TRANSPORTATION NOISE ENVIRONMENTS
OF THE TRAVELER AND THE SPECTATOR

by

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BIOGRAPHICAL SKETCH

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Webster defines sound as a: the sensation perceived by the sense of hearing,b: a particular auditory impression (noise, tone), c: mechanical radiant energy that is transmitted by longitudinal pressure waves in air or other material medium and is the objective cause of hearing. Noise has no precise definition - it is rather that part or kind of sound that is "annoying or unwanted". Unhappily what is annoying to one person may be pleasurable to another. (I prefer symphonies, but my children are avid rock 'n rollers - their ecstasy ofsound is my agony of noise.) In certain facets of transportation noise abatement we find similar dichotomies. The hotrod without the throaty roar of power has little appeal to the majority of young people. The sound of power has meaning to their group in our society.

Measurement of sound and abatement of noise have been relatively recent additions to man's endeavors and as such historians may address those of us today dealing with sound and noise abatement as primatives. Be that as it may, there are many things we do know with assurance and steps we may take to deal with that part of sound which we call noise. For example, the average person finds there is too much sound - too much noise - in our society. He recognizes that much of the sound is necessary for communication one to another, for warnings of impending danger, etc., but all in all he feels there is too much noise in our present society and that a great deal of it stems from our increasing utilization of power - particularly in transportation.

I congratulate society in its intuitive recognition of the ill effects of sound and its growing search for quiet. Perhaps one of the most vivid examples of societal control of noise is seen in the family automobile. Here societal control thru market forces has been at work ever since Henry

Ford availed his machine to public purchase. Today the automobile no longer frightens the horses but is now a very quiet machine possessing great power. This has come about because of the efforts of many engineers in Detroit reacting to the "votes" cast across the country each day in dealer showrooms. This metamorphosis in autos has not been accomplished because we know all there is to know about vehicular noise - indeed there are perhaps as many questions today as ever. Jack Venema of the Ford Motor Company recently presented a paper[1/] reflecting some of the unknowns in terms of auto noise outputs at 60 mph for 20 passenger cars (including some prototypes not produced). Figure 1 shows the variation in noise levels 50 feet from the cars in steady cruise (road load) and with the throttle wide open. Thus we can see a relatively small range of variation in noise outputs for the steady cruise condition. But given half a chance, someone can turn several of these models into roaring lions. Put another way, the people who vote to Detroit may be voting as a result of test rides in the quiet comfort of a well insulated car cruising at 60 mph or they may be voting for the "sound of power" with their foot in the carburetor.

Intake and exhaust muffling technology along with insulation and isolation techniques have been developed to a high state of perfection in the auto industry and a wide choice of models are available from which purchasers may select. The occasional ill repaired or inherently noisy vehicle and the wildly operated auto - however still presents a dissonant note in our environment. A recent study of Ottawa by G. J. Thiessen of the National Research Council[2/] (Fig. 2) depicts the impact of such noise when close to the spectator and as a contribution to the overall background noise level. This figure illustrates how the noise level grows with typical city size and by inference illustrates that one cannot readily escape the noise as a part of the interior auto environment or when residing in a metropolitan area. Thiessen's survey shows that there is roughly a 10dB difference in traffic background noise between night and day but that "night" is getting shorter in our modern society and that once a city size reaches a mile or so in diameter the levels stabilize at about 53 and 63 dBA for night and day respectively.

If the density of vehicles on the highways and side streets continue to increase the noise levels will also rise and the hue and cry about automotive noise and pollution can be expected to reach a crescendo perhaps approaching that now raging over airport noise. Evidence is clear as to the growing and organized opposition to new freeways in many localities which is partly attributable to noise.

Where then can we attack the problem. I believe the most effective solution to density of traffic is mass transit, but regardless of the success of mass transit, motorcycles, hotrods, truck engine, truck tire and auto tire noise must be abated. Figure 3 depicts the noise levels of various vehicles with some indication of the relative contributions of machinery and tire noise. Generally, technology is available to deal with the machinery noise largely due to the past pressures of the competitive market. As illustrated for the heavy truck, engine noise stays relatively level,but tire noise increases with speed. Similar results are evident for the other vehicles except for the lighter ones where tire noise is less of a contributor. In the case of the motorcycle, tire noise is nearly insignificant.

