Design and Nature II

Comparing Design in Nature with Science and Engineering

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Design and Nature

Objectives

Our understanding of the modern world is largely based on an ever increasing volume of scientific knowledge. Engineering designers have at their disposal a vast array of relationships for materials, mechanisms and control, and these laws have been painstakingly assembled by observation of nature. As space activity accustoms us to cosmic scales, and as medicine and biology to the molecular scale of genetics, we have also become more aware of the rich diversity of the structural world around us.

The parallels between human design and nature has inspired many geniuses through history, in engineering, mathematics and other subjects. Much more recently there has been significant research related to design and invention. Even so, current developments in design engineering, and the huge increase in biological knowledge, together with the virtual revolution in computer power and numerical modelling, have all made possible more comprehensive studies of nature. It is these developments which have led to the establishment of this international book series.

Its rationale rests upon the universality of scientific laws in both nature and human design, and on their common material basis. Our organic and inorganic worlds have common energy requirements, which are of great theoretical significance in interpreting our environment.

Individual books in the series cover topics in depth such as mathematics in nature, evolution, natural selection, vision and acoustic systems, robotics, shape in nature, biomimetics, creativity and others. While being rigorous in their approach, the books are structured to appeal to specialist and non-specialist alike.

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COMPARING DESIGN IN NATURE WITH SCIENCE AND ENGINEERING

Design and Nature II

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Preface

This book contains the papers presented at the Second International Conference on Design & Nature held in Rhodes 2004 and it forms part of the book series of the same name.

The meeting attracted participants from all over the world. This diversity was parallel to the various trans-disciplinary contributions to the Conference, the subjects varying from design philosophy and architecture through to biology, including human biology.

The whole is more than just the sum of the parts. It expresses the aspiration of a fuller understanding of the concept of Design, specifically by comparing such in Nature, the Sciences and in Engineering.

Bill Bryson's incisive comments [1,p.217] that – 'in terms of adaptability, humans are pretty amazingly useless' is probably absolutely true in biological terms, but the contrast with man's scientifically designed systems, including locomotion, is almost equally absolute! This Design & Nature conference would never have been possible without the extreme adaptability of powered flight. Taking things further, what about the further 'adaptation' to space travel – that is outside the biosphere?

This raises the question that man, being part of the biological world, should not his very scientific and engineering achievements form a seamless continuation of his biology? Should not the natural and scientific worlds be considered as basically one world?

The editors are particularly grateful to all the members of the ISAC who helped to review the papers included in this book. The generous support of the ONRIFO, Office of Naval Research International Field Office is also much appreciated.

The Editors
Rhodes, 2004

[1]. Bryson,B. "'A Short History of Nearly Everything", Doubleday, 2003.

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Introductory Address

By:
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Man the Engineer – an interpretation of homo sapiens based on engineering thermodynamics

One of the key developments in the academic scene since the publication of 'The Origin of Species' has been the emergence of Engineering as a key discipline in its own right. Another is the realisation that the Laws of Thermodynamics, addressing concepts such as work, heat and energy, and being universal in their scope, must also apply to biology and living systems. Milestones in this realisation are the 'What is Life?' interpretation of Schrödinger, and the Nobel Prize winning activities of Prigogine, involving far-from-equilibrium thermodynamics. Current interest is in the information content of the genome, chaos and complexity, all with thermodynamics overtones.

A desirable overall objective is to discern the common ground in various parallel studies of entropy, complexity and biology. Within this, it is feasible to interpret living systems in general, and homo sapiens in particular, in terms of engineering thermodynamics. Re-defining the concept of 'heat engine' in terms of output, we may view certain animal species and man as 'work engines' and man also as a 'complexity engine'. A number of the examples are taken from the process of building the dome of the cathedral at Florence, a defining moment in the history of the Renaissance.

1 Introduction

The ethos of the Book Series on Design and Nature rests on the 'parallels between human design and nature'. The former is self-evidently largely an engineering activity. Today Engineering, including even the various branches of engineering, is a highly regarded University discipline in its own right. But this was not always so, let alone the idea that biology and engineering could have an advantageous dialogue.

