The Noise Associated With Model Aircraft.

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Introduction.

The sport of model aircraft flying has been with us for many years. Indeed, Leonardo da Vinci, (a.d. 1452-1519), drew numerous sketches of futuristic flying machines. G.B. Danti, an Italian scholar, tried to fly with home made wings at Perugia in 1503 and was lucky to survive the attempt. The best known legend of all is that of Daedalus, the engineer who built the labyrinth on the Island of Crete in which the Minotaur lived. With his son Icarus, he was imprisoned by King Minos, but the prisoners escaped by making themselves wings of wax and feathers. With these Daedalus flew successfully all the way to Naples, but Icarus, excited by the thrill of the new experience of flying, let his youthful exuberance deafen him to his fathers' warning and flew too near to the sun, which melted the wax and sent Icarus crashing to his death in the sea below. Today however, modern technology has made the dream of flying a reality.

"The difference between men and boys is the price of the toys" is a quotation I have heard many times over the years and it's no wonder that aeromodellers guard their hobby jealously. (Typical cost of model, engine and radio gear approx., £600).

The sport of aeromodelling as we know it today, really began around the 1930's. The kitchen table was the modellers bench and any scrap piece of balsa wood, spare length of string was used and improvised upon by many a resourceful modeller.

The model flying club to which I belong is the Luton and District Model Aeronautical Society, founded in 1932 and has approximately 100 members who fly regularly from their own 5 acre purpose built site in Offley, Herts., complete with club house, electricity generator, tractor and gang-mower. There are at least 150 model flying clubs existing that I know of and aeromodelling is a rapidly growing sport in this country.

Since the 1950's materials technology has advanced in leaps and bounds and with most modern model aircraft today, one would be hard pressed to find a piece of balsa wood anywhere in the aircraft's structure. Most of the radio electronics is of Japanese origin, so to are the engines and recently, we have seen the introduction of the first miniature gas-turbine 'jet' engine for commercial production for use in a model aircraft. Very noisy indeed!

But aeromodellers are not oblivious to the sensitivity of others and for many years have been striving to reduce the noise emitted from their 'prides of joy'. Many hours have been spent burning the midnight oil not only to perfect the aerodynamics of the model, but also to find the many subtle ways of reducing the noise.

To date, very little research work has been published on noise from model aircraft, most people relying on word of mouth advice and their own experiences to tackle noise reduction techniques and as for official guidance, only one document has so far been published, that's the 1982 'Code of Practice on Noise from Model Aircraft'[1]. This COP suggests that noise measurements should be made using instrumentation complying to BS:5969(IEC:651)[2], type 1, set to 'A' weighting, 'slow' time weighting, and at a 7 metre(21 ft.) distance from the model and that the noise level should not exceed 82dB(A), taken from 4 readings with a muffler (silencer) fitted. (Readings to be taken fore, aft, port and starboard positions of the model and the model should be held between 1 and 2 metres (3-6 ft.) above the ground with the engine running at maximum revs).

There is some advice contained in the COP on methods of reducing noise levels, but this is rather limited, being mainly subjective, at best fit a silencer, at worst try to experiment!

The primary objective of this paper is to provide a fairly comprehensive while not too in-depth understanding of the nature, causes and cures of noise from model aircraft and to form a basis from which further study can be made. There has been a lack of published material on the subject of model aircraft noise and this paper also attempts to redress that balance, being the first of a series of papers investigating not only the physical nature of the noise, but also the human response to model aircraft noise.

Objective or Subjective?

There are two distinct areas where noise has to be addressed. One, is the noise source itself i.e., the model aircraft and the risk of noise induced deafness to the operator of the model aircraft and nearby onlookers and two, is the annoyance of the model aircraft noise to the local population, especially if two or more models are flown together. The perceived increase in noise level is generally proportional to the number of model aircraft in the air. Two models twice as much noise, three models three times as much noise.

