Modeling Of Highway Tunnel Ventilation System Noise For Compliance With Municipal Regulations, With Field Data Confirmation

Paper # 161

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ABSTRACT

The Central Artery/Tunnel (CA/T) Project in Boston, Massachusetts is the largest highway project ever undertaken in the United States. The CA/T Project is funded by the Federal Highway Administration (FHWA), the Massachusetts Turnpike Authority (MTA), and the Massachusetts Highway Department (MHD). Design and construction of the CA/T Project is managed by the joint venture firm of Bechtel Group and Parsons Brinckerhoff, referred to as Bechtel/ParsonsBrinckerhoff (B/PB).

In 1995, FHWA authorized the consideration of jet fan based longitudinal ventilation on CA/T ramp tunnels. Jet fans are being installed on ten CA/T ramp tunnels for each of which verification of compliance with City of Boston noise regulations must be provided. A spreadsheet based noise analysis model which accounts for tunnel interior geometry, fan location(s), fan quantities, fan noise spectrum, fan inlet and outlet attenuation, tunnel interior surfaces, location of closest abutter and classification (residential, commercial or industrial) was developed which greatly simplified and accelerated the analysis of acceptable operating conditions (multiple fans) on each ramp tunnel. After installation of the jet fans on each ramp tunnel, field noise measurements were obtained to verify model results. The spreadsheet based noise model provided results which enabled CA/T Project staff to verify compliance with all applicable noise regulations. This paper summarizes the development of the noise model, presents the modeling results, and provides relevant confirmatory field results.

INTRODUCTION

The CA/T Project in Boston, Massachusetts is the largest highway project currently in progress in the United States. Design and construction of this project falls under the jurisdiction of the Massachusetts Turnpike Authority (MTA), Massachusetts Highway Department (MHD) and Federal Highway Administration (FHWA). The aforementioned entities have retained a Management Consultant (MC) to prepare Conceptual and Preliminary Design Documents, and to supervise Final Design (performed by Section Design Consultants (SDC)) and Construction of the CA/T Project. A joint venture firm formed between Bechtel Group and Parsons Brinckerhoff, referred to as Bechtel/Parsons Brinckerhoff (B/PB) serves as the MC.

The CA/T Project includes approximately 64 lane-kilometers of tunnel roadways, ranging from one lane to five lanes of traffic. The project utilizes viaduct, bridge, open cut boat section, cut-and-cover tunnel and sub-aqueous tunnel to create a modern urban highway system, Figure 1. This system consists of two major Interstate highway components: I-90 and I-93. I-90 provides an east-west connection from the current terminus of the Massachusetts Turnpike (I-90) in the South Bay area through South Boston to Logan International Airport in East Boston via open cut boat section, cut-and-cover tunnel and sub-aqueous tunnel. I-93 provides a north-south route through downtown Boston via viaduct, open cut boat section, cut-and-cover tunnel, and rehabilitated existing tunnel structures replacing an existing elevated roadway.

CENTRAL ARTERY/TUNNEL PROJECT TUNNEL VENTILATION

Ventilation systems are provided in vehicle tunnels to fulfill two functions:

