Trimming Evolution Patterns For Complex Systems

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"From the very beginning the system starts increasing its main useful function at the expense of simplicity, 'picking up' a multitude of supplementary sub-systems ***– the expansion period of the technical system****. Later evolution is confronted with objective constraints on physical, economical, ecological complication of the system and* ***the convolution period of the technical system begins****. On the surface it may appear as simplification but in reality the useful functions acquired at an earlier stage and performed by supplementary subsystems are beginning to be delivered by an 'intelligent' (ideal) substance.*

Yuri Salamatov[1]

"Sometimes a system starts off simple and then becomes more complex and then becomes simple once again. This can be a normal process of evolution and adaptation to change. If the 'complex' phase is disallowed, then that system may be unable to evolve or adapt."

Edward DeBono[2]

INTRODUCTION

This brief article examines the evolution of a complex engineering system – the gas-turbine engine – from the perspective of its relationship to the 'trimming' technology evolution trend.

The article attempts to begin to provide answers to the questions:-

1) Where and when on a technical system evolution S-curve does the trimming process begin to take effect (or, in light of Salamatov's quote above, when does 'expansion' turn into 'convolution')?

2) Is it possible to plot a characteristic of 'complexity' for a technical system and to thus provide a tool which can assist in the planning of future R&D programmes?

THE GAS-TURBINE

Since it's conception and first successful demonstration during the 1930s, the gas-turbine engine has undergone dramatic improvements in terms of all measures of customer value. Parameters used to measure 'value' include mean time between failure (MTBF), mean time between overhaul (MTBO), maintainability, survivability, noise, unit cost, life-cycle cost, and the two most commonly used performance metrics:-

a) amount of useful output produced by the engine divided by its weight - thrust-to-weight (T/W) ratio, and,

b) a measure of how efficiently the engine burns fuel called specific fuel consumption (sfc).

Graphs showing how these measures of value have changed in the period since the 1930s (Figure 1) indicate quite profound levels of improvement.

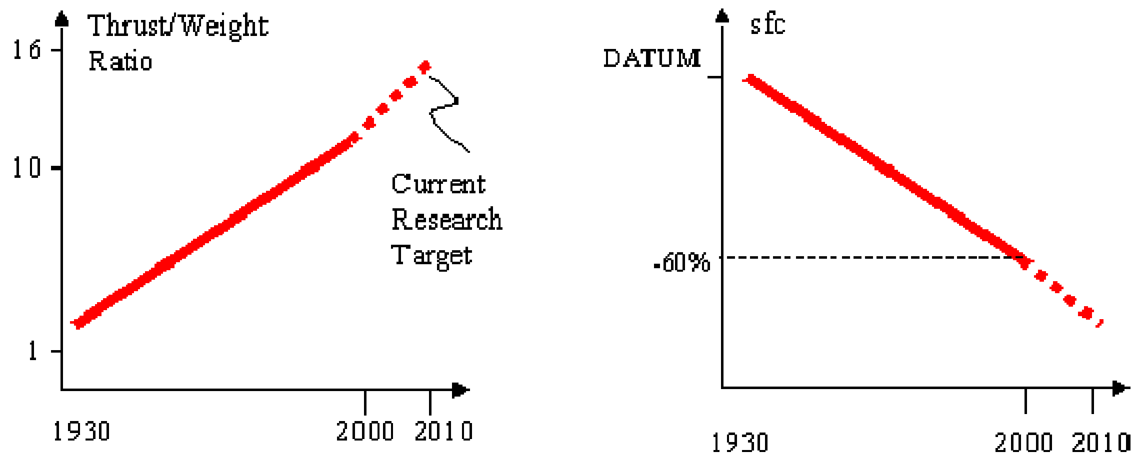

Figure 1: Improvements in Gas-Turbine Mean T/W And sfc As A Function Of Time
(information from Jane's Gas Turbine Directory)

Over this same period, it is useful to note how the engine complexity has altered. A vivid comparison comes through examination of the turbomachinery components of the engine. Figure 2 illustrates the rotating components of one of the first gas-turbines developed by Sir Frank Whittle. The system comprises a single rotating shaft, carrying a single stage of compressor – incidentally, manufactured from one, machined from solid, component – and a single stage turbine made up of 60 blades.