Technology is somewhat weak in the area of tire noise abatement. To an appreciable degree, however, the purchasing public can have an equal impact on auto tire noise as they have exerted on auto mechanical and exhaust noise. The amount of information with which they can make decisions is however considerably less in the case of tire purchase. They cannot take a trial spin on new tires and furthermore, tire mold changes are generally more frequent than replacement purchases. Tire advertisement has naturally dealt with safety and durability although some emphasis has been placed on squeal. Much progress has been made to reduce tire squeal on cornering, but more is possible in the area of cruise noise levels. The dominance of tire noise is evident here for the truck and for the heavier cars. I believe the public will choose quiet tires for their own ride comfort (particularly in the case of snow tires) if the relative noise qualities are reliably made known in a simple, understandable fashion at the time of purchase. It should also be noted that the highway engineer also has a strong role in selecting and controlling the road surface.

Beyond the family auto, the class of vehicles purchased or altered to produce a powerful noise represent a dissonant note, a noise not at all necessary, to the reasonable man. Motorcycles, powerful hot rods, and speedy sports cars are very much possible in quieter packages except for the desire of the purchaser. Truck engine and auxiliary equipment noise can also be considerably reduced thru the application of present knowledge - but at a cost. Here the reasonable man is perhaps more lenient in his attitude - at times. He realizes the value of commerce and tends to designate truck routes and take other diversionary actions to live with the noise that represents a benefit to his society. The manufacturer can do much to reduce truck noise thru shielding and muffling, but he is in an economic race with his competition - a race to produce the most economic hauler not the best aesthetic product. Noise doesn't show as an entry on the trucker's balance sheets. Voluntary standards by the manufacturers have been helpful, but the present levels are too high, many trucks are bought from the primary manufacturer without bodies, tailpipes or mufflers, and therefore little can be expected in the way of lowered voluntary manufacturing standards. As a result, the interior cab noise standards are precariously close to hearing loss levels for the drivers and external noise levels are greatly above the majority of other vehicular noises.

Standards imposed from without - by other than the manufacturers - may be the only means for reducing cab interior noise levels and nominal exterior noise produced by trucks. There will be a cost associated with such noise control - to be sure. But if reasonable standards are imposed against which all manufacturers of the primary vehicle and the body must produce, full competition will be maintained. The main difference would be the assignment of cost of noise in the manufacturing and operating books instead of in the hearing of drivers and the annoyance of spectators.

To further complicate the picture, the operation and maintenance of highway vehicles varies so widely that manufacturing standards, no matter how stringent, can only be partially effective. Each state and community must assume a responsibility for the preservation of its environment by developing enforceable standards of highway noise control. Efforts to date in such local control have proven little but beginnings have been made particularly in California which can complement, and make meaningful standards applicable to vehicle and tire manufacturing. We believe that efforts toward both manufacturing and road operation standards must be vigorously supported despite the legal and technical problems yet unsolved.

RAPID TRANSIT

Earlier I mentioned mass transit which must have triggered a reaction in many people who have been subjected to the very high noise levels in some of our nation's noisier subway systems. This type of conveyance in its monopolistic or semi-monopolistic posture must be carefully guided by the cognizant regulatory body. Unlike the private auto, the public cannot show its preference for relative features in mass transit. Here the public can say only "yes" or "no", representing a decision on many considerations with noise being perhaps only a remote deciding factor. Yet when we discuss subways today, somehow the conversation invariably comes around to the quiet comfort of the Montreal, Toronto or Berlin systems.

The tunnel enclosure of a subway, of course, presents a difficult situation for dissipation of acoustic energy, as shown in Figure 4, and may increase the cost of preventive measures. The subway tunnel, however, provides a natural barrier against noise exposure of the non-user unless the noise and motion of the train are transmitted as vibration to nearby buildings. The reverberant buildup of sound in a tunnel due to the non-absorptive walls may produce as much as 10dB increases in the noise level in the interior of a conventional rail vehicle. Travelling from grade to tunnel can, therefore, produce a noticeable and uncomfortable transition for the passenger. The Toronto subway and sections of other tubes have treated walls in attempts to lessen the reverberation in the tunnel and thus improve the noise level in trains and stations, but assessment of the true effectiveness of these efforts is difficult based on present data. If the subway operator and designer would place noise as a strong criteria and be willing to pay the price, however, efficient acoustic materials could be added to all tunnel walls or at least near portals which would reduce the noise levels.

