The Super Stream Augmented Approach for TRIZ and its Application to Aviation Safety.

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Keywords:

Innovation Sciences, TRIZ, Super Stream Augmented (SSA) approach, systems engineering, aviation safety, entry vector (EV), functional streams (FS), solution vector (SV) , solvecs, sustained innovation, strategic innovation planning, innovation management.

Abstract:

The Super Stream Augmented (SSA) approach has been developed by the author to provide a structural framework to facilitate the application of TRIZ, and other innovation tools, to engineering and technology problems.

The SSA approach inter-weaves concepts taken from TRIZ and Systems Engineering. Emphasis is given to the issues of multiple assumption forming at the outset, and the macro level steering of solutions towards effectiveness at the super-system level. The innovation activity is stratified at four + one levels thus both tactical and strategic goals can be formulated early. This stratification also provides a clearer indication of entry and exit criteria for innovation management.

The utility of the SSA approach is demonstrated by its application to a current issue in aviation safety with the generation of over 25 concepts; each of which is an advancement over the current state of the practice in the aviation industry.

Definitions (proposed):

- **Innovation** is the systematic germination of an idea into a realisable form of commercial value.
- **Solvec** is the in-process state of an innovation.
- **Sustained innovation** is the chained-germination of ideas, beginning at any point of interest and and migrating upwards towards the super-system.

- **Efficient innovation** results from the maximal utilisation of resources that are freely and readily available, and by the conversion of constraints into opportunities.

Introduction:

Systems engineering (SE) is essential for the structuring and execution of projects with any degree of size or complexity [9]. SE does not, however, provide built-in mechanisms for the rapid generation of new ideas and parallel, improved concepts.

Systematic design and engineering is another essential area, perhaps best exemplified by the outstanding work of German experts such as Pahl and Beitz [10]. Here, systematic approaches are presented to achieve efficiencies in the field of engineering design.

TRIZ has an extensive suite of innovation and idea generation tools which can be deployed to suit any task [1]. This flexibility transfers to the user the responsibility for planning, structuring and a successful execution. The typical user is so accustomed to precise, algorithmic approaches through their years of formal educational training, that this apparent lack of structure is construed as a handicap - something outside their comfort zone [3].

How to combine the diametrically opposed requirements of free association of ideas required for innovation with the predictability of algorithmic structures is a debate that will continue for some time. Recently, interesting new developments have been reported, such as the Bright Process [14] in UK . Hybrid-reasoning is a powerful and efficient approach in discursive problem solving. The super system augmented (SSA) approach is based on hybrid reasoning. For this reason SSA can be used alternately as an innovation add-on to systems engineering; or as a structuring and planning add-on to innovation tools such as TRIZ.

An outline of the SSA approach will be presented in the context of an airline safety issue dating to 1996. While the problem was originally addressed through root cause analysis, its recurrence in 2007 indicates the need for further work. The SSA approach invariably results in the generation of multiple solutions.

Each of these solutions can serve to germinate further innovative activity. This is an essential requirement for sustainable innovation. Here the goal is the daisy-chaining of inventive concepts, in linear or random patterns. In this instance over 25 new innovative concepts were generated, each of which is an advancement over the current procedures and practices of Airbus and Boeing airliners.

The description given below is a fairly detailed account of the two accidents.

Background to the airliner safety issue:

At 00:42 (42 minutes past midnight), 02 October 1996, AeroPeru Flight 603 with 70 occupants on board took off from Lima, Peru, and headed for Santiago, Chile [4]. The Boeing 757-23A registration N52AW was relatively new and in perfect condition. Soon after take-off the air data computer (ADC) started feeding erroneous data to the flight computer and to the two sets of instruments for the captain and first officer. While one set was indicating a condition of over-speeding, the other was warning of a low speed stall, both conditions being dangerous. Altitudes displayed were widely different, and seemingly contradictory alarms sounded off randomly - often simultaneously.

The resulting disorientation of the flight crew in the pitch black at night time led to their declaring an emergency and electing to return to Lima. Under conditions of extreme stress, the captain was able to able to get back to within 40 miles of Lima at a steady height of 1600 ft. by relying on the radio altimeter. Independent verification was sought from the Lima air traffic control radar, which acknowledged their position and confirmed their height as 8000 ft; ironically, a value received by it from the aircraft's own erroneous transponder.

Re-assured with this independent verification, the flight crew started their descent in pitch darkness and, ignoring miscellaneous warnings and alarms including ground proximity warnings, struck the crest of the sea waves. The left engine ingested water and flamed out. The flight crew tried to recover by initiating a climb but as the right wing of the plane rose, the left wing dropped and its wing-tip caught the waves. The aircraft cartwheeled and impacted upside-down at 01:16. Any initial survivors had perished by day-break.

The entire chain of events was established by the recovery of the voice / data recorders [7] and pieces of wreckage from a depth of 500 ft by the US Navy. The left side static ports were found covered with adhesive tape used by the cleaning and polishing crew (see Fig. 1a). The tape should have been removed prior to flight to ensure that the ports were absolutely clear of any obstruction. This lapse had not been detected during the night-time pre-flight inspection due to the metallic sheen and the unusual height of the B757 above the ground. The right side static ports panel could not be recovered from the sea during the salvage operation.

