BOLT BERANEK AND NEWMAN INC

CONSULTING • DEVELOPMENT • RESEARCH

Proposal No. P74-PSD-232

TECHNICAL EXPERTISE IN SUPPORT OF REGULATIONS OF NOISE FROM TRANSPORTATION AND RECREATIONAL VEHICLES

RFP No. WA 74-R322

19 July 1974

Submitted to:

Environmental Protection Agency
Contracts Management Division
R&D Procurement Section
Crystal Mall #2, Room 700
Washington, D.C. 20460

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PREFACE

Bolt Beranek and Newman Inc. (BBN) is pleased to submit this proposal in response to Request for Proposal No. WA 74-R322 subsection Transportation and Recreation Vehicles, issued June 1974 by the Environmental Protection Agency.

The proposed program is intended to be entirely responsive to the requirements of the request to provide technical expertise in the development of noise measurement tests and technology/cost reports for the control of product noise emissions in transportation and recreation vehicles. This expertise will be provided under task-order agreements to be defined as needs arise.

Any questions concerning technical or organizational matters should be addressed to Dr. Erich K. Bender. Inquiries related to contractual or financial matters should be addressed to Mr. Theodore Sihpol. Both may be reached at

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1. INTRODUCTION

The Noise Control Act of 1971 identified transportation as one of the major sources of noise requiring control. Certainly, transportation and recreational vehicles cause the most extensive impact on the community of any category of noise sources. Throughout the United States, the population is exposed daily to the 100 million automobiles and 20 million trucks currently in use. In fact, automobiles, because of their very large number, contribute substantially to the acoustic energy levels, L_{eq}, in urban areas. In a study of transportation noise conducted by Bolt Beranek and Newman Inc. for the Motor Vehicle Manufacturers Association, the automobile was identified more than any other vehicle class as a source of annoyance.

Other modes of transportation, such as railroads, urban and intercity bus lines, motorcycles, and rail rapid transit, also contribute substantially to environmental noise. Recreational vehicles, including off-the-road motorcycles, snowmobiles, and motorboats, contribute not only to environmental noise but to hearing damage of operators and passengers as well.

We believe that our proposed program is wholly responsive to the Environmental Protection Agency's RFP No. WA 74-R322 for a Basic Ordering Agreement to provide quick response task orders for the development of noise measurement standards and technology/cost studies. This RFP also requests a specific proposal on the development of measurement standards and technology/cost information on automobiles. We have structured our proposal to deal generally with transportation and recreational vehicles and specifically to study automobiles. Accordingly, Sec. 2 of this proposal discusses our general technical approach, which is divided into three major parts: the first deals with the development of measurement standards; the second with the noise reduction achievable through the application of the best available technology; and the third with the costs associated with such noise treatments. Section 3 presents our general organizational and management approach for dealing with a number of tasks anticipated in a BOA. In Sec. 4, we apply our general approach to the specific task of developing measurement standards and conducting technology/cost studies for automobiles. Section 5 presents our task organization and program plan for the automobile task, and Secs. 6 and 7 discusses our qualifications.

We believe that BBN is uniquely qualified to deal effectively with a wide range of tasks under a BOA on transportation and recreational vehicles and with the specific automobile task. We have already conducted technology/cost studies for EPA on new trucks, railroads, interstate motor vehicles, and rail rapid transit, as well as numerous types of other products, such as construction equipment and lawnmowers. For the Freightliner Corp., we have achieved greater success in quieting a motor vehicle, i.e., a heavy diesel truck, than any other research development, and consulting organization. For the Ford Motor Company, we have quieted vehicle cooling fans beyond that believed achievable. We have prepared and taught special noise and vibration courses to the technical staff of General Motors and Ford. For DOT, we have conducted in-depth R&D programs on rail system noise. We propose to apply this wealth of experience to the general problem of transportation and recreational vehicle noise and specifically to automobile noise control.

2. GENERAL TECHNICAL APPROACH

Our general technical approach to the development of the background material for product labeling and noise emission standards for transportation and recreational vehicles is to (1) review and develop measurement standards as needed, and (2) estimate the noise reduction and costs associated with the application of the best presently available technology. In this section, we will discuss this approach in general.

2.1 Measurement Standards

A measurement standard forms one of the key elements in a labeling or emission regulation. This standard must typically meet a number of requirements, which are often mutually conflicting. For example, it must be a reliable indicator of community impact, it must have relevance to the consumer or equipment purchaser, it should not be overly complicated or expensive to perform, it must be repeatable, it should yield data that are relevant to large existing data bases, and it must be suitable for field enforcement. Let us consider each of these requirements in some detail.

2.1.1 Relevance to public health and welfare

Since a primary responsibility of EPA is to develop regulations to protect the public health and welfare, it is necessary that noise measurement standards used for product regulations be consistent with the data required for assessing the impact of the noise of a product class on the public health and welfare. Developing these types of standards is difficult because of (1) the complexity of human response to a given noise signature; (2) the varied relation between noise sources and the public; and (3) the effect on noise level of the various operating modes and conditions of a particular class of equipment.

The general approach that we propose to follow in considering the relation between the measurement standard and human response criteria is to evaluate measurement standards principally in terms of criteria established by EPA. In its extensive document "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," EPA has focused on the energy equivalent sound level, L_{eq}, and the companion day-night sound level, L_{dn}, as measures of environmental noise. For a single pass-by, characteristic of transportation and recreational vehicles, an appropriate measure is then the sound exposure level, L_e, which is defined by

$$L_e = 10 \log_{10} \int \frac{p^2(t)}{p_0^2} dt ,$$

where p(t) is the A-weighted pressure as a function of time, t, and L_e is a basic element in predicting community energy levels. For example, the value of L_{eq} generated at the measurement distance by N cars of equal noise level passing in time, T, is given by

$$L_{eq} = L_e + 10 \log N/T .$$

If the sound radiated from a motor vehicle were omnidirectional, there would be a precise relation between peak level measured during a pass-by and L_e. However, the peak levels which result from directive sources imprecisely indicate the impact on the community as measured by L_e. Figure 1 shows the sound level along a line 50 ft from a quiet truck and parallel to its centerline (Bender and Patterson, 1974). This figure also shows the profile of the sound level from an omnidirectional source of equal peak level. Quite clearly, the area beneath both curves is not the same. The L_e for the truck is approximately 2.2 dBA greater than that of the omnidirectional source.

It is also necessary to account for the geometrical relationship between a source of noise and the people exposed. This is especially important for sources such as automobiles where both the user and community are exposed to substantially different noise sources or noise transmitted along substantially different paths. The noise level within automobiles, for example, may be only weakly correlated to automobile noise levels measured at community locations.

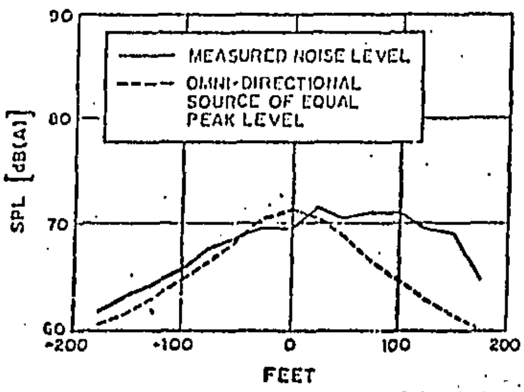


FIG. 1. SIDELINE NOISE FOR AN OMNIDIRECTIONAL SOURCE AND A TRUCK WITH A PARTIAL ENGINE ENCLOSURE.

Along these lines, it is also necessary to ensure that standard microphone positions are selected in a way that allows for extrapolation to locations occupied by people. For example, distances of 50 ft may be adequate for motorcycle or automobile measurements, but they are in the geometrical near field of railroad locomotives.

The third factor, determining appropriate values of operating variables, is extremely important for machinery that operates over a wide range of conditions, which is the case for most transportation and recreational equipment. For much of this equipment, noise is a strong function of at least two variables: speed and engine load. If sufficient operating cycle data are available, it then becomes desirable to consider as a baseline a histogram of percentage of time spent at various speed and load conditions, as illustrated in Fig. 2. Community noise estimates, measurement standards, and operating cost increments can all be built from this baseline.

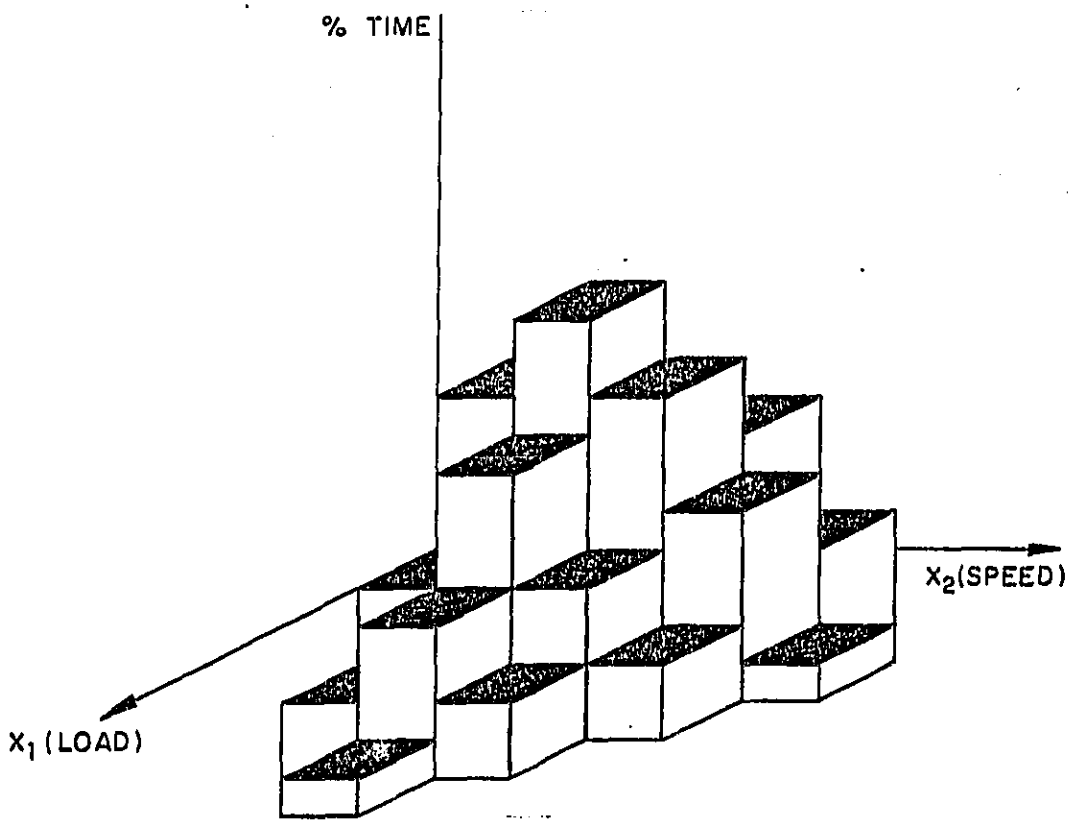


FIG. 2. HISTOGRAM OF MACHINERY SPEED AND LOAD VARIABLES. DATA SUCH AS THESE CORRESPOND TO ACTUAL USAGE.

An energy contribution to community noise is found by appropriately weighting and summing the noise levels corresponding to each element of the histogram as follows.

$$L_{eq} = 10 \log\left(T_1 10^{L_1/10} + T_2 10^{L_2/10} + \cdots\right) + C ,$$

or, equivalently

$$L_{eq} = 10 \log\left(\sum_i T_i^{L_i/10}\right) + C .$$

Here, T_i is the percentage of time the machinery operates at the *ith* set of load and speed variables, L_i is the A-weighted spatially averaged sound level generated at a standard distance by the machine, and C is a constant. The parameter, C, is important in determining specific values of community impact, but it need not be specified for purposes of developing a measurement standard.

2.1.2 Relevance to the consumer

Many of the same problems as discussed above, in addition to those of dealing with a group of people unfamiliar with the specialized field of acoustics, are found in making labels and noise emission standards relevant to product consumers. As with community noise, we would rely most heavily on existing EPA and OSHA criteria. However, we would also be sensitive to other factors that have been found to be significant by manufacturers of consumer products. For example, the annoyance associated with pure tones or rattles may not be adequately measured by A-weighted sound levels or energy equivalent levels.

2.1.3 Industry impact

Measurement standards must be evaluated in terms of industry impact from the viewpoint of cost and of industry attitude.

Product noise measurements of any kind cost money to conduct, and they often require special facilities that, in turn, require capital to construct. These expenditures are typically passed on in part through the chain of purchasers and users of the products being controlled and are absorbed in part by the product manufacturer. Both forms of costs should be minimized to the extent possible as an anti-inflationary measure and to allow for the optimal allocation of industrial resources.

In the broad political sense, it is necessary to account for industry attitude toward various types of measurement standards. A greater degree of environmental noise reduction will be achieved with a favorable attitude by industry than through an adversary procedure. The latter can easily lead to delaying actions in the courts, direct political influence, and a search for loopholes in regulations. Accordingly, our approach in these matters has been, and will continue to be, to use industry standards and to build on them when environmental protection will not be compromised. For example, we found during our work for EPA on developing technology and cost information for construction machinery that minor modifications of the SAE J88 test made through the use of *ad hoc* standards committees* resulted in well-accepted and meaningful test procedures.

*Typically, these committees were composed of representatives of EPA, BBN, NBS, manufacturers, and users.

2.1.4 Repeatability

One essential aspect of a measurement standard is that it must yield repeatable results. In a sense, repeatability is a measure of the accuracy or precision of a test. There are a number of causes of variation from one test to another, including variations in machinery operating conditions and test sites, changes in environmental effects, and instrumentation variability. In testing engine-powered equipment, such as trucks and automobiles, variations of ±1/2 dBA are often found in sequential tests of a particular machine. Test site variability involving slight variations in surface profile between the equipment and microphone and the impedance of the surface can lead to variations of the order of ±1 dBA. Also, even precision sound measuring equipment can drift during the course of a series of measurements or have variations of a fraction of a decibel from unit to unit. Such variations in machinery, test sites, and instrumentation can lead to ±2 dBA variations under good conditions. We propose to account for and attempt to minimize such variations in the development of labeling or emission standards.

2.1.5 Relevance to existing data base

Another factor to consider in the development of a measurement standard is its relevance to an existing data base. The importance of this factor is, in a sense, proportional to the extensiveness of the data. Products that have been extensively measured according to an existing standard are relatively well understood. Accordingly, new measurement standards, which can be related to existing data, facilitate the development of regulations by EPA and compliance by industry.

2.1.6 Feasibility of field enforcement

The feasibility of enforcing compliance with a regulation will be accounted for in any measurement standard to which we contribute. In this regard, measurements that can be conducted simply and quickly by an EPA field-enforcement officer are desired.

2.1.7 Procedure for developing measurement standards

The general procedure that we propose to follow in developing measurement standards is: (1) to assemble and review existing standards in terms of the criteria discussed above (see Secs. 2.1.1 to 2.1.6); (2) to conceive of new standards that satisfy the above criteria better and then to decide, in collaboration with cognizant EPA staff, whether or not to pursue the development of these new standards or rely on existing ones. If it is decided to develop new standards that are only marginally different from existing standards (e.g., adding a few more measurement locations or selecting different machinery-operating conditions), we would recommend the formation of a committee of EPA, NBS, BBN, and industry representatives to work out the details. On the other hand, if the new standards differed substantially from existing standards, we would first wish to conduct a series of preliminary tests, and then either form a committee as described above or meet with a standing committee of an industry organization. This would "bring the industry on board" and give each company an opportunity to evaluate the standard on its own products at its own facilities.

2.2 Technology/Cost Studies

In order to regulate noise effectively, the EPA must base its strategy on four factors:

1. Knowledge of the present scope of the problem.
2. Assessment of available quieting technology.
3. Knowledge of the costs incurred (and on whom they are imposed) as a result of noise control.
4. Estimates of the benefit to the public health and welfare in terms of people removed from noise exposure as a result of a given strategy.

This section describes BBN's approach toward providing the Agency with this material.

2.2.1 Baseline assessment

The first step in formulating noise control strategies is to understand the nature of the noise exposure problem. This problem is composed of the following elements.

Identification of the noise source population

The numbers, types, characteristics, and prices of the machine being studied must be determined. In the case of the proposed regulation governing newly manufactured units, this means that the composition of annual sales must be analyzed. In many cases, this information is available from governmental (U.S. Census of Manufacturers, Current Industry Surveys, etc.) or industry (trade association, trade journal) sources. BBN has used such sources to determine the sales composition of such goods as railroad locomotives, truck mufflers, diesel trucks, and portable air compressors. In a few cases, the required information is held proprietarily by the manufacturing firms; we have found this to be true, for example, in the cases of construction tractors and truck tires. In these cases, BBN relies on contacts among the subject industries to provide information on a confidential basis. Such data-gathering is done by telephone contact and by personal visit.*

For regulations aimed at retrofitting noise control treatments to sources already in place, it is necessary to analyze the composition of the existing population. This is normally more difficult to obtain than annual sales information. Again, government and industry sources are helpful to some extent. Government statistics are particularly helpful in the transportation industries. In the past, BBN has used industry publications to obtain population breakdowns for such sources as machine tools, coal cleaning equipment, and pulp mills. In a study of truck noise for EPA, we also analyzed data on 100,000 trucks stored on a digital tape provided by the Bureau of the Census. Where collected information does not exist, nonstructured surveys of the type outlined above may be necessary.

Determination of Noise Level Distribution

The extent to which a unit will require treatment depends on how noisy it is; the total level of treatments for all units,

*BBN has had considerable success with surveys of this type in the past. Under contract to the Department of Labor (Bruce *et al.*, 1974), within an eight-week period, BBN directly contacted 50 industry associations and 70 private firms to determine their problems regarding industrial noise control.

therefore, depends on the distribution of noise levels over the total population.

BBN will obtain noise level distributions from three sources:

(a) Previous work. As a result of our 25 years' experience in noise control, we have accumulated a large body of measurement data that is available for the purposes of this work.

(b) Industry sources. BBN has had considerable success obtaining, on a confidential basis, manufacturers' noise measurements of their products. An example of one such study is our analysis of noise distributions for portable air compressors; Table 1 shows one result of this.

TABLE 1. PRESENT STATUS OF PORTABLE COMPRESSORS WITH RESPECT TO NOISE EMISSIONS AND PRICE PER RATED cfm.

	Gasoline Driven		Diesel Driven			
			Below 501 cfm		Above 500 cfm	
	Standard	Quieted	Standard	Quieted	Standard	Quieted
Number of Units in Samples	32	26	45	35	32	24
Price/cfm						
Mean	$39.23	$43.32	$46.16	$52.11	$43.57	$48.70
Standard deviation	$ 4.40	$ 6.10	$ 4.57	$ 8.30	$ 3.56	$ 3.16
SPL at 7m						
Mean	82.8 dBA	76.1 dBA	86.1 dBA	76.4 dBA	92.8 dBA	78.7 dBA
Standard deviation	4.92 dBA	2.40 dBA	3.35 dBA	4.07 dBA	4.08 dBA	3.90 dBA
Quietest Machines (Lowest decile)						
No. in decile	3	3	6	4	4	2
Mean SPL at 7m	72.6 dBA	72.3 dBA	82 dBA	70 dBA	87.5 dBA	73.5 dBA
Deviation of average price in lowest decile from mean price of quieted	+$5.42	+$5.14	+$0.43	+$10.23	+$0.31	+$2.50

(c) Original measurements. In support of this project, BBN will measure noise from specified sources in cases where data do not already exist or sample sizes are too small. We have done this in support of past EPA studies, notably in the cases of railroad locomotives, construction equipment, and diesel trucks. An example of our results for construction equipment is given in Table 2.

Determination of the Nature of Noise Exposure

The optimal noise control strategy will vary depending upon how people are exposed to the offending sources. Some sources are very local in their influence (e.g., home appliances) but, because there are so many of them, many people are exposed. Other sources are few in number (e.g., railroad locomotives) but have high noise levels and high surrounding population densities. Still others (e.g., construction equipment) have elements of both of the two previous categories. Therefore, the distribution of people in space and time relative to the sources is important in developing cost-effective control strategies.

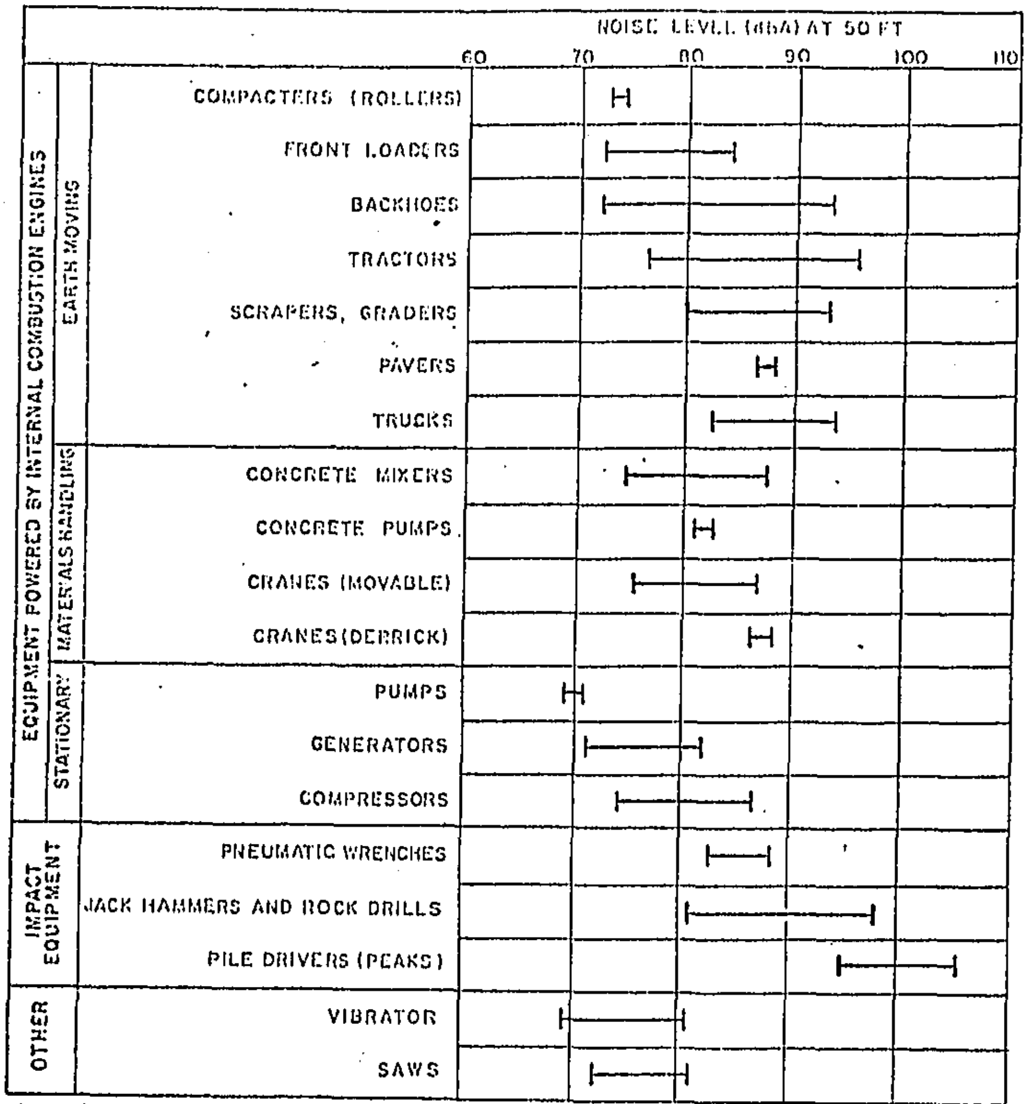
To perform this aspect of the baseline description, BBN will rely chiefly on population data developed by the U.S. Bureau of the Census as we have in the past. We have successfully used these data to estimate patterns of exposure to railroad, construction, industrial, and highway noise.

2.2.2 Noise control assessment

Literature Search

The first task in our assessment of noise control potential will be a survey of the existing literature on controlling emissions from the subject machine. The important information to be

TABLE 2. CONSTRUCTION EQUIPMENT NOISE RANGES.



Note: Based on Limited Available Data Samples obtained in this manner will include:

- Noise source diagnoses,
- Treatment case histories, including techniques and costs.

The survey will be conducted along several parallel paths. BBN has access to and experience with a number of automated literature retrieval services, such as the Northeast Academic Science Information Center at Massachusetts Institute of Technology and the Countway Library at the Harvard Medical School.

In addition, we are familiar with many of the trade and industry journals not commonly abstracted by technical literature reviewers, but which often contain user-oriented articles on noise control. These two search methods are complementary, and we have used them successfully in the past.

Noise Source Diagnosis

Using the literature search results as a starting point, we will conduct a detailed investigation of the noise-making mechanisms that contribute to the total output of the product. This will be done in two ways:

(a) Estimation based on knowledge of component levels. In many cases, BBN has prior knowledge of the noise levels produced by machinery components. This is true, for example, of electric motors, gears, and diesel engine casings; a summary of noise outputs of the latter is given in Table 3.

(b) Measurement. The levels of some noise sources depend critically on the details of their construction or installation. Fans, engine exhausts, and flow noise phenomena fall in this category. As required, we shall measure the contributions from such sources on representative product models to fill the gaps in

TABLE 3. TRUCK ENGINES (DIESEL).

Manufacturer	Model	Net Flywheel	Rated RPM (Max Torque RPM)	Displacement Cu In.	Estimated Sound Level dBA At Rated Speed 50 Ft	Factory List Price
Allis-Chalmers HD	3500 T	165-175	2400 (1700)	426	(82.2)	3775
Allis-Chalmers HD	21000 T	340-375	2100 (1400)	844	(85.1)	7358
Allis-Chalmers HD	25000 TA	385-450	2100 (1500)	844	(85.1)	9348
Caterpillar MD	1140	150	3200 (1800)	522	(88.7)	2360
Caterpillar MD	1145	175	3200 (1600)	522	(88.7)	2360
Caterpillar MD	1150	200	3000 (1600)	573	(88.6)	2775
Caterpillar HD	1160	225	2800 (1400)	636	(88.5)	3080
Caterpillar HD	1673C T	250	2200 (1600)	638	(83.8)	5720
Caterpillar HD	1674 TA	270	2200 (1400)	638	(83.8)	6945
Caterpillar HD	1693 T	325	2100 (1450)	893	(85.5)	10290
Caterpillar HD	1693 TA	375	2100 (1475)	893	(85.5)	11690
Caterpillar HD	3405 T	280	2100 (1100)	893	(85.5)	6470
Caterpillar HD	3406 TA	360	2100 (1400)	893	(85.5)	8440
Cummins MD	V8-210	210	3300 (1900)	504	(88.8)	3700
Cummins MD	V555	225	3300 (1800)	555	(89.6)	4015
Cummins HD	NH-230	230	2100 (1500)	855	(87.0)	5155
Cummins HD	NHC-250	250	2100 (1500)	855	(87.0)	5860
Cummins HD	NTC-270	270	2100 (1500)	855	(87.0)	6230
Cummins HD	NTC-290 T	290	2100 (1500)	855	(85.2)	6260
Cummins HD	NTC-335 T	335	2100 (1500)	855	(85.2)	7065
Cummins HD	NTC-350 T	350	2100 (1500)	855	(85.2)	7325
Cummins HD	NTA-370 TA	370	2100 (1500)	855	(85.2)	8130
Cummins HD	NTA-400 TA	400	2200 (1600)	855	(86.0)	(8800)
Cummins HD	V-903	320	2600 (1800)	903	(90.2)	6665
Cummins HD	VT-903 T	320	2600 (1800)	903	(89.3)	6800
Detroit Diesel HD	3-53	101	2800 (1800)	160	(86.4)	2012
Detroit Diesel HD	4-53	140	2800 (1800)	213	(88.6)	2613
Detroit Diesel HD	4-71	160	2100 (1600)	284	(85.8)	3489
Detroit Diesel HD	6V-53	216	2800 (1800)	318	(91.6)	3905
Detroit Diesel HD	6-71	238	2100 (1600)	426	(88.9)	4840
Detroit Diesel HD	6V-71	238	2100 (1600)	426	(88.9)	4848
Detroit Diesel HD	6-71T T	262	2100 (1600)	426	(88.9)	5430
Detroit Diesel HD	6V-71T T	262	2100 (1600)	426	(88.9)	5440
Detroit Diesel HD	8V-71	318	2100 (1600)	568	(91.1)	6316
Detroit Diesel HD	8V-71T T	350	2100 (1600)	568	(91.2)	7064
Detroit Diesel HD	12V-71	475	2100 (1600)	851	(94.1)	10219
Detroit Diesel HD	12V-71T T	525	2100 (1600)	851	(94.2)	12181
GMC MD	DH478	165	2800 (2000)	478	(86.3)	(2000)
GMC MD	DH637	210	2800 (1600)	637	(88.5)	(3000)
International Harvester HD	DV-550B	200	3000	459	(88.2)	4661
Perkins HD	6.354	120	2800	354	(84.0)	2750
Perkins HD	V8.510	180	2800	510	(86.8)	4370
Mack HD	END475	140	2400 (1300)	475	(84.2)	2670
Mack HD	END475 T	(195)	2400 (1300)	475	(83.0)	3645
Mack HD	END673E	180	2100 (1400)	672	(85.1)	5860
Mack HD	END707	205	2100 (1500)	707	(85.5)	6118
Mack HD	ENDT675 T	237	1700 (1200)	672	(79.7)	6879
Mack HD	ENDT 673 TA	250	2100 (1500)	672	(83.3)	(7200)
Mack HD	END864	270	2300 (1600)	866	(88.2)	(7700)
Mack HD	ENDT864 T	300	2350 (1600)	866	(86.8)	7930
Mack HD	ENDT865 T	325	2100 (1350)	866	(85.3)	7930
Mack HD	ENDT866 T	375	2400 (1500)	866	(87.6)	8031

*Parentheses enclose estimated values.

our prior knowledge. In general, the procedures used to take such diagnostic measurements must be designed to suit the nature of the product. Figure 3 shows the layout of a microphone array developed by BBN under EPA sponsorship to measure directive noise from concrete mixers; typical measurement results are contained in Fig. 4.

