# MEASUREMENT STUDY OF AIRCRAFT JET ENGINE NOISE EFFECTS AND CONTROL


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**الملخص**

تعتبر ضوضاء الطائرات مصدر قلق كبير وذات مردود سلبي على أولئك الذين يعملون أو يعيشون بالقرب من المطارات مثل الطيارين، والمهندسين، والفنيين، والطلاب والمجتمعات المحيطة بالمطارات. تتناول هذه الورقة قياس الضوضاء بنظام الديسيبل (dBA) لمحرك نفاث لطائرة التدريب العسكرية نوع (Soko G2 Galeb) ذات المحرك النفاث والجناح الثابت وإقتراح بعض الوسائل للسيطرة على تأثير هذه الضوضاء على جسم الإنسان. أجريت هذه القياسات باستخدام جهاز مندفع الدقة لمستوى الصوت موديل B&K 2209 المتمركزة في الأكاديمية الجوية بمدينة مصراتة والموجودة في محطة أو أرضية الطائرات أمام مجموعة من المواقع المأهولة بالعاملين مثل سرب الطيران، مدرسة الطيران وورش الصيانة، والذي يؤدي إلى تعرضهم لمستوى عالي من الضوضاء الخطرة خلال ساعات النهار والليل. تم قياس مستوى الضجيج في المحرك النفاث بسرعات مختلفة (40٪ و60٪ من الحد الأقصى لسرعة المحرك)، بإستخدام طائرة واحدة على المحطة الأرضية في العملية. تم تحليل النتائج المتمثلة في مستويات الضوضاء مع زمن التعرض المسموح بالساعات في مواقع مختلفة من خط الطائرة المركزي ومناقشتها وعرضها على شكل مخططات. من خلال النتائج، وجد أن أعلى مستوى للضوضاء حدث عند العادم النفاث، (عند زاوية = صفر) على طول الخط المركزي لجسم الطائرة وأدنى مستوى ضوضاء حدث في زاوية 120 درجة من الخط المركزي على دائرة نصف قطرها ثابت (r) لكل سرعات المحرك على أرض الواقع. تم الحصول على إختلافات مماثلة لمستوى الضوضاء عندما تم تثبيت زاوية التعرض في دائرة مختلفة من الخط المركزي لجسم الطائرة. نوقشت بعض المقترحات للحد من تأثير الضوضاء على العاملين حول الطائرة والمباني المجاورة لتحسين وسائل الراحة والسلامة للعاملين.

**ABSTRACT**

Aircraft noise is a significant concern to those who work or live near airports; it is an issue that persists and adversely impact pilots, engineers, technicians, students and surrounding communities. This paper deals with the noise measurements in decibel A-weighting (dBA) and suggests means to control its effect for a military trainer jet engine aircraft. The measurements were carried out using the Impulsive Precision Sound Level Meter, B&K 2209. SOKO G-2 Galeb is a fixed wing military trainer jet aircraft. The aircraft was located at the air academy (Misurata city) in the aircraft station and at the maintenance workshop, where workers are exposed to hazardous noise levels during day and night. The noise level was measured at different engine speeds (40% and 60% of maximum engine speed) with one aircraft in operation on the ground station. The results, noise levels with a permissible exposure time in (hours) at different locations to the aircraft centre line were measured and discussed and presented in a form of contours for the comfort and safety of the workers. It was found that the highest noise level occurs at the jet exhaust, (zero angle) along the fuselage centre line of the Galeb aircraft and the lowest noise level occurs at an angel of 120 degree for a fixed radius (r), for both engine speeds on the ground. Similar noise level variations were obtained when the exposure angle theta, θ was fixed at different radius from the fuselage centre line of the aircraft. Suggestions to reduce the noise effect on the workers around the aircraft and buildings were discussed to improve their comfort and safety.

**KEYWORDS:** Noise Measurement; Noise Control; Aircraft, Air Academy Misurata, Sound Level Meter, Permissible Exposure Time.

