An Experimental Investigation for the Relationship between Acoustic Power and exerted Load in Single Cylinder Four Stroke Air-Cooled Gasoline Engine

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Abstract:

Studying for sound and noise is of great importance nowadays. And since the internal combustion engines are main sources of noise pollution, this study established to investigate the relationship between the acoustic powers immersed from two different electric generators and the applied variable loads. The engines are of single cylinder four stroke air cooled gasoline type engaged with electric generator heads. The results show an agreement with other works on other types of engines (diesel engines), and it is found that used generators make noise much more than factory specifications and this noise lower with load increment, in contrary in brand new generators noise grow with load increment.

Key words: *acoustic power , noise attenuation , muffler*

تحقق عملي عن العلاقة بين الطاقة الصوتية والحمل المسلط على محرك بنزين احادي الاسطوانة رباعي الاشواط مبرد بالهواء

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الخلاصة

ان لدراسة الصوت والضوضاء الاهمية الكبيرة في هذه الايام. وحيث ان محركات الاحتراق الداخلي من المصادر الاساسية للتلوث الضوضائي فقد جائت هذه الدراسة للتحقق في العلاقة بين طاقة الصوت المنبعث من مولدين كهربائيين وحجم الحمل المسلط عليها. المحركات التي تم اجراء الاختبار عليها هي احادية الاسطوانة رباعية الاشواط ذات التبريد بالهواء وتعمل بوقود البنزين ومربوطة على مولد كهربائي. لقد اظهرت النتائج توافقا مع دراسات مقاربة على محركات من نوع اخر (محركات الديزل) حيث افرزت النتائج بأن المولدات المستخدمة تسبب ضوضاء اكثر بكثير من مواصفات المصنع وان هذه الضوضاء تقل مع زيادة الحمل عكس ما هو في المولد الجديد حيث الضوضاء تزيد مع زيادة الحمل.

١. Introduction

Internal combustion engines are major sources of environment noise pollution. These engines are used for various purposes such as, in power plants, automobiles, locomotives, and in various manufacturing machineries and also in domestic use. Noise health effects describe problems in both health and behavior. Unwanted sound (noise) can damage physiological and psychological health. Noise pollution can cause annoyance and aggression, hypertension, high stress levels, tinnitus, hearing loss, sleep disturbances, and other harmful effects.

Engine exhaust noise is controlled through the use of silencers and mufflers. The noise is caused either by pulses created when an exhaust valve opens and a burst of high pressure gas suddenly enters the exhaust system or by the friction of various parts of the engine. The exhaust noise is the most dominant. The limitation of the noise caused by the exhaust system is accomplished by the use of silencers and mufflers.

Many tests and researches into the field of noise emanating from I.C. engines in general are held for years. Studies are held for the theory of mufflers and testing procedures used to obtain the theoretical results. Research into the methods used for testing the acoustic performance of mufflers and ducts gave better understanding of the experimental procedure as well as giving information on the theoretical results expected during testing.

Muthana, et.al. [١], and Muna, et. al.[٢] & [٣] built a test rig and studied many design parameters affecting the muffler's performance. They also gave a survey on former works that dealt with sound attenuation tools for (I.C) engines. Studying the effect of mufflers and their design should coordinate with studying the effect of the residual noise on the environment especially for stationary engines like domestic electric generators. **Singh [٤]** gave a good survey for previous works that discuss the various sources of the noise in I.C. engines and methods to achieve facilities to gain power. In his work, **Singh**, studied the relationship between compression ratio and frequency with load for a single cylinder four stroke, VCR (Variable Compression Ratio) diesel engine connected to eddy current type dynamometer for loading. **Singh** concluded that acoustic power increases as load increases for all Compression ratios. He also named few other conclusions.

Zakhmi [٥] used single-cylinder two-stroke petrol engine in his study for generated noise at different speeds and loads with different types of mufflers. One of **Zakhmi's** conclusions is that the value of Sound Pressure Level varies linearly with respect to load and speed. When sound is produced, a transfer of energy from the source to the surrounding air molecules takes place. The rate of energy transfer is called Sound Power. The unit of Sound Power is W (Watt).