2.2.3 Noise treatment

For representative examples of the product, BBN will determine the noise control techniques necessary to reduce noise emissions to the target levels agreed upon by EPA and BBN staff. Ordinarily, we would select three levels:

1. The level associated with the quietest products currently on the market.
2. The level associated with using the best demonstrated technology (demonstrated on the product in question or a similar product).
3. A level between 1. and 2. if the difference between them is greater than 3 dBA.

However, it may turn out that these criteria do not lead to the most appropriate range of levels. For example, the quietest product on the market may be that way because it already employs the best demonstrated technology. Thus, the above three criteria lead to the selection of only one level. Clearly, EPA must view the costs associated with alternative levels and we would propose to select two others as well. In evaluating technology and costs, we will view target levels as "not-to-exceed" values and account for appropriate manufacturing tolerances.

It will not be possible, nor is it desirable, to design a complete noise control treatment for every model of each product. Rather, we will determine the significant classes (with regard to noise emissions) within each product category, and we will present the typical treatments which would be required for each class. In the case of diesel trucks, for example, we have found that the classes can be differentiated according to engine manufacturer, with a further breakdown into two subclasses for certain manufacturers corresponding to their medium- and heavy-duty engines (see Table 3).

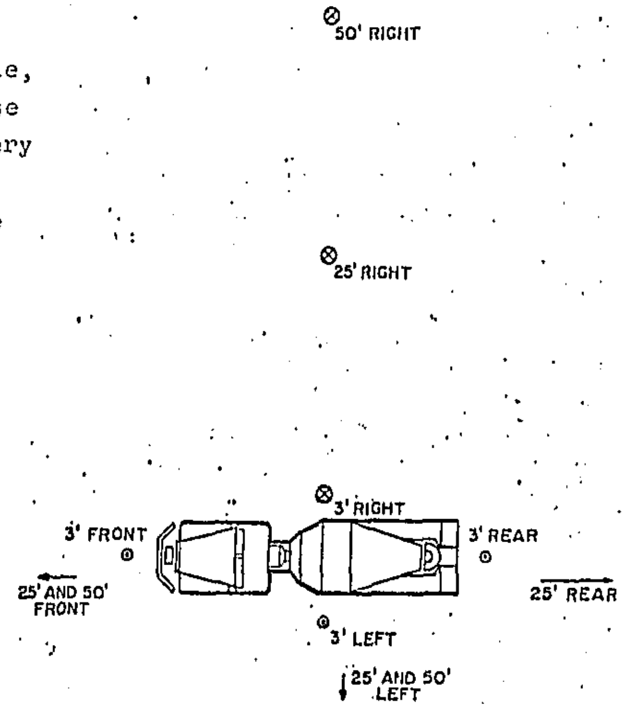


FIG. 3. NOISE MEASUREMENT LOCATIONS IN RELATION TO CONCRETE MIXER.

Once the product classes are defined, we will be able to apply our noise control expertise to determine the treatments appropriate to a typical model representing each class. The range of possible treatments is too great to treat here; however, we can discuss the general principles that will be applied.

Where possible, the noise control engineer seeks to reduce the noise at its *source*. This approach might involve replacement of a noisy process or item by a system that is inherently less noisy, e.g., changing from pneumatic to hydraulic systems, or changing from impact hammers to oscillatory shakers. Fans can sometimes be eliminated by redesigning cooling systems. Of course, such measures are generally feasible only in the case of new-product noise control; they are generally impractical as retrofit treatments.

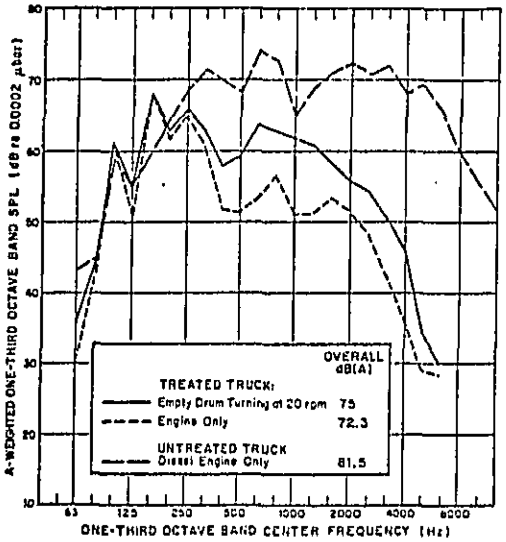


FIG. 4. EFFECTIVENESS OF ENGINE ENCLOSURE, EXTRA MUFFLING, AND FAN REMOVAL IN SUPPRESSING TRUCK NOISE BELOW MIXER NOISE, RIGHT SIDE AT 50-ft ENGINE AT 3200 rpm.

In many cases, it is possible to identify the process that is responsible for the noise made by a given equipment item and to modify or treat this process without materially altering the equipment or its performance. For example, it often is feasible to add resilient layers to cushion noise-producing impacts, to add mass, stiffness, or damping to critical components to reduce noise-producing vibrations; to modify noise-producing fluid flows by changing some orifices, valves, pipes or ducts; or to replace other noisy subsystems, such as fans and gears.

When the noise control engineer cannot treat the source of the noise, he deals with the *path* that the noise traverses from the source to the affected listener. This path may involve structural components and liquids (water and oil), as well as air. Noise control along the propagation path may involve the use of isolation (e.g., of internal vibrating components from sound-radiating surfaces and of machines from floors, etc., that transmit vibrations and radiate sound), treatments to reduce the radiation efficiency and/or acoustic transmission of equipment surfaces (e.g., by adding mass, damping, secondary panels, wrappings), provision of enclosures for entire pieces of equipment or of particular noise-radiating areas, installation of sound-absorptive surfaces (e.g., wall tiles, hanging baffles, curtains) in the reverberant spaces, and the provision of lined ducts or mufflers.

Tables 4 and 5 show the results of one study that we have performed for the EPA on quieting diesel trucks. Table 5 illustrates the division of the product population into noise classes and the selection of representative treatments within each class.

2.2.4 Cost assessment

To estimate properly the economic effect of changes in the product design or method of use, it is necessary first to define the appropriate cost categories and then to estimate the effect of design or usage changes on each category.

Expenditures can be categorized as either initial (or acquisition) cost or operating cost. The latter can be further divided into direct and indirect components. We will now summarize the most significant ways in which acoustic treatments may affect these costs.

TABLE 4. ESTIMATED CUSTOMER PRICE INCREASES FOR QUIETED TRUCKS.

Engine Class[1]	Market Share[2]	Level 1, 83 dBA					Level 2, 80 dBA					Level 3, 75 dBA				
		Fan	Exhaust	Engine	Cab	Total	Fan	Exhaust	Engine	Cab	Total	Fan	Exhaust	Engine	Cab	Total
Gasoline Engines	65%	a1	-	-	-		$100 a2	$ 25 b1	-	-	$ 125	$150 a3	$ 50 b2	-	[illegible]	[illegible]
M.D. Diesel Engines Manufacturer A	12%	$100 a2	$ 50 b1	-	-	$150	$100 a2	$ 50 b1	$200 c1	-	$ 350	$150 a3	$100 b2	-	[illegible]	[illegible]
M.D. Diesel Engines Manufacturer B	6%	$100 a2	$ 50 b1	$275 c1	-	$425	$100 a2	$ 50 b1	-	$850 d2	$1000	$150 a3	$100 b2	-	[illegible]	[illegible]
M.D. Diesel Engines Manufacturer D	6%	$100 a2	$ 25 b1	$200 c1	-	$325	$100 a2	$ 25 b1	-	$675 d2	$ 800	$150 a3	$ 75 b2	-	$775 d2	[illegible]
M.D. Diesel Engines Manufacturer C	4.8%	-	-	-	-	$0	$100 a2	$ 25 b1	-	-	$ 125	$150 a3	$ 75 b2	$200 c1	[illegible]	$525
M.D. Diesel Engines Manufacturer C	2.2%	$100 a2	$ 25 b1	-	-	$125	$100 a2	$ 25 b1	$ 85 c1	-	$ 210	$150 a3	$ 75 b2	-	[illegible] 1275 d2	[illegible]
H.D. Diesel Engines Manufacturer D	1.5%	a1	-	-	-		$100 a2	$ 50 b1	-	-	$ 150	$150 a3	$100 b2	-	[illegible]	[illegible]
H.D. Diesel Engines Manufacturer A	0.9%	$100 a2	$100 b2	-	-	$200	$100 a2	$100 b2	$200 c1	-	$ 400	$150 a3	$150 b2	-	[illegible]	[illegible]
H.D. Diesel Engines Manufacturer E	0.77%	$100 a2	-	-	-	$100	$100 a2	$ 25 b1	$175 c1	-	$ 300	$150 a3	$ 75 b2	-	[illegible] 1275 d2	[illegible]
H.D. Diesel Engines Manufacturer C	0.47%	$100 a2	-	-	-	$100	$100 a2	$ 25 b1	$175 c1	-	$ 400	$150 a3	$ 75 b2	-	[illegible] 1275 d2	[illegible]
H.D. Diesel Engines Manufacturer F	0.225%	$100 a2	$ 25 b1	-	-	$125	$100 a2	$ 25 b1	$200 c1	-	$ 325	$150 a3	$ 75 b2	-	[illegible]	[illegible]
H.D. Diesel Engines Manufacturer G	0.17%	$100 a2	$ 25 b1	-	-	$125	$100 a2	$ 25 b1	$150 c1	-	$ 275	$150 a3	$ 75 b2	-	[illegible] 1275 d2	[illegible]
H.D. Diesel Engines Manufacturer H	0.015%	-	-	-	-	$0	$100 a2	$ 25 b1	-	-	$ 125	$150 a3	$ 75 b2	$200 c1	[illegible]	$525

NOTES

[1] M.D. = medium duty, H.D. = heavy duty. M.D. and H.D. refer to severity of service. Exchange of a noisy engine by a quiet engine is possible within M.D. and H.D. classes.

[2] Percent of medium and heavy trucks powered by indicated engine family, 1972.

TABLE 5. NOISE CONTROL KEY.

System	Code (See Fig. 29)	Description of Noise Control Measure	Source Level or Noise Reduction
Fan	a1	Use of larger-slower turning fan with shrouding	80 dBA
	a2	Larger-slower turning fan with thermostat control to eliminate shutters or control their opening	75 dBA
	a3	Best technology fan system	65 dBA
Exhaust	b1	Best available system	75 dBA
	b2	Advanced system better than presently available	75 dBA
	b3	Best technology exhaust system	65 dBA
Engine	c1	Close fitting covers and isolated or damped exterior parts supplied by engine manufacturer	2-3 dBA NR
Cab	d1	Under hood treatment such as acoustic absorbing material, side shields, recirculation panels, etc.	2-4 dBA
	d2	Partial or full engine enclosures	10-15 dBA NR

Direct Initial Costs

One element of initial cost is the expense of manufacturing or procuring components. In general, acoustic treatments tend to affect these costs in the following ways:

- More materials may be required, such as damping compounds on stiffeners.
- More manufacturing steps may be required to provide for attachment of acoustic materials or devices.
- Tighter tolerances, to minimize vibrations, may result in greater quality control expenditures.
- Retooling costs must be recovered, thus increasing the indirect cost of the components.

Another part of initial cost is component assembly, where acoustic treatments could have a similar effect on cost. Naturally, such considerations as the need for more skilled labor, tighter tolerances, and better inspection procedures can add to the production costs.

BBN will estimate the magnitude of the initial cost changes using our long experience in noise treatment specifications and our many contacts among suppliers of noise control devices. We have used this approach, for example, in our studies of truck noise abatement; the initial costs associated with truck treatments are shown in Table 4.

Indirect Initial Costs

In the case of some products, especially those which are mass-produced, the introduction of noise abatement devices can create significant start-up costs. These arise from the need to re-tool and re-integrate assembly facilities. Data on case histories of this type are available to some extent in the industrial engineering literature; some Federal studies of this problem have also been done regarding the introduction of safety or antipollution devices.

Direct Operating Costs

Design changes can affect operations in a number of ways, but the most common effect on direct operating costs is the resulting change in power requirement to perform the given task. This may arise because of greater weight of the unit, the increased drag in ducts and pipes due to wall treatments, and the reduced engine performance resulting from increased muffler back-pressures. Examples of the changes in truck characteristics that may occur as a result of noise control are shown in Table 6; the resulting change in annual operating costs is shown in Table 7.*

TABLE 6. CHANGES IN TRUCK OPERATING CHARACTERISTICS FOR NOISE CONTROL TREATMENTS.[1]

Code	Treatment	ΔGVW (lb) Med	ΔGVW (lb) Hvy	ΔBackpressure (in. H_2O) Med	ΔBackpressure (in. H_2O) Hvy	Δhp Med	Δhp Hvy	ΔMaintenance Cost ($/yr) Med	ΔMaintenance Cost ($/yr) Hvy
a1	Large Fan					(3)	(7)		
a2	Large Fan with Thermostat Control					(6)	(15)		
a3	Best-Tech. Fan System					(6)	(15)		
b1	Best Available Muffler	0	0	0	0			$ 9[4]	$ 19[4]
b2	Advanced Muffler	100	200	0	0			$ 19[4]	$ 38[4]
b3	High-Tech. Muffler	100	200	15	15			$ 38[4]	$ 76[4]
c1	Covers	0	0						
d1	Under-Hood Treatment	0	0						
d2	Enclosure	250	500					$150[2]	$300[3]

[1]Source: Estimates by noise control engineers based on past truck-quieting experience

[2]Represents 10 man-hours per year at a burdened labor rate of $15/man-hour.

[3]Represents 20 man-hours per year at a burdened labor rate of $15/man-hour.

[4]Includes incremental cost of replacing muffler three times in eight years.

*The costs shown in Table 7 also include increased annual maintenance.

TABLE 7. ANNUAL OPERATING COST INCREASES AS A RESULT OF CHANGES IN GVW, BACKPRESSURE, AND ACCESSORY HORSEPOWER FOR HIGHWAY TRUCKS.

	Annual Operating Cost Increase Per Unit		
	GVW ($/lb)	Backpressure ($/in. Hz)	Accessory Horsepower ($/hp)
Gasoline - medium	0.016	0	17.50
Gasoline - heavy	0.029	0	17.10
Diesel - medium	0.011	3.15	11.97
Diesel - heavy	0.029	3.40	16.20

Indirect Operating Costs

For the purpose of this study, the chief elements of indirect operating cost with which we will be concerned are reliability and maintenance. Maintenance costs, however, may be affected by equipment modifications. Components, which are subjected, to harsh environments and heavy periodic loading, will be potentially subject to wear. This is especially true of vibration mounts and damping compounds, which transform mechanical motion into heat. For each acoustic treatment, therefore, we will estimate the mean time between repair or replacement based on our knowledge of the material's properties and load and environmental histories. The last column of Table 6 shows the estimated change in annual maintenance cost brought about by noise control treatments for trucks.

3. GENERAL MANAGEMENT APPROACH

3.1 Program Organization

In a Basic Ordering Agreement such as this, there are two levels of management: the Program level, and the Task level. The program management plan must provide for appropriate allocation of skills to the various tasks in a timely manner, and it must ensure that deliverable outputs are provided on time and within budget. The task management plan must coordinate the day-to-day technical work and assembly of outputs. The program management plan is presented here; the task plan is described in Sec. 5.

The structure of the program organization is displayed schematically in Fig. 5. Our overall philosophy is to define a Program Manager, who will have overall responsibility, and who will delegate the specific tasks to Task Managers, who will be chosen at the time that each task is formulated. The Program Manager will be supported by an Advisory Committee made up of high-level experts in various relevant fields, and by an administrative assistant.

The Program Manager for this effort will be Dr. Erich K. Bender. Dr. Bender is uniquely qualified to direct the proposed project. Having worked closely with EPA's Office of Noise Abatement and Control since its inception, he has a clear understanding of the needs for and application of the proposed investigation. He has managed most of BBN's efforts for EPA, and he has supervised extensive projects for the Department of Transportation (truck quieting, railway noise mechanisms) and many government laboratories (chiefly in the field of dynamics). In his role as Manager of one of BBN's largest departments, he is able to ensure that the most appropriate personnel are assigned to the

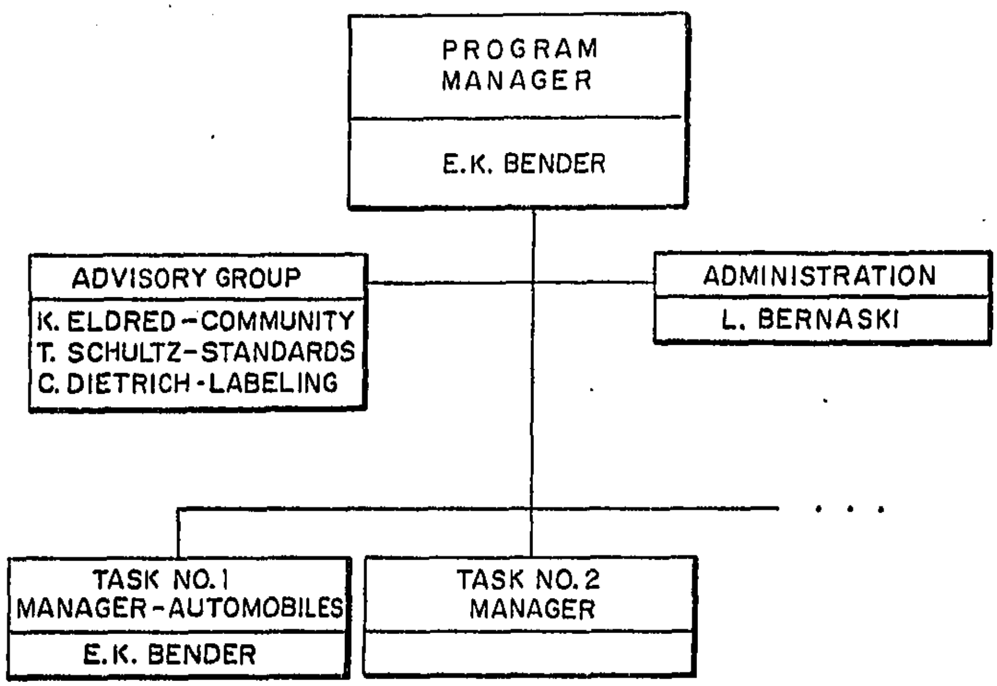


FIG. 5. STRUCTURE OF PROGRAM ORGANIZATION.

proposed program. Dr. Bender will have approximately 40% of his time available for his managerial and technical responsibilities on this project.

The Advisory Committee will consist of Dr. T. Schultz in the area of standards; Mr. K. Eldred in the area of community noise exposure; and Mr. C.W. Dietrich in the area of labeling technology. The expertise of these individuals is described in the Personnel Qualifications Section (Sec. 7).

To assist him in his supervisory tasks, Dr. Bender will have the use of BBN's internal management information system. This is described in the following section.

3.2 BBN Program Management Techniques

Two central problems arise in managing projects of this type. The first is to ensure that staff members with the appropriate skills are available at the time they are required. The second problem is ensuring that the overall project proceeds as scheduled with respect to deliverable outputs and rate of expenditure, and, as a corollary, that the effort is distributed properly among the various tasks. BBN has developed management information systems to assist the program supervisors in these areas.

Manpower Planning System

As part of BBN's normal internal planning, the Professional Services Divisions use an automated routine that combines the labor commitments of individual staff members to specific jobs into an overall personnel availability forecast for the succeeding 12 months. This routine permits immediate avoidance of future conflicts (such as an individual being overcommitted to a number of projects) or labor shortages. Using this system, it is possible to ensure, months in advance, that specific individuals will be available when they are needed and that sufficient total manpower will be applied to upcoming tasks.

Program Review System

To ensure proper allocation of effort within programs, BBN uses a formal review procedure. Each program is thoroughly analyzed by the Division's management at the 50% completion and 80% completion points. The percentages refer to either elapsed calendar time or allocated man-hours, whichever is reached first. The review establishes whether the progress to date is satisfactory and the prognosis for completion within schedule and budget is good. This procedure ensures that problem areas are revealed in adequate time to resolve them within BBN or to consult with the sponsor, as appropriate.

3.3 Program Personnel

The diversified range of skills demanded by this project is easily supplied by BBN. For this effort, we have made available a labor force whose qualifications in the required disciplines are well established. Table 8 lists the available personnel by area of expertise; their qualifications are described in Sec. 7.

TABLE 8. AVAILABLE PERSONNEL.

Area of Expertise	Investigators
Noise Control Engineering	Dr. E.K. Bender* Mr. W.N. Patterson Dr. P.J. Remington Dr. M.J. Rudd Dr. E.E. Ungar
Cost and Engineering Economy	Mr. G. Fax Mr. H. Fox
Measurements and Test Procedures	Mr. G.G. Huggins Mr. R. Ely Mr. M. Alakel
Labeling	Mr. C.W. Dietrich†
Community Noise Exposure	Dr. T. Schultz† Mr. K. Eldred† Dr. W. Galloway
Technical Writing	Ms. N. McMahon Ms. A. Rooney
Library and Information Sciences	Ms. C. Long Ms. M. Troy

*Project Manager

†Advisory Committee plus technical responsibility.

4. TECHNICAL APPROACH FOR AUTOMOBILES

The purpose of this section is to respond to Enclosure III of the subject RFP, which requires the inclusion of a sample task order. In this case, the specific topic is the development of measurement procedures, and the technology and costs of regulating automobile noise. The RFP requires a three-month program to develop pertinent information and deliver all findings. For many products three months is sufficient for a complete study. For example, BBN conducted a rather thorough study of medium and heavy trucks for EPA in two months (Bender and Patterson, 1974). However, the situation for automobiles is, in our judgment, substantially different.

First, the economic consequencies of automobile noise control may be far greater than for any source considered thus far by EPA's ONAC. Effects of price changes for roughly 10 million cars manufactured annually, effects of changing the fuel consumption of a 90 million car population in the U.S. (*Automotive News*, 1974), and effects on the balance of trade of one of the nation's leading import products* will all require most careful consideration and should be based on a thorough study.

Furthermore, as we shall discuss, the inadequacy of existing automobile noise measurement standards, such as the SAE J986a procedure, as indicators of community noise, necessitates a greater-than-three-month program. Developing a new standard alone takes *at least* three months. Technology/cost studies must follow the establishment of a standard, and, of course, time is needed for report preparation. Accordingly, we believe it is not

*1.7 million imported cars registered in U.S. in 1973 (*Automotive News*, 1974).

feasible to conduct a comprehensive study in three months. However, a preliminary study which produces a draft measurement standard and first-cut estimates of the technology and cost of automobile noise abatement would be very valuable and can be performed in three months. It is this level of effort that we address here.

4.1 Measurement Standards

4.1.1 Relevance to community impact

The impact of automobile noise on the community and the ability of a measurement standard to quantify the impact are a extremely critical issues. Although the automobile is currently one of the quietest transportation vehicles in operation, it is still a major community noise problem due to (1) the large number in use and (2) the proximity of the automobile to people.

Community impact of the automobile is of two types: (1) noise emitted during typical or average use of the vehicle, and (2) nuisance impact through improper use. The current measurement standard that has had wide employment — the SAE J986a standard — does not provide an adequate measure of either type of impact. This standard measures exterior noise under wide open throttle (WOT) conditions at speeds low enough that tire noise is not a concern. Wide open throttle operation, however, occurs only for a very small portion of average use time (Ford Motor Company, 1973). Accordingly, SAE J986a does not account for community response to noise generated during constant speed cruise, deceleration, or moderate acceleration. In addition, tire noise, which is a definite factor in community response to automobile noise, is not measured by SAE J986a.

The second aspect of the impact of automobile noise on people — a nuisance because of improper use — is also inadequately assessed by this standard. Although one's first impression is that WOT operation might correlate well with improper use, the nuisance value is closely associated with the listener's social feelings and attitudes. Because of the subjectiveness of nuisance impact and the lack of adequate measures, it is inappropriate at this time to attempt to include it as an aspect of a measurement standard.

There are a number of additional measurement standards or practices that are similar to SAE J986a. Some of these are:

1. ISO-R362, Measurement of Noise Emitted by Vehicles, 1964, developed by the International Standards Organization.
2. AESMC 1-72, from the Automotive Exhaust System Manufacturers' Committee.
3. An SAE proposed stationary test at no load and 75% rated engine speed, SAE Vehicle Sound Level Committee.
4. A test developed by A.E. Haines, Dept. of the Environment, Mechanical Engineering Division, England.
5. British Standard 3425:1966, Method for the Measurement of Noise Emitted by Motor Vehicles.

Some of these tests correlate fairly well with SAE J986a; others are intended primarily to measure exhaust noise. None of them provide a very good measure of community impact, however.

Additional studies that do attempt to measure locomotive noise in a manner meaningful to community impact are work being done by Ford Motor Co. (1974) and a current program being conducted by the Motor Vehicle Manufacturers Association (Wasko, 1974). In each of these studies, an approach similar to that described in

Sec. 2.1.1 is taken; i.e., a measure of the energy emitted during a typical-use scenario is obtained. The use scenarios for these studies were developed as part of the CAPE-10 program (to determine measures of vehicle exhaust emissions), and industry studies aimed at obtaining data relevant to vehicle noise emissions.

The approach BBN proposes is to use the data from these studies and others to generate the baseline histogram shown in Fig. 2 as a function of speed and engine load. The first step is to assemble the scenario information which shows, for typical automobile use, the amount of time the vehicle is at a given speed/load condition. These data can be directly correlated to noise emission, and the L_{eq} for the vehicle can be calculated as shown in Sec. 2.1.1. The next step is to devise a test methodology that is reasonable to conduct and will closely correspond to the L_{eq} determined from the scenario distribution.

4.1.2 Relevance to the consumer

Some means must exist to translate the measurement standard into a product label that is relevant to the consumer. For a one-to-one relationship to exist, the noise sources evaluated by the standard must be common to those affecting the consumer of the product.

SAE J986a again does not provide an adequate measure of automobile interior noise – i.e., a criterion relevant to the consumer. Studies (Raff and Perry, 1973; Ford *et al.*, 1970) have shown that automobile interior noise is controlled by engine noise, road surface excitation, and aerodynamic noise. Also, during a course on noise and vibration given by BBN to a major U.S. automobile manufacturer, we found that rear axle (i.e., differential) noise was important, principally because of its tonal quality.

The importance of these sources varies as a function of load, speed, and frequency. In addition, low-frequency noise is relatively more important in the interior than for the exterior, because of excitation of and reradiation from the car body. The latter condition is more true for cars than for trucks because the car body is larger and more susceptible to low-frequency forces (Raff and Perry, 1973). In addition, while exhaust noise is important to the truck interior, it is less so for the car for which the exhaust is more remotely situated. The overall result is that, while the SAE J366b test may be somewhat relevant to the consumer for trucks, SAE J986a is not relevant to the consumer purchasing an automobile.

