Journal of Mechanical Engineering

An International Journal

Volume 12 No. 2 December 2015 / ISSN 1823-5514

JOURNAL OF MECHANICAL ENGINEERING

An International Journal

Journal of Mechanical Engineering (ISSN 1823-5514) is published by the Faculty of Mechanical Engineering (FKM) and UiTM Press, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.

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An International Journal

Vol. 12 No. 2	December 2015	ISSN 1823-5514

Computer Aided Engineering Approach to the Development of a Lawnmower Blade: A Reverse Engineering Application to Reduce Noise Levels

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ABSTRACT

Engineering seeks to improve the quality of life taking into consideration factors of safety and environment amongst others. The use of the lawnmower in landscape maintenance is quite common throughout various parts of the world with significant noise generated during its operation. This study seeks to develop a blade design via Computer Aided Engineering (CAE) that will reduce the noise intensity of the lawnmower while in use; thereby, reducing discomfort to the user and environs. The design of the blade was developed by utilization of engineering techniques such as reverse engineering (RE) and re-engineering (ReE) of an actual blade, coupled with computer aided design (CAD), for simulation of performance prior to the production of a prototype. The results of design simulation as well as from physical testing of the prototype were compared to determine the success of the CAE approach based on variations of both test results.

The various procedures, from RE of the lawnmower blade and simulation of its improved design via CAD to the physical experimentation, proved that CAE was effective, since the prototype developed yielded a decrease in noise intensity when compared to the original lawnmower blade. Therefore, this study demonstrates the use of CAD and CAE in the development and enhancement of the blade design, as an effective approach, towards the improvement of quality of life based on reduced noise intensity.

Keywords: *Computer Aided Engineering (CAE), Computer Aided Design (CAD), Re-Engineering (ReE), Reverse Engineering (RE), Rapid Product Development (RpD)*

Introduction

Lawnmowers are widely used both domestically and commercially; however, noise emanating from consumer products can be very disturbing to the user as well as others occupying its vicinity. Developments such as solar powered lawnmowers are therefore currently being introduced as environmentally friendly alternatives to traditional gas powered lawnmowers. The developments made thus far however; with several prototypes built and two models commercially available on the market, have not had any significant impact on the reduction of noise pollution locally owing to their high costs and unavailability [1].

In 1961, an expert in grasses and lawns, C. B. Mills in relation to mowers stated "Today, if all of them in a single neighbourhood were started at once, the racket would be heard around the world" [2]. Research has identified that the major contributors to noise in rotary mowers are the blade and motor, but can also be generated by the radiation of vibrations through the deck, safety guards and loose parts [3].

Modifications to lawnmower blades are actively being sought in an effort to reduce noise. The design characteristics of the lawnmower blade were re-engineered by means of CAE to determine the effect of sharpening the leading and trailing edges. It has been shown that up to 5 inches of sharpening has an impact on reducing the noise level; as well as reducing the blade speed and using thinner and narrower blades [3]. It has been noted however; often times a trial and error method is used that results in numerous designs and time wastage [4].

It is for this reason, that a CAE approach is being soughtas the motivation for this study. In this paper, the blade noise of a solar/battery powered lawnmower is reduced by means of redesigning the cutting blade and employing the integrated design approach to increase design efficiency.

This undertaking primarily focuses on the reduction of noise through design enhancement of the cutting blade and neglects other significant sources of noise.

The integrated design approach [5] was used as the main technique for this study and involved RE of the original lawnmower blade. The RE facilitated the ReE of the blade design for lessened noise output, as well as reduced prototyping costs by advancing only the final design for development using Fused Deposition Modelling (FDM) technology.

Literature Review

The reviewed literature begins with explaining some of the fundamentals of noise production and effects on health followed by a description of the RE, ReE and rapid product development (RpD) concepts as used in the integrated design approach.

Fundamentals of Noise

Physics of Sound and Noise

Sound is defined as the propagation of longitudinal waves which gives rise to pressure variations about the mean atmospheric pressure generated by a vibrating surface [6]. Noise is defined as excessive or unwanted sound which causes annoyance and/or hearing loss [7]. Noise consists of complex mixtures of pressure variations for which there is no simple mathematical relation between its characteristics such as phase, frequency and amplitude [6].

Sound pressure is the amount of pressure fluctuation a source creates and is dependent on the environment in which the source is located and the distance from the source. Sound power is the sound energy transferred per second from the noise source to the surrounding air and is a fixed value for a piece of equipment. Sound pressure is what the human ear hears as a result of the sound power being emitted from the source of the sound. Sound measuring equipment records the sound pressure level of the measured sound [8]. Due to this and the fact that human perception of lawnmower blade noise is the basis for this study, only sound pressure level will be considered. Sound pressure level is a logarithmic measure of a sound pressure relative to a reference value, usually 0.00002 Pa and the unit is the decibel (dB) [9]. Manufacturers usually provide noise emission data such as the sound power of equipment as well as the sound pressure levels under standard conditions [10]. Sounds of the same sound pressure but different frequencies may not be heard the same by a human ear and an A-weighting is used to regulate sound measurement readings. The units for sound level measured using the A-weighting is dB(A), and serves the purpose of giving a single number measurement of noise level by integrating sounds levels at all frequencies and gives a scale for noise level as perceived by the human ear [8].

