

Design-Led Engineering Education, Industry Links and Product Innovation - a Global Imperative

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Abstract

Over the past 30 years, Engineering education has encompassed advances in engineering science and analytical techniques, greater engagement with societal and management issues, and increasing globalisation through mobility of academics and the advent of the Internet. In an environment of reducing per capita government funding of university students, this paper advocates design-centred Engineering education grounded in fundamentals of engineering science, and increasing engagement with business and industry. It also emphasises the importance of an entrepreneurial culture among our engineering graduates and the value of a strong ethos of commercial research and commercialisation of intellectual property.

At the undergraduate level, the beneficial use of industry-linked and co-supervised student team final year projects is described, with reference to the Mechanical Engineering Honours project system at the University of Canterbury in New Zealand, and similar systems developed by universities in the UK and USA. The case is also made for running Engineering postgraduate research degrees as a combination of theoretical study, system design, computer modelling and prototype development.

The value of international travel and exchange fellowships for academic staff is illustrated by a teaching partnership developed between the University of Canterbury and the University of Bath which led to Internet-based collaborative design projects between final year students. The value of student international study abroad experience is also emphasised.

1. Introduction – the Environment for Engineering Education Today

The environment for Engineering education differs greatly from that which prevailed when as an assistant lecturer the author first lectured hapless students in Thermodynamics nearly 35 years ago. Comments in this paper reflect a career initially spent working in industry and subsequently 18 years in teaching Engineering Design¹, Product Innovation and Management. Many of the author's undergraduate and postgraduate project activities have been linked with industry, and in latter years increasingly involved in the commercialisation of intellectual property from university research and invention².

A number of factors have marked the past 20-30 years in engineering education:

- Advances in engineering science, analytical techniques, materials and processes.
- The advent of mechatronics, bio-engineering, and now nanotechnology.
- The advent of the internet and multi-time zone working by engineering project teams
- Greater international mobility in employment.
- Growing awareness of the need for sustainability in the design of engineering systems in a world with looming shortages of energy and material resources.
- Greater awareness of the need for engineers to have at least an introductory grasp of principles of management and finance, preferably some education in the humanities, and a broader grasp of societal issues so that the professional engineer can take more of a leading role in defining key public issues of the day.

- In the past 15 years, a decline in the per student capita public funding of universities and necessarily greater engagement between universities and business and industry (a good outcome from an otherwise serious situation).
- Emergence of a focus on entrepreneurship, assisted through the encouragement of students to develop commercial products from the outcomes of their project work.

These developments mean that today's engineering educator and student must both embrace a wider and more complex world than was required of them 30 years ago. This is a good thing but raises questions about how we educate and whether we should be lobbying our governments once again for funded five year degrees - or do we continue to rely on postgraduate degrees and on the job training for adding deeper knowledge?

A key risk we face in professional engineering is that the loss of fundamentals from engineering education means that graduates emerge with patchy understanding of basic laws of physics. The author believes that a strong grounding in the fundamentals of mathematics, physics and chemistry should continue as mandatory content, and that undergraduate education must also provide the student with an integrated body of engineering science and knowledge of engineering materials and processes, focused through the core of engineering design activity in learning which is strongly project-focused and which connects well with industry. There is nothing new about this but it provides a professional platform that has been repeatedly validated over time. Medical students spend much of their senior university years in a clinical environment. By analogy engineering schools need strong connections with industry partners, actively engaged in co-supervision of student projects in exchange for commitment of students to the partner industry for vacation practical work or sandwich years.

A focus for the paper is on the building of an entrepreneurial culture in our graduates by the shaping of a proportion of postgraduate projects as product design and development projects.

The past 20 years has seen huge growth in internationalisation of tertiary education,^{3,4,5} and throughout Australasia universities are dependent upon their international business to meet annual targets for operating surpluses. In some disciplines, particularly the Humanities and Social Sciences, a more international perspective is entering degree curricula. Engineering has always been an international discipline, in which practitioners share science, engineering methods and to a significant extent standards, and therefore engineering education has always been amenable to international collaborative activities. The paper describes how international visiting fellowships have been used at the University of Canterbury, Christchurch, New Zealand, to promote collaborative working with partner universities in the UK and USA.

