



The Large and the Small of the MEASUREMENT OF ACOUSTIC EMISSIONS IN A FLYING AIRCRAFT WING

From 7 years of Successful Problem Solving with TRIZ - Airbus and
BAE Systems TRIZ their problems with Oxford Creativity

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Photograph by Bob Robinson

In 1999 in the Director's Box of the Raebou Stadium an historic three-day TRIZ course was organised to see if the TRIZ Tools and processes offered by Oxford Creativity would be useful and should be adopted. Those present were from both Airbus and BAE Systems - and the organisers Bob Robinson and Pauline Marsh were so enthusiastic about TRIZ and they used it so effectively that they soon received a Chairman's Award for Innovation. This success and enthusiasm ensured that TRIZ was tested and tried in many other parts of both organisations.

TRIZ is now successfully applied in many places and in many areas in both organisations – TRIZ is an official and recognised route to innovation and problem solving as part of BAE Systems Engineering Life Cycle Management and anyone in BAE Systems can apply to do an Oxford Creativity TRIZ course through Xchanging. TRIZ has been used extensively for management and engineering problem solving (see at the end of this article for an example of management problem solving- on military regulation)

Airbus have several TRIZ projects underway in the UK, France and Germany and are working with Oxford Creativity and Bath University to ensure TRIZ is more widely known and used by their engineers.

Below is a case study involving in flight test equipment.

**PROBLEM: THE MEASUREMENT OF ACOUSTIC EMISSIONS IN A FLYING AIRCRAFT WING****PROBLEM CONTEXT**

During flight testing of a commercial aircraft wing there is a requirement to measure acoustic emissions while the aircraft is in flight. The measurements are required to be very accurate, however there are constraints imposed by the testing environment, which make the use of accurate sensors difficult. In particular, the test aircraft imposes a restriction on the weight and volume of the test equipment that can be used.

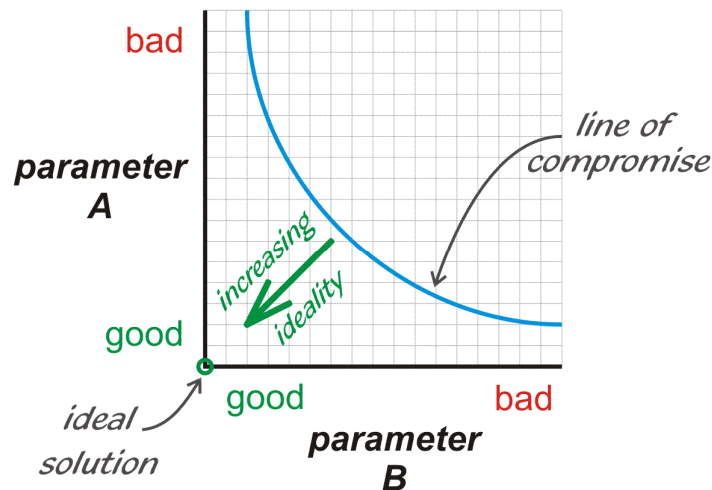
Before this problem was addressed using TRIZ, two possible approaches had been considered:

1. An electrical sensor was available. This was an excellent system that provided the required accuracy, however it was too heavy to be used in flight.
2. A much lighter optical sensor was also available; however this did not provide sufficient accuracy.

DISCUSSION OF PROBLEM

This is an excellent example of a non-trivial (and hence interesting) problem. There is a desirable output/characteristic that we need (in this case *measurement accuracy*) that unfortunately appears to be associated with something harmful, costly or unwanted (in this case, *weight*). In the language of TRIZ we call this a *contradiction*.

We can express this contradiction as a simple graph, which typically takes this form:



As we try to improve one parameter (accuracy) the other (weight) becomes worse, and vice-versa. It would appear that we are constrained to remain on the blue curve, which defines the set of possible compromise solutions available to us. What we would like to be able to do is to move off the blue compromise curve to a more ideal solution – i.e. in the direction shown by the green arrow. To achieve this we need to find a way of resolving the contradiction.

