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Fan Technology: Evolutionary Potential and Evolutionary Limits

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ABSTRACT

For the last 5 years, the world has generated an average of 400 new patents per year in relation to the design of fans. This article describes a programme of systematic analysis of these and earlier patents. The purpose of the research has been to establish the evolutionary status of fan technology across a number of the different sectors of the fan industry, to benchmark the capabilities of the different sectors relative to one another, to benchmark capabilities relative to a *global* measure of evolutionary maturity and then, most importantly, to identify future development directions and opportunities for the industry.

INTRODUCTION

This article is aimed at setting a global context for fan technology. Such a broad-ranging ambition requires the foundation provided by TRIZ (Reference 1). One of the main findings from the TRIZ research, as regular Journal readers will know, is that different scientific and engineering disciplines spend a large proportion of their time re-inventing what has already been discovered in other areas.

A large part of the focus of the more recent (1998-2004) research has been on the mechanics of system evolution (Reference 2). The research has had a particular focus on what happens when systems evolve in a non-linear, discontinuous manner from one way of doing things to another. A large part of the interest here has been on the identification of jumps that are common to all industries and disciplines. To date, the research has uncovered 35 such generically applicable discontinuous technology evolution trends. Although it is something of an over-simplification, it is useful to think of these trends as different s-curves as illustrated in Figure 1.

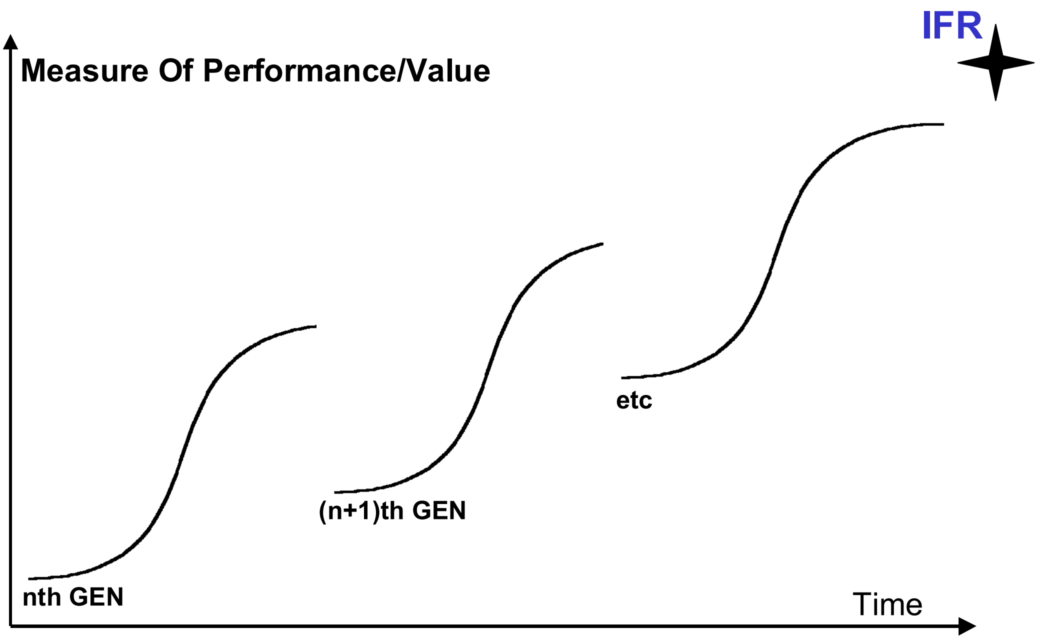

Figure 1: The Fundamental Dynamic Of System Evolution

The evolutionary s-curve dictates the evolution of all systems. The research into evolution dynamics has also shown that all successful innovations possess an attraction to an ideal end-state. That end-state – defined as 'Ideal Final Result' (IFR) – is that the system delivers the functions and benefits that a customer requires, without any cost or negative harms. While this end-state might often sound somewhat theoretical, there are many examples of systems and components that have evolved to such a state (Reference 3). What Figure 1 shows is that the dynamic of evolution towards this end-state occurs through a succession of s-curves. Key to the understanding of the overall dynamic is the recognition that all systems hit fundamental limits: The flattened profile at the top of an s-curve is not an indication that the market or engineers cease to be interested in improving a system, rather that something emerges to prevent the improvement from taking place. In other words a conflict or contradiction emerges and a system hits a fundamental limit as a consequence. The only way, then, to go beyond this fundamental limit is to find a new s-curve. Finding a new s-curve means resolving the contradiction. The 35 uncovered trends (there may be more waiting to be uncovered, but 35 is the current total) in turn represents patterns describing how those contradictions have been resolved.