Much the same could be said of thermodynamics. In Kondepudi and Prigogine's historical introduction to the Second Law of Thermodynamics, pride of place is given to James Watt who 'obtained a patent for his modifications of Thomas Newcomen's steam engine in the year 1769' [1, p67]. Now in a popular Encyclopaedia [2] Watt is explicitly described as a 'Scottish engineer'. Little did the Victorians of Darwin's day deem that thermodynamics had anything useful to say about biology. With the benefit of hindsight, however, the signs were already there, with Clausius' famous summary of 'the two laws of thermodynamics…

> The energy of the universe is constant.
> The entropy of the universe approaches a maximum'. [1, p84]

If thermodynamics could cope with the universe, why not with the biological material generated in the universe?

Now one of the key concepts of engineering thermodynamics is that of the *heat engine*, an 'engine that performs mechanical work through the flow of heat' [1, p69] and this was what Sadi Carnot studied in developing the origins of the Second Law. This is paralleled by the latest developments in Second Law interpretation originated by Prigogine and based on nonequilibrium thermodynamics. This allows 'a nonequilibrium system to evolve to an ordered state as a result of fluctuations' [1, p426] arising from the dissipation of free energy. Such are called *dissipative structures.*

The above brief discussion epitomises Kondepudi and Prigogine's approach to the extent that the subtitle of [1] is 'From Heat Engines to Dissipative Structures'. Also, from another Conference in 1986 in Piscataway, USA, Prigogine discussed [3] Schrödinger's 'What is Life?' study of 1943 [4] – which he termed 'Schrödinger's beautiful book'. One of the focuses is that 'living matter escapes approach to equilibrium', and Prigogine notes that it was one of the sources for his own interest. Now in the same Conference volume, Sungchal Ji [5] gives an exhaustive exposition of what he calls "Biocybernetics": A Machine Theory of Biology. One of his biological machines is the living cell, the model [5, p80] being named the Bhopalator, form another Conference at Bhopal, India in 1983. A crucial component of this machine analogue of the cell is 'Dissipative Structures of Prigogine'.

We end this introduction by noting that Ji concentrates on the internal workings of his biological machines, whether, for example, they are living cells, the human body, or even human society. However, if instead we view such living systems as 'Black Boxes', then perhaps they can be interpreted as adapted versions of Heat Engines. In so doing we will be able to combine the earliest and the latest studies of the Second Law of Thermodynamics.

2 Engineering thermodynamics

2.1 Engineering, T H Huxley and Kelvin

…now he lashed the techno-flunkeys from the temple – the 'Engineers…

Adrian Desmond [6, p249]

He deserves to be called a mathematician, as well as a physicist and even an engineer

Denis Weaire [7, p57]

I. K. Brunel, Engineer 1859 (Monumental lettering on the Royal Albert Bridge)

R C Riley [8, p8]

In contrast to today, the University status of engineering at the time of Darwin and T H Huxley was poor, to say the least. Whereas the former was happy to consult the Cambridge *mathematician* 'Professor Miller… this geometer' [9] on the structure of the honeycomb, Huxley saw *engineering* as a contamination of the purity of science. Desmond expresses Huxley's fear that the public veneration of Science would switch to its products, 'it *engines* and telegraphs' [6, p250, my italics]. We glance rather longer at Lord Kelvin (William Thomson), the 'Victorian superman' [10], p68): physicist, mathematician, and 'even an engineer', Denis Weaire so describes him. In the biological debate he loomed large, with his celebrated failure in mathematically modelling the earth in terms of its age. It has the added bittersweet for this paper, in that even at that time, Kelvin's elevated status included 'propounder of the laws of thermodynamics' ([11], p370). So Huxley 'in his role of defence counsel' ([11], p370) was right on this issue. Despite Kelvin studying the question over 'much of the second half of his career… he never came anywhere near getting it right' ([10], p69). The problem was the lack of the effect of radioactive heating (then unknown) in his model. Turning to engineering, J G Crowther, while noting Kelvin's 'seventy engineering patents' and his 'theoretical and practical engineering ability' insists this was at the expense of his not achieving highest scientific success. Had he 'concentrated … on a few fundamental problems he might have become … the second Newton' ([12], all quotes p236). These days Kelvin is viewed essentially as a physicist ([13], [14]). It seems to me, that apart from apologising for concentration on the preceding negative comments, a fresh appreciation of his engineering and thermodynamics is long overdue.

