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AUTHORITY

USNCEL ltr dtd 17 Mar 1969

Technical Note N-944

AN INTENSE NOISE GENERATOR FOR POSSIBLE USE IN TUNNEL CLEARANCE

BY

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October, 1968

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AN INTENSE NOISE GENERATOR FOR POSSIBLE USE IN TUNNEL CLEARANCE

Technical Note N-994

64-008

by

E. J. Back

ABSTRACT

A small pulse jet engine formerly used for heat transfer studies was operated briefly in a section of a model tunnel, the size of which is representative of those found in Vietnam. Because the noise had been a continual problem in doing the original heat transfer research, it was predicted that a larger version might be suitable for tunnel clearance, provided the sound intensity attenuation with distance from the tunnel's mouth was not too rapid. Free field tests as well as those in single right angle of a 3 x 3 foot cross section duct showed that attenuation was not rapid. It was concluded that a larger engine suitably mounted at the tunnel mouth might provide a lightweight, convenient noise source for the intended purpose.

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INTRODUCTION

This short report is an account of the first results of tests with a small pulse-jet aeroplane engine* used to, in this case, generate an intense noise. This sample device fires about 800 times a second, emitting a sharp staccato of shock waves; it had originally been used at the Naval Civil Engineering Laboratory (NCEL) to study heat transfer at rapidly varying velocities. For that purpose, it was envisioned that a compact, simple boiler useful for heating water for cooking, sterilization, etc., could be made which would be useful under battle or expeditionary conditions. A report of that work is soon to be released as NCEL Technical Report R-586 (Beck, 1968). It was concluded that the concept was valid, that the high heat-transfer rate would allow the type of design desired, and that the unit would be simple. However, the small engine tested proved very noisy, and the frequency of firing was in the range of maximum damage to the human ear. No relation of source frequency to irritation of the ears was found, but a source describing similar (but less definitive, heat-transferwise) studies (Reynst, 1961) mentioned noise as a major problem in industrial uses. Reynst spent most of his active engineering career developing pulsating burners, with a hope to making useful and simple boilers. His work deals mostly with the details of construction and operation of numerous experiments and do not include measurements of heat transfer, sound level and firing frequency, although he recognized the physical basis for the firing frequency. Important to this work is that apparently his boilers, which burned many fuels, including pulverized coal, were not accepted in Europe because of the noise generated. He described approaches (including using two burners with common exhaust, and hopefully securing cancelling in the stack) to quieting the pulse burners tested, but with no real success. He died quite young and did not complete the work as he had hoped.

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*Curtis Dyna Products, Westfield, Indiana, Dyna Jet Engine

It was recognized at NCEL that the small pulse-jet engine, manufactured as a model airplane or boat engine, would not produce sufficient noise for the purpose under consideration - tunnel clearance in Vietnam. However, two simple experiments were planned which would allow, by similitude, a projection of whether a much larger and noisier engine would accomplish the purpose. Two assumptions were made: first, a suitably designed larger engine would produce an intolerable noise, and second, the small engine tested here would give results of attenuation with distance in a tunnel (duct) comparable to that of the larger engine.

Since no reference was found from which these two assumptions could be verified, they remain for later experiments if and when conducted; this would be the principal purpose of the recommended future work. Reynst's work might have provided the answer to the matter of scale, since he used much larger engines and noise was found highly objectionable. However, there is no indication in the reference that he made actual noise measurements. Other applications of the pulse-jet engine have been largely related to ordnance, where a high noise level would be tolerated to receive other benefits.

DESCRIPTION OF EXPERIMENT

Two short but definitive series of noise readings have been run using the 18-inch long by 1-1/4-inch-diameter small pulse-jet engine, shown schematically in Figure 1. The first series was run in open air (free field) with the nearest reflecting object ahead of the engine about 42 feet away. Readings were taken some 18 inches from the ground (pavement) at 2-foot intervals along a line in line with the engine tube and at 30 degrees to the centerline as shown in Figure 2. The attenuation of noise level with distance as measured with a sound level meter with essentially flat sensitivity characteristics in the frequency range of the engine is shown in Figure 2. The rate of drop-off in sound level with distance was very low, much lower than $1/r^2$ rate which would be expected with an isotropic sound source. It is thus clear that the source is <u>not</u> isotropic in any sense.

