9. WORKBOOK EXAMPLES

9.1. Example No. 1: Nitrogen Venting

In the first example, we assume that nitrogen is to be vented after a low-temperature wind tunnel experiment (described in Example No.3). Our attention will be focused in this example on noise from the gas vent and flow noise from the gas rushing through the piping on the way to the vent.

First, we evaluate the criteria based on the methods of the *Specifications Guide*.

Noise Criteria:	**Gas Vent**	
	Group 2:	85 dB(A) Baseline for Group 2
	Adjustments:	+5 dB(A) Remote Location
	MPSL:	90 dB(A) @ 1 meter
	Outdoor PWL:	Applicable

	Outdoor Piping to Vent	
	Group 3:	80 dB(A) Baseline for Group 3
	Adjustments:	+5 dB(A) Remote Location
	Adjustments:	+5 dB(A) Infrequent Operation
	MPSL:	90 dB(A) @ 1 meter
	Outdoor PWL:	Applicable

Next, we evaluate component noise emission beginning with the Gas Vent. Assume that after coming to rest the nitrogen gas pressure is 600 kPa (8.5 atmospheres) and the temperature is 115 °K (200 °R). Pressure and temperature at the exit are assumed to be 1 atmosphere and 100°F. The valve and downstream pipe diameter are assumed to both be 400 mm (16 inches), and the remote observation position is 137 meters (450 ft.) away. Since no silencer is yet present, the silencer diameter is entered as that of the discharge pipe. The vent discharges skyward, so the observation angle relative to the opening is greater than 90°.

This data is entered in the appropriate cells in the "Gas Vents and Reliefs Spreadsheet". Without a silencer, the sound pressure level at 1 meter is 140 dB(A) and 98 dB(A) at 137 meters! A vent silencer is clearly required.

A preliminary silencer selection is made on the Silencers Spreadsheet. Some knowledge of the flow conditions downstream of the valve is required. The first input is the gas volume flow (actual volume) 224 m^3/sec that was computed on the Gas Vents and Reliefs Spreadsheet. Next the assumed flow conditions upstream and downstream of the silencer are entered: (guess 600 kPa and 115°K upstream, 100 kPA and 300°K downstream). In this case, a vent silencer is appropriate, and the most aggressive model is chosen (2VS-5). The effective flow diameter (the diameter of the pipe with the same open area as the silencer) should be varied until the warning indicator on the "Silencer Velocity" line (row 26) is no longer highlighted. Note that a hint (Minimum Flow Path Diameter) is given in the row above. The Insertion Loss and Self-Noise computed in Section 3.a and highlighted with the salmon colored background are copied into Section 4.a of the Gas Vents and Reliefs Spreadsheet.

With the silencer "installed", the estimated level at 1 meter is reduced to 104 dB(A). At the remote location, the estimated level is 61 dB(A). Note that both the A-weighted sound pressure level and sound power level output are higher than permitted by the *Specifications Guide*. Note also that much of the noise at higher frequencies is actually a consequence of self-noise. Thus, it appears that a silencer with a still larger flow area would have been more beneficial.

Finally, the flow noise estimation is performed. With the gas "Nitrogen" selected, the mass flow (once again calculated on the Gas Vents and Reliefs Spreadsheet) and flow parameters are entered. The pipe diameter, wall thickness and length are entered next. Finally, the piping complexity is computed based on components present in the piping system: we assume that the pipe has one welded 90° turn in a 100 ft. length.

The estimated sound level 1 meter from the pipe is 100 dB(A) in the absence of lagging (see Section 6.a). Also, the outdoor sound power level limit is exceeded. In Section 6.b a 4 inch thickness of lagging is selected, which brings the radiated flow noise down to a more bearable 89 dB(A) at 1 meter. Radiated sound power is expected to be only slightly above the maximum permissible emission in two octave bands.

The relevant Spreadsheets are copied onto the following six pages. This concludes the discussion of Example No. 1.

GAS VENTS AND RELIEFS
All Gases Except Steam

1. Initial Upstream Gas Conditions

1a. Select Gas

1.a.1 Gas	Nitrogen (N2)		
MW	28.016	[mass/mole]	
γ	1.398	[1]	
R	55.15	[(ft lbf)/(lbm °R)]	

1b. Enter Reservoir Initial Pressure and Temperature

1.b.1 Reservoir Pressure	600	[kPa]	P_1	
1.b. 2 Reservoir Temperature	115	[° K]	T_1	
1.b.3 Reservoir Volume (optional)	*2450*	[m^3]	V	*(for use in fixed volume blowdown applications)*

1c. Calculate Reservoir Initial Density

Reservoir Density	17.848	[kg/cu m]	ρ_0

2. Downstream Gas Conditions, assuming isentropic flow

2a. Enter Downstream Conditions

Exit Pressure	14.7	[psia]	P_2
Exit Temperature	100	[° F]	T_2

2b. Calculate Jet Flow Parameters

Exit Density	0.069	[lb/cu ft]	ρ_2
Stream Mach Number	1.83	[1]	M_j
Stream Density	4.939	[kg/cu m]	ρ_j
Stream Temperature	124	[° R]	T_j
Stream Sonic Velocity	379	[mi/hr]	c_j
Stream Velocity	61079	[ft/min]	U_j

3. Vent and Observation Conditions

3a. Enter Vent and Observation Conditions

3.a.1 Valve Diameter	16.0	[in]	D_V
Valve Open Area	1.4	[ft^2]	A_j
3.a.2 Nozzle Coefficient Cn	0.850	[1]	C_N
3.a.3 Downstream Pipe Diameter	16.0	[in]	D_D
3.a.4 Silencer Outlet Diameter	2500.0	[mm]	D_U: *If no silencer, use Pipe Diameter*
3.a.5 Observation Distance	137.0	[m]	r

3.a.6 Observation Angle re Axis of Opening		> 90°	θ

3b. Calculate Blowdown Parameters

Initial Flow Rate	205	[m3/s]	scfm
Initial Flow Rate	224	[m3/s]	acfm
Initial Mass Flow	246	[kg/sec]	
Blowdown Time	341.34	[sec]	

4. Estimated Noise Emission, Silenced

4a. Estimated Silenced Sound Power Level (L_W)

	31.5	*63*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*	**A**
L_W, Vent	126	133	140	145	147	146	142	135	128	**150**
IL, Silencer [from Mfr or Silencer Sheet]	**11**	**22**	**26**	**36**	**50**	**58**	**60**	**58**	**52**	
L_W, Vent, Silenced	115	111	114	109	97	88	82	77	76	**103**
L_W, Silencer Self Noise	**130**	**125**	**120**	**115**	**115**	**115**	**115**	**115**	**115**	
L_W, Total	130	125	121	116	115	115	115	115	115	**122**
Directivity, Silencer Outlet	0	-1	-2	-5	-7	-10	-12	-15	-17	
Directional L_W, Silenced	130	[redacted]						100	98	**112**
Maximum Permissible Outdoor Sound Power Levels		*121*	*120*	*113*	*110*	*108*	*107*	*107*	*106*	

4b. Estimated Silenced Sound Pressure Level (L_P) at Observation Position

	31.5	*63*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*	**A**
Directional L_W, Silenced	130	124	119	111	108	105	103	100	98	**112**
Geometric Divergence to Obs. Position	-51	-51	-51	-51	-51	-51	-51	-51	-51	
Lp, Silenced, at 449 ft.	79	73	68	60	57	54	52	49	47	**61**
A-weighted Sound Pressure Level Target										**85**

4c. Estimated Silenced Sound Pressure Level (L_P) at 1 meter

	31.5	*63*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*	**A**
L_W, Total	130	125	121	116	115	115	115	115	115	**122**
Directivity, 90°	0	-1	-2	-5	-7	-10	-12	-15	-17	
Geometric Divergence to 1 meter	-8	-8	-8	-8	-8	-8	-8	-8	-8	
L_P, Silenced, at 1 meter	122	116	[redacted]		100	97	95	[illegible]	90	104
Maximum Permissible Sound Level (MPSL) for Gas Vent										**95**

5. Estimated Noise Emission, Unsilenced

5a. Estimated Sound Power Level for use in the System Analysis

	31.5	*63*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*
L_W, Vent	**126**	**133**	**140**	**145**	**147**	**146**	**142**	**135**	**128**

These values may be used in Section 4.b. of the System Input/Output sheet.