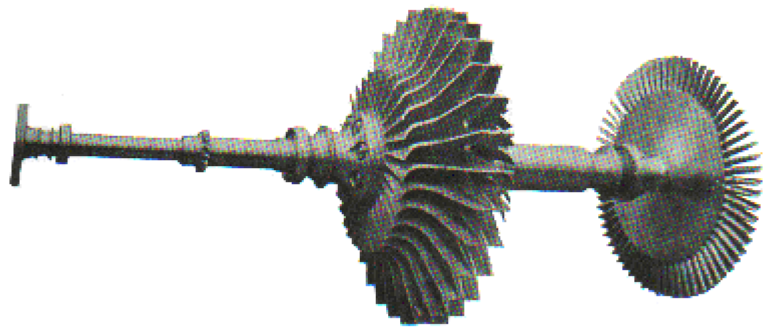

Figure 2: Rotating Components In First Experimental Gas Turbine

Compare this with the construction of a typical 1970s design military combat engine. The compressor system in this engine has evolved from the original single stage, single component design to comprise three shafts, with three compressor stages on the first shaft, three on the second, and another six on the third, with, overall, over a thousand individually manufactured blades. Similarly, the turbine section has increased from 60 to over 300 rotating blades.

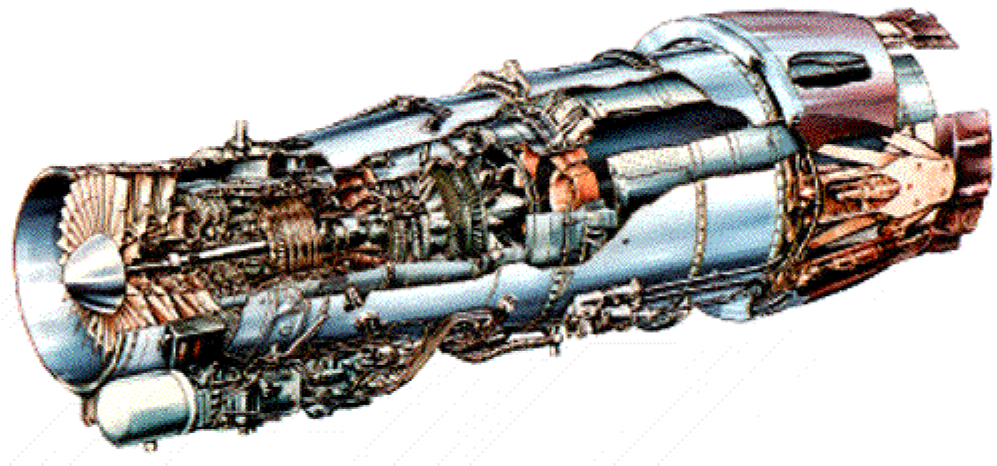

Figure 3: Schematic Of 1970s Technology Gas Turbine

If we examine this change in complexity by considering the number of components in the engine as a function of time, we obtain the picture shown in Figure 4.

Again, examination of the turbomachinery is instructive in demonstrating how complexity – as measured in terms of part count - has been trimmed since the 1970s. For example, a modern engine is able to achieve better overall performance than its thousand component 1970s equivalent, using two shafts instead of three, 8 stages of compression instead of twelve, and – thanks to the use of one-piece ‘blisk’ manufacturing technology –reducing the number of components by a factor of over two. Ongoing R&D programmes look set to further and substantially reduce even these figures.

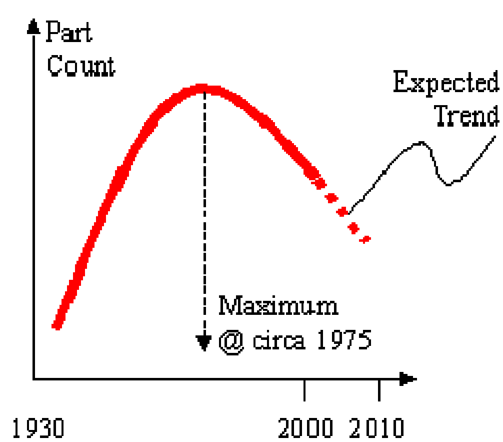

Figure 4: Engine Part-Count Evolution As A Function of Time

DISCUSSION

1) Relationship Between Evolution S-Curve and Part-Count (Complexity) Characteristic

In relation to the first question being posed in this article – where and when on a technical system evolution S-curve does the trimming process begin to take effect – the implications from Salamatov's TRIZ text and the suggestion here based on an analysis of the gas-turbine evolution picture is that the transition from expansion to convolution stages occurs at or around the point on the overall value S-curve where the slope of the characteristic stops increasing, and begins decreasing – Figure 5.

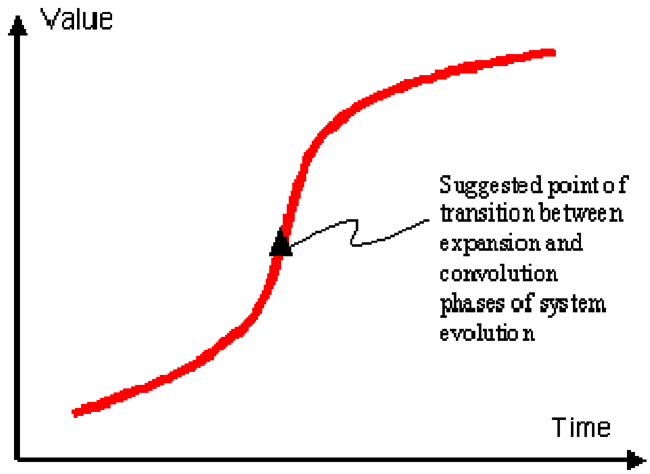

Figure 5: Expansion-Convolution Transition

It is further suggested following the gas-turbine analysis that the same point denotes the time in the evolution path where 'complexity' – and particularly in relation to the trimming trend, 'part count' – reaches its maximum – Figure 6.