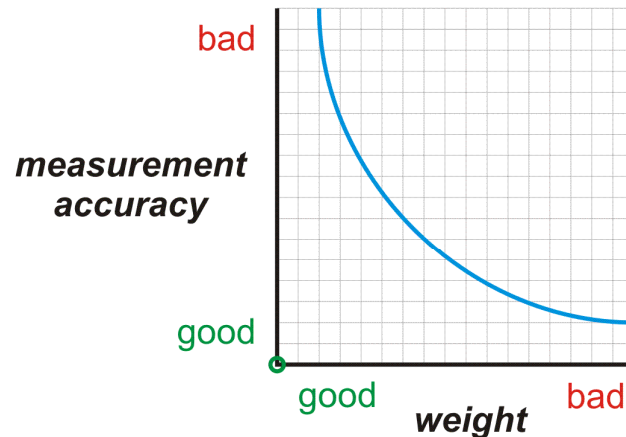
The identification and resolution of contradictions is a key element of the TRIZ problem-solving ethos. Inside all interesting problems we invariably find one or more such contradictions. If we can identify these contradictions and resolve them we will have devised a high quality solution to our problem – not merely a better compromise, but an innovative solution that breaks free from the existing constraints and provides a step-change towards an ideal system.

In the case of this particular problem we are looking for:

- A sensor solution that is accurate (like the existing electronic sensor, which is too heavy)
AND
A sensor solution that is light (like the existing optical sensor, which not accurate enough)



Our conceptual contradiction curve looks like this:



We want a sensor solution that has BOTH good accuracy AND good (which, in this case, means low) weight.

Ideally we are looking for 'good' accuracy and 'good' weight. At first glance (if we stay on the blue curve) we appear to be asking for the impossible, however it is important to suspend such judgements for the moment, to follow the systematic TRIZ method and allow the possibility that our particular contradiction(s) can be resolved - even if we have no idea of how it might be done. So we accept that it is possible that there is a solution that gives us the benefits we need without the associated costs or harms. With our mind open to the existence of such a solution, we can set out to find it.

TACKLING THE PROBLEM

In this case, the Airbus / BAE Systems team decided to use one of the classic tools from the TRIZ toolkit for solving contradictions: the Contradiction Matrix.

As with much of TRIZ, this particular method provides a way of 'tapping in' to the world's experience of problem solving – in this case the world's experience of resolving contradictions. The method is a three-step systematic process:

- Step 1: Identify the contradiction(s) in the problem, and classify them according to the nature of the contradictory system parameters
- Step 2: From the TRIZ toolkit, use a statistically derived look-up table (the Contradiction Matrix) to determine which generic Inventive Principles have been successfully used in the past to resolve contradictions of the same generic type as those in our specific problem.
- Step 3: Take the generic Inventive Principles suggested in Step 2 and interpret/apply them to our specific problem. Though this final step it is possible to generate not just one possible solution, by usually a surprisingly large set of candidate conceptual solutions.

STEP 1: IDENTIFYING THE CONTRADICTION(S)

TRIZ deals with two types of contradictions: Technical Contradictions and Physical Contradictions. A Technical Contradiction is characterised by having different system parameters that constitute the contradiction, such as (in this case) measurement and accuracy. A Physical Contradiction, on the other hand, is characterised by having the contradiction derived from the same system parameter – for example an umbrella needs to be both large (when in use) and not large (when not in use).



What is a Technical contradiction?

When improving one parameter another gets worse - such as when designing a table, the stronger and more rigid we make it, the heavier it becomes - is called a **technical contradiction** of strength versus weight. Instead of trying to optimise or choose between them (compromise) we can use the TRIZ Contradiction Matrix to find out how to resolve the technical contradiction – how to get more strength without increasing weight and achieve a more ideal solution.

In this case the BAE/Airbus team identified two Technical Contradictions.