Noise and Health

The Environmental Management Authority (EMA) regulation for noise in commercial areas of Trinidad and Tobago specifies 80 dB at day and 65 dB at night [6]. The more significant the noise intensity the lesser the safe exposure limits. An example of this is the Occupational Safety and Health Act that specifies the safe amount of exposure at 90 dB is 8 hours, whilst that at 95 dB is 4 hours as can be seen in Table 1. Exceeding the permitted limit can result in hearing loss, physical and psychological stress and loss of concentration [11].

Table 1: Safe exposure limits specified by OSHAT

Exposure Time/hrs	Sound Intensity/dB
8	90
6	92
4	95
3	97
2	100
1	105

Table 2: Effect of sound pressure level changes (Hansen 2015)

Change in sound level/dB	Change in apparent loudness
3	Just perceptible
5	Clearly noticeable
10	Half or twice as loud
20	Much quieter or louder

Blade Noise

Blade noise can be classified as rotational or vortex. Rotational noise, also referred to as periodic noise, arises due to rotation and interaction-distortion effects. Vortex noise, also known as broad band noise, arises due to vortex formation and turbulence. Tests conducted on lawnmower blades indicate that vortex noise is the dominant noise source in rotating blades. The blade passage frequency, f_b is given by Equation (1), where N is the number of blades and Ω is the rotational speed in rev/sec [3].

$$f_b = N\Omega \quad (1)$$

The effects of blade noise may be reduced by: reducing the rotational speed of the blade, sharpening of the blade edges, reducing the thickness and width of blades [3], adjusting the curves and by placing holes and winglets to break the air vortices [12].

Integrated Design Approach

The integrated design approach involves the incorporation of RE, ReE and RpD which provides agility in manufacturing and allows last minute changes to be made easily [5]. These methods are further explained below.

Reverse Engineering (RE)

RE is a method by which an existing product is evaluated, documented, modelled using CAD software and then virtually tested in order to repair, replace, improve or re-design it. In most cases, the product is physically taken apart, handled, measured, sketched and modelled. Tools used in measurement, range from hand-held instruments such as rulers, scales, micro-meters and callipers, to large complex instruments such as laser scanners, optical comparators and digital coordinate measuring machines (CMM) [13].

Re-Engineering (ReE)

ReE is the process whereby the design of a product is modified to enhance its performance by changing the material or optimizing the geometry [5].

Rapid Product Development (RpD)

RpD involves the use of rapid prototyping (RP) techniques for the quick and cost effective physical construction of three dimensional models using Computer Aided Design (CAD) software. RP is becoming a growing area of development as an enabler to industry facilitating rapid and effective conversion of designs into working models and even end-use parts [14]. The idea of RP was introduced in 1987 with stereo-lithography technology, where lasers were used to harden layers of ultraviolet light-sensitive liquid. Alternative methods were then introduced, such as selective laser sintering, laminated object manufacturing and FDM.

Research Methodology

The research methodology followed in this study is shown in Figure 1. The main phases are RE, ReE and RpD and are explained in detail in the subsequent sections.

Reverse Engineering (RE)

As described in the process of RE, an existing product was studied and tested in order to make improvements on key characteristics affecting the noise intensity. In this investigation, the original blade from the solar powered lawnmower underwent RE to arrive at a design that would reduce the noise intensity emanating from the blade.

Physical Object:
The dimensions of the original lawnmower blade were acquired with the use of a Vernier calliper and rule and recorded using hand drawings and photos.