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PRELIMINARY SILENCER SELECTION WORKSHEET

Nelson Acoustical Engineering

1. Enter Flow Conditions

1.a. Select Gas	Nitrogen (N2)		
Gas Mol. Weight	28.02	[1]	MW
γ	1.398	[1]	
R	55.15	[(ft lbf)/(lbm °R)]	
1.b. Gas Volume Flow (acfm)	224	[m3/s]	Q
1.c. Approx. Inlet Pressure (after Valve)	600	[kPa]	P_1
1.d. Stream Temperature	115	[° K]	T_j
1.e. Downstream Ambient Pressure	100.0	[kPa]	P_a
1.f. Downstream Ambient Temperature	300	[° K]	T_a
1.g. Downstream Ambient Density	0.071	[lb/cu ft]	ρ_a
1.h. Sonic Velocity	353	[m/sec]	c_j

2. Select Silencer

2.a. Silencer Type	Vent			
2.b. Silencer Selection (see Section 8)	2VS-5			
2.c. Effective Flow Diameter	2500	[mm]		D_f
Minimum Flow Path Diameter	93	[in]		
Silencer Velocity	8976	[ft/min]	Below Design Velocity	
Maximum Design Velocity	167	[ft/sec]		
Silencer Diameter	245	[in]		
Silencer Length	84	[ft]		
Silencer K Value	21.88	[1]		K
Pressure Drop	65.4	[kPa]		ΔP

3. Estimate Insertion Loss (IL) and Self-Noise

3a. Estimated Data for Use in System Analysis

	31.5	*63*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*
Estimated Insertion Loss (dB)	11	22	28	36	50	58	60	58	52
Estimated Self-Noise (L_W dB re 1 pW)	128	123	118	113	113	113	113	113	113

Silencer performance can be affected by many factors, some of which are accounted for only approximately here. Manufacturer's Data should be used wherever available.

Silencer Insertion Loss (IL) and Self-Noise sound power level (L_W) data may be entered into Section 4c of the System Input/Output sheet (using Paste- Special-Values) of the System Inputs Worksheet.

4. Silencer Types

Silencers are manufactured in a variety of configurations to accomadate many applications. For the purposes of this Guide various silencer types are designated by letters and a number. The letters indicate the components of the silencer: Dissipative (D), Reactive (R), Vent (V) with corresponding subtypes. Some silencers combine aspects of each of these basic types. The number designation corresponds to a generic grade of performance: (2) is Commercial, (3) is Semi-Residential, (4) is Residential, and (5) is Critical grade. Refer to the Manual for guidance in the selection of appropriate silencer types for your application.

	Dissipative				React.	Vent		Note
Silencer Type	Concentric	Annular	Splitter	Tube	Chambers	Single Diffuser	Dual Diffuser	Grade, Description
DC-2	×							Commercial
DC-4	×							Residential
DA-3		×						Semi-Residnt'l
DA-4		×						Residential
DA-5		×						Critical
DS-50			×					50% Open
DS-33			×					33% Open
DS-25			×					25% Open
DT-33-1				×				Short
DT-33-2				×				Medium
DT-33-3				×				Long
R-2-L					×			Low ΔP
R-2-H					×			High ΔP
R-3-L					×			Low ΔP
R-3-H					×			High ΔP
R-4-H					×			High ΔP
R-5-H					×			High ΔP
DCR	×				×			
VDR	×				×	×		
VDA		×			×	×		
VDC-3	×					×		Semi-Residnt'l
VDC-4	×					×		Residential
VDC-5	×					×		Critical
VS-2						×		Commercial
VS-3						×		Semi-Residnt'l
VS-4						×		Residential
VS-5						×		Critical
2VS-2							×	Commercial
2VS-3							×	Semi-Residnt'l
2VS-4							×	Residential

FLOW NOISE IN PIPES

OVERVIEW

Flow noise is a special case of noise emission because it arises from the interaction of the turbulent boundary layer in the gas with the pipe walls and is therefore generated throughout the system. This Spreadsheet provides computations for use in evaluating a single length of piping or in evaluating a System. This Spreadsheet performs computations of Sound Power Level (L_W) and Sound Pressure Level (L_P) at 1 meter for piping with and without acoustical lagging.

Noise emission data for use in the Integrated System Analysis is presented in Line 6c and corresponds to radiation from an unlagged pipe 10 feet in length. The effects of lagging and actual pipe length are accounted for by selections made in the System Input-Output Spreadsheet. Note however that there is no automatic "feedback" from the System Input-Output Spreadsheet regarding other important parameters such as gas flow conditions and pipe dimensions and thickness. Those inputs must be made manually in this Spreadsheet in order for the computation to be correct.

Computations are based on the number of components in a 10-ft length of pipe. The most correct way to perform this computation is to obtain noise emission estimates for each 10-ft. length and then sum the results (on an energy basis) as shown in the Calculator Spreadsheet, Section 7. An approximate method is to use as inputs the total number of each component in the piping system divided by the number of 10-ft lengths in the system.

1. Select Gas

1a. Gas Nitrogen (N2)		
Molecular Weight	**28.02** [mass/mole]	*MW*
Ratio of Specific Heats	**1.398** [1]	γ
Gas Constant	**55.15** [(ft lbf)/(lbm °R)]	*R*

2. Flow Parameters

2a. Mass Flow Through Pipe	**224**	[kg/sec]	m'
2b. Interior Total Pressure	**600**	[kPa]	P
2c. Gas Flow Total Temperature	**115**	[° K]	T

3. Piping Dimensions

3a. Pipe Inside Diameter	**400.0**	[mm]	D_p
3b. Pipe Wall Thickness	**0.310**	[in]	t_p
3c.Length of Pipe	**100**	[ft]	L

4. Piping Complexity

4a. Enter the total number of listed components used in the piping section under consideration.
This information is used to determine K, the number of velocity heads per 10 ft (3 m) of piping.

Straight Pipe		1				
45° Elbow	Screwed	0	Welded, R/D=1	0	Welded, R/D=1.5	0
90° Elbow	Screwed	0	Welded, R/D=1	1	Welded, R/D=1.5	0
180° Elbow	Screwed	0	Welded, R/D=1	0	Welded, R/D=1.5	0
Tees (Screwed)	Thru Branch	0	Through Run	0		
Tees (Welded)	Thru Branch	0	Through Run	0		
Reducer	D_2/D_1= 0.3	0	D_2/D_1= 0.5	0	D_2/D_1= 0.7	0
Expander	D_2/D_1= 3	0	D_2/D_1= 2	0	D_2/D_1= 1.25	0
Sudden Contraction	D_2/D_1= 0.1	0	D_2/D_1 = 0.33	0	D_2/D_1 = .80	0

Sudden Expansion	D_2/D_1= 10	0	D_2/D_1= 3	0	D_2/D_1= 1.25	0

Total "K" factor 0.17 [1]

5. Flow Parameters (calculated)

Density	1.114	[lb/cu ft]	ρ
Face area of pipe	1.353	[ft^2]	A_p
Flow Velocity	327.7	[ft/sec]	U
Sonic Velocity	218.8	[m/sec]	c_2
Mach Number	0.456	[1] Warning: Velocity > 0.3 M	M
Ring Frequency of Pipe	4115	[Hz]	f_r
Jet Spectrum Peak Frequency	49.94	[Hz]	f_p
1st Mode Pipe Cutoff Frequency	320.6	[Hz]	f_c