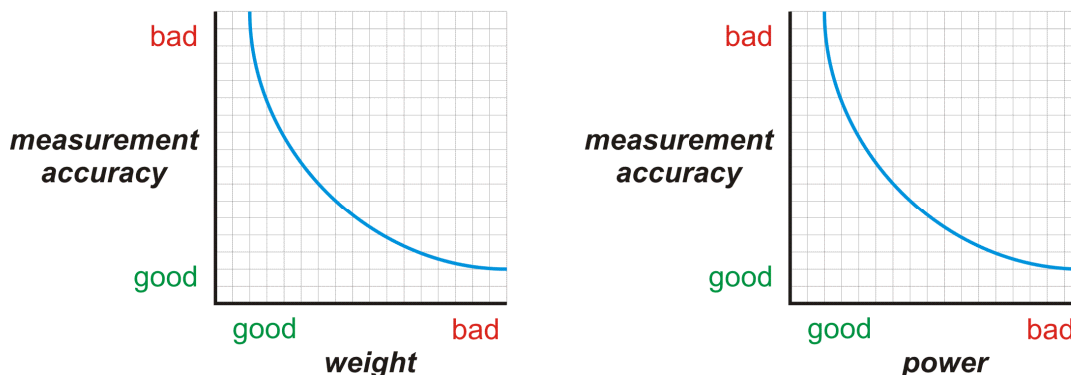
Defining contradictions can be tricky and normally in TRIZ we recommend that you try several possibilities (don't agonise trying for the one perfectly defined contradiction)

We want a sensor that is accurate **but we don't want** it to be heavy.

For this contradiction we could ask why is it heavy – the answer may be to get enough power - this suggested the possibility of another type of contradiction in the problem:

We want a sensor that is accurate **but we don't want** it to require lots of power.

The Airbus/BAE team at Filton had identified both these *Technical Contradictions*:



The Two Technical Contradictions: Expressed in terms of problem-domain Parameters

What is an Engineering Parameter?

There are 39 generic engineering parameters that, when combined in opposing pairs, can define any engineering contradiction. The parameters describe both the things we want (or inputs we must make) and the consequences - the things we don't want. We choose on the vertical axis what we want or an input we must make – and some other parameter on the horizontal axis will then describe some output we get which we don't want.

The list starts with relatively simple parameters (weight, length, area etc). Towards the end of the list the parameters become a little more complex and include things such as speed, forces / loads, stresses, pressures, stability, duration of action, use of energy, power, reliability, convenience of use, reparability, adaptability, accuracy of manufacture, manufacturability, productivity etc. The list also includes clearly identifiable harms (outputs we don't usually want) such as device complexity, waste of energy, loss of information, waste of time, control complexity and harmful effects.



STEP 2: USING THE CONTRADICTION MATRIX

Before the Contradiction Matrix can be used it is necessary to map the specific problem parameters (measurement accuracy, weight & power) onto the generic parameters used by the Contradiction Matrix.

What is the Contradiction Matrix?

When improving one parameter another gets worse - such as when designing a table, the stronger and more rigid we make it, the heavier it becomes - is called a **technical contradiction** of strength versus weight. Instead of trying to optimise or choose between them (compromise) we can use the TRIZ Contradiction Matrix to find out how to resolve the technical contradiction – how to get more strength without increasing weight and achieve a more ideal solution.

The Contradiction Matrix is based upon a statistical analysis of a very large number of existing patents. Each patent was found to solve a problem using one (or more) of a very limited number of generic Inventive Principles (just 40). The matrix maps the inventive principles according to the generic contradictions (defined by opposing engineering parameters) that were most frequently solved by them. Thus the 39 x 39 Engineering Parameter contradiction matrix maps the solutions to over 1200 generic contradictions. The matrix guides us to the relevant solutions in the 40 Inventive Principles which will help us solve technical contradictions.

The 39 generic matrix parameters are:

1 Weight of Moving Object	14 Strength	27 Reliability
2 Weight of Stationary Object	15 Duration of Action by Moving Object	28 Measurement Accuracy
3 Length of Moving Object	16 Duration of Action by Stationary Object	29 Manufacturing Precision
4 Length of Stationary Object	17 Temperature	30 Object-Affected Harmful Factors
5 Area of Moving Object	18 Illumination Intensity	31 Object-Generated Harmful Factors
6 Area of Stationary Object	19 Use of Energy by Moving Object	32 Ease of Manufacture
7 Volume of Moving Object	20 Use of Energy by Stationary Object	33 Convenience of Use
8 Volume of Stationary Object	21 Power	34 Ease of Repair
9 Speed	22 Loss of Energy	35 Adaptability or versatility
10 Force	23 Loss of Substance	36 Device Complexity
11 Stress or Pressure	24 Loss of Information	37 Difficulty of Detecting and Measuring
12 Shape	25 Loss of Time	38 Extent of Automation
13 Stability of Object's Composition	26 Quantity of Substance	39 Productivity



