ASSESSING QUALITY OF IDEAS IN CONCEPTUAL MECHANICAL DESIGN

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ABSTRACT
A recurring theme in engineering design is the need to upgrade the performance of existing systems and products as potential defects overlooked in the original design come to light during operation and maintenance. This paper is concerned with the evaluation of skills exercised by designers when trying to solve "improvement" problems with attention focussed on their creative effort during the conceptual design phase. An investigation has been carried out in which an "improvement" problem selected from industrial practice was presented individually to thirty senior mechanical engineering students. Systematic analysis of their responses required the development of new research tools, firstly for assessing the quality of the design concepts proposed, and secondly for modelling the processes of ideation and argument used by each designer. Results are presented in terms of metrics for fluency of ideation, quality of concept, and branching preference, a new characteristic of designer performance found in this investigation. Further research is being undertaken to confirm the utility of the new research tools and the validity of the results obtained from their use.

Keywords: conceptual design, design modelling, quality of design

1 INTRODUCTION
Our research is concerned with the assessment of the performance of engineering designers when confronted with challenging problems from industrial practice. This is a wide-ranging topic, so we begin by describing the aspects of designer performance on which we will concentrate attention, and the context in which our investigation has been undertaken. Successful designers deploy a complex array of cognitive skills. From this array we focus on those skills associated with the generation of design concepts in the conceptual phase of the design process [1], when it is required to design significant enhancements to an existing product or system as part of a programme of continuous improvement and renewal. In this type of design problem innovative thinking is called for, and designer performance can then be assessed in terms of the quantity and quality of the design concepts proposed, and possibly also by the originality and flexibility of thinking displayed [2, 3]. Putting quality of concept on one side for the moment, we note that the other performance characteristics can be directly measured by quantitative evaluations based on the number and type of concepts proposed, and can thus be dealt with in an objective manner. On the other hand, assessments of quality typically require global subjective evaluations, usually by a panel of experts as in Yilmaz *et al.* [4]. It would greatly assist research into designer performance to have a systematic procedure for assessing quality, i.e. an orderly procedure that eliminated, or at least, markedly reduced the scope of any subjective decisions. The initial objective of our research was to develop such a procedure, investigate its applicability to the solution of a design problem drawn from industrial practice, then to report the results obtained in the context of other measures of designer performance. However, a necessary pre-requisite for such measurements is a means of representing designers' processes of ideation and argument during conceptual design. So a second research objective emerged, namely to devise a procedure for modelling the conceptual design process for the "improvement" problems selected for investigation. While the paper is intended as a contribution to the development of research methods, significant results from the application of these methods will also be reported.

2 THE CHOSEN PROBLEM IN CONCEPTUAL MECHANICAL DESIGN

2.1 Choice of Problem for Investigation — Design Brief — Administration

The research issues identified in Section 1 guided and informed the choice of design problem and the conduct of the subsequent experimental programme. As will become evident in what follows, the chosen problem (i) provided a significant challenge in conceptual engineering design, (ii) admitted a wide range of possible solutions and was thus capable of eliciting evidence of the creative effort of individual designers, and (iii) was embedded in mainstream mechanical engineering, i.e not an exotic or rare species of design problem, while at the same time being sufficiently limited in scope to ensure a manageable experimental procedure.

The chosen problem in conceptual mechanical design arose some years ago as part of an engine company's programme of continuous improvement. A maintenance issue had arisen calling into question the suitability of using a spit pin for retention of critical components. A summary of the design brief setting out relevant aspects of the case problem and the instructions given to those participating in this project is included as Appendix A.

The design brief was presented to mechanical engineering students in the third year of a four-year programme. All students had previously completed an introductory course on the discipline of engineering design constructed around the text by Samuel and Weir [5]. The students worked to a five week schedule with one design laboratory class per week covering successively problem formulation, conceptual design, detailed design of chosen concept, construction of demonstration model, reporting orally and in writing. In this investigation attention is focused on the second stage — conceptual design, where at the conclusion of the relevant design class students submitted their "idea logs" in the form of folios of sketches of the mechanisms they proposed. Students were strongly encouraged to generate ideas and proposals in a free flowing manner, postponing evaluations until the next stage of the design process. Thirty students worked individually on the project; they were designated S1 to S30 to preserve anonymity. The experimental evidence relevant to conceptual engineering design thus consisted of 30 sets of sketches of design concepts as recorded in the idea logs.

2.2 Generic Characteristics of Chosen Design Problem

Methods of classifying problems in engineering design have been proposed by a number of researchers, e.g. Ullman [6] and Samuel and Weir [7] at a general level, and Griffin [8] in relation to product development. It is sufficient for our purposes to consider here the two most important generic characteristics of engineering design problems, namely novelty and complexity.

