Silencer Back Pressure Calculation

COEFFICIENT	SILENCER MODEL	NAME OF MODEL	COEFFICIENT	SILENCER MODEL	NAME OF MODEL
4.8	SFH	Super Critical Grade	4	RFH	Residential Grade
6	LPRS	Super Critical Grade	3.2	RSL	Residential Grade
4	SCSC	Super Critical Grade	2.4	IRTS	Residential Grade
4	VCS	Super Critical Grade	4	SASR	Residential Grade Spark Arrestor
3.6	VRS	Critical Grade	3.2	RSL	Residential Grade Spark Arrestor
4.2	CFHI	Critical Grade	3.6	VRSA	Critical Grade Spark Arrestor
4	CSCS	Critical Grade	4	VCSA	Super Critical Grade Spark Arrestor
4	CFH	Critical Grade	2.6	M	Industrial Grade

Choose Silencer Model	
Introduce Exhaust CFM	
Introduce Diameter of Outlet (in)	
Introduce Temp. (F)	
Introduce Max. BP of Engine	

Introduce Lbs/Hr	
or Kg/s	
Introduce Temp. (C)	
Introduce BP of Piping & Elbows	

$$ACFM = \frac{\text{Exhaust Temp.} + 460}{2275} \times \frac{Lbs}{Hr}$$

$$TempF = 9x \frac{C}{5} + 32$$

$$1 \frac{Lbs}{Hr} = 7936.56x1 \frac{Kg}{Second}$$

Calculate Outlet Flow Area

Flow Area = .005454 x $(\text{Diameter})^2$

Outlet Flow Area	0.000
Temp (F)	32
CFM	0

Calculate Velocity ft/min (V)

$$V = \frac{\text{Exhaust CFM}}{\text{Silencer Flow Area}} =$$

Calculate Back Pressure (in H20)

$$P = cx \frac{V^2}{4005^2} \times \frac{530}{(T + 460)} =$$

NOTE: Exhaust Velocity should not exceed 9,000 ft/min on all Critical and Super Critical applications and velocity should not exceed 12,000 ft/min for the rest of the applications

VRS & VCS Series Features:

- Noise reduction is accomplished by a combination of absorption and annulling of noise waves
- Exhaust gases flow through the silencer in a vortex motion which is created by a centrifugal diffuser
- VCS Attenuation 30 to 40 dBA
- VRS Attenuation 19 to 32 dBA
- The rotation of the exhaust gas allows for a clean transition through the silencer with limited pressure loss
- This type of design allows for a change in the noise frequency to a higher band, the results are a much simpler sound to attenuate
- This is accomplished by the annulling of the noise by a series of chamber with acoustical packing
- The multi-chambered design also allows us to attenuate the lower frequency bands present in the exhaust
- A side branch designed chamber provides the last step to de-energize the noise. The external shell temperature is greatly reduced by the chambers with internal packing

Example of Calculation of Back Pressure and Velocity

In our example we have used a CAT 3516 Engine that has the following characteristics:

- Exhaust Flow = 15757 CFM
- Max. Back Pressure 27 in H2O
- Exhaust Temp 945°F
- Exhaust Mass Flow 25480 lbs/Hr
- Exhaust Outlet Diameter 8” 2 Ports

In this formula we've chosen a Super Critical Grade Low Profile SFH 20" OUTLET with 4.8 coefficient of Pressure Drop.

1. Calculate Area Flow

Diameter of Outlet Pipe (in) = 20"

From Page F Log Data Choose Area Flow

For 20" Diameter = 2.182 $(ft)^2$ Area Flow

2. Transform Temp C to F (if needed)

Formula: $Temp(F) = 9x \frac{C}{5} + 32$

3. Calculate Lbs / Hr from Kg / Second (if needed)

Formula: $1 \frac{Lbs}{Hr} = 7936.56x1 \frac{Kg}{Second}$

4. Calculate ACFM (if needed)

Formula: $ACFM = \frac{\text{Exhaust Temp} + 460}{2275} \text{ x } \frac{Lbs}{Hr}$