Model aircraft are usually powered by miniature internal combustion engines and due to their small size, these engines produce very high noise levels, predominantly in the low to mid frequencies and it's the varying levels and the perceived 'high frequency' noise that's the most annoying. Manufacturers of these engines have made some attempts to produce quieter engines by making four-stroke engines instead of the more widely used two-stroke variety, but in the beginning, these were relatively underpowered and the quest to increase power has brought with it increasing rpm and consequently, higher noise levels.

When a complaint is received, the Local Authority has a statutory duty to investigate and invariably chooses to make an assessment using the BS 4142:1990 Method for "Rating Industrial Noise Affecting Mixed Residential and Industrial Areas"[3], which in my opinion is incorrectly chosen because there is nothing else available or suitable. Additionally, BS:4142 assessments are made on premises with fixed noise sources, but due to the nature of model aircraft flying, the noise sources involved are mobile which will give a temporal structure that's entirely different to that expected in BS:4142.

Hearing Damage Risk.

The area to be tackled first will be concerning the risk of noise induced deafness to the operator and possibly nearby onlookers. The first step was to measure the noise levels at the operators ear position and to save considerable time, the octave band spectra information was also gathered simultaneously, so that the correct type of ear protectors could be specified, if and when necessary.

This first step would be simply achieved by using a RION NA-29E Precision Sound Level Meter and Real Time Octave Band Analyser, this instrument giving 'A' weighted Leq in each octave band, (31.5Hz-8kHz including ALL-PASS) and then stored in nonvolatile memory. Leq is the 'equivalent continuous noise level', which simply put means an energy average over a given time period. So for each individual club member, a unique octave band spectra for that combination of model, engine and modeller was kept permanently in club records which would be available for inspection at any time. This information proving to be useful not only for the current combination in use, but also for comparison with future changes to the model/engine combination, prop size, etc.,. The first stage in the measurement procedure was to make an assessment of the noise exposure to the individual operators of the model aircraft to ascertain the actual noise levels that they were being subjected to; knowingly or otherwise! This was done because of the current H.S.E Noise at Work Regulations 1989 [4]. If any of the club members worked in a noisy industry, then the model aircraft noise could actually be adding to the daily dose received during their day at work. This could possibly bring them towards or above the first or second action levels as described in the regulations. The danger here could be the individual receiving an $L_{EP,d}$ of greater than 85dB(A) (first action level), or 90dB(A) (second action level). If this were the case then the use of hearing protectors, (of a suitable type), would be strongly advised.

So, the microphone was placed at the operators ear positions whilst the engine was being started, run and warmed up. Both left and right ears were monitored and the fast, 'A' weighted Leq measured. As fig.1 shows, these levels were quite high, in the region of 90-100dB(A), mainly in the mid to high frequencies, with the ear positions being about 12-15 inches away from the noise source.