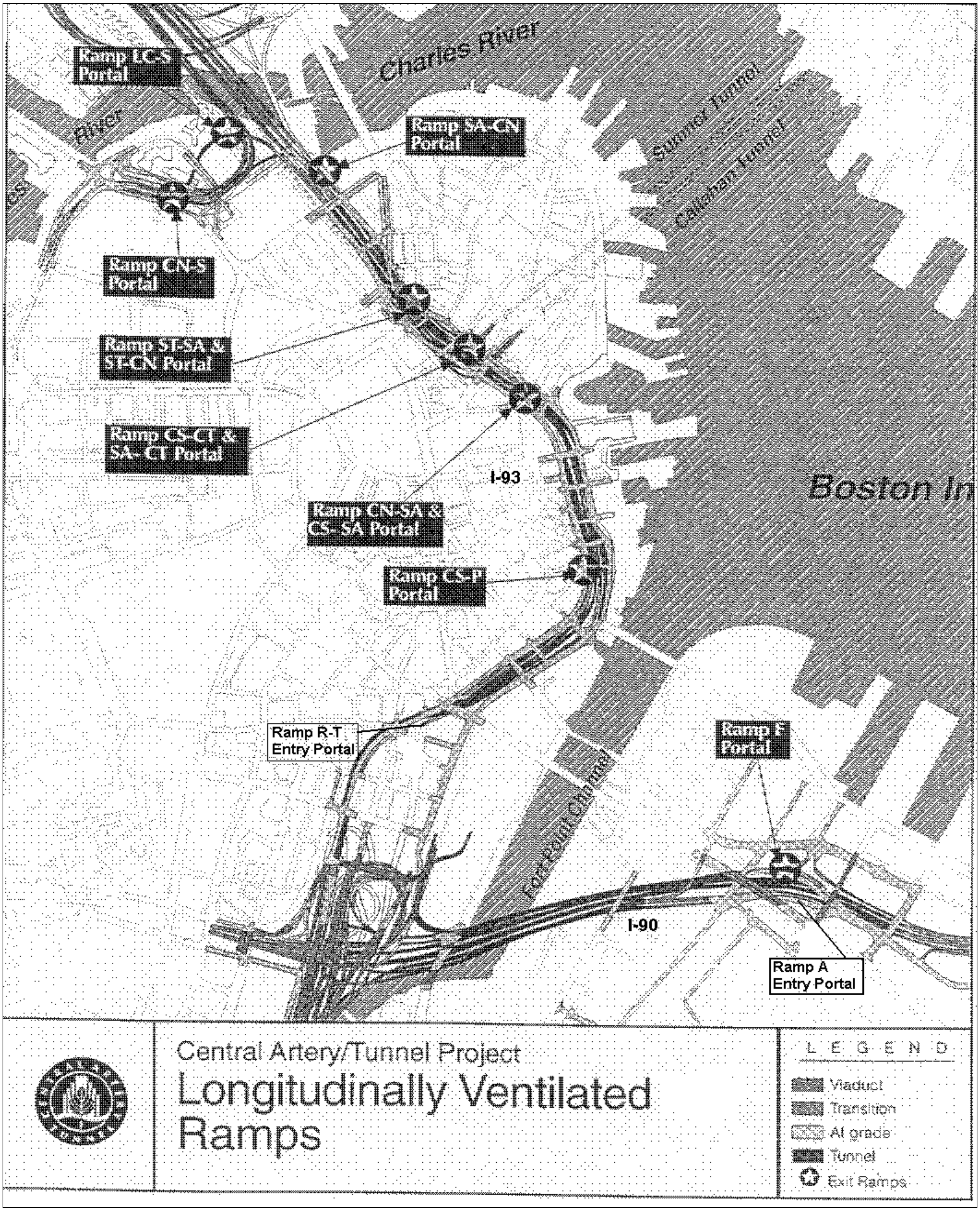
1) To control the movement of hot gases and smoke resulting from a fire. Fires in vehicle tunnels pose a significant threat to human life. During an emergency in a tunnel involving a fire, high temperatures and the release of smoke and hot gases endanger motorists and fire-fighting personnel. Tunnel ventilation systems are designed to protect patrons from the effects of a fire by providing a safe evacuation path.

2) To control the concentration of automobile emissions in a tunnel. As vehicles pass through a tunnel the by-products of petroleum combustion (Carbon Monoxide (CO), Oxides of Nitrogen (NOx) and Particulate Matter (PMx) etc.) are emitted in an enclosed environment. Build-up of these gases and particles can create an unhealthy or dangerous environment for motorists or tunnel operations personnel. Maximum time averaged exposure limits for CO in tunnels promulgated by FHWA/EPA and incorporated into the CA/T Project Design Criteria are provided in Table 1. Ventilation systems are typically employed to provide dilution and/or evacuation of contaminated air. The CA/T Project utilizes four types of tunnel ventilation systems: Full-Transverse, Longitudinal, Longitudinal (and Semi-Transverse (supply)) with jet fans, and Longitudinal with injection.

Table 1. Maximum Tunnel Carbon Monoxide (CO) Exposure Levels

Exposure Time (minutes)	Time Averaged CO Exposure Limit (ppm)
15	120
30	65
45	45
60	35

Figure 1. Central Artery/Tunnel Project Alignment



In 1995, the CA/T Project initiated a Jet Fan Implementation Program[1] which was aimed at incorporating jet fan based longitudinal ventilation on CA/T ramp tunnels, with considerable potential cost savings compared to full-transverse ventilation. This program resulted from direction provided by the FHWA after favorable results for jet fans were obtained from the Memorial Tunnel Fire Ventilation Test Program (MTFVTP) conducted in West Virginia in 1995.

With a longitudinal ventilation scheme, air moves through the tunnel as the result of the "piston" effect created by moving vehicles and is discharged at the outbound portal. In order to preserve the mass-flow balance an equivalent amount of air must enter the tunnel. In the case of an unconnected tunnel, the make-up air is drawn through the entry portal and contains ambient levels of pollutants, Figure 2. If the ramp tunnel exits from the mainline tunnel the source of make-up air is the mainline tunnel which can be assumed to have a higher concentration of pollutants than air drawn from the surface (25-50 ppm CO versus 3 ppm CO). In order to maintain air quality levels within the tunnel, a supply air duct must be utilized to provide a source of fresh air to the augment the air drawn from the mainline tunnel creating a semi-transverse (supply) ventilation arrangement, Figure 3. A jet fan based longitudinal or semi-transverse ventilation system is achieved by utilizing jet (axial flow) fans mounted in the tunnel. Tunnel air is ingested by the fans and discharged at high velocity. The high velocity air imparts an impulse to the surrounding air causing it to flow. The fans are typically operated only in emergency (fire) or stalled traffic (high CO) situations as the "piston" effect is generally sufficient to maintain in-tunnel air quality[2].