## INTRODUCTION

The word noise carries the meaning of unwanted sound, disgust or discomfort. Noise pollution is generally refers to unwanted or harmful noise, such that of automobiles, airplanes, or industrial workplaces, [1]. Unlike other forms of pollution, noise does not remain long in the environment. However, its effects are immediate in the form of annoyance; they are cumulative in terms of temporary or permanent hearing loss. The loud noise can also cause other physical problems such as high blood pressure, increased or abnormal heart rate, insomnia or difficulty sleeping, [1-2].

Aircraft noise is one form of noise pollution produced by aircraft or its components, during various phases of a flight or on the ground while parked such as auxiliary power units, while taxiing, on run-up from propeller and jet exhaust. Most people who work with or near the aircraft have soundproof ear plugs, which prevent them from the deafening noise of the plane. However, people who reside near the airports or places where aircraft are serviced or repaired have to bear the brunt of aircraft noise. They are the victims of aircraft noise pollution and their suffering has no solutions. It is disturbing people because of several different factors. First, the sound may include a combination of low frequency rumble and higher-pitched from jet engines, the throbbing of helicopters, or the steady, annoying buzz of small aircraft. Second, unlike highway noise, which is generally constant and may fade into the background, each aircraft overflight is likely to be recognized as a distinct event, calling attention to itself when it interrupts speech or some other activity, [3].

The aviation noise became a public issue in the late 1960s, and governments have enacted legislative controls. Aircraft designers, manufacturers, and operators have developed quieter aircraft and better operating procedures. Researchers and doctors have talked about the harmful effects of heavy noise pollution for many years but government's bodies are just not taking it seriously. Many countries have authorized programs to insulate homes and airports and imposed night flying restrictions from 11 p.m. to 7 a.m. to reduce noise exposure at night as examples: at Heathrow, Gatwick and Stansted airports in the UK, and Frankfurt airport in Germany, [4-5]. Noise limits were specified in the A-weighted sound levels in the Occupational Safety and Health Act (OSHA) of the United State of America and the Environmental Protection Agency (EPA), also developing noise-emission standards, determining appropriate noise levels that would not infringe on public health and welfare, see [6-7]. The American Speech-Language-Hearing was also specified and classified the noise levels in Decibel, dB starting from the painful to the faint effect, [8].

Most of noise-control measures have focused on reducing the amplitude of the sound after it is produced. Reference [7] and [9] are working on a method of cutting down on noise at the source. His idea is to "fill in" the wake behind each rotor blade by pushing air through the trailing edges of the rotating blades. This recently became feasible with the advent of newer engines having fan blades that are larger than ever before at 1m to 1.5 m high. The new technique is a trend toward larger fan blades in engines.

The main aim of this paper was first to measure the noise level of the jet trainer Galeb aircraft in A-weighting decibel (dBA) at different conditions (engine speeds), distances and directions on the ground during the daytime and then to control its effect on the workers. The permissible exposure time in hours, Tp is then estimated and presented as contours for the safety and comfort of the workers working at the Air Academy (also limited international airport for the city of Misurata).

**SOUND LEVEL METER**

The sound level meter is the heart of any noise measuring program. The basic elements of a typical impulse sound level meter are: microphone, a preamplifier, special weighting network, amplifier, meter, and output terminal. Three weighting networks, A, B and C are commonly incorporated in most sound level meters. These were designed to provide a response that approximate the way in which the human ear responds to the loudness of pure tones. The B-weighting is rarely used in practice. The scale of the C-weighting is essentially linear over the frequency range of the greatest interest.

The A-weighting sound level meter has found much use in noise measurement, since it correlates reasonably well with hearing damage risk in industry and with subjective annoyance for a wide category of industrial, transportation and community noise. D-weighting was found on some sound level meters for aircraft fly-over noise. The readings obtained using these networks were designated sound levels rather than sound pressure levels with the octave filter set B&K type 1613, see Figure (1). When reporting sound level readings, the weighting employed is always indicated. For example, "77 dBA" means the A-weighting sound level is 77 dB.