$ACFM = \frac{946 + 460}{2275} \text{x}25480 = 15747.2 \text{ (CFM)}$

5. Calculate Velocity FPM

Formula: $V = \frac{\text{Exhaust ACFM}}{\text{Flow Area}}$

$V = \frac{15747}{2.182} = 7216.7 \text{ FPM}$

6. Calculate Back Pressure

Formula: $P = cx \frac{v^2}{4005^2} \text{ x } \frac{530}{(T + 460)}$

For SFH Super Critical Grade c = 4.8

$P = 4.8x \frac{7217^2}{4005^2} \text{ x } \frac{530}{(946 + 460)} = 4.8x3.24719x0.3769 = 5.9 \text{ in H2O}$

NOTE: Velocity should not exceed 12,000 ft/min regardless of allowable Back Pressure Limitations

Exhaust Piping Pressure Drop Chart

I.D. SIZE D (in)	LENGTH L (ft)	TEMP L (F)	CFM	PER FOOT P (“H2O)
1.5	1	1000	150	0.45" H2O
2.0	1	1000	190	0.17" H2O
2.5	1	1000	275	0.12" H2O
3.0	1	1000	710	0.31" H2O
3.5	1	1000	710	0.14" H2O
3.5	1	1000	1028	0.30" H2O
4	1	1000	880	0.11" H2O
4	1	1000	1175	0.20" H2O
5	1	1000	2190	0.23" H2O
5	1	1000	2656	0.34" H2O
6	1	1000	2656	0.14" H2O
6	1	1000	2900	0.16" H2O
6	1	1000	3200	0.20" H2O
8	1	1000	3860	0.07" H2O
8	1	1000	4600	0.10" H2O
10	1	1000	8850	0.12" H2O
10	1	1000	9100	0.12" H2O
12	1	1000	13025	0.10" H2O
12	1	1000	20000	0.24" H2O
14	1	1000	14500	0.06" H2O
14	1	1000	15500	0.07" H2O
16	1	1000	15500	0.03" H2O
16	1	1000	16500	0.04" H2O
16	1	1000	25000	0.09" H2O
18	1	1000	18800	0.03" H2O
18	1	1000	20500	0.03" H2O
20	1	1000	22800	0.02" H2O
22	1	1000	22800	0.02" H2O
22	1	1000	25000	0.02" H2O
24	1	1000	23000	0.01" H2O
24	1	1000	25000	0.01" H2O
24	1	1000	30000	0.02" H2O
24	1	1000	65000	0.08" H2O
26	1	1000	31700	0.01" H2O
28	1	1000	33500	0.01" H2O
30	1	1000	60000	0.02" H2O
32	1	1000	80000	0.03" H2O

Formula for Pressure Drop

$$P = \frac{.22xLxQ^2}{D^5(460 + T)}$$

Where:
P = Pressure drop inches H2O
L = Total length in feet of pipe
Q = Gas flow in cu. Ft. per min.
D = I.D. of pipe in inches
T = Exhaust temperatures F

Table to fifth power

1.5	=	7.6
2	=	32.0
2.5	=	97.7
3	=	243.0
3.5	=	525.2
4	=	1024.0
5	=	3125.0
6	=	7776.0
8	**=**	**32768.0**
10	=	100000.0
12	=	248832.0
14	=	537824.0
16	=	1048576.0
18	=	1889568.0
20	=	3200000.0
22	=	5153632.0
24	=	7962624.0
26	=	11881376.0
28	=	17210368.0
30	=	24300000.0
32	=	33554432.0

NOTE:
Data based on exhaust temperature of 1000°F and the length of 1 ft.

Example: For D = 8", CFM = 4600, T = 1000°F, L = 1 ft.

$$P = \frac{.22x1ftx4600^2}{32768x(460 + T)} = \frac{.22x21160000}{32768x(460 + 1000)} = \frac{4655200}{32768x1460} = 0.1" H_2O \qquad P= 0.1" H_2O$$

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Calculation of Back Pressure on Elbows, Flex Connectors and Pipes

Introduce CFM		*Introduce # Short Radius Elbow*	
Introduce Temp. (F)		*Introduce # Long Radius Elbow*	
Introduce Diameter (in)		*Introduce # 45 Elbow*	
Introduce Length of Pipe (ft)		*Introduce # 90 Square Elbow*	
Introduce Length of Flex Pipe (ft)			

To obtain equivalent length of exhaust pipe (ft):