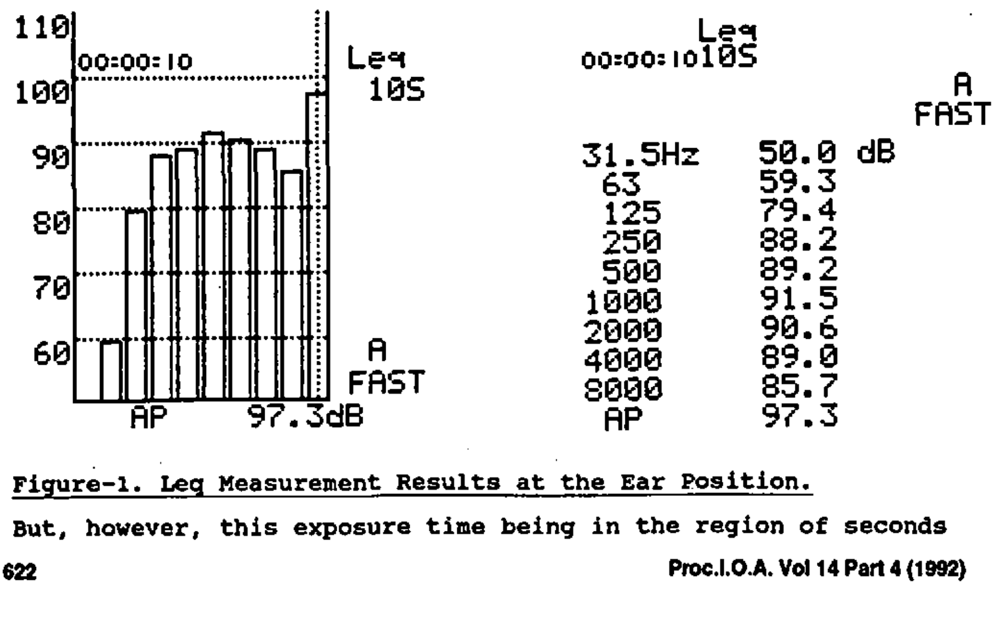
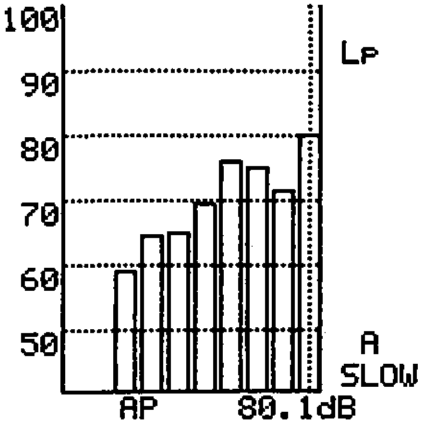


Figure-1. Leq Measurement Results at the Ear Position.

But, however, this exposure time being in the region of seconds rather than minutes or hours. The worst case scenario would be when the engine needed adjusting or tachometer readings were required, then total exposure time would be in the region of 4 to 5 minutes.

Included with the above Leq information, are the measurement levels taken according to the procedure in the 'Code of Practice on Noise from Model Aircraft 1982'[1]. These being recorded as a complete octave band spectra. See figure 2.



LP

A SLOW

31.5Hz	40.0 dB
63	40.0
125	58.8
250	64.5
500	64.8
1000	69.6
2000	76.0
4000	74.9
8000	71.3
AP	80.1

Figure-2. Sound Pressure Level Data According to the COP.

With the previous octave band spectra information and these noise exposure figures, the individual operators could be informed about their models noise performance and given appropriate advice concerning the correct type of hearing protection that they should use if necessary.

The next stage would be a bit more time consuming to say the least, due to the nature of the noise source components and more importantly, trying to perform the diagnostic noise tests without annoying my fellow aeromodellers too much!

Diagnosis, Reduction and Isolation.

So how do we go about reducing the noise from the model. The best way is to reduce the noise at source. At first sight, it appears that there is only one noise source, the engine itself, but, is there only one source, or are there multiple noise sources? What needs to be done is to diagnose in detail the noise emanating from the model aircraft. We need to discover the noise generating mechanisms involved, the transmission paths of each individual noise source and if it is obvious that there is more than one, then, we need to tackle the most dominant noise source first. Once this has been done, we can then begin the work of noise reduction which will work and be cost-effective.

The diagnostic techniques used involve:

1) Frequency Analysis (Narrow Band and Octave Band).

2) Altering Operating Characteristics (e.g., Change Prop size, Pitch, etc.,).

3) Aural Sensation (listening for changes in the character of the noise).

The initial requirement was detailed information on the frequency content of the noise source to try to enable isolation of any major contributory noise sources. But, however, the plethora of octave and third octave band sound level meters, dataloggers, etc., currently available would be inadequate and very time consuming. Real-Time Narrow-Band Analysis was obviously order of the day and consequently, the handheld RION SA-77 FFT Signal Analyser was chosen to permit quick and accurate diagnosis of the noise source involved. For narrow band diagnostics a frequency resolution of 1Hz would be sufficient to isolate any tonal components of the noise.