The second series of measurements was taken in a 3- by 3-foot concrete duct buried in sand which has been used for shielding studies for nuclear radiation; the small duct simulates an entrance tunnel to a large shelter. The area in the immediate corner (shaded part of Figure 3) was lined with 1/8 inch of lead for the nuclear work. The lead would have some effect in sound attenuation; it was obviously trivial if observable, as there was no major discontinuity at the corner. The traverses of the two legs of the duct were made about an hour apart, and the difference in sound level (as indicated by a slight discontinuity) at the corner (point A, Figure 3) might be attributed to a slight difference in reading method, microphone position or engine fuel rate, or a combination of these. No importance is placed on it as it is a small effect in any case.

DISCUSSION OF RESULTS

The data for the free-field and duct runs were replotted on log-log paper; the log of distance versus log of sound-level intensity in db referred to 0.0002 microbar @ 1,000 cps. The slope of plot for the free-field data allows writing of the equation for the attenuation of sound intensity with distance:

$$I = I_o r^{-0.06}$$

where: I is the intensity in db at a point (2) a distance r feet away from the source of intensity at the tube mouth I_o. Similarly, the curve for the concrete duct data would be approximately:

$$I = I_o r_1^{-0.03} r_2^{-0.01}$$

where: r_1 is the distance along the first leg from the source, and r_2 the distance along the second leg, measured from the corner.

The very low attenuation with distance along the centerline in both the free-field and duct cases provides an optimistic impetus to further development and/or testing of larger units which might be suitable for tunnel clearance in Vietnam - a very noisy source at a tunnel entrance would be effective over a great distance. It had been planned that if results were sufficiently optimistic at this point (which they are), then similar tests would be made in the U. S. Army Mobility Equipment Research and Development Center, Fort Belvoir, Virginia, tunnel facility. This facility consists of a number of intersecting 5-foot-diameter holes bored into hillsides, simulating Vietnam tunnels. However, inspection of the data shown in Figures 2 and 3 suggests that even with the somewhat higher absorption which might be expected with bare soil walls, the difference in attentuation between that data and those of Figure 3 probably would not have been important. Further, the difference between the concrete duct and free-field data is so small as to be trivial for the proposed application. The soil-tunnel data would probably lie quite close to the concrete duct and certainly above the free-field measurements, which would predict the maximum dispersal of the energy in the unconfined field.

Finally, it was learned by telephone that no one is allowed to enter the tunnel system; readings could be taken only at or near the openings. It is believed that because of the considerable cost of conducting a series of tests there and the questionable value of the small additional information to be gained, the probable benefits outweigh the disadvantages; a trip is not planned.

An estimate of probable results in going to an alternate and larger sound source should be made at this point. Morse shows data (1948) indicating that while the threshold for hearing is a rapidly varying function of frequency or pitch, the threshold of pain is nearly uniform at an intensity level of about 120 to 130 db over the range of human hearing, from 20 cps to 20,000 cps; there is a slight increase in tolerance for noise at about 800 cps, that of the small engine tested here. Larger engines (because of their increased length - Beck, 1968) would have a lower frequency and the threshold of pain would be essentially uniform at 125 db over the entire probable design range. Morse states that about 5 db above this threshold value, the effect on the human auditory system can best be described as "pure pain." Coincidentally, the small pulse jet gave sound levels of this order. Morse also states that the ear is most sensitive at the ear diaphragm to sound at about 1,000 cps. Therefore, noise sources of a lower pitch might do less damage to the ear than those at higher pitches, but pain felt might be slightly greater. Therefore, a larger (longer and lower pitched) puse-jet engine might be more effective in terms of fuel utilization in producing pain to a tunnel inhabitant, but not in destroying his hearing; this point is not absolutely clear from the information obtained to date and will require further investigation if development and/or testing of a larger engine should be undertaken.

An unmeasured but observed facet of the small concrete tunnel test should be mentioned. The pulse-jet heater typically fires single or short bursts several times before it fires continuously These single explosions were very objectionable to the observer who was carrying the sound meter ahead of himself in the duct. Even with very effective sound-deadening earmuffs, these bursts were almost intolerable. The energy released was obviously much greater than the individual explosions afforded by continuous operation. From this, it is concluded that infrequent (10 to 100 times per second) but intense explosions from a large pulse tube should provide an intolerable noise level. At the much lower firing rate, the average fuel consumption might be comparable or only moderately higher than with this small engine.

