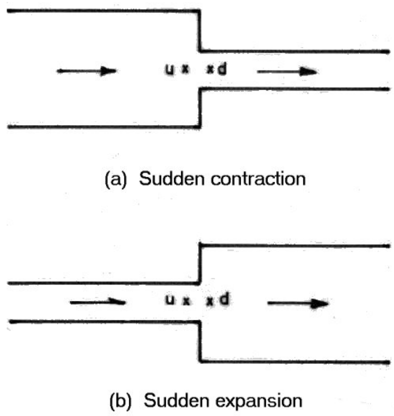


Fig. 5. Simple area discontinuities

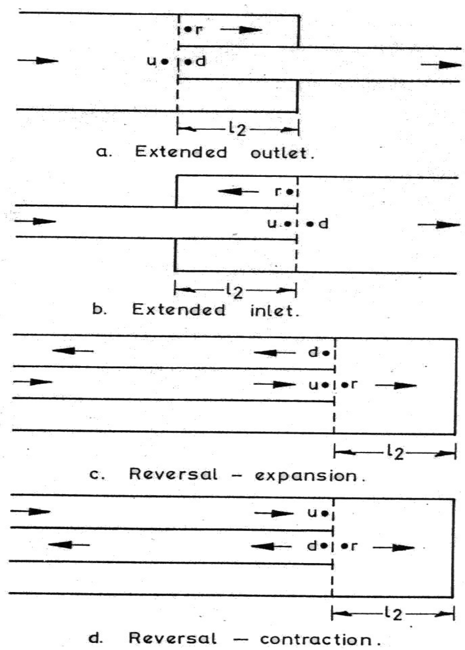


Fig. 6. Extended tube resonators

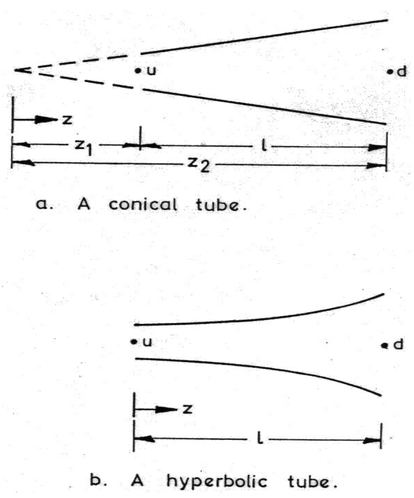


Fig. 7. Two types of variable area tubes

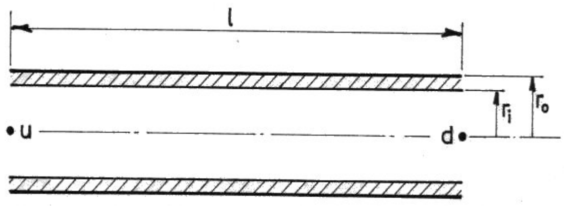


Fig. 8. A Flexible hose

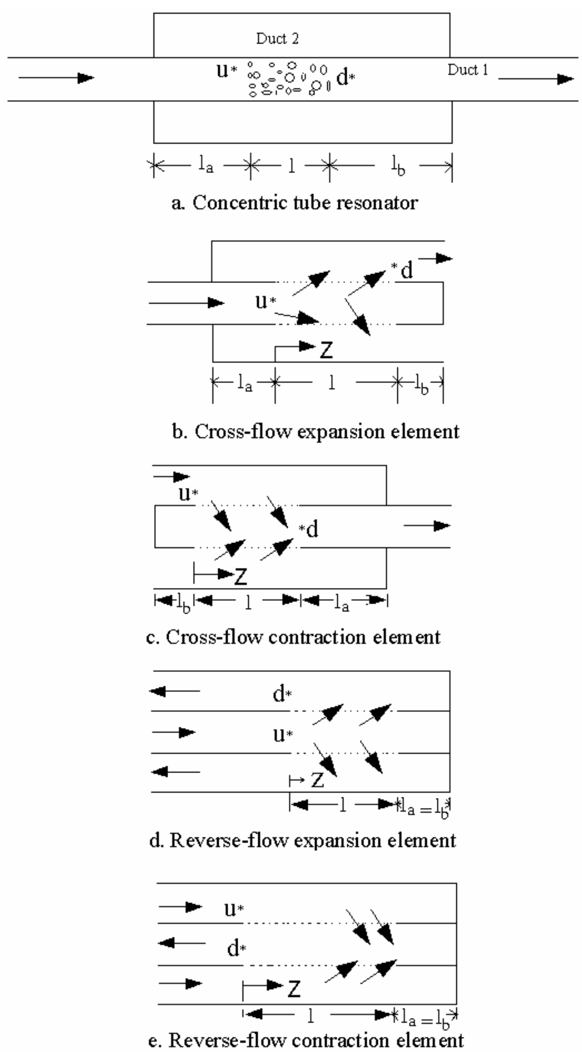


Fig. 9. Two – duct perforated elements

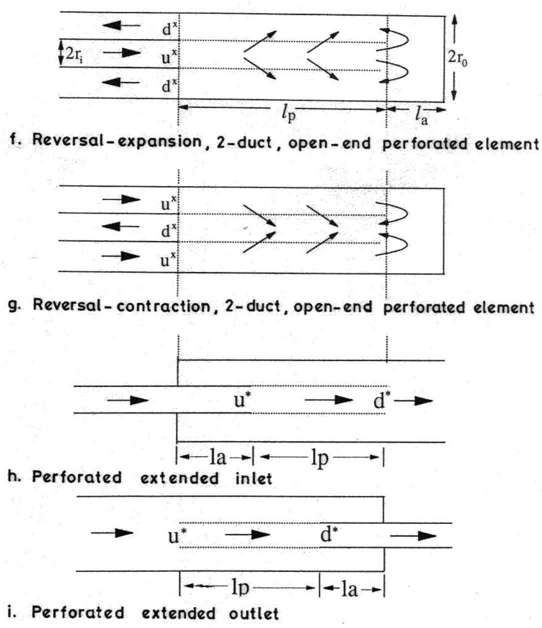
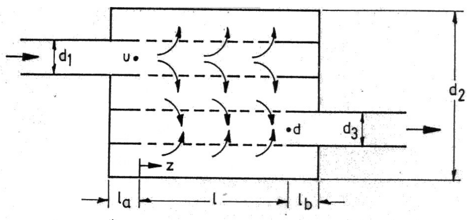