What is needed is an adaptation to the data obtained by the measurement standard to devise an automobile labeling technique that provides the required information to the consumer. Moreover, the data must be presented in a fashion that is meaningful to the lay person unfamiliar with the field of acoustics.

4.1.3 Industry impact

One of the major concerns of any product noise measurement procedure is its impact on industry. An involved and complicated test is costly to conduct and much of the burden is eventually assumed by the buyer. SAE J986a has a significant impact on the industry for a number of reasons:

1. It is a complex test that is costly to conduct. A rather high degree of skill is required of those performing the test.
2. The results are variable and not repeatable enough. This can cause the manufacturer to design his product a few "safe" dB below the regulated level in order to

ensure that a high enough percentage of his cars passes the test. This result also adds to costs.

3. This technique is unsatisfactory for enforcement and for use by local governments who rarely have the required site available. A new-product standard promulgated by EPA using SAE J986a will force manufacturers to reduce noise sources emphasized by this test, and to reduce different sources to meet local in-use regulations that employ a different measurement procedure.

Minimizing the costs associated with each of the above three factors requires the employment of a measurement standard that evaluates the appropriate parameters, is accurate, and is repeatable. Accompanying the standard should be a brief enforcement test that accurately identifies those automobiles that would fail the standard procedure.

A second factor to minimize industry impact is to incorporate fully the experience, facilities, and cooperation of the manufacturers in the development of a new noise-emission test. Particularly in the case of automobiles, the industry is very concerned about appropriate noise measurement techniques and is currently conducting studies to derive improved techniques. We would enlist the support and assistance of the industry to the maximum extent possible.

4.1.4 Repeatability

Any successful measurement standard must have a high degree of repeatability. A lack of repeatability has a major impact on the manufacturer, since he must counter the wide variance in the test by designing his auto quieter than called for by the regulation. As before, the result is increased costs that are passed on to the consumer. A desirable goal in repeatability is to reduce the variance of the test procedure to a value on the order of or less than the variance due to other factors (e.g., propagation and the source itself).

SAE J986a has an unsatisfactory variance due to:

1. The long measurement zone of 100 ft, variations of several dB can occur, especially between high- and low-powered cars.
2. Variations in driver skill and timing.
3. Site-to-site physical variations causing measured noise variations of up to 3 dBA (Ford Motor Company, 1973).

The development of an automobile noise-emission standard with good repeatability can be accomplished by attention to a number of factors. One of these is a test requiring minimal driver skill. Another is to minimize the effect of the surface-reflected transmission path, which is primarily responsible for site-to-site variations. Another would be a source-to-microphone distance of less than 50 ft. We will explore these and other approaches to increased repeatability.

4.1.5 Relevance to Existing Data Base

Although a great deal of data have been accumulated on automobiles through the use of SAE J986a, there is still a need to develop a new standard because:

1. The inadequacy of SAE J986a as a measure of community noise is widely recognized by the industry and regulatory agencies alike.
2. A significant amount of data has been collected using other measurement techniques.

One important aspect of developing a new measurement procedure to regulate automobile noise is the relevance of the data obtained by that procedure to existing data. One way to judge the appropriateness of a new procedure is to compare its results to the current data base. The ability of a new test is degraded if no satisfactory means exists to make this comparison.

Relevancy to the community and the consumer has a bearing on the relevancy to an existing data base. The weight given the latter must be modified by the relevancy to community and consumer. In the case of the automobile, for example, SAE J986a does not provide the correct measure of community impact. Therefore, less importance has to be attached to the relevancy of a new measurement procedure to the known data. Fortunately, a reasonable amount of noise data on automobiles has been gathered using procedures other than the WOT technique of SAE J986a.

4.1.6 Feasibility of field enforcement

A test procedure as complex as SAE J986a possesses minimal use as a field enforcement test. The requirements of a feasible procedure are speed and simplicity. In fact, it is preferable if such a test can be performed on-site at the manufacturing plant, near the end of the production line.

An enforcement test that is a corollary to a new standard test procedure is described in Sec. 4.1.3. The objective of the brief field test is to determine, with a high probability, those cars that would fail the standard measurement procedure. A field test of this sort would be useful to the manufacturer as well as to EPA enforcement personnel.

As a part of developing a draft of a new automobile measurement standard, BBN will also develop a draft test methodology for field enforcement.

4.1.7 Procedure for developing new measurement standard

It has been stated that the SAE J986a standard is inadequate for a number of reasons, the principal one being that it is not a good measure of community impact. We propose to develop a new draft measurement standard for automobile noise emission following a three-step program:

1. Document inadequacy of SAE J986a.

2. Conceive new test procedures.

3. Conduct tests to determine feasibility of new procedures.

All three phases will be accomplished using the speed and load scenario discussed in Sec. 2.1.1.

The first phase will be to quantify the ability of SAE J986a to satisfy the criteria of Secs. 4.1.1 to 4.1.6 and document the results. Second, one or more new standard measurement techniques that more closely meet these criteria will be developed. Finally, preliminary tests will be conducted to evaluate the procedures, and select one of them.

4.2 Technology/Cost Studies for Automobiles

4.2.1 Baseline assessment

The baseline assessment for the proposed study of automobile noise comprises two parts: (1) a description of the salient features of automobiles and the automotive industry and (2) the preparation of a data base on automobile noise levels, component characteristics, and price. In prior technology/cost studies conducted for EPA, we have found it useful to describe the products and companies. We therefore propose to provide a description of automobile classifications, typical construction configurations and noise sources, a distribution of number of vehicles produced by manufacturer, numbers of vehicles imported and exported, the sales volume of each manufacturer, and an identification of which components relevant to noise are made by automobile manufacturers and which are supplied by vendors. These data will provide an important picture to EPA and will be a valuable data base for any economic impact analyses EPA chooses to conduct. Moreover, such data are readily available from the MVMA, the government, and other sources and thus will require very little time to acquire and present.

We also propose to provide EPA with a thoroughly documented set of baseline interior and exterior noise levels measured according to the SAE J986a standard and a draft test procedure developed as part of the proposed study. We will use three basic sources for this information: the open literature, the automobile manufacturing industry, and our own measurements. We find that, in the open literature, there already is a significant body of data on foreign models but not on domestic cars. Domestic manufacturers treat their data rather confidentially. However, we are reasonably optimistic that domestic manufacturers will provide us with data, at least for purposes of statistical analyses. This view is based on the success we have had in obtaining proprietary data for truck and construction noise studies and on our reasonably close working relationship with certain automobile manufacturers. Finally, we believe that EPA should not base its regulations solely on data provided by an industry that is about to be regulated. Accordingly, we propose to conduct independent noise measurements on a cross-sectional sample of new automobiles.

The format in which we propose to acquire data is given in the following table. We will present interior and exterior noise

NOISE DATA

	SAE J986a					Community Standard				
	Run 1	Run 2	Run 3	...	Test Result	Run 1	Run 2	Run 3	...	Test Result
Interior Level										
Exterior Level										
Gear Step										
Approach Speed										

VEHICLE DATA

Automobile

Make:
Model:
Model Year:
Serial No.
Transmisson:
Rear Axle Ratio:

Engine

Model:
Displacement:
No. of Cylinders:

Exhaust Muffler

Make:
Model:

Intake-Air Cleaner

Make:
Model No.:

Cooling Fan

Make:
Model No.:
Diameter:
No. of Blades:
Fan/Engine Speed:

Tires

Make:
Model No.:
Rib Type:
Condition:

data for each run made (for purposes of evaluating variability) as well as the test result for the SAE J986a standard and what we may call the "community standard." We will also provide all relevant parameters on each automobile tested. We are not optimistic that data gleaned from the literature or the industry will be sufficiently comprehensive to fill out this table completely for each vehicle. However, data that we acquire under the proposed program will be documented in this manner.

4.2.2 Noise control assessment

To assess the technology and cost of controlling automobile noise, we propose a four-part program involving: (1) the acquisition and analysis of existing information; (2) measurements of component source contributions; (3) estimation of the cost and effectiveness of state-of-the-art application of noise control technology; and (4) an evaluation of noise reduction that can be achieved by means of a component interchange.

Acquisition of Existing Information

We propose to collect two kinds of information for purposes of noise control assessment. First, we will determine the degree of noise reduction that has been achieved by existing techniques. We expect it will be relatively easy, for example, to determine the insertion loss and price of automobile mufflers. It will be somewhat more difficult to estimate the cost associated with the application of quieting to automobile interiors.

The second type of information that we will collect is component noise contribution to interior and exterior total noise levels. Components that we will evaluate include

- engine intake
- engine exhaust
- engine structure
- cooling fan
- tires.

We will also acquire data on other sources, such as rear axles and air conditioners (interior only) as the need and opportunity arise.

Source Identification

Anticipating that industry-supplied data and data in the literature will be inadequate, we propose to measure the contribution of the above five sources to interior and exterior levels. The following table summarizes the diagnostic test procedures we propose to follow.

Source	Test Procedure
Engine Intake	Operate vehicle at low speed, with fan removed, with exhaust equipped with extra muffler and possibly with engine wrapped.
Engine Exhaust	Operate vehicle at low speed, with microphone located approximately 1 ft from exhaust line terminus.
Engine Structure	Operate vehicle at low speed, with fan removed, with intake and exhaust equipped with extra mufflers.

Source	Test Procedure
Cooling Fan	Drive fan with electric motor.
Tires	Coast vehicle by stationary microphone with transmission disengaged and engine turned off.

Noise Treatment

We propose to evaluate the application of the best available technology required for automobiles to meet the three levels selected in a manner described in Sec. 2. This evaluation involves an assessment of replacing noisy components with quiet ones, ineffective noise-suppression devices with effective ones, and incorporating various stages of noise control technology. The following is a summary of the application of these techniques to the major sources.

Engine Intake: Apply a more effective air cleaner, aim the intake nozzle forward, apply under-hood sound-absorptive treatment.

Engine Exhaust: Apply a more effective muffler. (It is likely that off-the-shelf hardware is suitable for most objectives; if not, we could readily estimate muffler effectiveness through a preliminary design.)

Engine Structure: Apply under-hood sound-absorptive material, side shields, damped and vibration-isolated valve covers, oil pan, intake manifold, and accessories.

Cooling Fan: Use a larger, more slowly turning fan and possibly a larger radiator.

Tires: Replace noisy tires with quiet ones. (Unfortunately, the state of the art of designing quiet tires is too undeveloped to do much more.)

4.3 Cost Analysis for Automobiles

Estimating the direct and indirect costs of automobile noise control will take several steps. The first will be to develop models for cost computations; these models will take into account automobile design characteristics, operating profiles, and production techniques. Specific consideration will include:

Direct Initial Costs: These costs are primarily the cost of labor and materials for the noise treatments themselves and do not require an extensive modeling effort.

Indirect Initial Tests: The automobile production process is highly sensitive to perturbations of the assembly line operation; in this fashion, noise control treatments may cause considerable indirect costs in the form of retooling or assembly line integration. We can estimate the extent of such cost on the basis of similar events. In particular, much literature is available on the indirect cost impacts of air pollution systems and safety devices (such as collapsible bumpers).

Direct Operating Costs: Noise control treatments can be expected to affect automobile operating characteristics (weight, backpressure, etc.) and, therefore, fuel economy. The magnitude of this effect in terms of annual cost depends on a car's average annual mileage, speed, and load factor, which we shall estimate on the basis of data from the industry and from the U.S. Transportation Census.

Indirect Operating Costs: The effects of noise treatments on the required maintenance effort can be estimated on the basis of our knowledge of the wear and deterioration properties of the applicable materials and does not require extensive modeling.

The second phase of cost estimation will be to assimulate and critically evaluate cost data obtained under the literature search and industry interview phases. Clearly, cost estimates by interested parties such as manufacturers must be carefully analyzed. We have found cases in the past, for example, of some product manufacturers estimating their cost of noise control by using list prices for abatement devices which would normally be obtained at a substantial discount. This is not to say that such information is valueless, only that it must be independently assessed.

The third phase of the process is to combine the data with the models to obtain estimates of the four cost categories by class of automobile.

5. PROGRAM PLAN: AUTOMOBILE TASK

The proposed program consists of seven subtasks, as shown in the attached Program Schedule.

Subtask 1. Develop Measurement Procedure

This subtask has as its objective the development of a draft measurement procedure. Following this initial three-month program, a final measurement procedure can be developed, for example, by convening a committee comprising government and industry representatives. Specifically, we propose to:

1.1 Review automobile use data and develop a speed and load use scenario.

1.2 Select approximately four representative operating conditions to be used in the Technology subtask.

1.3 Use information from vehicle standard test and diagnostic studies to develop vehicle noise measurement procedures.

1.4 Evaluate comparatively these measurement procedures and such measurement standards as SAE J986a from the standpoint of community noise, industry impact, repeatibility, relevance to existing data base, enforcement feasibility, etc.

1.5 Draft a recommended automobile measurement procedure.

Subtask 2. Conduct Literature Review

Under this subtask, we will:

2.1 Acquire noise, cost, and use data from industry sources.

2.2 Acquire noise and cost data from sources other than industry – e.g., government, foreign sources, the literature, and our own data.

2.3 Characterize the automotive industry economically and in terms of production volume, variety and types of models, role of imports, etc.

Subtask 3. Industry Interviews

Since consultation and cooperation with the automotive industry are of paramount importance to the success of this study, we identify as a specific subtask interviews with the industry. Maintaining this type of contact with the industry has proved important to the success of past programs with EPA – e.g., trucks and portable air compressors. Specifically, we propose to:

3.1 Contact a large number of industry personnel via telephone.

3.2 Follow the telephone contacts with in-depth visits to a smaller number of industry representatives.

3.3 Maintain contact and maximum communication with the industry through continuing follow-up discussions.

Subtask 4. Noise Control Technology

The development of noise control technology involves total vehicle tests, diagnostic tests, and an evaluation, based on these tests and data gathered elsewhere, of noise control technology. Specifically, we propose to conduct the following:

4.1 Select vehicles. We propose to select representative vehicles for testing that will give us a cross section of a product line as well as a cross section of major manufacturers. For example, we might select a compact, intermediate, standard, and luxury model from one manufacturer and one standard size car from each of four manufacturers.

4.2 Arrange for Vehicle Tests. We expect to conduct tests on cars made available by vehicle manufacturers in exchange for noise data acquired on these vehicles. (This arrangement has worked well in the past for tests conducted on trucks, railroads, and construction machinery.) If manufacturers choose not to make cars available, we will rent appropriate models from car-rental agencies.

4.3 Conduct Standard Tests. With approximately seven cars selected under Subtask 4.1, we propose to measure exterior and interior noise according to

- SAE J986a
- ISO-R362
- An SAE-proposed stationary test at no load and 75% rated engine speed.
- Operating conditions identifed in Subtask 1.2.

4.4 Conduct Diagnostic Tests. On four to seven automobiles, we propose to conduct diagnostic tests as described in Sec. 4 of this proposal to determine interior and exterior contributions from

- engine exhaust
- engine intake
- engine structre
- cooling fan
- tires.

4.5 Evaluate Noise Control Effectiveness. Using data acquired from the diagnostic tests conducted in Subtask 4.4, we propose to evaluate the effectiveness of noise treatment for the vehicles considered.

4.6 Estimate Total Noise Control Requirements. We propose to combine the results of Subtask 4.5 with data acquired from the industry (Subtask 3) and literature (Subtask 2) to estimate the technology required to reduce automobile noise to three target levels.

Subtask 5. Costs

This task involves the development of cost estimates for reducing automobile noise and comprises the following three parts.

5.1 Define Cost Model. We propose to develop a cost model relating noise control measures to direct and indirect capital and operating costs.

5.2 Evaluate Cost Data. We propose to evaluate and put into usable form all cost data acquired as a result of literature (Subtask 2.2) and industry (Subtask 3) surveys.

5.3 Estimate Direct and Indirect Costs. We propose to estimate the costs of noise control developed in Subtask 4 and combine these data with the modeling (Subtask 5.1) and other data (Subtask 5.2) to obtain first-cut estimated values of direct and indirect, capital and operating costs associated with reducing automobile noise to three target levels.

Subtask 6. Documentation and Reporting

6.1 Documentation. We propose to document thoroughly all data acquired under the proposed program. This will be done by providing work sheets and check lists for all data-gatherers and will be separately monitored.

6.2 Final Report. We propose to prepare a final report documenting all findings.

Subtask 7. Meet With EPA

We propose to meet with the cognizant EPA program supervisor

- during the first week of the program
- approximately midway through the program, and
- several weeks after submission of the final report.

The purpose of these meetings will be to review work accomplished and plans for accomplishing remaining work.

Organization

The organization that we have developed for the proposed task on automobiles is illustrated in Fig. 6. The task will be managed by Dr. Erich Bender who will also be responsible for the industry interviews and technology studies (Subtasks 3 and 4). Measurement standards (Subtask 1) will be developed under the supervision of Mr. Geoffrey Huggins, who will also be the principal technical contributor to this effort. Ms. Charlene Long will supervise the literature acquisition and review (Subtask 2). Mr. Gene Fax will be the principal contributor to cost analyses (Subtask 5). Reporting and documentation will be coordinated by Ms. Nancy McMahon, Manager of our Publications Department.

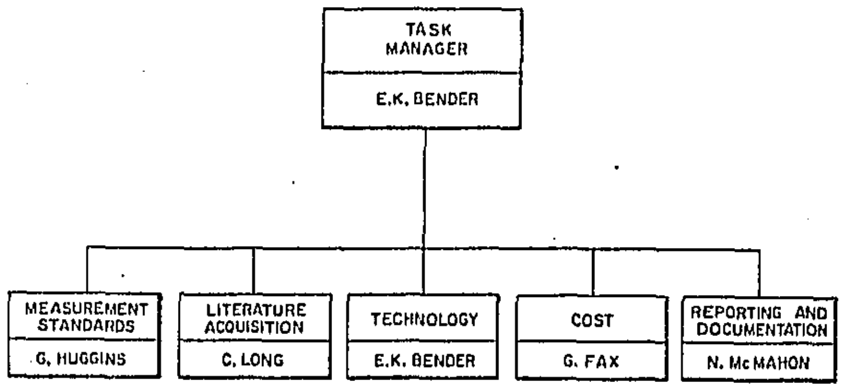


FIG. 6. TASK ORGANIZATION.

Summaries of the qualifications of these senior people are found in Sec. 7 of this proposal; complete resumés are appended.

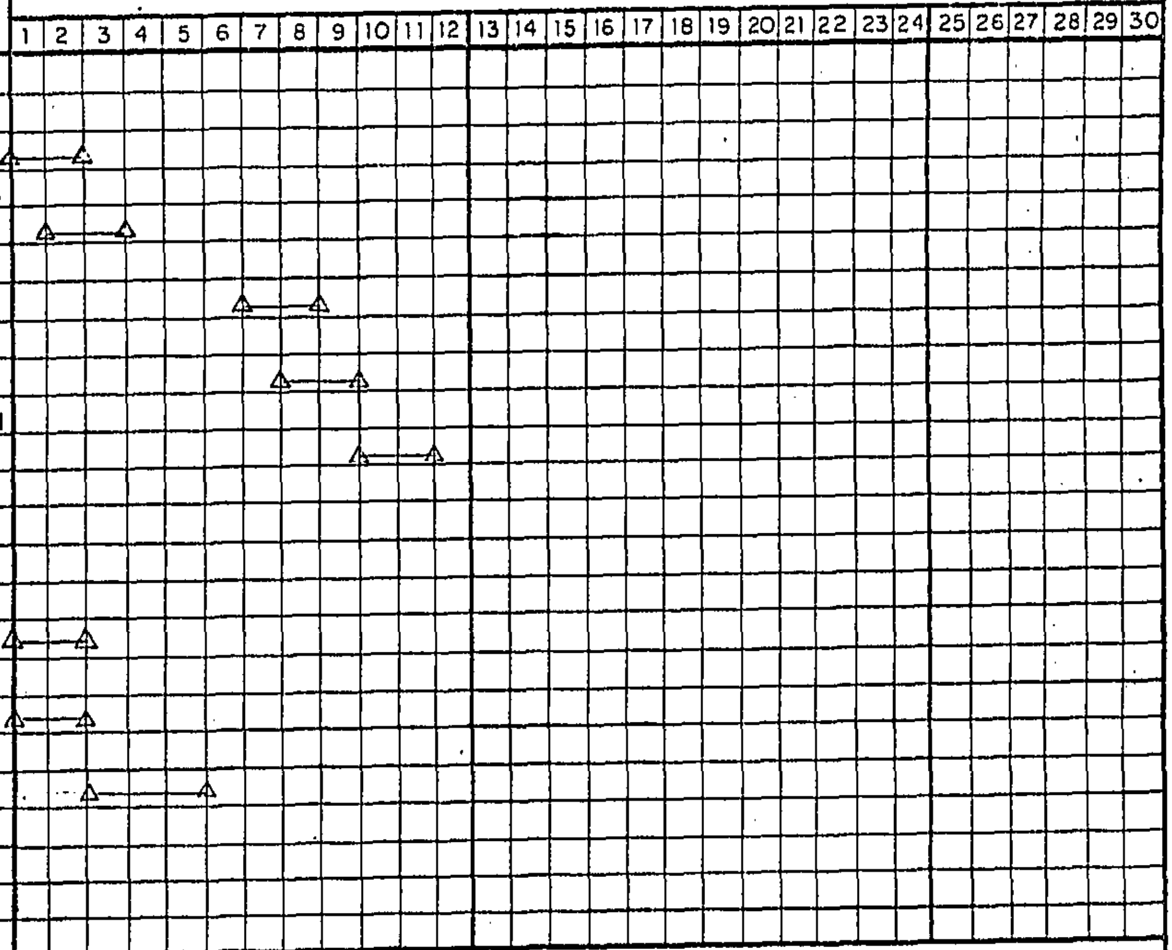
PROGRAM SCHEDULE

PROJECT TITLE: Automobiles

REFERENCE: BBN Proposal P74-PSD-232

DATE: 19 July 1974

Weeks From Task Start Date



TASK DESCRIPTION

1. Develop Measurement Standard
   - 1.1 Review Use Data
   - 1.2 Select Rep. Operating Conditions
   - 1.3 Develop New Procedures
   - 1.4 Evaluate Proc. & Standards
   - 1.5 Draft Recommended Procedure
2. Conduct Literature Review
   - 2.1 Acquire Industry Data
   - 2.2 Acquire Noise & Cost Data
   - 2.3 Characterize Industry

Δ—Δ REPRESENTS TIME SPAN OF ACTIVITY ▲ REPRESENTS COMPLETED ACTION

PROGRAM SCHEDULE

PROJECT TITLE: Automobiles

REFERENCE: BBN Proposal P74-PSD-232

DATE: 19 July 1974.

Weeks From Task Start Date (1–30)

TASK DESCRIPTION	
3. Industry Interviews	
3.1 Telephone Contact	
3.2 Visits	
3.3 Follow-up Discussions	
4. Technology	
4.1 Select Vehicles	
4.2 Arrange for Vehicle Tests	
4.3 Conduct Std Tests	From (1.2) to (1.3)
4.4 Conduct Diagnostic Tests	
4.5 Evaluate Noise Control	
4.6 Estimate Total Noise Control	
5. Costs	
5.1 Define Cost Model	
5.2 Evaluate Cost Data	(2.3) (3.2)
5.3 Estimate Direct & Indirect Costs	

Δ——Δ REPRESENTS TIME SPAN OF ACTIVITY ▲ REPRESENTS COMPLETED ACTION

PROGRAM SCHEDULE

PROJECT TITLE: Automobiles

REFERENCE: BBN Proposal P74-PDS-232

DATE: 19 July 1974

Weeks From Task Start Date

TASK DESCRIPTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6. Reporting & Documentation																														
6.1 Documentation																														
6.2 Final Report																														
7. Meetings With EPA																														

Δ——Δ REPRESENTS TIME SPAN OF ACTIVITY ▲ REPRESENTS COMPLETED ACTION

6. RELATED EXPERIENCE.

For more than fifteen years, BBN has been studying and solving noise control problems associated with transportation and recreational vehicles. Activities in this field range from detecting noise sources and collecting data to making cost/effective recommendations for noise reduction. In addition, BBN has conducted numerous studies of traffic noise and its environmental impact, assisted city, local, and national agencies in the regulation of vehicular noise, and participated in the development of noise measurement standards. Some specific projects performed in these areas are summarized below.

6.1 Technology and Cost Studies: Motor Vehicles

Medium- and Heavy-Duty Trucks (EPA)

For EPA, BBN conducted a two-month study of the technology and associated costs of controlling the noise of medium- and heavy-duty trucks. We identified the costs to the industry of reducing truck noise to (1) the level associated with the quietest trucks currently on the market, (2) the level associated with using the best demonstrated technology, such as the DOT Quiet Truck Program, and (3) a level between (1) and (2), if the difference between them is greater than 3 dBA. In the course of our investigation, we found that the quietest truck available on the market has a diesel engine rated between 350 and 400 hp and has SAE J366a test results of 78 dBA. The truck representing the best that available noise control technology can produce has a 350-hp diesel engine and an SAE reading of 72 dBA.

Motor Carrier Regulation (EPA)

In support of EPA's development of the regulation of noise from interstate motor carriers, BBN first studied and characterized both the industry and the vehicles subject to regulation. We then evaluated means for developing (1) a large data base, (2) an effective measurement methodology, and (3) possible enforcement strategies. Also included in the study were investigations of the best available technology, cost of and schedule for compliance, identification of major noise sources, and the economic impact of the proposed regulation.

Quiet Truck Program (DOT)

For the Department of Transportation, BBN and Freightliner Corporation, Portland, Oregon, have together undertaken a program to design, build, and extensively road test a quiet diesel truck. Sound power level measurements have been used to diagnose the major noise-producing mechanisms. Ordinary diesel trucks have noise levels of 88 dBA at 50 ft. The BBN-designed prototype, which has successfully completed a year of road testing, now operates at a significantly reduced noise level of 72 dBA at 50 ft.

Some of the salient noise control features of the Quiet Truck are:

- An exhaust system, which includes a manifold muffler mufflers within the exhaust line, and fiberglass and aluminum wrappings on the exhaust lines.
- Two-stage engine mounts for vibration isolation.
- A thermostatically controlled fan, which operates only when necessary.

- A partial engine enclosure to provide adequate attenuation of engine structural noise without decreasing engine access or cooling ability.

Of three parallel DOT-sponsored efforts with teams of manufacturers, research firms, and universities, this program has been the most successful in terms of quieting achieved and delivery into service.

Also under this contract, BBN analyzed the economics of line-haul diesel trucks that use advanced technology to achieve low noise levels. The work involved estimating changes in truck manufacturing and operating costs for a variety of noise control measures and selecting the optimal mix of treatments for any specified noise reduction.

Studies for Highway Research Board

For several years, BBN has worked closely with the Highway Research Board of the National Academy of Sciences. Two projects conducted in 1965 involved (1) development of a simulation method for determining noise from highway traffic and (2) identification of the physical measure of vehicle noise which predicts with the highest degree of correlation the average subjective reaction of a group of observers. In 1970, we developed an engineering design guide for calculating the acoustic impact of any highway configuration and the effect on this impact of design modification.

In February of this year, we submitted a 6-volume final report on a major study for the HRB to establish standards for highway noise levels:

Vol. 1. Design Guide for Highway Noise Prediction and Control
Vol. 2. Assessment of Vehicular Noise Sources and Reduction Technology
Vol. 3. Highway Noise Propagation and Traffic Noise Models
Vol. 4. Evaluation of Community Measures to Control Highway Noise
Vol. 5. Economic Trade-Offs of Highway Noise Control Strategies
Vol. 6. Time-Varying Noise Criteria

6.2 Technology and Cost Studies: Rail Systems

Contribution to Background Document for Rail Carrier Noise Regulations (EPA)

BBN compiled all data on train noise up to 1973, in a search for information on measurements of noise caused by trains. Among the sources utilized were technical journals published in the United States, Canada, Europe, and Asia; acousticians; personnel from the two locomotive factories still in existence; personnel from the Association of American Railroads; and railroad employees.

As part of this program, BBN also studied the costs of fitting mufflers on all diesel-electric railroad locomotives in the U.S. Included in the study was an investigation of the effects of such a retrofit program on the railroads' maintenance activities and on peak-load capacities. Projections of effects on revenues and expenses were made for each of the Class I railroads. Estimates were also made of the impact on freight rates and quality of service.