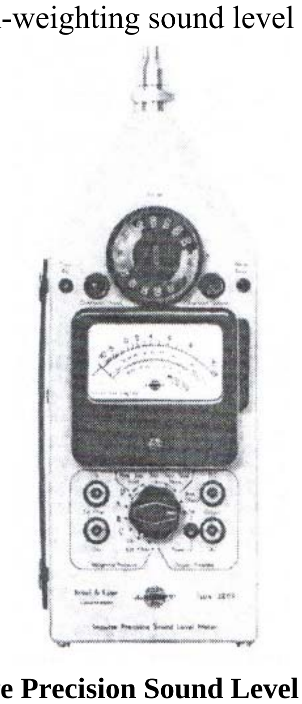


**Figure 1: Impulsive Precision Sound Level Meter, B&K 2209**

## GALEB AIRCRAFT

The outdoor noise measurements on the ground with only one aircraft in operation, was carried out on a Galeb jet engine aircraft. The maximum speed of the engine is 13800 r.p.m. The measurement was done at two different engine speeds 40% and cruise speed, 60 % of maximum engine rotations, at different distances and directions.

SOKO G-2 Galeb is was manufactured by "Moster Soko" factory of Former Yugoslavia. The aircraft was all metallic structures. The G-2A-L is an all tandem, two seat basic advanced military training aircraft fitted with a single Rolls-Royce Bristol Viper MK-22-6 turbojet engine installed in the fuselage centre line as shown in Figure (2). It was equipped with guns, rockets and bombs. The overall aircraft weight is 3988 Kg and empty weight is 2620 kg. the overall length of the aircraft is 10.34 m, 11.62 m wing span and overall height is 3.28 m, see [10].

The station of Galeb aircraft was not large and there were many aircraft on this station. Large hangar and class rooms made from concrete were used for aircraft maintenance and teaching student pilots. It was located close enough to the station by about 5 meters. Workers includes, Pilots, students, engineers and technicians and others were working in the stations and the hanger for 8 hours daily continuous and may be in the night.


**Figure 2: Galeb Aircraft**

## NOISE MEASUREMENTS AND RESULTS

Noise equipment (Impulsive Sound Level Meter, B&K 2209) was calibrated and noise measurements were then taken when one aircraft was in operation and the measuring points were at different distances and orientations from the aircraft centre line. Noise level was measured at the workers ear position using the A-weighting network in many positions at 40% idling engine speed and 60% cruise engine speed. Sample of the noise level readings and effective decibels were estimated for different locations using the method of Combined Octave-Band Levels by successive pairs presented in [2-3], Figures (3-4), and presented in Tables (1-7) and (8-9) respectively for completeness. All effective noise levels in dBA of both engine speeds with the permissible exposure time in hours, Tp at different locations were plotted in Figures (5-6) as contours around the Galeb aircraft for the safety and comfort of the workers.