6. Estimated Noise Emission

6a. Estimated Noise Emission with No Lagging

Sound Pressure Levels (L_P), 1 m	*31.5*	*63*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*	*A*
L_W Radiated from Pipe per 10 ft.	118	117	115	114	109	99	88	82	63	110
Geometric Divergence to 1 meter	-10	-10	-10	-10	-10	-10	-10	-10	-10	
L_P at 1 meter	108	107	[redacted]	104	100	[redacted]	78	72	53	100
Maximum Permissible Sound Level (MPSL) for Pipe-Radiated Flow Noise										90

Sound Power Levels (L_W)	*31.5*	*63*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*	*A*
L_W Radiated from Pipe per 10 ft.	118	117	115	114	109	99	88	82	63	110
Correction from 10 ft. to Full Length	10	10	10	10	10	10	10	10	10	
L_W Radiated from Full Length	128	[redacted]	125	124	119	109	98	92	73	120
Maximum Permissible Outdoor Sound Power Levels		127	120	113	110	108	107	107	106	

6b. Estimated Noise Emission with Lagging

Sound Pressure Levels (L_P), 1 m	*31.5*	*63*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*	*A*
L_W per 10 ft. Length, Unlagged	118	117	115	114	109	99	88	82	63	110
Lagging IL 4 in.	-2	-4	-5	-10	-15	-27	-30	-24	-20	
L_W per 10 ft. Length, Lagged	116	113	110	104	94	72	58	58	43	99
Geometric Divergence to 1 meter	-10	-10	-10	-10	-10	-10	-10	-10	-10	
L_P at 1 meter	106	103	100	94	85	62	48	48	33	
Maximum Permissible Sound Level (MPSL) for Pipe-Radiated Flow Noise										90

Sound Power Levels (L_W)	*31.5*	*63*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*	*A*
L_W Radiated from Full Length	128	127	125	124	119	109	98	92	73	120
Lagging IL (from above)	-2	-4	-5	-10	-15	-27	-30	-24	-20	
L_W Full Length, Lagged	126	[redacted]	120	114	104	82	68	68	53	109
Maximum Permissible Outdoor Sound Power Levels		127	120	113	110	108	107	107	106	

6c. Estimated Sound Power Levels (L_W) for use in the System Analysis

	31.5	*63*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*
L_W per 10 ft., Unlagged	118	117	115	114	109	99	88	82	63

For piping on the Intake side of the system (Upstream of the main equipment group, whether indoors or outdoors), these values should be entered into Section 4.a of the Systems Input/Output sheet.
For piping on the Discharge side of the system (Upstream of the main equipment group, whether indoors or outdoors)), these values should be entered into Section 4.b of the Systems Input/Output sheet.

9.2. Example No. 2: Control Valve

The control valve from the nitrogen venting system of Section 9.1 is considered. The first order of business is to determine the noise emission criterion for the valve according to the *Specifications Guide*.

Control Valve	
Group 1:	85 dB(A) Baseline
Adjustments:	+5 dB(A) Remote
Adjustments:	+5 dB(A) Infrequent
MPSL:	95 dB(A) @ 1 meter
Outdoors PWL:	Applicable

We will assume that the mass flow of 224 kg/sec passes through one butterfly control valve that is 60° open. The gas pressures upstream and downstream of the valve are assumed to be 900 kPA and 600 kPA, respectively.

An crude valve selection is made by means of an iterative process in which the selected valve C_V, diameter D_V and open angle are adjusted until they are similar to the approximate C_V and diameter required.

Note - It turns out that the sound power level inside the pipe due to the control valve operation exceeds the structural fatigue criterion. This situation could be alleviated by addition of a pressure-reducing plate downstream of the valve. Also note that the fatigue criterion was developed in relation to petrochemical plants and refineries, where operation is more or less continuous. Infrequent operation may provide some leeway here.

Section 5.a of the Spreadsheet shows that the control valve sound pressure level at 1 meter from the pipe wall is estimated at 130 dB(A) with no noise control treatments. Section 5.b permits the ad hoc addition of noise control options. Addition of a downstream resistance plate brings the SPL down to 115 dB(A), which condition is marginally acceptable from a fatigue standpoint, but not yet acceptable from a hearing conservation standpoint. The further selection of a downstream in-line silencer brings the SPL down to a more bearable 105 dB(A). Further noise control options include addition of valve trim (if available for this valve), an upstream in-line silencer, or external pipe lagging (not addressed on this Spreadsheet).

The Control Valve Spreadsheet is reproduced on the following two pages. This concludes the discussion of Example No.2.

NASA

CONTROL VALVE NOISE ESTIMATION

Nelson Acoustical Engineering

1. Select Flow Conditions

1a. Gas	Nitrogen (N2)			
Specific Gravity	0.97	[1]		G
Ratio of Specific Heats	1.40	[1]		γ
1b. Gas Compressibility Factor	1	[1]		Z
1c. Mass Flow w [lbs/sec]	224	[kg/sec]		m'
1d. Upstream Pressure	900	[kPa]		P_1
1e. Upstream Temperature	115	[° K]		T_1
1f. Downstream Pressure	600	[kPa]		P_2

2. Select a Candidate Valve Type, Perform Approximate Sizing

2a. Select Valve Type

Type: Butterfly valve, swing-through vane, Flow To: N/A, Travel: 60° open

Flow is	Sonic			
Approx. C_V required	4067		C_V	(Iterate with Line 3.a)
Approx. D_V required	368.2	[mm]	D_V	(Iterate with Line 3.b-3.d)
Approximate C_V Wide Open	11297		C_V	

3. Make Valve and Pipe Selection

3a. Select C_V	4100	[Cv]	C_V
3b. Valve Nominal Diameter	400	[mm]	D_V
3c. Pipe Diam. Downstream	400	[mm]	D_D
3d. Pipe Diam. Upstream	400	[mm]	D_U
3e. Pipe Thickness	0.31	[in]	t_p

4. Relevant Acoustical Parameters

Jet Peak Frequency	546	[Hz]	f_p
Pipe First Mode Cut-on Freq.	1539	[Hz]	f_c
Pipe Ring Frequency	4019	[Hz]	f_r

Internal Overall L_W -	173 dB L_W	L_W -	
Structural Limit Overall L_W	167 dB L_W	L_{WS}	
Internal PWL - Structural Limit	6 dB L_W		ABOVE STRUCTURAL FATIGUE CRITERION

5. Estimated Noise Emission

5a. Calculate Octave Band Sound Pressure Levels 1m from Pipe

	31.5	63	125	250	500	1000	2000	4000	8000	A
Internal L_P	164	167	170	175	178	175	172	168	165	180
Pipe TL	82	76	70	64	58	52	49	52	56	
L_g	3	3	3	3	3	3	3	3	3	
L_P at 1 m from Pipe Centerline	85	94	104	115	123	126	125	119	111	130
Maximum Permissible Sound Level (MPSL) for Control Valve										**95**

5b. Add the Benefit of Control Valve Noise Control Options

☐ Valve Trim ☑ Downstream Valve Silencer ☐ Upstream Valve Silencer ☑ Downstream Resistance Plate

Sound Pressure Level (L_P) at 1 m	31.5	63	125	250	500	1000	2000	4000	8000	A
L_P at 1 m from Pipe Wall	85	94	104	115	123	126	125	119	111	130
Insertion Loss of Selected Noise Control	25	25	25	25	25	25	25	25	25	
L_P 1 m from Pipe Wall, Noise Control	60	69	79	90	98	101	100	[illegible]	86	105
MPSL for Control Valve										**95**

Sound Power Level (L_W) Radiated	31.5	63	125	250	500	1000	2000	4000	8000	A
External L_W of 10 ft. length of pipe	70	79	89	100	[illegible]	111	110	[illegible]	96	115
Maximum Permissible Outdoor Sound Power Levels		*127*	*120*	*113*	*110*	*108*	*107*	*107*	*106*	

5c. Estimated Sound Power Level (L_W) for use in System Analysis

	31.5	63	125	250	500	1000	2000	4000	8000
L_W Inside Pipe, Downstream	**120**	**123**	**126**	**131**	**134**	**131**	**128**	**124**	**121**

These values may be used in Section 4.d. of the System Input/Output sheet

9.3. Example No. 3: Low-Temperature Wind Tunnel Drive Fan

A low-temperature drive fan is to be designed for a wind tunnel using nitrogen gas at 200°R at approximately 8.5 atmospheres. The desired flow rate at the test section is Mach 1.0 across an area approximately 12 feet in diameter.