This article uses these 35 trends as the global benchmark against which fan technology can be compared. The article describes some of the main trends and the concept of evolutionary potential as a means of comparing the absolute maturity of a system against a global standard of discontinuous system evolution. Beyond this, the article describes the analysis of two extreme ends of the fan technology spectrum to demonstrate that, despite the fact that many in the industry would assume that fans are a well-matured technology, even those designs pushing the state of the art have considerable untapped evolutionary potential left in them. Conversely, the article also indicates areas where technologies are hitting fundamental limits.

TRENDS OF EVOLUTION AND EVOLUTION POTENTIAL

By way of introduction to the form and content of the discontinuous trends uncovered during the innovation research, Figure 2 illustrates a trend known as 'space segmentation'.

This trend describes the evolution of the use of space inside structures. According to the trend, when engineers and designers first configure a system it is likely to comprise a solid structure. Then later, a hole or cavity of some description is added. The reason why such a jump occurs changes across different industries – so that in some it will be to reduce weight, or the amount of material used, in others it will be to change inertia properties, in others to increase surface area, and in yet others it will be space to add something else. The jump from solid to hollow, however, is consistent across all of them. Likewise, the jumps to the next stages of the trend – multiple hollows and then capillary and porous structures – are common across different industries, but for shifting reasons.

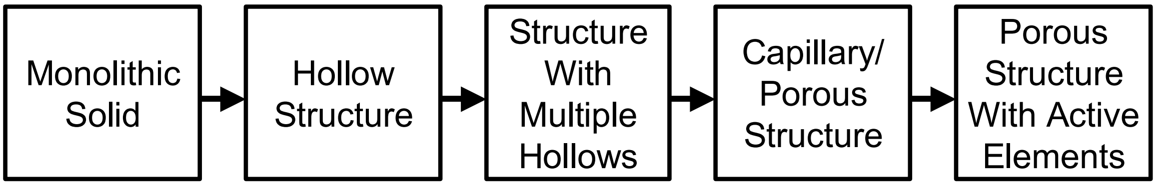

Figure 2: 'Space Segmentation' Discontinuous Evolution Trend

The main idea suggested by the trend, then, is that systems generally evolve in a left-to-right direction, becoming 'more ideal' at each stage. Again the important idea is that the jump from one stage to the next represents a discontinuous shift from one way of doing things to another. Occasionally systems will evolve 'the wrong way' along a trend. There are a number of underlying reasons why this might happen – all of them so far are predictable. The most common reason for a backward jump is that a backward step in along one trend is (in the short term) necessary to facilitate a forward jump along another – more important – trend.

Thinking specifically about fan technology, it is possible to observe the fact that a fan-blade on a gas-turbine has evolved to the third stage of this space segmentation trend (and is already heading towards the fourth in some companies) – Figure 3, while a cooling fan for a micro-processor is still likely to be at the first stage. The reason why the gas-turbine fan has made the advance is because the strength-versus-weight conflict is considerably more acute in a component weighing several kilograms compared to one measurable in grams. Nevertheless, according to the trend, because the micro-processor cooling fan is still at the first stage, it possesses considerably more untapped potential. As the demands on these fans continue to evolve, they are highly likely to have to use up the unused space segmentation potential in order to achieve the desires that engineers require from them. These desires may have nothing to do with weight of course – in which case the evolution to hollow and multi-hollow systems is likely to occur for other reasons. Like for example in this specific case to achieve noise absorption or improved (self)-balancing properties.