The first series of tests was conducted using my own model, an aerobatic type with a wingspan of 5 ft. 6 ins and powered by an O.S.70, 0.70 cu.in capacity, 4-stroke engine, turning a 12 inch dia x 10.5 inch pitch propeller, the model being called a "SAPHIR SPORT 40". For convenience, the measurement method adopted for diagnostic purposes would be in accordance with the F.A.I. rules (FAI-Federation Aeronautique Internationale) the French based organization responsible for the European activities of model flying including competitions, safety, noise, etc., which measures noise at a distance of 1 metre.(3 ft.)

The first noise test, using the SA-77, was made to determine the frequency spectra of the overall noise content of the model, this would enable a base to be established from which subsequent analysis could be compared.

Figure 3 shows the narrow-band noise spectra, from 3Hz to 2kHz for the SAPHIR 40, clearly showing the 'peaks' at 80Hz, 160Hz, 320Hz, 480Hz and 640Hz frequencies. From this we can see the very high levels at the low to mid frequencies and this suggests that initially, there indeed may be multiple noise sources involved.

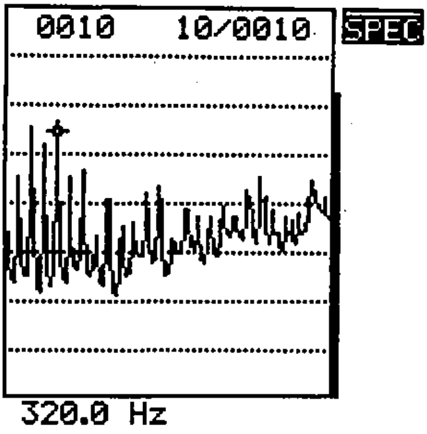


Figure-3. Narrowband Noise Spectra of Model. (3Hz-2kHz).

The first, being the most dominant (320Hz), was looked at and traced to the propeller and its blade passing frequency. The engines revolutions were measured to be 9600 rpm, therefore, the blade passing frequency is calculated using the following formula:

$$\frac{RPM \times N}{60} \text{ Hz}$$

RPM = Rotational Speed of Engine

N = Number of Blades of Prop

i.e. $$\frac{9600 \times 2}{60} = 320 \text{ Hz}$$

Using the above formula, the blade passing frequency was calculated to be 320Hz, which coincides with the 'peak' at 320Hz on the spectra shown in figure 4. But, however, to prove that this was a dominant noise source, it would have to be isolated. This would be accomplished using experience from my other branch of modelling, 'power boats'. It was not feasible to just take the

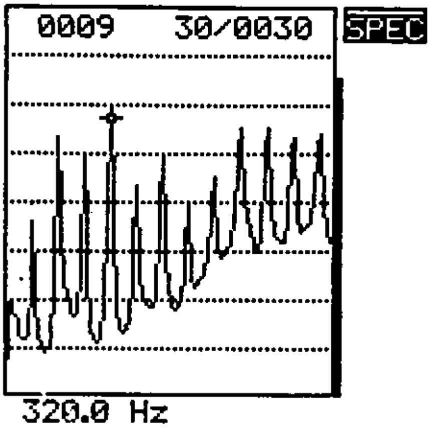


Figure-4. Noise Spectrum Showing Peak at 320Hz.

propeller off and start the engine to see what difference this would make to the noise spectrum and overall noise level, because this would eventually destroy the engine. A 'load' would be needed on the engine without the prop tearing through the air and this was achieved using a 'flywheel' from a marine water-cooled engine in place of the propeller.