9.3.1. Gas Properties

The Gas Flow Calculator Spreadsheet permits us to estimate the mass flow rate required. In Section 2 "Ideal Gas Properties", the pressure and temperature are entered to find the density of 1.66 pounds per cubic foot. Next, Section 3 "Ideal Isentropic Expansion" is used to find the sonic velocity in the gas of 704 ft/sec. The product of the test section area and the sonic velocity gives a volume flow rate of approximately 80,000 cubic feet per second and a mass flow rate of approximately 130,000 pounds per second.

9.3.2. Silencer and Pressure Drop

The silencer selection is performed next because it gives an estimate of the pressure drop into which the drive fan will be working. A dissipative concentric silencer (designation DS-50) is planned both upstream and downstream of the drive fan. The Insertion Loss, Self-Noise and Pressure Drop are estimated within the Silencer Spreadsheet. Note that the flow velocity within the silencer exceeds the typical design velocity: special design requirements should be discussed with the manufacturer. The pressure drop across each silencer is estimated at 1.4 atmospheres. Thus, the discharge and intake pressures of the drive fan are 9.9 and 7.1 atmospheres respectively. The Insertion Loss and Self-Noise estimates in Section 3 will be transferred to Section 4.c of the System Input-Output Spreadsheet.

9.3.3. Component Analyses

The initial steps in a System Analysis include noise emission estimates for the relevant components: in this case the drive fan, flow noise and duct wall transmission loss.

Drive Fan

The Drive Fan noise emission criterion (for noise radiated from its attached piping) is determined as follows:

Group 3:	80 dB(A) Baseline
Adjustments:	+5 dB(A) Infrequent
Adjustment:	+20 dB(A) Enclosure
Adjustment:	-5 dB(A) High Equipment Density
MPSL:	100 dB(A) @ 1 meter
Outdoors PWL:	N/A

The Fan/Compressor Spreadsheet is utilized to estimate the drive fan noise emission. The planned drive fan consists of a single stage rotor 20 ft. in diameter, rotating at 360 rpm with 25 rotor blades. Typical values for other parameters have been entered to complete the analysis. The noise emission estimate includes broadband noise and discrete tones from both inlet and discharge and combination tones from inlet. The far-field sound pressure level estimation is not relevant in this case because the fan is installed within the wind tunnel. The upstream and downstream sound power levels given in Section 3.c will be transferred to Section 4.d of the System Input-Output Spreadsheet.

Flow Noise

The Flow Noise emission criterion is determined as follows:

- Indoor Piping

Group 3:	80 dB(A) Baseline
Adjustments:	+5 dB(A) Infrequent
Adjustment:	+20 dB(A) Enclosure
Adjustment:	-5 dB(A) High Equipment Density
MPSL:	100 dB(A) @ 1 meter
Outdoors PWL:	N/A

- Outdoor Piping

Group 3:	80 dB(A) Baseline
Adjustments:	+5 dB(A) Infrequent
MPSL:	85 dB(A) @ 1 meter
Outdoors PWL:	Applicable

The Flow Noise Spreadsheet makes use of the mass flow rate, temperature and pressure, and pipe dimensions in Sections 2 and 3. An average pipe diameter of 16 ft. is assumed. The piping complexity is determined in Section 4 as follows:

- four welded 90 degree turns (R/D=1) in a total of 400 ft. length.
- one expansion and one contraction at the test section in a total of 400 ft. length

Note that the Spreadsheet computes many flow parameters in Section 5 and warns that the flow velocity in the pipe is above 0.3M. Section 6.a indicates the estimated sound pressure level 1 meter from the piping as 94 dB(A) (acceptable indoors without the addition of pipe lagging) and that the estimated sound power level radiated from 200 ft. of exposed piping outdoors as in excess of the criterion at several octave bands. The addition of 4 inches of pipe lagging to outdoor piping (as indicated in Section 6.b) brings the levels to 89 dB(A) at 1 meter (acceptable both indoors and outdoors) and the octave band sound power levels much closer to the criterion.

The sound power levels tabulated in Section 6.c will be transferred to Section 4.a and 4.b of the System Input-Output Spreadsheet.

Pipe Wall Transmission Loss

The Pipe Wall Spreadsheet makes use of the interior and exterior pressures and sonic velocity within the pipe in Section 1, and the pipe geometry in Section 2. Critical frequencies of the piping system are computed in Section 3. None of the critical frequencies align with the blade passage tone of 150 Hz. The Transmission Loss estimates from Section 4 will be transferred to Section 4.a and 4.b of the System Input-Output Spreadsheet.

9.3.4. System Analysis

Section 1 shows a diagram of the stylized system being analyzed.

Piping and site geometry is entered in Section 2. Assume that the wind tunnel totals 400 ft. in length and averages 16 ft. in diameter. Of this, 200 ft. are assigned to the "Inlet" and 200 ft. to the "Discharge", which are then connected together to form a "Closed Loop". Of each 200 ft., 50 ft. are assumed to be within the building. An observation position is set at the location of some residences 450 ft. away. Environmental noise data indicates that existing plant equipment does not exceed 66 dB(A) at any time, which serves as a convenient additional community noise criterion.

The drive fan building has dimensions of 100 x 200 x 50 ft. high with 20% area coverage of sound-absorbing material.

Section 3 permits entry of criteria and displays overall results. Section 3.a criteria are those of the *Specifications Guide*. Section 3.b criteria and results are those for the overall system at observation points specified by the user.

Data from the Component Spreadsheets (referred to in preceding paragraphs) are entered in Section 4. No lagging was selected initially for indoor piping and 4 inch lagging was selected initially for all outdoor piping, as determined from the Flow Noise analysis.

The overall results (viewed in Section 3.a) indicate that the outdoor sound pressure level criteria are not met (as indicated by the red highlighting) and the emitted sound power levels are also exceeded in at least one octave band (again, red highlighting). Indoor criteria are just barely met for the intake and discharge piping respectively (orange highlighting). Section 3.b indicates that the goal for sound pressure level at the nearby residences is met, but that the overall sound level (comprising contributions from all sources) inside the drive fan building was not achieved.

Sound pressure level criteria can be achieved by increasing indoor pipe lagging thickness from 4 inches to 6 inches, and adding 2 inch thick outdoor pipe lagging.

Reference to the System Calculations Spreadsheet indicates that the exceedance of the outdoor sound power level criterion is significant but not severe. Because of its low frequency character, it also appears that additional lagging is unlikely to completely address the issue. Noise control concepts that should be considered include:

- Increase silencer area to reduce velocity, thus reducing self-noise
- Increase pipe diameter to reduce flow noise
- Thicken pipe wall to increase transmission loss

The relevant spreadsheets are reproduced on the following pages:

- Calculator (3 pages)
- Silencer (2 pages)
- Drive Fan (2 pages)
- Flow Noise (2 pages)
- Pipe Wall (1 page)
- System Input-Output (4 pages)

This concludes the discussion of Example No. 3.

