The importance of the use of physical engineering models in design

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Abstract

The varying functions of physical engineering models within a design/development environment are explored and their significance in the progression and overall success of a project evaluated.

Based largely on the author's first hand experience within industry, the function of a model as an ergonomic, engineering design, laboratory and field service performance vehicle is examined using case study material (a lawnmower design) to identify the practical aspects of these critical areas. The relationship between engineering models and industrial design models is also considered.

The conclusions drawn are that the use of physical engineering models affords real benefits in terms of time scale progression by providing a strong focus on the state-of-the-art of a project. In addition, their psychological benefits in terms of being able to convey ideas rapidly, using a hands-on approach, to third parties concerned with design within an organisation e.g. Marketing, Production etc. cannot be understated. This is particularly true when they are used in conjunction with computer aided design and/or industrial design models.

Introduction

Engineering models have been used knowingly, or unknowingly, throughout history to help determine the suitability of certain principles, objects or products prior to final design, construction or product build. The role that these models play within a design evolution has, I feel, not diminished despite the advent of new technologies such as Computer Aided Design and the role of the model can be seen to harmonise well with these new technologies.

To begin with it is important to define what is meant by a physical engineering model and to make basic comparisons between it and an industrial design model in the way that both are used extensively in industry. Physical engineering models (as opposed to computer generated models) can be of very simple form, such as cardboard, all the way through to fully engineered prototypes prior to absolute commitment to final design and production. Their complexity, cost and functional capabilities normally increasing in line with the evolution of the particular design or project that they are concerned with. Their functions can vary from a very simple proving ground for an engineering principle used within a given context, e.g. use of a pushchair wheel brake under certain load and use conditions; to a full ergonomic analysis and working simulation of a product using a model that is, to all intents and purposes, indistinguishable from the intended final product. (Middendorf[1] and Ray[2] detail this variety of form in a much broader context than space allows here.)

Industrial design models on the other hand tend to be more concerned with aesthetic form and the manner in which this relates to the function of the product. They give a good indication of the customer perception of a product and, similar to engineering models, can be used for ergonomic evaluation.

The physical engineering model can therefore be considered to be a testbed facility that may, or may not, convey the form of a design, but can be used to convey, test and evaluate the principle(s) of a design to gain confidence in its capabilities prior to absolute commitment to that design.

The varying role of the engineering model

Having defined the role of the engineering model it is now necessary to examine the way in which this varies throughout the design and development life of a typical engineering project. In order to do this it is intended to use a case study of a lawnmower design as an example. From my own first hand involvement with this project, and in the belief that this can be considered fairly representative of the general industrial use of engineering models in design, it is hoped to show the development of the role and it's overall importance to the project and final design.

THE DESIGN PROJECT

Background

This project was aimed at replacing an existing out-dated lawnmower design with a potentially market leading product with a number of innovative features. The mower was going to be an electrically powered, 30cm blade diameter, rotary domestic machine with the following features:

- Mainly plastic moulded construction
- Optional metal or plastic cutting blades (plastic for safety)
- Integral electric brake on the motor to stop the blade(s) rotating within a few seconds of being switched off
- Turbo grass collection using both mechanical action from the cutter blade and airflow from a fan mounted above the blade to carry grass cuttings into a rear-mounted grassbox
- Front wheels and rear roller to give striping of the cut grass together with cutting height adjustment for use in differing lawn conditions
- Retail cost at least comparable with equivalent competitor models, at best, cheaper than these.

Design Problems

A number of areas needed addressing in order to satisfy the design specification summarised above, these namely being:

- The overall design and materials selection for all of the plastic mouldings used on the machine, bearing in mind general use and abuse, as well as specific problems associated with stone impact damage on the plastic body during use, electrical safety and UV degradation, etc.

- The design and performance of the "heart" of the machine i.e. electric motor-fan-cutting assembly and their inter-relationship as a result of the constraints that were imposed on motor size and power and fan size to allow room for the cutting blade(s), etc.

- Grass cutting and collection performance in a variety of conditions.

- Blade Brake design and performance to meet the short stopping criteria without causing heat or cooling airflow problems to the motor.

- Wheel and roller design coupled with integral height of cut adjustment

- Handle and switch design for optimum ergonomics in both use and storage (the handle was required to fold down when not in use).

All of these problems required resolution within an approximate two year time frame for the project from initial "blank sheet" concepts to volume production. This included 6-8 months necessary for tooling the product from final design sign-off to initial production.

Initial Concept Models

The project was initiated along two modelling lines running in parallel covering both industrial and engineering design.

The initial engineering models were made using card to get a feel for the approximate size of the machine very quickly and to generate design ideas for the shape of the main body moulding, or mouldings, as they could have been at this stage. These models, complete with judicious use of plasticine and draughting tape, managed to highlight a number of potential design pitfalls with the body mouldings that would need to be overcome and work progressed on this.

Concurrent with this work, assessments were made of competitor products and their performance to establish benchmark criteria for the proposed machine. These competitor products were subsequently used for engineering models by modifying them in a number of areas using very basic mechanical components and customised parts, which could quickly be modified, to enable performance evaluations to be undertaken.
These evaluations were then compared to original performance specifications on these machines and obvious improvements noted. This work took place both in the laboratory measuring, for example, electrical power and in the field (literally!) measuring grass cutting performance.

In addition, assessments were also being made of possible suitable materials for the body mouldings to meet the legislative requirements for strength and impact protection.
This was done using a simple off-the-shelf component (a washing up bowl) moulded in various grades of plastic which were then tested against each other using laboratory test rigs.