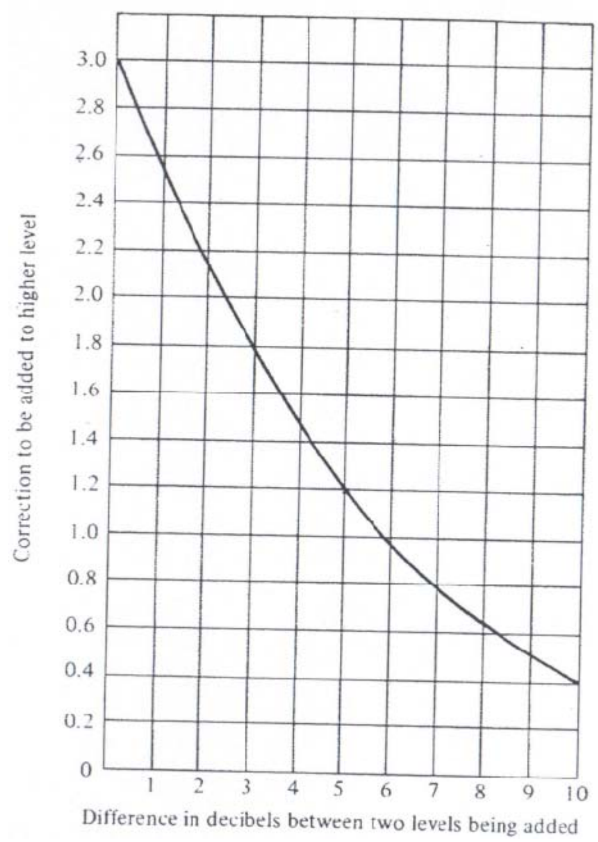



**Figure 3: Adding levels, [2]**

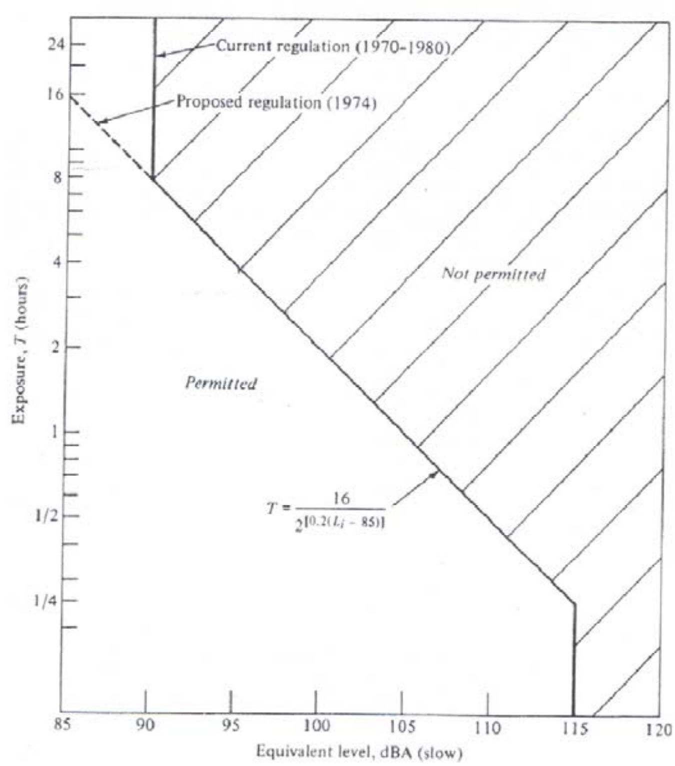



**Figure 4: Allowed exposure for continuous level, (OSHA), [2].**

**Table 1: Noise level at 10.6 m from the aircraft engine exhaust.**

| Engine speed | Octave band centre frequency (Hz) | Noise level (dBA) |
|---|---|---|
| Idling speed 40 % r.p.m | 31.5 | 76 |
| | 63 | 82 |
| | 125 | 75 |
| | 250 | 83 |
| | 500 | 76 |
| | 1000 | 80 |
| | 2000 | 81 |
| | 4000 | 84 |
| | 8000 | 76 |
| | 16000 | 82 |
| | 31500 | 79 |

**Table 2: Noise level at 15.0 m from the aircraft engine exhaust**

| Engine speed | Octave band centre frequency (Hz) | Noise level (dBA) |
|---|---|---|
| Idling speed 40 % r.p.m | 31.5 | 75 |
| | 63 | 80 |
| | 125 | 72 |
| | 250 | 80 |
| | 500 | 73 |
| | 1000 | 78 |
| | 2000 | 80 |
| | 4000 | 75 |
| | 8000 | 75 |
| | 16000 | 80 |
| | 31500 | 78 |

**Table 3: Noise level at 5.80 m from the aircraft nose**

| Engine speed | Octave band centre frequency (Hz) | Noise level (dBA) |
|---|---|---|
| Idling speed 40 % r.p.m | 31.5 | 84 |
| | 63 | 84 |
| | 125 | 84 |
| | 250 | 84 |
| | 500 | 84 |
| | 1000 | 84 |
| | 2000 | 84 |
| | 4000 | 84 |
| | 8000 | 84 |
| | 16000 | 84 |
| | 31500 | 84 |

**Table 4: Noise level at 10.60 m from the aircraft nose**

| Engine speed | Octave band centre frequency (Hz) | Noise level (dBA) |
|---|---|---|
| Idling speed 40 % r.p.m | 31.5 | 79 |
| | 63 | 79 |
| | 125 | 79 |
| | 250 | 79 |
| | 500 | 79 |
| | 1000 | 79 |
| | 2000 | 79 |
| | 4000 | 79 |
| | 8000 | 79 |
| | 16000 | 79 |
| | 31500 | 79 |