GAS FLOW CALCULATOR

Introduction

Calculations and Conversions useful for Gas Flows and decibel mathematics are provided.
No noise emission computations are performed on this Spreadsheet.

1. **Select Gas:** The gas selected in Section 1 affects Sections 2 through 5 as well.
2. **Ideal Gas Properties:** solves for either Pressure, Density or Temperature given the other two.
3. **Isentropic Expansion/Contraction:** gas properties based on upstream and downstream Pressure.
4. **Velocity, Mass Flow and Volume Flow:** solves for any two of the three given the other and a pipe diameter.
5. **Sonic Velocity and Mach Number:** solves from Flow Velocity and Gas Temperature
6. **Units Converter:** converts flow quantities between useful units
7. **Decibel Mathematics:** Add and subtract spectra and calculate A-weighted levels

1. Select Gas

Gas	Nitrogen (N2)	
MW	28.016	[mass/mole]
γ	1.398	[1]
R	55.15	[(ft lbf)/(lbm °R)]

2. Ideal Gas Properties

Use known Pressure and Temperature to find Density

Total Pressure	8.5	[atm]
Total Temperature	200	[° R]
Density	26.5931	[kg/cu m]

Use known Temperature and Density to find Pressure

Total Temperature		[° R]
Total Density		[lb/cu ft]
Total Pressure	0	[mB]

Use known Density and Pressure to find Temperature

Total Density		[lb/cu ft]
Total Pressure		[atm]
Total Temperature	#DIV/0!	[° F]

3. Ideal Isentropic Expansion/Contraction

Upstream Pressure	8.5	[atm]
Upstream Temperature	200	[° R]
Density	1.660201	[lb/cu ft]
Downstream Pressure	8.5	[atm]
Stream Mach Number	0.0	[1]
Stream Density	26.5931	[kg/cu m]

Stream Temperature	-260	[° F]
Stream Sonic Velocity	704	[ft/sec]
Stream Velocity	0	[ft/min]

4. Velocity, Mass Flow and Volume Flow

Solve for Velocity and Volume Flow

Mass Flow Through Pipe		[lb/sec]
Total Density		[lb/cu ft]
Pipe Diameter		[in]
Flow Velocity	#DIV/0!	[ft/sec]
Volume Flow	#DIV/0!	[cfs]

Solve for Mass Flow and Volume Flow

Flow Velocity		[ft/sec]
Total Density		[lb/cu ft]
Pipe Diameter		[in]
Mass Flow	0	[lb/sec]
Volume Flow	0	[cfs]

Solve for Volume Flow and Flow Velocity

Volume Flow	80000	[cfs]
Total Density	1.660	[lb/cu ft]
Pipe Diameter	4	[m]
Flow Velocity	180.2717	[m/sec]
Mass Flow	132800	[lb/sec]

5. Sonic Velocity and Mach Number

Flow Velocity		[ft/sec]
Upstream Temperature		[° R]
Sonic Velocity	0	[ft/sec]
Mach Number	#DIV/0!	[1]

6. Units Converter

Pressure	900.0	[kPa]	→	8.88239	[atm]
Temperature	115	[° K]	→	207.6	[° R]
Mass		[lbm]	→	0	[kg]
Density	26.77	[kg/cu m]	→	1.671245	[lb/cu ft]
Mass Flow	73600	[kg/sec]	→	162288	[lb/sec]
Volume Flow	2750	[m3/s]	→	97040.77	[cfs]
Volume		[in^3]	→	0	[m^3]
Area	12.566	[m^2]	→	135.2588	[ft^2]
Velocity	219	[m/sec]	→	718.5025	[ft/sec]
Distance	4	[m]	→	157.48	[in]
Power		[HP]	→	0	[kW]
Time		[sec]	→	0	[hr]
Frequency	360	[rpm]	→	6	[Hz]

7. Decibel Mathematics and Wave Divergence

7a. Addition

	31.5	63	125	250	500	1000	2000	4000	8000	A
Spectrum 1										0
+ Spectrum 2										0
+ Spectrum 3										0
= Total	0	0	0	0	0	0	0	0	0	0

7b. Subtraction

	31.5	63	125	250	500	1000	2000	4000	8000	A
Spectrum 1										0
- Spectrum 2										0
= Total	0	0	0	0	0	0	0	0	0	0

7c. Comparison to a Criterion

	31.5	63	125	250	500	1000	2000	4000	8000	A
Sound Pressure Level Spectrum										0
									Criterion Level	85

7d. Wave Divergence with selectable units

7.d.1 Sound Pressure Level from a Point Source at distance r (r >> source dimension)

Distance 6 [ft]

	31.5	63	125	250	500	1000	2000	4000	8000	A
Sound Power Level Spectrum										0
Wave Divergence (Hemispherical)	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13
Sound Pressure Level Spectrum	-13	-13	-13	-13	-13	-13	-13	-13	-13	-6

7d.2 Sound Pressure Level from a Distributed Source given L_W and distance r

Width 6 [ft]
Height 6 [ft]
Distance 6 [ft]

	31.5	63	125	250	500	1000	2000	4000	8000	A
Sound Power Level Spectrum										0
Wave Divergence (Hemispherical)	-14	-14	-14	-14	-14	-14	-14	-14	-14	-14
Sound Pressure Level Spectrum	-14	-14	-14	-14	-14	-14	-14	-14	-14	-7

7d.2 Sound Pressure Level at distance r2 from a Distributed Source given L_P at distance r1

Width [ft]
Height [ft]
L_P Measured at Distance 1 [ft]
L_P Desired at Distance 2 [ft]

	31.5	63	125	250	500	1000	2000	4000	8000	A
L_P Spectrum at Distance 1										0
Wave Divergence from 1 to Source	0	0	0	0	0	0	0	0	0	0
Sound Power Level Spectrum	0	0	0	0	0	0	0	0	0	0
Wave Divergence from Source to 2	0	0	0	0	0	0	0	0	0	0
L_P Spectrum at Distance 2	0	0	0	0	0	0	0	0	0	0

PRELIMINARY SILENCER SELECTION WORKSHEET

Nelson Acoustical Engineering

1. Enter Flow Conditions

1.a. Select Gas	Nitrogen (N2)		
Gas Mol. Weight	28.02	[1]	MW
γ	1.398	[1]	
R	55.15	[(ft lbf)/(lbm °R)]	
1.b. Gas Volume Flow (acfm)	80000	[cfs]	Q
1.c. Approx. Inlet Pressure (after Valve)	8.5	[atm]	P_1
1.d. Stream Temperature	200	[° R]	T_j
1.e. Downstream Ambient Pressure	8.5	[atm]	P_a
1.f. Downstream Ambient Temperature	200	[° R]	T_a
1.g. Downstream Ambient Density	1.66	[lb/cu ft]	ρ_α
1.h. Sonic Velocity	214.7	[m/sec]	c_j

2. Select Silencer

2.a. Silencer Type	Dissipative			
2.b. Silencer Selection (see Section 8)	DS-50			
2.c. Effective Flow Diameter	20	[ft]		D_f
Minimum Flow Path Diameter	332	[in]		
Silencer Velocity	15279	[ft/min]	Exceeds Design Velocity	
Maximum Design Velocity	133	[ft/sec]		
Silencer Diameter	240	[in]		
Silencer Length	80	[ft]		
Silencer K Value	0.60	[1]		K
Pressure Drop	987.4	[lb/sq ft]		ΔP

3. Estimate Insertion Loss (IL) and Self-Noise

3a. Estimated Data for Use in System Analysis

	31.5	63	125	250	500	1000	2000	4000	8000
Estimated Insertion Loss (dB)	10	22	30	35	38	34	23	15	8
Estimated Self-Noise (L_W dB re 1 pW)	149	144	139	134	134	134	134	134	134

Silencer performance can be affected by many factors, some of which are accounted for only approximately here. Manufacturer's Data should be used wherever available.