Figure 2. Longitudinal Ventilation Schematic Diagram

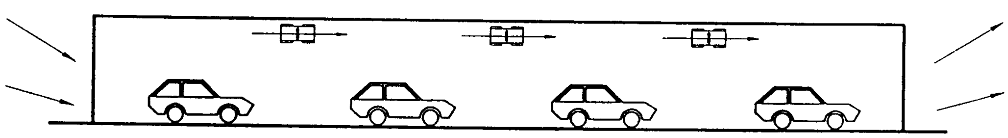
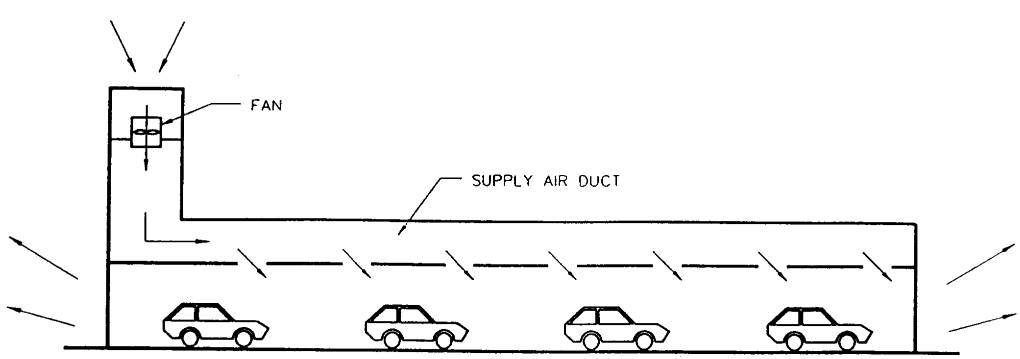
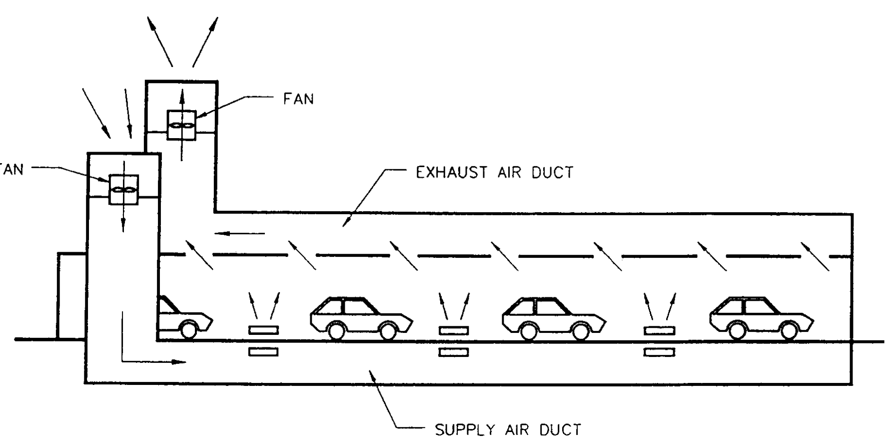


Figure 3. Semi-Transverse Ventilation Schematic Diagram



In contrast to the relatively short and narrow (1 or 2 lanes) tunnel segments described above, all CA/T mainline tunnels employ full-transverse ventilation systems. Full-transverse ventilation systems at the CA/T use separate supply and exhaust ducts that parallel the roadway and are served by fans centrally located in ventilation buildings, Figure 4. In general, the exhaust ducts are located above the roadway while the supply ducts are located beneath the roadway. The supply air sweeps the tunnel cross-section, diluting pollutants to an acceptable level. Exhaust air is then transported back to a ventilation building via an exhaust duct and is discharged into the atmosphere at a sufficient elevation and velocity to promote effective dispersion[3]. During emergency situations, air in an incident zone is typically over exhausted to promote the removal of heat and smoke while the adjacent ventilation zones are pressurized to prevent the migration of hot air and smoke from the incident zone.

Figure 4. Full-Transverse Ventilation Schematic Diagram



The location of the CA/T Project longitudinally and semi-transversely (supply) jet fan ventilated exit ramps are provided in Figure 1. In total, thirty-five jet fans will be installed on ten CA/T ramps. The jet fans are of various sizes and provide various airflow quantities as determined during design and scheduled[2]. The manufacture and installation of the jet fans is part of the CA/T Project C20B1 contract. As part of this contract, the fan manufacturer is to perform a noise test on each fan at the factory per AMCA 300 (Air Movement and Control Association, Reverberant Room Method for Sound Testing of Fans) prior to delivery. Testing of the fans for Ramp A and Ramp F was conducted in the first and second quarters of 2000 to support tunnel openings in late 2000 (December, Ramp A) and early 2001 (March, Ramp F).

The C20B1 contract also requires the contractor to perform field tests of jet fan noise levels in the tunnel(s) after installation of the fans. The testing performed by the contractor is only intended to verify compliance with specified in-tunnel noise levels of 85 dBA (for compliance with OSHA long-term exposure limits). Consequently, the CA/T Project had to perform additional testing and analysis to verify compliance with the City of Boston Noise Code for jet fan noise that might affect nearby noise sensitive receptors.