Progress in technologies may be the result of a series of incremental improvements, i.e. evolutionary change as in Marples [9], Covington [10], or in contrast to this it may be the result of step changes involving entirely different methods or principles of operation [11]. While the chosen design problem is of the former type, it affords considerable scope for the exercise of mechanical ingenuity. We conclude that it rates highly on the dimension of novelty, but not so high as to require advanced creative skills, such as those necessary for a patentable invention [12].

Complexity in design is a multi-dimensional construct [13, 14]. In this investigation we consider complexity firstly, as an attribute of the problem space, essentially the number of functions the artifact being designed had to satisfy and the relationships between these functions, and secondly, as an attribute of the solution space, the geometrical complexity of instantiations of design concepts. Ratings of complexity are then as follows. *Functional complexity* — rated low as the design brief sets out only two functional requirements to be satisfied. *Configurational complexity* — rated low as the existing mechanism described in the design brief consists of a small number of components arranged in a straightforward manner. Its configurational complexity is low as will that of any practical alternative.

2.3 Overview of Responses to Chosen Design Problem

The responses of the student designers in the conceptual design phase of the project occupied 154 pages of sketches, often with some accompanying notes and commentary. 184 separate sketches depicting aspects of designers' conceptual thinking were initially identified and catalogued. Some sketches were excluded from subsequent analysis because they did not respond to the problem posed in the design brief, or because they offered vague, preliminary ideas that were later superseded. However, a few sketches indicated infeasible ideas that could, however, have provided springboards for further ideation, and so could not be dismissed out of hand. These sketches were included in the

experimental evidence for later interpretation and analysis, on the basis that “Being wrong is often an essential part of creativity” [18].
At this stage of the investigation 156 design concept sketches were available for examination. Two typical sketches are shown in Figure 1. The great majority of proposals retained the idea of a lever and a kinematic joint, either along the lines of the existing design by providing for a lever, pin joint and fork as three separate components, e.g. concept #1 in Figure 1, or incorporating the hinge pin with the lever as one component, e.g. concept #2 in Figure 1. (The reader is referred to Appendix A for explanation of the technical terms used, and to Appendix B — Section 5.3 — and Figure 4 for other examples of design concept sketches.) A few proposals were based on some form of ball and socket using curved surfaces to accommodate the required relative motion. Finally, in other more radical proposals the unison ring was replaced or extensively modified as the source of the input motion, some form of circumferential mechanism being created to impart the prescribed rotary motion to the Variable Inlet Guide Vane (VIGV) spindles.

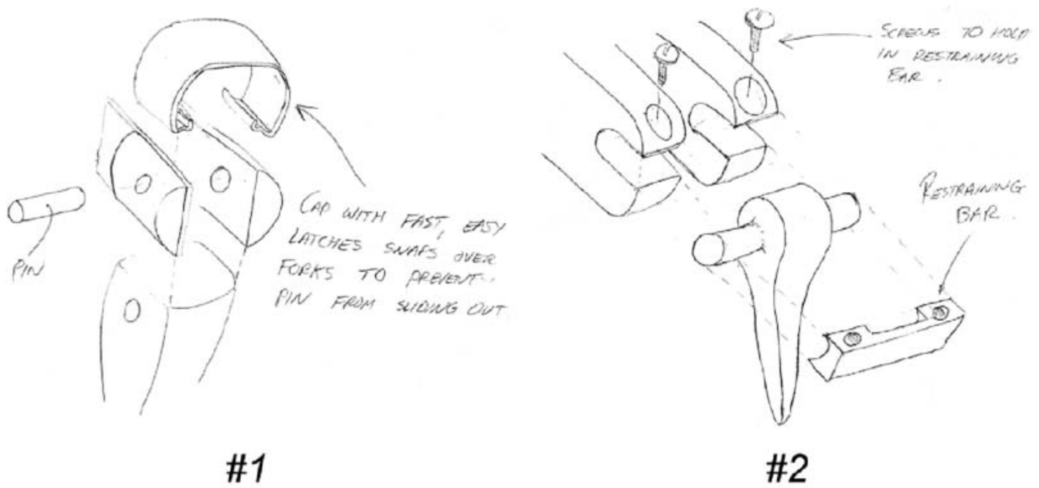


Figure 1. Examples of design concept sketches.

Further examples of design concept sketches are given in Appendices B and C where they illustrate the application of the quality rating schemes described below in Sections 3 and 5 of the paper.