Silencer Insertion Loss (IL) and Self-Noise sound power level (L_W) data may be entered into Section 4c of the System Input/Output sheet (using Paste- Special-Values) of the System Inputs Worksheet.

4. Silencer Types

Silencers are manufactured in a variety of configurations to accomadate many applications. For the purposes of this Guide various silencer types are designated by letters and a number. The letters indicate the components of the silencer: Dissipative (D), Reactive (R), Vent (V) with corresponding subtypes. Some silencers combine aspects of each of these basic types. The number designation corresponds to a generic grade of performance: (2) is Commercial, (3) is Semi-Residential, (4) is Residential, and (5) is Critical grade. Refer to the Manual for guidance in the selection of appropriate silencer types for your application.

	Dissipative				React.	Vent		Note
Silencer Type	Concentric	Annular	Splitter	Tube	Chambers	Single Diffuser	Dual Diffuser	Grade, Description
DC-2	×							Commercial
DC-4	×							Residential
DA-3		×						Semi-Residnt'l
DA-4		×						Residential
DA-5		×						Critical
DS-50			×					50% Open
DS-33			×					33% Open
DS-25			×					25% Open
DT-33-1				×				Short
DT-33-2				×				Medium
DT-33-3				×				Long
R-2-L					×			Low ΔP
R-2-H					×			High ΔP
R-3-L					×			Low ΔP
R-3-H					×			High ΔP
R-4-H					×			High ΔP
R-5-H					×			High ΔP
DCR	×				×			
VDR	×				×	×		
VDA		×			×	×		
VDC-3	×					×		Semi-Residnt'l
VDC-4	×					×		Residential
VDC-5	×					×		Critical
VS-2						×		Commercial
VS-3						×		Semi-Residnt'l
VS-4						×		Residential
VS-5						×		Critical
2VS-2							×	Commercial
2VS-3							×	Semi-Residnt'l
2VS-4							×	Residential

TURBOMACHINERY
FAN AND COMPRESSOR NOISE ESTIMATION

Nelson Acoustical Engineering

1. Flow Conditions

Mass Flow Rate	80000	[kg/sec]	M_3
Inlet Pressure	7.1	[atm]	P_1
Total Temperature at Fan Face	200	[° R]	T
Discharge Pressure	9.9	[atm]	P_3
Temperature Rise across Fan	20	[° F]	ΔT
Fan Diameter	20	[ft]	D_f
Rotational Speed	360	[rpm]	*RPM*
Number of Rotors	25	[1]	N_b
Number of Stators	60	[1]	N_s
Inlet Guide Vanes	Yes		
Inlet Guide Vane Stator Chord	4	[in]	C_1
IGV/Fan Spacing	8	[in]	S_1
Fan Rotor Chord Length	4	[in]	C_2
Rotor/Stator Spacing	8	[in]	S_2
Tip Mach Number, Design	1.20	[1]	M_{TRD}
Stage	First		*(1st and 2nd stage noise estimated separately)*
Tip Mach Number, Actual	0.53	[1]	M_{TR}
Fundamental Tone Cutoff Factor	0.38	[1]	δ
Rotor/Stator Spacing Coefficient	200	[1]	*RSS*
Blade Passage Frequency	150	[Hz]	f_b

2. Observation Conditions

Observation Distance	450	[ft]	r
Observation Angle	0	[Deg. from Inlet]	θ

3. Octave Band Sound Pressure Level (SPL) at selected angle and Sound Power Level (PWL) Spectrum

3a. Estimated Sound Pressure Level (L_P) at Obs. Pos.

	31.5	63	125	250	500	1000	2000	4000	8000	A
Broadband from Inlet	81	90	97	100	100	98	92	82	70	102
Broadband from Discharge	15	25	32	35	35	33	26	17	5	37
Discrete Tones from Inlet	0	0	100	93	90	84	67	0	0	91

	31.5	63	125	250	500	1000	2000	4000	8000	A
Discrete Tones from Discharge	0	0	42	35	31	26	9	0	0	33
Combination Tones from Inlet	51	51	0	0	0	0	0	0	0	25
Total L_P	81	90	102	101	101	98	92	[illegible]	70	102
A-weighted Noise Emission Criterion										85

3b. Estimated Sound Power Level L_W in Obs. Direction

	31.5	*63*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*	A
Broadband Inlet	131	141	148	151	151	148	142	133	121	152
Broadband Discharge	66	76	83	86	86	83	77	68	56	87
Discrete Tones Inlet	0	0	151	144	141	135	117	0	0	142
Discrete Tones Discharge	0	0	93	85	82	77	60	0	0	83
Combination Tones Inlet	102	102	0	0	0	0	0	0	0	76
Total L_W	131	141	153	152	152	149	142	133	121	153
Maximum Permissible Outdoor Sound Power Levels		[illegible]	[illegible]	113	110	108	107	107	106	

3c. Estimated Sound Power Level (L_W) for use in System Analysis

Intake	*31.5*	*63*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*
Broadband	128	138	144	148	148	145	139	130	117
Discrete Tones	0	0	149	142	138	133	115	0	0
Combination Tones	105	105	0	0	0	0	0	0	0
Total L_W	**128**	**138**	**150**	**149**	**148**	**145**	**139**	**130**	**117**

Average for all angles 0-90° from intake. Enter in Section 4.d. of the System Input/Output sheet as an Equipment L_W for sound traveling upstream.

Discharge	*31.5*	*63*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*
Broadband	129	138	145	148	149	146	140	131	118
Discrete Tones	0	0	150	143	140	135	118	0	0
Total L_W	**129**	**138**	**152**	**150**	**149**	**146**	**140**	**131**	**118**

Average for all angles 90-180° from intake. Use in Section 4.d. of the System Input/Output sheet as an Equipment L_W for sound traveling downstream.

FLOW NOISE IN PIPES

OVERVIEW

Flow noise is a special case of noise emission because it arises from the interaction of the turbulent boundary layer in the gas with the pipe walls and is therefore generated throughout the system. This Spreadsheet provides computations for use in evaluating a single length of piping or in evaluating a System. This Spreadsheet performs computations of Sound Power Level (L_W) and Sound Pressure Level (L_P) at 1 meter for piping with and without acoustical lagging.

Noise emission data for use in the Integrated System Analysis is presented in Line 6c and corresponds to radiation from an unlagged pipe 10 feet in length. The effects of lagging and actual pipe length are accounted for by selections made in the System Input-Output Spreadsheet. Note however that there is no automatic "feedback" from the System Input-Output Spreadsheet regarding other important parameters such as gas flow conditions and pipe dimensions and thickness. Those inputs must be made manually in this Spreadsheet in order for the computation to be correct.

Computations are based on the number of components in a 10-ft length of pipe. The most correct way to perform this computation is to obtain noise emission estimates for each 10-ft. length and then sum the results (on an energy basis) as shown in the Calculator Spreadsheet, Section 7. An approximate method is to use as inputs the total number of each component in the piping system divided by the number of 10-ft lengths in the system.

1. Select Gas

1a. Gas	Nitrogen (N2)		
Molecular Weight	28.016	[mass/mole]	*MW*
Ratio of Specific Heats	1.398	[1]	γ
Gas Constant	55.15	[(ft lbf)/(lbm °R)]	*R*

2. Flow Parameters

2a. Mass Flow Through Pipe	130000	[lb/sec]	m'
2b. Interior Total Pressure	8.5	[atm]	*P*
2c. Gas Flow Total Temperature	200	[° R]	*T*

3. Piping Dimensions

3a. Pipe Inside Diameter	16.0	[ft]	D_p
3b. Pipe Wall Thickness	0.310	[in]	t_p
3c.Length of Pipe	400	[ft]	*L*

4. Piping Complexity

4a. Enter the total number of listed components used in the piping section under consideration.
This information is used to determine K, the number of velocity heads per 10 ft (3 m) of piping.