JET FAN NOISE MODEL

As part of the Central Artery/Tunnel Project's final construction and installation process, a noise prediction model was developed to assess the potential noise consequences associated with the operation of various roadway tunnel ventilation system jet fans. The overall goal was to ensure that the jet fans, when operating in the tunnels, would not produce and propagate objectionable noise levels into the abutting communities. Towards that end, predicted jet fan noise levels were evaluated for acceptability against the City of Boston Noise Code[4].

It should be noted that this jet fan noise model did not develop any new mathematical nor computer code approaches, but rather made use of existing acoustical relationships and equations which were repackaged in a useful spreadsheet format for this specialized application involving jet fan noise. The resulting spreadsheet model greatly aided CA/T Project engineers to evaluate potential jet fan noise impacts to the surrounding community in a quick and efficient manner. Moreover, with the successful comparison exercise of modeled vs measured jet fan noise, other acoustical engineers who routinely use and rely upon these previously established equations can do so with renewed confidence.

Even though preliminary jet fan noise predictions had been published in 1996 in the CA/T Project's Longitudinal Ventilation Notice of Project Change (NPC)[5], improved noise predictions were needed because of the noise-sensitive nature of many of the abutting communities. When the first of the jet fans were manufactured and tested, it provided an opportunity to update the NPC study with improved jet fan noise source strength data. Using the fan manufacturer's actual sound power test results for the various fans[6] and given the typical insertion losses expected with various-sized silencers, the resulting broadband A-weighted and octave band noise levels anticipated in the community were more accurately predicted based on the acoustic properties of the tunnel interior, intervening barriers or walls, and the geometries involved with the tunnel portal openings. The predicted noise levels in the community were then compared against applicable City of Boston Noise Code broadband and octave band noise criteria limits for specific receptor land-use classifications.

If predicted jet fan noise levels were found to exceed City of Boston Noise Code criteria, then noise mitigation options could be considered and evaluated within the jet fan noise model. The merits and potential noise reduction benefits of mitigation options such as an alternative-sized silencer, restrictions on the number of fans operated at one time during non-emergency situations, or the provision of acoustical absorption material to the tunnel's interior surfaces, were readily evaluated. Moreover, should the City of Boston Environmental Department, or any other concerned party such as an abutter to the tunnel portals, question the noise levels expected with the operation of the jet fans, then the Project will be well positioned to provide reassuring answers that jet fan noise levels have been adequately assessed and mitigated if needed.

With the jet fan noise model developed, the prediction accuracy of the model was tested through a model validation measurement exercise. Broadband and octave band noise readings were collected at the portal openings with the first of the tunnel jet fans operating (Ramps A and F). These noise measurements were then compared against the corresponding jet fan noise model predictions, and the results revealed additional adjustments that needed to be incorporated into the jet fan noise prediction model. Namely, the jet fan's initial sound power source levels needed to be adjusted to better differentiate inlet vs outlet sound power contributions, the acoustical absorption provided by the open ends of the tunnel needed to be accounted for, and the pure tones expected from the manufacturer's sound power source data did not reveal themselves in the field so the pure tones were smoothed out of the model's source spectra.

With the jet fan noise prediction model calibrated, actual measured noise levels were in good agreement (i.e. within +/- 1 dBA) when compared to predicted noise levels. Such a good modeled vs measured match provided confidence that the jet fan noise prediction model could be relied upon to accurately predict jet fan noise levels in CA/T Project and other project's similar tunnel installation applications.

Through the use of this jet fan noise prediction model, tunnel design engineers and environmental engineers can gain the following advantages:

- Predict expected jet fan noise levels at receptor locations during the project design phase before the actual fans are installed.
- Evaluate predicted jet fan noise levels against applicable federal, state, or local criteria.
- Select noise code compliant fans from alternate manufacturers.
- Experiment with noise mitigation alternatives such as absorptive treatments and/or silencers.
- Evaluate the number(s) of fans which can be operated simultaneously for maintenance and non-emergency purposes.
- Prepare realistic noise performance criteria for fan manufacturers and installers to follow.

JET FAN NOISE SPREADSHEET

The jet fan noise prediction model was developed in a spreadsheet format using Lotus123 (or Excel) as shown in Figure 5. The user simply enters some input conditions including narrative text describing the jet fan location and receptor of interest being modeled, as well as:

- the tunnel portal's cross section opening, in sq.ft.
- the number of jet fans operating at any given time
- the distance from the nearest jet fan to the portal opening, in feet
- the surface areas of the pavement, walls, and ceiling, inside the entire tunnel, in sq.ft.
- the distance from the tunnel portal to the receptor of interest, in feet
- the distance from the portal to any intervening barrier such as a boatwall, in feet
- the depth of the tunnel's roadway surface below grade at the portal, in feet
- and an indication of the land-use of the receptor and the time period (day/night) to assess

The user then also selects from a menu (1) the type and size of jet fan to include in the model, (2) the size and length of any associated inlet and outlet silencers, and (3) the types of materials used on the tunnel's roadway surface, walls, and ceiling. Again, these equipment and materials assumptions can be easily altered to explore possible beneficial noise reduction effects, if needed.