All factors influencing interior and exterior rail vehicle noise have not been well defined primarily because the existing systems have been built largely without regard to noise. Furthermore, the existing systems have been constructed and equipped over a large span of time, by different organizations operating under varying constraints of geography and finance. The result therefore is an assortment of operating systems which can be compared only superficially in an acoustic analysis. For example, the next figure portrays the interior car noise levels of four well known subway systems. The only common point of comparison here is a forced one -- the car speed of 30 miles per hour. The New York, Chicago and Toronto vehicles have steel wheels on steel rails while the Paris cars ride on pneumatic tires. Ventilation in the Paris cars is provided thru open clerestory ports which permits passage of much noise. The octave band data clearly indicates the lower levels of the newer Paris and Toronto systems as compared to the U.S. subways. The overall levels converted to the A weighting network shows the Paris car to be the quietest and probably most acceptable to passengers from a noise standpoint.

Some general statements can be made regarding the design practices which should be beneficial for passenger noise levels in subways based on experience developed by the existing systems. Specific values and positive comparisons are not readily available, but tests do indicate, however, that use of welded rail, and vigilant maintenance of rail surface and alignment may produce as much as 10dB in reduced noise levels. Ballasted track may also provide acoustic benefits over that of a solid concrete deck.

Maintenance of round, balanced wheels must go with good rail surface as degradation of either will rapidly produce damage to the other. In combination, welded rail and round, balanced wheels may account for on the order of 15dB. Sliding of wheels is necessary if tight turns are required with rigid axle wheel sets. Wheel slide is noisy and in turns usually is accompanied by flange squeal. Some damped wheel experience has indicated a potential for reduction of wheel radiated noise. As far back as the 1930's, for example, the PCC streetcar which has often been cited as a quiet vehicle operated in many cities in the U.S. with resiliant wheel inserts. Little research has come to light however regarding the potential of a wheel really engineered for noise reduction. Truck design to minimize rattling and banging of springs, etc., is also of paramount importance to noise and ride comfort. Liberal use of rubber is conventionally suggested to produce quiet trucks,but the Toronto system as an exception, uses little rubber in the suspension and is en toto a quiet system.

Finally, the car body design affords numerous avenues to attenuate noise generated by the wheels, rail, and suspension. Double glazing of fixed windows (air conditioning assumed), resiliant or dampened underflooring, rugs on the floor, and body insulation are obvious areas of consideration. Once again considering the Toronto system, however, there is little in the way of damping material used in these cars. Perhaps Toronto's success resides in the noise generators themselves, the acoustic treatment sprayed on the tunnel walls or perhaps it is connected with the use of aluminum instead of steel in the body construction. Without belaboring the issue, suffice it to say that the subway engineer can work on many items within his system to provide an attractive acoustic environment for the passenger. As in all such endeavors, however, a test program with good simulation of operations should precede large scale production of cars or extensive construction.

But what about the passenger not yet on the car? What can we do for him? Perhaps, I should say what are we doing to him? The next figure depicts the acoustic environment in stations as a car is arriving for the same four subways systems. As you can see the overall noise levels are about 10dB higher on the station platforms than they are in the cars. Here in the station is where the use of acoustic material under the parapets, on the walls and on the ceilings appear to be the only solution unless the cars are made considerably quieter. Good wheel and rail surfaces could permit braking without the use of sand and care in the design and maintenance of brakes would also aid greatly. An interesting approach has been suggested which could be a compromise for all these approaches - that is the use of an acoustic apron attached directly to the car and covering all the noise generators previously discussed. I know of no vehicle which has been built with such a device, but it is an interesting thought.

In designing a quiet rapid transit system many items must be considered. For example, no less than 46 separate paragraphs of the San Francisco Bay Area Rapid Transit District specifications deal with noise control. Items include all car and station equipment and operations, e.g., how much noise should the opening and closing of the car door produce? The architectural standards even go so far as to consider vending machine noise and heel noise from pedestrians as contributers to the overall level.