Evaluation of Railroad Noise Reduction Techniques (EPA)

In an earlier BBN report, two techniques were suggested for quieting the operation of railroads: fitting mufflers to locomotives and erecting barriers around retarders. In the "Evaluation" report, BBN scientists considered the technical aspects of both techniques, the cost (both for new locomotives and for retrofit programs), the economic impact on railroads, and the benefit to the community from noise reduction thus achieved.

Measurement and Evaluation of the Impact of Railroad Noise Upon Communities (EPA)

In an interim report, published in 1973, BBN described recent measurements of noise caused by railroad operations. Numerical measures of the intrusiveness of the noise upon communities were listed, and important noise sources were ranked in order of their intrusiveness. Programs for improving the descriptions of poorly understood noise sources were recommended, and procedures for determining the need for control of those sources were described.

Computer Program for Prediction of Noise from Line-Haul Locomotives (EPA)

BBN developed an automated technique to predict community exposure to railroad noise, taking environmental details into account. Factors affecting the radiation of such noise are numerous: they include geometrical spreading of the wavefronts, absorption by atmospheric water vapor, ground absorption, atmospheric refraction, and shielding by ground barriers. Any or all of the factors may vary with frequency and range.

BBN wrote a special computer program, EXATMO (Excess Atmospheric Attenuation Model), to perform the calculations needed to predict attenuation of railroad noise.

Wheel/Rail Noise (DOT)

BBN has been studying rail system dynamics for many years. Currently, we are completing a study for DOT/TSC on noise generated by the interaction of wheels and rails in rapid transit systems. This study involves modeling interactions of the wheel and rail and represents the state of the art in analyzing rail system dynamics. The advanced analytical techniques developed under this program will be used to reduce noise and vibration from wheel/rail interaction. This fundamental research on rail/wheel interaction is needed to help characterize the physical mechanisms by which trains generate noise and vibration. We are also investigating methods of detecting high levels of stress before they can cause wheel failure. These activities represent an important step toward achieving greater safety, comfort, and quiet through design of improved suspension systems, tracks, and track-mounting methods.

As part of this wheel/rail noise study, BBN developed an algorithm for the Urban Mass Transit Administration to use in determining the most cost-effective treatment from a set of proposed noise control treatments.

Noise in Rail Transit Cars: Incremental Costs of Quieter Cars (EPA)

Rail rapid transit systems, car operations, and the car building industry are described in relation to the procurement of quieter cars. All combinations of car noise-control modifications that are considered technically and economically feasible for implementation are described. Estimates are presented of initial and operating costs.

6.3 Technology and Cost Studies: Recreational Vehicles

Work on Four Privately Owned Yachts

Kalamoun, a 94-ft aluminum diesel Express cruiser, was launched in Bremen, Germany, June 1973, and achieved a 44-kt light displacement speed trial. Work on *Kalamoun* was aimed at control of all onboard noise sources that might contribute to underway or at-anchor noise, plus provision of a high level of speech privacy between compartments. Absolute minimization of the weight of acoustic treatments was required to prevent reducing the boat's exceptional speed potential. Sources treated ranged from main engine exhaust to toilet flush noise. Participation in preliminary and final design stages, as well as on-site inspection of acoustic treatment installation, resulted in noise levels considerably below those found on boats much heavier and much less powerful.

Sea Star is a 123-ft steel three-masted schooner and BBN performed retrofit work on her. Problems consisted of noise being transmitted from diesel generators into staterooms, from the engine room vent fan onto the quarter deck, and from the roll-stabilizer hydraulic pump into the galley and crews' quarters. Significant reductions (8 to 12 dBA) were achieved by treatments which included enclosing the generators, remounting the generators and hydraulic units, and muffling the engine room vent fan.

In the 15-m wooden high-speed cruiser, *Corsara*, the diesel generator was causing an annoying vibration in the cabin sole. Simple tuned vibration dampers, designed and fabricated at BBN, were installed causing an 8-dB reduction of the critical vibration frequency.

The problem with *Capricia*, a 20-m wooden yacht, was noise during motoring. At moderate speed, noise on the deck and in the aft cabin was louder than at full throttle. Increased noise at reduced throttle was determined to be due to an under-pitched propeller that face-cavitated at speed less than hull speed. Engine noise was being transmitted through the engine compartment top and also by vibration transmission through age-hardened rubber mounts. Recommendations included a smaller-diameter, higher pitched propeller, special carpent underlayment over the engine enclosure, and replacement of the aged engine mounts.

Regulations for Recreational Vehicles (Chicago)

As part of a broad study to assist the City of Chicago in regulating all sources of community noise, BBN identified the various noise sources of recreation vehicles, suggested remedial steps for abatement of these sources, and described the practical limits of noise control with present technology and the attendant costs. We also reviewed the fundamentals of noise measurement and specific measurement procedures likely to be useful in the noise abatement efforts of the City of Chicago.

6.4 Work Performed for Transportation Industry

Noise and Vibration Courses (GM, Ford)

Over the past several years, BBN has developed a close working relationship with manufacturers of both transportation and recreational vehicles. A good indication of the regard in which we are held by the automotive industry is that, in 1971, we presented a 72-lecture-hour course on "Understanding and Solving Automotive Noise and Vibration Problems" to about 40 specialists from most divisions of General Motors Corporation. This course proved so successful that we were asked to, and did, present the same course at Ford Motor Company.

Truck Fan Study (Ford)

BBN undertook a study of diesel truck fan noise for the Ford Motor Company. Initial research proved that the fan noise levels were due, in part, to poor cooling system configuration. Therefore, in addition to redesigning the shroud as originally planned, we extended our research to include a new basic design for the truck fan. Our shroud and fan design changes reduced the noise by 11 dBA, increased cooling effectiveness 15%, and reduced power requirements by 50%. The efficiency of the entire fan system increased from 15% to 27%.

Studies for Motor Vehicle Manufacturers Association

For the MVMA, BBN has conducted several studies of motor vehicle noise. Among the most recent of these are research projects to determine the contributions of various types of motor vehicles (1) to the physical characteristics of noise that are judged most annoying and (2) to most common traffic situations; a study of the trends in motor vehicle noise, including technical and social/economic/legal variables; and noise measurements of several makes and models of motorcycles and trucks under varying operating conditions.

Studies for Association of American Railroads

For the Association of American Railroads (AAR), BBN measured noise levels from railroad operations in and around the Missouri-Pacific yard and line facilities in Ft. Worth, Texas. AAR needed this information to respond to questions published by EPA concerning measurement, control, and impact of noise from railroad operations. Among the measurements made during this contract were noise levels from retarders, engines, horns, and car-car impacts, wayside noise, and community noise. Techniques used for data interpretation included time histories, distributions, A-weighting, and 1/3-octave band analysis.

In another study for AAR, BBN assembled information on railroad noise, then measured sound characteristics encountered during both line and yard operations. The report focused on three aspects of railroad noise: its environmental effects, identification of the relative importance of various sources, and prediction of noise levels that may be reached through the application of various noise control strategies.

Studies for Transit Authorities

BBN has conducted a number of studies for transit authorities in the U.S. and abroad. Some of these studies have involved the evaluation and development of design techniques for the reduction of noise and vibration caused by rail transit systems. Some of the approaches we have considered include "floated" slabs, rail fasteners, rail welds, and track design. For example, the New York City Transit Authority, we evaluated the dynamics of resiliently supported concrete track slabs to provide guidance for slab design. Included in this study were the physical aspects of slab response, sound radiation, and vibration isolation; predictions of noise and vibration for several slab configurations; and recommendations for slab parameters.

Also for the New York City Transit Authority, BBN conducted a study of the influence of rail-fastener design on noise and vibration control. The basic mechanisms of noise and vibration generation were considered in light of the effects of fastener parameters; then, two types of fastener design were considered: the resilient rail fastener and the resiliently supported tie. In a study for the Washington Metropolitan Area Transit Authority on the effects of rail-fastener stiffness on the vibration transmitted to buildings adjacent to subways, BBN developed design parameters for track fasteners. A sample fastener design was used to illustrate how one may obtain a fastener with the required vertical and lateral values of stiffness. Implementation of our recommendations could result in a 15-dB reduction of noise transmitted to neighboring buildings.

Other transit authorities for whom we have conducted studies ranging from wayside noise measurements to designs for reducing noise in subways include those in Boston, Calgary, Toronto, Munich, and London.

6.5 Measurements and Test Procedures

As a well-recognized leader in the field of acoustics, BBN has over the last 25 years made significant contributions to the development of measurement technology. Because of these contributions and because of the outstanding qualifications of our personnel, members of the BBN staff have served on several committees for the establishment of measurement standards. Technical staff members who will be participating in the proposed program and who have served on such committees are E.K. Bender and W.N. Patterson (ad hoc committees on the development of measurement standards for construction noise and rail transit noise) and K. McK. Eldred, who served on the ISO Noise Measurement Standards Committee. Currently, G.G. Huggins is conducting for EPA an evaluation of measurement procedures to be used to assure compliance of trucks with EPA truck noise regulations.

Examples of recent programs involving measurements or the development of test procedures are summarized below.

Measurements of Noise from Portable Air Compressosr (EPA)

BBN, under EPA sponsorship, performed diagnostic noise measurements on three portable air compressors. The measurement results were used to identify levels from individual sources, so that techniques and cost of noise control could be estimated. The data were also used to establish the effects of phenomena such as noise directivity on the suitability of existing test procedures for predicting actual community exposure levels.

Motor Vehicle Noise Investigation (California)

In an investigation sponsored by the California Highway Patrol, BBN provided the technical basis from which the State of California enacted legislation to limit motor vehicle noise. Comprehensive noise measurements were made on passenger and sports cars, motorcycles, and trucks under a number of different operating conditions. The relative amount of noise produced by motor vehicle exhausts as compared to the residual vehicle noise (i.e., gears, engine, tire noise) was examined.

Analysis of Noise from Individual Highway Vehicles (HRB)

Data were presented and analyzed for noise produced by passenger cars and diesel trucks. The report discussed the observable effects for such variables as the vehicle speed, kind of road surface, the existence of an up or down grade, the load on the vehicle engine. A simulation method for determining the noise from highway traffic was developed. This method allows analysis of complex highway situations and enables prediction of traffic noise levels on a statistical basis.

Railroad Locomotive Noise Measurements (EPA)

During a study of railroad locomotive noise for the EPA (referred to above), the Agency determined that it was necessary to obtain additional measurements; BBN was requested to perform them. The measurement team was in the field within 10 days after the Agency's request; 15 locomotives were measured in the course of a week; and a summary report was issued a week after the measurements were completed.

Environmental Noise Measurement Procedures (DOT)

Under contract to the Office of Noise Abatement, BBN investigated the rationale and plans for the measurement of environmental noise on a nationwide basis. The survey was designed so that actual site selection and data acquisition could be carried out by relatively unskilled personnel in local communities; hence, rather specific guidelines were developed for measurement, selection of measurement sites, data collection, and field observation.

6.6 Labeling

Noise Emitting and Attenuating Devices (EPA)

We are currently under contract to EPA to perform technical analysis in support of the development of labeling regulations for noise-emitting and attenuating devices. This project is just getting underway.

Research on Child Seat Safety Standards (Juvenile Product Manufacturers, Car Seat Group)

In this project, we developed specific language for the labeling requirements of Federal Motor Vehicle Safety Standard 213 (49 C.F.R. 571.213), based on our research for safety performance and on an extensive social survey that investigated actual usage patterns of U.S. families in widely separated geographical areas and in different socio-economic levels. Specific lines of inquiry included the user's age, the extent of the user's exposure to the hazardous situation, and the reasons for product purchase and use, including the value of information contained on product labels or hang-tags.

Investigation of the Design and Performance of Traffic Control Devices (FHWA)

For the Federal Highway Administration, we assembled from our technical staff a multidisciplinary team of engineering and experimental psychologists, engineers, and graphic designers to conduct a design and an experimental study. The work encompassed an analysis of the legal background for uniform traffic control signs, an extensive series of laboratory investigations and controlled road testing, and a group of graphic design exercises. The experimental investigation was directed to the communications performance of graphic elements: color, outer shape, border width, type style, stroke width, word placement, and the meaning and recognizability of pictographs. Experimental design and data analysis methods were developed through the application of statistical decision theory.

Regulation of Baby Bouncers or Walker-Jumpers (Juvenile Products Manufacturers, Baby Walker Group)

BBN recommended specific language for a product label to be required by Federal regulation. Our recommendations included the language and the size of type, as well as the information to be furnished in order to meet the purposes of the Federal statute involved. In addition, we analyzed the requirements for a separate label on the package or shipping container for the purposes of Federal enforcement. We also examined the need for manufacturer record-keeping requirements relating to the sales and distribution of these articles and recommended specific regulatory language on this subject.

6.7 Technical Writing

In addition to writing and editing, BBN's Publications Staff members coordinate the work of typists, illustrators, designers, and printers to produce BBN proposals, reports, and journal articles. Working closely with BBN scientists, they have completed various papers and undertaken original research. The members of the department are published writers in their own fields.

Some examples of their work include:

- HUD *Noise Assessment Guide* and and accompanying *Training Program*
- *Shipboard Noise Control Handbook* (see below)
- *Handbook for the Assessment of DE 1052 SHIPALT Machinery on Sonar Self-Noise*
- *Noise from Construction, Home Appliances, and Building Equipment*

Some journal articles include "Design and Calibration of a High-Volume Cascade Impactor," and "Noise in Stamping Industries." Below is a more detailed discussion of one of the above-mentioned projects.

Shipboard Noise Control Handbook (DOT)

Under the joint sponsorship of the U.S. Navy and Coast Guard, BBN developed a handbook to assist ship designers in controlling airborne noise. The work required us to present a large amount of technically complex information and procedures in a simple, structured format for use by shipyard designers untrained in acoustics. The completed document represented the first time that all the relevant techniques had been assembled in one place and reduced to a worksheet format.

6.8 Library and Information Sciences

BBN has designed, developed, and implemented computer-based information systems since 1959, particularly in the areas of information managing, time-sharing, computer networks, medical applications, and educational technology.

Information Sciences

BBN has developed information-management systems for the management and operation of a major Boston hospital, for the study of the structure of complex organic molecules by the National Institute of Health, and for the storage and retrieval of underwater acoustic data by the Naval Scientific and Technical Intelligence Center. We have also developed an experimental data-management system to explore the problems of file security and access posed by a large data base embedded in an interactive, time-shared environment.

Each of these BBN-developed systems provides: the means for specifying the logical and physical organization of data, for updating files, and for manipulating and retrieving data; a language for specifying queries; and the ability to display and print query responses and reports in a specified format. Most of the systems operate in a time-shared, on-line mode. Our principal design criteria were ease of application, simplicity of design, responsiveness, and economy of hardware and software.

Library

The BBN Library is one of the finest specialized technical libraries in the area. In addition to maintaining current references in our areas of interest, the librarians prepare literature searches, develop special-interest collections, and coordinate all BBN reports and technical publications.

7. PERSONNEL QUALIFICATIONS

This section presents brief summaries of the qualifications of key personnel under each area of expertise. Those cases where individuals have project responsibilities in addition to their technical work are so noted. Complete resumes may be found in Appendix A.

7.1 Noise Control Engineering

Dr. Erich K. Bender — Program Manager
Task No. 1 Manager

Dr. Bender's contributions to engineering system and design include evaluations of fan noise mechanisms, design of duct silencers, evaluation of noise treatment for diesel engines and gear trains, and analysis of the response and sound transmission in complex structures. He has contributed to rail system noise control through studies of the effectiveness of resiliently supported track slabs, resilient rail fasteners, the effectiveness of welded rail, and the acoustic treatment of stations and tunnels. In the field of motor vehicle noise control, Dr. Bender has been BBN's principal investigator in a DOT-sponsored truck-quieting program. In support of the EPA's report to Congress, Dr. Bender supervised an intensive study of the sources, impact, control potential, and industrial activities concerning noise from various sources.

William N. Patterson

Mr. Patterson is engaged in research, development, and consulting in the fields of noise, vibration, and testing. He has evaluated rapid transit vehicle designs and prediction of subway-induced noise as well as vibration in adjacent structures. On the Quiet Truck Program, he has designed and tested the engine exhaust system for a new heavy-truck generation. He has investigated the noise-producing mechanisms on dump trucks, concrete mixers, bulldozers, and compressors, as well as analyzing the costs to manufacturers and owners of quieting this machinery. Other recent work includes engine-vibration isolation and muffler design for the Mk 48 and refrigerator compressor-noise control.

Dr. Paul J. Remington

At Bolt Beranek and Newman Inc., Dr. Remington has participated in a number of projects involving the dynamics of complex structures, numerical analyses, and control system studies. These include studies of the transmission of sound through complex aerospace structures, viscoelasticity with application to compliant coating technology, automobile exhaust system dynamics, and the unsteady dynamics, and the unsteady dynamics of parachute deployment. He has also been principal investigator in a project for analyzing mechanisms of wheel noise in rail transit vehicles and evaluating abatement techniques.

Dr. Michael J. Rudd

Dr. Rudd is involved in several projects related to aerodynamic and hydrodynamic turbulence and noise. He has also participated in projects sponsored by the Environmental Protection Agency, including ones aimed at setting noise limits for trains and home appliances. At New York University, he conducted research on the reduction of jet noise by particulates and on methods of predicting noise in structural spaces due to sonic boom; he also taught courses on noise, vibration, and dynamics, and engaged in consulting activities on jet and turbine noise problems.

Dr. Eric E. Ungar

Dr. Ungar, an Associate Division Director, is concerned with various aspects of structural dynamics and noise and with the direction of multidisciplinary approaches to the solution of technological problems. A recognized authority in the mechanical engineering field, he is listed in *American Men of Science;* he is a fellow of the Acoustical Society of America; Chairman of the Technical Committee on Vibration and Sound, Design Engineering Division of the American Society of Mechanical Engineers; Referee of the National Academy of Sciences, and is a member of many other scientific organizations.

7.2 Cost and Engineering Economy

Gene E. Fax

Mr. Fax is involved in the application of engineering economy techniques to noise control programs. In the course of his work, he has investigated for EPA the economic effects of a proposed noise control standard requiring the installation of mufflers on railroad locomotives, and performed a cost/benefit study for the Department of Transportation of the worker noise-exposure standard of 85 dBA on the manufacturing industries. Mr. Fax has performed economic and demographic studies to determine the extent of construction noise in the community. As task leader under the Department of Transportation Quiet Truck Program, he is studying the economic impact of high-technology quieting techniques on line-haul trucking operations.

Herbert L. Fox

Mr. Fox is a Senior Economist at BBN and a Lecturer in Economics at Northeastern University. Under the sponsorship of the National Science Foundation, he has performed basic research in the dynamics of developing economics, and is completing a socioeconometric survey of Massachusetts. He has conducted studies of the economic impact of regulating noise from air compressors, construction equipment, and coal cleaning machinery.

7.3 Measurements and Test Procedures

Mr. Geoffrey G. Huggins

Mr. Huggins, formerly manager of BBN's Washington-based Applied Research Department, has recently moved to the BBN Cambridge office to pursue his interest in noise control research. He has measured and examined the results of air compressor measurements for various manufacturers in a project sponsored by the Environmental Protection Agency. Presently, he is responsible for evaluating noise test procedures for medium- and heavy-duty trucks. He recently served as Project Manager for a noise measurement and control program under the sponsorship of the Washington Suburban Sanitary Commission.

Mr. Richard Ely

Mr. Ely is involved in predictions, design of experiments, and measurements related to acoustic and rheological properties of metals and viscoelastic materials, and noise from machines and vehicles. He is active in evaluating the impact of noise and noise regulations on the health and welfare of the community. One of his recent projects was the development and application of techniques for measuring noise from railroad locomotives and retarder yards.

Mr. Richard N. Alakel

Mr. Alakel, a research technician, works closely with scientists in system integration and design for experimental analysis and data collection, and also in field measurement work in areas of noise and vibration control. Recent applications of his work have been toward measuring and analyzing noise from portable air compressors, rail transit wheels, and aggregate screens.

7.4 Labeling

Mr. Charles W. Dietrich — Advisory Committee

Mr. Dietrich, the head of our Regulatory Acoustics activities, is widely known for his work for governmental agencies in the development of noise control statutes and regulations that have had national impact. He is presently working with the EPA Office of Noise Abatement and Control on the development of the Interstate Motor Carrier Regulation and has participated in the development of the Interstate Railroad Regulation. Prior to that, he assisted the EPA during the hearings held pursuant to Title IV of the Clean Air Amendment of 1970 in the areas of Standards and Measurement Method, Legislation and Enforcement Problems, and Technology and Economics of Noise Control: National Programs and their Relations with State and Local. He has been a principal in the development of labeling regulations, as well as past and current noise regulations projects for local government (Boston, Cook County, Chicago), for States (Illinois, Florida, New York, Maryland) and for industry groups. He is presently principal investigator for BBN's efforts under EPA sponsorship to develop labeling regulations for noise sources and noise-attenuation devices.

7.5 Community Noise Exposure

Dr. Theodore Schultz — Advisory Committee

Dr. Schultz currently is working on the establishment of realistic criteria and monitoring procedures for abatement of urban noise, particularly the noise from road and air traffic. Recently, he prepared a state-of-the-art review of impact noise testing and rating, in support of ongoing research efforts at the National Bureau of Standards. He has also dealt with problems of measurement and design in architectural acoustics; design and evaluation of acoustical-testing laboratory facilities; noise and vibration criteria and control for high-speed trains and for aircraft. He has also prepared two surveys on undersea reverberation. He is active in the writing and reviewing of acoustical standards at the national (ASTM and ASA) and international (ISO) levels.

Mr. Kenneth Eldred — Advisory Committee

Mr. Eldred is Director of the Architectural Technologies and Noise Control Division of BBN. In addition to his 20-year involvement in noise generation and control, he is a recognized authority on criteria for measuring the effect of noise on communities. He has consulted extensively in this field for the Office of Noise Abatement and Control since its inception. Among his recent projects in this area has been the estimation of the distribution of the U.S. population by degree of noise exposure. His many professional affiliations include membership in the National Academy of Sciences — Committee on Hearing, Bioacoustics, and Biomechanics, and Fellowship in the Acoustical Society of America.

Dr. William J. Galloway — Advisory Committee

Dr. Galloway has performed research and consulting in physical acoustics, noise control, and the response of people to noise. He has directed work on noise problems associated with jet aircraft, wind tunnels, rocket and ramjet engines, motor vehicle noise, and many industrial projects. His major efforts have been concerned with physical measurements, development of predictive models, and establishment of acceptability criteria for jet aircraft noise and noise produced by motor vehicular traffic.

7.6 Technical Writing

Nancy McMahon

Ms. McMahon, the Manager of the Publications Department, is responsible for coordinating the publication services with the printing, illustration, and photo departments. She has recently completed a booklet for the Department of Housing and Urban Development and prepared other technical papers on noise in various industries.

E. Ashley Rooney

Ms. Rooney is responsible for editing and writing technical reports. Working closely with the scientists, she prepares proposals, reports, and journal articles in addition to undertaking original research.

7.7 Library and Information Sciences

Margaret Troy

Ms. Troy, the Chief Technical Librarian at BBN, is responsible for the complete administration of the library. She also prepares literature searches and reference work.

Charlene Long

Ms. Long has developed and applied a simple computer-based system for information retrieval, which is presently being considered by a major scientific abstracting service. She has been responsible for over 20 major bibliographic compilations on such topics as man-computer interaction, robotics, learning aids for the deaf, decision aids, ultrasonics in medicine, and linear prediction - state of the art. She has conducted demographic and industrial surveys in diverse areas, including crib injuries, characteristics of populations near railroads, and the effects of OSHA and NIOSH regulations on industry.

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Bender, E.K. and Patterson, W.N. (1974). "The Technology and Cost of Quieting Medium and Heavy Trucks," BBN Report 2710.

Ford, R.D., *et al.* (1970). "The Measurement of Noise Inside Cars," *App. Acoustics* 3:69-84.

Ford Motor Company (1973). "Noise Control for Heavy Duty Trucks and Passenger Cars," Presentation to EPA, October, 1973.

Raff, J.A. and Perry, R.D.H. (1973). "A Review of Vehicle Noise Studies Carried Out at The Institute of Sound and Vibration Research With a Reference to Some Recent Research on Petrol Engine Noise," *J. Sound Vib.* 28(3): 433-470.

Wasko, R.J., Motor Vehicle Manufacturers Association, private communication, July, 1974.

APPENDIX A

RESUMÉS

ERICH K. BENDER – Manager, Applied Physics Department

Education: S.B., 1962, S.M., 1963, M.E., 1966, Sc.D., 1967 (Mechanical Engineering), Massachusetts Institute of Technology.

Professional Experience: Engineer, Grumman Aircraft Engineering Corp., summers, 1961 and 1962; Research Assistant, Staff Engineer, MIT Instrumentation Laboratory, 1962-1965; Research Assistant, MIT Mechanical Engineering Dept., 1965-1967; Bolt Beranek and Newman Inc., 1967-present.

Honors and Societies: Acoustical Society of America; Institute of Noise Control Engineering (Board of Examiners); Sigma Xi; American Society of Mechanical Engineers; American Institute of Aeronautics and Astronautics.

Professional Responsibilities and Projects: Dr. Bender has been engaged in research, development, and consulting in the fields of noise, vibration, control systems, and fluid mechanics. For the majority of his projects, he has served as principal investigator with the accompanying technical and managerial responsibilities.

At Bolt Beranek and Newman Inc., Dr. Bender has contributed to the evaluation and solution of noise and vibration problems, as well as the assessment of community noise levels. Noise problems have included diagnosis of fan noise mechanisms, the design of duct silencers, the evaluation of noise treatment for diesel engines and gear trains, and the analysis of the response and sound-transmission in complex structures. He has contributed to rail system noise control through studies of the effectiveness of resiliently supported track slabs, resilient rail fasteners, the effectiveness of welded rail, and the acoustical treatment of stations and tunnels. In addition, he has conducted field measurements of various North American and European subways. In the field of motor vehicle noise control, Dr. Bender has been BBN's principal investigator in a DOT-sponsored truck-quieting program with the Freightliner Corp., and has been active on an ASA motor vehicle noise group. He has also taught automotive noise and vibration courses at General Motors and the Ford Motor Co. In support of the Environmental Protection Agency's report to Congress, Dr. Bender supervised an intensive study on the sources, impact, control potential, and industrial activities concerning noise from various sources.

At BBN and previously at MIT, Dr. Bender has contributed to engineering system analysis and design, including evaluations of hydrofoil ship and spacecraft control systems, and the use of analog multiplexing circuits to improve system reliability through the use of redundant components.

Technical Papers:

"Sampled-Data Velocity Vector Control of a Spacecraft," ASME 63-WA-314, November 1963.

"Multiple Sensors Boost Signal Quality" (with D.C. Karnopp), *Control Eng.*, 13, No. 7, pp. 68-73, July 1966.

"Frequency Effects in Analog Channels Multiplexed for Reliability" (with D.C. Karnopp), *Proceedings of the Joint Automatic Control Conference* 1967:447-453 (1967).

"Optimum Linear Control of Random Vibrations," *Proceedings of the Joint Automatic Control Conference* 1967:135-143 (1967).

"On the Optimization of Vehicle Suspensions Using Random Process Theory" (with D.C. Karnopp and I.L. Paul), *Proceedings of the Sesquicentenial Forum Transportation Engineering,* Aug. 1967, New York; ASME Paper 67-TRAN-12.

"Multiplexing of Continuous Signals to Improve Accuracy and Reliability" (with D.C. Karnopp), *Regelungstechnik,* 11:494-498 (1967).

"Optimum Linear Preview Control with Application to Vehicle Suspensions," *ASME Trans. J. Basic Eng. (Ser. D)*, 90-2:213-221, June 1968.

"Some Fundamental Limitations of Active and Passive Vehicle-Suspension Systems," *1968 SAE Transactions*, pp. 2910-2915.

"Noise Problems of High Speed Ground Transportation" (with C.W. Dietrich and P.A. Franken), *Proceedings of the Carnegie-Mellon Conference on High Speed Ground Transportation*, Pittsburgh, Pa., pp. 141-156, May 1969.

"On the Generation and Reduction of Automotive and Rail Vehicle Noise," *1970 Proceedings of the Institute of the Environmental Sciences*, pp. 221-227.

"Environmental Effects of Transportation Noise" (with P.A. Franken), ASME Paper No. 70-TRAN-52 (1971).