So there was certainly no dialogue between the Victorian biologists and engineers. But Huxley (Darwin's bulldog) was biting a very vigorous species that would not only survive, but thrive. In this case, too, the signs were already there. In the year of the 'Origin', I K Brunel completed his masterpiece railway bridge over the river Tamar. He wanted the world to know *he* was an engineer, so he told them so on his bridge! Also, Kelvin's brother James became a Professor of Engineering in 1873 ([7], p57).

Today things are so different, to the extent that biology and engineering seem to have a natural affinity. A few examples make the point. Apart from relevant papers in this Conference, there is the ethos of the recently published Volume 4 in the Design and Nature Series ‘Optimisation Mechanics in Nature’ [15]. Within this volume, the term biomimesis (or biomimetics) appears, describing the two-way interchange between biological and engineering materials [16. 17].

We conclude with a personal example. In joint research by two of the Series Editors, we are using design optimisation algorithms combined with a commercial Computational Fluid Dynamics code applied to the stenting problem in human arterial blood flow [18, 19]. The use of Genetic Algorithms rests on the fact that evolution of the fittest in micro-evolution is a parallel process to searching for optimum designs in engineering. Conversely, CFD is an engineering method which models the fundamental Navier-Stokes equations for fluid flow, but applied here to human biology. So a combined biological/man made situation is addressed by a combined engineering/biological approach, a further instance of the two-way interchange referred to above.

In conclusion, then, in complete contrast to the days of Darwin and Huxley, engineering is a ‘cutting edge’ discipline in Universities today. Part of that cutting edge are the numerous interfaces with biology.

2.2 Thermodynamics

The idea of stressing the engineering focus of thermodynamics is almost a tautology. However, the point is made by Mikielewicz et al, in their chapter on Thermodynamics in the introductory volume of the Design and Nature Series [20], that ‘a careful progression of precise definitions’ is crucial. We have already given Prigogine’s definition of a heat engine. This could be extended to: ‘a Heat Engine is a system operating continuously over a cycle, exchanging heat with thermal reservoirs and producing work’. This is shown in Fig 1 (Figure 8 of [20]), where the number of reservoirs is the conventional two. (Also, a direct Heat Engine is shown, but reversed heat engines for refrigerators and heat pumps are also possible – Figure 9 of [20]).

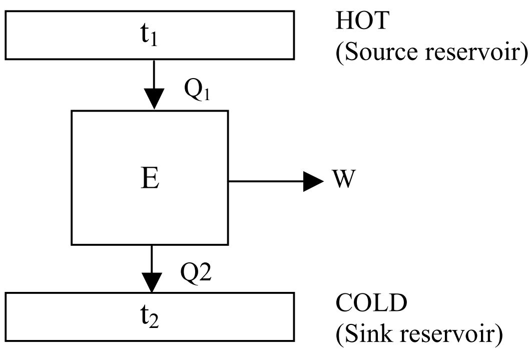

Figure 1: Heat engine diagram

The second aspect of engineering thermodynamics is the association of entropy with information, due to Claude Shannon, and dating from 1949 [21]. Because information is an *ordered* concept, a quantity of information is conventionally termed *negentropy*. The significance of information/complexity/entropy is discussed in the Series Introduction to the Design and Nature Series [22]. Here, we merely refer to the discussion by Paul Davies under the heading 'Where does biological information come from?' [23, pp 32/33] which concludes 'life ….imports information or negative entropy from its surroundings'. A rather fuller discussion, again in commenting on Schrodinger, is given by Prigogine [3, p 239]. Finally, we note that complexity, rather than information, is a preferred term ('…the complexity, or number of lists of information…' Hawking [24, p 163]).

We propose to present a unified treatment of biological organisms as thermodynamic Engines. We will re-define 'Heat Engine' in terms of *output*, and identify three alternative modes:

i) Survival Engine, relating to all species, including man (engineering equivalent, an idling Heat Engine)
ii) Work Engine, relating to draught animals and man (engineering equivalent, a Heat Engine proper)
iii) Complexity (or Information) Engine, relating to man only (engineering equivalent, Designing, Computing etc).

We will examine to what extent the biological and engineering aspects are self-consistent, and whether the Complexity Engine concept can shed light on the entropy/information equivalence.

Finally, the focus on the output of such Engines, allows the inclusion of pre-Industrial Revolution engineering in its scope. In fact, Brunelleschi's building of the dome of the cathedral at Florence will provide the majority of the examples used in this study. Information is derived from the recent publication of Ross King [25] and Paolo Galluzzi [26].

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