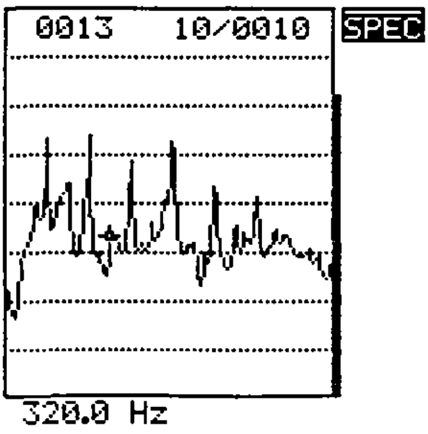


Figure-5. Noise Spectra With Flywheel Fitted.

This would provide the load necessary to keep the engine turning over without overheating and seizing up, but eliminate the 2 blades of the propeller actually passing through the air. The engine was again started and a frequency spectra measurement taken. As can be seen from fig 5, the difference is considerable. The level at the blade passing frequency (320Hz), has dropped significantly, by as much as 15dB, so suggesting something had to be done with the propeller. Increasing the diameter, hence the mass, would slow the engine down, so the original 12 inch diameter prop was replaced with a 14 inch diameter one, cut down to 13 inches and another measurement taken. Looking at figure 6a (without larger propeller), and figure-6b (with larger propeller), shows the difference in noise level. Although it can clearly be seen that the level is lower, however, this would not be sufficient.

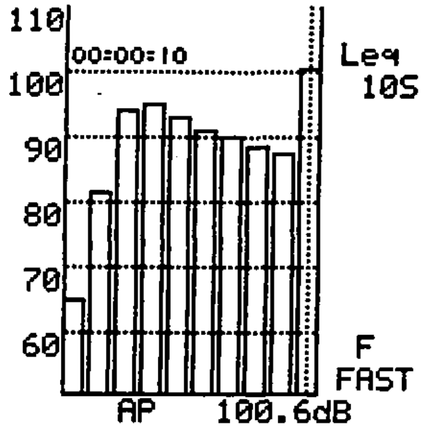


figure-6a.

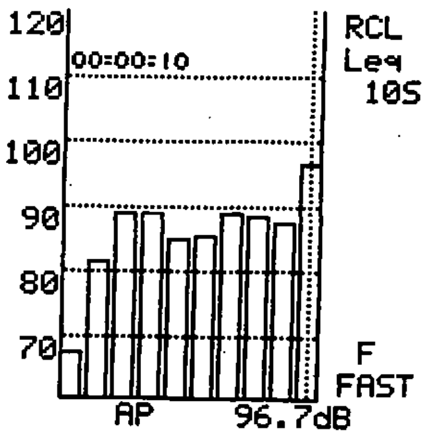


Figure-6b.

Figure-6a and 6b. Octave Band Noise Levels Without and With Larger Propeller fitted.

There seemed little scope left on the engine itself, I looked at carburettor intake noise, but this seemed insignificant compared to the propeller noise, also mechanical noise was considered, but this too seemed inappropriate. There was one other potential source of noise, vibration induced noise. The method involved here would be 'vibration isolation', in other words, isolating the engine from the airframe. Looking at the way the engine is fastened to the model reveals the engines' crankcase bolted solidly to the engine mount. This in turn was rigidly bolted directly to the airframe. The engine of course needed to be solidly mounted for rigidity reasons, but the engine mount itself was a different 'kettle of fish'.

To complement the previous measurement results, realtime vibration analysis was undertaken, using a lightweight, hand-held vibration analyser. In this case a RION VA-10 FFT Vibration Analyser, chosen for speed of analysis. A RION PV-85 accelerometer was chosen with a sensitivity of 65mV/G, with a frequency range of 1Hz to 7kHz and this was attached to the model. The direction of vibration measured was the vertical direction, (x-axis). The actual point of attachment chosen was just behind the engine cowling, on the top surface of the fuselage and the method of attachment of the accelerometer being cyanoacrylate adhesive, more commonly known as 'superglue'. The VA-10 Vibration Analyser was initially set up to measure in the 'vibration meter' mode which would give direct vibration levels in terms of rms acceleration, in m/s^2. Pressing the 'spectrum' button, the narrowband spectra, in this instance from 3Hz to 1kHz, would be displayed giving that vital frequency information. Figure 7 shows the vibration spectra from 3Hz to 1kHz and the most dominant peak can be seen at 320Hz.

