

# DESIGN, MAKE, TEST

**Peter R N CHILDS and David A ROBB**

Department of Mechanical Engineering, Imperial College London, SW7 2AZ, UK

## **ABSTRACT**

In the UK in the 1970s and early 1980s examples of best practice pedagogic experience included the egg-race type of design and make projects embodied in the student projects run by Ken Wallace at the University of Cambridge and Heinz Wolff at Brunel University. These experiences were widely acclaimed in the media and inspired a generation of students. The technically demanding and interdisciplinary nature of such projects has, in some cases, pushed them towards the domain of mechatronics degrees. A further challenge to this form of project is the high resource requirements from staff, to hardware and space. In order to provide a stepping stone between the introductory projects such as bridge or crane building using balsa wood, a group exercise has been introduced that is inspired by the egg-race type leading edge pedagogic practice activities. A project has been developed where students are challenged to build a small hovercraft. Fans and motors are supplied but the students are required to design and build their own hulls. The activity is associated with lectures in sketching, machine elements and fluid mechanics and the fans have been sized requiring careful consideration of the air gap, hull area and mass in order to ensure that the design is compatible with the flow capacity. A further constraint is that the craft must be autonomous and navigate a specified route, with various obstacles. This paper describes the project developed for 160 Year 1 MEng students along with resource requirements and options for scaling and development.

*Keywords: Design, make, manufacture, test, prototype, project, hovercraft*

## 1 INTRODUCTION

In the UK in the 1970s and early 1980s examples of best practice pedagogic experience included the egg-race type of design, make and test projects embodied in the student projects run by Ken Wallace at the University of Cambridge and Heinz Wolff at Brunel University. These experiences were widely acclaimed and featured in the media at the time and inspired a generation of students with many now middle aged practitioners retaining a fond memory of 'The Great Egg Race' (see, for example, [1]). In the university context, the technically demanding and interdisciplinary nature of such projects, where skills are often required that span mechanisms, electronics and control, has, in some cases, pushed them towards the domain of mechatronics degree programmes. A further challenge to this form of project is the high resource requirements necessary from staff support time, to hardware and space to undertake the activity. All design lecturers are familiar with the substantial overhead associated with a design project set to a large cohort of students, where despite use of virtual learning environments (VLEs), there remains a high demand for consultation style advice.

An option considered and trialled in some engineering and design courses is to make use of technical toy components. Such an approach is subject to potential criticism from the Higher Education student population, in that they feel that have 'moved on' from toys and are at university to do 'proper' engineering. Further challenges to the use of toy components include the level of sophistication possible with programmable controllers, the variety of pre-formed components often negating the impetus for students to engage in self-generated design, and the difficulties in getting across concepts of detail design, bearings, fasteners, high stress/temperature design, rotodynamics, fatigue; lifting and design for manufacture.

In order to provide a stepping stone between the introductory design, make and test projects such as bridge or crane building using balsa wood, often undertaken by students in induction to a mechanical engineering degree and in team-bonding exercises, a group exercise has been introduced that is inspired by the egg-race type activities of 1970s leading edge pedagogic practice. A project has been

developed where first year students are challenged to build a small hovercraft. Fans and motors are supplied but the students are required to design and build their own hulls. The activity is associated with lectures in fluid mechanics and the fans provided have been deliberately sized requiring careful consideration of the air gap, hull surface area and craft mass in order to ensure that the design is compatible with the flow capacity of the fan. A further constraint, inspired by the egg-race pedigree of projects is that the craft must be autonomous and navigate a specified route, with various obstacles and pathways. Sketches and Solidworks solid models are used in the design stage to encourage visualization of the final product before manufacture.

This paper explores the need to develop projects that are both fun and practical for a large student cohort and also provide learning experiences with the development of appreciation of trade-offs in design identified through both creative sketching and analysis and the importance of accompanying engineering science in the design process. A key requirement in the formation of a professional mechanical engineer is an understanding of the value of analysis enabled by the use of scientific principles combined with appreciation of limitations involving practical considerations. Many first year students have limited interest in design as an engineering subject (only 48 % compared with 78 % wanting to find out how things work) as reported in a previous paper (Robb et al. (2009) [2]). The particular exercise developed for the 160 students in Year 1 of the Mechanical Engineering MEng concerned is described along with the resource requirements and options for scaling and development of the project.