Until the above brief investigation was completed, no effort to obtain larger pulse jets was made. Accounts of some performance and construction characteristics of at least two larger engines have been obtained (Giles, 1944; Aldag, 1965). In addition, there is the extensive collection of accounts of Reynst's (1961) work which should provide some additional information when inspected in detail.

The small engine tested proved troublesome in its operation on two counts. First, in spite of the reputation for simple operation, it usually, if not frequently, proved difficult in starting. It is believed that some of the difficulties were identified during the final moments of testing. Certainly if it should continue to act more like itself and less like its describers recount, it would be an unsatisfactory field device no matter how effective a noise maker. Most of the difficulty is attributed at this point to an overly simple fuel entrainment and feed system, which is highly responsive to small changes in compressed-air feed rate; during starting only, compressed air is needed. The flow rate appears to be critical. The engine is normally air cooled. Here it was, for convenience, fitted with a water jacket but not reservoir or method of separating the steam rapidly generated from the water ejected with the steam. A simple and light separator would be required for field use. Finally, the problems with cooling in this incomplete system (lacked separator and adequate water reservoir) point out the efficiency of the pulse-jet burner for producing hot water in a hurry with very simple equipment (Beck, 1968).

CONCLUSIONS

It is concluded that:

1. The limited but definitive attenuation with distance of the noise from a small pulse-jet engine reinforces the prediction that, as a noise source, the output will drop but little with distance along a small underground tunnel.

2. In a suitable size (so that the sound intensity will be higher than that in the small engine), the pulse-jet engine promises to produce a highly objectionable sound well above the pain level for some distance along a tunnel.

3. Further work along the lines of (2), using a larger, longer engine of lower firing frequency, and therefore pitch, are justified at this point.

4. An optimum design (length, diameter, etc.) cannot be deduced from the limited literature searched on larger engines, but that further study of the physiological effects of sound and contact with known manufacturers may readily produce this information.

5. Any device obtained and/or developed would probably be an effective hot-water heater for field use if properly modified with a water jacket and some method of circulation or steam separation.

RECOMMENDATIONS

It is recommended that the work started and reported herein be continued on a regularly authorized work unit as a potentially valuable development for tunnel clearance in Vietnam, with additional potential application as a rapid water heater for field use.

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Reynst, F. H. (1961). "Pulsating combustion, the collected works of F. H. Reynst, Ed. M. W. Thring. Permgamon Press, Oxnard, London, New York, Paris.

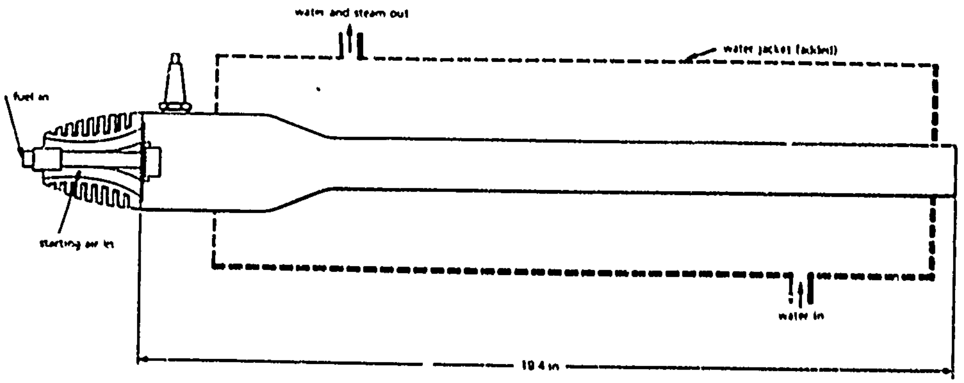

Figure 1. Dimensioned schematic of small pulse-jet engine with water jacket.