One important criterion which must be considered in setting maximum noise levels deals with the ability of passengers and crew to communicate. The next figure (Figure 7) shows the ability of people to communicate under different noise conditions and with differing levels of speaking effort. This shows how the range of intelligible communication is lessened as the background noise level is increased and how people react with an automatic elevation in speech intensity in response to such masking noise. We can take a few examples of the subway situations and determine how close you would have to be to converse with a friend. For example, in a Toronto car (80dBA) you would have to be within six inches to communicate in a normal voice, but in response to the noise you would naturally speak somewhat louder such that you would be able to converse at a distance of nearly two feet. On a Chicago car (87dBA) your expected voice level would only carry intelligently for about one foot. With the station levels during arrivals, which were cited earlier - being some 10dB higher than car interiors - you can see the futility of trying to communicate during these noisy periods. Public announcements also are subject to poor understanding or non-intelligibility during these car arrivals.

Before moving on from this point, I should say something regarding the lower limit of noise in a public conveyance. Based on this data and the seating arrangement of the vehicle, the designer should be cautious about reducing noise so far as to take away the semi-privacy which is generally expected in public conveyances. For example, if the car interior noise level were reduced to 50dBA, conversations would carry too far. A level of 60dBA would be a good minimum goal which permits free conversation across isles but still provide some acoustic "deoderant".

It is evident, however, that if the subway or rapid transit system is to attract the affluent American commuter,much more in the way of comfort will have to be provided - including effective noise control approaching such a minimum level. If a system is designed with such passenger and station spectator in mind, it is also well along towards being an acceptable noise source in the community.

AIRCRAFT

Very quickly I would like to discuss some aircraft cabin noise levels. The next figure (Figure 8) depicts some worst case cabin noise levels for cruise of two military helicopters and two commercial jet aircraft. Also shown is a typical mid body location in a small military executive jet (T-39). The helicopter noises were taken near the transmission units and the commercial jet noise levels are representative of cabin stations at the rear, in the plain of the engine inlets.

The aircraft acoustician of course is allocated very little weight with which he attempts to attenuate the high noise levels produced by the engines and by the rapid motion of air over the fuselage. The commercial aircraft and the T-39 have double glazing and pressure tight bulkheads. Air gaps and very lightweight acoustic material (including such things as paper honeycomb) are used in most passenger aircraft installations.

From the previous figure these speech interference levels translate to normal voice communications at slightly less than a foot for the commercial jets or two feet at expected voice level. (This is just barely enough to be sure the stewardess has gotten your drink order correctly.) The T-39 cabin would permit expected voice level communications over a distance of about one foot. The two helicopters present difficult to virtually impossible speech communications environments. Commercial helicopter noise levels are somewhat lower than these military versions indicate.

The connotation of this data is much the same as that for subways or other public conveyances: passengers require quiet interiors along with low vibration levels and convenient, fast service. The developers of the new jumbo jets have recognied this and are working diligently to achieve low interior noise objectives in the selection of all aircraft equipment, and in all design efforts. Consideration is being given cabin cooling ducts and outlets, cabin public address, body skin gage, triple glazing, and inner wall insulation to mention but a few areas.

Unfortunately most of the cures for cabin noise level in cruise flights are not related to the needed cures for the aircraft noise problems external to the cabin. The most effective cure for the external airport noise problem is reduction of noise at the source - the engine. This will also aid the internal noise situation and happily technology improvement in this area is near at hand for the new commercial jet aircraft using high bypass ratio fan engines.

The interior or cabin noise is an environmental factor somewhat like the auto noise situation in that public choice may have an influence on the degree of technological progress sought by the manufacturer. In the aircraft case, however, the impact of passenger choice is not likely to be discernible insofar as any improvement in the external airport noise is concerned. One possible exception in the aircraft field may be the V/STOL craft. In the short-haul market there are many alternative modes of travel. Some of these alternatives are also comfortably quiet. Passenger preference may aid in accelerating noise reduction efforts in V/STOL craft and spectators may benefit also.

Where there is competition - where there is a user choice, I believe the market forces of free enterprise will avail the public a continuing stream of improvements in efficiency and comfort balanced by cost to the user. Where there is not competition and where the particular mode of transportation has an adverse effect on the non-user (the non-voter in the particular market place), there is need for government intervention to be considered. The auto, train, intercity bus and the aircraft <u>interior</u> noise levels can generally be assumed to achieve self-regulation thru competition. The interior and station noise levels of city or regional rapid transit systems falls in the other category because of public fund investment or monopolistic franchise grants by the government.