In this work, the procedure used by both **Singh** and **Zakhmi** to estimate the generated sound power from (I.C.) engine is used to investigate the sound power generated from two (٥ K.V.A and ٢ K.V.A) electric generators which are derived by single cylinder four stroke gasoline air cooled engines. The sound power ((which may be considered as dissipated power)) is considered against the generating load. In a previous work, **Ehsan, S. [٦]** used two electric generators to investigate the relationship between fuel consumption and generating load. He suggested a method which couples two ١٦٣cc engines to drive one generating head by means of epicycle gear box instead of one ٣٣٧cc engine. In this work, the same engines are used.

The audible range of sound power extends from ١٠^{-٩} W to more than ١٠٠٠ W. ١٠^{-٩} W is the lowest level which can be heard by a listener close to the source, and ١٠٠٠ W will create immediate hearing damage. Lower levels can also create hearing damage, when the listener is exposed for a long period of time.

Pulses released by the exhaust are the main cause of engine noise beside the friction between engine parts. When the expansion stroke of the engine comes near the end, the outlet valve opens and the remaining pressure in the cylinder discharges exhaust gases as a pulse into the exhaust system. These pulses are between ٠,١ and ٠,٤ atmospheres in amplitude, with a pulse duration between ٢ and ٥ milliseconds. The frequency spectrum is directly correlated with the pulse duration. The cut-off frequency lies between ٢٠٠ and ٥٠٠ Hz.

When a source produces sound power (P) it will create a certain Sound Intensity (I) at a distance away from the source. The intensity is a measure for the amount of power through a certain area at this distance. None of these units can be measured directly. Their values can be calculated after measuring the sound pressure level, knowing the area over which measurements are being made.

Decibel (dB) is logarithmic ratio which defines the sound pressure level (SPL) as follows:

$$SPL = ٢٠ \log_{١٠} (P / P_o) \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where:

P is the sound pressure measured

P_o is the reference sound pressure i.e. ٢٠µPa (the threshold of hearing).

Environmental conditions at different SPL values are shown in Table (١). Generally, (I.C) engines (equipped with silencers) produce noise of ٧٠ to ١٢٠ dB depending on the size and the type of the engine. Table (٢) shows sound power for some sound sources.

Table ١: Environmental conditions at different SPL.

Sound pressure ($N/m^٢$)	SPL (dB)	Environmental Conditions
$١٠^{٢}$	١٣٣	Threshold of pain
١٠	١١٤	Loud Automobile horn
١	٩٤	Inside subway train
$١٠^{-١}$	٧٤	Average traffic on street corner
$١٠^{-٢}$	٥٤	Living room, Typical business office
$١٠^{-٣}$	٣٤	Library
$١٠^{-٤}$	١٤	Broadcasting Studio
$٢*١٠^{-٥}$	٠	Threshold of Hearing

Table ٢: Sound power for some sound sources.

Situation or sound source	sound power P_A watts	SPL dB re ١٠$^{-١٢}$ W
Rocket engine	١،٠٠٠،٠٠٠ W	١٨٠ dB
Turbojet engine	١٠،٠٠٠ W	١٦٠ dB
Siren	١،٠٠٠ W	١٥٠ dB
Heavy truck engine	١٠٠ W	١٤٠ dB
Machine gun	١٠ W	١٣٠ dB
Jackhammer	١ W	١٢٠ dB
Excavator, trumpet	٠,٣ W	١١٥ dB
Chain saw	٠,١ W	١١٠ dB
Helicopter	٠,٠١ W	١٠٠ dB
Loud speech, vivid children	٠,٠٠١ W	٩٠ dB
Usual talking, Typewriter	١٠$^{-٥}$ W	٧٠ dB
Refrigerator	١٠$^{-٧}$ W	٥٠ dB

The acoustic power (P_A) is calculated from equation (٢) as it stated in **[٤], [٥] & [٧].**

$$P_A = SPL + 10\log_{10}\left({}^{S}/_{S_o}\right) \quad \text{.......................... (٢)}$$

Where

SPL = Sound pressure level, dB .

S = Hypothetical surface area (m^{٢})

S_o=Reference area (m^{٢})

٢. Experimental setup

Two different size portable electric generators are used (figures ١ and ٢), each equipped with single cylinder four stroke air cooled gasoline engine (specifications in table ٣). The generators are placed outdoor. A Sound pressure level (SPL) meter (figure ٣) is used to find SPL values in selected locations.