2. Engineering Education and the Economic Development Imperative

The continuing rapid pace of technological and social change demands responsiveness from the education system to its current environment. In business and industry competitive advantage has moved from having skilled craftsmen in the 19th century, through achievement of production economies with mass production early to mid 20th century, cost efficiencies, quality and the exploitation of high technology in the mid-late 20th century, and being fast to market with new products as the turn of the century approached. After 2000 advanced communications and management of information in global workplaces and markets have become key competitive tools. Global engineering teams with 24 hour working and high speed communications are now commonplace. In this context, today's engineers not only need a broader skill base needed but have to deal with the following:

- More complex systems: larger numbers of components, greater variety of technologies; mechatronics and computer-based activation systems now the norm
- Rapid product development environments and concurrent engineering demand a higher level of systematic working than in the past

Australasian universities now operate with government funding of teaching of undergraduates typically at about 40% or less of total revenue. Additional sources of income are essential, and are delivered significantly by international students in a market which at best is highly competitive and turbulent. The decline in per capita student funding over the past 15 years has had the positive effect of driving universities to broaden their spectrum of activity, with traditional teaching and fundamental research functions augmented by stronger relationships with business, industry and community, and stronger streams of applied research, consulting and commercialisation of intellectual property. Figure 1 shows the interaction of the three functions of the modern university, teaching, research and community engagement. Figure 2 illustrates the mutual benefits of joint activities between universities and industry.

In recent years Governments have also looked for greater efficiencies from their research investment systems and sought closer collaboration among universities and between universities and organisations such as Crown research Institutes in New Zealand, or CSIRO in Australia. In New Zealand there universities have been encouraged to contribute to economic development by delivering graduates with more relevant professional skills, and by generating and commercialising intellectual property from research and product development activity. This has been accompanied by efforts between universities and the industrial sector to work more effectively together, given the difference in drivers for the two:

- for industry rapid product development, fast problem solving, production and profit
- for universities: primarily undergraduate and postgraduate teaching and excellent research, with generally longer time horizons than those of industry.

The New Zealand government has endeavoured to assist this process with funding through Technology New Zealand programmes such as Technology for Business Growth, Technology in Industry Fellowships for undergraduates, postgraduates and postdoctoral employees, the Pre-Seed Accelerator Fund and the Growth and Innovation Pilot Programmes.

In Engineering education today we have conflicting demands: the need for an increasing quantity of highly specialised knowledge and analytical techniques set against the need for greater breadth of education to enable the engineer to be more broadly effective in professional life, to make the transition to management more easily and to be able to contribute more to the wider issues that concern society. The modern professional engineer needs not only to understand principles of management and finance, but should have at least a smattering of the humanities in order to get by without seriously boring others in social situations! Today's engineers should have a key role in defining the important issues for society (especially in relation to sustainability), not simply being the problem solvers helping out in the backroom. Excellent communication skills are therefore vital and no professional engineer should graduate unless he or she has demonstrated good written and oral communication skills. This is even more important in a global commercial environment where well developed communication and negotiation skills can be vital.

Conflicting demands for greater educational breadth combined with depth in the engineering sciences and applied subjects lead to the risk of superficial treatment in some areas that were given much more emphasis in the past, for example strength and deflection calculations for machine or structural components, a heat transfer analysis, the variety of thermodynamics or

electrical engineering experiments, and time spent on detail design. Many Engineering graduates now emerge with a limited grasp of fundamentals, and having had minimal drills in engineering science. They may be proficient in using computer software packages but have a mediocre ability to get to the heart of real problems or carry out engineering sense checks.

There is a concurrent risk of fundamental know-how being lost as understanding of basic principles is perhaps shallower than in the past, and as areas of engineering education analysis or material selection become more automated and answers generated swiftly through high performance computing. We must manage this risk and sacrificing deep understanding of basic principles is not an option. Moreover, where some of today's graduates emerge with limited form design skills, there is the risk of re-introducing historically-solved performance problems in an engineering system because institutional expert knowledge in an area of practice has been lost. Managing this phenomenon is an area for research in its own right.

Design-centred Engineering education with strong grounding in the fundamental sciences provides a timeless and robust path for engineering learning. Overall, however, the author's view is that conflicting demands for both breadth and depth outlined above may only be met by a five year undergraduate degree, with specialisation still focused at postgraduate level.

3. Design-Centred Engineering Education and a Culture of Product Innovation

Over 2002-2003, New Zealand's Ministry of Economic Development funded a Design Task Force⁶. The author was fortunate to be a member of this group, which comprised a mix of design specialists from industrial design, furniture, fabric and packaging design, architectural design and engineering. A key outcome was a government-funded initiative to provide design audit services for industry, and an education programme to develop design thinking in business professionals and business understanding among design professionals. The global aim was to greatly increase the number of design-led companies in New Zealand achieving major export earnings over the next 10 years. The role of design-centred Engineering education (and possibly a mandatory module in entrepreneurship) is self-evident here.