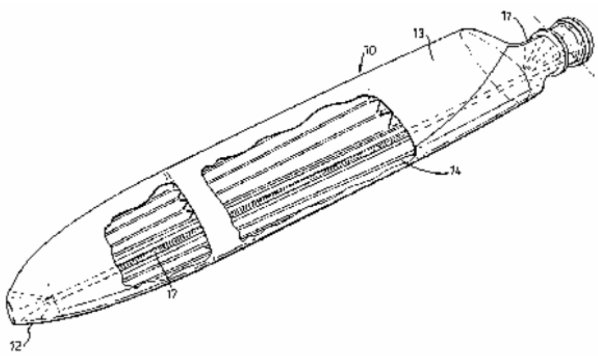

Figure 3: Typical Fan/Propellor Blade At 'Multi-Hollow' Evolution Stage

Figure 4 illustrates another of the trends, this time the one known as 'dynamization'. This is a trend concerned, as the title suggests, with the way in which things move relative to other things. Again the trend is drawn in such a way that systems evolve in a left-to-right direction, with each stage representing a discontinuous advance on the preceding stage.

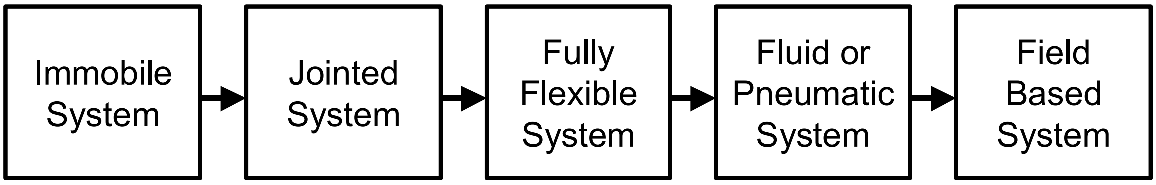

Figure 4: ‘Dynamization’ Discontinuous Evolution Trend

Here is another trend with direct relevance to the evolution of fan systems. This time, however, it is necessary to think a little more abstractly to connect between the design of a fan and a stage on the trend. Fans rotate, but yet the majority of them would be classified at the first ‘immobile’ stage of the trend. The important connection here – and an indication of the way in which the best advantage can be made of the trends – is that there is *some* aspect of a fan that is immobile. If the fan blades operate with a fixed pitch then they would be classed as ‘immobile’ since the orientation of the blades is not designed to shift. In modern gas-turbine fan designs, the designer makes functional use of the inevitable inertia-generated movement of the blade when it is spinning at different speeds in order to produce a functional benefit. In this case, the design style has jumped over the jointed stages (although there have been several examples of variable pitch fans which have made use of joints) to the third stage. This trend stage leap-frogging action occurs frequently – especially since more and more users become familiar with the trend.

The fourth and fifth stages of the dynamization trend are difficult ones as far as fan evolution are concerned. If a fan design is at the third stage of the trend, then it has two stages of untapped potential remaining. Both of these jumps are, however, comparatively large ones – away from mechanical to fluidic and ultimately field-based methods (where ‘field’ is intended to signify any type of field – whether it be electrical, magnetic, gravitational or any other connection that a user can make from the deliberately generic label). In both of these cases, current technological limitations prevent gas-turbine fans from making the jump (but the trend has given us a good indication of where enabling technology research would be well-placed). In micro-processor cooling systems on the other hand, we are already beginning to observe solutions that are eliminating mechanical fan components in favour of ‘field-based’ cooling systems – e.g. Peltier Effect based cooling devices. The jump from left-to-right in this case is occurring because field-based systems tend to be inherently more reliable (the fan is usually the life-limiting component in a PC), more controllable and less noisy.

In reality, these two trends, and the other 33 presently known, all operate in an integrated fashion. The ‘evolution potential’ concept is a means of observing the trends together. The basic concept is very simple: In order to examine the overall evolution potential of a system, it needs to be compared against each of the trends in turn. Immediately it will be seen that some of the trends are not relevant – typically, in fact between 10 and 25 of the 35 will be useful in analyzing any one system. The non-relevant trends (which will shift from one application to another) are eliminated from the analysis. Each of the remaining ‘relevant’ trends is then compared to the system under evaluation and an assessment made of how far along the trend a system has reached.

Thus, if the fan of a gas-turbine is under evaluation relative to the ‘space segmentation’ trend, a state-of-the-art design will be at stage 3 of 5 possible stages. Likewise, relative to the ‘dynamization’ trend, a state-of-the-art fan will be at stage 3 of 5. Repeating this process for each trend in turn, and then arranging each trend as one spoke on a radar plot reveal a picture of the overall current evolutionary state of the fan. The basic idea is illustrated in Figure 5.