3 DEVELOPMENT OF QUALITY RATING SCHEME

3.1 Quality — Hierarchy of Criteria

We envisage an assessment scheme comprising four levels in which quality is rated on a scale of 0 to 4 according to the answers given to an ordered sequence of binary yes/no questions as set out in Table 1 below. Successful completion of one level with an affirmative answer is a pre-condition for moving to the next level. The sequence of questions in Table 1 applies to all problems in engineering design having characteristics of novelty and complexity similar to those of the chosen design problem (as set out in Section 2.2). The contents of the Table specify a general procedure applicable to that class of engineering design problems of which the problem chosen for this investigation is a typical example.
The first three levels require straightforward binary yes/no decisions to be made. Thus, the first question in the sequence checks that a proposed design concept satisfies the functional requirements explicitly specified in the design brief and cannot be ruled out as a “non-starter”. The second question checks that a proposal satisfies functional requirements implicit in the design brief, which although not explicitly stated are essential to a successful final outcome, i.e. “hidden” requirements in Shah’s terminology [3]. In the case of the chosen design problem the need to be able to disassemble and reassemble the components of the mechanism for maintenance purposes is such a requirement. The third question, level 3 in Table 1, checks that the proposal under consideration does indeed improve product performance — for the chosen design problem by eliminating a potential defect or mechanism of failure, the factor which constituted the original reason for initiating the project. The criterion of

elegance is introduced at level 4. In the authors' experience, design professionals have an intuitive understanding of this criterion and readily arrive at consistent assessments.

Table 1. Scheme for rating the quality of design concepts.

	Question	Quality Rating after Answer	
		Yes	No
(1)	Are the explicit functional requirements satisfied?	1	0
(2)	Are the implicit functional requirements satisfied?	2	1
(3)	Is the potential defect or mechanism of failure eliminated?	3	2
(4)	Is the potential defect or mechanism of failure eliminated in an elegant manner?	4	3

Each level corresponds to an intellectual barrier to be surmounted by the designer in the pursuit of a design concept of high quality, and thus constitutes a necessary step on the path to success. All steps are equally necessary; there is no way of distinguishing between them, so in establishing a metric for quality we effectively assign the same value to all levels. Examples of the application of this quality rating scheme and of a later extension to it (see Section 5.2) are given in Appendix B; the rating so obtained being denoted *QRH*. The examples of elegant and inelegant ideas in Appendix B demonstrate that the notion of elegance can be readily apprehended and applied by professionals. To conclude this Section we point out that because we are searching for the best solution to the chosen design problem the quality rating assigned to the work of an individual designer is the highest of the various ratings awarded for his/her design concept proposals.

3.2 Quality — Independent Criteria

At this point we foreshadow later argument by acknowledging the possibility of a designer proposing a concept which does not satisfy the explicit functional requirements but which, nonetheless, contains an interesting and potentially valuable idea for eliminating the potential defect or mechanism of failure. Such a concept would be assigned a score (*QRH*) of zero according to the quality hierarchy procedure. But would this be a fair assessment? It could well be argued that the rating scheme adopted for assessing the quality of proposed design concepts should recognise and reward those concepts capable of stimulating further constructive ideation and thus act as springboards for innovative design thinking. This in turn suggests the adoption of an alternative quality rating scheme, but one still using a scale of 0 to 4. In the revised scheme one point would be allocated for each level successfully completed, so that a zero at an early level would not rule out the possibility of scoring points at later levels. In effect we replace a gated hierarchy by a set of independent criteria, and so denote the new quality score as *QRI*.

4 MODELLING DESIGN IDEATION AND ARGUMENT

4.1 Theory

The theme of this paper is the generation of design concepts as candidates for subsequent evaluation and decision. Our concern is with the provenance of ideas, the nature and extent of the problems to be identified and hopefully solved along the way to establishing the design concepts proposed as candidates for achieving the original design goal. Given the availability of designers' sketches and supporting commentary, we need some method of representing their design logic, i.e. the patterns of ideas and argument leading to the candidate solutions proposed. Marples found that he could model an innovative design process by a branching tree-like structure (here referred to as a design tree) as a new design evolved through the progressive solution of a series of problems and subproblems [9]. Thus a characteristic of innovative engineering design is that the attempt to solve the initial problem throws up subproblems for which subsolutions have to be generated, and these in turn lead to the next level of problems and possible solutions, and so on until problems at all levels of the design tree have been dealt with and a final solution obtained. A design tree of this hierarchical form has been adopted as the

basis for this research. In principle, it is relatively simple to construct, it graphically depicts the flow of design argument, and the provenance of each strand of argument is displayed.
We now extend the design tree methodology by including the successive sequences of ideation and argument which are an inherent feature of conceptual design, namely:
(1) recognition of problem or subproblem (chapter 5);
(2) generation of working principle or principles for potential solutions (chapter 6);
(3) embodiment of working principles in engineering hardware (chapter 7);
where the chapters in Pahl and Beitz [19] describing these phases of the design process are noted in parentheses. This formulation is similar to the step procedure incorporated into the design guidelines proposed by Günther and Ehrlenspiel [20] for improving the working methods of experienced designers.

4.2 Application of Theory — Construction of Design Trees

As expected, the analysis of students' responses revealed a common pattern of three stages, a pattern which was replicated at successive levels of the design trees. We provide two examples — the concepts sketched in Figure 1 — to illustrate the modelling process introduced in Section 3, noting that the initial problem at the top of each design tree consists of designing a mechanism to fulfill two kinematic functional requirements — FR1 and FR2 defined below. The relative position of components is indicated by the schematic diagram in Figure 2, where for each VIGV spindle to rotate by a prescribed amount (determined by the gas flow through the compressor) the functions FR1 and FR2 must be achieved.