## 2 DESIGN MAKE TEST ASSIGNMENTS

The year 1 design and manufacture course forms an important part of the curriculum for the MEng in Mechanical Engineering at Imperial College. The course aims to provide an integrated introduction for students to ideation, sketching, machine elements, manufacture, solid modelling and the design process. Design education has been the subject of much debate and research and the particular challenge of needing skills in order to design but not being able to develop these without doing design is well recognised. Many educational establishments use design, make and test assignments in both product design and engineering degrees in order to develop students' experience. Examples include the balsa wood bridge and crane exercises common to the induction experience for many institutions, chair design and manufacture (e.g. [2]), mini-dragster build exercises, the design and test of winches and pumps, and some adventurous courses offer the design of gas turbine engines and race vehicles (e.g. Formula Student [3] and Racing Green [4]). Such design and manufacture assignments provide opportunities for the novice engineer or designer to gain experience across the highly relevant topics of marketing, specification, conceptual idea development, detailing, prototyping and manufacture as well as team working and competitive design evaluation and takes advantage of the benefits of learning by doing [6].

Challenges exist in the development and specification of design, make and test projects. A project needs to be sufficiently open ended to provide scope for ideation, challenging enough to be of interest and exciting to the range of students concerned and novel enough so that a solution has to be developed. Critical to intensive and comparatively expensive degree subjects such as engineering, in comparison to the humanities, the project needs to be compatible with the resources available. In addition any project needs to be achievable, at least to a base standard, by all participants while also providing scope for students to clearly demonstrate different levels of achievement.

The purpose of the assignment described in Section 3 is to enable students to explore the totality of the design process from initial brief to realisation of the design in a basic craft-based physical prototype at an early stage in the development of their engineering skills, prior to more challenging engineering assignments later in the degree program. This project takes place in weeks 8 to 11 of the first term in Year 1 for the MEng students in Mechanical Engineering and replaces a more conventional focus on detail drawing in the first half of the design course.

## 3 HOVERCRAFT ASSIGNMENT

The hovercraft provides an accessible example of technology that is reasonably familiar to the majority of students. The principles of its operation can be readily explored and explained and if combined with appropriate learning materials can lead to deeper understanding of a range of subjects such as Bernoulli's equation, fan thrust, prime mover power and efficiency and energy sources.

The specifics of the brief developed to date are listed below.

- The hovercraft is required to navigate a channel constructed of side walls and obstacles as indicated in Figure 1 and travel from the launch pad to the destination indicated. A series of about 40 minor obstructions will be distributed in the channel comprising ca. 26 mm diameter, 4 mm high cylinders. These will be clustered particularly near the channel walls. The hovercraft is required to successfully navigate the 6 m straight section of the channel and then turn into the right hand channel and navigate its path for a further 1.5 m to the destination pad.
- Reflecting the collaborative nature of design whereby the engineering activity typically involves implementation of diverse disciplinary skills and the exploitation of the collective insights of various people, this is a group-based assignment to be undertaken in a pre-assigned group of typically four students.
- Two commercial DC Motors and fans can be used in the hovercraft. Each group is supplied with two integral propeller fan-motor units for use with a 6 V DC supply. Two battery boxes for 4 AAA batteries with integrated on-off switches will also be supplied for each group.
- Power is supplied by DC batteries mounted on the vehicle. All wiring must be insulated and securely mounted. The maximum voltage allowed is 12 V. Students source and supply their own batteries for this assignment.
- An on and off switch for the vehicle must be incorporated in the design (if the battery boxes supplied are being used then these already have a switch). It is not acceptable to have to twist wires together to turn the vehicle on and off at the launch pad and destination respectively.
- Each group must construct the hull of its craft. Adaptations from 'model kits' are not permitted for this assignment. Groups may chose to construct the hull for their craft using material such as expanded foam, card or wood board. Light-weight construction is an important consideration. It is essential that appropriate attention is made to the health and safety requirements of the use or processing of materials. The maximum permissible plan form dimensions of the craft must be less than 500 mm by 600 mm.
- Wheels in contact with the running surface are not permitted.
- The vehicle must be autonomous, and self-contained, for its journey from the launch pad to the destination pad. Remote control is not permitted for this assignment.

In addition each group will be supplied with a limited supply of;

- expanded foam sheets;
- card;
- polymer sheeting (e.g. Corex);
- wood;
- adhesive and tape.

Students are not limited to the items supplied and are welcome to source their own motors, propellers and materials. Any materials to be formed or machined must however be accompanied by a CoSHH (Control of substances hazardous to health) statement and if necessary a risk assessment describing how any risk is to be mitigated against.