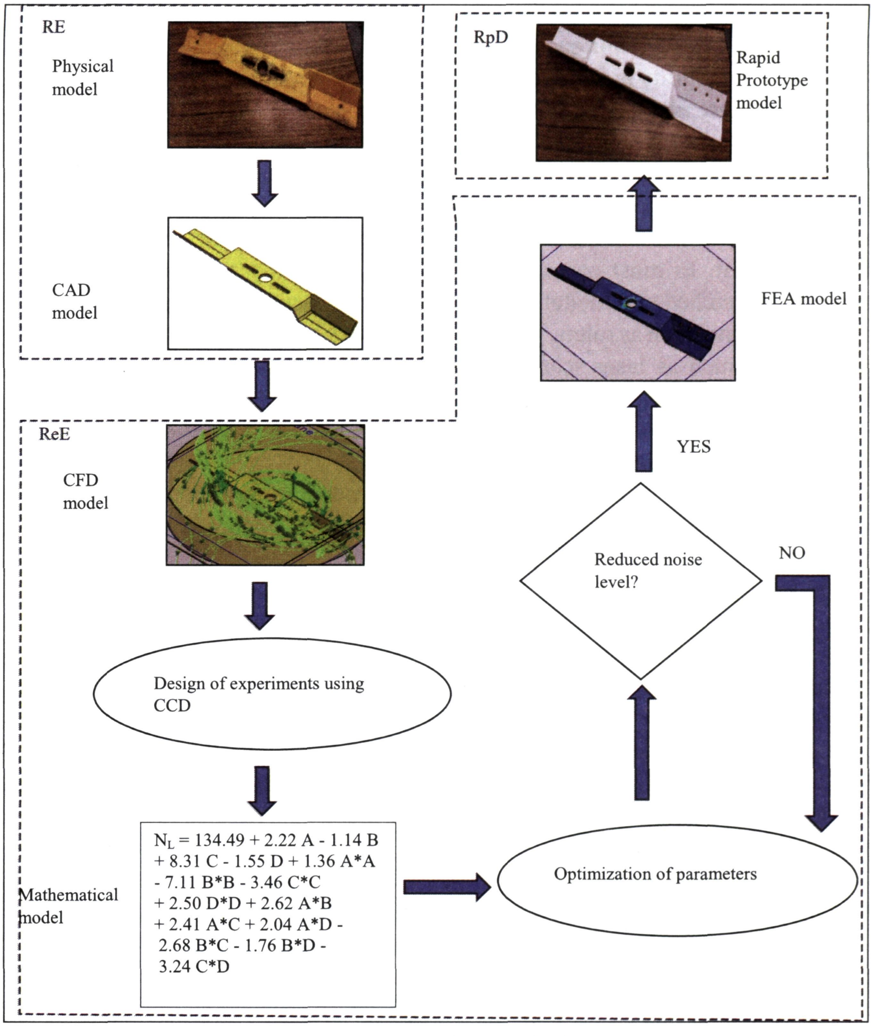

Figure 1: Integrated process flow for the design and development of a low noise intensity lawnmower blade

Computer Aided Design (CAD) Model:

Using the dimensions of the original blade, a three dimensional model was developed using the software package Solidworks. Due to the distortion of some faces of the blade as a result of prolonged use, and the complex curvature of some areas, the CAD model was simplified by making use of assumptions as illustrated in Figure 2.

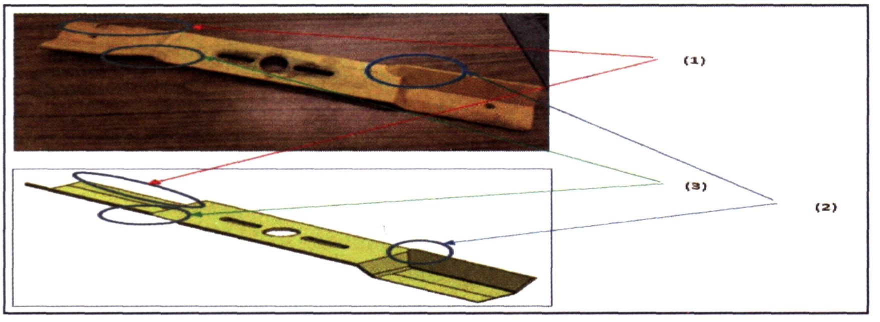

Figure 2: Comparison of physical object and CAD model showing assumptions: (1) cutting edge is straight with thickness of 1 mm (2) curves are simple fillets and (3) blade is straight

Re-engineering (ReE)

Computational Fluid Dynamics (CFD) Model:

Setup of Virtual Model

The Solidworks Flow Simulation add-in module was used to establish a CFD model of the rotating blade and was employed to perform virtual experiments on varying blade geometries to arrive at a design with the desired outcome of lessened noise intensity. In performing the experiments, several assumptions were made and they are as follows:

1. Only air is moved by the blade
2. Blade rotates at 3000 rpm
3. Angular velocity is constant (angular acceleration is zero)
4. Initial conditions: Pressure = 101.3 kPa; Temperature = 293 K
5. Air flow is laminar and turbulent
6. The difference in average dynamic pressures of the top and bottom surfaces of the rotating blade by virtue of the air flow around it represents the sound pressure
7. The material of the blade is polycarbonate (PC)

Computational domain: The computational domain was reduced from its default size to 0.65 m in the x-direction, 0.19 m in the y-direction and 0.80 m in the z-direction with the blade at the centre. This was done to reduce the computational time since less iteration would have to be done on a smaller volume.

Rotating regions: An extruded cylinder was created beforehand that contained the entire blade and represented the volume of air that will rotate with the blade. This cylinder was selected as the rotating region and the velocity specified as -3000 rpm.The speed was selected based on that quoted on the name plate of the solar powered lawnmower's motor with the negative sign indicating clockwise rotation.