The experimental procedure is as follows:

١- the generators dimensions are measured in order to calculate the area for acoustic power measurement (S_o) and a hypothetical surface of rectangular parallel-piped is made to surround each generator with area (S)

٢- Five points (locations) are selected, four points (A, B, C & D) each ٤٠ cm away from the center of the generator's faces (figure ٤) and the fifth point (E) at the exhaust which is going ٥m away from the generator through a steel pipe (figure ٥).

٣- SPL is measured in each point from the five points for each generator when in operation taking readings starting from no load increasing gradually to (٧ Amp/Hr) for the small generator and (١٠ Amp/Hr) for the big one. These values are plotted against load for discussion.

٤- Additional SPL values at designated points on the hypothetical surface are measured (figure ٦).

٥- The average value of SPL is obtained (SPL_{av}) from the points mentioned in paragraph ٤ above to calculate the acoustic power level (P_A) using equation ٢.

Table ٣: Specifications of the generators.

Generator model		٢٥٠٠	٥٠٠٠
Engine model		١٦٠	٣٤٠
Displacement in $cm^٣$		١٦٣	٣٣٧
Rated Horsepower (HP)	@ ٣٠٠٠ rpm	٣,٥	٧,٢
	@ ٣٦٠٠ rpm	٤	٨
AC Output (KVA)	Rated	٢,٢	٤,٥
	Maximum	٢,٥	٥
Dimensions (mm)	Length	٦١٠	٦٩٥
	Width	٤٢٠	٥٢٠
	Height	٦١٠	٦٥٠
Noise Index dB	@ ٧ m	٦٧	٧٢

Figure ١: The ٥٠٠٠-model generator


Figure ٢: The ٢٥٠٠-model generator

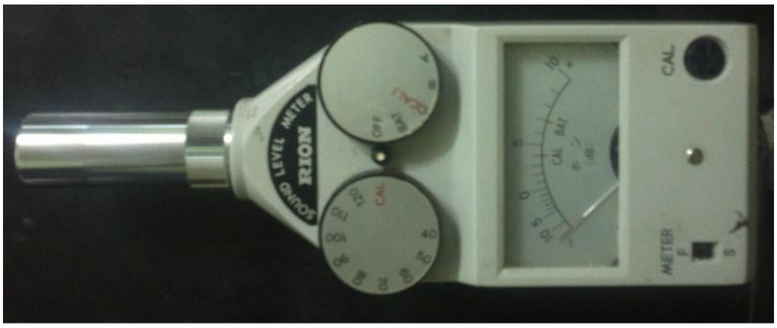

Figure ٣: SPL meter

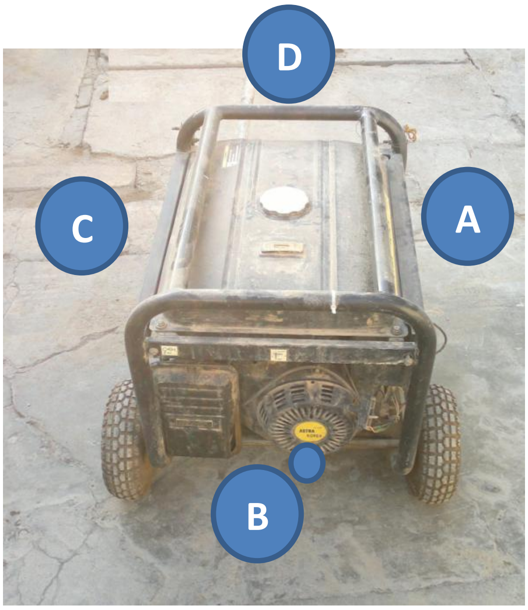

Figure ٤: The ٤ selected locations

Figure ٥: ٥ meter exhaust pipe

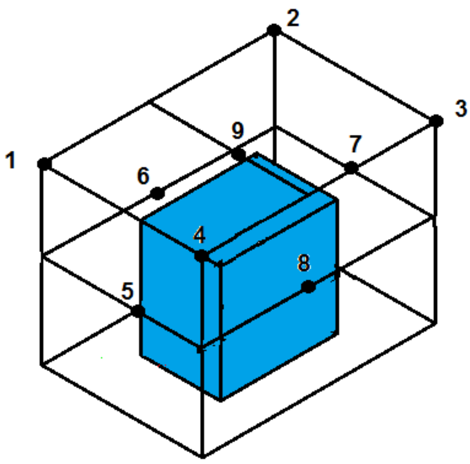

Figure ٦: rectangular parallel-piped hypothetical surface.