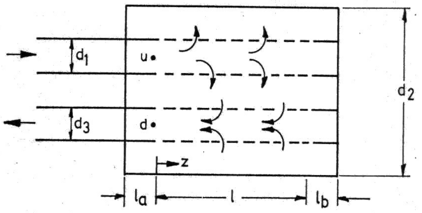


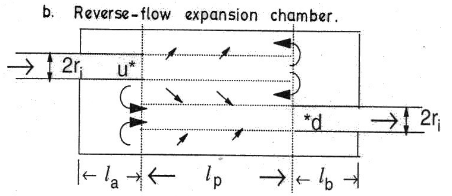
Fig. 10. Two-duct perforated elements (contd.)



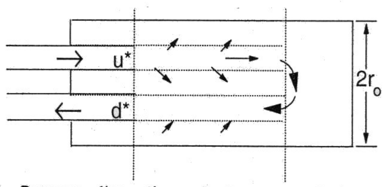
a. Cross-flow expansion chamber.



b. Reverse-flow expansion chamber.

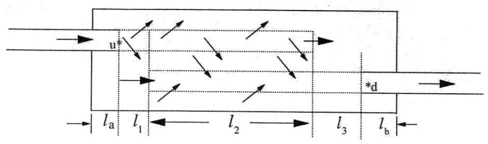


c. Cross-flow, three-duct, open-end element

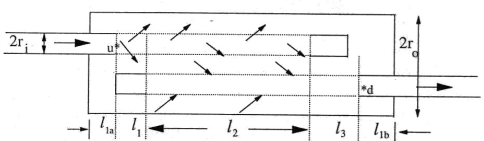


d. Reverse-flow, three-duct, open-end element

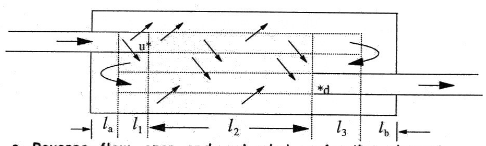
Fig. 11. Three – duct perforated elements