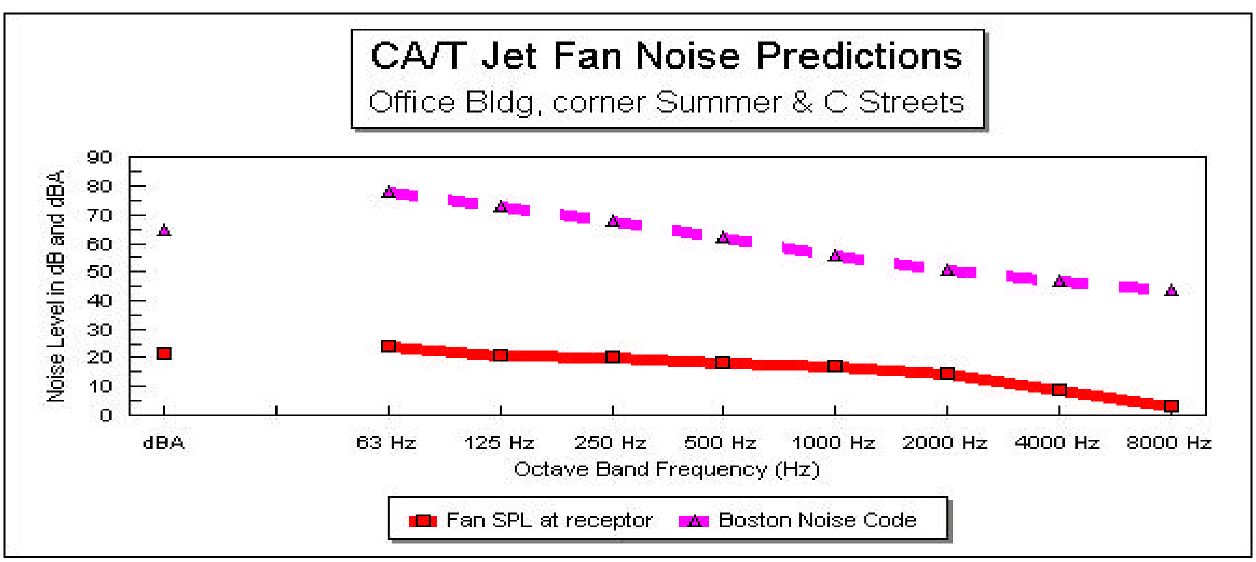
Figure 5. Jet Fan Noise Prediction Model, Example Input and Output

filename:	FANNOISE.WK4
date:	05/17/00
revised:	11/27/00
purpose:	Predict jet fan noise from various CA/T tunnels to nearest lot-lines per City of Boston Noise Code

INPUT CONDITIONS:

Effected Ramp:	**A**	
Portal Opening:	**Entry**	
Portal cross section:	**340**	sq.ft.
Number of Jet Fans:	**1**	operating at one time
Distance fans to portal:	**120**	feet
Pavement surface area:	**11600**	sq.ft., inside entire tunnel
Interior walls surface area:	**19720**	sq.ft., inside entire tunnel
Ceiling surface area:	**11600**	sq.ft., inside entire tunnel
Distance portal to receptor:	**350**	feet
Distance portal to boatwall:	**15**	<-- enter distance in feet, or enter "None" for no intervening barrier
Portal roadway depth:	**-25**	feet below grade to roadway surface
Receptor description:	**Office Bldg, corner Summer & C Streets**	
Receptor Zoning:	**B**	<-- R = Residential, R/I = Residential/Industrial, B = Business, I = Industrial
Time of day to evaluate:	**D**	<-- D = daytime (7am-6pm), N = nighttime (7pm-6am and Sundays)