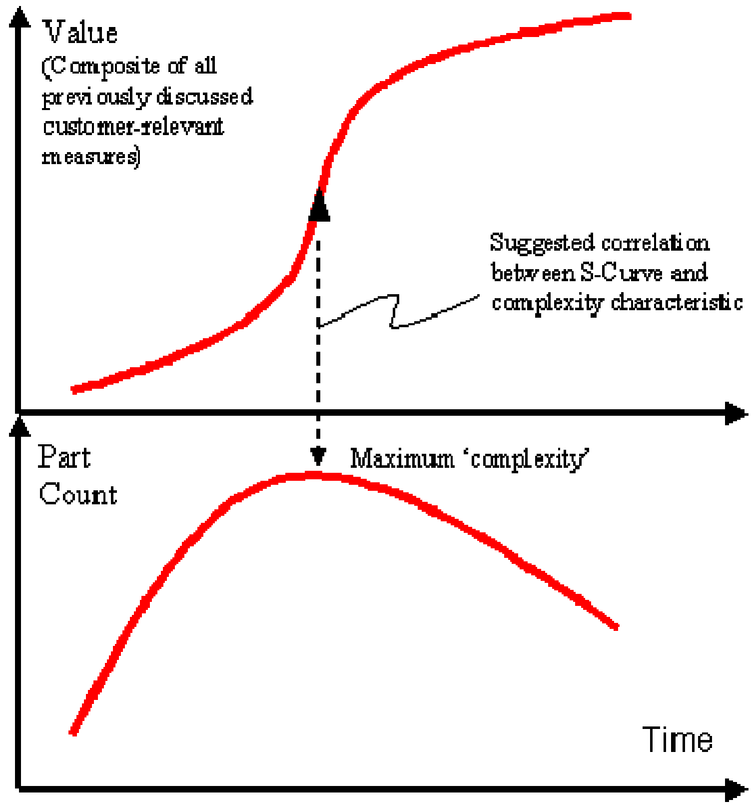

Figure 6: Suggested Relationship Between Expansion-Convolution Transition and System Part-Count

Obviously, data from other system types will be required in order to establish whether this suggested relationship is applicable generically, but in the meantime it is offered as a potentially useful theory.

2) Impact On R&D Activities

The S-curve – complexity relationship is potentially useful in identifying the relative maturity of an industry (see Reference 3 also). Of course, the trend – along with all of the existing known TRIZ trends of technology evolution are just a small part of a much bigger picture – Figure 7 – in that strategic decisions on how future R&D budgets should be allocated depend on far more than just the engineering possibilities. The complexity (or we might call it 'trimming') trend, however, provides a useful technical steer, indicating the emergence of a limiting contradiction between the desire to obtain performance benefits and the increasing prohibitive cost and overall engineering difficulty of achieving such benefits.