a. Cross-flow, open-end, extended-perforation element

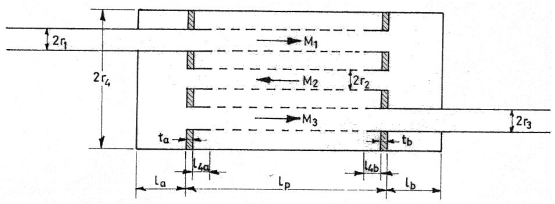


b. Cross-flow, closed-end, extended-perforation element

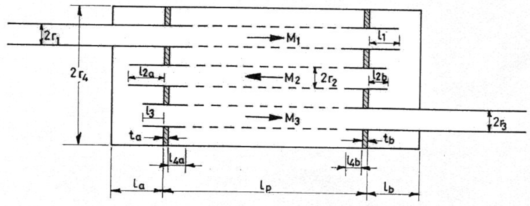


c. Reverse-flow, open-end, extended-perforation element

Fig. 12. Three-duct perforated elements with extended (non-overlapping) perforations

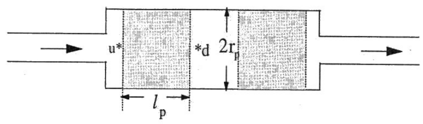


a. Flush-tube, three-pass perforated element chamber

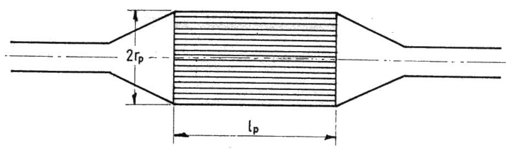


b. Extended-tube, three-pass perforated element chamber

Fig. 13. Three – pass perforated elements



a. Pellet-block catalytic converter element



b. Capillary-tube monolyth catalytic converter element

Fig. 14. Catalytic converter elements

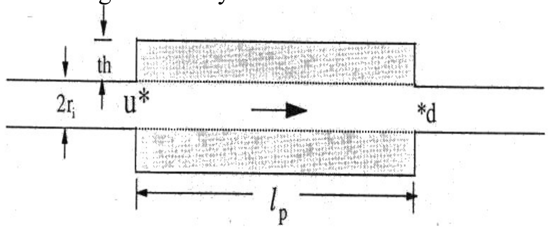