			dBA	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
A-weighting Correction				-26.2	-16.1	-8.6	-3.2	0.0	1.2	1.0	-1.1
Fan PWL	**5JF-A-1**	Inlet	117	93	96	107	117	114	103	96	89
Fan PWL	**5JF-A-1**	Outlet	113	88	91	102	111	111	102	94	86
Average Fan PWL Source Spectra			115	90	94	104	114	112	103	95	87
Silencer IL	**2x1m**	Inlet		5	9	19	30	27	17	12	8
Silencer IL	**2x1m**	Outlet		3	7	17	26	25	17	13	9
PWL fans through silencers			95	90	89	90	89	89	89	86	82
PWL all fans/silencers added together			95	90	89	90	89	89	89	86	82
Pavement absorption coef.	**Concrete**			0.01	0.01	0.02	0.04	0.06	0.08	0.10	0.10
Walls absorption coef.	**Glazed tile**			0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02
Ceiling absorption coef.	**Concrete**			0.01	0.01	0.02	0.04	0.06	0.08	0.10	0.10
Portals absorption coef.	**Open End**			0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Average absorption coef.				0.03	0.03	0.03	0.04	0.05	0.07	0.08	0.08
SPL at portal opening			77	75	75	74	73	72	70	66	63
PWL over the portal opening			92	90	90	89	88	87	85	81	78
Insertion Loss due to boatwall (per Maekawa)				18	20	20	20	20	20	20	20
Molecular absorption loss per 1000 ft				0.1	0.2	0.4	0.7	1.5	3.0	7.6	13.7
Molecular absorption loss				0.0	0.1	0.1	0.2	0.5	1.1	2.7	4.8
Anomalous attenuation per 1000 ft				0.4	0.6	0.8	1.1	1.5	2.2	3.0	4.0
Anomalous attenuation				0.1	0.2	0.3	0.4	0.5	0.8	1.1	1.4
SPL at receptor location			22	**24**	**21**	**20**	**18**	**17**	**14**	**9**	**3**
City of Boston Noise Code			*65*	*78*	*73*	*68*	*62*	*56*	*51*	*47*	*44*
Exceedance, if any			OK	OK	OK	OK	OK	OK	OK	OK	OK



With all the input information established, the jet fan noise model computes the predicted broadband (A-weighted) and octave band (63 Hz to 8000 Hz) noise levels at the receptor location. Starting from the sound power levels provided by the jet fan manufacturer[6] for the specific jet fan selected from the model's menu, the insertion loss properties of the selected silencer[6] are then applied on an octave band basis. The sound power source strength of the jet fans are then summed over the number of jet fans expected to be operating at a given time.

At this point in the model, the octave band sound power levels are converted into sound pressure levels and projected to the tunnel portal opening using "the room equation"[7] . The room equation accounts for both the direct sound path assuming point-source spreading against a reflecting surface (where Q=2 due to the tunnel ceiling) as a function of distance, as well as the reverberant noise contribution due to the tunnel's interior acoustical properties. The octave band absorption coefficients for each type of interior surface material are automatically retrieved from the model's selection menu, and the tunnel ends (portal areas) are assumed to provide 100% acoustical absorption.

At the portal opening, the jet fans' projected sound pressure levels are converted back into sound power levels by taking into account the surface area of the portal opening. Next the insertion loss attributable from some intervening barrier or boatwall embankment (if any) is computed on an octave band basis using Maekawa's path-length-difference method involving Fresnel numbers[7]. The geometries defining the noise barrier’s position and height were provided by the user when the distance from the portal opening to the barrier, the distance from the barrier to the receptor, and the depth of the portal opening relative to grade, were entered into the model.

From this point, the model predicts the broadband and octave band sound pressure levels at any receptor location in the community based on the sound power levels at the portal opening. The primary equation used for this sound pressure projection assumes that the jet fan noise is escaping through the portal opening only (i.e. a hole in a wall) and radiating in a hemi-spherical pattern into a free-field environment[8]. The effects of molecular absorption and anomalous attenuation are also taken into account by the model over the distance from the portal opening to the receptor location[8]. These latter acoustical loss factors are relatively insignificant at lower frequencies, but can account for significant mid- and high-frequency losses as distances increase. Climatic conditions assumed in the model are standard temperature and humidity (60 deg.F and 70% RH).

Finally, the resulting broadband and octave band sound pressure levels are predicted at the receptor location. These results are then compared in the model against applicable City of Boston Noise Code criteria limits for the given receptor's land-use classification (residential vs commercial vs industrial) and time of day or night of interest. The model then immediately tells the user if either the resulting predicted broadband (A-weighted) or octave band (63 Hz to 8000 Hz) levels comply with, or exceed, the City of Boston Noise Code criteria limits. The results of the model are displayed graphically as well as in tabular form for easy print-out and presentation, as shown in Figure 5.

MODEL CALIBRATION EXERCISE

In order to test the predictive accuracy of the jet fan noise model, a series of field tests were conducted on 11/16/00 in which broadband and octave band noise measurements were obtained at tunnel portal openings with the jet fans installed and operating in Ramps A and F. These noise measurements were then compared against jet fan noise model predictions for the same circumstances. The modeled results, in all cases (quantity of fans operating, entry versus exit portal) over-predicted the jet fan noise impacts. As such, the model needed to be adjusted to better account for the acoustical absorption provided by the tunnel's open portal ends. Also, the model's jet fan sound power source spectra needed to be adjusted to better differentiate inlet vs outlet sound power contributions, and pure tones anticipated from the manufacturer's sound power data[6] at 4,000 Hz did not reveal themselves in the field measurements and were subsequently eliminated from the model.

With these model calibration adjustments incorporated, the model's predicted noise levels matched the actual measured noise levels with good agreement (+/- 1 dBA). Example predicted and measured broadband and octave band noise levels at the Ramp A entry portal (Ramp A merges into the mainline tunnel, no exit portal) and at the Ramp F exit portal are compared in Tables 2 and 3, respectively. These two specific model calibration example exercises are also graphically displayed on two spectral plots in Figures 6 and 7, respectively.