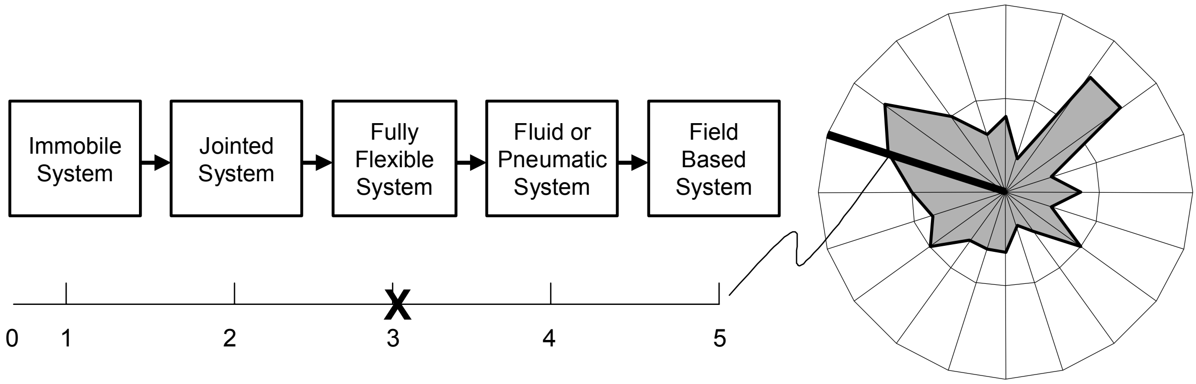

Figure 5: Evolution Potential Radar Plot Structure

The perimeter of the radar plot represents the frontier of engineering knowledge against each of the known trends. Thus the empty space between the current evolutionary state of the system described by the shape at the centre of the picture and this perimeter represents the untapped potential of the system. If, therefore, there is a desire to improve some aspect of a current system, the trend lines and the untapped potential act as sign-posts indicating the directions that other successful systems have evolved in. (Reference 2 describes this evolution potential evaluation process in more detail for interested parties.)

It is almost impossible to convince anyone that *all* of the jumps on *all* of the trends lead to better designs in *every* area, on *every* occasion. In twelve years of using the trends, however, this author has not found a single exception. This despite having a full-time research team who spend every day examining new inventions in an attempt to disprove the known trends and to find new trends. Sometimes we aren't smart enough to work out why a jump should take place, but inevitably over the fullness of time we will see that reason becoming apparent. Whether or not people 'believe' the trends – and it is certainly not the purpose of this article to attempt such a feat – at the very least they should be viewed as a potent way of focusing and directing short-cuts to better solutions. In part this is where the term 'systematic innovation' – the emerging name of the overall methodology surrounding these trends – comes from.

EVOLUTION OF GAS-TURBINE FAN SYSTEMS

Given the basic evolution potential 'global benchmarking' concept and the radar plot format, it becomes possible to use the capability in a number of ways. Examining the various generations of design of fan systems in the gas-turbine industry and overlaying the plots for each, it becomes possible to see how quickly the evolution potential is being used. Figure 6 illustrates such a composite picture highlighting the jumps that have taken place from the first fan blades to the most recent.

The plot labeled '1' describes the evolutionary state of the first generation fan blades. In simplified terms, then, stage '2' represents the evolution of the first hollow blades and the use of 3D aerodynamic designs (hence jumps along the 'space segmentation' and 'geometric evolution' trends). Beyond that, stage '3' represents what may be thought of as the current generation of metal-technology blades. As suggested by the trend jumps, these designs possess multi-hollow, honeycomb construction, are snubberless ('reducing system complexity' trend), and make full use of all of the available geometric freedoms (including things like sweep in both radial and axial dimensions), and are designed to operate 'optimally' at several design conditions rather than just a single design point, due to the use of the untwist that occurs at different operating speeds ('design point' trend). The fourth stage may be seen to represent the recent incorporation (or rather ‘re-incorporation’ – reference the problems of Rolls-Royce in 1971!) of composite elements to the blade – represented in discontinuous jump terms as advances along the ‘decreasing density’, ‘webs-and-fibres’ and Mono-Bi-Poly trends.