Finally industrial design models were also being produced from conceptual rendered drawings of the overall anticipated visual look of the machine. These drawings and models were based upon "first guess" estimates of general size and function of the machine made by design engineering personnel and were useful to get first impression feelings from Marketing and Production. A number of options were presented and this gave allowance for a reasonable degree of freedom of choice for "liked" and "disliked" features at this early stage in the project, when the highest degree of design flexibility was available.

At this initial stage then the engineering models being used were of very simple form consisting either of card or competitor product modified with proprietary parts to give indicators to desired performance and highlight component design problem areas. The card models also proved useful in talks with potential suppliers of mouldings to give pointers in terms of costing and tooling, etc. The industrial design models were in foam, for speed and ease of manufacture, and allowance had to be made for the limitations of these models in terms of crudity, lack of gloss finish and so on.

This stage showed the way in which both engineering and industrial design models could work in parallel with each other, the industrial design models using assumptions gained from the engineering models to pinpoint functionally constrained design areas, e.g. estimated size and position of the electric motor.

First Prototypes

Collating all the data that had been gained from the initial concept stage led to the design and build of the first stand-alone prototype. The design of this prototype incorporated the following aspects:

- Improvements made to competitor models
- General design requirements for the body mouldings from the card models
- Capability for fitting both our own design motor and other motors to give direct comparisons of the two within the same testbed
- Different fan design options for field and laboratory evaluation
- External appearance roughly in line with the "liked" areas on the industrial design models

The model itself was made from a similar grade of plastic to that proposed as being suitable for production (from the strength and impact testing data). A relatively large amount of time and money was expended on it both to incorporate the above-listed features and retain a high degree of flexibility in terms of the adjustments and comparisons that could be made using this prototype.

This engineering model was extensively used in the field and laboratory for a very full evaluation of the specification and, as data became available, two more prototypes were commissioned incorporating the required design modifications to meet, or exceed where possible, the original specification and also to satisfy changes requested by third parties such as Production to assist in the final manufacture of the product.

Again, in parallel with this, wooden block industrial design models were also being produced using the same data coupled with that provided as feedback from Marketing in terms of required styling to enhance customer perception of the product.

The engineering models used at this stage in the project gave significant impetus to the project taking it from a relatively low quality modelling platform to the point where relatively high quality and high specification models could be commissioned. A number of design issues were resolved and the psychological benefit of having a working model, based on the project team's initial concept ideas, helped to maintain the flow of these ideas. It also greatly assisted in focusing the team members' minds on the deadlines that had to be met for design by continually highlighting problem areas until they were resolved.

Second Prototypes

These models were of a similar construction to the first prototype but were obviously more detailed. Where design problem areas had been resolved, this was reflected in the prototypes and flexibility was only retained for outstanding design aspects requiring resolution that had not been capable of evaluation using the first prototype. They also highlighted the progress made in terms of decisions taken on industrial design and were, at this stage, fairly representative of the look of the final product.

One of the models was used for further field and laboratory proving of performance. The other model was used for discussions with suppliers of custom parts to obtain rapid feedback on both costs and areas of technical query. It was also used for Production evaluation including assembly trials and for discussions on both Patents and legislative safety requirements. Again, this ensured a much more rapid and positive response than the likely response from the use of drawings only.

Third Prototypes

Following on from this further models were made which more accurately reflected the design that was rapidly approaching a state of "freeze" prior to commitment to tooling and production facilities. These were used for product life testing in the field and laboratory and were subsequently modified to incorporate custom production parts as they were ordered, tooled and became available.
These hybrid machines then continued testing and evaluation until they became obsolete due to the preponderance of incoming sample production parts that allowed "production" engineering models to be built with little, or no, prototype parts involvement. The prototypes were also used for a

video shoot for a product promotional video allowing the product to be visibly demonstrated and "sold" without it being in production yet - an indication of the confidence perceived in the product by the use of engineering models.

Final Prototypes

The final models built were those utilising all production parts at various stages of correction and modification dependant on the results of both product testing and quality evaluation of incoming production parts.

The project completed successfully within the allotted and planned time span and went into volume production on time. As a measure of the success of this project it is also worth noting that, since it's launch in 1990, this lawnmower has become the best selling rotary machine within the UK market for the years 1992 and 1993.

As can be seen from the above study, the importance of the use of physical engineering models in achieving this was highly significant and, without their relatively strong influence in terms of physical and financial resourcing, the project would have floundered.

Summary and Conclusions

Obviously the nature of a particular design or development project will to a large extent determine the usefulness of physical engineering models as part of its resourcing to enable successful completion.
It is the view of the author that, in the main, engineering models play a significant role in achieving design success by the following criteria:

- Providing a rapid response to design queries from all parties, both internal and external to the organisation, for a design project.

- Maintaining a focus on the current status of a project's development.

- Highlighting shortcomings in a product design and maintaining awareness of these design issues until they are resolved.

- Providing impetus to a project as "design successes" are achieved using the model.

- Greatly assisting in the process of concurrent engineering when used in conjunction with other design aids, in particular CAD and industrial design models. Indeed the generation of solid models from CAD using rapid prototyping is a good example of the way in which the two work well together.

- Accelerating the process of product development by giving early-on confidence in products that may not have been achieved so easily by other means.
  (This point is reinforced by Williams[3] where the use of 2D CAD followed by solid modelling is considered to be preferable to 3D CAD modelling.)

It is therefore felt to be fundamental that the benefits accrued from the use of physical engineering models should be an important feature to be acknowledged within any design project undertaken. Further to this, the education of design students should provide an emphasis on this area to ensure recognised continuity of its importance - a factor that is considered to be a fundamental aspect of design courses within the authors own organisation.

References

1 Middendorf, W H Engineering Design. pp151-153, Allyn & Bacon, Boston.(1969)

2 Ray, M S Elements of Engineering Design. pp243-244, Prentice Hall International (1985)

3 Williams, G Head on the Block. Design (March 1994)

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