The plot in Figure 6 shows the measured and modeled noise levels at the entry portal of Ramp A located some 120 feet away from jet fan 5JF-A-1 which was equipped with 2-diameter long x 1 meter wide silencers on the fan's inlet and outlet sides. In this case, the floor of Ramp A was made of 11,600 sq.ft. of concrete, the tunnel walls were 19,720 sq.ft. of ceramic tile, and the ceiling was similarly 11,600 sq.ft. of concrete. Figure 6 shows an excellent match between measured and modeled noise levels in the mid-frequency octave bands which tend to dictate the broadband A-weighted noise level as well. The modeled A-weighted noise level slightly under-predicted the measured A-weighted noise level by only 0.2 dBA.

The plot in Figure 7 shows the measured and modeled noise levels at the exit portal of Ramp F located some 195 feet away from jet fan 5JF-F-1 which was equipped with 2-diameter long x 1 meter wide silencers on the fan's inlet and outlet sides. In this case, the floor of Ramp F was made of 15,200 sq.ft. of concrete, the tunnel walls were 21,280 sq.ft. of ceramic tile, and the ceiling was similarly 15,200 sq.ft. of concrete. Figure 7 shows an excellent match between measured and modeled noise levels in the mid-frequency octave bands which tend to dictate the broadband A-weighted noise level as well. The modeled A-weighted noise level slightly over-predicted the measured A-weighted noise level by only 0.6 dBA.

Table 2. Ramp A Predicted and Measured Broadband and Octave Band Noise Levels

Test Location	Broadband SPL (dBA)	Noise Level (dB) for Octave Band Center Frequency (Hz)							
		63	125	250	500	1000	2000	4000	8000
Predicted SPL (1) at Entry Portal	76.7	75.1	74.6	74.2	72.5	71.7	69.6	66.0	62.6
Measured SPL (2) at Entry Portal	76.9	73.2	72.9	66.8	67.9	74.1	69.9	67.3	58.1
Difference (Predicted - Measured)	-0.2	1.9	1.7	7.4	4.6	-2.4	-0.3	-1.3	4.5

(1) Predicted SPL are the predicted sound pressure levels using the jet fan noise model.
(2) Measured SPL are the measured sound pressure levels using a CEL 593.C.1 Noise Analyzer.

Figure 6. Ramp A - Predicted and Measured Noise Spectra

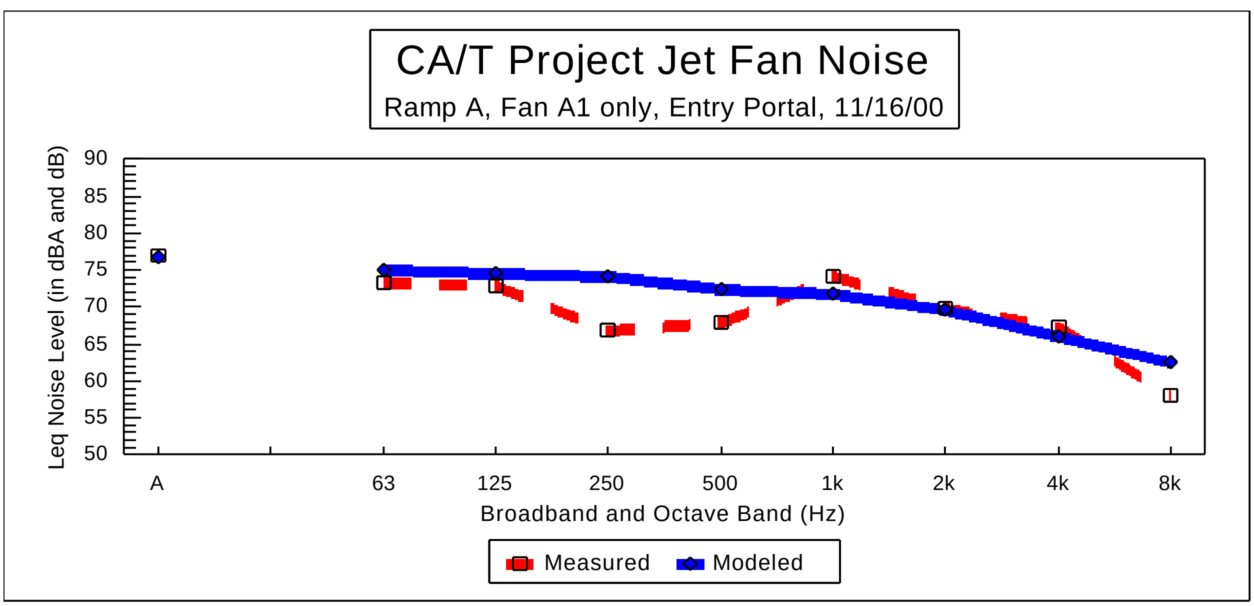
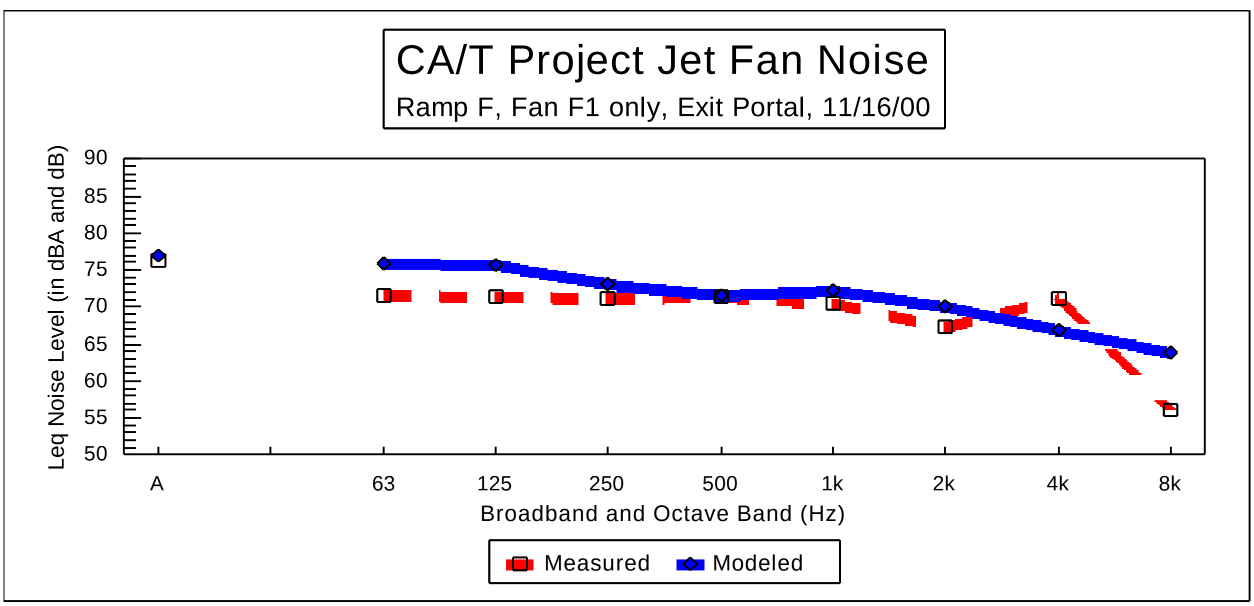