For Short Radius Elbow (R = D): $L_1 = 2.75xD$

For Long Radius Elbow (R > 1.5xD: $L_2 = 1.67xD$

For 45° Elbow: $L_3 = 1.25xD$

For 90° Square Elbow: $L_4 = 5.5xD$

For Flex Pipe: $L_5 = 2x$ (Flex Length)

Length of Pipe

Total Length

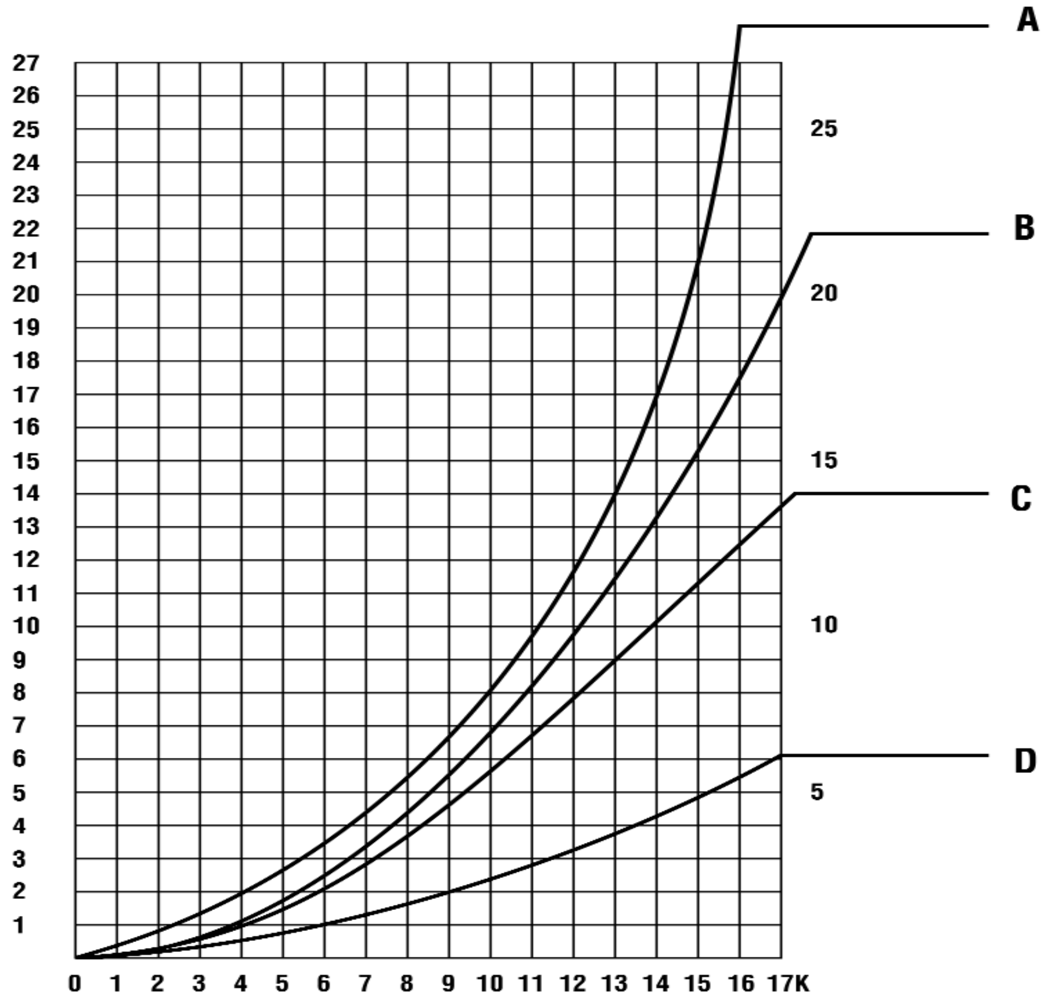
$L = \Sigma \ (L_1 + L_2 + L_3 + L_4 + L_5 + L_6)$

Calculate Back Pressure

$$P = \frac{.22xLxQ^2}{D^5(460 + T)}$$

Where:
P = Pressure drop inches H2O
L = Total length in feet of pipe
Q = Gas flow in cu. Ft. per min.
D = I.D. of pipe in inches
T = Exhaust temperatures F