Goal plots: Two surface goals were created: the average dynamic pressure on the entire top surface of the blade (all surfaces seen from a standard top view) and the average dynamic pressure on the entire bottom surface (all surfaces seen from a standard bottom view).

Results and calculations [15]:

$$Average\ dynamic\ pressure\ on\ top\ blade\ surface = 1093.38\ Pa$$
$$Average\ dynamic\ pressure\ on\ bottom\ blade\ surface = 1087.74\ Pa$$
$$Sound\ pressure = 1093.38 - 1087.74 = 5.64\ Pa$$
$$Sound\ pressure\ level = 20\log_{10}(P/P_o) = 20\log_{10}(5.64/0.00002) = 109\ dB$$

Validation

Virtual simulation was verified by conducting a noise-rotational speed experiment with the original blade within the Solidworks Flow Simulation package; and then performing a physical experiment. The results of both tests were compared as shown in Figure 3 to determine if the virtual model was adequate based on variations between the test results to predict the actual noise produced by the rotating blade.

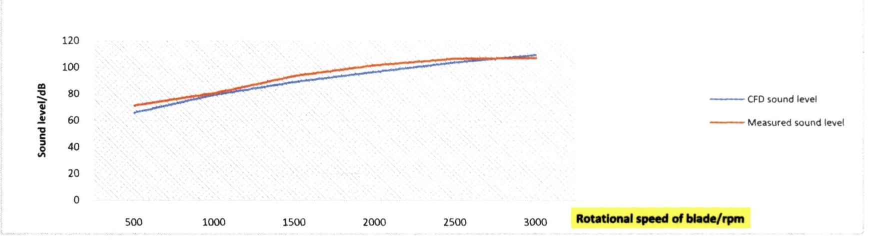

Figure 3: Comparison of the sound level from the virtual and physical results

The noise intensity level values obtained in the virtual CFD model varied from the physical values between +1.3 dB and +5.3 dB. Considering that physical experimentation is subject to error and that the virtual model was simplistic in nature, it can be deduced that the virtual model is anapposite approximation and will be used to conduct subsequent experiments which will be the foundation of this investigation.

Design of Experiments:

The parameters chosen for this study, refer to Figure 5, were thickness of central section of the blade (A), thickness of cutting edge of the blade (B), height of winglet (C) and diameter of air passage holes (D) due to their noise reducing attributes as identified in the review of literature [3 and 12]. The winglet feature is a transverse extension from the distal end of each of the blade arms as can be seen in Figure 5. Furthermore, these parameters are all geometrical features, thereby facilitating rapid adjustments within CAD/CAE systems, to produce the numerous design iterations for experimentation in this study without the need to physically prototype.

The selected parameters and their respective limits can be seen in Table 3. Assigned parameter values were based on assembly constraints owing to the lawnmower deck and blade mounting mechanism.

Response surface modelling was then employed in determining a mathematical relationship between the response noise level (N_L), and selected parameters.

Table 3: Design parameters and their limits

Factors/Coding of levels	**-1**	**0**	**+1**
Thickness of central section of blade, A (mm)	5.08	6.67	8.26
Thickness of cutting edge of blade, B (mm)	0.8	0.9	1
Height of winglet, C (mm)	0	25	50
Diameter of air passage holes, D (mm)	0	6	12

The Central Composite Design (CCD) method [16] was utilized with thirty one experiments performed using the verified virtual model, the results of which can be seen below in Table 4.

The CCD equation for the number of experimental runs for K parameters is given by Equation (2):

$$\text{Factorial points } (2^K) + \text{star points } (2*K) + \text{centre points} \quad (2)$$

Therefore, for 4 parameters and 7 centre points, the number of runs is equal to: $2^4 + 2x4 + 7 = 31$ runs

Table 4: Experimental design matrix comparing results of virtual experimentationto those calculated using the mathematical model generated (average variation of 3.85 dB)

Experiment No.	Coded values				Noise level/dB		dB Variation
	A	*B*	*C*	*D*	***Experimental value***	***Calculated value***	
1	-1	1	1	1	100.21	116.43	16.22
2	0	-1	0	0	116.66	128.52	11.86
3	-1	1	-1	1	124.86	116.47	8.39
4	1	0	0	0	133.26	134.07	0.81
5	1	1	-1	1	121.72	125.41	3.69
6	0	0	1	0	140.93	139.34	1.59
7	0	0	0	0	136.64	134.49	2.15
8	-1	1	-1	-1	114.83	120.69	5.86
9	0	0	0	0	135.09	134.49	0.6
10	1	1	1	-1	140.82	144.03	3.21
11	-1	-1	1	-1	140.94	142.97	2.03
12	0	0	0	0	135.59	134.49	1.1
13	1	-1	1	1	141.09	140.93	0.16
14	0	0	0	0	135.59	134.49	1.1
15	0	1	0	0	135.53	126.24	9.29
16	1	1	-1	-1	119.43	121.47	2.04
17	0	0	0	0	135.59	134.49	1.1
18	0	0	0	0	135.09	134.49	0.6
19	0	0	0	1	135.84	135.44	0.4
20	1	-1	1	-1	140.91	142.91	2
21	-1	-1	-1	1	119.66	122.15	2.49
22	1	1	1	1	141.07	135.01	6.06
23	1	-1	-1	-1	120.14	109.63	10.51
24	0	0	0	0	135.59	134.49	1.1
25	0	0	-1	0	118.56	122.72	4.16
26	1	-1	-1	1	119.66	120.61	0.95
27	-1	1	1	-1	140.91	133.61	7.3
28	-1	0	0	0	135.86	133.63	2.23