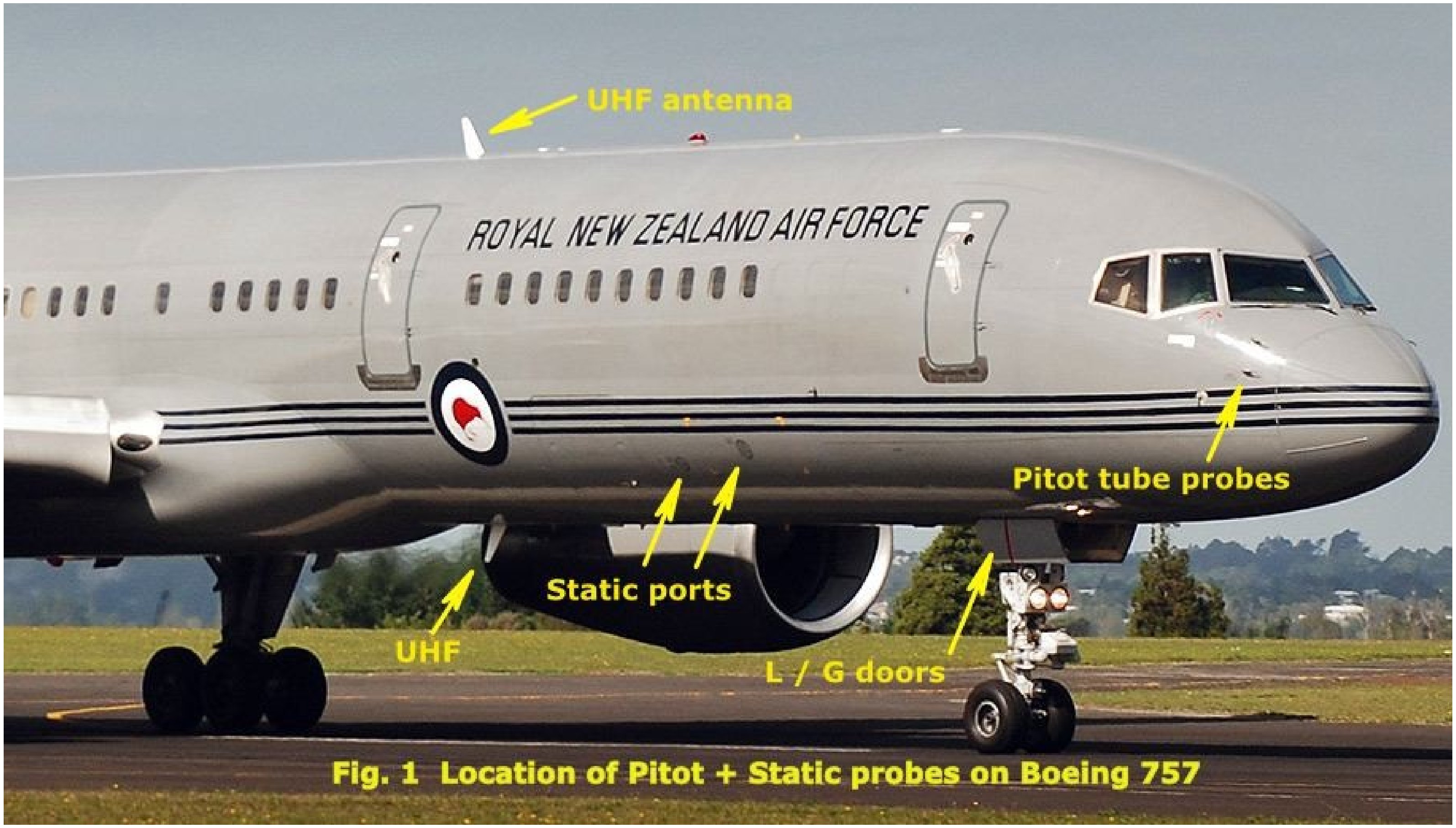

Fig. 1 Location of Pitot + Static probes on Boeing 757

The irony is redoubled in that an almost identical accident had taken place only 7 months ago, on 06 February 1996, when another Boeing 757-225, registration TC-GEN, operated as a charter flight by Birgenair, crashed into the ocean at night time soon after take-off [5] .

Birgenair Flight301 took off at 23:42 (18 minutes before midnight) from the Dominican Republic and headed for Newfoundland and then to Germany. The captain's set of instruments displayed erroneous airspeed readings. The confusion on board was compounded by the autopilot which operating on erroneous data, automatically reduced engine thrust during the critical climb-out phase.

This caused the plane to slow down, almost to the point of entering a stall when the wings stop generating lift. As the aircraft descended in complete darkness towards the ocean below, the flight crew had no external horizon for reference. The instruments were giving conflicting readings which were disregarded. By the time the captain dis-engaged the autopilot and increased engine thrust to recover manually, the aircraft was too low and impacted with the sea at 23:47. Total flight time was 5 minutes from take-off; of the 189 on board, none survived.