Straight Pipe		1				
45° Elbow	Screwed	0	Welded, R/D=1	0	Welded, R/D=1.5	0
90° Elbow	Screwed	0	Welded, R/D=1	4	Welded, R/D=1.5	0
180° Elbow	Screwed	0	Welded, R/D=1	0	Welded, R/D=1.5	0
Tees (Screwed)	Thru Branch	0	Through Run	0		
Tees (Welded)	Thru Branch	0	Through Run	0		
Reducer	D_2/D_1= 0.3	0	D_2/D_1= 0.5	1	D_2/D_1= 0.7	0
Expander	D_2/D_1= 3	0	D_2/D_1= 2	1	D_2/D_1= 1.25	0
Sudden Contraction	D_2/D_1= 0.1	0	D_2/D_1 = 0.33	0	D_2/D_1 = .80	0

Sudden Expansion	D_2/D_1= 10	0	D_2/D_1= 3	0	D_2/D_1= 1.25	0

Total "K" factor 0.18 [1]

5. Flow Parameters (calculated)

Density	1.660201	[lb/cu ft]		ρ
Face area of pipe	201.0619	[ft^2]		A_p
Flow Velocity	369.451	[ft/sec]		U
Sonic Velocity	214.77	[m/sec]		c_2
Mach Number	0.552707	[1]	Warning: Velocity > 0.3 M	M
Ring Frequency of Pipe	337.5	[Hz]		f_r
Jet Spectrum Peak Frequency	4.868138	[Hz]		f_p
1st Mode Pipe Cutoff Frequency	25.80687	[Hz]		f_c

6. Estimated Noise Emission

6a. Estimated Noise Emission with No Lagging

Sound Pressure Levels (L_P), 1 m	31.5	63	125	250	500	1000	2000	4000	8000	A
L_W Radiated from Pipe per 10 ft.	131	126	114	104	89	79	68	57	46	103
Geometric Divergence to 1 meter	-10	-10	-10	-10	-10	-10	-10	-10	-10	
L_P at 1 meter	122	116	[illegible]	[illegible]	80	69	58	47	36	94
Maximum Permissible Sound Level (MPSL) for Pipe-Radiated Flow Noise										90

Sound Power Levels (L_W)	31.5	63	125	250	500	1000	2000	4000	8000	A
L_W Radiated from Pipe per 10 ft.	131	126	114	104	89	79	68	57	46	103
Correction from 10 ft. to Full Length	16	16	16	16	16	16	16	16	16	
L_W Radiated from Full Length	147	142	130	120	[illegible]	95	84	73	62	119
Maximum Permissible Outdoor Sound Power Levels		127	120	118	110	108	107	107	106	

6b. Estimated Noise Emission with Lagging

Sound Pressure Levels (L_P), 1 m	31.5	63	125	250	500	1000	2000	4000	8000	A
L_W per 10 ft. Length, Unlagged	131	126	114	104	89	79	68	57	46	103
Lagging IL 4 in.	-2	-4	-5	-10	-15	-27	-30	-24	-20	
L_W per 10 ft. Length, Lagged	129	122	109	94	74	52	38	33	26	99
Geometric Divergence to 1 meter	-10	-10	-10	-10	-10	-10	-10	-10	-10	
L_P at 1 meter	120	[illegible]	99	84	65	42	28	23	16	[illegible]
Maximum Permissible Sound Level (MPSL) for Pipe-Radiated Flow Noise										90

Sound Power Levels (L_W)	31.5	63	125	250	500	1000	2000	4000	8000	A
L_W Radiated from Full Length	147	142	130	120	105	95	84	73	62	119
Lagging IL (from above)	-2	-4	-5	-10	-15	-27	-30	-24	-20	
L_W, Full Length, Lagged	145	138	125	[illegible]	90	68	54	49	42	115
Maximum Permissible Outdoor Sound Power Levels		127	120	113	110	108	107	107	106	

6c. Estimated Sound Power Levels (L_W) for use in the System Analysis

	31.5	63	125	250	500	1000	2000	4000	8000
L_W per 10 ft., Unlagged	131	126	114	104	89	79	68	57	46

For piping on the Intake side of the system (Upstream of the main equipment group, whether indoors or outdoors), these values should be entered into Section 4.a of the Systems Input/Output sheet.

For piping on the Discharge side of the system (Upstream of the main equipment group, whether indoors or outdoors)), these values should be entered into Section 4.b of the Systems Input/Output sheet.

DUCT & PIPE WALL TRANSMISSION LOSS

1. Flow Conditions

1.a. Pressure inside Duct or Pipe	8.5	[atm]
1.b. Pressure outside Duct or Pipe	1	[atm]
1.c. Sonic Velocity inside Pipe	704	[ft/sec]

2. Pipe or Duct Geometry

2.a. Cross-Section	Circular	
2.b. Pipe Diameter	16	[ft]
2.c. (No Input Required)		[in]
2.d. Pipe Thickness	0.31	[in]

3. Estimate Relevant Parameters

Critical Frequency	26	[Hz]			
Ring Frequency	330	[Hz]			
Pipe Flexural Mode Resonances	1	2	5	7	[Hz]

4. Estimated Transmission Loss (TL)

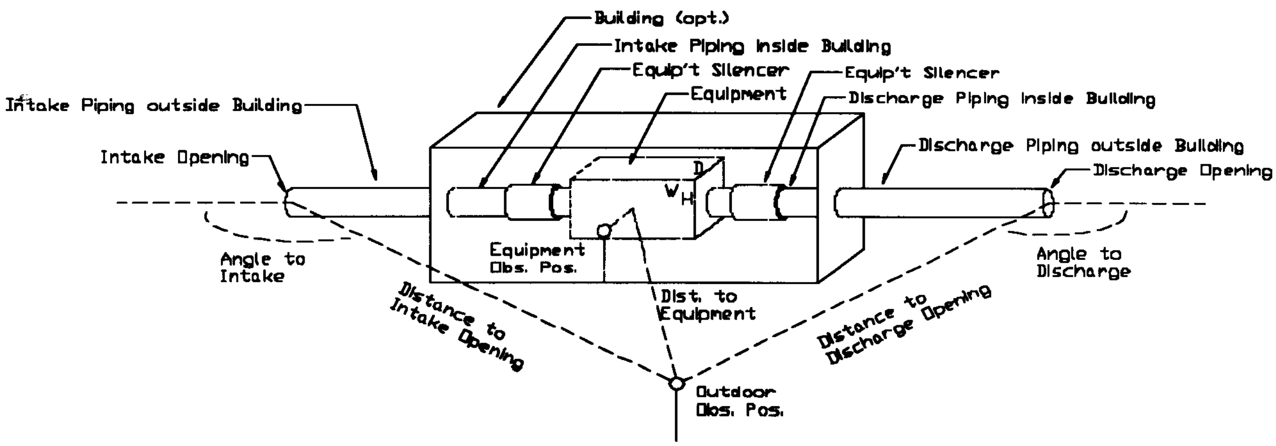
4a. Estimated Data for Use in System Analysis

	31.5	*63*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*
Transmission Loss (dB)	9	27	33	39	45	51	57	63	69

Pipe Transmission Loss data may be entered into Section 4a or 4b (using Paste- Special-Values) of the System Input/Output sheet depending on the location of the pipe or pipe opening being evaluated.