Exhaust Velocity
Pressure Loss Sizing Chart



A = VRS, SCSC, VCS, CSCS
B = SFH, CFH, RFH, VRS, RSL, SASR, VMS, VCSA, LPRS
C = M, SAM
D = IRTS, VCTS
NOTE: Exhaust gas velocity feet per minute at 900ºF

NOTE: On A and B Velocity should not exceed 9000 ft/min

Method for Sizing HAPCO Engine Exhaust Silencers

Series: VCS, VRS, SFH, CFH, LPRS, SCSC, CSCS, M RFH, RLS, SAM, SASR VCSA, VCTS, VMS & Spark Arrestor

INLET DIAMETER	INLET AREA (FT) ^{2}
1.25	0.0085
1.5	0.0123
2.0	0.0218
2.5	0.0341
3.0	0.0491
3.5	0.0668
4.0	0.0873
5.0	0.1364
6.0	0.1963
8.0	0.3491
10.0	0.5454
12.0	0.7854
14.0	1.069
16.0	1.396
18.0	1.767
20.0	2.182
22.0	2.640

INLET DIAMETER	INLET AREA (FT) ^{2}
24.0	3.142
26.0	3.687
28.0	4.276
30.0	4.909
32.0	5.585
34.0	6.305
36.0	7.069
38.0	7.876
40.0	8.727
42.0	9.621
44.0	10.559
46.0	11.541
48.0	12.566
54.0	15.904
56.0	17.104
58.0	18.348
60.0	19.635

REQUIRED DATA:
- Engine Exhaust CFM
- Exhaust Temperature
- Allowable Pressure Drop
- Grade of Silencer

PROCEDURE:
It is necessary to convert CFM to Velocity (FPM) Divided CFM by Inlet Area (See Chart)
Example: 6" Inlet with 2600CFM (2600 Divided by .1964 = 13238) FPM

NOTE:
Velocity is extremely important when sizing exhaust systems. The following silencers design flow must not exceed 9000 FPM:
VCS, VCSA, VRS, SFH, CFH, RFH AND Rectangle Type Silencers (LPRS)

HAPCO
Steel Exhaust Pipe Dimensions and Thermal Pipe Expansion Formula

	Schedule 40			
SIZE	**O.D.**	**WALL THICKNESS**	**I.D.**	**WEIGHT LB./FT**
1.5	1.9	0.145	1.61	2.72
2.0	2.375	0.154	2.067	3.653
2.5	2.875	0.203	2.459	5.793
3.0	3.5	0.216	3.068	7.58
3.5	4.0	0.226	3.548	9.109
4.0	4.5	0.237	4.026	10.79
5.0	5.563	0.258	5.047	14.62
6.0	6.625	0.28	6.065	18.97
8.0	8.625	0.322	7.981	28.55
10.0	10.75	0.365	10.02	40.48
12.0	12.75	0.406	11.938	53.56
14.0	14.0	0.438	13.124	63.37
16.0	16.0	0.5	15.0	82.77
18.0	18.0	0.562	16.876	104.76
20.0	20.0	0.594	18.812	123.06
24.0	24.0	0.688	22.624	171.17

	Schedule 10			
SIZE	**O.D.**	**WALL THICKNESS**	**I.D.**	**WEIGHT LB./FT**
1.5	1.9	0.109	1.682	2.09
2.0	2.375	0.109	2.157	2.64
2.5	2.875	0.12	2.635	3.53
3.0	3.5	0.12	3.26	4.33
3.5	4.0	0.12	3.76	4.97
4.0	4.5	0.12	4.26	5.61
5.0	5.563	0.134	5.295	7.77
6.0	6.625	0.134	6.357	9.29
8.0	8.625	N/A	N/A	N/A
10.0	10.75	N/A	N/A	N/A
12.0	12.75	N/A	N/A	N/A
14.0	14.0	0.25	13.5	36.71
16.0	16.0	0.25	15.5	42.05
18.0	18.0	0.25	17.5	47.39
20.0	20.0	0.25	19.5	52.73
24.0	24.0	0.25	23.5	63.42

Steel pipe expansion data from ambient temperature steel exhaust pipe is rated at .00076 per ft for each 100ºF rise in temperature.