"The Minimization of Hydrofoil Ship Control Power" (with P.J. Remington and W.C. O'Neill), *Proceedings of the Third Ship Control Systems Symposium*, Bath, England, 26-28 September 1972.

"Noise From Construction, Home Appliances, and Building Equipment," *J. Inst. Environmental Sciences*, September-October 1972 (to be published).

"A Review of Internal Combustion Engine Induction and Exhaust Noise" (with T. Brammer), *J. Acoust. Soc. Amer.* (to be published).

"Analysis of the Response, Sound Radiation, and Vibration Transmission of a Resiliently-Mounted Track Slab" (in preparation).

<u>Book Review</u>:

Introduction to Terrain-Vehicle Systems, by M.G. Bekker (The University of Michigan Press, Ann Arbor). Review published in *The Shock and Vibration Digest*, 1:7 (1969).

Sponsored BBN Technical Reports:

"Some Noise and Vibration Problems Associated with Pneumatic-Tube Transportation" (with K.S. Lee), BBN Rept. No. 1590, February 1968.

"High-Speed Ground Transportation: Noise Sources" (with C.W. Dietrich, R.D. Bruce, H.H. Heller, and P.R. Nayak), BBN Rept. No. 1741, October 1968.

"Analysis and Reduction of Strapdown Navigation System Errors Induced by Random Vibration" (with R. Abilock), BBN Rept. No. 1748, January 1969.

"Effects of Vibration on Human Performance: A Literature Review" (with A. Collins), BBN Rept. No. 1767, February 1969.

"Development of Prototype Muffler-Diffuser Assemblies for S-IVB Workshop Ventilating Fans" (with I. Ver and E. Ungar), BBN Rept. No. 1774, March 1969.

"An Analysis of the Noise Reduction of Orthotropic Cylindrical Shells," BBN Rept. No. 1775, April 1969.

"Predictions of Subway-Induced Noise and Vibration in Buildings" (with U. Kurze, K. Lee, and E. Ungar), BBN Rept. No. 1823, May 1969.

"Effects of Rail-Fastener Stiffness on Vibration Transmitted to Building Adjacent to Subways" (with U. Kurze, P. Nayak, and E. Ungar), BBN Rept. No. 1832, June 1969.

"Effects of Resiliently Mounted Track Slabs on Noise and Vibration" (with U. Kurze and E. Ungar), BBN Rept. No. 1878, September 1969.

"Noise Generated Aboveground and in Stations" (with M. Heckl), DOT Rept. No. OST-ONA-70-1, January 1970.

"Noise and Vibration Measurements in the Toronto Transit Commision Subway" (with R. Bruce and E. Ungar), BBN Rept. No. 1899, November 1969.

"The Acoustical Treatment of Stations to Alleviate Wheel-Squeal Noise" (with P. Hirtle), BBN Rept. No. 2052, October 1970.

"Sources and Control of Ground Vehicle Noise," BBN Rept. No. 2058, November 1970.

"A Feasibility Study of Active Landing Gear" (with E.F. Berkman and M. Bieber), Technical Rept. No. AFFDL-TR-70-126, December 1970.

"The Unsteady Hydrodynamics and Control of Hydrofoils Near a Free Surface" (with J.I. Smullin), BBN Rept. No. 1970, January 1971.

"Noise From Construction Equipment and Operations, Building Equipment, and Home Appliances" (*et al*), Rept. No. 2192, December 1971. Also, Environmental Protection Agency Rept. No. NTID300.1.

"Station Acoustics" (with P. Hirtle and R. Stern), BBN Rept. No. 2380, July 1972.

"The Effect of Tunnel Acoustic Treatment on the Noise Inside Subway Cars" (with H. Heller), BBN Rept. No. 2391, August 1972.

"Resiliently Supported Track Slabs: Analysis and Design Recommendations," BBN Rept. No. 2398, August 1972.

MICHAEL N. ALAKEL – Engineer

Education: B.S. (Electrical Engineering), Lowell Technological Institute, 1971.

Professional Experience: Draftsman, Western Electric Company, Summer, 1969; Draftsman, Consultants and Designers, 1971-1972; Electronic Technician, Bolt Beranek and Newman Inc., 1972-1973; Engineer, 1973-present.

Professional Responsibilities and Projects: At Bolt Beranek and Newman Inc., Mr. Alakel works closely with scientists in system integration and design for experimental analysis and data collection, and also in field measurement work in areas of noise and vibration control.

As a technician at BBN, he maintained and calibrated sound and vibration equipment and other related equipment.

Recent projects on which Mr. Alakel worked include:

1. EPA Compressor Noise Project: field measurements to determine SPL and directivity of sound generated and spectral analysis of 1/3-octave and 1/10-octave bands.

2. EPA Wheel Rail Noise: setting up and running experiments to determine directivity, sound power, radiation efficiency, impedance, and phase.

3. United States Coast Guard Fog Horn: testing directivity of new baffle designs in the anechoic chamber.

4. Bureau of Mines: reduction of taped data, which involved 1/3 octave bands (real-time analysis); reducing and calculating reverberation time by generating a computer program to assist in the calculations.

5. Man Labs Damping Mats: experiments in progress on damping of various materials.

CHARLES W. DIETRICH – Senior Engineering Scientist, Regulatory Acoustics

Education: S.B., Massachusetts Institute of Technology, 1956; S.M. (Electrical Engineering), Massachusetts Institute of Technology, 1958.

Professional Experience: Teaching Assistant (Electrical Engineering), Massachusetts Institute of Technology, 1956-1958, Bolt Beranek and Newman Inc., 1958-present; Guest Lecturer, Massachusetts Institute of Technology, 1964, 1967-1970, 1972.

Honors and Societies: Member, Tau Beta Pi, Eta Kappa Nu, Sigma Xi, Acoustical Society of America, Audio Engineering Society, Society of Automotive Engineers, Highway Research Board, Human Factors Society, Electrical Railroaders' Association, Institute of Noise Control Engineers.

Professional Responsibilities and Projects: Mr. Dietrich has worked in the fields of instrumentation, data acquisition, and environmental studies. His responsibilities have included experimental programs, including extensive field measurements, in studies of random vibration and acoustic response of structures, and the assessment of community noise pollution.

Mr. Dietrich has participated in and led several studies for governmental agencies at local, state, and Federal levels concerned with the development of rules and regulations for safety and the protection of the environment. His current responsibilities include the development of noise pollution standards and comprehensive regulatory programs for the control of environmental noise arising from such sources as property uses, utility and recreation vehicles, and other engine-powered equipment.

CHARLES W. DIETRICH – Senior Engineering Scientist,
Regulatory Acoustics

Education: S.B., Massachusetts Institute of Technology, 1956; S.M. (Electrical Engineering), Massachusetts Institute of Technology, 1958.

Professional Experience: Teaching Assistant (Electrical Engineering), Massachusetts Institute of Technology, 1956-1958, Bolt Beranek and Newman Inc., 1958-present; Guest Lecturer, Massachusetts Institute of Technology, 1964, 1967-1970, 1972.

Honors and Societies: Member, Tau Beta Pi, Eta Kappa Nu, Sigma Xi, Acoustical Society of America, Audio Engineering Society, Society of Automotive Engineers, Highway Research Board, Human Factors Society, Electrical Railroaders' Association, Institute of Noise Control Engineers.

Professional Responsibilities and Projects: Mr. Dietrich has worked in the fields of instrumentation, data acquisition, and environmental studies. His responsibilities have included experimental programs, including extensive field measurements, in studies of random vibration and acoustic response of structures, and the assessment of community noise pollution.

Mr. Dietrich has participated in and led several studies for governmental agencies at local, state, and Federal levels concerned with the development of rules and regulations for safety and the protection of the environment. His current responsibilities include the development of noise pollution standards and comprehensive regulatory programs for the control of environmental noise arising from such sources as property uses, utility and recreation vehicles, and other engine-powered equipment.

Papers and Publications:

"Relaxation Oscillations in Some Cord Reinforced Rubber Structures," S.M. Thesis, Department of Electrical Engineering, Massachusetts Institute of Technology (1958).

"Study of a Response Load Recorder" (with D.U. Noiseux, P.W. Smith, Jr., and E.A. Starr), ASD-TDR-62-165, Vol. II (Jan. 1963).

"Random Vibration Studies of Coupled Structures in Electronic Equipments" (with D.U. Noiseux, E.E. Eichler, and R.H. Lyon), ASD-TDR-63-C-205, Vol. II (Oct. 1963).

"Dynamic Response, Energy Methods, and Test Correlation of Flight Vehicle Equipments" (with D.U. Noiseux, R.H. Lyon, and E.A. Starr), AFFDL-TR-65-92, Vol. I (May 1965); AFFDL-TR-65-92, Vol. II (July 1965).

"High-Frequency Vibration Isolation" (with E.E. Ungar), *J. Sound Vib.* 4, 224-241 (1966).

"Modeling of Spacecraft for Low-Frequency Noise Reduction" (with R.H. Lyon and R.E. Apfel), *Shock Vib. Bull.* 35, Pt. 5, 235-242 (Feb. 1966).

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Oral Presentations:

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"Vibration Mounts for Nonrigid Structures" (with E.E. Ungar), presented at the 69*th* Meeting of the Acoustical Society of America, Washington, D.C. (June 1965). *J. Acoust. Soc. Amer.* 37, 1207 (A) (1965).

"An Investigation of Automobile Driver Information Processing" (with J.W. Senders, W.H. Levison, and J.L. Ward), presented at the 46*th* Annual Meeting, Highway Research Board, Session 44 (Jan. 1967). *Highway Res. Abstr.* 36 (12):95 (1966).

"Measuring Noise and Vibration, and Interpreting the Data," presented at the 1969 Design Engineering Show, New York, N.Y. (May 1969).

Testimony on Highway Safety, Design, and Operations - Traffic Signs, Signals, and Pavement Marking, presented to the Special Committee on the Federal Aid Highway Program of the Committee of Public Works, U.S. House of Representatives, Washington, D.C. (May 1969).

"Traffic Signs for the Seventies--and a Look Back," presented at the Transportation Systems Center, Department of Transportation, Cambridge, Mass. (January 1971).

"The Ideal Infant Car Seat" (with W.F. Rowley), presented to the New England Medical Center Hospitals, Boston, Mass. (March 1971).

"Preparation of Community Noise Ordinances," presented at CHABA Meeting, Cocoa Beach, Florida (April 1971).

"Noise Test Scores - 1970 Clean Air Car Race" (with N.R. Paulhus), presented at the 81*st* Meeting of the Acoustical Society of America, Washington, D.C. (April 1971).

"Municipal Noise Ordinances," presented at the Institute of Environmental Sciences, 17*th* Annual Meeting and Equipment Exposition, Los Angeles, California (April 1971).

"Noise and the Inflatable Restraint System," presented to the White House Office of Science and Technology *Ad Hoc* Committee Concerned with Cumulative Regulatory Effects on the Cost of Automotive Transportation (RECAT), Washington, D.C. (Sept. 1971).

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"Noise Pollution and the Construction Industry," presented to the Associated General Contractors of Massachusetts, Chestnut Hill, Mass. (Nov. 1971).

Testimony on Deficiencies in Highway Signing at Hearings on Highway Safety, Design, and Operations - Operational Deficiencies, presented to the Subcommittee on Investigations and Oversights of the Committee on Public Works, U.S. House of Representatives, Washington, D.C. (April 1972).

"Motor Vehicle Noise Control - Regulation and Enforcement," presented at the Motor Vehicle Noise Conference, sponsored by the N.Y.S. Dept. of Environmental Conservation and the Dept. of Transportation, Valhalla, New York (December 1972).

"The Noise Control Act of 1972: Pre-emption and New State Noise Regulations," presented at the Conference on Noise Pollution and Public Policy, University of California, Berkeley (March 1973).

Sponsored Technical Reports:

"Instrumentation System for New Surgical Wing, National Institutes of Health, Bethesda, Md." (with J.J. Baruch), BBN Rept. No. 857 (July 1961).

"Measurement of Acoustic and Vibration Response of Atlas Guidance Computer" (with D.U. Noiseux and E.A. Starr), BBN Rept. No. 1010 (April 1963).

"New Principles and Techniques for Reducing Noise at the Ears and Enhancing Intelligibility of Communication in Protective Helmets" (with C.H. Allen),

BBN Rept. No. 1173 (Nov. 1964) BBN Rept. No. 1356 (Mar. 1966).
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"Low-Frequency Noise Reduction of Spacecraft Structures" (with R.H. Lyon, E.E. Ungar, R.W. Pyle, Jr., and R.E. Apfel), BBN Rept. No. 1344 (March 1966).

"An Investigation of Automobile Driver Information Processing" (with J.W. Senders, A. Kristofferson, W.H. Levison, and J.L. Ward), BBN Report No. 1335 (April 1966).

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"The MBTA South Shore Project - II. Recommendations for Control of Noise and Vibration in Rapid Transit Cars" (with T.J. Schultz), BBN Rept. No. 1446 (Sept. 1966).

"Noise and Vibration Effects Study - New Orleans Riverfront Expressway," BBN Rept. No. 1452 (Oct. 1966).

"Air Pollution Effects Study - New Orleans Riverfront Expressway" (with H.G. Petrow), Prototech Rept. No. 110 (Oct. 1966).

"Noise Reduction for Forced-Draft Blowers":

"Vol. I - Blower Design Guide" (with C.L. Morfey, L.F. Smith, and T.E. Emerson), BBN Rept. No. 1454 (Dec. 1966).
"Vol. II - Blower Installation and Noise Control Guide" (with H.H. Heller), BBN Rept. No. 1455 (Dec. 1966).

"Attentional Demands of Automobile Driving" (with J.W. Senders, W.H. Levison, and J.L. Ward), BBN Rept. No. 1482 (March 1967).

"Investigation of Some of the Problems of Vehicle Rear Lighting" (with R.S. Nickerson *et al.*), BBN Rept. No. 1586 (March 1968).

"High Speed Ground Transportation: Noise Sources," BBN Rept. No. 1741 (Oct. 1968).

"An Investigation of the Design and Performance of Traffic Control Devices" (with J. Markowitz), BBN Rept. No. 1726 (Dec. 1968).

"Study of New Traffic Signs, Markings, and Signals" (with G. Jones and J. Markowitz), BBN Rept. No. 1762 (Jan. 1969).

"Comments on Child Seat Safety Standards" (with D.C. Miller), BBN Rept. No. 1828 (June 1969).

"Kansas City International Airport - A Review of Proposed Guide Signing," BBN Rept. No. 1886 (Sept. 1969).

"Noise Test Scores - 1970 Clean Air Car Race" (with N.R. Paulhus), BBN Rept. No. 2065 (Aug. 1970).

"Noise and Inflatable Restraint Systems" (with C.H. Allen, R.D. Bruce, and K.S. Pearsons), BBN Rept. No. 2020 (Sept. 1970).

"Noise Control by Law - A New Noise Ordinance," Chicago Urban Noise Study: Phase II (with G.W. Kamperman), BBN Rept. No. 1412 (Nov. 1970).

"Analysis of Community Noise and a Plan for Noise Control for the City of Boston Air Pollution Control Commission" (with P.A. Franken and G. Jones), BBN Rept. No. 2069 (March 1971).

"Comments on Proposed Safety Regulation on Baby Bouncers or Walker-Jumpers" (with J.C. Heine), BBN Rept. No. 2152 (May 1971).

"State of Illinois: Development of Regulations for Noise at Property Lines," BBN Rept. No. 2177 (July 1971).

"Consolidated Federal Law Enforcement Training Center: Evaluation of Alternative Roadside Safety Measures for Pursuit Track" (with N.R. Paulhus), BBN Rept. No. 2336 (March 1972).

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"Comments on the Proposed Regulations for the Prevention and Control of Environmental Noise Pollution from Construction and Stationary Sources," BBN Rept. No. 2510(b) (February 1973).

"Noise Pollution Legislation Study - Background Report" (with A.S. Harris, N.M. Sober, and C. Warner), BBN Rept. No. 2553 (May 1973).

"Feasibility of Vehicle Noise - Inspection Regulations" (with W.N. Patterson and C. Warner), BBN Rept. No. 2571 (August 1973).

"Noise Pollution Legislation Study - Working Report" (with A.S. Harris), BBN Rept. No. 2610 (July 1973).

KENNETH McK. ELDRED - Director of Architectural Technologies and Noise Control Division Vice President

Education: S. B. (General Engineering) Massachusetts Institute of Technology, 1950; graduate courses in acoustics, Massachusetts Institute of Technology; graduate courses in mathematics, University of California at Los Angeles.

Professional Experience: Engineer, Boston Naval Shipyard, 1950-1954; Chief, Physical Acoustics Section, Bio-Acoustics Branch, Wright Air Development Center USAF, 1954-1957; Vice President and Consultant, Western Electro Acoustic Laboratory, 1957-1963; Vice President and Technical Director, Wyle Laboratories, 1963-1973; Bolt Beranek and Newman Inc., 1973-present.

Honors and Societies: Fellow, Acoustical Society of America; Member, Institute for Noise Control Engineering (member of Board of Directors), American Institute of Aeronautics and Astronautics, Audio Engineering Society, Institute of Environmental Sciences, National Academy of Sciences - Committee on Hearing, Bioacoustics, and Biomechanics, Society of Automotive Engineers, Alabama Society of Professional Engineers, California Society of Professional Engineers.

Professional Responsibilities and Projects: Mr. Eldred is responsible for all activities of the Architectural Technologies and Noise Control Division of BBN. This division develops and applies engineering techniques for quieting machines, controlling vibration, protecting workers from hearing loss, and minimizing community noise. It provides measurement analysis, and control of environmental noise, for Federal, state and municipal agencies, airports, highway builders, urban planners and others concerned with noise impact. The division also undertakes acoustic design of schools, offices, apartments, performing arts centers, and fine arts facilities.

At Wyle Laboratories, he directed the technical efforts of the Scientific Systems and Services Group over a wide range of scientific disciplines including acoustics, dynamics, aerodynamics, biodynamics, reliability, and architectural acoustic consulting.

Mr. Eldred's consulting work for Western Electro Acoustic Laboratory including missile and aircraft noise and vibration, simulation of environment in model scale, sonic fatigue, investigation of basic factors controlling aerodynamic generation of noise in jets, boundary layers and wakes, investigation of vibration transmission in complex vehicle structure, development of dynamically similar structural models, evaluation of community and factory noise and vibration problems, acoustical design of auditoriums, office buildings and schools.

At Wright Air Development Center, he directed research for evaluation and control of major USAF noise sources, including extensive measurements of rocket and jet noise, investigation of noise radiated from aircraft, development of methods for predicting community reaction to noise from air base operations, evaluation of engine test cell treatments, and development of prototype ground runup noise suppressors for jet aircraft.

As Engineer in charge of the Vibration and Sound Laboratory of Boston Naval Shipyard, Mr. Eldred's responsibilities included evaluation of shipboard vibration and noise problems of all types, evaluation of underwater noise radiated by submarine auxiliary machinery, research to determine fundamental sources of vibration in rotating machinery, and development of precision portable balancing instrumentation and techniques.

Publications:

"Resume of Applications of Vibration Engineering to Solution of Marine Operational Problems" (co-author), *Trans. SNAME*, 1953.

"Results of Experience in Balancing Submarine Auxiliaries," Summary of USN Underwater Sound Symposium, May 1954.

"Criteria for Short Time Exposure of Personnel to High Intensity Jet Aircraft Noise" (co-author), WADC TN 55-355.

"Noise Radiation from Jet Aircraft in Flight" (co-author), *J. Acoust. Soc. Amer.*, 28:519 (A).

"Prediction of Rocket and Turbojet Noise," presented at ASA Fall Meeting, 1956.

Comments on "Noise Characteristics of the Caravelle Jet Airliner," *Noise Control*, 4(3):46-48, May 1958.

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"Review of the Noise Generation of Rockets and Jets," *J. Acoust. Soc. Amer.*, 32(11):1502 (A).

"Base Pressure Fluctuations," *J. Acoust. Soc. Amer.*, 33(1): 59-63, January 1961.

"Structural Vibration in Space Vehicles" (co-author), WADD TR 61-62, 1961.

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"Empirical Prediction of Space Vehicle Vibration," *Shock, Vibration and Associated Environ. Bull.* 29, Part 4, June 1961.

"Noise Generated by Aircraft in Flight," *J. Acoust. Soc. Amer.*, 33:6, 845 (A), June 1961.

"Acoustical Evaluation of the (various) Ground Runup Noise Suppressor" (co-author), ASD TR Nos. 61-540, 61-541, 61-542, 61-544, October 1961 and Tech. Documentary Reports Nos. 62-21, 62-22, 62-23, 62-24, and 62-25, Aerospace Med. Research Div., April 1962.

"Utilization of Dynamically Similar Structural Models in Predicting Vibration Responses of Flight Vehicles" (co-author), *Shock, Vibration and Associated Environ. Bull.* 31, Part III, April 1963.

"Noise Radiation In and Near a Jet Flow" (co-author), *J. Acoust. Soc. Amer.*, 35 (A), May 1963.

"Investigation of a Method for the Prediction of Vibratory Response and Stress in Typical Flight Vehicle Structure" (co-author), ASD-TDR-62-801, August 1963.

"Suppression of Jet Noise with Emphasis on the Near-Field" (co-author), ASD TR 62-578, September 1963.

"Problems in the Laboratory Qualification of Structures and Equipment Exposed to Intense Acoustic Environments," *Proc. IES*, 1964.

"Noise and Aerodynamic Pressure Fluctuations Anticipated for Space Vehicles," or "Laboratory Simulation of an Acoustic Environment for Qualification Testing," Presented at the Second International Conference on Acoustic Fatigue, 1964.

"Noise Reduction of Jets by Multiple Nozzles and Turbo Fans," *J. Acoust. Soc. Amer.*, 36:1035 (A), 1964.

"Empirical Correlation of Excitation Environment and Structural Parameters with Flight Vehicles Vibration Response" (co-author), WPAFB TR-64160.

"High Intensity Acoustic Testing — Reverberant or Progressive Waves," Presented at the Fifth Congress International D'Acoustique, Liege, Belgium, September 1965.

"Estimating the Acoustic Loading on Building Structures Near Launch Sites," Presented at the Acoustical Society of America, Washington, D.C., June 1965.

"Basic Model for the Correlation and Prediction of Flight Vehicle Vibration" (co-author), Presented at the 35*th* Symposium on Shock & Vibration, October 1965.

"Performance of a New 100,000 Cubic Foot Reverberation Room," Presented at the 71*st* ASA Meeting, Boston, June 1966.

"No Sonic Barrier to the Moon," *Test Engineering*, 1966.

"Gas Turbine Noise Control" (co-author), Presented at the 1967 Annual Meeting of the SAE, January 1967.

"Large Acoustic Facilities for Environmental Simulation" (co-author), Presented at the 1967 Annual Meeting of the IES.

"Development of Acoustic Test Conditions for Apollo Lunar Module Flight Certification" (co-author), *Shock & Vibration Bulletin*, 37: Part 5, January 1968. Also presented at the 37*th* Shock & Vibration Symposium, Orlando, Florida, 1967.

"Concept, Design, and Performance of the Spacecraft Acoustic Laboratory" (co-author), *Shock & Vibration Bulletin*, 37: Part 5, January 1968. Also presented at the 37*th* Shock & Vibration Symposium, Orlando, Florida, 1967.

"Large Vibroacoustic Test Facilities — Vibroacoustic Environmental Simulation for Aerospace Vehicles," *Shock & Vibration Bulletin*, 37: Part 5, January 1968. Also presented at the 37*th* Shock & Vibration Symposium, Orlando, Florida, 1967.

"Coupling of Finite Sized Sources to a Modal Reverberant Sound Field" (co-author), Presented at the 76*th* ASA Meeting, Cleveland, Ohio, 1968.

"Vibration and Acoustic Test Techniques," Presented at the IES 15*th* Annual Technical Meeting & Equipment Exposition, Anaheim, California, April 1969.

"Simulation of Space Vehicle Launch Environment, with Emphasis on Acoustics" (co-author), Presented at the 77*th* ASA Meeting, Philadelphia, Pa., April 1969.

"Some Technical Aspects of Noise Abatement Regulations," Presented at the 1970 Annual Meeting of the National Association of State Aviation Officials (NASAO), Hartford, Conn., September 1970.

"High Transmission Loss Wall Panels" (co-author), Presented at the 80th ASA Meeting, Houston, Texas, November 1970

"Theoretical and Experimental Results for Coaxial Flow Jet Noise" (co-author), Presented at the *80th* ASA Meeting, Houston, Texas, November 1970.

"Standards for Noise Monitoring Systems for Industrial or Community Noise" (co-author), Presented at the ASME 1970 Winter Annual Meeting, New York, December 1970.

"A Redetermination of the NOY Contours" (co-author), Presented at the *81st* ASA Meeting, Washington, D. C., April 1971.

"Control of Noise Generated by Aircraft at Subsonic Speeds," Presented at the *81st* ASA Meeting, Washington, D.C., April 1971.

"Future Trends in Airport Noise," Presented at the *81st* ASA Meeting, Washington, D.C., April 1971.

"Airport Noise," Presented at Purdue Noise Control Conference, Purdue University, Indiana, July 1971.

"Review of Aircraft Noise, Rotor Noise, Jet Noise and Sonic Boom" (co-author), Presented at the *82nd* ASA Meeting, Denver, Colorado, October 1971.

"Airport Noise Monitoring," Presented at the *82nd* ASA Meeting, Denver, Colorado, October 1971.

"Using Engineering, Research and Development Results to Implement a Noise Control Program," Presented at the National Safety Congress and Exposition, Chicago, Ill., October 1971.

"Community Noise," NTID 300.3, Environmental Protection Agency, Wash., D. C., December 31, 1971.

"Noise Pollution," Presented at the Arden House Workshop on Noise Control Engineering, Columbia University, Harriman, New York, January 1972.

"Effective Modal Density in Reverberant Sound Fields for Finite Sized Sources" (co-author), Presented at the 83rd ASA Meeting, Buffalo, N.Y., April 1972.

"Community Noise," Presented at the 18th IES Meeting, New York, May 1972.

"Transportation Noise," Presented at the 18th IES Meeting, New York, May 1972.

RICHARD A. ELY – Senior Engineering Scientist

Education: B.S. (Physics), Oklahoma State University, 1960; M.S. (Physics – Acoustics and Rheology), Oklahoma State University, 1962; graduate courses in Statistics and Economics, Southern Methodist University (Engineering Administration program), Dallas, Texas, 1966; U.S. Navy Electronics Technician School, 1955; recent short courses on Fluids in Porous Media, Rock Mechanics, Economic Analysis, Fundamentals of Finance, Principles of Management.

Professional Experience: U.S. Navy, 1954–1956; Oklahoma State University Research Assistant (Acoustics), 1960–1962; Acoustics Engineer, Ling Temco Vought, 1962–1964; Research Physicist, Senior Research Physicist, Research Scientist and Physics Section Head, Sun Oil Company Research Laboratory, Richardson, Texas, 1964–1972; Bolt Beranek and Newman Inc., 1973–present.

Honors and Societies: Member, Sigma Pi Sigma, Phi Kappa Phi, Society of Petroleum Engineers, Society of Rheology, and Acoustical Society of America (1960-1966).

Professional Responsibilities and Projects: Mr. Ely has been working in the fields of acoustics and rheology for 13 years. He has experience in designing acoustical equipment, in noise and vibration control, and in fluid dynamics. He supervised a group of his own for five years. He served as a liaison for university and industry research laboratories, served on inter-industry steering committees, and worked in community relations. He has considerable experience with computers.

At Sun Oil Company, he was a research scientist, supervising and participating in research on many aspects of fluid flow. His duties included project planning, logistics, materials coordination, budgeting, and project accounting. He prepared economic analyses of alternative investments in research and development, and he wrote computer programs for use in those analyses.

As an acoustics engineer with Ling Temco Vought, he predicted and measured noise and vibration levels and resulting structural fatigue in land, air, and sea vehicles. He emphasized studies of propeller noise, and predicted and measured the propagation of propeller noise, jet noise, and rocket noise through the atmosphere. The work also involved studies of human factors - voice communication, hearing damage, vibration of the human body, stress and fatigue of human beings.

As a research associate at Oklahoma State University, he designed, built, and calibrated test equipment, and measured and theoretically analyzed the mechanical parameters of viscoelastic fluids. Acoustical methods were used, and computer programming and operation were involved. He also assisted in computer analyses of acoustic wave propagation through layers of viscoelastic material.