Fig. 15. Acoustically lined circular duct

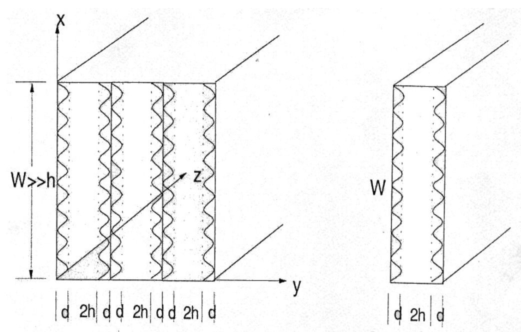


Fig. 16. Parallel-baffle muffler; an equivalent rectangular duct

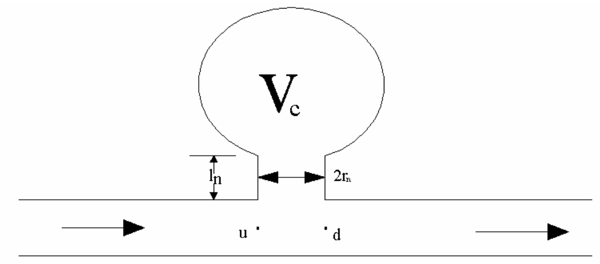


Fig. 17. Helmholtz Resonator

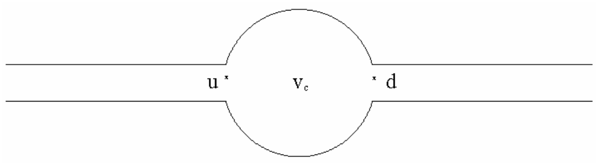


Fig. 18. Inline Cavity

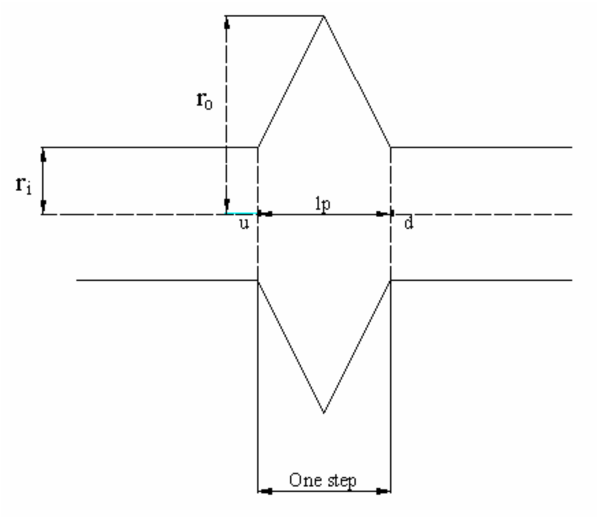


Fig. 19. Flexible Bellows

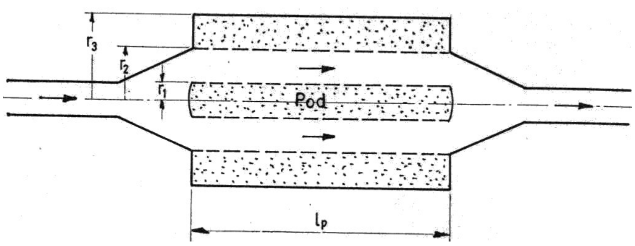


Fig. 20. Pod Silencer

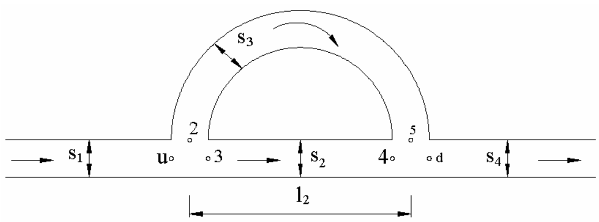


Fig. 21. Quincke tube

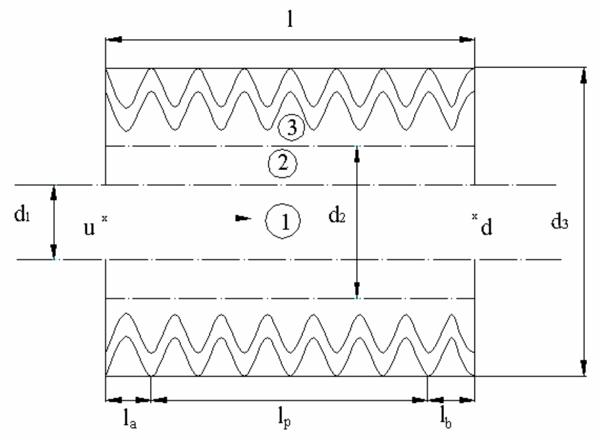


Fig. 22. Annular airgap lined duct

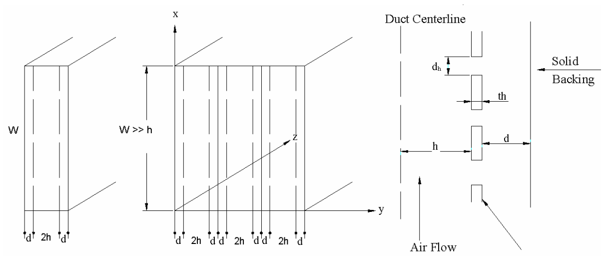


Fig. 23. Micro-perforated Helmholtz panel parallel baffle muffler

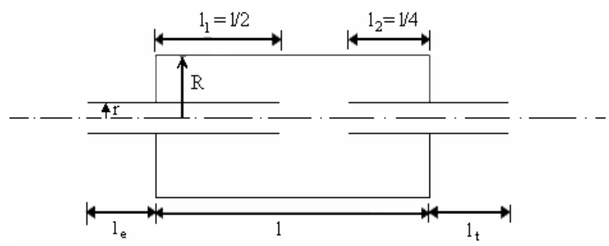


Fig. 24. Schematic of a double-tuned expansion Chamber (adopted from Ref. [13])