For some problems this mapping of real-world problem-domain parameters onto the 39 parameters used by the matrix can be a little tricky – the matrix parameters are generic, and a certain amount of thought and careful consideration may be necessary to map the ‘real world’ problem parameters to the ‘Matrix’ generic parameters. In this particular case it was not very difficult to arrive at an appropriate mapping as:

Parameter 28 = **MEASUREMENT ACCURACY** matched well, as did
 Parameter 1 = **WEIGHT OF A MOVING OBJECT**
 and
 Parameter 21 = **POWER**

The full description of each of these parameters is:

1	Weight of moving object	The mass of the object in a gravitational field. The force that the body exerts on its support or suspension.
28	Measurement accuracy	The closeness of the measured value to the actual value of a property of a system. Reducing the error in a measurement increases the accuracy of the measurement.
21	Power	The time rate at which work is performed. The rate of use of energy.

Thus the two real-world contradictions, when mapped onto Matrix parameters become:

1. Measurement accuracy vs. Weight of Moving Object

2. Measurement accuracy vs. Power

Each of these contradictions are used with the Contradiction Matrix to obtain suggested Inventive Principles.

First Contradiction

Improving Parameter

We want this to get better

MEASUREMENT ACCURACY

Worsening Parameter

but we don't want this to get worse

WEIGHT OF MOVING OBJECT

These two parameters are used to cross-index the Contradiction Matrix to obtain the following four Inventive Principles that (statistically) have been found to be the most successful ways of obtaining better measurement accuracy without getting worse weight (for moving objects):

Inventive Principles:

Measurement Accuracy vs. Weight of Moving Object

32	Colour Change
35	Parameter Change
26	Copying
28	Replace Mechanical system

Second Contradiction

Improving Parameter

We want this:

MEASUREMENT ACCURACY

Worsening Parameter

but we don't want this:

POWER



(i.e. we don't want to have to provide lots of power)

In this case the Contradiction Matrix suggests the following three inventive principles:

Inventive Principles:

Measurement Accuracy vs. Weight of Moving Object

32	Local Quality
35	Universality
26	Colour Change

STEP 3: APPLY THE SUGGESTED INVENTIVE PRINCIPLE(S)

Having derived some suggested generic Inventive Principles; the team's next task was to apply them to their particular problem. This is part of a recurring theme in TRIZ: we take our specific problem, generalise it in order to access known generic solutions and then finally apply the general solution to our specific problem.

As **Inventive Principle 32 Colour Change** was suggested by the Contradiction Matrix twice: i.e. it was suggested by both of the two contradictions that were considered, the team gave particular attention to this as a solution trigger for their problem.

The next task for the team was therefore to understand the Colour Change Inventive Principle. This was important – the names of the 40 Inventive Principles are just convenient labels and it is important to appreciate the full definition of each principle before attempting to apply it. In the case of Colour Change, the definition (together with some examples) is:

**PRINCIPLE 32 Colour change****A - Change the colour of an object or its external environment**

- Use safe lights in a photographic darkroom.
- Use colour-changing thermal paint to measure temperature
- Thermochromic plastic spoon
- Temperature-sensitive dyes used on food product labels to indicate when desired serving temperature has been achieved.
- Electrochromic glass
- Light-sensitive glasses
- Camouflage
- Dazzle camouflage used on World War 1 ships
- Employ interference fringes on surface structures to change colour (as in butterfly wings, etc)

B - Change the transparency of an object or its external environment

- Use photolithography to change transparent material to a solid mask for semiconductor processing.
- Light-sensitive glass
- Smoke-screen

C - In order to improve observability of things that are difficult to see, use coloured additives or luminescent elements