29	0	0	0	-1	135.57	138.54	2.97
30	-1	-1	1	1	141.23	132.83	8.4
31	-1	-1	-1	-1	119.61	119.33	0.28

Mathematical Model:

Development of a non-linear regression model using the experimental data collected from the virtual model was then effected within Minitab version 17. This mathematical model embodies the fitness function used for optimization in Matlab.

The regression equation for predicting the noise level of the lawnmower blade can be expressed as follows in Equation (3):

$$N_L = 134.49 + 2.22\,A - 1.14\,B + 8.31\,C - 1.55\,D + 1.36\,A*A - 7.11\,B*B - 3.46\,C*C + 2.50\,D*D + 2.62\,A*B + 2.41\,A*C + 2.04\,A*D - 2.68\,B*C - 1.76\,B*D - 3.24\,C*D \quad (3)$$

Using experimental run, number 31, and the coded values for the respective parameters:

$$\begin{aligned} N_L = {} & 134.49 + 2.22(-1) - 1.14(-1) + 8.31(-1) - 1.55(-1) + 1.36(-1 \times -1) - 7.11(-1 \times -1) \\ & - 3.46(-1 \times -1) + 2.50(-1 \times -1) + 2.62(-1 \times -1) + 2.41(-1 \times -1) \\ & + 2.04(-1 \times -1) - 2.68(-1 \times -1) - 1.76(-1 \times -1) - 3.24(-1 \times -1) = 119.33\,dB \end{aligned}$$

This calculated value, 119.33 dB, does not have significant deviation to the experimental value, 119.61 dB, and thus demonstrates a good fit of the mathematical model.

Optimization:

The Genetic Algorithm from Matlab's Optimization toolbox was employed to determine an optimal noise level with corresponding values for the selected parameters withinthe bounds as specified in Table 6. The regression equation developed was used as the fitness function and the default options chosen for application of the genetic algorithm are shown in Table 5. A number of optimization trials were performed, the results of which are shown in Table 7.

Table 5: Default Genetic Algorithm settings

Option	Settings
Population	Population type: Double vector Population size: 20 Creation function: Constraint dependent Initial population: [] Initial score: [] Initial range: [0;1]
Fitness Scaling	Rank
Selection	Stochastic uniform
Reproduction	Elite count: 2 Crossover fraction: 0.8
Mutation	Constraint dependent
Crossover	Scattered
Migration	Direction: Forward Fraction: 0.2 Interval: 20
Constraint parameters	Initial penalty: 10 Penalty factor: 100
Hybrid functions	None
Stopping criteria	Generations: 100 Time limit: Inf Fitness limit: -Inf Stall generations: 50 Stall time limit: Inf Function tolerance: 1e-6 Nonlinear constraint tolerance: 1e-6
Plot functions	Plot interval: 1
Output function	None specified
Display to command window	Off
User function evaluation	In serial

Table 6: Upper and lower bounds of the parameters entered into Matlab

Parameter	**Bounds**	
	Lower	***Upper***
A	5.08	8.26
B	0.6	1
C	0	50
D	6	15

Table 7: Predicted Results of the Matlab optimization

Parameter	**Optimization number**				
	1	**2**	**3**	**4**	**5**
A	5.080	5.080	5.080	5.080	5.080
B	0.998	1.000	0.999	1.000	1.000
C	2.978	1.803	1.588	0.916	12.296
D	6.000	6.000	6.000	6.000	6.191
Noise level N_L(dB)	101.57	99.96	101.34	103.60	107.27

The results indicate optimization number 2 produced the lowest noise level which was also less than that produced by the original blade. The CFD simulation results of the optimized design is shown in Figure 4 whilst the comparison between the original and optimized blade can be seen in Figure 5 and Table 8. These parameters will be used in the final blade design.