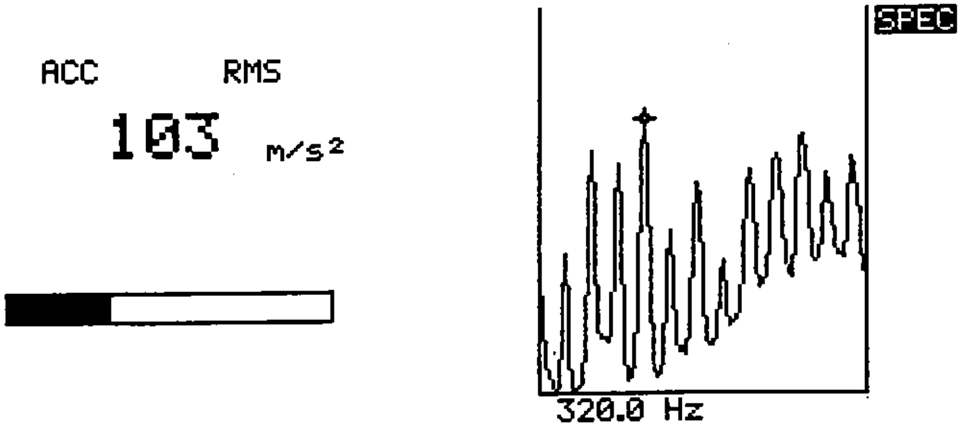


Fig-7. Vibration Level and Spectra Using PV-85 Accelerometer.

The engine was again started and the vibration level monitored The measured acceleration level of 103 m/s^2 rms is very high, considering that this is only a 'model' aircraft and it is interesting to note at this point the significant number of harmonics present in the spectra. This suggests that all the vibration from the engine is being transmitted directly to the model through the engine, engine mounting, bulkhead and through to the fuselage, to be radiated throughout the rest of the model, i.e., wings, tailplane, fin, etc.. By comparing this vibration spectra in figure 7 with that of the noise spectra shown in figure 4, this would suggest strongly that due to the coinciding peaks at 80Hz, 160Hz, 320Hz, 480Hz and 640Hz with that of the noise spectra, most of the noise was attributable to vibration. In addition to the main components of the airframe, the subsidiary components, i.e., ailerons, elevators, rudder, flaps if any, would also contribute to the overall noise levels and possibly in some extreme cases causing the component part to fall into resonance and fail mechanically.

So the diagnostics have been completed, next would be isolation to achieve, hopefully reduction. Again with the help of my boating experience the retaining bolts holding the engine and engine mount combination to the main firewall, were replaced with rubber mounts and with the silencer isolated from the fuselage, in the same way using rubber mounts, then this should give the vibration isolation we are looking for.

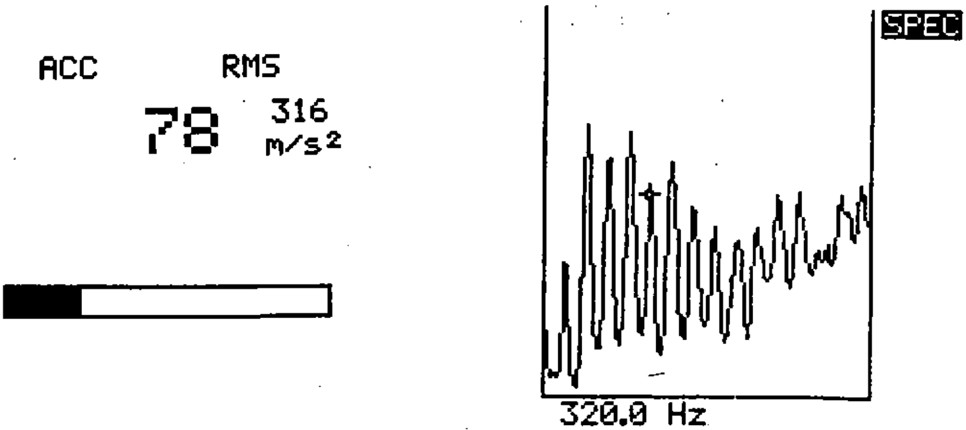


Figure-8. Vibration Level and Spectra With Rubber Mounts Fitted.