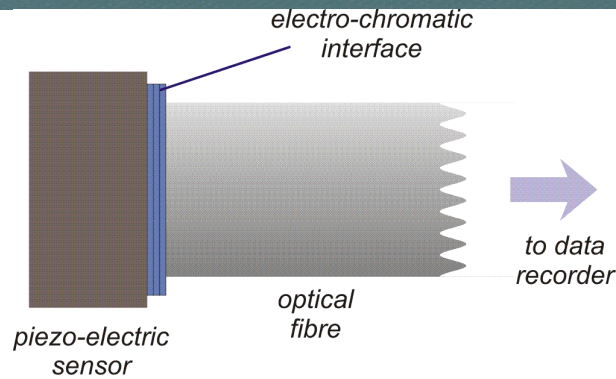
- Fluorescent additives used during UV spectroscopy
- UV marker pens used to help identify stolen goods
- Use opposing colours to increase visibility e.g. butchers use green decoration to make the red in meat look redder

D - Change the emissivity properties of an object subject to radiant heating

- Use of black and white coloured panels to assist thermal management on space vehicles.
- Use of parabolic reflectors in solar panels to increase energy capture.

At this point in the problem solving process appropriate problem domain and technology domain knowledge is important.

The final solution that the team derived from this principle was to use of an electro-chromatic material to convert the signal from the electric sensor into a colour change, that could be interrogated by an optical fibre. The team was able to quickly identify a suitable material that was already being used for adaptive camouflage applications.



The final solution developed by the team

In this way TRIZ pointed them quickly towards the right solution.

This covers the tool of contradictions for solving problems.

The TRIZ Toolkit covers both problem understanding and problem solving. In the Problem Solving Toolkit there is another tool called Standard Solutions. The Standard Solutions contain all the answers contained in the Contradiction Toolkit and the 40 Principles and much more. TRIZ Trained engineers will use both tools depending on the front end of the problem (if contradictions aren't obvious the Standard Solutions can be much easier if a little more longwinded to solve a problem). The TRIZ Standard Solutions are simple, straightforward and powerful.

Why use the TRIZ Standard Solutions?

Understanding the problems may be all we need to solve them, and all other 'problem solving kits' assume this and send us to our own brains to solve – using brainstorming to get answers out of our own brains and experience, whenever we don't have immediate answers. TRIZ offers us much more and gives us answers to our problems (in the very general form of TRIZ Standard Solutions and 40 Principles). We then use structured, very effective, directed brain storming to translate the very general answers to specific and relevant answers to our problems.

This unique power of TRIZ is that it includes these simple solution lists - all the solutions the world knows of how to solve problems. Once we have identified the problems then we can use the TRIZ Standard Solutions and 40 Principles to help us locate solutions. These TRIZ lists are very simple and general lists of all the ways to solve problems, recorded by science and technology, particularly in patents.

The Standard Solutions are often accessed using a simple version of function analysis. This TRIZ function analysis process shows how our problem can be mapped to produce a problem list which can be divided into categories of action - missing, insufficient, harmful and / or excessive and these can then be matched against comprehensive lists of all the world's known solutions – the TRIZ Standard Solutions.

These are in 5 parts including how to do something if an action is missing, how to deal with harmful functions, how to improve insufficient actions, how to simplify and reduce cost of systems and the routes to the next generation system. This matching of problems to solutions is unique and powerful. So if we can identify a harmful action, we then check all the ways the world knows to deal with harmful actions – with the simple TRIZ list of all the different (19) ways of dealing with harmful actions; similarly with insufficient and excessive actions. Using this method we will be given simple solution triggers to turn into real solutions. This is like using the 40 Principles or 8 Trends but with more detail because the Standard Solutions contain the most useful of the distilled TRIZ knowledge from contradiction and trends plus frequently used knowledge in the patent database.

Oxford Creativity TRIZ Standard Solutions are in 5 classes



1. how to do something we want to do (from 2,500+ engineering /scientific principles in the patent database)
2. dealing with harm (prevent, transform, block) and reduce costs by looking to eliminate the most expensive or problematic parts
3. how to improve something (or an action) we already have (improve insufficiencies)
4. detecting or measuring something
5. simplifying (remove excess)and developing systems (includes the 8 trends of system development)

The Standard Solutions (Section 4) also would have sent the Airbus Team to the same solutions. In the September 2006 Case Study for The Institute of Mechanical Engineers website we will show you how the Standard Solutions have recently helped engineers solve problems in the automotive and aerospace industries.

For further information...contact Oxford Creativity