The strong design focus of the Mechanical Engineering Degree at the University of Canterbury, as described in Reference 1, has produced generations of engineers who combine a strong grounding in the engineering sciences with capability in problem solving and design. The key to this programme has been the prominence of project-oriented learning in design as an integrating core subject every year, into which feed the inputs from the engineering sciences, mathematics, and materials science. An increasing focus on control and robotics in the 3rd and 4th year of this degree led to a separate Mechatronics degree option sitting between Mechanical and Electrical & Computer Engineering in 2003. This has also occurred earlier and frequently elsewhere. The introduction of a mandatory final year course in Industrial Management in 1993 was another development intended to give students a broader perspective on their future professional roles. This course also incorporated a section on Product Innovation as a pre-cursor to a Masters course in Product Innovation, both of these with a view to encouraging a more entrepreneurial outlook in our Engineering graduates.

What is engineering design? A general definition might be, "*Design is the creative, synthesising, problem solving and integrating process in engineering into which feed the various elements of the sciences and mathematics, business considerations and societal needs.*" Commonly, textbooks use definitions such as, "*Engineering design is the process of converting an idea or market need into the detailed information from which a product or technical system can be produced*" or, "*Engineering design is the use of scientific principles,*

technical information and imagination in the definition of a mechanical structure, machine or system to perform pre-specified functions with the maximum economy and efficiency.”

Design-centred Engineering education continually involves students in the open-ended ill-conditioned and often incompletely specified and conflicted problems of real life engineering. The comparison between the typical closed-form problem of science education and the design problems typical of engineering problems is simply summarised in Table 1 below.

| Table 1: Comparative Characteristics of Design and Analytical Problems | | |
|---|-------------------------------|-------------------------------------|
| | Analytical Problems | Open-ended (Design) Problems |
| Problem Area | Well Defined | Poorly Defined |
| Problem Statement | Precise | Vague |
| Information State | Sufficient | Insufficient |
| Solution | "Correct" Solution Obtainable | No Unique Solution |

In essence, design is an activity involving creative thought, synthesis of ideas, analysis and communication, with inputs that are incomplete or ambiguous and where there is no single correct answer. The complete design process from problem identification to production was well captured in Stuart Pugh's⁷ model, shown as developed further by the author in Figure 3.

So, what is the value proposition from design-centred Engineering education? It encourages

- The graduation of more broadly able and flexible professional engineers
- It helps universities fulfil their third mission – engagement with the community for economic and social benefit to both the university and the community
- A potentially higher number of product innovations from the university research and invention, and more graduate entrepreneurs working in product innovation.

Moreover, the engineer steeped in design thinking is used to making decisions under uncertainty and moves far more easily into senior management roles, the design problem solving approach being also typical of textbook management problem solving processes.

Industry-linked Final Year Project systems as used at the University of Canterbury and the University of Bath⁸ are now widespread. The Canterbury system, in which teams of four students work with an industry co-supervisor on a problem financially sponsored and co-supervised by the industry partner, is based closely on that which has been used very successfully by Harvey Mudd College⁹ in the USA. Many of these projects lead to design innovations with an industry partner or are pursued as postgraduate projects¹⁰.

The Harvey Mudd and Bath links to Canterbury were facilitated through the University of Canterbury Erskine Fellowship scheme which provides for 3-4 month hosting of senior academic visitors from overseas universities or other partner organisations. At Canterbury over a 12-year period this enabled reciprocal visits with Engineering Design staff from the Universities of Bath (3), Cambridge (2) and Strathclyde in the UK, and Harvey Mudd College, Montana State University, MIT, University of Dayton and Triodyne Corporation in the USA. Substantial numbers of staff from a large number of other engineering specialisations and overseas universities have also visited over the same period.

This interchange has been extremely valuable in mutual benchmarking of courses, and sharing and adoption of good features from each other's courses. International staff mobility, always a characteristic of university employment, has become more intensive and its benefits

have been extended through the use of the internet¹¹. International staff mobility will continue to assist teaching and research collaboration, but international student mobility is also important, and we need to seek all possible ways to enable students to experience a semester in study abroad at a partner overseas university. Such experiences are enormously expanding to the students' world view and their confidence.