FR1: rotate VIGV spindle about its axis, the axis being radial in a plane perpendicular to the horizontal axis of the compressor

FR2: provide motion in the third dimension as the end of the VIGV spindle moves "up" and "down" with respect to a given point on the rotating unison ring.

The reader is referred to Appendix A for further explanation of the technical terms used here.

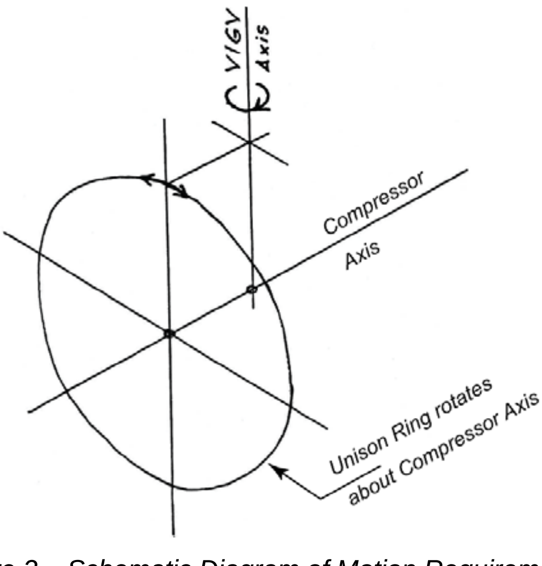


Figure 2. Schematic Diagram of Motion Requirements..

The two strands of design argument corresponding to concepts #1 and #2 in Figure 1 are shown in Table 2 with the following notation.

FR1 and FR2:	as above.
WP:	working principle for candidate solution.
EMB:	physical embodiment of candidate solution.
SubPr:	subproblem thrown up by a candidate solution.

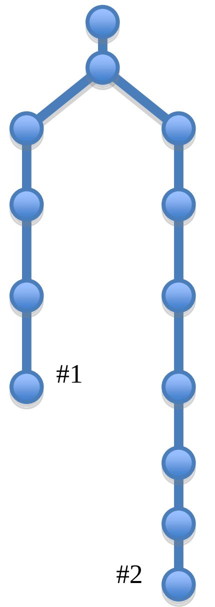
It will be seen that Table 2 contains three sets of triads comprising (i) Levels 1, 2 and 3, (ii) Levels 4, 5 and 6, and (iii) Levels 7, 8 and 9, respectively. The design tree constructed to represent the sequences of ideation and argument is shown on the right hand side of Table 2 (on next page). Each node corresponds to the completion of one stage of the design argument by a designer. The top node at Level 1 represents the identification of the primary functions FR1 and FR2, whilst the lowest node in each strand represents the final outcome, a sketch of the candidate solution proposed. Design trees were constructed to represent the work of each designer, and the resultant individual design trees (IDT's) provided the input to the next stage of the investigation.

5 CHARACTERISTICS OF DESIGNER PERFROMANCE

5.1 Introductory Remarks

We focus attention on what were found to be the leading characteristics of designer performance in this investigation, namely, (i) ideational fluency, measured by the number of strands encompassed by the IDT of the designer, (ii) quality of design concept achieved, as explained in Section 3, and (iii) a new metric derived from the designers' IDT's, as explained in Section 5.2 below. Other characteristics such as ideational flexibility and originality were investigated but did not yield distinctive information. Flexibility was extremely highly correlated with fluency, so much so that it had to be regarded as a different aspect of the same creative attribute. And as the majority of designers generated original proposals not duplicated by any of their colleagues, originality also could not be considered a distinguishing characteristic in this investigation.

Table 2. Examples of strands of ideation and corresponding design trees.

Level in Design Tree	Examples of Design Concepts		Design Tree for examples #1 and #2
	#1	#2	
1 — FR1, FR2	As specified in text of paper		
2 — WP	Lever and Pinned Joint		
3 — EMB	Lever, Hinge Pin, Fork, as separate components	Hinge Pin integral with Lever	
4 — SubPr	Maintaining integrity of assembly	Method of assembly	
5 — WP	Retaining force provided by elastic deformation of component	Split surfaces on end of Fork	
6 — EMB	Clip-on external cover (as sketched)	Plane of split perpendicular to VIGV axis	
7 — SubPr	—	Maintaining integrity of assembly	
8 — WP	—	Retaining cap	
9 — EMB	—	Embodiment with retaining screws (as sketched)	

5.2 Branching Preference

Analysis of branching in an IDT yields a finer grained picture of a designer's creative effort. To illustrate this point we examine the work of three designers — S1, S2, S3 — who each generated six strands of ideation in their IDT's, but did so in significantly different ways. Figure 3 shows in skeleton format the IDT's representing their patterns of ideation.