Table ٤: SPL values for the ٩ designated points on the hypothetical surface for (٥٠٠٠-model)

Load (amp/hr) / Grid points	٠	١,١	١,٨	٣,٢	٤,٣	٥,٨	٦	٧,٣	٨,٥	١٠
١	٩٧	٩٧	٩٦,٥	٩٦	٩٦	٩٥,٥	٩٥	٩٤,٥	٩٤	٩٤
٢	٩٦,٥	٩٧	٩٦	٩٦	٩٥,٥	٩٥	٩٤,٥	٩٤	٩٤,٥	٩٤,٥
٣	١٠١	١٠١	١٠١	١٠١	١٠٠,٥	١٠٠	١٠٠	٩٨	٩٧,٥	٩٧,٥
٤	١٠١	١٠١	١٠١,٥	١٠٠	١٠١	٩٩	٩٧	٩٦	٩٥	٩٥
٥	١٠١,٥	١٠١,٥	١٠١,٥	١٠٠,٥	١٠١	٩٩	٩٧	٩٦,٥	٩٦	٩٥
٦	٩٨	٩٨	٩٨	٩٨	٩٧	٩٧	٩٦	٩٥	٩٣,٥	٩٣,٥
٧	١٠٢	١٠٢	١٠٢	١٠١,٥	١٠١,٥	١٠١	١٠١	٩٩,٥	٩٨	٩٨
٨	١٠٢	١٠٢	١٠١,٥	١٠١	١٠١,٥	٩٩	٩٨	٩٨	٩٧,٥	٩٧
٩	٩٠	٩٠	٩٠	٩١	٩١	٩١,٥	٩١,٥	٩٢	٩١,٥	٩١,٥
Ave.	٩٨,٧٨	٩٨,٨٤	٩٨,٦٧	٩٨,٣٤	٩٨,٣٤	٩٧,٤٥	٩٦,٦٧	٩٥,٩٥	٩٥,٢٨	٩٥,١١

Table ٥: SPL values for the ٩ designated points on the hypothetical surface for (٢٥٠٠-model)

Load (amp/hr) / Grid points	٠	١	١,٧	٣	٣,٩	٤,٨	٥,٦	٦,٩
١	٨٦	٨٥,٥	٨٥	٨٥,٥	٨٥,٥	٨٦	٨٧	٨٧
٢	٨٦	٨٥,٥	٨٥,٥	٨٦	٨٥,٥	٨٦	٨٦,٥	٨٧
٣	٩٢	٩١	٩١	٩١,٥	٩٢	٩٢	٩٢,٥	٩٣
٤	٩١	٩٠	٩٠,٥	٩١	٩١	٩١	٩١,٥	٩٢
٥	٩٢	٩١,٥	٩١	٩١,٥	٩١,٥	٩٢	٩٢	٩٢,٥
٦	٨٧	٨٦	٨٥,٥	٨٦	٨٦	٨٦,٥	٨٧	٨٧,٥

٧	٩٣	٩٣	٩٢,٥	٩٢,٥	٩٣	٩٣	٩٤	٩٤
٨	٩٢,٥	٩٢	٩٢	٩٢,٥	٩٣	٩٣	٩٣,٥	٩٣,٥
٩	٨٥	٨٥	٨٥	٨٥	٨٥	٨٥,٥	٨٦	٨٦
Ave.	٨٩,٣٩	٨٨,٨٤	٨٨,٦٧	٨٩,٠٦	٨٩,٢	٨٩,٤٥	٩٠	٩٠,٢٨

٣. Results and Discussion

It is clear from the specifications shown in table (٣) that the noise index for the (٥٠٠٠ model) generator is ٧٢ dB and it is ٦٧ dB for the other generator. These values are for brand new generators ٧ meters away from the source. This distance is supposed to be the ideal distance for health safety.