At Bolt Beranek and Newman Inc., he is studying methods for measuring and controlling noise and vibration in hydraulic systems. He is also assisting in measurements of noise generated by refrigerator compressors, and is participating in studies of vibrations in some vehicle components.

Publications and Oral Presentations:

"Acoustic Fatigue Testing of Aircraft Structures by Simulated Propeller Noise" (with E.D. Griffith and R.N. Hancock), Chap. 36 of *Acoustical Fatigue in Aerospace Structures*, Syracuse University Press, Syracuse, N.Y. (1965).

"Measurement and Reduction of the Dynamical Mechanical Parameters of Aqueous Solutions of Milling Yellow Dye," Oklahoma State University (Physics), M.S. Thesis, May 1962.

"The Guerra Experiment — A field Test of Tertiary Detergent Flooding," Society of Petroleum Engineers Paper SPE 3800, Presented at the SPE Improved Oil Recovery Symposium, Tulsa, Okla., April 16-19, 1972.

Public speaker for the Oil Information Committee of the Mid-Continent Oil and Gas Association, 1972.

Technical Reports:

"The Role of Network Models and Cinephotomicrography in the Development of a Tertiary Oil Recovery Process," Sun Oil Co., 1971.

"The Application of Rolling-Ball Viscometers to Non-Newtonian Fluids" (with S. West), Sun Oil Co. Research Report No. 7250-70-8 (September 1970).

"Use of Monte Carlo Methods in Computerized Network Models of Porous Media With Randomly Varying Surface Properties" (with L.F. Rice), Sun Oil Co. Research Report No. 416-68-3 (May 9, 1968).

"Computer Predictions of the Steady Laminar Flow Characteristics of an Incompressible Non-Newtonian Viscous Fluid in a Cylindrical Tube," Sun Oil Co. Research Report No. 416-67-5 (May 1967).

"Machine Calculation of Capillary Pressure Curves by Means of Network Models of Porous Media" (with R.M. Rice), Sun Oil Co. Research Report No. 410-66-1 (November 1966).

"A Feasibility Study of Polymer Flooding of the Gloriana Path 'A' Reservoir," Sun Oil Co. Research Report No. 415-67-1 March 1967).

GENE E. FAX – Senior Scientist

Education: B.S. (Mechanical Engineering), Massachusetts Institute of Technology, 1967; Graduate Study in Ocean Engineering, Massachusetts Institute of Technology, 1967-68.

Professional Experience: Research Assistant, Westinghouse Research Laboratory, Churchill, Pa., Summers 1966 and 1967; General Oceanology, Inc. (a subsidiary of Bolt Beranek and Newman Inc.), 1968-1969; Bolt Beranek and Newman Inc., 1969-present.

Honors and Societies: Sigma Xi, Pi Tau Sigma, American Society of Mechanical Engineers.

Professional Responsibilities and Projects: Mr. Fax's recent work at Bolt Beranek and Newman Inc. has involved the application of engineering economy techniques to noise control programs. Examples of studies in which he has participated include the investigation of the economic effects of a proposed noise control standard requiring the installation of mufflers on railroad locomotives (under the sponsorship of the Environmental Protection Agency) and a study of the costs and benefits involved in imposing a worker noise exposure standard of 85 dBA on the manufacturing industries (sponsored by the Department of Labor). Mr. Fax has performed economic and demographic studies to determine the extent of construction noise in the community environment. He is currently leading a task under the Department of Transportation Quiet Truck Program to determine the economic impact of high-technology quieting techniques on line-haul trucking operations.

While associated with General Oceanology, his projects in engineering economy included a feasibility study and synthesis of a financial plan for a fish protein concentrate plant. He also performed collection and analysis of data on the operations of the New England ground-fishing fleet.

Publications:

"A Generalized Analysis for Urban Power Systems," B.S. Thesis, Massachusetts Institute of Technology, Department of Mechanical Engineering (June 1967).

"Contributions to Background Document for Rail Carrier Noise Regulations" (with E. Bender, R. Ely, M. Rudd and S. Swanson), prepared by BBN for the Environmental Protection Agency (November, 1973).

Other Reports to which Mr. Fax has been a Major Contributor:

"Project Bosporus," MIT Student System Project, MIT Rept. No. 21 (1970).

"Commercial Feasibility of Fish Protein Concentrate in Developing Countries, Vol. II - Chile," General Oceanology Inc., Rept. No. 12 (1970).

"Noise from Construction Equipment and Operations, Building Equipment, and Home Appliances," prepared by Bolt Beranek and Newman Inc. for the U.S. Environmental Protection Agency, 1971.

"Impact of Noise Control at the Workplace," BBN Report No. 2671 (in progress).

HERBERT L. FOX – Senior Physicist/Economist

Education: B.A., 1959, M.A. (Physics), Boston University, 1962; Ph.D. Program (Physics), Boston University.

Professional Experience: Design Engineer, Technical Products Co., Hollywood, California, 1955-1958; Teaching Fellow, Physics, Boston University, 1963; Lecturer in Economics, University College of Northeastern University, 1971-present; Bolt Beranek and Newman Inc., 1958-present.

Honors and Societies: National Science Foundation Fellow, 1962-1963, 1963-1964. Sigma Xi. Member, American Physical Society, American Association of Physics Teachers, American Association for the Advancement of Science, Scientists and Engineers for Social and Political Action. Past member, Acoustical Society of America, past Fellow, Instrument Society of America.

Professional Responsibilities and Projects: At Bolt Beranek and Newman Inc., Mr. Fox has given technical leadership in quantum optics, atmospheric optics, atmospheric acoustics, the physics of air pollution, nonlinear mechanics, and socio-econometrics. Presently, Mr. Fox is contributing to studies of edge noise and cost analysis of noise reduction and completing a socioeconometric study of Massachusetts on which he is co-principal investigator. He is also involved in developing BBN's capabilities in economics particularly with respect to problems that require a substantial engineering input.

Other projects on which Mr. Fox has been a principal contributor or project manager have been in the areas of kinetic theory (1963-1965), stochastic processes (1961-1964), computer control (1963-1964), geometrical acoustics (1964-1966), electroacoustic transducer (1958-1960, 1966), optical pumping (1964), quantum optics (1968-1969), meteorology (1967-1968), atmospheric acoustics (1965-1968), signal processing instrumentation (1967-1968), meteorological instrumentation (1965-1967), vibrations in nonlinear systems (1970-1973), and socioeconometrics (1971-1973).

Papers and Publications:

"An Automatic Analyzer for Spectral Density Plots" (with R.C. Moody), *Proceedings of the Third National Flight Test Symposium, Flight Test Instrumentation* (May 1957).

"Wave Analyzer Tracks Automatically," *Electronic Design*, 24-25 (Dec. 1, 1957).

"Measurements of Probability Densities of Small Ensembles of Periodic Waveforms" (with E.A. Starr), *Proc. IRE* 50:2118 (Oct. 1962).

"Probability Density Analyzer Instruction Manual" (originally issued as BBN Rept. 895, 1961), B&K Instruments Inc., Cleveland Ohio (1963).

"Propagation and Reflection of Sound in Rarefied Gases: I. Theoretical" (with G. Maidanik and M.A. Heckl), *Phys. Fluids* 8:258-265 (Feb. 1965).

"Comments on a Paper by L. Sirovich and J.K. Thurber, 'The Propagation of Forced Sound Waves in Rarefied Gasdynamics'" (with G. Maidanik), *J. Acoust. Soc. Amer.* 38:477-478 (L) (1965).

"A Quantum Optical Phenomenon: Implication for Logic" (with E.M. Ring and L.C. Clapp), in *Optical and Electro-Optical Information Processing* (MIT Press, Cambridge, Mass., 1965), Chap. 2, pp. 31-43.

"Vertical Profiles of Wind and Temperature by Remote Acoustical Sounding," in *Atmospheric Exploration by Remote Probes*, Vol. II of the Final Report on the Panel of Remote Atmospheric Probing and Committee on Atmospheric Sciences, National Academy of Sciences, National Research Council (May 1969).

"Development Through Induced Polarization in Turkey," Dept. of Economics, Northeastern University, Research Report No. 10 (Oct. 1969).

"Dynamics of Structural Changes" (with G. Schachter) (1972) (to be published).

"Socioeconomic Conversion: The Problem of Development in Massachusetts" (with G. Schachter), *Northeast Regional Science Review* 2, (1972).

"Feasibility Study of F/S Dynamic Model of Structural Change to One Region" (with G. Schachter), *Dynamic Modelling and Control of National Economics,* International Federation of Automatic Control, Dusseldorf, FDR (1973).

Selected Oral Presentations:

"A Wide Band Carrier System for Condenser Microphones," *J. Acoust. Soc. Amer.* 33:853 (A) (1961).

"The Measurement of Probability Density," *J. Acoust. Soc. Amer.* 33:853 (A) (1961).

"Errors in the Averaging of Logarithmic Estimators of Sound Pressures," *J. Acoust. Soc. Amer.* 34:738 (A) (1962).

"Automated Psychoacoustic Laboratory" (with R.J. McQuillin, J.I. Elkind, and J.A. Melaragni), *J. Acoust. Soc. Amer.* 34:1999 (A) (1962).

"Response Spectra for Nonlinear Dynamical Systems," *J. Acoust. Soc. Amer.* 34:2004 (A) (1962).

"Dispersive Properties of Sound Propagation in Gases" (with G. Maidanik and M.A. Heckl), *J. Acoust. Soc. Amer.* 35:1909 (A) (1963).

"A Simple Algorithm for Determining the Location of a Focus in Atmospheric Sound Propagation" (with F.M. Wiener), *J. Acoust. Soc. Amer.* 39:1260 (A) (1966).

"Propagation of Sound in Fog," presented at the U.S. Coast Guard Aids to Navigation School, Groton, Conn. (October 1966).

"On the Relationship between Theory and Experiments in the Kinetic Theoretic Description of Sound Propagation," invited paper presented at the Kinetic Theory Seminar, Harvard University, Cambridge, Mass. (Dec. 1966).

"Growth Poles as a Tool of Economic Development in Southern Italy" (with G. Schachter), invited paper at the Economics Colloquium, University of Connecticut (Dec. 1967).

"A Multifold Correlation Technique for Azimuth Determination," invited presentation of the Sound Ranging Seminar, Picatinny Arsenal, Dover, N.J. (June 1968).

"Development through Induced Polarization in Turkey" (with G. Schachter), presented at the Middle East Technical University, Ankara (April 1969).

"Remote Acoustic Sensing of Low-Level Winds and Temperatures" (with R. Abilock), invited presentation at the Air Pollution Control Association 62*nd* Annual Meeting, New York City (June 1969).

"Dynamics of the Development, Polarization, and Spread Effect in Underdeveloped Regions" (with G. Schachter), presented at the Italian Section, Regional Sciences Assoc., Rome Italy (Sept. 1970).

"Science for the People," invited paper of the *Symposium on Social and Economic Sciences,* 138*th* Meeting of the American Association for the Advancement of Science, Philadelphia, Pennsylvania (Dec. 1971).

"The Problem of Development in Massachusetts" (with G. Schachter), *Northeast Regional Science Conference,* Penn State (April 1972).

"Organizing Scientists for Political Action" (with S. Uhuru), Forum on Physics and Society, American Physical Society Spring Meeting, Washington, D.C. (April 1972).

"Growth, Development and Dynamic Modelling," invited Seminar at the Instituto Demografia e Statistica, Università di Roma, Rome, Italy (Dec. 1972).

"Is the F/S Model Suitable for the Problems of Mezzogiorno?" (with G. Schachter), invited talk at Centro di Specializzazine e Ricerche, Università di Napoli, Naples, Italy (Dec. 1972).

"Feasibility Study of F/S Dynamic Model of Structural Change to One Regime" (with G. Schaechter), IFAC/IFORS International Conference on Dynamic Modelling and Control of National Economics (July 1973).

Sponsored Technical Reports:

"The Potential Application of Ultrasonics to the Depolymerization of Polyethlene" (with C.H. Allen), BBN Rept. 642 (March 1959).

"Description and Instructions for BBN 339A Bilateral Logarithmic Converter" (with E.A. Starr), BBN Rept. 680 (Nov. 1959).

"Description and Instruction Booklet for BBN 338A Average and RMS Detector" (with E.A. Starr), BBN Rept. 682 (Oct. 1959).

"Low Noise Level Carrier Microphone System," BBN Rept. 723 (Oct. 1960).

"Description and Instructions for BBN 334C Absolute Value and Squaring Unit," BBN Rept. 735 (April 1960).

"Summary Report on the Probability Density Analyzer," BBN Rept. 895 (Jan. 1962).

"The Influence of Phase Distortion on Random Signals" (with G. Maidanik) (June 1963).

"Report on Joint Probability Density Measurements" (with E.A. Starr) (March 1964).

"Sound Propagation in Rarefied Gases — Final Report" (with G. Maidanik), BBN Rept. 1169 (Nov. 1964).

"Development of Techniques for the Automatic Control of Experiments in a Psychology Laboratory — Final Report" (with J.I. Elkind, J. Brown, and W.E. Fletcher), ESD-TDR-65-175 (Feb. 1965).

"Analytical Studies of the Generation Mechanism, Propagation and Measurement of Rocket Noise, Final Report" (with F.M. Wiener, E.A. Starr, and D.U. Noiseux), BBN Rept. 1322 (Sept. 1965).

"Meteorological Techniques for Sound Ranging: Conceptual Basis," ECOM-00151-4 (Dec. 1966).

"Meteorological Techniques for Sound Ranging: Computer Programs for Research," ECOM-00151-5 (Jan. 1967).

"Meteorological Techniques for Sound Ranging: Results of Computer Studies" (with P.E. Sherr), ECOM-00151-F (Aug. 1967).

"Meteorological Techniques for Sound Ranging — II, Interim Report" (with P.E. Sherr), ECOM-0233-1 (June 1967).

"Signal Processing Techniques for Sound Ranging: Preliminary Studies — 1st Quarterly Report" (with D.U. Noiseux, E.A. Starr, K.L. Chandiramani, and S.P. Robinson), ECOM-0378-1 (Oct. 1967).

"A Quantum Optical Phenomenon: Implications for Logic" (with E.M. Ring and L.C. Clapp), BBN Rept. 1567 (Nov. 1967).

"Continuous-Wave Three Component Sonic Anemometer," USAFCRL-68-0180 (March 1968).

"Signal Processing Techniques for Sound Ranging: Quantizing Delay Vectors" (with K.L. Chandiramani), ECOM-0378-3 (June 1968).

"Meteorological Techniques for Sound Ranging: Theory of Errors," ECOM-0233-2 (Oct. 1968).

"On the Feasibility of Remote Acoustic Sensing of Low-Level Winds and Temperatures" (with R. Abilock, R.H. Lyon, and U. Ingard), BBN Rept. 1735 (Nov. 1968).

"Meteorological Techniques for Sound Ranging: The Influence of Meteorological Variability" (with P.E. Sherr), ECOM-0233-F (Dec. 1968).

"Spontaneous-Emission Lifetimes of Strongly Coupled Atomic States," BBN Rept. 1768 (Dec. 1968).

"Signal Processing Techniques for Sound Ranging: From Correlation Functions to Target Coordinates" (with R. Abilock), BBN Rept. 1746 (Dec. 1969).

"Problems in the Theory of Laser Modulation," BBN Rept. 2060 (Oct. 1970).

"The Possibility of Conversion Within the Framework of American Capitalism: Three Views" (with B. Fischer *et al*), Socioeconomic Conversion Research Project, Northeastern University T.M. 006 (Dec. 1971).

"The Static Description: Link Charts and Structure Functions" (with D. Hamilton and G. Schachter), Socioeconomic Conversion Research Project, Northeastern University T.M. 007 (Jan. 1972).

"Ten-Month Summary Technical Report" (with G. Schachter) Socio-economic Conversion Research Project, Northeastern University T.M. 014 (May 1972).

"Contributions to the Theory of Randomly Forced, Nonlinear, Multiple-degree-of-freedom, Coupled Mechanical Systems" (with P.W. Smith, Jr., R.W. Pyle, P.R. Nayak), AFFDL-TR-72-45 (Jan. 1973) (also BBN Rept. 2279).

"Impact of Noise Control at the Workplace" (with R.D. Bruce, G.E. Fax, C. Coelen, R. Merrill), BBN Report 2671 (in 3 volumes) (Jan. 1974).

"Noise Control in Surface Mining Facilities: Working Information on the Industry, Its Noise, and the Cost of Noise Control" (with G.E. Fax, W.N. Patterson, and E.E. Ungar), BBN T.M. 183 (Feb. 1974).

"Portable Air Compressors: The Costs, Benefits, and Penalties of Reducing Their Noise" (with T.W. Freeze and W.N. Patterson), BBN Report 2566c (March 1974).

"Portable Air Compressor Noise Diagnosis and Control" (with W.N. Patterson *et al*), BBN Report 2795b (March 1974).

WILLIAM J. GALLOWAY - Principal Consultant

Education: B.S. (Applied Physics), 1949; M.S. (Applied Physics), 1950; Ph.D. (Physics), 1953; University of California at Los Angeles.

Experience: U.S. Army 1942-1946, 1951-1952; Teaching Assistant, Research Assistant, University of California at Los Angeles, 1950-1951; 1952-1953; Research Staff Physicist, Signal Corps Engineering Laboratories, 1951-1953; Bolt Beranek and Newman Inc., 1953-present. Commercial pilot's license with current instrument rating.

Societies: Fellow, Acoustical Society of America; Member, American Institute of Aeronautics and Astronautics, Institute of Noise Control Engineering, Sigma Xi.

Committees: Chairman, National Academy of Science/Highway Research Board Committee on Transportation Noise Research; Precision Measurement of Aircraft Noise, ANSI S1-62; Land Use Planning with Respect to Noise, ANSI S3-55. Member, International Standards Organization Technical Committee 43 on Aircraft Noise and 20 on Aircraft Noise; Society of Automotive Engineers A-21 Aircraft Noise; American Institute of Aeronautics and Astronautics Committee on Aero-Acoustics; National Academy of Science/National Research Council Committee on Hearing and Bioacoustics. Advisor, Bioacoustics Panel, Federal Interagency Transportation Noise Abatement Program.

Responsibilities and Projects: Dr. Galloway has performed research and consulting in physical acoustics, noise control, and the response of people to noise. He has directed work on noise problems associated with jet aircraft, wind tunnels, rocket and ramjet engines, motor vehicle noise, and many industrial projects. His major efforts have been concerned with physical measurements, development of predictive models, and establishment of acceptability criteria for jet aircraft noise and noise produced by motor vehicular traffic.

Papers and Publications:

"Transistors and the Military" (with I.R. Obenchain), *Proc. Inst. Radio Engrs.*, 40, 1287-1288 (1952).

"A Simple Calibration Technique for Low Sensitivity Transducers," *J. Acoust. Soc. Amer.*, 25, 1127 (1953).

"Apparatus for the Study of Cavitation in Liquids," *J. Acoust. Soc. Amer.*, 26, 149 (A) (1954).

"Experimental Study of Acoustically Induced Cavitation in Liquids," *J. Acoust. Soc. Amer.*, 26, 849 (1954).

"Noise Characteristics of Turbojet Engines in Test Cells" (with A.C. Pietrasanta), *J. Acoust. Soc. Amer.*, 27, 203 (A) (1955).

"Procedures for Performing and Evaluating Acoustical Surveys of Turbojet Engine Test Facilities" (with A.C. Pietrasanta), WADC Technical Report No. 55-145 (April 1955).

"Explosive Noise Source" (with B.G. Watters and J.J. Baruch), *J. Acoust. Soc. Amer.*, 27, 220 (1955).

"Acoustical Evaluation of Jet Engine Test Facilities" (with N. Doelling and A.C. Pietrasanta), *J. Acoust. Soc. Amer.*, 28, 163 (A) (1956).

"Noise Produced on the Ground by Jet Aircraft in Flight" (with K.N. Stevens and A.C. Pietrasanta), *J. Acoust. Soc. Amer.*, 28, 163 (A) (1956).

"Noise Produced by Aircraft During Ground Runup Operations" (with W.E. Clark and A.C. Pietrasanta), WADC Technical Note No. 56-60 (June 1957).

"Preliminary Investigation of Vehicular Noise Associated with Super Highways" (with W.E. Clark and V.A. Clark), *J. Acoust. Soc. Amer.*, 29, 779 (A) (1957).

"Noise Intrusion into Community Areas Due to Aircraft Flight Operations" (with W.E. Clark, A.C. Pietrasanta, and K.N. Stevens), *J. Acoust. Soc. Amer.*, 30, 692 (A) (1958).

"Equipment and Procedures for Field Measurements of Aircraft Noise and Flight Paths" (with D.N. Keast and W.E. Clark), *J. Acoust. Soc. Amer.*, 30, 693 (A) (1958).

"Behavior of Sound Waves" (with L.L. Beranek) in *Noise Reduction*, L.L. Beranek, ed., McGraw-Hill Book Company, Inc., New York (1960).

"Aircraft Noise," "Noise Control," and numerous other articles on acoustics, noise, sound and wave motion, *Encyclopedia of Science and Technology*, McGraw-Hill Book Company, Inc., New York (1960).

"Wind Tunnel Noise Measurements," *J. Acoust. Soc. Amer.*, 32, 932 (A) (1960).

"Noise Control," *McGraw-Hill Encyclopedia of Science and Technology Year Book*, McGraw-Hill Book Company, Inc., New York (1961).

"Prediction of Noise from Motor Vehicles in Freely Flowing Traffic" (with W.E. Clark), *Proc. IV International Congress on Acoustics* (1962).

"Frequency Analysis of Short-Duration Random Signals," *Sound*, 1 (6), 31-34 (Nov.-Dec. 1962).

"Noise Control of a Jet Engine Converted to a Fixed-Plant Installation," A.S.M.E. Paper No. 63-AHGT-43.

"Land Use Planning with Respect to Aircraft Noise: Discussion of a New Procedure" (with E. Guild, J. Cole, H. Von Gierke, and A. Pietrasanta), *Aerospace Medicine*, 35 (8), 719-723 (August 1964).

"Land Use Planning Relating to Aircraft Noise" (with A.C. Pietrasanta) for FAA (October 1964).

"Effect of Departure Procedures on Jet Aircraft Noise Control" (with J.F. Woodall), *Proc. V International Congress of Acoustics*, Liége (September 1965).

"Study of the Effect of Departure Procedures on the Noise Produced by Jet Transport Aircraft (with A.C. Pietrasanta and K.S. Pearsons), FAA-ADS-41 (October 1965).

"Selection of an Objective Measure for Motor-Vehicle Noise," *J. Acoust. Soc. Amer.*, 37, 1198 (A) (1965).

"Measurement and Description of Aircraft Noise Around an Airport," Alleviation of Jet Aircraft Noise Near Airports, Office of Science and Technology Report 28-34 (March 1966).

"Individual and Community Reaction to Aircraft Noise; Present Status and Standardization Efforts" (with H.E. Von Gierke), *Proceedings of London Conference on Reduction of Noise and Disturbance Caused by Civil Aircraft* (November 1966).

"Urban Highway Noise: Measurement, Simulation and Mixed Reactions" (with W.E. Clark and J.S. Kerrick), Highway Research Board, NCHRP Report 78 (1969).

"Opening Remarks, Problems of Recent Technological Development," *Proc. Conf. on Noise as a Public Health Hazard,* pp. 205-207; ASHA Report No. 4 (February 1969).

"Predicting Community Response from Laboratory Data," in *Transportation Noises: A Symposium on Acceptability Criteria,* J.D. Chalupnik, ed., Univ. of Washington Press, Seattle (1970).

"Noise" (with P.A. Franken), *Environmental Health Manual,* U.S. Conference of City Health Officers (in press).

"Real-Time Spectral Analysis of Aircraft Flyover Noise," *J. Acoust. Soc. Amer.,* 47, 87 (A) (1970).

"Methodology for Highway Noise Prediction" (with D.L. Nelson and C.G. Gordon), *J. Acoust. Soc. Amer.,* 47, 111 (A) (1970).

"Noise Exposure Forecasts as Indicators of Community Response," *Proc. SAE/DOT Conf. on Aircraft and the Environment,* Part 1, 56-63 (Feb. 1971).

"Noise Certification of Business Jet Aircraft," SAE Annual Business Aircraft Meeting, Paper No. 710384 (1971).

"Highway Noise – A Design Guide for Highway Engineers" (with C.G. Gordon, B.A. Kugler, and D.L. Nelson), Highway Research Board, NCHRP Report 117 (1971).

"Criteria for Selection of Measurement Positions for Maximal Jet Aircraft Sideline Noise," *J. Acoust. Soc. Amer.,* 50, 149 (A) (1971).

"Motor Vehicle Noise: Identification and Analysis of Situations Contributing to Annoyance" (with G. Jones), SAE Automotive Engineering Conference, Paper No. 720276 (1972).

"Noise annoys who? when? why?" (with G. Jones), *Concepts for Traffic Safety*, 4 (3), 1-6 (1971).

"Motor Vehicle Noise," *Proc. 17th Annual Meeting, Institute of Environmental Sciences* (April 1971).

"Motor Vehicle Noise and Highway Planning," *Proc. Society of Engineering Science* (June 1972) (in press).

"Introduction to Traffic Noise and Its Effect on People," Highway Research Board, Highway Research Record (in press).

"Predicting the Reduction in Noise Exposure Around Airports," *Proc. Inter-Noise 72*.

GEOFFREY G. HUGGINS — Supervisory Scientist

Education: B.S. (Electrical Engineering), Michigan Technological University, 1963; M.S. (Engineering Mechanics), University of Michigan, 1965; doctoral course work completed, The Catholic University of America, 1972.

Professional Experience: Student Engineer, General Motors Proving Ground, 1963; Senior Research and Development Engineer, Electric Boat Division, General Dynamics Corporation, 1965-1968; Bolt Beranek and Newman Inc., 1968-present.

Professional and Honorary Societies: Associate Member, Acoustical Society of America; Member, Tau Beta Pi, Eta Kappa Nu.

Professional Responsibilities and Projects: As a member of our Cambridge office, Mr. Huggins conducts research in environmental noise control. A recently completed project for the Environmental Protection Agency provides technical information for the establishment of EPA regulations for the control of noise from portable air compressors. Currently, Mr. Huggins is developing truck noise testing procedures for use in assuring compliance with EPA noise emission standards for medium- and heavy-duty trucks.

Prior to joining the Cambridge Office, Mr. Huggins was Manager of our Washington-based Applied Research Department. As manager of that group, he developed a research staff of scientists and engineers working primarily in underwater acoustics. He has led several projects involving analytical and experimental research and development as applied to the generation, propagation, and reception of underwater noise.

Also while in Washington, Mr. Huggins began his work in noise control research and development by doing a number of studies for a public utility. In Cambridge, he is applying his experimental and analytical experience in acoustics to assisting both government agencies and manufacturers in their efforts to control sources of environmental noise.

Sponsored Technical Reports (a representative list):

"Acoustic Criteria and Characteristics of Attack Submarine Concepts for Near Term Concept Formulation Program (U)" (with R. Collier and N. Paulhus), BBN Rept. No. 1747 (Dec. 1968) (Secret).

"Multi-Sensor Signature Comparison (U)" (with R. Hershey and R. Stern), BBN Rept. No. 1629 (June 1969) (Secret-NFD).

"Theoretical and Experimental Analysis of SSN 637 Class Low-Frequency Sonar Self-Noise Characteristics (U)" (with K.L. Chandiramani, P.H. White, and R.D. Collier), BBN Rept. No. 1880 (Nov. 1969) (Confidential).

"IDNA Sonar Program. A Preliminary Analysis of Towed Arrays for Low Frequency Detection and Classification (U)" (with staff members), BBN Rept. No. 1920 (Feb. 1970) (Confidential).

"Analysis and Design Guidelines for an Improved Towed Line Array for DNA Sonar Functions (U)" (with D.M. Chase), BBN Rept. No. 2156 (March 1971) (Confidential).

"Next Generation Sonar: Description and Physical Mechanisms of Submarine Self Noise (U)" (with E.F. Berkman, *et al*), BBN Rept. No. 2140 (May 1971) (Confidential).

"Ambient Noise Spatial Characteristics and Sonar Array Response" (with C.B. Burroughs and R.C. Cavanagh), BBN Rept. No. 2458 (June 1972) (Confidential).

"AN/BQQ-5 Low-Frequency Array Acoustic Studies: SSN 688 and SSN 594/637 Class Backfit Programs (U)" (with E.F. Berkman and P.H. White), BBN Rept. No. 2458 (June 1972) (Confidential).