A hovercraft will float over a surface when the pressure beneath it, contained within its skirt is high enough to counteract the weight. It is possible to make a crude estimation of the flow rate from a lift fan in order for the craft to hover using Bernoulli's equation and this provided an opportunity to introduce the equation and the principle of conservation of energy and static pressure and flow velocity exchange. The corresponding model showing the fluid stations and principal dimensions for this analysis are illustrated in Figure 2. Propeller fans can also be used to increase the momentum of a fluid and produce a forward propulsive force and this subject was also explored as part of the project.

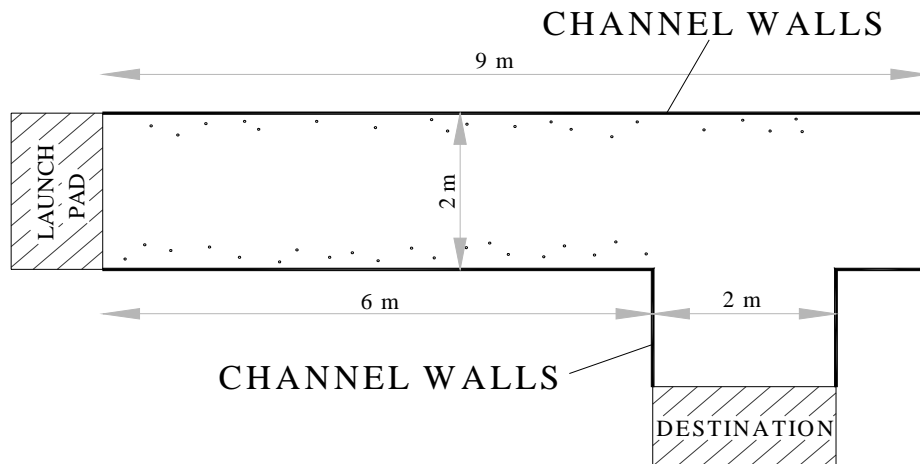


Figure 1. Sketch of the hovercraft test channel

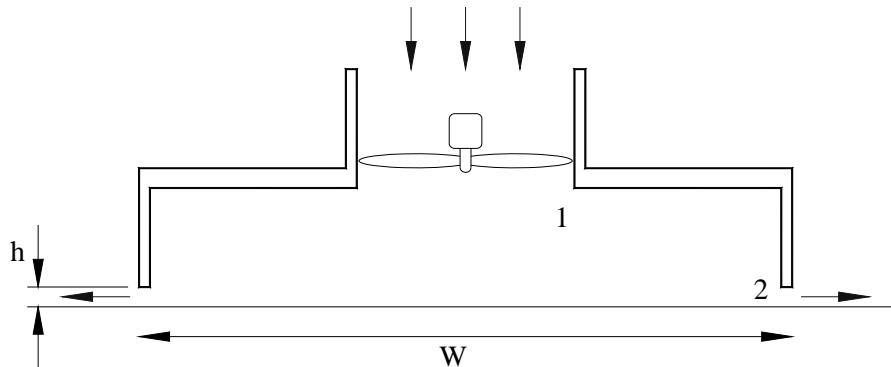


Figure 2. Crude hovercraft model

Course learning provision included weekly lectures, weekly subject tutorials, a VLE and CAD tutorials. The major element was the two hour subject tutorial where teams of four students met with a design tutor for two hours to explore and develop the project and subject materials.

The analysis strategy introduced and recommended to the students is outlined below. Students were encouraged to explore this both on paper and by means of a spreadsheet or mathematical package.

- Estimate the craft mass,  $m$
- Propose a flow gap,  $h$
- Estimate the efficiencies for the motor, fan and transmission  $\eta_{\text{motor}}$ ,  $\eta_{\text{fan}}$ ,  $\eta_{\text{transmission}}$
- Propose an area for the hull,  $A$
- Calculate the flow area for the gap,  $A_{\text{gap}}$
- Calculate the outward flow velocity component through the gap,  $u_{\text{gap}}$
- Calculate the volumetric flow rate through the gap,  $Q_{\text{gap}}$
- Calculate the pressure inside the hull,  $p_{\text{internal}}$
- Calculate the power required for the fan.