Table 3. Ramp F Predicted and Measured Broadband and Octave Band Noise Levels

Test Location	Broadband SPL (dBA)	Noise Level (dB) for Octave Band Center Frequency (Hz)							
		63	125	250	500	1000	2000	4000	8000
Predicted SPL (1) at Entry Portal	76.9	75.8	75.6	73.1	71.5	72.2	70.2	66.8	63.8
Measured SPL (2) at Entry Portal	76.3	71.5	71.3	71.2	71.4	70.5	67.4	71.2	56.2
Difference (Predicted - Measured)	0.6	4.3	4.3	1.9	0.1	1.7	2.8	-4.4	7.6

(1) Predicted SPL are the predicted sound pressure levels using the jet fan noise model.
(2) Measured SPL are the measured sound pressure levels using a CEL 593.C.1 Noise Analyzer.

Figure 7. Ramp F - Predicted and Measured Noise Spectra



CONCLUSION

The Central Artery/Tunnel Project is in many ways the premier tunnel construction project in the country. Because, in part, of this heightened stature, the Project is held to aggressive and conservative standards, including that of avoiding noise hardships on neighboring communities. Tunnel ventilation jet fans pose the risk of creating and propagating disturbing noise levels out into neighboring communities through the tunnel portal openings, so the Project had to accurately assess the potential noise disturbances, and mitigate the fan noise if needed.

To assist with this process, a jet fan noise model was developed which allowed for the quick and accurate prediction of various jet fan tunnel ventilation configurations. The model makes use of reference jet fan sound power source strength data and silencer insertion loss data. The model can be custom tailored to account for the unique geometries involved with various jet fan installations and abutting receptor locations. Determination can be made quickly regarding the jet fan's likelihood of meeting or exceeding applicable City of Boston Noise Code (or other) criteria limits. If mitigation is needed, various noise control options can easily be experimented with in the model until a desirable and satisfactory configuration is determined. As a result of this jet fan noise model development effort, the CA/T Project can better assure City of Boston regulators and tunnel portal abutters that their concerns regarding jet fan noise have been thoroughly assessed and that the fans will not pose a noise problem.

If, as anticipated, jet fans continue to play a more prominent role in the ventilation of highway tunnel entry and exit ramps, then the promulgation and use of noise models to assess potential noise impacts to abutters due to roadway alignment and potential future development can be expected to expand. As detailed in this paper, a simple and easy-to-use spreadsheet jet fan noise model can be a significant design aid for ventilation and environmental engineers and planners, particularly when supported through field test verifications. As construction of the CA/T Project progresses, additional field test noise results will become available leading to further model enhancements and increased practical usefulness.

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