Case Studies in TRIZ: Helicopter Engine Particle Separator

Darrell Mann
Systematic Innovation
5A Yeo-Bank Business Park
Kenn Road, Clevedon
BS21 6UW, UK
Phone: +44 (1275) 337500
Fax: +44 (1275) 337509
E-mail: Darrell.Mann@systematic-innovation.com

Introduction

Modern day helicopter powerplants are highly sophisticated pieces of machinery. A state of the art military engine may typically generate up to 20 times more power than an automobile engine of a comparable size. On the downside, the engines can be particularly vulnerable to damage from contaminants like sand and dust. In extreme cases, a helicopter engine could be made inoperative with as little as half a dozen pounds of sand. Consequently, the large majority of engines are fitted with some form of inlet protection device.

The design of such devices demands a complex juggling act between conflicting requirements for effective particle removal capability versus drives for minimum weight, minimum volume, minimum pressure loss, maximum reliability ('fit and forget' operation) and, these days, minimum cost.

While customers continue to demand improvements to all of these parameters, particle removal efficiency is often still the dominant design driver. This article will look at how TRIZ was used to overcome deep rooted psychological inertia problems to derive a more efficient separator design, and will touch on some of the limitations of the current TRIZ method.

Helicopter Engine Particle Separator State of the Art

Starting with the first of the type in the mid 70s, the engine-mounted particle separator has been designed as an axi-symmetric, bifurcated duct of the form shown in Figure 1.

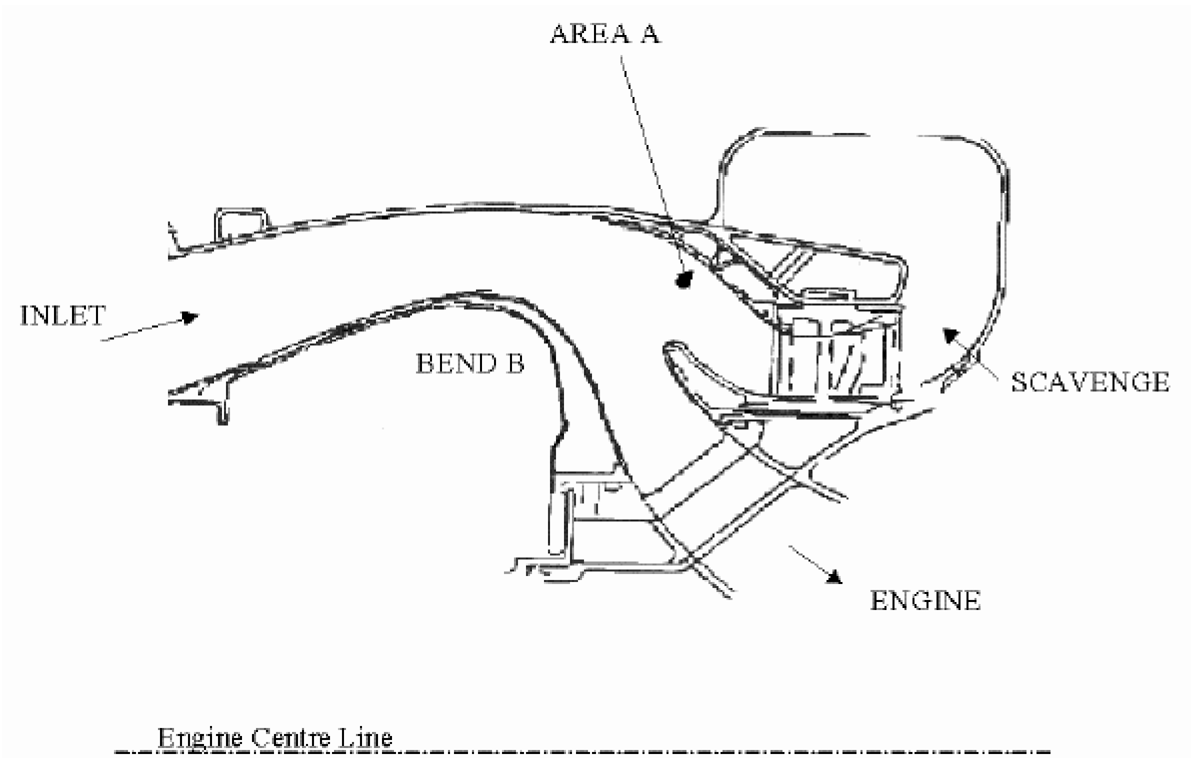

Figure 1: Typical Axi-symmetric Helicopter Engines Particle Separator

Each of the variants available today is very similar. Contaminated air enters the device through the inlet annulus on the left, and around a sharp bend, B. The bend is designed in such a manner that the inertia of the contaminants is sufficient to prevent them from following the air around the bend. Thus contaminants pass into the scavenge passage, A, and the contaminant-free clean air passes into the engine along the inner annulus.

This type of separator has evolved consistently across every manufacturer through hundreds of design iterations, many man-years of design effort and probably hundreds of millions of dollars of R&D to achieve an acceptable balance of performance attributes. Every manufacturer has frozen the design at a subtly different point on the trade-off map, but every separator looks pretty much the same to the non-specialist eye.