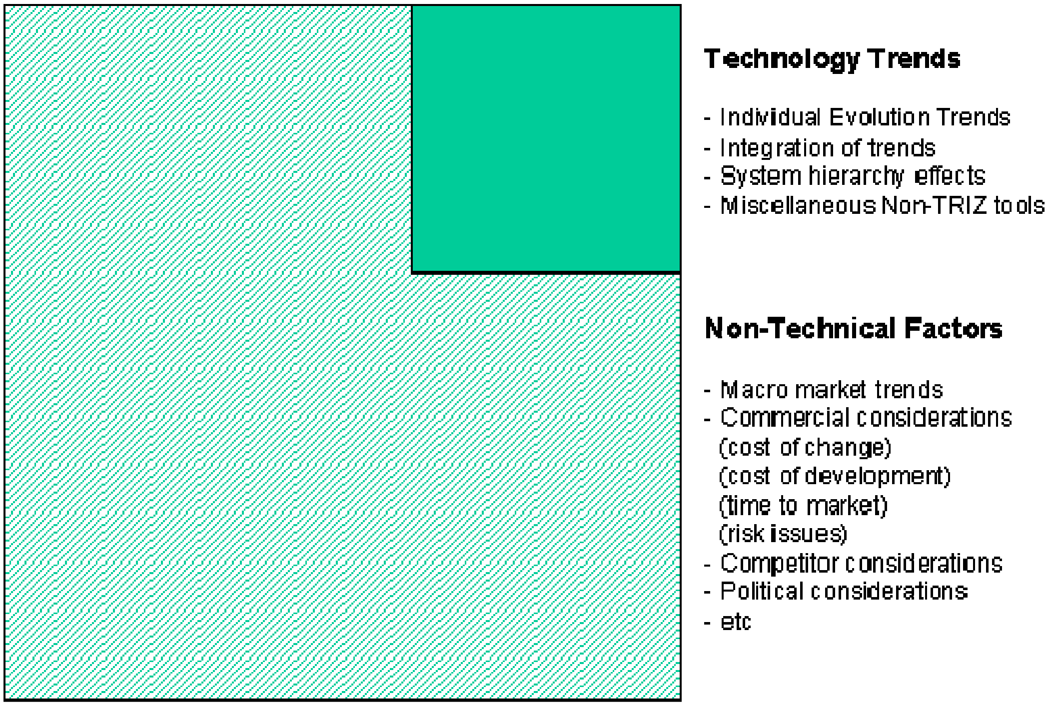

Figure 7: Technology/Business Evolution Relationship

By way of example, looking again to the compressor parts of the gas-turbine, it is evident that the R&D cost of achieving now quite modest performance improvements is a phenomenally increased over what it was during the early stages of engine development. Other parts of the engine, of course, are not so mature, and consequently, the overall engine technology maturity is at a somewhat lower level. A large part of the R&D task these days involves the need to make careful assessments to identify where the greatest value benefit per dollar of R&D spend (‘bang per buck’) rests.

Looking back to Figure 1 and its extrapolation to include the approximate performance goals of the US IHPTET programme, it is clear that the market still demands the same levels of T/W and sfc improvement as were achieved in the early years of engine development. In light of the trimming trend’s suggestion that the gas-turbine engine is now well and truly in the ‘convolution’ phase, it will be particularly interesting to discover whether the gas-turbine concept has enough performance improvement development potential left in it to turn the goals into reality.

3) Impact of New Design Tools

An issue surrounding all of the TRIZ technology evolution trends concerns whether the emerging awareness of those trends has an impact on the way in which we develop new systems in the future. This issue seems particularly relevant in the case of the 'trimming' trend. The main reason for this suggestion is that 'trimming' – alongside the closely related work of Boothroyd & Dewhirst (Reference 4) on Design For Manufacture an Assembly – seems to be one of those design tools which has seen broadest and most effective deployment in the design office at this point in time.

With this in mind, it is likely that the designers of future systems will be much less inclined towards the complexity 'extravagances' of the 1970s and before. Figure 8 is proposed as the likely consequence of improved design methodologies emerging from trimming and DFM on future system designs.

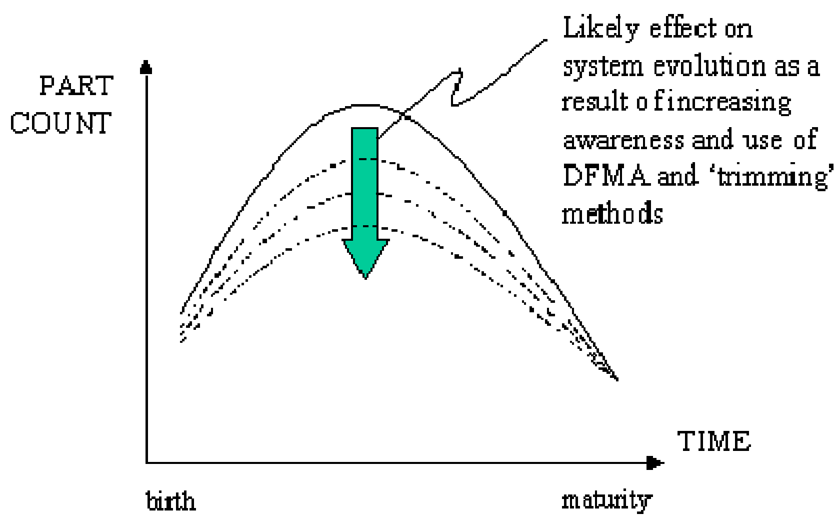

Figure 8: Predicted Impact of Trimming Awareness on Future System Developments

CONCLUSIONS

1) Based on an analysis of one product type, it appears feasible to correlate the 'trimming' trend to the overall product evolution S-curve.

2) It is suggested that systems reach a maximum viable level of complexity, after which time, the product evolution paradigm is forced to shift from a period of expansion to a period of convolution.

3) It is further suggested that for the gas-turbine, this shift occurs at or around the point on the overall S-curve at which the achievable rate of value increase begins to decline.

4) This theory requires validation against other technical system types.

5) Awareness of 'trimming' and other similar design techniques like Design For Manufacture may well affect the future evolution trend pattern.

REFERENCES

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