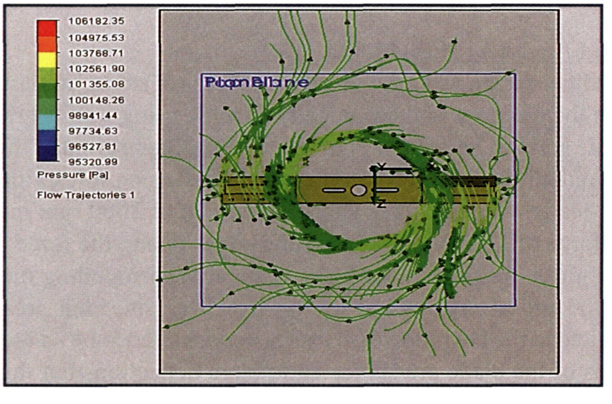

Figure 4: CFD trajectory of optimal design showing the pressures of the air particles

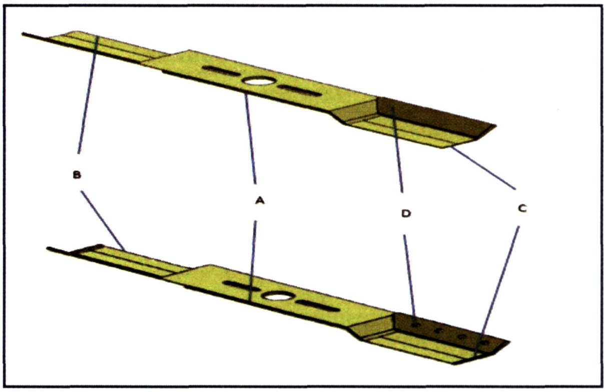

Figure 5: Geometrical comparison of initial CAD drawing and optimized design

Table 8: Comparison of the parameter values for the original and optimized design

Parameter	Original blade design	Optimized blade design
Thickness of central section of blade, A (mm)	5.08	5.08
Thickness of cutting edge of blade, B (mm)	1	1
Height of winglet, C (mm)	0	1.803
Diameter of air passage holes, D (mm)	0	6
Noise level (dB)	109.0	99.96

Finite Element Analysis (FEA) Model:

Testing of the final design was carried out in the areas of stress, strain and deflection to ensure that the design was mechanically feasible using Solidworks Simulation Xpress module and can be seen in Figure 6. One fixture prevented the central hole from moving radially and the geometry was stabilised using soft springs. The forces acting on the blade were gravity, a centrifugal force of 3000 rpm imposed by the motor and a force of 11.51N on both cutting edges due to the force needed to cut the blades of grass. As seen in the figures, the area surrounding the central hole experienced the largest stresses and strains. However, since this area is where the blade is mounted to the lawnmower, it was not considered to be an area of concern. The both ends of the blade are subjected to huge deflections but this is expected due to the rotational forces of the blade. The design can thus move to the rapid product development phase.