One of the main challenges facing the separator designer trying to improve particle separation efficiency is the physical conflict at region A between the need for a large duct area – to trap the largest possible number of contaminant particles – and the need for a small duct in order to minimise the amount of air required to be pumped through the scavenge system (pumping losses are expensive from an efficiency point of view) and to minimise the overall dimensions – and thus weight – of the overall separator. An awful lot of the separator development dollars have been spent optimising and re-optimising this trade-off.

Looking at such a ‘duct must be large and small’ physical conflict as a technical contradiction in the Altshuller Matrix (e.g. thing we’re trying to improve; area of stationary object, thing which gets worse; length of stationary object) has done little to provide any useful answers in this area. Certainly little that has been applied to any great effect. This has not stopped designers from continuing to focus on this trade-off area.

There is also another important physical conflict associated with this type of particle separator; this time concerned with the duct taking the cleaned air into the engine. In essence the conflict is the opposite of the scavenge duct contradiction. In the engine duct, we want the duct size to be big because we want most of the inlet air to pass along it (typically 80-90%) with minimum pressure loss, and we also want it to be small in order to minimise the opportunities for particles to enter. We might also notice that we would like the engine duct to be small because the duct resides inside the scavenge duct and consequently the bigger we make it, the bigger the scavenge duct gets and hence the bigger the overall separator gets. Again little of use has emerged from the Contradiction Matrix to help solve this engine duct conflict. And again, designers have continued to devote much effort to finding the best trade-off compromise between the two conflicting requirements.

Both problems exist at the same component-level of an overall separator problem hierarchy (Figure 2).

TRIZ and the process of conflict identification can of course be applied at any of the levels. Generally speaking, the design benefits we might expect to achieve will be greatest at the top of the hierarchy and smallest at the bottom. Conversely we can expect the problem definition at the top to be more abstract and difficult ('is an inertial particle separator the right answer?'), and then to become gradually easier as we work through to the micro-scale ('an erosion resistant coating that is immune to sand damage and has low weight' for example). Pitching the problem definition at the 'right' level is an often troublesome task.

Even finding the 'right' level, though, can still often not lead to the 'right' answer. This was certainly the case with both of the 'big and small' conflicts identified on the particle separator.

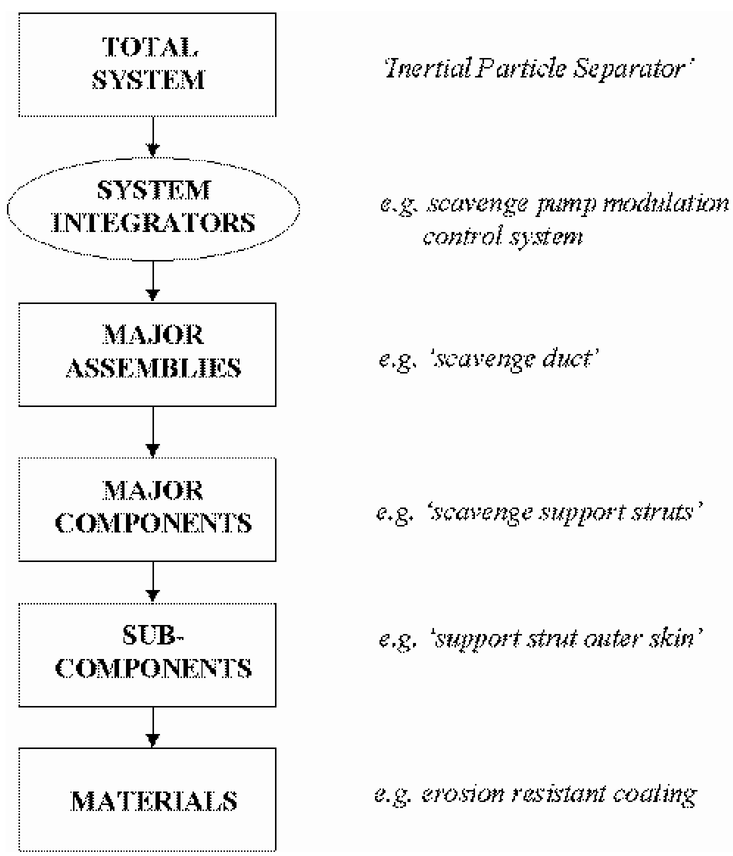

Figure 2: Typical Problem Hierarchy

(NB It is common practice to distinguish Assemblies and Components into two rather than the three layers shown. Both conventions are equally valid.)

A very potent next step in such circumstances – and often a good step in any event – is to look at groups of physical conflicts together. Such grouping of conflicts may be done either within the same levels of a problem or by looking at conflicts across different layers.

In the case of this particular particle separator, the best solution emerged by looking at the two 'big and small' conflicts together. The inventive principle used was 'the other way around'. The resulting novel particle separator is illustrated in Figure 3.