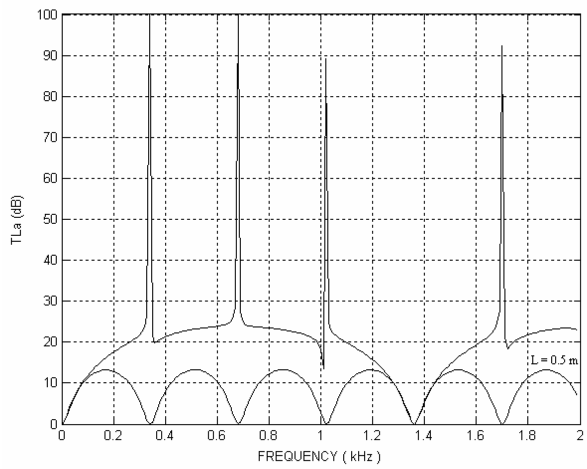


Fig. 25. Comparative performance of the double-tuned expansion chamber and the corresponding simple expansion chamber. $l = lc_1 = 0.5$ m, $l_1 = 0.25$ m, $l_2 = 0.125$ m, L = 0.5 m (adopted from Ref. [13])

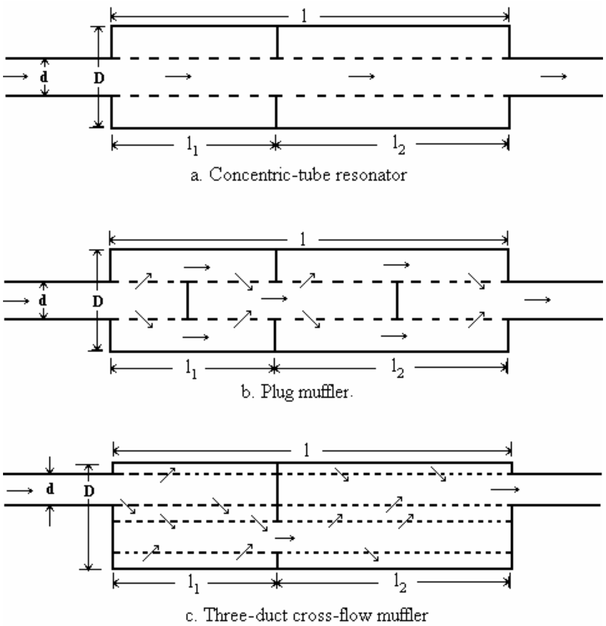


Fig. 26. Schematics of the two-chamber configurations of three types of the perforated-tube mufflers (adopted from Ref. [8])