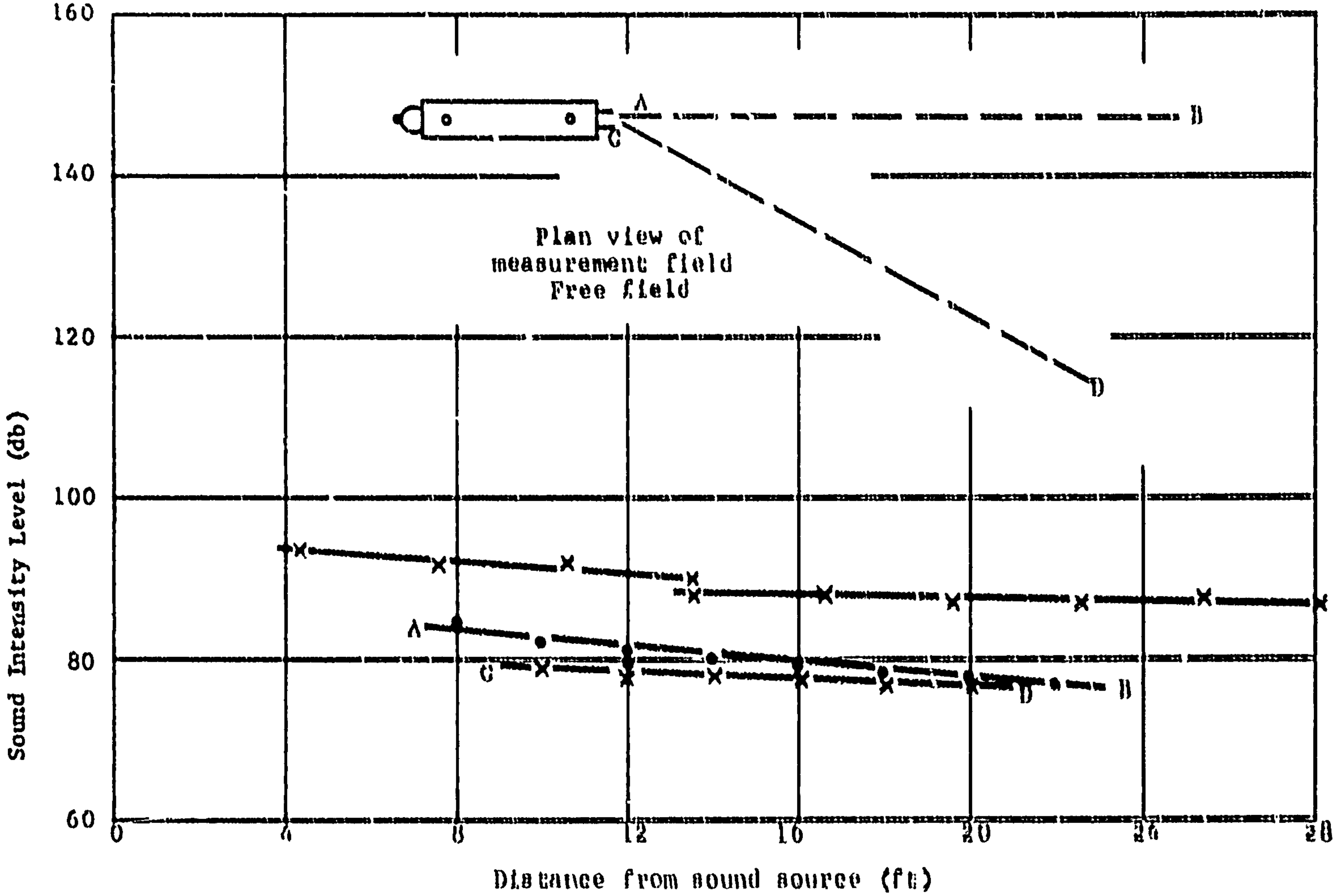

Figure 2. Noise attenuation with distance in a free field.