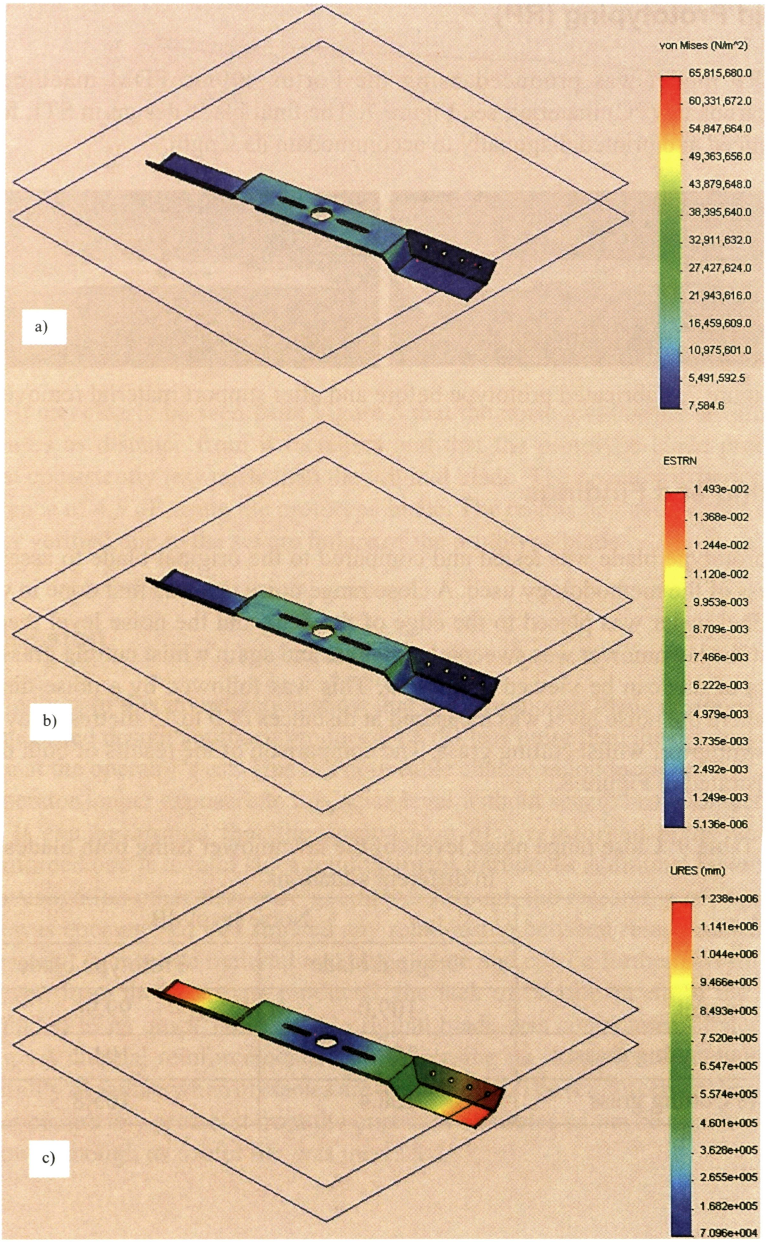

Figure 6: FEA results (a) stress distribution (b) strain distribution and (c) deflection

Rapid Prototyping (RP)

The RP model was produced using the Fortus 400mc FDM machine and Polycarbonate (PC) material; see Figure 7. The final blade design in STL format was sliced and printed diagonally to accommodate its length.

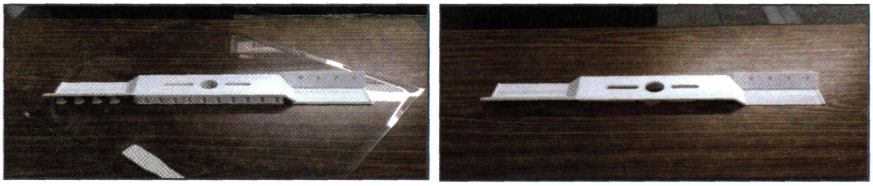

Figure 7: Fabricated prototype before and after support material removed

Testing and Findings

The prototype blade was tested and compared to the original blade to assess the success of the methodology used. A close range noise test was first done in which a decibel meter was placed to the edge of the deck and the noise level recorded whilst the lawnmower was sweeping air alone and again whilst cutting grass. The results of this can be viewed in Table 9. This was followed by a noise-distance test where the noise level was measured at distances of 0 to 15 metres away from the lawnmower whilst cutting grass. The comparison of the results of both blades is illustrated in Figure 8.

Table 9: Close range noise levels of the lawnmower using both blades in different situations

Case	Noise level/dB	
	Original blade	Prototype blade
CFD model	109.0	99.96
Without cutting grass	108.8	101.2
While Cutting grass	108.4	105.8

Distance from lawnmower/m	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Original blade	82.7	81.9	79.6	78.8	76.8	75.4	74.2	73.1	72.2	71.4	69.7	67.7	65.2	64.3	63.8	63.1
Prototype blade	78.2	76.6	74.8	73.3												

Figure 8: Comparison of both blades in the noise-distance test

It can clearly be seen from Figure 8 that the noise level of the lawnmower decreases as distance from it increases and that the prototype blade produced almost consistently less noise than the original blade. The operator experienced a difference of 4.5 dB using the prototype blade. The results however, could not be further verified due to the severe failure of the prototype blade.

Discussion

The findings of this investigation show that the lawnmower blade designed using the integrated design approach produced 4.5 dB less noise than the original blade design at the operator's ear. This is a noticeable change in loudness and will allow the operator longer exposure to this noise level without severe health defects.

It can be argued that the comparison of a reinforced blade with an unreinforced one is invalid since reinforcement introduces additional factors into the investigation other than pure geometry. Through the research performed, no study was encountered that showed any relationship between reinforcement and blade noise, or more so material and blade noise and can be further investigated. However, from the prototype produced, the lack of reinforcement of the blade contributed to its quick failure. The original blade was constructed of steel and fibre glass internal reinforcements, thus increasing its strength and reducing the probability of failure when obstacles are encountered. The reinforcement however, did not completely protect it from the impact of obstacles as can be seen in Figure 9 below, although its useful life was increased.

Figure 9: Failure of original blade due to obstacle impact

In the case of the prototype, the material properties were acontributing factor that affected the mechanical strength of the blade. The material available for fabricating the blade was polycarbonate, which is strong in tension but not impact. The FDM prototyping technique also affected the strength and performance of the blade. As seen in Figures 10 and 11, the material is deposited in layers which are visibly noticeable in the produced part. These layers allow for the build-up of shear stresses which can lead to mechanical failure especially in thin sections such as the cutting edge of the blade. It is suggested therefore that the if the final product is to be produced on a larger scale, it should be manufactured using the process of injection moulding which provides a better quality finish and more material options.