Multiple branches emanating from a node at a Subproblem Level (Levels 4 and 7) represent the generation of alternative working principles for solution of the subproblem concerned. Multiple branches emanating from a node at a Working Principle Level (Levels 2, 5 and 8) represent the generation of alternative embodiments of a particular working principle. It is clear from an examination of the Design Trees in Figure 3 that some designers create more branches at a WP level while others create more branches at an EMB level. This observation leads us to define Branching Preference (B) as a characteristic of designer performance as follows (equation 1).

$$B = \frac{n_{EMB} - n_{WP}}{n_{EMB} + n_{WP}} \qquad (-1 \le B \le 1) \qquad \text{Equation 1}$$

Where n_{EMB} = the number of nodes where branching occurs at an EMB Level.

Where n_{WP} = the number of nodes where branching occurs at a WP Level.

These definitions cater for cases where one of the four quantities in the numerator and denominator is zero.

If $B > 0$ designer has a preference for creating embodiments.

If $B < 0$, designer has a preference for creating working principles.

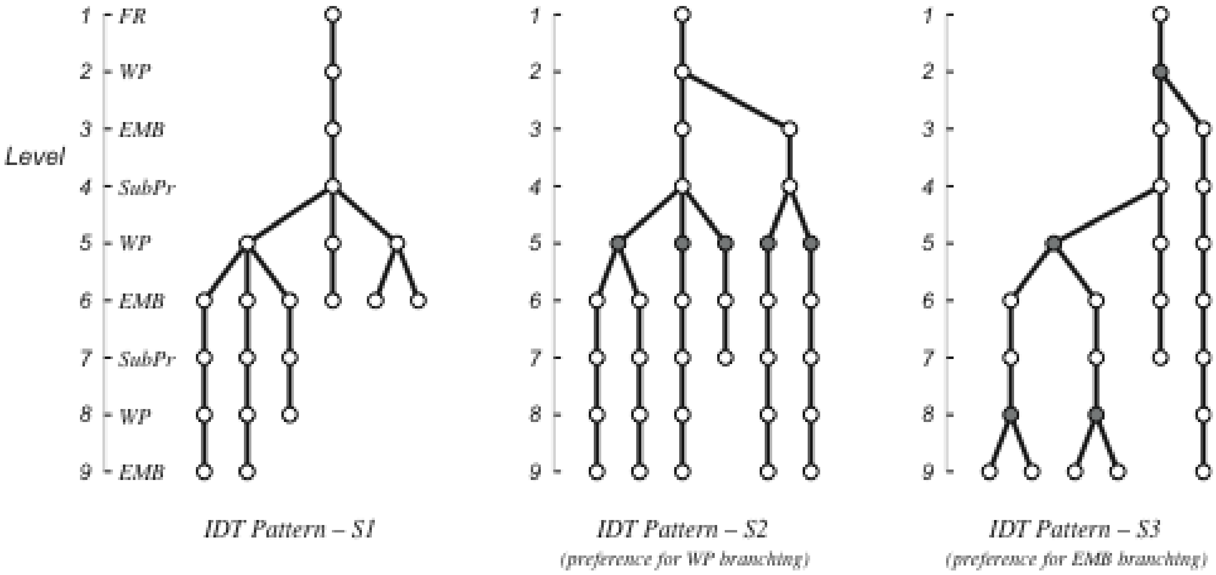


Figure 3. Patterns of ideation — Skeleton IDT's.

5.3 Extended Quality Rating Schemes: QRH_5 and QRI_5

We have seen how the creation of working principles, when identified as a separate step in design ideation, led to the formulation of branching preference as a new parameter of designer performance. In a similar manner the quality rating (*QR*) schemes developed in Section 3 can be extended to include a question based on the elegance of a new working principle proposed by a designer. We are thus led to extended *QR* schemes of five questions, in the order as set out below and producing scores in the range 0 to 5. For scores based on a hierarchy of criteria, denoted QRH_5, we have -

Question	Quality Rating After Answer: Yes	Quality Rating After Answer: No
Questions (1) to (3)	(as previously in Table 1)	
(4) Is the working principle of an elegant solution proposed, WP level in Design Tree ?	4	3
(5) Does the embodiment of this working principle represent an elegant solution to problem posed, EMB level in design Tree ?	5	4

Examples to demonstrate the application of this procedure to the assessment of the quality of design concepts at each of the five levels are given in Appendix B.

Furthermore, as pointed out earlier in Section 3 it is possible to derive quality scores by considering each question independently of the others and allocating one point for each affirmative answer. The resultant metric can take values in the range 0 to 5 and is denoted QRI_5. An example of a proposal which scores positively on *QRI* but for which *QRH* = 0 is given in Figure 4. The sketch in Figure 4 shows a mechanism that does not satisfy the explicit functional requirement of transmitting motion in three dimensions. On the other hand, the concept of a set of cam operated, spring-loaded sliders has merit, recognized in this instance by a positive *QRI* score.