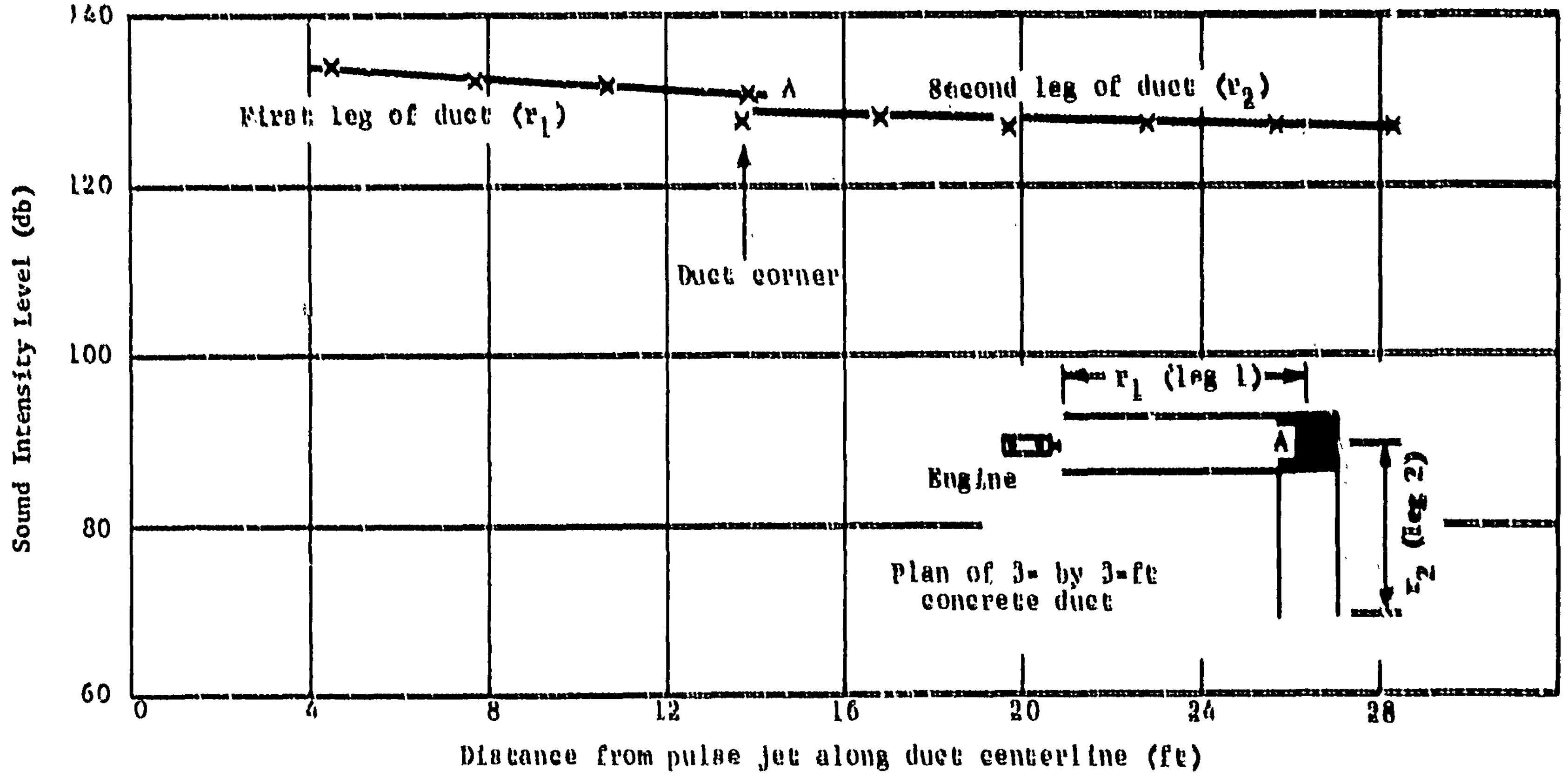

Figure 3. Noise attenuation with distance in a concrete duct.