The analysis leads to a proposal for principal dimensions and features. However the power required by the fan dictates the current to be drawn from the batteries. This provides an opportunity for students to explore use of Ohm's law to see what the magnitude of the current is, check whether this is compatible with wiring and windings, and also to determine the life of the batteries based on the mAh rating for the batteries being used. If the values for power, current and battery life are inappropriate, alternative values for the area,  $A$ , gap,  $h$ , and mass,  $m$  can be explored.

The theoretical treatment offered for a hovercraft is extremely crude and merely provides an estimate of the internal static pressure required to support the craft. Real world influences such as surface form variations due to, for example, waves make the situation much more complex. More sophisticated analyses are possible, using for example an annular jet to model the air flows under the hull (see for example Houghten and Carpenter (1993) [5], Yun and Bliault (2000) [7] and Gates (1962) [8]).

Nevertheless the crude analysis presented here allows estimates to be made for primary quantities enabling the magnitude of system parameters and dimensions to be explored.

Following this rudimentary analysis, the groups of four students sketched out possible design concepts, and then used Solidworks to produce solid models of their designs before starting to construct their working hovercraft. This activity led to several design revisions before the final prototypes were produced, and stressed the many skills required to produce a manufacturable design, including the benefits of simple testing and effective team work. Two examples of hovercraft produced by student teams are given in Figure 3. Student designs from the first cohort of designs produced in 2009 could be broadly classified as:

- wall hugging (directed thrust);
- wall hugging (rotation);
- timed impulse mechanism (e.g. dropping ball);
- tethered anchor;
- timed vectored thrust;
- arc trajectory.



*Figure 3. Two examples of hovercraft produced by the student teams*

Timed mechanism devices included use of a 555 timer circuit to actuate a fan at a specific time, to control thrust flaps to provide thrust in a particular direction. A variation of the timer circuit that negated use of a 555 timer was a fuse wire connected to a power source, which was sized such that the fuse link burned through after about 5 seconds, compatible with the design's requirement to begin to turn right.

The assignment was assessed by means of the solid model produced, an annotation of the design and the performance of the prototype in a track set out at the end of term. Criteria recorded for performance of the prototypes included comments and data for the following criteria.

- Was the hovercraft presented for testing on time?
- Was the model finished?
- Did it hover?
- Did it only run straight, thereby not fulfilling the objective of the mission?
- Did the hovercraft turn right and complete the mission?
- What was the time for completion of the mission (this was recorded but was not a criteria for the

assessment and largely recorded due to popular demand by students and tutors)?

- What timing mechanism or other form of control was used?

A subsequent marking session where each of the student models was scrutinised by the course leaders was used to determine marks for the concept, construction quality, detailed design, control, mass and performance. The models were then deconstructed to ensure that the fans, battery boxes and any other re-usable items could be saved for subsequent years.

The assignment proved popular with students in Year 1 and was subject to considerable interest from the 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> year cohorts who had not taken the course, many of whom noted that they wished they had been given the opportunity to do it in their first year. The assignment led to substantial use of the mechatronics laboratory, a resource that otherwise had rarely visited voluntarily by year 1 students. A particular characteristic of the project was the huge amount of testing undertaken by the students outside of specified periods for the project to develop their craft. Students made great use of the corridors in the department, particularly those with a right-angled turn for testing. The motors typically drew about 2 A on start up leading to effective battery life of the order of ten to twenty minutes. This meant that teams each consumed several sets of batteries during the project and an unintended additional cost. The project has since been repeated with a Masters level cohort of students and similar behaviour was noted, although the level of build quality and sophistication was higher. It is recommended that two sets of rechargeable batteries are provided to each team and that several charging units be made available. It is proposed that water trays be used for subsequent projects for part of the course and additional or alternative pathways and obstacles can be implemented.

#### 4 CONCLUSIONS

The hovercraft assignment has provided an engaging activity for students in their first term of a mechanical engineering degree programme. One beneficial outcome in the context of mechanical engineering has been that students discover the value of electrical elements in design and this has already led to greater use of electronics related resources within the department.

The integration of basic engineering science analysis, sketching and solid modelling to produce practical designs which are then refined and made using their craft prototyping skills provides an early overview of the complete design process. Its introduction in the first term raises the profile of design to new students, and provides a change of style and pace from the more formal first year lecture courses plus tutorials which focus on detailed analysis of pre-created problems. Many of our students are not comfortable with the idea that there is no single 'right answer' and this project helps to reinforce that message at an early stage in the overall course. The later years of the undergraduate course build on this process with group and individual assignments of increasing complexity.

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