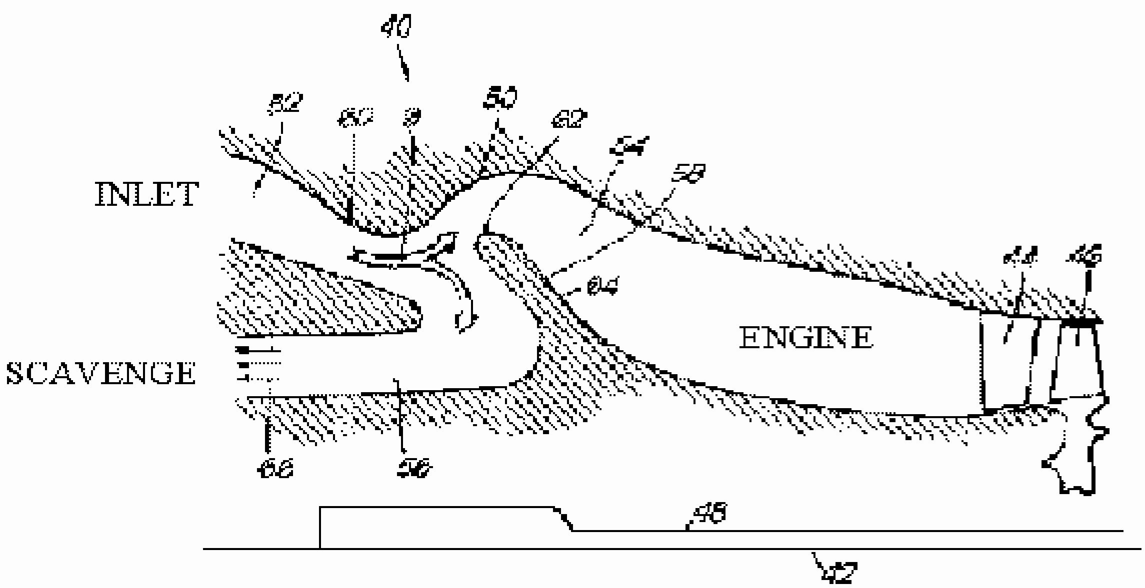

Figure 3: US Patent 5,139,545 Particle Separator

All that has happened in this design is that the engine and scavenge ducts have been transposed. The duct demanding the majority of the air flow is now on the outside and therefore has a bigger area than the inner scavenge duct (while still maintaining a small duct height in order to minimise the prospects of particles entering the duct). Both 'big and small' conflicts have been eliminated. All in all an almost unbelievably simple (in retrospect) shift in thinking which went unobserved through what must be several hundreds of man years design effort.

While the primary motivation for trying to find a better particle separator than the originally conceived device was to improve the separation efficiency (particles entering the low flow region A in Figure 1 are prone to be re-entrained into the main flow into the engine duct), the improved separator achieved in Figure 3 illustrates a feature common to designs in which trade-offs are eliminated rather than accommodated; the realisation of a number of additional benefits above and beyond those being sought. In this case, those additional benefits included the potential beyond a doubling of separation efficiency, for simultaneous:-

- halving of weight
- halving of volume

- 40% reduction of scavenge pressure loss
- 30% reduction of anti-icing power required

Aside: Contradiction Matrix Issues

Attempts to analyse the paradigm shift which gave rise to the new separator as a single technical contradiction, for example:-

Thing we're trying to improve	**Thing which gets worse**
area of stationary object	length of stationary object
volume of stationary object	device complexity
Loss of substance	object generated harmful factors
	loss of energy

never produced the suggestion 'The other way around' from the Contradiction Matrix. This case study is one of a rather large and growing number of cases conducted by the author in which the Matrix has failed to suggest the inventive principle eventually used to solve a problem.

While recognising that the Matrix was never intended to be wholly comprehensive, one of the objectives of the ongoing research at Bath is to derive an updated version of the Matrix.

In the meantime, 40 inventive principles may actually turn out to be a small enough number that problem solvers may care to look at all of them at some stage in the process of trying to eliminate contradictions.

Conclusions

1. Engineering systems operate at a number of levels from the macro down to the micro-scale. Looking for physical contradictions amongst the hierarchy of levels present in order to find the ones most likely to generate innovative design solutions is an often nebulous and unpredictable process. Generally speaking, we will have the greatest chances of success in such matters if we work top-down; starting from a total system level and working towards the micro scale.
2. In some cases – like this example – finding a single contradiction is not sufficient to generate the very best possible solution. The example firmly suggests a problem solving strategy in which multiple physical contradictions need to be handled in an integrated fashion.
3. The example also provides further profound – and expensive – evidence of the problem of psychological inertia; a whole industry caught up in trying to find the best compromise solution to the wrong problem.

4. As in many other examples, this case study demonstrates the ‘magic’ of unplanned for additional benefits that can often occur when contradictions are successfully removed.
5. It is unwise to rely too heavily on the Altshuller Contradiction Matrix when trying to identify candidate Inventive Principles. This case study is not the only one in which the inventive principle used to solve the problem is not one recommended by the matrix.