**Table 5: Noise level at 15.0 m on the right side with $60^o$ from the aircraft centre line**

| Engine speed | Octave band centre frequency (Hz) | Noise level (dBA) |
|---|---|---|
| Idling speed<br>40 % r.p.m | 31.5 | 64 |
| | 63 | 64 |
| | 125 | 64 |
| | 250 | 64 |
| | 500 | 64 |
| | 1000 | 64 |
| | 2000 | 65 |
| | 4000 | 64 |
| | 8000 | 64 |
| | 16000 | 64 |
| | 31500 | 65 |

**Table 6: Noise level at 15.0 m from the aircraft nose**

| Engine speed | Octave band centre frequency (Hz) | Noise level (dBA) |
|---|---|---|
| Idling speed<br>60 % r.p.m | 31.5 | 85 |
| | 63 | 85 |
| | 125 | 85 |
| | 250 | 85 |
| | 500 | 85 |
| | 1000 | 85 |
| | 2000 | 85 |
| | 4000 | 85 |
| | 8000 | 85 |
| | 16000 | 85 |
| | 31500 | 85 |

**Table 7: Noise level at 5.80 m on the right side with $120^o$ from the aircraft centre line**

| Engine speed | Octave band centre frequency (Hz) | Noise level (dBA) |
|---|---|---|
| Idling speed<br>60 % r.p.m | 31.5 | 84 |
| | 63 | 84 |
| | 125 | 84 |
| | 250 | 84 |
| | 500 | 84 |
| | 1000 | 84 |
| | 2000 | 84 |
| | 4000 | 84 |
| | 8000 | 84 |
| | 16000 | 84 |
| | 31500 | 84 |

**Table 8: Effective dBA at 10.60 m from the exhaust, 40% rpm**

<table>
<tr><th colspan="12">Centre frequency (Hz)</th></tr>
<tr><td></td><td>31.5</td><td>63</td><td>125</td><td>250</td><td>500</td><td>1000</td><td>2000</td><td>4000</td><td>8000</td><td>16000</td><td>31500</td></tr>
<tr><td>Band level</td><td>76</td><td>82</td><td>75</td><td>83</td><td>76</td><td>80</td><td>81</td><td>84</td><td>76</td><td>82</td><td>79</td></tr>
<tr><td>Step 1*</td><td colspan="2">83</td><td colspan="2">83.65</td><td colspan="2">81.5</td><td colspan="2">85.8</td><td colspan="2">83</td><td>79</td></tr>
<tr><td>Step 2*</td><td colspan="4">86.35</td><td colspan="4">87.1</td><td colspan="3">84.5</td></tr>
<tr><td>Step 3*</td><td colspan="4">86.35</td><td colspan="7">88.8</td></tr>
<tr><td>Combined</td><td colspan="11">90.8 dBA</td></tr>
</table>

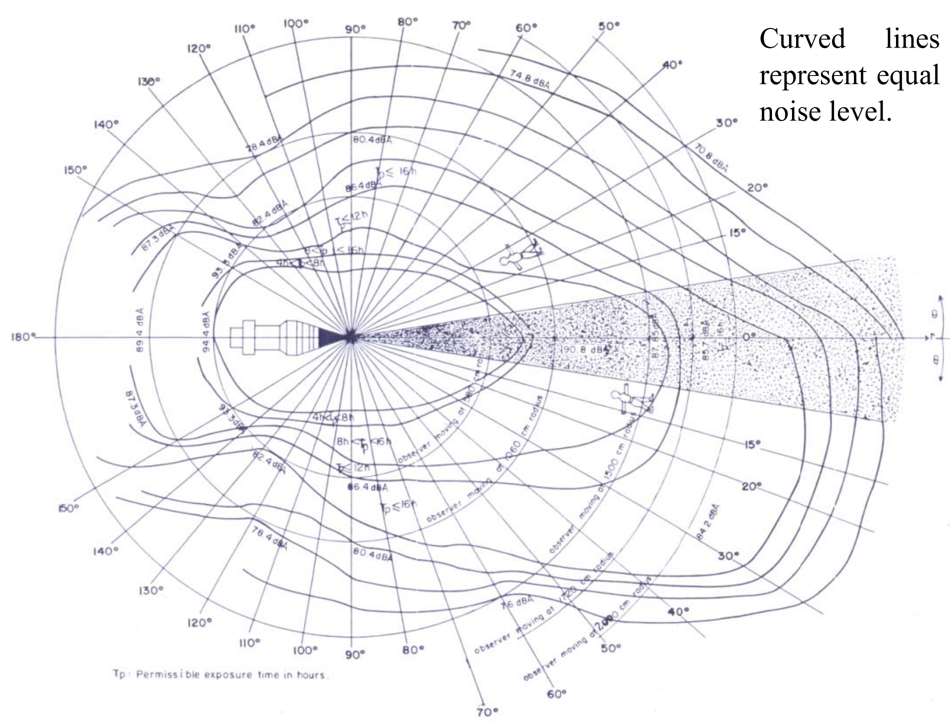
**Table 9: Effective dBA at 15. 0 m from the exhaust, 40% rpm**