Medland and Gooch⁸ report on an internet-enabled collaborative student design project between Bath and Canterbury Universities, dealing with devices to assist elderly and disabled personal mobility in the home. Although the Bath students were working on a project that more closely resembled the Canterbury final year Project (as distinct from final year Design), useful collaboration took place with the Bath and Canterbury students sharing concept designs and the different teams continuing to do their own embodiment and detail design work. The exercise was important in gaining understanding of the challenges in remote design collaboration, and in web-based and video communications.

4. The Postgraduate Project as Product Development Process

During the 1990's the author ran a number of postgraduate research projects towards Masters or Doctoral degrees as product design and development exercises. Examples were Henderson ambulance stretcher suspension¹², the scaling up of the Len Lye kinetic sculpture, *Blade*¹³ (Figure 4) and the development of the prototype for the WhisperGen Stirling engine based micro-cogeneration system¹⁴ now manufactured by WhisperTech Ltd in Christchurch, New Zealand. Launched in 1995 the company spent five years in pre-commercial development and trialling, with significant overseas testing and international expert business and technical input. Its markets are largely export and its first volume order of NZ\$300m was received from Europe in August 2004. Products include both an a.c. version (Figure 5) and a d.c. version (Figure 6). All of the above projects included the following elements:

- Creative and systematic conceptual design
- Theoretical analytical work and computer simulation of system performance
- Optimisation towards an objective embodiment and detail design of a prototype
- Supervision of manufacture, then testing (+ modification and re-testing) and analysis of experimental results.
- Comparison of test results with simulated performance
- Recommendations for future prototype work and/or technology transfer to industry.

For students in engineering this type of project offers the benefit of a broad and deep experience that involves theory, system modelling, design and development activity, with the potential bonus of a wealth generating product at the end of the process. This type of project provides students who have design aptitude and good analytical skills with an optimal postgraduate research experience.

Projects leading to pre-commercial prototypes provide feedstock for the high technology incubators which are now commonly located close to or in partnership with universities. The e-centre¹⁵ at Massey University is one such typical incubator and acts as an engine for industry and economic development on Auckland's North Shore. Benefits of collaboration will in the future lead to increasing concentrations of incubator activity and government research institutes operating in collaboration with universities and collocated on or close by university campuses.

Space does not allow discussion of technology commercialisation from research and invention, although these are now an integral part of most universities' activities². Such activities must be managed well to yield good returns and universities do not always make

money from this activity¹⁶. The potential benefits from and roadblocks to strong university-industry collaboration and commercialisation of intellectual property are also well covered by the Lambert Review of Business-University Collaboration¹⁷.

5. Conclusion

This paper has briefly advocated design-centred Engineering education, underpinned by a broad base of engineering science and basics of management. Mechanical engineers also need, through a systems approach to learning, a grounding in mechatronics, advanced materials, and an introduction to nanotechnology. Cultivating entrepreneurship is also vital to make the most of the creative and potential business talents of our engineering graduates. Demands on student time mean that we should again consider moving to a five year degree.

Growth of university-industry linkages can only benefit our students, whether through projects partnered with industry, or through enhanced opportunities for commercialisation of intellectual property arising from university research and invention. Student learning activities, research and technology commercialisation are all enhanced through the current opportunities for international student and staff mobility, and through internet communications. International partnerships will be of increasing strategic importance to universities both in their core teaching and research, and in their commercialisation activities.

6. Acknowledgement

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8. Biographical Information

Professor John Raine is Deputy Vice-Chancellor – Auckland & International at Massey University, New Zealand. He worked in product development and as Technical Manager at Froude Consine Ltd, U.K. 1975-77 and 1980-84. He worked at University of Canterbury, New Zealand, 1971-74, 1978-80 and 1984-2004, was Professor and Head of Mechanical Engineering 1998-2001, and Pro Vice-Chancellor (Enterprise and International) 1999-2004. He founded the University of Canterbury commercial arm, Canterprise Ltd in 1999, and co-founded WhisperTech Ltd in 1995 and the Canterbury Innovation Incubator in 2001.