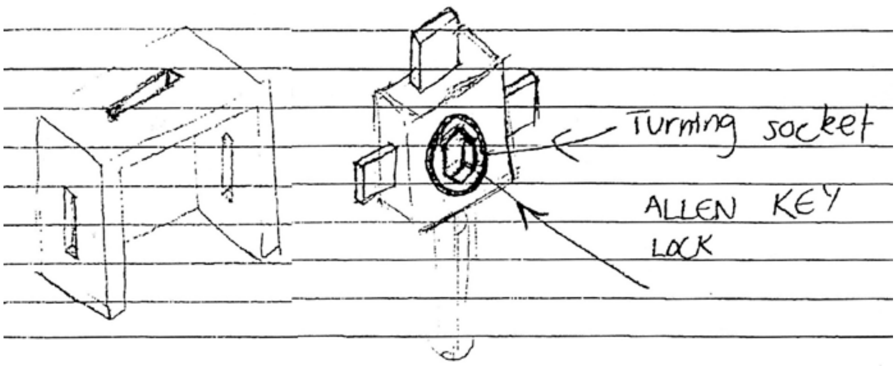


Figure 4. Example of Design Concept of Ambivalent Quality

6 APPLICATION TO CHOSEN DESIGN PROBLEM

6.1 Results

The theme of this paper is the assessment of quality of design concepts, and the investigation of possible correlates, notably designers' fluency of ideation and branching preference. Results relating to quality of design concept and the correlations obtained are set out below.

Statistics:	Original *QR* Scheme		Extended *QR* Scheme	
	QRH_4	QRI_4	QRH_5	QRI_5
Range	1 to 4	2 to 4	1 to 5	2 to 5
Mean Value	3.03	3.40	3.30	3.67
Standard Deviation	1.17	0.80	1.44	1.07

Correlations:	Original *QR* Scheme (QRH_4 & QRI_4)		Extended *QR* Scheme (QRH_5 & QRI_5)	
	Fluency (*F*)	Branching Preference (*B*)	Fluency (*F*)	Branching Preference (*B*)
Quality of concept (*QRH*)	0.41 **	0.34 **	0.50 ***	0.38 **
Fluency of ideation (*F*)	–	0.20 *	–	0.20 *
Quality of concept (*QRI*)	0.43 **	0.48 ***	0.55 ***	0.50 ***
Fluency of ideation (*F*)	–	0.20 *	–	0.20 *
Explanation of notation:	*	correlation is not significant.		
	**	correlation is significant, $p < 0.05$.		
	***	correlation is highly significant, $p < 0.01$.		

Regression analysis:

Analysis of the dependence of Quality Rating (*QR*) on Fluency (*F*) and Branching Preference (*B*) yielded the following results for the 5-point rating scales.

$$QRH_5 = 2.58 + 0.65\,B + 0.16\,F \quad (r = 0.58) \qquad \text{Equation 2}$$

$$QRI_5 = 3.40 + 0.76\,B + 0.10\,F \quad (r = 0.75) \qquad \text{Equation 3}$$

Equation 3 shows that 75% of the quality measure QRI_5 can be explained by fluency (approx 50%) and branching preference (approx 25%). Branching preference has much less influence on QRH_5 (equation 2); the reason for this is obscure, but hopefully will be uncovered by further research.

6.2 Discussion

Overall: The inter-correlations between the four measures of quality (*QRH*, *QRI*, 4- and 5-point) were very high (in the range 0.7 to 0.8), indicating that they all derive from the same fundamental characteristic of creative designer performance.

Quality: The general method proposed for assessment of quality of design concepts consists of a series of domain-independent decisions which are straightforward to apply. The element of subjectivity — an inevitable component of judgments of quality — is significantly reduced, but not eliminated, by requiring the negotiation of three binary decisions before asking that a subjective judgment of elegance be made.

Quality versus Quantity: No matter which of the four quality measures is used, there is a highly significant correlation between designer's quality of concept and ideational fluency. This is consistent with the results of psychological studies of engineering creativity in which it as been found that the quality of ideas generated by engineering problem solvers is significantly correlated with their quantity, i.e. with their fluency of ideation [21, 22]. That this is the case provides evidence to support the use of the quality metrics proposed in this paper.

Branching Preference: No matter which of the four quality measures is used, there is no significant correlation between branching preference and ideational fluency. This evidence supports the conclusion that branching preference is an independent characteristic of the performance of designers engaged in conceptual mechanical design.

Differences between Quality Metrics: When the statistically significant correlations are considered, results for the 5-point scales show higher levels of significance than those for the 4-point scales, perhaps indicating a richer information content. On the basis of this evidence use of 5-point scales is provisionally recommended, but confirmation of this recommendation must await the results of future research into quality issues.