T = Temperature of exhaust
L = Length of pipe
AT = Ambient temperature
G = Growth

Equation growth of Steel Pipe

$$G = 0.0076xLx \frac{(T - AT)}{100} \text{ (in)}$$

To offset expansion on piping be sure there is ample length of stainless flex between two fixed points.
Example of calculation:
Exhaust Temperature is t = 900ºF
Ambient Temperature is AT = 60ºF
Length of Pipe is L = 10ft
Growth of Pipe is

$$G = 0.0076x10x \frac{(900 - 60)}{100} = 0.076x8.4 = 0.6384 \text{ (in)}$$

The result is that a 10ft length of pipe at an ambient of 60ºF, and an exhaust temperature of 900ºF will increase in length to 0.6384".

The exhaust pipe must be isolated from the engine with flexible connection. They should be installed as close to the engine's exhaust outlet as possible. A flexible connection has three primary functions:

1. To isolate the weight of the exhaust pipe from the engine.
2. To relieve exhaust components of excessive vibration fatigue stresses.
3. To allow for relative shifting between reference points on engine exhaust components.

NOTE: Outlet of exhaust silencer must also include a flexible section if exhaust pipe is fixed or welded solid.

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Rev. 03/11

Exhaust Flow at Maximum Ratings
Cubic Feet per Minute for 4 Cycle Carbureted Engine
Volumetric Efficiency 80% - Exhaust Temperature 1200ºF

ENGINE DISPLACEMENT C.C.	REVOLUTIONS PER MINUTE																					
	C. IN.	1600	1800	2000	2200	2400	2600	2800	3000	3200	3400	3600	3800	4000	5000	6000	7000	8000	9000	10000	12000	14000
20	1.22	1.3	1.5	1.7	1.8	2.0	2.2	2.3	2.5	2.6	2.8	3.0	3.2	3.4	4.2	5.0	5.9	6.8	7.5	8.4	10.0	11.8
40	2.44	2.7	3.0	3.4	3.7	4.0	4.3	4.7	5.0	5.4	5.7	6.0	6.4	6.8	8.4	10.0	11.8	13.6	15.0	16.8	20.0	23.6
60	3.66	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	12.5	15.0	17.5	20.0	22.5	25.0	30.0	35.0
80	4.88	5.3	6.0	6.7	7.3	8.0	8.7	9.3	10.0	10.6	11.3	12.0	12.7	13.4	16.7	20.0	23.4	26.8	30.0	33.4	40.0	46.8
100	6.10	6.7	7.5	8.4	9.2	10.0	10.9	11.7	12.5	13.4	14.2	15.0	15.9	16.8	20.9	25.0	29.3	33.6	37.5	41.8	50.0	58.6
120	7.32	8.0	9.0	10.1	11.0	12.0	13.0	14.0	15.0	13.0	17.0	18.0	19.1	120.2	25.1	30.0	35.2	40.4	45.0	50.2	60.0	70.4
140	8.54	9.4	10.6	11.7	12.9	14.1	15.2	16.4	17.6	18.8	20.0	21.2	22.3	23.4	29.3	35.2	41.0	16.8	52.8	58.6	70.4	82.0
160	9.76	10.7	12.1	13.4	14.7	16.1	17.4	18.7	20.1	21.4	22.8	24.2	25.5	26.8	33.5	40.2	16.6	53.6	60.3	67.0	80.4	93.8
180	10.98	12.0	13.6	15.1	16.5	18.1	19.6	21.0	22.6	24.0	25.6	27.2	28.7	30.2	37.7	45.2	52.8	60.4	67.8	75.4	90.4	106
200	12.20	13.4	15.1	16.8	18.4	20.1	21.7	23.4	25.1	26.8	28.5	30.2	31.9	33.6	41.9	50.2	58.7	67.2	75.3	83.8	100	117
220	13.42	14.7	16.6	18.5	20.2	22.1	23.9	25.7	27.6	29.4	31.3	33.2	35.1	37.0	46.1	55.2	64.6	74.0	82.8	92.2	110	129
240	14.65	16.0	18.1	20.1	22.0	24.1	26.1	28.0	30.1	32.0	31.1	36.2	38.2	40.2	50.2	60.2	70.3	80.4	90.3	100	120	141
260	15.87	17.4	19.6	21.8	23.9	26.1	28.2	30.4	32.6	34.8	37.0	39.2	24.4	43.6	54.4	65.2	76.2	87.2	97.8	109	130	152
280	17.09	18.7	21.1	23.5	25.7	28.1	30.4	32.7	35.1	37.4	39.8	42.2	44.6	47.0	58.6	70.2	82.1	94.0	105	117	140	164
300	18.31	20.2	22.6	25.2	27.6	30.1	32.6	35.1	37.6	40.0	42.6	45.2	47.8	50.4	62.8	75.2	88.1	101	113	126	150	176
320	19.53	21.4	24.1	26.8	29.4	32.1	34.8	37.4	40.1	42.8	45.5	48.2	50.9	53.6	66.9	80.2	93.6	107	120	134	160	187
340	20.75	22.7	25.6	28.5	31.2	34.1	36.9	39.7	42.6	45.4	48.3	51.2	54.1	57.0	71.1	85.2	99.6	114	128	142	170	199
360	21.97	24.1	27.1	30.2	33.1	36.1	39.1	42.1	45.1	48.2	51.2	54.2	57.3	60.4	75.3	90.2	106	121	135	151	180	212
380	23.19	25.4	28.6	31.9	34.9	38.1	41.3	44.4	47.7	50.8	54.0	57.2	60.5	63.8	79.6	95.4	112	128	143	159	191	224
400	24.41	26.7	30.1	33.6	36.7	40.2	43.4	46.7	50.2	53.4	56.8	60.2	63.7	67.2	83.6	100	117	134	151	167	200	234
500	30.51	33.4	37.7	42.0	48.9	50.2	54.3	58.4	62.7	66.8	71.1	75.4	79.7	84.0	105	125	147	168	188	210	250	294
600	36.61	40.1	45.2	50.3	55.1	60.2	65.2	70.1	75.2	80.2	85.3	90.4	95.7	101	126	150	176	202	226	252	300	352
700	42.71	46.8	52.8	58.7	64.3	70.3	76.0	81.8	87.8	93.6	99.8	106	112	117	147	176	205	234	263	284	352	410