"Portable Air Compressor Noise" (with W.N. Patterson and R.A. Ely), BBN Rept. No. 2795a (March 1974).

Oral Presentations:

"Some Aspects of Array Performance in Empirically Derived Non-Isotropic Noise Fields (U)" (with R.L. Spooner), presented at the 27*th* Navy Symposium on Underwater Acoustics, San Diego, Calif. (Nov. 1969) (Confidential).

"Acoustic Criteria for SSN Concept Formulation Studies (U)" (with R.D. Collier), presented at the 1970 Ship Silencing Symposium, Washington, D.C. (Mar. 1970) (Secret).

"Ambient Noise Spatial Properties," presented at a NSRDC Workshop on Sonar Self Noise, Washington, D.C. (Sept. 1972) (Confidential).

"A Simplified Description of Wind-Generated Noise for Sonar Response Applications" (with C.B. Burroughs), presented at the 84*th* Meeting of the Acoustical Society of America, Miami Beach, Florida (Nov. 1972).

"Sonar Array Response to Ambient Noise Directional Fields, Comparing Numerical Results to Closed-Form Estimates" (with C.B. Burroughs), presented at the 84*th* Meeting of the Acoustical Society of America, Miami Beach, Florida (Nov. 1972).

CHARLENE D. LONG - Research Associate,
Educational Technology Department

<u>Education</u>: B.S. (Biological Sciences), Florida State University, 1959; M.S. (Zoology), University of New Hampshire, 1963; numerous science courses at Northeastern University and Harvard University, 1963 to date.

<u>Professional Experience</u>: Intern, Smithsonian Institution, Washington, D.C., 1959; Assistant Preparator, Peabody Museum of Natural History, Yale University, New Haven, Connecticut, 1960-1962; Editor, Ginn and Company Publishers, Boston, Mass., 1963-1967; Instructor, Massachusetts Bay Community College, 1967-1968; Editor, Harvard Economic Research Project, Cambridge, Mass., 1968-1970; research associate, Marine Invertebrates, Harvard University, 1963 to date; Teaching Assistant, Harvard University, 1967 to date; Bolt Beranek and Newman Inc., 1971 to date.

<u>Honors and Societies</u>: Phi Sigma Award for Most Outstanding Undergraduate Research, Florida State University, 1959; Sigma Xi, Life Membership.

<u>Scientific Projects</u>: Miss Long has directed and been involved in numerous life cycle and pollution studies relating to the marine environment with particular reference to industrial sites such as desalinization plants. Her responsibilities at Harvard University include developing and up-dating marine biology curricula and directing students in various aspects of applied marine research: pollution indicator organisms, taxonomy of marine animals, etc.

<u>Information Retrieval Projects</u>: An outgrowth of her scientific work has been the development and application of a simple computer-based system for information retrieval, which is presently being

considered by a major scientific abstracting service. At BBN, she has been responsible for over twenty major bibliographic compilations on such topics as man-computer interaction, robotics, learning aids for the deaf, decision aids, ultrasonics in medicine, and linear prediction--state of the art. She has conducted demographic and industrial surveys in diverse areas, including crib injuries, demographic characteristics of populations near railroads, and effects of OSHA and NIOSH regulations on industry.

Publications, Talks, and Work in Progress:

Taxonomy of Phoronida, Bulletin of Marine Science of the Gulf and Caribbean 10 (2):204-207, 1960.

Bibliography of Polychaeta, Vol. 1 (References to Polychaeta in the Zoological Record, 1864-1964), 400 pages, private publication, 1969.

Bibliography of Polychaeta, Vols. 2 and 3.

Polychaete Colonization of Artificial Sponges from Bimini, Paper presented to 10th Meeting of the Association of Island Marine Laboratories of the Caribbean, September 5, 1973, Mayaguez, Puerto Rico.

Pectinariidae from Caribbean and Associated Waters, Bulletin of Marine Science, in press, scheduled for publication March 1974.

NANCY M. McMAHON – Manager, Publications Department

Education: A.B. (English), Radcliffe College, 1960; Graduate Study (English), Boston College, 1964-1968.

Professional Experience: Teacher (English, French, History, Mathematics), Cambridge School System, Cambridge, Mass., 1960-1968; Free-lance Writer/Editor and Tutor, 1968-1969; Bolt Beranek and Newman Inc., 1969-present.

Professional Societies: Member, Society for Technical Communications; The Technical Art Group.

Professional Responsibilities and Projects: At Bolt Beranek and Newman Inc., Ms. McMahon is responsible for coordinating the publication services and editing technical reports. Also, using technical inputs from various authors as reference material, she organizes ideas and writes copy. A recently completed project for the Department of Housing Urban Development resulted in a booklet entitled *Noise Assessment Guidelines* and an accompanying *Training Program.* Other projects include technical papers on noise in various industries, preparation of proposals, and executive summaries of technical reports.

In the Cambridge School System, Ms. McMahon taught senior high school college preparatory English courses, in which particular emphasis was given to expository writing. She also participated in curriculum development and supervision of student teachers.

Publications:

"Noise Assessment Guidelines" (with T.J. Schultz), BBN Rept. No. 2176 (August 1971).

"Training Program for Noise Assessment Guidelines" (with T.J. Schultz), BBN Rept. No. 2267 (October 1971).

WILLIAM N. PATTERSON - Senior Engineering Scientist

Education: B.M.E., 1971; M.S. (Mechanical Engineering), 1971; Ph.D. Candidate, Ohio State University.

Professional Experience: U.S. Navy, 1959-1961; Patterson & Sons Inc., 1961-1964; Patterson Machinery, 1964-1966; Automatic Welding, 1966-1969; Ohio State University (Research Associate), 1969-1972; Bolt Beranek and Newman Inc., 1972-present.

Honors and Societies: Engineering Honor Scholar, 1971. Member, Tau Beta Pi, Sigma Xi, Pi Tau Sigma Honoraries. Member, American Society of Heating, Refrigeration and Airconditioning Engineers, American Society of Mechanical Engineers, National Society of Professional Engineers.

Professional Responsibilities and Projects: Mr. Patterson has been engaged in research, development, and consulting in the fields of noise, vibration, and testing. He has extensive experience in manufacturing processes and sales and service of industrial and farm equipment.

As Vice President of Patterson and Sons, Mr. Patterson supervised sheet metal fabrication. At Automatic Welding, he was production engineer supervising the fabrication of acoustical enclosures for turbine generators. His duties included design and cost accounting.

As a Research Associate at OSU, Mr. Patterson was involved in free-jet noise analysis and was in charge of the acoustic laboratory. He designed a room construction allowing conversion of a reverberant chamber to a listening room. He was in charge of the construction and subsequent calibration of a large isolated anechoic chamber.

His master's thesis involved analyzing and measuring the noise producing mechanisms in an impacting-type production machine.

Since joining BBN, Mr. Patterson has been working with the Noise Control Research and Development section of the Applied Physics Department. His duties have included evaluation of rapid transit vehicle designs and prediction of subway-induced noise as well as vibration in adjacent structures. He has worked on the Quiet Truck Program designing and testing the engine exhaust system for a new generation of heavy trucks.

His work on other large vehicles includes the investigation of the noise-producing mechanisms on dump trucks, concrete mixers, bulldozers, and compressors, as well as analyses of the costs to manufacturers and owners of quieting this machinery. Other recent work includes engine vibration isolation and muffler design for the Mk 48 and refrigerator compressor noise control. His duties have included overall program management as well as technical responsibility.

__Publications:__

"A Noise Study of Impacting Type Production Machines," M.S. Thesis, Ohio State University (1971).

"Noise: What It Is and Where We as Engineers are Involved," *The Ohio State Engineer* (April 1971).

"Noise Pollution in the Coal Mining Industry" (with R.D. Bruce), presented at the Kentucky Industrial Coal Conference, Lexington, Kentucky (April 1973).

"The Design of a Cost-Effective Quiet Diesel Truck" (with D. Averill), *Society of Automotive Engineers*, West Coast Annual Meeting, Portland, Oregon, SAE #730714 (August 1973).

"The Design of a Quiet Diesel Truck" (with D. Averill), presented at the National Conference on Noise Control Engineering (*Noise-Con 73*) (October 1973).

"Hearing Damage Risk in Farm Operations," *Hearing Aid Journal* (February 1974).

Sponsored Technical Reports:

"Preliminary Noise Diagnosis of Freightliner Datum Truck-Tractor" (with M. Kaye and E.K. Bender), Department of Transportation No. DOT-TST-73-6, May 1973, BBN Report No. 2317 (November 1972).

"Analytic and Experimental Development of Intake Mufflers for Reciprocating Refrigerant Compressors," BBN Report No. 2508 (April 1973).

"Evaluation and Design of Sealing Spool Between Engine Output Shaft and Propeller Shaft for Mk 48 Mod 1" (with E.E. Ungar), BBN Tech Memo No. 153.

"Evaluation of Propeller Shaft Bearing Vibration Isolation Provided by Elastic Linings," BBN Tech Memo No. 161 (July 1973).

"Feasibility of Vehicle Noise Inspection Regulations" (with C.W. Dietrich and C. Warner), BBN Report No. 2571 (August 1973).

"Traction Vehicles: Noise and Cost of Abatement" (with T. Freeze), BBN Report No. 2566b (August 1973).

"Specialty Construction Trucks: Noise and Cost of Abatement" (with P. Rentz and E.K. Bender), BBN Report No. 2566e (Sept. 1973).

"Rationale for the Identification of Major Sources of Noise" (with K. Eldred), BBN Report No. 2636 (Sept. 1973).

"The Technology and Cost of Quieting Medium and Heavy Trucks" (with E.K. Bender), BBN Report No. 2710 (January 1974).

"Noise Control in Surface Mining Facilities: Working Information on the Industry, Its Noise, and the Cost of Noise Control" (with E.E. Ungar *et al*), BBN Tech Memo No. 183 (February 1974).

PAUL J. REMINGTON – Senior Scientist

Education: S.B. and S.M. (Mechanical Engineering), Massachusetts Institute of Technology, 1966; Ph.D. (Mechanical Engineering), Massachusetts Institute of Technology, 1969.

Professional Experience: Dynatech Corp., summer, 1966; Bolt Beranek and Newman Inc., 1969-present.

Honors and Societies: Member, Tau Beta Pi, Pi Tau Sigma; Associate Member, Acoustical Society of America. Shell Companies Foundation Fellowship, MIT, 1966; National Science Foundation Fellowship, MIT, 1966-1969; Union Carbide Corp., Engineering Scholarship, 1961-1965.

Professional Responsibilities and Projects: At Bolt Beranek and Newman Inc., Dr. Remington has participated in a number of projects involving the dynamics of complex structures, numerical analyses, and control system studies. These include studies of the transmission of sound through complex aerospace structures, viscoelasticity with application to compliant coating technology, automobile exhaust system dynamics, and the unsteady dynamics of parachute deployment. He has also been principal investigator in a project for developing ride quality criteria in STOL aircraft, in a study involving the analyses of tent deflections under snow loads, and in a study for the optimization of hydrofoil control power.

Publications:

"An Active Vibration Isolation System with Optimum Shock Protection," Master's Thesis, Massachusetts Institute of Technology, Mechanical Engineering Department (June 1966).

"Vibration of a Continuum Excited by Random Motions of a Continuous Foundation" (with Stephen H. Crandall), Revue Romaine des Science Technique – *Mécanique Appliquée*, Tome 15:1(25-34) (1970).

"Response of a Covering Plate to Noise in a Viscoelastic Half-Space" (with Stephen H. Crandall), *J. Acoust. Soc. Amer.*, 48: 5, Part 2 (1970).

"Dynamic Properties of Modelling Clay" (with Stephen H. Crandall, *et al*), Massachusetts Institute of Technology, Acoustics and Vibration Lab Report No. 76205-3.

"Response of a Plate Bonded to a Viscoelastic Half Space," *J. Acoust. Soc. Amer.*, 51:3 (1972).

"Hydrofoil Design for Minimum Control Power" (with E.K. Bender and W.C. O'Neill) presented at the 3*rd* Ship Control System Symposium, Bath, England (Sept. 1972).

"Comparison of Statistical Energy Analysis Prediction with an Exact Calculation (with J.E. Manning), to be published in the *J. Acoust. Soc. Amer.*

"Nonlinear Analyses of a Shock Loaded Membrane" (with R. Madden) to be presented at the AIAA Aerodynamic Deceleration Systems Conference, Palm Springs, California (May 1973).

E. ASHLEY ROONEY - Technical Writer/Editor

Education: B.S. (English), Columbia University, 1964.

Professional Experience: Young & Rubicam, 1964-1965; Editor of *New York Academy of Sciences Transactions* and *Small Annals*, 1965-1966; Consultant at Polaroid Corp., 1966; Writer/Editor at Mitre Corp., 1966; Freelance Writer/Editor, 1966-1974; Technical Writer/Editor, Bolt Beranek and Newman, 1974-present.

Professional Responsibilities and Projects: At BBN, Ms. Rooney is responsible for writing and editing technical reports, proposals, and journal articles. She also coordinates the work of typists, illustrators, and printers.

As a freelance writer, she has published in the *Boston Globe*, *Redbook* and *American Home*, in addition to having a feature column in a local newspaper. As a freelance editor, she handled many technical papers and acted as senior technical editor of the *Rock Mechanics Seminar*, two volumes, which has been translated into 18 languages. As a writer/editor at Mitre, she edited and rewrote technical reports to format specifications. At the New York Academy of Sciences, she was in full charge of the *Transactions*, a monthly periodical composed of papers from all scientific fields. Her duties included editing, proofreading, processing artwork, page layout, and coordinating between the authors, printers, and other Academy departments. At Young and Rubicam, she acted as coordinator between *Time* magazine and the copy department of Young & Rubicam, advertising agency.

MICHAEL J. RUDD – Senior Engineering Scientist

Education: B.A. (Physics), 1966; M.A., 1969; Ph.D. (Fluid Dynamics), 1970; University of Cambridge, England.

Professional Experience: Undergraduate Apprentice, British Aircraft Corp., 1962-1969; Engineer, Acoustics Department Weybridge Division of BAC, 1969-1970; Research Assistant Professor, Department of Aeronautics and Astronautics, New York University, 1970-1972; Bolt Beranek and Newman Inc., 1972-present.

Professional Responsibilities and Projects: At Bolt Beranek and Newman Inc., Dr. Rudd is involved in several projects related to aerodynamic and hydrodynamic turbulence and noise, particularly as related to advanced electro-optical sensors and signal processing. He has also participated in projects sponsored by the Environmental Protection Agency, including ones aimed at setting noise limits for trains and home appliances. At New York University, he conducted research on the reduction of jet noise by particulates and on methods of predicting noise in structural spaces due to sonic boom; he also taught courses on noise, vibration, and dynamics, and engaged in consulting activities on jet and turbine noise problems.

At the Cavendish Laboratory of Cambridge University, he worked under Dr. A.A. Townsend in the Fluid Dynamics Section, also working part of the time at the Bristol Division of the British Aircraft Corporation. He devised the first self-aligning laser dopplermeter, then used this instrument to study the drag reduction produced by dilute polymer solutions. At BAC, he worked on jet noise reduction by means of additives and on methods for analyzing aircraft noise, in particular for the BAC 1-11 and Concorde.

Publications:

"A Laser Doppler Velocimeter Employing the Laser as a Mixer-Oscillator," *J. Sci. Instr.*, Series 11, 1, 723-726 (1968).

"A New Theoretical Model for the Laser Dopplermeter," *J. Sci. Instr.*, Series 11, 11, 55-58 (1969).

"A Self-Aligning Laser Dopplermeter," *8th* International Commission for Optics Conference, Reading, England, July 1968. Published in *Optical Instruments and Techniques*, Oriel Press (1969).

"The Laser Dopplermeter — A Practical Instrument," *Optics Technology*, 264-265 (November 1969).

"Measurements Made on a Drag Reducing Solution with a Laser Velocimeter," *Nature*, 224, 587-588 (November 1969).

"The Laser Dopplermeter and Polymer Drag Reduction," 67*th* National Meeting of the American Institute of Chemical Engineers Atlanta, Georgia, February 1970. Published in Chemical Engineering Progress Symposium Series No. 111, 67, *Drag Reduction* (1971).

"The Laser Anemometer — A Review," *Optics and Laser Technology*, 200-207 (November 1971).

"Velocity Measurements Made with a Laser Dopplermeter on the Turbulent Pipe Flow of a Dilute Polymer Solution," *J. Fluid Mech.*, 51, 673-685 (February 1972).

"A Note on the Scattering of Sound by Jets and the Wind" (to be published).

"Laser Velocimetry of Phase Objects" (to be published).

The Laser Anenometer (with Dr. B.M. Watrasiewicz) (to be published by Butterworth and Co., London).

"Lawn Mowers: Noise and Cost of Abatement" (with E. K. Bender), BBN Report No. 2566a (in progress).

"A Preliminary Study of the Reduction of Acoustic and Infrared Emissions from a Military Standard 1.5 kW Engine Generator" (with P. J. Remington), BBN Report No. 2650, October 1973.

"Contribution to Background Document for Rail Carrier Noise Regulations" (with E. Bender, R. Ely, and S. Swanson), prepared by BBN for the Environmental Protection Agency, November 1973.

Patents Granted:

Improvements Relating to the Measurements of Fluid or Surface Velocities. U.K. Patent No. 1182658.

Improvements to or Relating to Laser Detector Systems. U.K. Patent No. 1183492.

Also, corresponding U.S., West German and Japanese patents.

THEODORE J. SCHULTZ - Principal Scientist - Acoustics
Technical Director of Architectural Acoustics and Noise Control

Education: University of Rochester (Eastman School of Music), 1940-1941; University of Missouri, 1941-1943; University of Texas, 1943-1944; U.S. Naval Academy, 1944; M.S. (Acoustics), Harvard University, 1947; Ph.D. (Acoustics), Harvard University, 1954.

Professional Experience: Instructor in Physics, Mathematics, Electrical Engineering, Electronics, U.S. Naval Academy, 1944-1946; Research Physicist, Naval Research Laboratory, 1947-1948; Instructor, Harvard University, 1948-1953; Research Fellow in Acoustics, Harvard University, 1953-1955; Assistant Chief, Acoustics Section, Douglas Aircraft Co., Santa Monica, 1956-1960; Consultant in Electronics and Acoustics, 1950-1960; Instructor, Summer Course in Noise and Vibration, Massachusetts Institute of Technology, 1964 and 1967; Bolt Beranek and Newman Inc., 1960-present.

Honors and Societies: Fellow, Acoustical Society of America; Member, ASA Technical Committee on Architecture, ASTM Standards Writing Committee E-33; U.S. Member of several technical working groups of International Standards Organization; Member, Tau Beta Pi, Eta Kappa Nu, Sigma Xi.

Professional Responsibilities and Projects: Dr. Schultz has worked in the areas of acoustical instrumentation, architectural acoustics, electroacoustic transduction, underwater sound, and community noise. At the Naval Research Laboratory, he set up a high-frequency microphone calibration facility, and also studied bioacoustical effects of high-intensity noise. Dr. Schultz has been a consultant on electronics and acoustics, calibration and testing of phonograph pickups, design of telemetering equipment for meteorological studies, and the design of aircraft soundproofing. He has made a theoretical study of electrostatic transducers, and has conducted research on plastic-elastic instability in vinyl plastics. For four years, he was Assistant Chief of the Acoustics Section of Douglas Aircraft Company, dealing with problems of interior and exterior noise control and of structural fatigue due to acoustical excitation, in both jet transport aircraft and missiles.

His recent work at Bolt Beranek and Newman Inc. has dealt with problems of measurement and design in architectural acoustics, particularly of concert halls; design and evaluation of acoustical testing laboratory facilities; noise and vibration criteria and control for high-speed trains and for aircraft; he has prepared two surveys on undersea reverberation. He has been active in acoustical standards writing and reviewing, at the national (ASTM and ASA) and international (ISO) levels. He has prepared for the U.S. Department of Housing and Urban Development a set of guidelines in support of their recently adopted policy of withholding support for housing proposed for locations judged too noisy to be suitable as a living environment. He is chairman of ASTM writing groups preparing standards for measurement of airborne transmission loss in the field, and for improved methods of evaluating impact noise isolation of floor-ceiling constructions. He is currently working on the problem of establishing realistic criteria and monitoring procedures for abatement of urban noise, particularly the noise from road and air traffic. He has recently spent six months in Europe visiting numerous acoustical laboratories to review the state of on-going acoustical research abroad, and to investigate current efforts for enforcement of noise ordinances and noise control requirements in building codes in various countries. He has recently prepared a state-of-the-art review of impact noise testing and rating, in support of on-going research efforts in that field, at NBS.

Representative Consulting Projects

Serendipity
Transportation Noise Study

Pratt & Whitney Aircraft, Middletown, Conn.
Jet Engine Test Cells

Summerhill Square Project, Toronto,
Railway Noise Study
Webb Zerafa Menkes, Architects

Victorian Arts Centre, The North End,
Melbourne, Australia
Roy Grounds & Co. Pty. Ltd.

City of Chicago Noise Survey

City of Chicago Building Code

NASA - Ames 40' x 80' Wind Tunnel,
Feasibility of Use for Acoustical Measurements

U.S. Department of Housing and Urban Development (HUD)
Handbook on Community
Noise Assessment Guidelines
Technical Background for Noise Assessment Guideline
Noise Barrier Design and Evaluation Guidelines

National Bureau of Standards
Impact Noise Testing and Rating, State-of-the-Art Review

Indiana University Musical Arts Center, Bloomington, Ind.
Evans Woollen & Associates, Architects

EPA/DOT
Noise Survey

Baltimore Concert Hall
Pietro Belluschi/Jung Brannen, Assoc. Architects

Milwaukee Center for the Performing Arts
(Uihlein Hall, Vogel Hall, Wehr Hall)
Harry Weese & Associates, Architects

Garden State Arts Center, New Jersey
Edward D. Stone, Architect

Houston Astrodome
Wilson, Morris, Crain & Anderson, Architects

WGBH-TV - Studio Treatment
Boston, Massachusetts

EXPO '67 Theme Buildings, Montreal
ARCOP

Remodeling of Orchestra Hall, Chicago
Harry Weese & Associates

Budd Company
Noise Control on Northeast Corridor Railroad Cars

National Gypsum Company
Acoustical Test Facility Evaluation

Massachusetts Bay Transit Authority
South Shore Transit Noise Control

Kaman Corporation
Quiet Helicopter, HH 43 F

Fairchild Hiller Corp.
Noise Control on the FH 227B

Office of Economic Cooperation Development - Paris
Enforcement of Traffic Noise Regulations

United Aircraft - Noise Control on Car Ferry
- Noise Control on Turbine Train

DeHavilland - Twin Otter Exterior Noise Measurements

Trane Company
Acoustical Test Facility Design

Rohr - BART Car Design

IURD - Impact of BART Train System Noise on Community

St. Louis Car - Noise Control

Pullman Standard - Noise Control

NYCTA - Noise Control in Subway Stations

<u>Papers and Publications:</u>

"Triode Cathode-Followers for Impedance Matching to Transformers and Filters," *IRE Trans. Audio*, 28-37 (March-April 1955).

"Measurement of Membrane Tension," *Rev. Sci. Instr.* 26, 624-625 (June 1955).

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"On the Use of Decibel Terminology in Multiplying Circuits," *J. Acoust. Soc. Amer.* 28, 498-499 (L) (1956).

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"Effect of Altitude on Output of Sound Sources," *Noise Control* 5, No. 3, 17-21, 54 (May 1959).

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"Impact-Noise Recommendations for the FHA," *J. Acoust. Soc. Amer.* 36, 729-739 (1964).

"FHA Guide to Impact Noise Control," *Building Res.* 1, No. 1, 45-51 (January-February 1964).

"Propagation of Sound Across Audience Seating" (with B.G. Watters), *J. Acoust. Soc. Amer.* 36, 885-896 (1964).

"The Perception of Music Heard via Interfering Paths" (with B.G. Watters), *J. Acoust. Soc. Amer.* 36, 897-902 (1964).

"Acoustics of Philharmonic Hall, New York, during its First Season" (with L.L. Beranek, B.G. Watters, and F.R. Johnson), *J. Acoust. Soc. Amer.* 36, 1247-1262 (1964).

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"Electrostatic Loudspeakers for Aircraft Communication," *Sound and Vib.* 1, No. 2, 19-29 (February 1967).

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"Wrappings, Enclosures and Duct Lining," Chapter 15, *Noise and Vibration Control*, L.L. Beranek, ed., McGraw-Hill Book Co., Inc., New York (1971).

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Oral Presentations (representative listing):

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"Developments in Acoustical Standards," presented at Los Angeles Architects Symposium (October 1966).

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"Relations Among the Various Single-Number Ratings of Environmental Noise," presented at the 79th Acoustical Society of America Meeting (April 1970).

"Privacy for Apartment Dwellers," presented at the 82nd Acoustical Society of America Meeting (October 1971).

"Recent Developments in the Design and Evaluation of Concert Halls: Models and Simulation", Seminar on Environmental Noise, AAAS Meeting in Philadelphia, December 1971.

"Community Noise Ordinances in the United States and Europe", Seminar on Environmental Noise, AAAS Meeting in Philadelphia, December 1971.

"Motor Vehicle/Highway System Planning and Noise," International Conference on Transportation and the Environment, Washington, D.C., June 1972.

"Noise Control in Dwellings: - United States, 1972", presented at Symposium on the Micro-Environment of Human Dwellings, Warsaw, Poland, 4-8 December 1972.

Sponsored Technical Reports (representative listing):

"Design Procedure for the Sound Absorption of Resonant Plywood Panels", Bolt Beranek and Newman Inc. Rept. 925 (Apr. 1962).

"Intensity Measurements in Near Fields and Reverberant Spaces" (with P.W. Smith, Jr., and C.I. Malme), Bolt Beranek and Newman Inc. Rept. 1135 (July 1964).

"Noise and Vibration Criteria for the Northeast Corridor Trains", Bolt Beranek and Newman Inc. Rept. 1276 (Dec. 1965).

"General Design Recommendations for Control of Noise and Vibration in High-Speed Trains for the Northeast Corridor", Bolt Beranek and Newman Inc. Rept. 1277 (Dec. 1965).

"The MBTA South Shore Project II. Recommendations for Control of Noise and Vibration in Rapid-Transit Cars" (with C.W. Dietrich), Bolt Beranek and Newman Inc. Rept. 1446 (Sept. 1966).

"Extrapolation of AMA Ceiling Attenuation Data to Field Situations", Bolt Beranek and Newman Inc. Rept. 1733 (Nov. 1968).

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"Program for the Measurement of Environmental Noise", Report No. DOT-TST-74-4, Sept. 1973, submitted to DOT, Office of Noise Abatement.

<u>Patents Granted</u>:

No. 2,836,656 "Acoustic Wattmeter" [J.Acoust.Soc.Amer. 31, 392 (1959)]

No. 2,868,894 "Miniature Condenser Microphone" [J.Acoust.Soc.Amer. 32, 1089 (1960)]

MARGARET HASSON TROY - Chief Technical Librarian

Education: A.B. (Biochemical Sciences), Radcliffe College, Cambridge, Mass. Graduate study, University of London (England), Certificate in General Studies.

Professional Experience: Research Technician, Harvard Medical School, Dept. Physical Chemistry; Associate, Harvard Medical School, Dept. Pediatrics; Scientific Coordinator at National Research Corporation, Cambridge, Mass.; Head Research Librarian, National Research Corporation; Head Research Librarian, United Fruit Company, Executive Offices, Boston, Mass; Executive Assistant, Sloan-Kettering Institute for Cancer Research, New York City; and Chief Technical Librarian, Bolt Beranek and Newman Inc., Cambridge, Mass.

Responsibilities include complete administration of the library, preparation of literature searches and reference work.

Professional Societies: Society of the Sigma Xi; Special Libraries Association.

Awards and Professional Activities: Chairman, Hospitality Committee, SLA; Chairman, Employment Committee, SLA; Instructor, course for library assistants, SLA. OSRD Award of Merit for Research Work on behalf of government effort in World War II.

Publications:

"Preparation and Properties of Serum and Plasma Proteins, XII," J. Amer. Chem. Soc. 69:1747-1753 (1947).

"The Nophrotic Syndrome in Children," J. Clinical Invest. 30: 471-491 (1951).