| | Centre frequency (Hz) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 31.5 | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 | 16000 | 31500 |
| **Band level** | 75 | 80 | 72 | 80 | 73 | 78 | 80 | 75 | 75 | 80 | 78 |
| **Step 1*** | 81.2 | | 80.65 | | 79.2 | | 80.2 | | 80.2 | | 78 |
| **Step 2*** | 84.00 | | | | 82.8 | | | | 82.2 | | |
| **Step 3*** | 84.00 | | | | 85.55 | | | | | | |
| **Combined** | 87.85 dBA | | | | | | | | | | |

## DISCUSSION OF RESULTS

Tables (1-5) refer to the samples of measured noise level of the Galeb aircraft at 40% of the engine maximum speed (5520 rpm). This is the idling speed of the engine on the ground. The workers are exposed to this speed most of the time on the ground. That is why this speed is very important to be considered. From the tables, it can be seen that the noise level near the exhaust of the engine changes with increase of frequency. This is due to the uneven burning in the combustion chamber and to the wind velocity. However, this variation should not affect the analysis. The noise level at various points near the sides and the nose of the aircraft was constant due to the conditions of both compressor and turbine was not changed at a particular speed and steady state was everywhere.

Figures (5-6) show the relation between the radial distance r from the jet to the moving observer and the angle θ from the line of the fuselage reference. At the nozzle $\theta=0^o$ and at the nose $\theta=180^o$, please refer to Figures (5-6). Permissible exposure time is computed using Figure (4) shown above using method recommended by [2].




Curved lines represent equal noise level.

**Figure 5: Noise field from a jet engine aircraft at idling engine speed (40% r.p.m).**

It can be seen from Figures (5-6) that the highest noise level occurs at the jet exhaust ($\theta = 0^o$) along the fuselage centre line of the Galeb aircraft and the lowest noise level occurs at $\theta = 120^o$ for a fixed radius (r), for both engine speeds on the ground.

Similar noise level variations were obtained when the exposure angle, θ was fixed at different radius from the fuselage centre line of the aircraft.

The permissible exposure time, Tp was shown at each noise level for safety and comfort of the worker around the Galeb aircraft. The obtained noise readings were only for one aircraft in operation and this will be changed accordingly if more than one aircraft in operation and as a result, the noise level will be higher and the permitted time will be less. It also clear from Figures (5-6) to conclude that the higher the engine speed, the higher noise level.