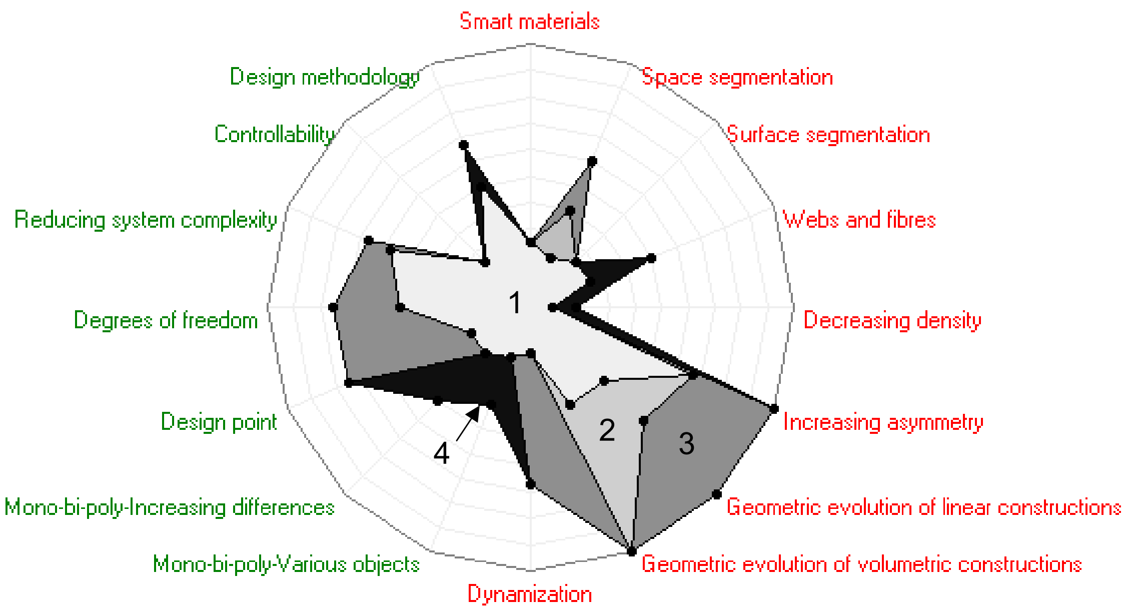

Figure 6: Evolutionary History Of Gas-Turbine Fan Blade Technology

What is perhaps most interesting about the current evolutionary state is the amount of remaining untapped potential still available. Undoubtedly fan technology may be seen to be mature in terms of geometric evolution – once all of the available dimensional freedoms have been used, there is nowhere else to go, for example – but this is merely the perspective of the aerodynamicist. Looking beyond geometry, however, and the plot shows there is still considerable potential for future improvement.

It is beyond the scope of this article to explore this untapped fan potential. What can be said with some confidence though is that each unused trend represents opportunity for not only the step-change improvement in some aspect of the design of a gas-turbine fan, but perhaps more importantly, in the direction of future research and the generation of new intellectual property.

EVOLUTION OF COMPUTER COOLING FAN SYSTEMS

Without wishing to denigrate the design maturity of fan-systems for computer cooling applications, an equivalent evolution potential of a typical micro-processor cooling fan reveals rather more untapped potential. Figure 7 illustrates a schematic of a recent Compaq cooling fan patent and the corresponding evolution potential radar plot. The plot in this case reveals that the designers of this fan have not taken advantage of many of the jumps utilized by gas-turbine fan designers. From a geometric evolution perspective, for example – a series of jumps that need have no negative impact on manufacture cost – the cooling fan still has a considerable way to go to catch up with what has been done by aerodynamicists in the gas-turbine sector.