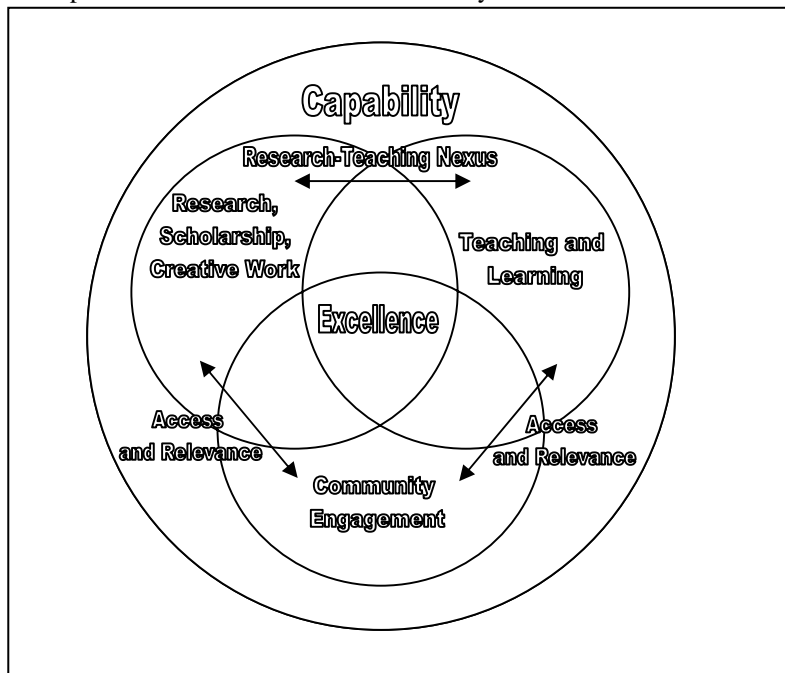


Figure 1: Interrelationship between teaching, research and community engagement

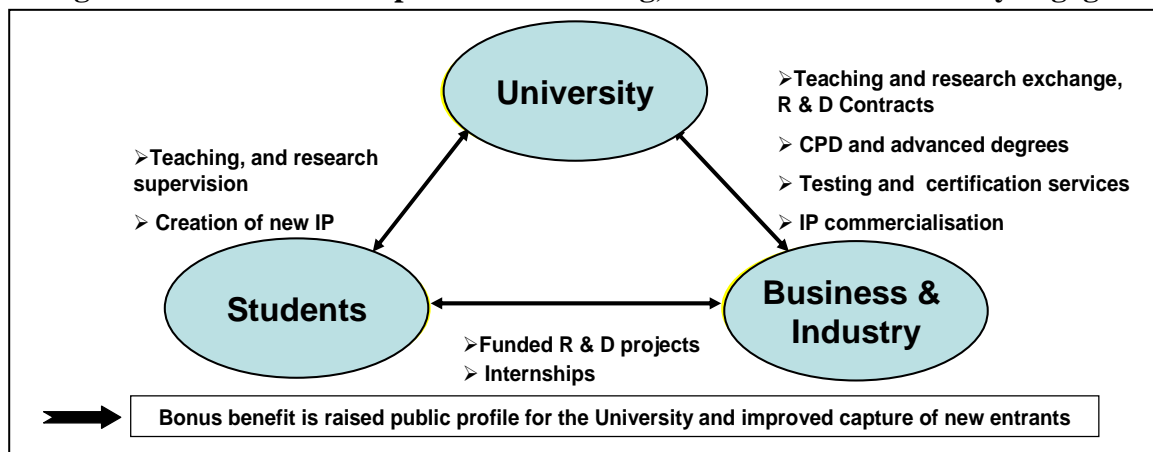


Figure 2: University-industry activities for mutual benefit

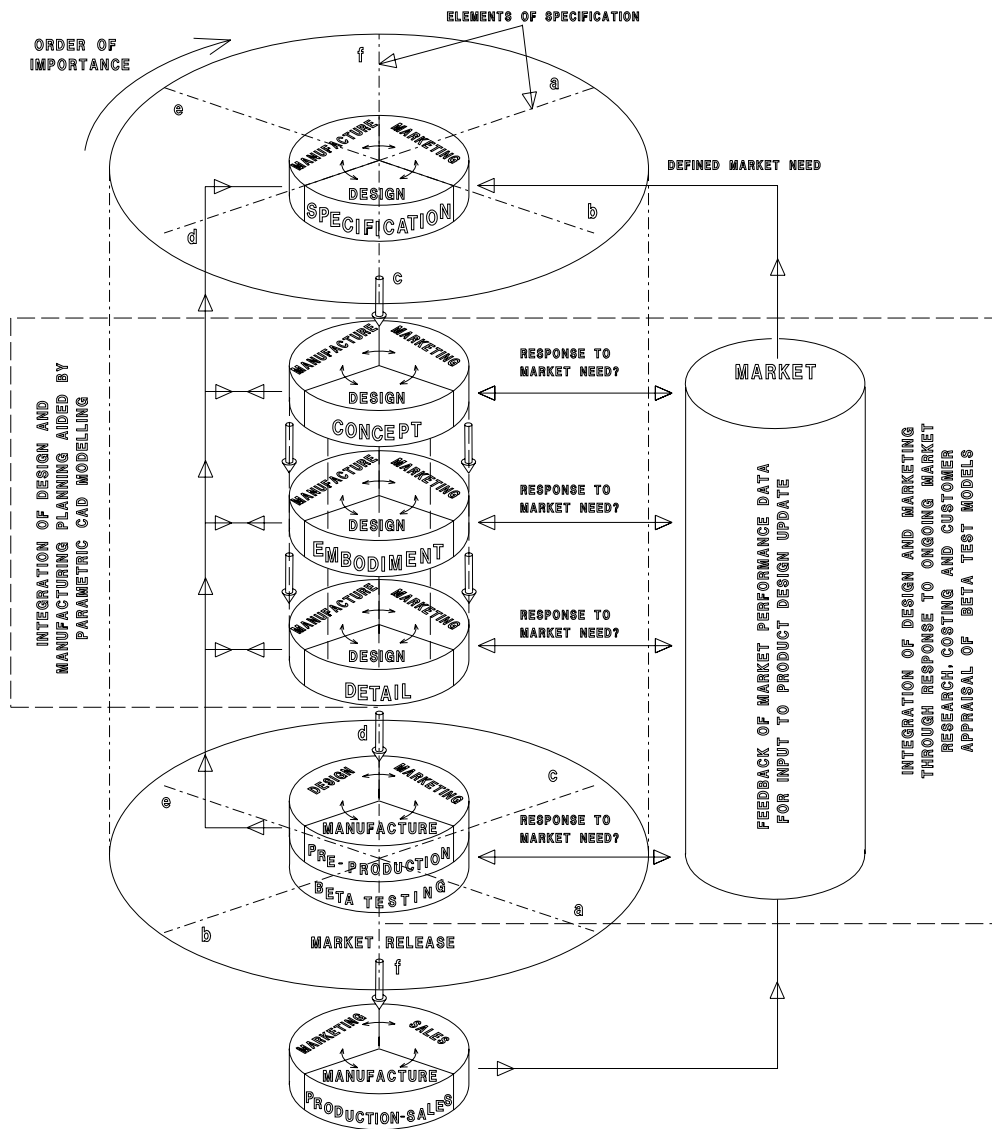


Figure 3 Development of Pugh [8] Total Design Activity