In this work, it is intended to study old (used) generators to get data for the sound index in the nearby locations in order to be more realistic for the general situation and to state the actual effects. The (٥٠٠٠- model) generator has been used for more than ٢٠٠٠ hour and faced many non-professional repair and maintenance while the second generator (٢٥٠٠-model) has worked for ٧٥٠ hour under fair treatment of professional maintenance, as stated in the Following results:

١- For the (٥٠٠٠-model) generator, it is found that the maximum sound pressure level is for point C as compared to A, B and D. SPL is at maximum value at point C, which is ١٠٣ dB with load (٠ amp/hr.) as shown in Fig.٧.

٢- For the (٢٥٠٠-model) generator, the maximum sound pressure level is for point B as compared to other points. SPL is maximum at this point, which is ٩٦ dB at load (٦,٩ amp/hr) as shown in Fig.٨.

٣- From Fig. ٧, the SPL decreases while the load increases in all locations except at the exhaust for the (٥٠٠٠-model) generator. This fact is due to the effect of the mechanical noise generated by various impacts between the engine parts. There are lots of moving parts, for example, valves, and rocker arms, piston and cylinder liner. When the load increases, there will be a compressive push on these parts reducing the impact and contact clearance between parts.

٤- Fig. ٨ shows an inverse derivation for the above paragraph. The SPL values increase with load increment for the (٢٥٠٠- model) generator, and this is reasonable for unworn engines where the general noise is due to combustion activity.

٥- For both generators, the sound index range is within about ١١ dB that is (٩٢ – ١٠٣) for (٥٠٠٠-model) and (٨٦ – ٩٦) for the (٢٥٠٠-model). The minimum of these values are higher than the factory specifications by about ١٥ dB for the first and ٨ dB for the second.

٦- Tables ٤ and ٥ show the values of average SPL. These values are used in equation ٢ to find the sound power as in the following

$$P_A = SPL + 10\log_{10}\left({}^{S}/_{S_o}\right)$$

For (٥٠٠٠-model)

S_o= ab + ٢(ac + bc) = ١,٩٤٠٨ m٢, where a, b and c are length, width and height.

S= a' b' + ٢(a'c' + b'c') = ٦,١٨٤ m٢ where a', b' and c' are hypothetical length, width and height.

SPL_{av} @ ١,١ load = ٩٨,٨٤

P_A = ٩٨.٨٤ + ١٠ log١٠ (٦,١٨٤ / ١,٩٤٠٨) = ١٠٣.٨٧ watt

For (٢٥٠٠-model)