Research Tools: The methods developed for assessing the quality of design concepts (Section 3) and for modelling design thinking in "improvement" problems (Sections 4 and 5) yield useful and consistent results, and provide new insights into the skills exercised by engineering designers. Within the designated scope of this investigation (Sections 1 and 2), the use of these tools in engineering design research is confirmed.

7 CONCLUSION

In an investigation into the skilled performance of engineering designers, the authors were confronted by the need to develop a scheme for rating the quality of ideas generated during conceptual design. The investigation had been initiated in the context of a class of design problem arising from companies' desire for continuous product improvement, with attention paid to the components of assemblies critically affecting product performance. [Section 2]

A new scheme for rating the quality of design concepts was developed in which global judgement was replaced by an orderly step-by-step procedure constructed around a sequence of binary yes/no decisions. [Section 3]

A model for the representation of designers' ideation and argument was developed by extending previous research of decision trees in conceptual design to include the generation of the working principles of proposed design concepts as a separate stage in design thinking. Design trees were constructed for each designer taking part in the investigation, enabling the measurement of designer performance in terms of ideational fluency and branching preference. [Section 4]

Characteristics of skilled designer performance were identified. These included a new metric, branching preference, derived from the individual design tree of the designer concerned. Branching preference indicates the extent to which his/her creative effort depends on the generation of working principles for new design concepts as against the generation of embodiments of previously established working principles. [Section 5]

The quality rating scheme devised in Section 3 was successfully applied to the chosen design problem, and yielded measures of designer performance susceptible to statistical analysis. Subsequent analyses revealed significant correlations between quality of design concept on the one hand and the designer's fluency in generating ideas and his/her branching preference as exhibited in the relevant design tree. Fluency and branching preference were not significantly correlated, a result which suggests that branching preference is a useful characteristic for distinguishing between the skilled performance of different designers. [Section 6]

To test and extend the generality of the results reported here, further research is being undertaken based on the responses of other engineering designers to design problems of a similar level of novelty and complexity to that employed in this investigation.

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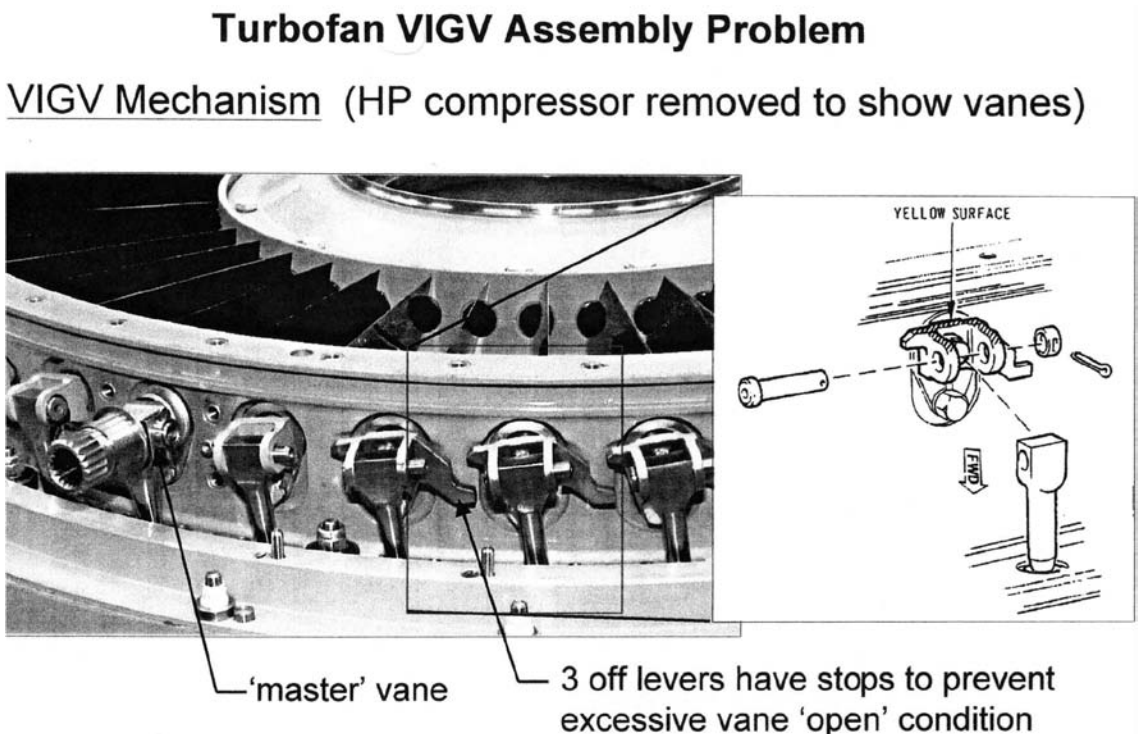
APPENDIX A: DESIGN BRIEF