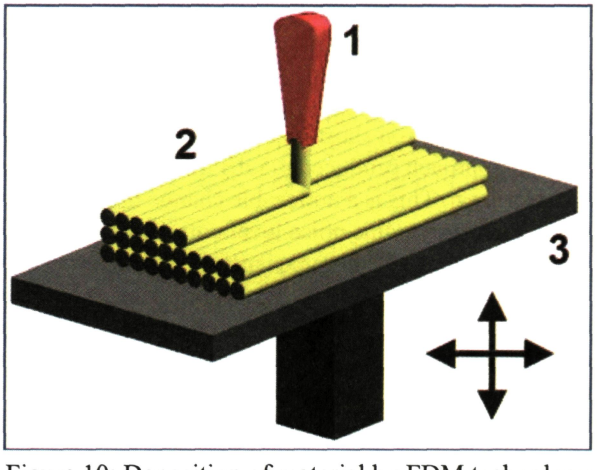

Figure 10: Deposition of material by FDM technology

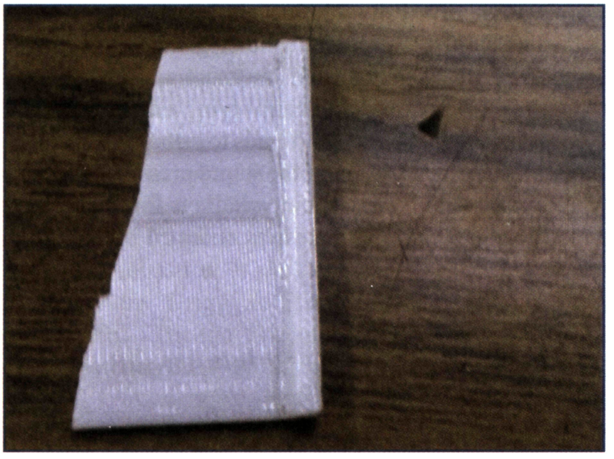

Figure 11: Broken cutting edge showing the layers of material

The integrated design approach was chosen as a structured investigation route instead of using trial and error approaches like some of the previous research. It also incorporated new techniques of optimizing the lawnmower blade design which was not previously used in any research paper encountered. This systematic approach to the problem proved to be efficient and ultimately effective but has room for major improvements. The RE phase involved the measuring of the physical object with hand tools, which may have introduced parallax and random errors into the dimensioning. These dimensions were used to create the CAD model but due to assumptions that had to be made and the process of extruding each face separately, inconsistencies developed on the underside of the blade as shown in Figure 12.

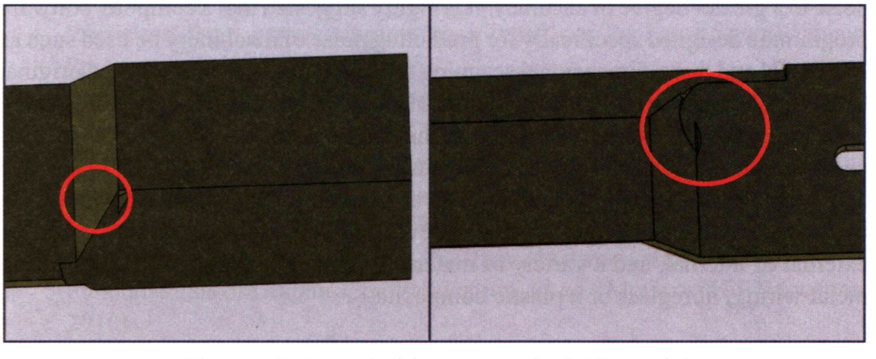

Figure 12: Irregularities present in CAD model

The ReE phase involved the various models, the fundamental one being the CFD model which served to predict the noise generated by the different blade geometries without having to physically construct and test them. This reduces development time and cost but the act of simplifying a complex phenomenon such as the generation and propagation of sound leads to errors. Also, since the simulated geometries were different, the location of the sound pressure waves may have been different which could have led to inaccurate readings for further processing. This is one explanation for the variations in results obtained by the virtual testing and the mathematical model.

Conclusion

This research has presented a systematic approach to the design, testing and development of a reduced noise emanating lawnmower blade. The prototype blade was fabricated entirely using the Fortus 400mc FDM machine with Polycarbonate (PC) material, and a simple Computational Fluid Dynamics model was sufficient enough to predict the output noise level to around ± 5 dB. Using this approach, the operational noise of a solar/battery powered lawnmower was reduced by 7.7 dB if measured without cutting grass, 2.6 dB if measured at the edge of the deck whilst cutting grass and 4.5 dB if measured at the level of the operator whilst cutting grass.

Future Work and Recommendations

Future research is in the direction of optimization of the current cutting blade design. It is recommended that a more complex model be developed that predicts the blade noise to a greater degree of accuracy. It is highly suggested that a computer software programme designed specifically for predicting noise of machinery be used such as ACTRAN and three-dimensional scanning to obtain the CAD model of the original blade. Other parameters that could affect blade noise should be investigated using a similar approach to what was done in this study. Some of these factors include changing the shape of the curves and adjusting the angled faces of the blade, age and height of the grass to be cut, as well as material of the blade. Moreover, the blade design should be reinforced to prevent failure. Reinforcements could be external or internal, and a variety of materials could be used such as sheet metal, metal wiring, fibreglass or a plastic composite.

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