S= ٤,٥٦ m٢

S_o= ١,٤٤ m٢

SPL_{av} @ ٦,٩ load = ٩٠,٢٨

P_A = ٩٠,٢٨ + ١٠ log١٠ (٤,٥٦ / ١,٤٤) = ٩٥.٢٨٦ watt

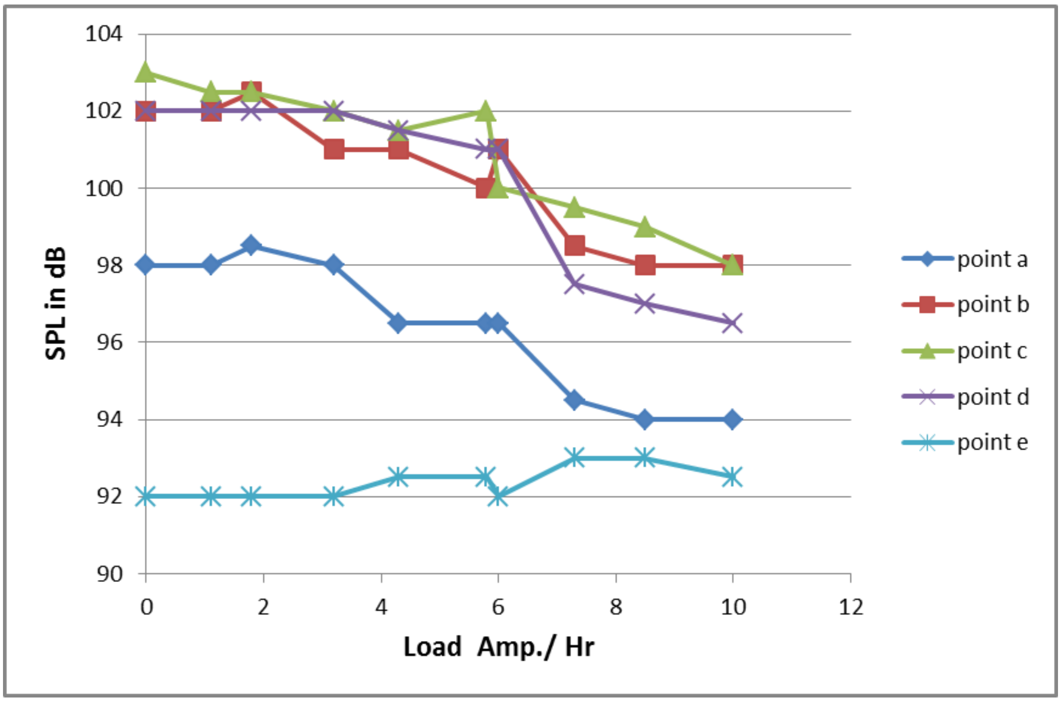

Figure ٧: SPL VS Load for ٥٠٠٠-model generator

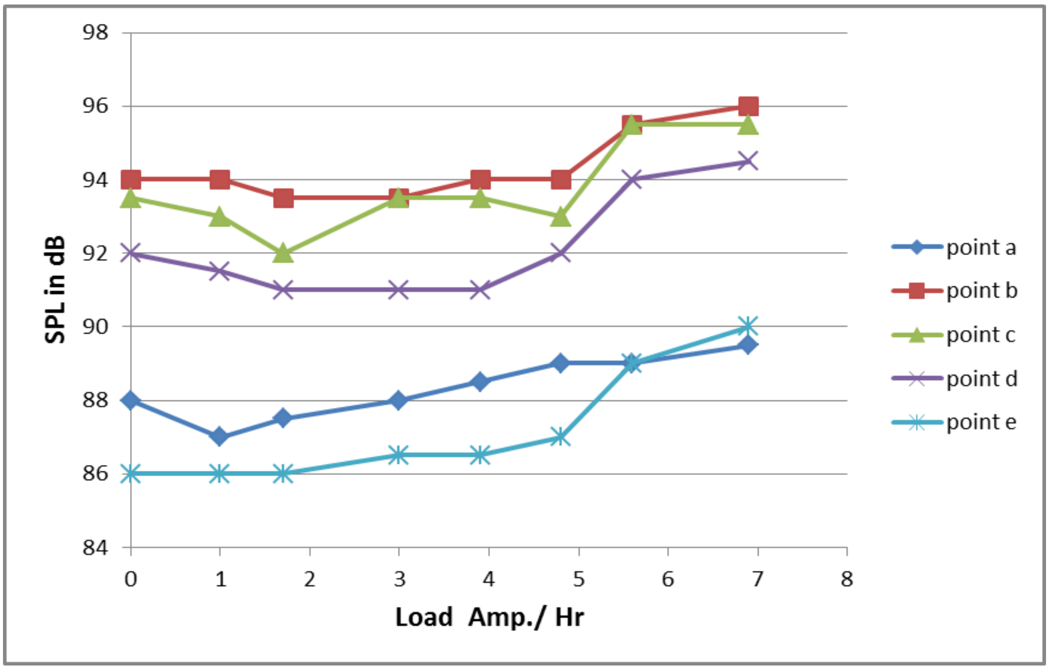

Figure ٨: SPL VS Load for ٢٥٠٠-model generator

٤. Conclusions and Recommendations

١- The study showed that there is a large difference in sound index between the brand new factory specification and the real case for used generators. There are many reasons like prescription of parts and non-regular maintenance procedures.

٢- The use of (٥٠٠٠ model) generator for loads less than ٦ (amp/hr.) has a wide effect on noise pollution in addition to fuel consumption as mentioned by Ehsan [٦]. It is recommended to use (٢٥٠٠-model) for such loads, and use the (٥٠٠٠-model) for loads greater than (٧ Amp/hr.).

٣- The maximum noise is emitted from location (C) for both generators, that is the cylinder head of the engine where the mechanical parts (valves & rockers) are placed. For this reason, it is supposed to locate the generator at the farthest side from human ear.

٤- For used generators, the frictional effect on noise index arises more in proportion to combustion effect, this fact shows the importance of expert maintenance to keep the engines near factory specifications. Otherwise, great harmful effects on human sense of hearing and other injuries may occur.

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