External noises of all modes of transportation generally fall into a category which may need local, state, or federal attention due to the lack of market force self-regulation or representation of the effected non-users. For example, Public Law 90-411, passed last summer, <u>directed</u> the FAA to regulate aircraft external noise. Manufacturing standards for type certification are presently proposed for some aircraft under this authority. Other standards and procedures must follow under this authority in terms of manufacturing standards and operating procedures to curtail the ever-growing aircraft noise problem near airports.

Interfaces between modes may also present cases for some governmental action. An illustration of this has come about due to the progress made in reducing interior auto noise. The insulation, the heating and cooling systems of autos today presents numerous problems in audible warnings. One railroad concerned with grade crossing safety under these circumstances installed new high intensity horns on their diesel locomotives. Notwithstanding the increased neighborhood annoyance, the railroad was discouraged by the test because of the resultant temporary crew hearing loss and resultant inability of the engineer and brakeman to communicate following hornblowing. The Federal Railroad Administration is contracting for a study of improved grade crossing warning devices.

Throughout the ages it has been man's mobility that has given him and his society an ability to grow and draw upon the resources of the earth to provide for trade and to hold sway over his fellow societies. As Americans we can be proud of our record of mobility from the Yankee Clipper through today. Secretary Volpe eloquently stated his thought last month before the Fourth International Conference on Urban Transportation as follows:

> "Our roads and rails and airways have given us greater mobility--for all its frustrations--than any other people have had in history. They have made the name of America synonymous with movement, change, and adventure. They have conditioned our mentality, formed our attitudes, [and] opened new horizons to [our] restless vitality."

We have used our technological might to ensure our defense and explore space. We have also introduced new efficiency and in many instances new levels of comfort and safety for the passenger.

To assure that factors such as noise, congestion or pollution do not impede continued growth of our national mobility, the Department of Transportation, working with state and local governments, industry and the public, has accepted the challenge to evolve means whereby technology is advanced and applied in transportation to meet the totality of national interests. I shall close with the words used by Dr. A. J. Eggers, Jr., of NASA in concluding this year's AIAA President's Forum:

> .... "The real issue, in the last analysis, is how well the various elements of our free society are going to work together to cope with our complex problems. We the people who are most concerned with the technology are but one element of

this system. We are going to have to understand the rest of the system a good deal better than we have ever understood it before, if we are going to develop technology in a way that will benefit the [societal] system. If we don't, then society may unduly limit application of this technology or possibly not even support its development. In either event, the consequences are to the distinct disadvantage of our whole system, and progress is stifled. This is an unacceptable alternative. Our work is cut out for us."

REFERENCES

1/ Venema, J. H., "Transportation Noise" to be published in proceedings of the University of Washington Symposium "Evaluating the Noises of Transportation", (1969).

2/ Theissen, G. J., "Community Noise Levels", ibid.

3/ Anon; "Objective Limits for Motor Vehicle Noise", BB&N Report 824, (1962).

4/ Tetlow, Derek, "Truck Tire Noise: An Initial Survey of Tire Noise Variables"; General Motors Proving Ground, (1968).

5/ Deitrich, C. W. et al, "High Speed Ground Transportation Noise Sources", BB&N Report 1741, (1968).

6/ Davis, E. W., "Comparison of Noise and Vibration Levels in Rapid Transit Vehicle Systems", NCTA Technical Report, (1964).

7/ Enright, J. J., "An Investigation of Steel Wheel-Rail Noise and Techniques for Its Suppression", Battelle Memorial Institute, Monograph No. 15, (1967).

8/ Webster, J. C., "Rating of Noise with Respect to Speech Interference", presented at the 76th Meeting of the Acoustical Society of America, Cleveland, Ohio. (1968).

9/ Gasaway, D. C., Major, USAF AMD, "Characteristics of Noise Generated by Secondary and Auxiliary Aircraft Systems", ibid.

10/ Stone, R. B., "Interior Noise Levels of Airline Aircraft", presented at the 74th Meeting of the Acoustical Society of America, Miami, Fa., (1967).