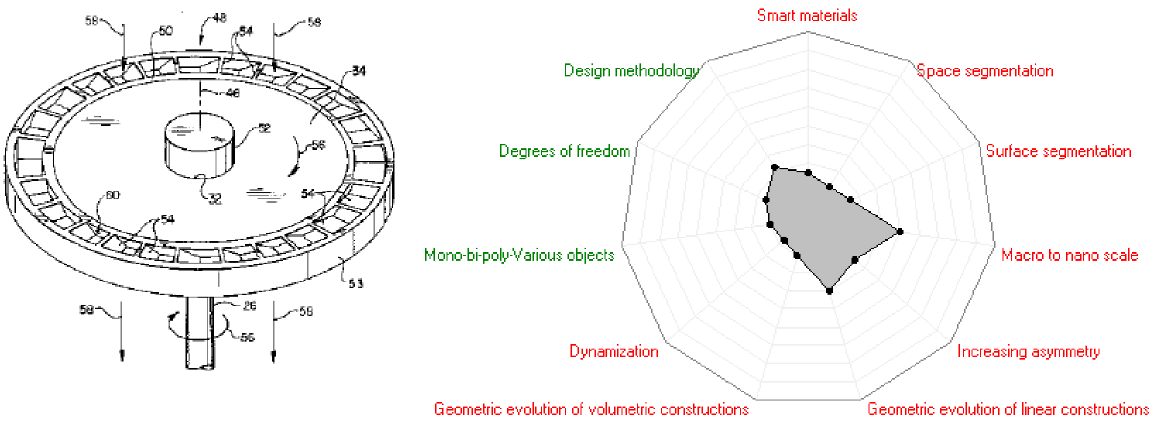

Figure 7: Evolutionary Potential Of US6,359,856 Fan (Compaq)

One of the most interesting aspects of the Figure 7 Compaq design is that it has integrated the design of the fan into the disc-drive motor, and as such has eliminated the need for a separate motor drive. In this regard, we may observe that the fan motor has reached its ideal final result state since the required drive function has been delivered, but now it is done by something else that already exists in the system. This is an important aspect of the overall innovation dynamic – components may well be eliminated from systems before they use up all of their untapped potential. The important issue here is that the possibility of eliminating some components emerges when other components use up more of their untapped potential. Thus, the elimination of the separate fan motor in the Compaq case is made possible by an advance along the Mono-Bi-Poly trend of the disc-drive motor.

A much more important point about the evolution dynamic emerges when we examine a more recent patent than the Compaq one. US6,699,013 was granted to Quantum Corporation in March 2004. This patent also integrates the cooling fan into the disc-drive motor drive chain. Looking at the evolution potential plot for this system and comparing it with the Compaq design, however, reveals an important advance along the 'dynamization' trend Figure 8.

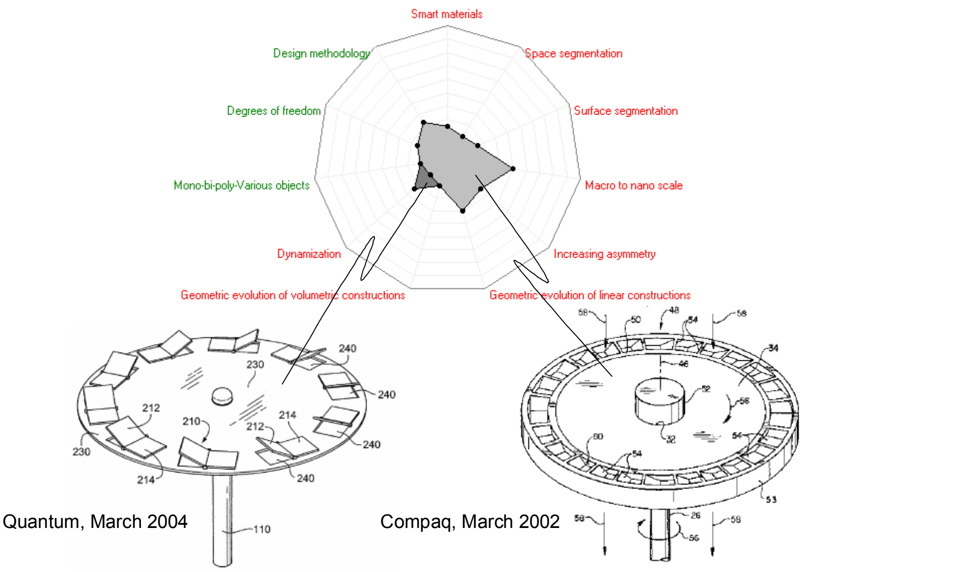

Figure 8: Evolutionary Comparison Between US6,359856 And US6,699,013 Fans

What Quantum have recognized that Compaq perhaps didn't is that the disc-drive motor acts in both forwards and backwards directions and that while the fan might operate well traveling in one direction, it may well not operate as efficiently in the other. Here is an important contradiction. It is one that Quantum solved by making a single jump from an immobile to a jointed system.