"The Literature of Titanium Metal and Its Alloys," presented at the American Chemical Society, Division of Chemical Literature, Annual Meeting, Chicago, Illinois (Sept. 1953).

ERIC E. UNGAR - Associate Division Director, Dynamics and Structures

Education: B.S. (Mechanical Engineering), Washington University, 1951; M.S. (Mechanical Engineering), University of New Mexico, 1954; Eng. Sc.D., New York University, 1957.

Professional Experience: Aero-Ordnance Engineer, Sandia Corporation, 1951-1953; Instructor, Assistant Professor of Mechanical Engineering, Research Scientist, New York University, 1954-1958; Bolt Beranek and Newman Inc., 1958-present.

Professional Honors and Societies: Fellow, Acoustical Society of America (Member, Committee on Shock and Vibration, 1974-77), Associate Editor, *Journal of the Acoustical Society of America*, 1974-75; Contributing Editor, *Sound and Vibration*, 1974.

American Society of Mechanical Engineers: Executive Committee, Design Engineering Division, 1974-80; Chairman, Technical Committee on Vibration and Sound, Design Engineering Division, 1964-74; Chairman, Shock and Vibration Committee, Applied Mechanics Division, 1972; Chairman, Program Committee, 1969 Vibrations Conference.

Institute of Noise Control Engineering (Board of Examiners, 1973); Founding Member, U.S. Council for Theory of Machines and Mechanisms; American Institute of Aeronautics and Astronautics; American Academy of Mechanics; Tau Beta Pi, Sigma Xi, Phi Kappa Phi; Reviewer, Applied Mechanics Reviews.

Professional Engineer, Missouri and District of Columbia.

Listed in *American Men of Science, Who's Who in Aviation, Who's Who in the East; Dictionary of International Biography*.

Professional Responsibilities and Projects: Dr. Ungar has been engaged in research and development in various fields of mechanical engineering since 1951. At Sandia Corporation, he worked in atomic weapons development and delivery concept analysis. At New York University, he taught and did research in machinery dynamics and applied mechanics and engaged in consulting in stress analysis and heat transfer. At Bolt Beranek and Newman Inc., Dr. Ungar is concerned with various aspects of structural dynamics and noise, and with the direction of multidisciplinary approaches to the solution of technological problems.

Representative List of Publications:

Damping

"Loss Factors of Viscoelastically Damped Beam Structures", *J. Acoust. Soc. Amer.* 34:1082-1089 (1962).

"A Guide to Designing Highly Damped Structures Using Layers of Viscoelastic Material", *Machine Design* 35:162-168 (Feb. 1963).

"On Panel Vibration Damping Due to Structural Joints" (with J.R. Carbonell), *AIAA J.* 4:1385-1390 (Aug. 1966).

"Panel Loss Factors Due to Gas Pumping at Structural Joints" (with G. Maidanik), NASA CR-594 (Nov. 1967).

"Damping of Panels", *Noise and Vibration Control*, Chap. 14, L.L. Beranek (Ed.), McGraw-Hill Book Co., Inc., New York (1971).

"The Status of Engineering Knowledge Concerning the Damping of Build-up Structures", *J. Sound Vib.*, 26:141-154 (Jan. 1973).

Vibration Isolation

"Mechanical Vibrations", *Mechanical Design and Systems Handbook*, Sec. 6, H.A. Rothbart (Ed.), McGraw-Hill Book Co., Inc., New York (1964).

"Wave Effects in Viscoelastic Leaf and Compression Spring Mounts", *Trans. ASME, Ser. B. (J. Eng. Ind.)*, 85:243-246 (Aug. 1963).

"High Frequency Vibration Isolation", (with C.W. Dietrich), *J. Sound Vib.*, 4:224-241 (Sept. 1966).

Isolation of Mechanical Vibration, Impact, and Noise (Ed. with J.C. Snowdon), Amer. Soc. Mech. Engrs., New York, 1973.

Vibrations of Complex Structures

"Steady-State Responses of One-Dimensional Periodic Flexural Systems", *J. Acoust. Soc. Amer.*, 39:887-894 (1966).

"Statistical Energy Analysis of Vibrating Systems", *Trans. ASME, Ser. B. (J. Eng. Ind.)*, 89:626-632 (1967).

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"Vibrations of Nonhomogeneous Plates and Shells in Terms of Refracted Waves" (with O.A. Germogenova, K.L. Chandiramani and K. Lee), BBN Rept. 2007 (Aug. 1970).

Stress Analysis

"Maximum Stress in Beams and Plates Vibrating at Resonance", *Trans. ASME, Ser. B. (J. Eng. Ind.)*, 84:149-155 (Feb. 1962).

"Transmission of Plate Flexural Waves Through Reinforcing Beams; Dynamic Stress Concentrations", *J. Acoust. Soc. Amer.*, 33:633-639 (1961). Also, 35:934 (L) (1963).

"Consideration in the Design of Supports for Panels in Fatigue Tests" (with K.S. Lee), AFFDL-TR-67-86 (June 1967).

"Estimation of Probability of Structural Damage Due to Combined Blast and Finite-Duration Acoustic Loading" (with Y. Kadman), *Shock Vib. Bull.*,39, Pt. 3, 65-71 (Jan. 1969).

"Residual Stresses and Displacements in Wide Curved Bars Subject to Pure Bending" (with B.W. Shaffer), *Intern. J. Mech. Sci.*, 11:525-543 (1969).

"Stress Resultants and Out-of-Plane Deformations in Stiff Rings Attached to Elastic Cylinders and Subject to Concentrated Loads" (with B.W. Shaffer), *Trans. ASME, Ser. B. (J. Eng. Ind.)*, 93:835-844 (Aug. 1971).

"Excitation, Response, and Fatigue Life Estimation Methods for the Structural Design of Externally Blown Flaps", *Shock and Vib. Bull.*, 43:165-183 (June 1973).

Noise; Acoustics; Fluctuating Pressures

"Vibrations and Noise Due to Piston-Slap in Reciprocating Machinery" (with D. Ross), *J. Sound Vib.*, 2:132-149 (1965).

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"Feasibility of Aircraft Stall Detection by Means of Pressure Fluctuation Measurements" (with H.H. Heller, D. Bliss, and S.E. Widnall), AFFDL-TR-70-147 (Nov. 1970).

"Transonic Rocket-Sled Study of Fluctuating Surface Pressures and Panel Responses" (with H.J. Bandgren and R. Erwin), *Shock and Vib. Bull.*, 42, Pt. 4 (Jan. 1972).

"A Guide for Predicting the Aural Detectability of Aircraft" (with several members of BBN Staff), AFFDL-TR-71-22 (July 1971).

Structure-Borne Sound; Structural Vibrations and Sound Radiation at Audio Frequencies (with L. Cremer and M. Heckl), Springer Verlag, New York, 1973.

Noise Control Engineering

"Guidelines for the Preliminary Estimation of Vibrations and Noise in Buildings near Subways" (with E.K. Bender), BBN Rept. 2500B (Jan. 1973).

"Noise Comparison of Enclosed and Muffled Piston and Rotating Combustion Engines for Light Aircraft" (with M. Rudd), BBN Rept. 2489 (Jan. 1973).

"Development of Prototype Muffler/Diffuser Assemblies for S-IVB Orbiting Workshop Ventilation Fans" (with E.K. Bender and I. Vér), BBN Rept. 1774 (March 1969).

"Effects of Resiliently Mounted Track Slabs on Noise and Vibration" (with E.K. Bender and U. Kurze), BBN Rept. 1878 (Sept. 1969).

"An Investigation of the Generation of Screech by Railway Car Retarders" (with R.D. Strunk and P.R. Nayak), BBN Rept. 2067 (Dec. 1970).

"Acoustic and Performance Test Comparison of Initial Quieted Truck with Contemporary Production Trucks" (with M.C. Kaye), Rept. DOT-TSC-74-2 (Sept. 1973).

"Promising Noise Reduction Measures for Rapid Transit Systems; Background Information for In-Service Test Planning" (with several members of BBN Staff), BBN Rept. 2642 (Feb. 1974).

"Preliminary Estimates of Wayside and Interior Noise of the General Electric MTA Gas Turbine/Electric Rail Car" (with L.E. Wittig), BBN Rept. 2723 (Jan. 1974).

"Noise in Rail Transit Cars: Incremental Costs of Quieter Cars", BBN Rept. 2566d (March 1974).

"Coal Cleaning Plant Noise and Its Control" (with G.E. Fax, W.N. Patterson, H.L. Fox), BBN Rept. 2827 (June 1974).

Structural Dynamics

"Preliminary Vibration Study of 330 MWe Ft. St. Vrain Reactor" (with K.L. Chandiramani, H.H. Heller, W.D. Mark), BBN Rept. 1543 (June 1967).

"Study of Cable Deflections and Cable/Trolley Dynamics of Emergency Egress Slide Wire System at Launch Complex 39, Kennedy Space Center" (with K.S. Lee, Y. Kadman), BBN Rept. 1694 (June 1968).

"Effects of Saturn V Launches on LCC Window Structures" (with Y. Kadman), BBN Rept. 1691, (June 1968).

"Impact Analysis of 30-in. 600# USA Standard Swing Check Valve" (with S. Hariharan), BBN Rept. 1944 (March 1970).

"A Guide for Predicting the Vibrations of Fighter Aircraft in the Preliminary Design Stages" (with R. Madden, R.H. Lyon, E.K. Bender, B. Zapotowski), AFFDL-TR-71-63 (May 1972).

"Wind-Related Factors in the Design of the DBS and CPF Buildings; Part 1. Structural Loads and Motion of the DBS Building" (with R.E. Hayden), BBN Rept. 2337 (Feb. 1972).

"Noise and Vibration Evaluation. GTX Baggage Handling System, SEA/TAC Airport" (with W.E. Blazier, M.A. Porter), BBN Rept. 2448 (Sept. 1973).

"New Field-Measurement Technique for Attacking Loading Line Vibration Problems" (with M.A. Porter), Gas Compressor Institute Conference, Liberal, Kansas (April 1974).

APPENDIX B

CAPABILITIES AND FACILITIES

BOLT BERANEK AND NEWMAN INC.

CAPABILITIES AND FACILITIES

Bolt Beranek and Newman Inc. (BBN) is engaged in consulting, research, and development in science and technology. Our primary activities are conducted by the following operating units.

- Physical Sciences Division
- Architectural Technologies and Noise Control Division
- Behavioral Sciences Division
- Computer Science Division
- Computer Systems Division
- Technical Operations Group
- Geomarine Operations

The BBN technical staff consists of approximately 450 scientists and engineers, of whom about two-thirds hold advanced degrees. These staff members have at their disposal extensive laboratory and computer facilities, which are described in the following pages. Project teams are assembled from personnel in all the divisions to solve problems that require a combination of specialties and skills.

BBN has its headquarters in Cambridge, Massachusetts, and maintains regional offices in Washington, D.C., Chicago, Los Angeles, San Francisco, Houston, and Waltham, Massachusetts.

PROFESSIONAL SERVICES

BBN's technical staff provides research, development, and consulting services in the following areas.

Physical Sciences

Δ Underwater Acoustics: Underwater sound propagation, reverberation, reflection, and scattering. Modeling and analysis of signals and noise. Analysis, design, systems testing and evaluation, and performance modeling and prediction of passive and active sonars. Signal processing, including analysis, software, and displays. Ship silencing, including flow noise, machinery noise, structural vibration and radiation, propulsors, and noise control technology. Marine engineering studies, such as hydrodynamics, control systems, and systems analysis. Marine geophysics.

Δ Aerospace Dynamics: Steady and unsteady aerodynamic loads, including hypersonic and supersonic regimes. Dynamic responses of structures, components, and equipment. Sound radiation from vehicles and structures. Quiet propulsion and lift systems. Conceptual design, development, and evaluation of test facilities and equipment. Ground wind loads. Wind tunnel simulation of noise and structural dynamics. Prediction of dynamic environments and protective design.

Δ Noise and Vibration: Diagnosis and control of noise and vibration in machinery, vehicles, and power sources. Product design incorporating noise abatement techniques. Cost-benefit studies of noise treatment. Fabrication, testing, and delivery of prototype products.

Δ Instrument Systems: Design and production of sensors for measuring sound, vibration, stress, pressure, temperature, and heat flow. Measurement systems for monitoring noise on ships, aircraft, and land vehicles. Monitoring systems for ships, airports, highways, and buildings. Portable measurement equipment.

Δ Geophysics: R & D support in marine subbottom survey techniques and instrumentation, marine and land seismic propagation data analysis, shoreline and nearshore sedimentation processes, marine sediment sampling and analysis, and signal processing. Field and laboratory services in seismic reflection profiling, sidescan sonar applications, sediment sampling and analysis, geological surveys, and data interpretation.

Δ Structural Dynamics: Analysis and testing of the response of structures to static and dynamic loads. Data acquisition and analysis. Flexible structures, shell analysis, and finite element analysis. Fluid/structure interaction and impact phenomena. Composite materials.

Δ Ultrasonics and Medical Technologies: Research and development in high-resolution ultrasonic diagnostic techniques and techniques for therapy and surgery. Design and development of ultrasonic diagnostic equipment and biomedical instrumentation. Consulting services in biomedical engineering and nondestructive testing.

Architectural Technologies and Noise Control

Δ Building Acoustics: Consulting services to insure satisfactory acoustical environments in new and existing buildings of all types, including auditoriums, performing-arts centers, schools, office buildings, apartments, and research facilities. Areas of study and design include room acoustics, sound isolation, sound-amplification systems, and mechanical system noise and vibration control.

Δ Building Aerodynamics: Climatological and wind tunnel studies of buildings and complexes. Prediction of wind-induced vibrations and their effects on structures, building occupants, and equipment. Studies of ground-wind effects in pedestrian areas. Selection of favorable sites and configurations. Consultation on design for vibration reduction. Field measurements on existing structures.

Δ Environmental Noise Control: Evaluation of noise in the community, including consulting with governmental agencies, airports, transportation systems, power systems, and industry. Development of environmental impact statements, noise monitoring systems, and noise regulations. Application of noise control engineering technology for solving existing problems and planning for future compatibility.

Δ Regulatory Acoustics: Definition of noise control needs based on present and predicted noise levels. Establishment of goals based on factual testimony and state-of-the-art technology. Development and drafting of regulations, including research on legal aspects and suggestions for enforcement procedures and test methods. Regulation evaluation guidelines. Management planning for administering regulations. Public education programs to increase awareness of noise as a pollutant and the role of regulatory agencies.

Δ Environmental Vibration Studies: Field measurement of vibrations in and near buildings and transportation systems. Evaluation of acceptability. Diagnosis of vibration sources and paths. Consultation on modifications for vibration reduction. Prediction of vibrations and their effects.

Δ Industrial Noise Control: Consulting services for quieting factories, power plants, petrochemical plants, machine products, and manufacturing equipment. Services include field evaluation of noise levels and worker exposure, development of compliance plans, detailed analysis of noise problems, and design of such cost-effective noise and vibration control measures as mufflers, enclosures, machine modifications, and sound absorptive treatments.

Δ Machinery Noise and Vibration Control: Analysis of noise-generating mechanisms of machinery either in situ or in our semianechoic laboratory. Machine design incorporating noise abatement measures. Design, fabrication, testing, and analysis of prototype products or treatments.

Δ Education in Applied Acoustics: Training manuals and lecture courses to acquaint clients' staffs with the role of acoustics and noise control in their plants and products. Special training courses for architects, engineers, building owners, plant engineers and foreman, safety and industrial engineers, and highway engineers on safety and for industrial and highway engineers on practical engineering approaches to noise control.

Δ Arts Programming and Facilities: Feasibility studies and studies to define the artistic, physical, and economic scope of proposed projects for the visual and performing arts.

Δ Theatre Consulting: Comprehensive consulting services covering functional planning of theatres, auditoriums, and concert halls, including space requirements and performance equipment requirements. Layout, design, and specification of stage lighting, rigging, and other performance systems and equipment.

Δ Audiovisual and Television Facilities: Comprehensive consulting in planning and equipping facilities for audiovisual presentation of teaching, for CCTV educational and broadcast television, for video tape recording, and for monitoring and information display.

Behavioral Sciences

Δ Experimental Psychology: Studies of basic human capabilities, including signal detection, pattern recognition, attention, memory, decision making, reaction time, and speech. Human factors engineering, survey techniques, social psychology.

Δ Control Systems: Development of analytic models of human behavior in relation to computers and machines. Studies of control theory and information theory and their application to analysis, optimization, and evaluation of systems.

Δ Psychoacoustics: Studies of human sensory capabilities for the detection and classification of acoustic signals. Basic research on the relative contributions of spectral composition, intensity, and duration of a signal to the perceived noisiness or to annoyance.

Δ Educational Technology: Applications of computers in education, including research on classroom use of computers and development of computer languages, instructional systems, and other tools for teaching and learning.

Computer Science

Δ Artificial Intelligence: Studies of representation of meaning. Development of programs to obtain syntactic and semantic analyses of written text. Mixed initiative discourse systems. Sensory motor control and intelligent processing for robots. Natural language question-answering systems for fact retrieval. Acoustic-phonetic and phonological analysis of continuous speech; integration of syntactic and semantic knowledge into continuous speech understanding systems. Digital signal processing systems. Techniques of speech compression for efficient transmission of speech signals. Research in automatic and computer-assisted programming. Research and development of special techniques to facilitate interaction between the scientist and the computer in AI research, including the design and implementation of computer display systems and the design, implementation, maintenance, and extension of the programming languages BCPL and LISP.

Δ Interactive Systems: Operating system research and development, including research into time-sharing systems which are distributed across communication networks, development of software protocols to enable an operating system to have its peripherals remote from an accessible to a system's computational processor via a mini-computer connected to a communications network. Continued development and support of the BBN TENEX time-sharing system. Research and development of computer tools to help with office automation problems.

Δ Transportation Systems Research, Development, and Consulting: General research and development in traffic control and information management problems of air, marine, and surface transportation systems. Simulation studies and development of simulators and training systems in these areas.

Computer Systems

Δ Systems Development: Development of time-shared and special-purpose computer systems to facilitate data management, information retrieval, real-time processing, and communication for a variety of applications.

Δ Computer Networks: Development and operation of networks that permit interactive communication among dissimilar time-shared computers. Design and implementation of Interface Message Processors that connect computers to the network and attend to routing, store-and-forward, buffering, and error control.

Δ Medical Computer Systems: Development of computer systems for use in pharmacology, the life sciences, and the medical profession. Automation of clinical testing procedures, development of information storage and retrieval systems for medical data bases, design of user interfaces for the study of complex molecular models, and development of aids to practicing primary physicians.

Δ Signal Processing: Design and development of both on-line and off-line computer systems for editing, storage, and retrieval of time-series data from arrays or networks of sensors.

Technical Operations

Δ Systems Analysis Services: Advanced analysis and evaluation of complex technical systems relating to antisubmarine warfare and peripheral areas. Problem-oriented development and engineering studies conducted by dedicated project groups. On-site investigations. Focused research and advanced technical analysis combined with engineering design to solve complex technical problems. Creation of custom technical support teams to provide on-site hardware and software support.

Geomarine Operations

Δ Petroleum Exploration and Production: High-resolution profiling of ocean bottom and subbottom formations using standard and proprietary techniques and equipment. Data acquisition, reduction, and interpretation.

Δ Civil Engineering Studies: Geophysical surveys for use in dredging operations, siting offshore facilities, pipeline routing, and locating sand and gravel deposits. Geotechnical services, including bottom samples, shallow and deep coring (to 1000 ft subbottom). Data acquisition, laboratory analysis, and recommendations for foundation design.

Δ Environmental Impact Studies: Shallow bottom surveys to determine possible environmental hazards relating to drilling, operation of offshore power plants, and construction of other offshore facilities.

RESEARCH FACILITIES

BBN's laboratory and research facilities provide a wide range of instruments and equipment for experimentation, testing, and calibration.

Δ Instrumentation: This facility stocks and maintains transducers, amplifiers, sound and vibration sources, recorders, analyzers, signal-display devices, and associated electronic equipment. Calibration apparatus includes an anechoic chamber, reverberant rooms, a high-intensity pistonphone system for microphone calibrations, and calibrators for hydrophones and accelerometers. Electrical and acoustical calibrations are referenced to the National Bureau of Standards. There are also data analysis facilities for obtaining real-time one-third octave band and narrowband spectrum analysis, correlation, and spectral density.

Δ Low-Speed Wind Tunnel: A free-jet, low-speed, low-turbulence wind tunnel for studying flow phenomena over various test objects. The tunnel can be fitted with a 25-ft long boundary layer channel. The test section, which may be an open or closed jet up to 20 ft long, is enclosed within a 4000 cu ft semireverberant sound field which can be converted to a semianechoic state. In the open-jet configuration, the 20-hp blower can produce a maximum wind speed of 120 fps at the 16-in. square or 18-in. diameter nozzle exit as well as in the boundary layer channel. Measurements are made with the aid of pressure transducers and hot-wire probes.

Δ High-Speed Wind Tunnel: A 22,000 cu ft, high-performance, aeroacoustic facility which is one of the quietest and most versatile of its kind. It can be used for aeroacoustic model studies of jets, STOL flap configurations, edge noise, fan, propeller, and rotor noise. The tunnel has a volumetric flow of 140,000 cfm. Its 3.1-ft diameter primary jet has a maximum velocity of 300 fps. Its secondary jets can produce 6000 cfm at up to 1.0 atm. overpressure, and higher pressures and volumes are possible. The tunnel can be operated in either an anechoic or a reverberant mode. In addition, it is equipped with a quiet device for rotating propellers, fans, and rotors. A variety of rpm ranges is available, with power consumptions up to 40 rpm provided by a hydraulic drive system. A 6-degree-of-freedom force balance is part of the tunnel's standard equipment.

Δ Underwater Laboratory: This laboratory is designed for underwater noise control projects and underwater transducer evaluation. It contains a calibrated, 14 x 22 x 33 ft reverberant water tank with very low ambient noise levels designed for accurate measurement of underwater sound power levels. It is equipped with hydrophones, sound projectors, and analyzers, and it has truck access and a travelling 2-ton crane. The time-gating technique can be used for transducer measurements.

Δ Physics Laboratories: These general-purpose laboratories are used for a variety of acoustical and other experiments. Included in the laboratories are paired reverberation rooms for transmission-loss tests and a 900 cu ft anechoic chamber.

Δ Acoustic/Dynamometer Laboratory: This laboratory is used to conduct noise diagnosis and control experiments on machinery that either generates, converts, or transmits power (e.g., diesel engines, hydraulic pumps, or gear units). The reverberant test cell has nonparallel walls and a rotating diffuser for precise measurements of acoustic power; it can easily be made anechoic. The laboratory is equipped with a dynamometer capable of absorbing 500 hp at 4000 rpm, engine parameter instrumentation (e.g., for monitoring oil and water temperature and oil pressure), air cooling capability, heat exchanger for water-cooled machinery, noise and vibration instrumentation, and mechanical and hydraulic power supplies.

Δ Semianechoic Laboratory: This 8000 cu ft laboratory is used for machinery noise measurements, modeling of acoustic test facilities and other scale-model studies, and a variety of other acoustical test programs. Associated measuring equipment includes a 1/3-octave band real-time analyzer equipped for sequential sampling and/or averaging of an array of up to 16 microphones or other transducers. A data reduction suite adjacent to the laboratory is equipped for acoustical test data analysis, including impedance tube measurements of sound absorption, as well as 1/10th and 1% spectrum analysis and statistical distribution analysis of sound levels. Associated model shop facilities permit construction of acoustical models.

Δ High-Velocity Airflow Equipment: Used for experimental studies of noise generated by subsonic airflow over surfaces, this facility consists of an aircraft engine compressor capable of supplying continuous airflows at up to 6000 cfm and 15 psi.

Δ Psychoacoustics Laboratory: The laboratory contains equipment for conducting experiments on speech-intelligibility test methods, subjective effects of noise, masking of speech, and speech compression. Apparatus includes sound-recording and playback equipment, noise generators, audiometers, speech-compression instrumentation, a large soundproof semidiffuse room for testing subjects, a library of tape-recorded speech material, and a PDP-8 computer for experimental control and data analysis.

Δ Psychophysics Laboratory: Experiments are conducted in this laboratory to study the relationships of human sensory capabilities to decision making in tasks that require the detection or classification of signals. The laboratory contains a PDP-8/L computer, which is used on-line and in real time, that generates auditory, visual, and vibratory stimuli; controls the procedure of an experimental session; and records and analyzes data on decision accuracy and latency.

Δ Manual-Control Laboratory: The laboratory is equipped for experiments that study the characteristics of the human as a controller of dynamic systems. A PDP-10 digital computer and an AD/4 hybrid analog computer are used on-line to generate input signals, to record, and to analyze data.

Δ Transducer Laboratory: This facility is used for the development and precision assembly of miniature instrument transducers, including pressure transducers, microphones, heat-transfer gauges, and hot-wire probes. Equipment includes watchmakers' lathes, electrometers, and other special instruments.

Δ Mechanical Services: Traditional machine shop and mechanical drafting facility, including lathe, milling machine, etc. Drawings are done to Mil-D-1000 or good commercial practice and files are maintained. Printed circuit board layout and taping are a normal part of the activity.

Δ Electronic Fabrication: Equipment and work stations for the efficient fabrication of electronic apparatus, including printed circuit etching and wire-wrapping.

COMPUTER FACILITIES

BBN's digital computer installations provide facilities for on-line computation and problem solving, real-time processes, and information storage and retrieval.

Δ PDP-10: Time-shared computer for up to 64 simultaneous users. Three arithmetic processors, 192K* words of core memory, 1.6M words of high-speed drum storage, and a 70M word disk pack file system. The system uses BBN TENEX pagers to run the BBN TENEX operating system, providing 256K words of virtual memory to each user process. System is accessible to the ARPANET. Peripheral equipment includes magnetic tape transports, DECtape transports, Calcomp plotter, real-time analog and digital I/O capability with high accuracy and high resolution clocking, and 2 high-speed line printers. Two more complete PDP-10 service systems to be installed by FY 75.

Δ PDP-8: 4K words of core memory, disk. Peripheral equipment includes high-speed paper-tape I/O, digital-to-analog and analog-to-digital converters, and auditory and visual display capabilities. [1 in Cambridge, 1 in Los Angeles]

Δ PDP-1D: Time-shared computer for up to 64 simultaneous users. 24K words of core memory, fast-access 120K-word drum, and a total of 60 million words of high-speed drum storage (Univac Fastrand 1). Peripheral equipment includes two Univac magnetic tape transports. User programs include STRCOMP, ISRCOMP, LOGO, and many others.

The Analog-Computer Laboratory has equipment for general purpose analog simulation. Hybrid computation capability is achieved by means of a versatile patching system that connects the analog computers to the PDP-10. Equipment in the laboratory includes the following:

Δ Applied Dynamics AD/4 Hybrid Analog Computer: 100-V machine with 56 operational amplifiers, nonlinear equipment, and general-purpose digital logic, capable of high-speed repetitive operation.

Δ Associated Equipment: Oscilloscopes, signal generators, multichannel analog tape recorders, X-Y plotters, strip-chart recorder, and sound-isolated rooms for psychological experiments.

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*K = 1024

GOVERNMENT CONTRACTING INFORMATION

Since 1948, Bolt Beranek and Newman Inc. has successfully completed hundreds of prime contracts undertaken on a CPFF, CPIF, T&M, or fixed-price basis for various government agencies, including the Department of Defense (Air Force, Navy, Army, Office of Civil Defense, ARPA, etc.), NASA, Department of Health Education and Welfare (including National Institutes of Health, Office of Education, National Air Pollution Control Center), Department of Housing and Urban Development, Department of State, Department of Commerce, Department of Transportation (Federal Aviation Administration, Federal Railroad Administration, Transportation Systems Center, etc.), and the Environmental Protection Agency. In addition, BBN has undertaken many major subcontracts for organizations such as Aerospace Corporation, Arthur D. Little, Inc., IBM Corporation, Raytheon Company, TRW Systems, AVCO Corporation, General Electric Company, Litton Industries, and Douglas Aircraft Company. Under contract to several states with federal grant funds, BBN has studied various matters ranging from computer applications in education to air and noise pollution.

The cognizant government auditing agency for BBN is the Defense Contract Audit Agency, 424 Trapelo Road, Waltham, Massachusetts 02154.

The Cambridge and Washington offices have top-secret facility clearance. The Los Angeles office has secret facility clearance. Security procedures for each office of the Company are conducted through the nearest Defense Contract Administration Services regional office.

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