Model with concurrent design, manufacturing planning and market development, plus increased focus on customer needs and the market

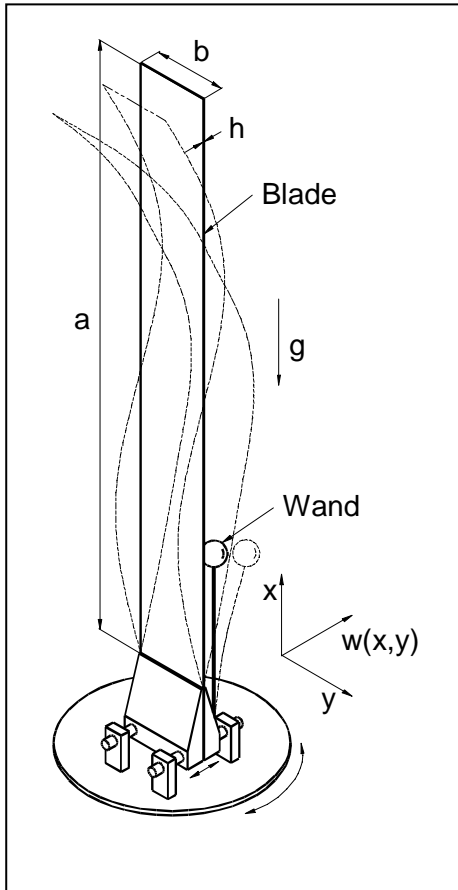


Figure 4: Schematic of *Blade* kinetic sculpture



Figure 5: WhisperGen a.c. system 2003



Figure 6: WhisperGen 1997 d.c. prototype field evaluation system