ACCELERATED EVOLUTION – IMPLICATIONS AND OPPORTUNITIES

The real issue here is that it took two years to make this simple jump. Had Compaq been thinking about the trends of evolution in general, and the dynamization trend in particular, it is interesting to speculate on whether they would have made the connection that Quantum did somewhat more rapidly. Irrespective, though, of whether Compaq actually chose to incorporate such a design into one of their systems, an evolution potential analysis would have allowed them to at the very least recognize and protect the idea so that none of their competitors could have used it. This connection to the generation of IP is probably the most important aspect of all when the implications of the discontinuous trends of evolution uncovered during the systematic innovation research are considered.

The discontinuous trends offer the potential to considerably accelerate the evolution of systems (References 4 and 5). Every unused stage on the gas-turbine fan or the Quantum Corporation design or any other fan system we may care to put under the spotlight represents the opportunity to design a better system. The trends encourage designers to ask new questions when they are designing any kind of component. As suggested in Figure 9, by comparing our current system with each of the trends (in this case 'dynamization' has been used as an example again) and making a connection with one trend stage, all of the unused trends stages to the right of that connected stage represent potential solutions. We may not know what problems such jumps might solve yet, simply that based on what other successful inventors and problems have found, somewhere, somehow there is an advantage in moving from left-to-right.

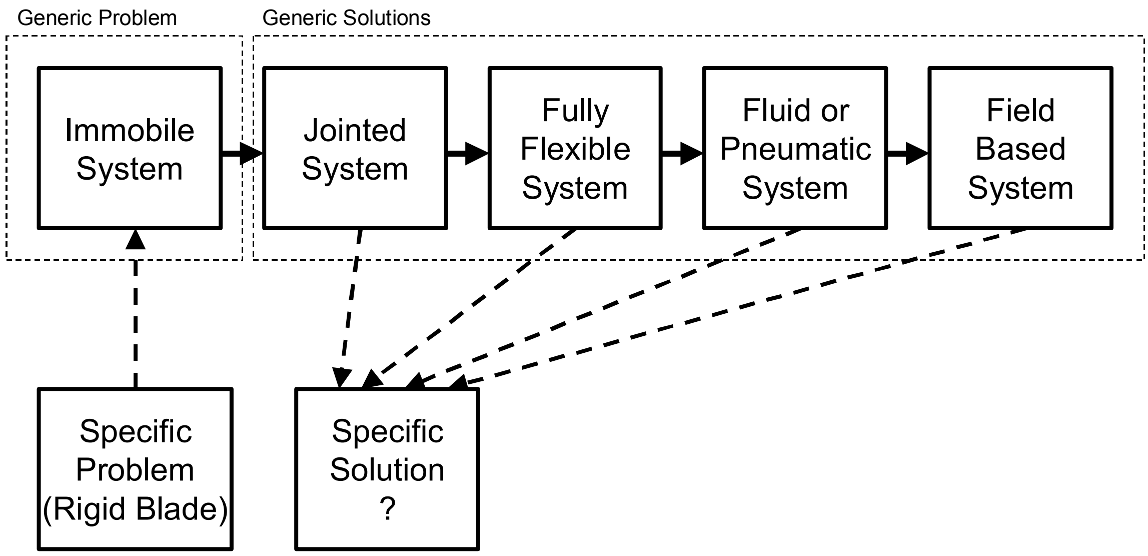

Figure 9: Trends As Evolution Sign-Posts

One of the big ideas in systematic innovation is that someone, somewhere already solved a problem like yours. The trends represent a summation of the general directions those problem solvers have taken.

SUMMARY

1) The systematic innovation methodology has uncovered some of the underlying fundamentals of system evolution: successful systems evolve through a series of discontinuous jumps in a direction towards an Ideal Final Result end-state.
2) The same generic jumps may be seen to occur across different industries. By using the jumps that other industries have already made, it is possible to accelerate the pace of innovation in others. The implications of the possibilities opened up by this accelerated knowledge transfer – particularly in relation to IP issues – are potentially profound. Historically, organizations have not been very good at making step-change innovations (Reference 6). It may still be true. The difference now, however, is that through TRIZ they can at least they can see what is coming, and thus take the necessary avoiding steps.
3) Comparison of fan technologies at two different ends of the industry spectrum reveals that in some areas, the high end technologies have hit some fundamental limits in relation to some possible evolution directions. At both ends of the spectrum, however, there remains considerable untapped evolution potential when comparing to the global measure of evolutionary possibility. The implications for the industry as a whole may be expected to be significant on both counts.

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