With this exercise completed the engine was again fired up and the vibration level and spectra measured. Looking at figure 8, vibration level and spectra respectively, shows the net results of this exercise. The overall vibration level has dropped, suggesting that indeed, we have somewhat successfully isolated the engine from the airframe and by studying the noise spectra diagram in figure 9, the overall levels show a significant drop.

To confirm these figures a quick check of octave band noise levels was made and the results of this are shown in figure 10.

By comparing this measurement result with the spectra in figure-2, shows that a difference of approximately 5dB has been achieved. This is by no means the be all and end all, but It does demonstrate that with a simple modification like the rubber mounts exercise a significant reduction in noise levels can be achieved simply and easily.

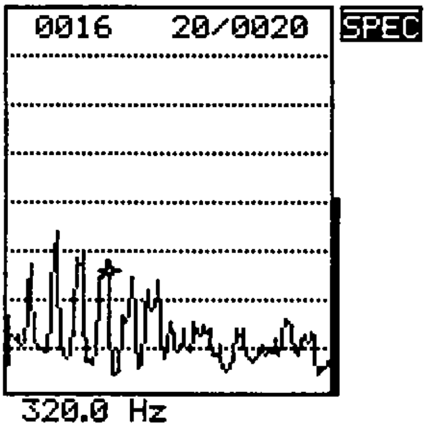


Figure-9. Final Noise Spectra Showing Lower Overall Levels.

The perceived reduction in noise level was unanimously agreed to be in the region of 'half' as loud as before by club members.

LP

A
SLOW

31.5Hz	30.0 dB
63	38.3
125	58.5
250	66.6
500	57.9
1000	61.4
2000	68.5
4000	71.0
8000	68.8
AP	75.4

Figure-10. Final Noise level Measurement Results.

Conclusions.

It would appear from the foregoing results that a single modification or treatment is insufficient and that a number of modifications are required to significantly reduce the overall noise levels. The perceived noise reduction by the general public would have to be in the region of 10dB which is by no means an easy task. In addition, a majority of lay people were surprised to find that by halving the energy content of a noise signal the reduction in overall noise level would only be 3dB.

It was also important to note that for every doubling of distance from the noise source there would be a drop of only 6dB so, therefore, advising modellers to fly their models as far away from the noise sensitive areas as possible seemed like a good idea. Also the noise heard in the air is not necessarily the same as that heard on the ground.

The major contributory factor to the noise from model aircraft would seem to come from vibration induced noise and models with polystyrene foam wings, as opposed to the built-up with tissue and dope variety, are better at providing damping and reducing resonance in the structure. In other words, models with foam wings are quieter!

Although prop noise was a contribution, it was not as much as expected. Increasing the mass of the prop would indeed slow the engine down but this would have the effect of reducing the power output of the engine and consequently, may cause the model to be underpowered, making it difficult to fly and possibly dangerous.

Finally the diagnostics, isolation and reduction exercises carried out with my own model, indicated that the same 'treatment' could be applied to other types of models, regardless of size of model/engine combination and that the largest contributory factor to the overall noise level was indeed vibration.

References.

Code of Practice on Noise from Model Aircraft 1982. D.O.E.[1].

BS 5969:1981(IEC 651:1979) Specification for Sound Level Meters.[2].

BS 4142:1990 Method for Rating Industrial Noise Affecting Mixed Residential and Industrial Areas.[3].

Noise at Work Regulations 1989, HMSO, London.[4].

Acknowledgements.

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