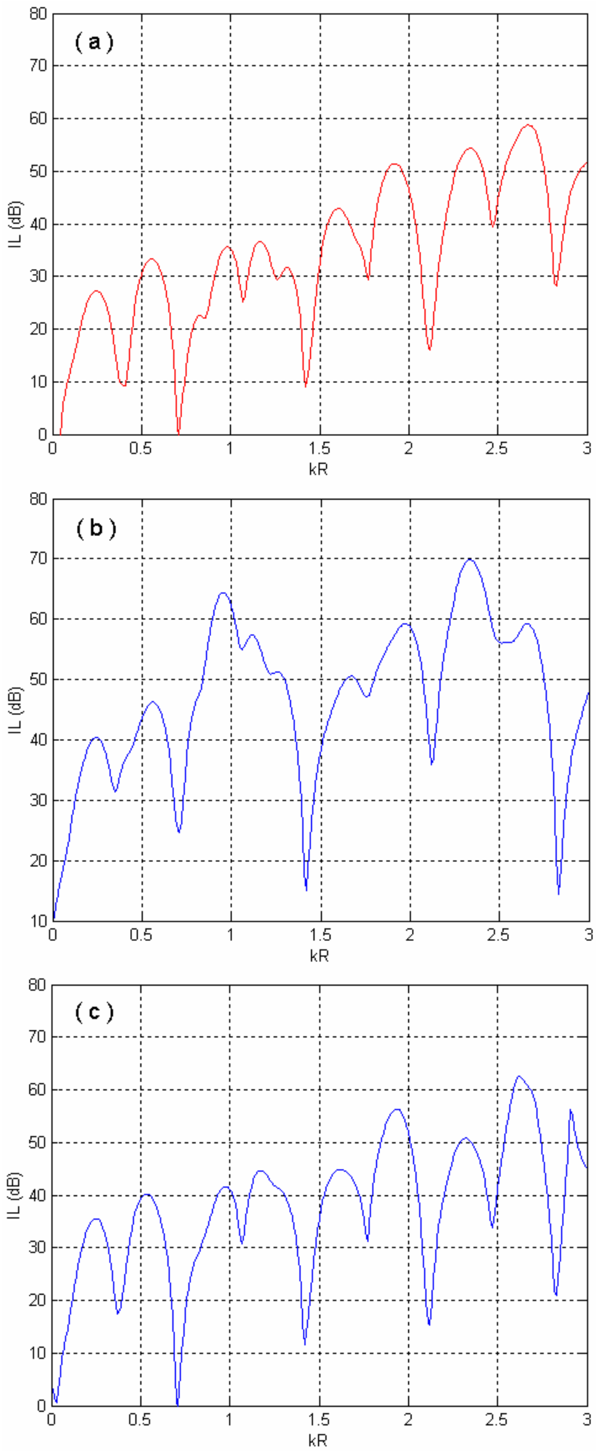


Fig. 27. Performance of (a) Concentric-tube resonator, (b) Plug muffler, and (c) 3-duct muffler, shown in Fig. 26, with two un-equal partitions and l = 10d (adapted from Ref. [8])

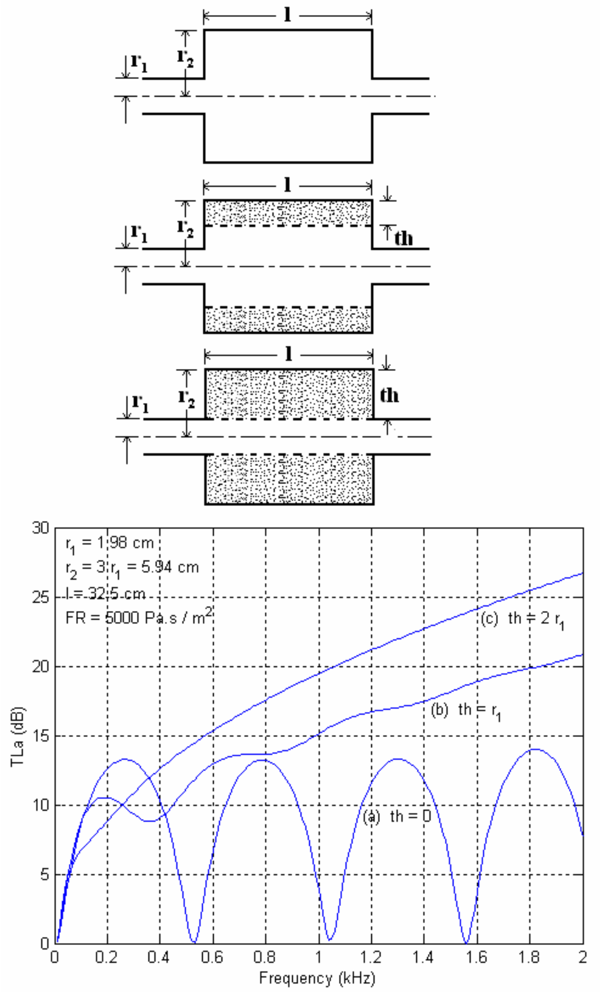


Fig. 28. Reactive elements versus dissipative elements within the same overall shell radius (adopted from Ref. [13])

The basic elements shown above in Figs. 4 to 23 may be combined into hundreds of different muffler configurations. That is why no two commercial mufflers are identical or even similar. Some relatively simple but effective configurations developed by the Author over the years and their acoustic performance in the form of axial transmission loss are shown in Figs. 24 to 28. Variations of these configurations have been used by the Author in reducing the automotive exhaust noise and hence the pass-by noise to the prescribed limits, listed in Tables 1 and 2.

Concluding Remarks

In this plenary paper, an overview has been attempted for the scene emerging in India regarding the automotive industry with particular emphasis on the technologies dealing with designing for quietness. The remarkable progress achieved in the last decade in automotive noise control in India is a result of the recent socio–economic changes accompanying the process of liberalization and globalization.

Acknowledgements

The author would like to thank the Department of Science and Technology of the Government of India for providing experimental and computation facilities through the Facility for Research in Technical Acoustics (FRITA). Mr. A. S. Rao's help in preparation of the manuscript is gratefully acknowledged.

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