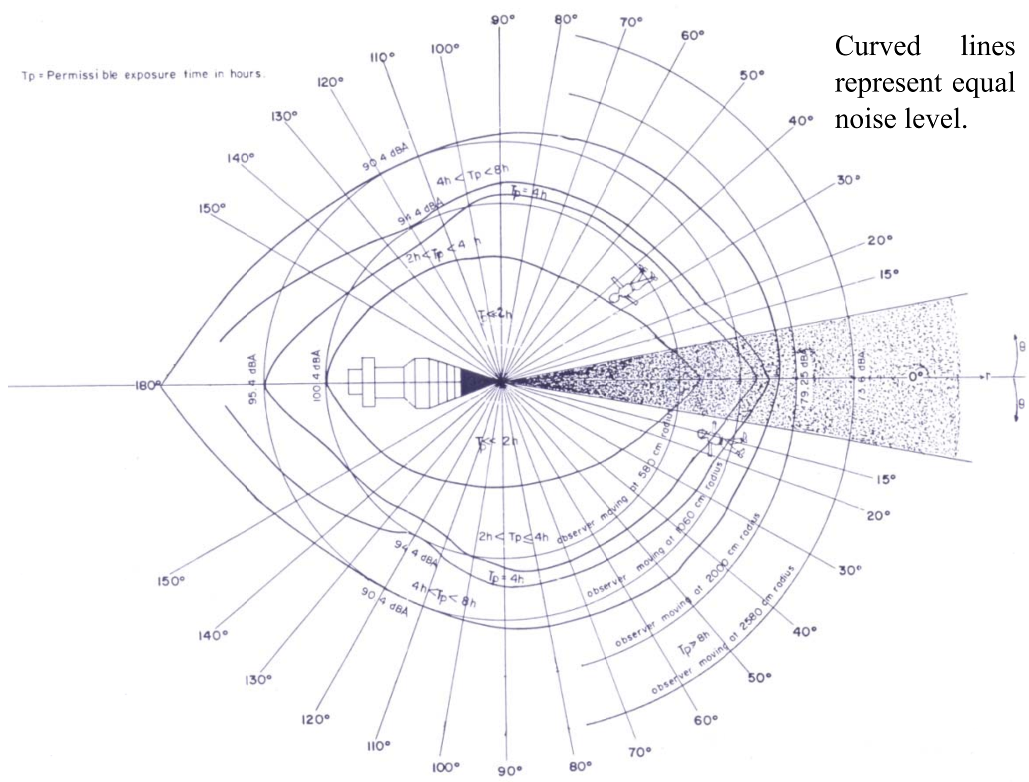



**Figure 6: Noise field from a jet engine of Galeb aircraft at engine speed (60% r.p.m).**

## SUGGESTIONS AND IMPROVEMENTS

When more than one aircraft are operating at the same time, the noise level will increase and will cause annoyance, hearing loss, speech interference to others. There were class rooms for the students and technicians close enough to the aircraft station.

Some suggestions regarding the reduction of noise effect on the workers around the aircraft and in the building to improve the comfort and safety to the workers are presented. The suggestions listed below should minimize the effect of noise on the workers in a low cost manner without changing the noise source (expensive):

- The distance between the workshop (hanger and class rooms) and the aircraft station (noise source) should be increased. Putting or growing belts of trees between the noise source and the receivers will also reduce noise level.
- Area of the aircraft station should be increased to make large space between one aircraft and another.

- Providing proper design of the building structures, taking into account the use of sound absorbent materials, such as sound walls and curtains.
- Enclose or isolate the noise source in the case of engine tests in the workshop.
- Limiting the amount of permitted exposure time, Tp in hours to the higher noise levels for the workers as shown in Figures (5-6).
- Providing all the accessories for eliminating higher noise level such as headphones, earmuffs and plugs to the workers.
- Replacement of the old engines or aircrafts with new lower noise levels one, which is very expensive and may be avoided.

## CONCLUSIONS

Noise measurements and controlling its effect on workers were carried out successfully on Galeb trainer jet aircraft at aircraft station. The study was made when one aircraft was in operation at two engine speeds 40% and 60% of the maximum engine R.P.M. Permissible exposure time to noise, Tp in (hours) was obtained using the graph provided by OSHA, in which we conclude that all workers must not exceeded this time for their health and safety.

The highest noise level was found at zero angle (jet exhaust) in which it is advised that all workers to avoid this location and stick only to the time allowed to stay, whereas the lowest noise was found at $\theta = 120^o$ from the fuselage centre line.

Some suggestions were addressed in this work to be taken in considerations to reduce the effect of noise level in the outdoor and indoor areas for the comfort and safety of the workers.

## ACKNOWLEDGMENT

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