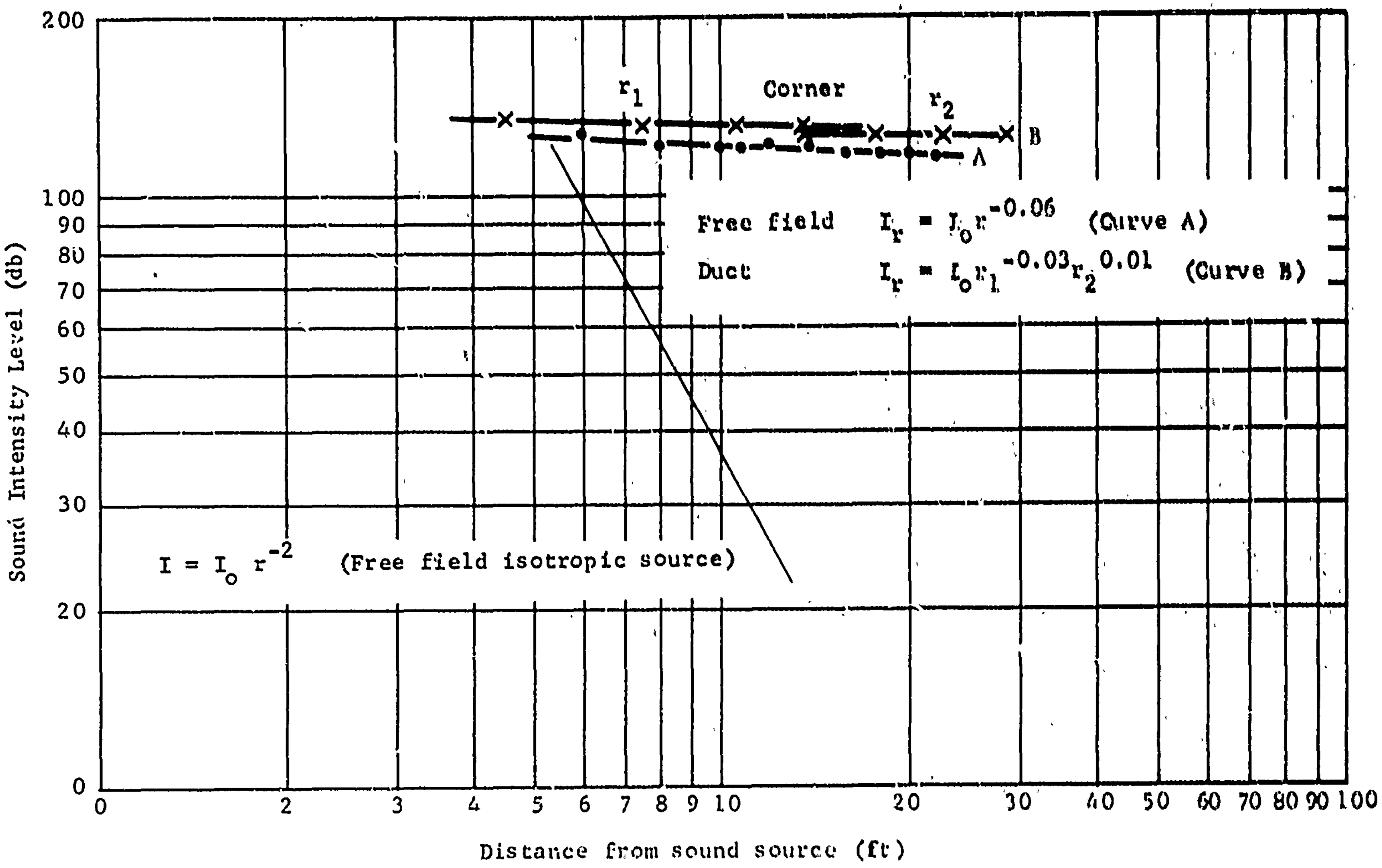

Figure 4. Data of Figures 2 and 3 replotted on common log scale.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Civil Engineering Laboratory Port Hueneme, California 93041	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

AN INTENSE NOISE GENERATOR FOR POSSIBLE USE IN TUNNEL CLEARANCE

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
January - July 1968

5. AUTHOR(S) (First name, middle initial, last name)

E. J. Beck

6. REPORT DATE October 1968	7a. TOTAL NO. OF PAGES 16	7b. NO. OF REFS 4

8a. CONTRACT OR GRANT NO. b. PROJECT NO. 64-008 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) TN-994 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Each transmittal of this documet outside the agencies of the U. S. Government must have prior approval of the Naval Civil Engineering Laboratory.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Facilities Engineering Command Washington, D. C. 20390

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Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Pulse jet engines Noise generators Tunnels Clearing Vietnam						

Unclassified

Security Classification

SUPPLEMENTARY

INFORMATION

IDENTIFICATION	FORMER STATEMENT	NEW STATEMENT	AUTHORITY
AD-843 468L Naval Civil Engineering Lab., Port Hueneme, Calif. Technical note. Jan-Jul 68. Rept. no. NCEL-TN-994 Oct 68	USGO: others to Commander, Naval Civil Engineering Lab., Port Hueneme, Calif.	No limitation	USNCEL ltr, 17 Mar 69