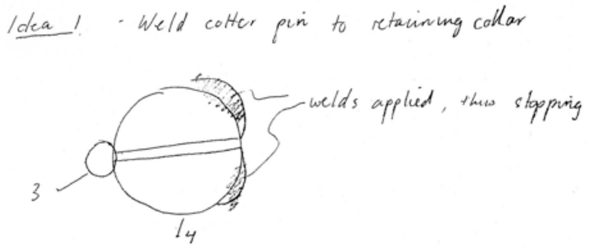
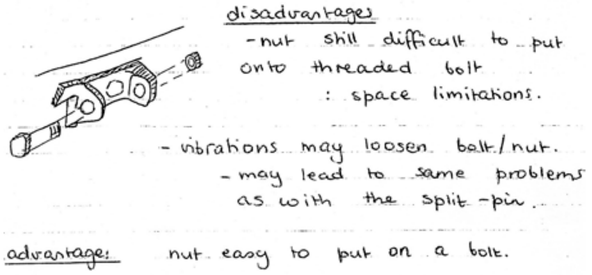
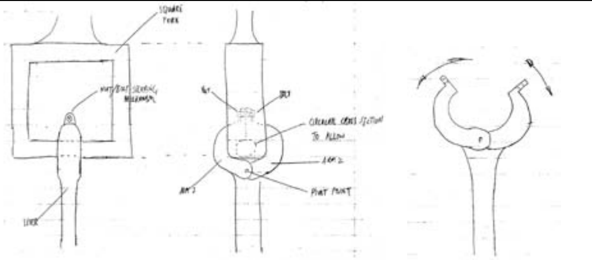
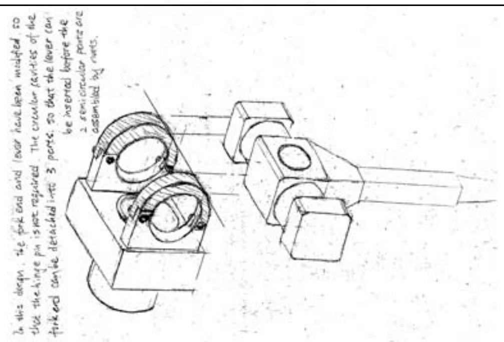
A potential problem has been identified in relation to the assembly of the variable inlet guide vane (VIGV) mechanism of a medium-sized turbofan jet engine, a two-spool turbofan having two compressors each separately driven by its own turbine. The compressors consist of successive stages of rotor blades and stator vanes. In order to match the orientation of the compressor blade and vane aerofoils to the velocity of the air flowing past them over a wide range of engine speeds, the stator vanes are adjusted relative to the speed and power setting of the engine. The existing mechanism for doing this is illustrated in the diagrams below. The engine under consideration has a single row of 42 variable vanes (VIGV's) at entry to the HP compressor. At the outer end of each of these vanes is a fork, set at a precise angular position relative to the vane aerofoil. An actuating lever is attached to the fork end by means of a hollow hinge pin. This allows the lever to control the angle of the vane, whilst also allowing the lever to pivot in a plane at right angles to that of the vane angular movement. The hinge pin is retained in place by a split pin, which in turn is held in place by having its two legs bent apart. The VIGV levers of all 42 vanes engage in spherical bearings, which are housed in and equally spaced around an actuating ring, also known as a unison ring. The actuating ring is located axially and radially by several small bearings, so that it rotates concentrically with the row of vanes and the engine centreline. The ring is turned through a set angle by a rotary actuator, which drives through a master vane and lever.

As a result of an in-service incident some years ago there appears to be a risk of the split pins not being fitted correctly, due to human error. Although rigorous inspection practices will minimise any risk, design improvements are being sought to completely eliminate the risk. The objective of this exercise is to evolve potential design solutions to the split pin problem and prepare a report for company management. During the conceptual phase of the design it is essential that you keep an Idea Log of your design thinking, and fill it with hand sketches and brief notes.



APPENDIX B: QUALITY RATING SCHEME

Criteria are defined in Sections 3.1 and 5.2 of paper. The right hand column of the table below contains examples of design concepts for each of the quality ratings *QRH* = 1 to *QRH* = 5.

Quality Rating	*Criterion satisfied by design concept*	*Criterion failed by design concept*	*Example design concept*
$QRH = 1$ (for QRH_4 and QRH_5)	1 (concept satisfies explicit requirement)	2 (concept fails to satisfy implicit requirements)	
$QRH = 2$ (for QRH_4 and QRH_5)	1, 2 (concept satisfies implicit, explicit requirements)	3 (concept liable to similar mode of failure)	
$QRH = 3$ (for QRH_4 and QRH_5)	1, 2, 3 (concept satisfies first three criteria)	4 (clumsy, inelegant working principle proposed)	
$QRH = 4$ (for QRH_4 and QRH_5)	1, 2, 3, 4 (acceptable working principle proposed)	5 (clumsy, inelegant embodiment proposed)	
$QRH_5 = 5$	1, 2, 3, 4, 5 (elegant embodiment of working principle proposed)	n.a.