SYSTEM INPUT-OUTPUT

1. System Diagram



2. System Geometry

2a. Intake Geometry

Pipe Diameter	16.0	[ft]
Length of Piping Outdoors	150	[ft]
Length of Intake Piping Indoors	50	[ft]
Open Intake or Closed Loop		Closed Loop
Observation Distance	137	[m]
Observation Angle re Axis of Opening	>90°	0°, 45° or ≥90°

2b. Discharge Geometry

Pipe Diameter	16.0	[ft]
Length of Piping Outdoors	150	[ft]
Length of Discharge Piping Indoors	50	[ft]
Open Discharge or Closed Loop		Closed Loop
Distance to Observation Point, Outdoors	137	[m]
Observation Angle re Axis of Opening	>90°	0°, 45° or ≥90°

2c. Equipment Geometry

Equipment Located Indoors or Outdoors		Indoors	
Building Height	50	[ft]	
Building Width	100	[ft]	
Building Length	200	[ft]	
% Building Surfaces Covered with Absorptive Material	20	[%]	*(includes floor)*

Building Volume	1E+06	[ft^3]	"See Manual for Definitions
Building Surface Area	70000	[ft^2]	of Sound Absorptive Materia

Typical Equipment Dimensions*

Equipment Height	20	[ft]
Equipment Width (as viewed from observation point)	40	[ft]
Equipment Depth	20	[ft]
Distance to Indoor Observation Position	10	[ft]
Distance to Outdoor Observation Position	1	[m]

** A group of equipment items may be considered as a single unit when the equipment items are essentially identical and have similar noise emission, or when the distances from all equipment items to the observation point are similar. In such an event, the equipment dimensions may be taken as those of the box that just encloses the equipment group. Otherwise, a separate analysis for each piece of noise emitting equipment may be most appropriate.*

3. System Criteria and Overall Results*

3a. Maximum Permissible Sound Pressure Level (MPSL)

Intake	**Criterion**		**L_P Estimate**		**L_W Estimate**	
Intake Opening at 1 meter	N/A	dB(A) L_P	0	dB(A) L_P	0	dB(A) L_W
Outdoor Intake Piping at 1 meter	85	dB(A) L_P	86	dB(A) L_P	112	dB(A) L_W
Indoor Intake Piping at 1 meter	100	dB(A) L_P		dB(A) L_P		

Discharge						
Discharge Opening at 1 meter	N/A	dB(A) L_P	0	dB(A) L_P	0	dB(A) L_W
Outdoor Discharge Piping at 1 meter	85	dB(A) L_P	86	dB(A) L_P	112	dB(A) L_W
Indoor Discharge Piping at 1 meter	100	dB(A) L_P		dB(A) L_P		

3b. A-weighted Sound Pressure Level Targets

Desired A-wt. Sound Pressure Level at Outdoor Observation Position

All Outdoor Openings, Piping, Equipment	66	dB(A) L_P		dB(A) L_P

Desired A-wt. Sound Pressure Level at Indoor Observation Position

Equipment and Indoor Piping	100	dB(A) L_P	101	dB(A) L_P

** CONSULT THE SYSTEM CALCULATIONS SHEET FOR DETAILED COMPUTATIONS AND INTERMEDIATE RESULTS*

4. Component Data

Outdoors

4a. Intake	*31.5*	*63*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*	**A**
Intake Vent L_W in Pipe, Unsilenced										0

	31.5	63	125	250	500	1000	2000	4000	8000	A
Intake Control Valve L_W, Downstream, Unlagged										0
Intake Silencer Insertion Loss										
Intake Silencer Self-Noise L_W										0
Reflection Loss at Intake Opening										
Inlet Debris Screen L_W										0
Intake Piping Transmission Loss	9	27	33	39	45	51	57	63	69	
Flow Noise L_W Radiated, Unlagged, 10 ft. Length	131	126	114	104	89	79	68	57	46	103
Intake Pipe Lagging Thickness (4 in.)	-2	-4	-5	-10	-15	-27	-30	-24	-20	

4b. Discharge	31.5	63	125	250	500	1000	2000	4000	8000	A
Discharge Vent L_W, Unsilenced, from Opening										0
Discharge Control Valve L_W, Downstream, Unlagged, In Pipe										0
Discharge Silencer Insertion Loss										
Discharge Silencer Self-Noise L_W										0
Reflection Loss at Discharge Opening										
Discharge Piping Transmission Loss	9	27	33	39	45	51	57	63	69	
Flow Noise L_W Radiated, Unlagged, 10 ft. Length	131	126	114	104	89	79	68	57	46	103
Discharge Pipe Lagging Thickness (4 in.)	-2	-4	-5	-10	-15	-27	-30	-24	-20	

Indoors

4.c Silencers and Lagging	31.5	63	125	250	500	1000	2000	4000	8000	A
Equipment Intake Silencer Insertion Loss	10	22	30	35	38	34	23	15	8	
Equipment Intake Silencer Self-Noise L_W	149	144	139	134	134	134	134	134	134	141
Indoor Intake Pipe Lagging (None)	0	0	0	0	0	0	0	0	0	
Equipment Discharge Silencer Insertion Loss	10	22	30	35	38	34	23	15	8	
Equipment Discharge Silencer Self-Noise L_W	149	144	139	134	134	134	134	134	134	141
Indoor Discharge Pipe Lagging (None)	0	0	0	0	0	0	0	0	0	

4d. Equipment Component Noise Emission Data and Criteria

	31.5	63	125	250	500	1000	2000	4000	8000	A
Enter Name of Equipment Item 1	**Equipment Item 1**									
L_W Traveling in Upstream Direction	128	138	150	149	148	145	139	130	117	149
L_W Traveling in Downstream Direction	129	138	152	150	149	146	140	131	118	150
L_W from Casing to Environment, Unlagged										0
Lagging Thickness (None)	0	0	0	0	0	0	0	0	0	
L_W Radiated from Casing, Lagged	0	0	0	0	0	0	0	0	0	0

	31.5	63	125	250	500	1000	2000	4000	8000	A
Enter Name of Equipment Item 2	**Equipment Item 2**									
L_W Traveling in Upstream Direction										0
L_W Traveling in Downstream Direction										0
L_W from Casing to Environment, Unlagged										0
Lagging Thickness (None)	0	0	0	0	0	0	0	0	0	
L_W Radiated from Casing, Lagged	0	0	0	0	0	0	0	0	0	0

Enter Name of Equipment Item 3	31.5	63	125	250	500	1000	2000	4000	8000	A
	Equipment Item 3									
L_W Traveling in Upstream Direction										0
L_W Traveling in Downstream Direction										0
L_W from Casing to Environment, Unlagged										0
Lagging Thickness: None	0	0	0	0	0	0	0	0	0	
L_W Radiated from Casing, Lagged	0	0	0	0	0	0	0	0	0	0

Enter Name of Equipment Item 4	31.5	63	125	250	500	1000	2000	4000	8000	A
	Equipment Item 4									
L_W Traveling in Upstream Direction										0
L_W Traveling in Downstream Direction										0
L_W from Casing to Environment, Unlagged										0
Lagging Thickness: None	0	0	0	0	0	0	0	0	0	
L_W Radiated from Casing, Lagged	0	0	0	0	0	0	0	0	0	0

Enter Name of Equipment Item 5	31.5	63	125	250	500	1000	2000	4000	8000	A
	Equipment Item 5									
L_W Traveling in Upstream Direction										0
L_W Traveling in Downstream Direction										0
L_W from Casing to Environment, Unlagged										0
Lagging Thickness: None	0	0	0	0	0	0	0	0	0	
L_W Radiated from Casing, Lagged	0	0	0	0	0	0	0	0	0	0

Enter Name of Equipment Item 6	31.5	63	125	250	500	1000	2000	4000	8000	A
	Equipment Item 6									
L_W Traveling in Upstream Direction										0
L_W Traveling in Downstream Direction										0
L_W from Casing to Environment, Unlagged										0
Lagging Thickness: None	0	0	0	0	0	0	0	0	0	
L_W Radiated from Casing, Lagged	0	0	0	0	0	0	0	0	0	0

End of System Inputs