2 Cycle Engines, Multiply above values by 2.

All figures proportional, that is, 800 CC engine will have double the flow of 400 CC engine with all other factors equal.
Double RPM will double the flow, etc.

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Exhaust Flow (CFM)
4 Cycle Carbureted Engines
(Volumetric Efficiency - 80% Exhaust Temp - 1200ºF

ENGINE DISPLACEMENT (Cu. In.)	REVOLUTIONS PER MINUTE										
	800	1000	1200	1400	1600	1800	2000	2400	2800	3200	3600
200	110	137	164	182	219	247	274	329	384	438	493
240	132	164	197	230	263	296	329	395	460	526	592
280	153	192	230	269	307	345	384	460	537	514	690
320	175	219	263	307	351	395	438	526	614	701	789
360	197	247	296	345	395	444	493	592	690	789	888
400	219	274	329	384	438	493	548	658	767	877	987
440	241	301	362	422	482	543	603	723	844	964	1085
480	263	329	395	460	526	592	658	789	921	1052	1184
520	285	356	427	499	570	641	712	855	997	1140	1282
600	329	411	493	575	658	740	822	986	1150	1315	1480
680	373	466	559	652	745	838	932	1118	1304	1491	1677
760	416	521	625	729	833	937	1041	1249	1458	1666	1874
840	460	575	690	806	921	1035	1151	1381	1611	1841	2071
920	504	630	756	882	1008	1134	1260	1512	1765	2017	2269
1080	592	740	888	1036	1184	1332	1480	1776	2071	2367	2663
1160	636	795	954	1112	1271	1430	1589	1907	2225	2543	2861
1320	723	904	1085	1266	1447	1628	1808	2170	2532	2893	3255
1480	811	1014	1217	1419	1622	1825	2028	2433	2839	3244	3650
1660	910	1137	1365	1592	1820	2047	2274	2729	3184	3639	4094
1820	997	1247	1496	1745	1995	2244	2493	2992	3491	3989	4488
1980	1085	1356	1628	1899	2170	2441	2713	3255	3798	4340	4883
2140	1173	1466	1759	2052	2345	2639	2932	3518	4150	4691	5277

(For other RPM or displacement, values may be increased or decreased in direct proportion.)

NOTE:
1. Figures given represent C.F.M. at maximum ratings.
2. For 4 cycle turbo-charged engines, multiply above values by 1.40.

Notes:

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