Fig. 3 Birgenair Boeing 757-225 TC-GEN

The cause of the crash was attributed to a possible build-up of wasp's nests inside the exposed pitot tubes, as the chartered aircraft had been sitting unattended on the tarmac for several days prior to the flight.

In 2008 The Sydney Morning Herald [13] reported that between January and March 2006, five Qantas A330 Airbus flights had to abort take-off due to wasp-related blockages of the pitot systems. In one case the turn-around time, the on ground time between flights, was less than one hour. Emergency braking during one of the aborted take-off caused six of eight landing gear tyres to burst on the runway.

Even more recently (on 05 March 2009), it was reported that the likely cause to the crash of the Turkish Airlines Boeing 737-800 at Schiphol, Amsterdam, was a faulty altimeter. This erroneously indicated ground level height while on approach, causing the autopilot/flight computer to enter the post-landing phase and to automatically reduce engine thrust and likely deploy spoilers while the plane was still in the air. The aircraft stalled, dropped like the proverbial brick, and broke up in three about one kilometre from the runway. Of the 135 occupants, there were 50 injuries and 9 fatalities that included 3 flight crew and 4 of Boeing's own engineers.

As an aside, and as another example of advanced technology cutting both ways, the anti-hijacking door to the cockpit prevented the rescuers from reaching the injured and dying flight crew in time. After a delay of almost a day, a large opening had to be axed cut from the outside top front of the fuselage to gain access.

The pitot + static system:

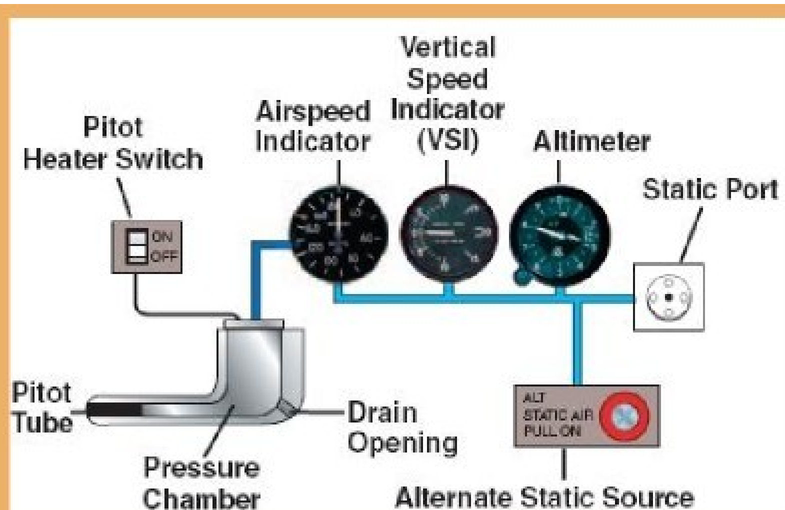

Fig. 4 Pitot + Static schema

The pitot + static system is an established and reliable method of obtaining speed and height related information [8]. The method is as simple as it is rugged. A pitot tube, pointing in the direction of flight, gathers dynamic air pressure, which is fed to the airspeed indicator. Static ports, that measure non-dynamic (static) air pressure from the side of the aircraft, provide data on altitude and is also used to compensate for the effect of altitude on airspeed data.

As long as the pitot and static ports are free of obstructions, the system works perfectly. However, obstructions caused by icing, external object ingestion, and blocked ports will generate erroneous data which may be difficult to detect in time.

Current procedures for Airbus and Boeing aircraft [6].

Fig. 5 Boeing recommended current practice

As a remedy to covering the static holes problem (issued 1998) Boeing recommends that maintenance personnel should place one end of a 3-ft piece of orange barricade tape over the static port and secure the orange barricade tape with yellow vinyl adhesive tape (Fig.5c). In addition, a red paper tag that reads "STATIC PORTS COVERED" must be attached to the left control wheel in the flight deck (Fig. 5a). The remedy devised by Airbus is to have specially designed bright orange polymer covers placed over the ports, which are removed before flight. Both current remedies are entirely manual, and do not completely eliminate the possibility of error by the maintenance crew.

Selecting Entry Vectors (EV) into the problem space:

The outcome of any innovation activity is almost entirely contingent upon the following five factors:

1. How accurately the problem is defined and framed.
2. What assumptions are made at the inception..
3. What directions for investigation are adopted
4. What knowledge base is available at the outset.
5. What additional resources can be utilised, in due course, to bridge the knowledge-gap

The author proposes that these factors are encapsulated in the form of Entry Vectors (EV). The accident descriptions given above provide sufficient information for us to define the problem, form assumptions, and decide on the directions for investigation. These are transformed into entry vectors (EV) leading into the problem solving space. The proposed approach aims to convert each EV into four functional streams, for detailed analysis.

An important issue in the design of entry vectors is the mandatory requirement to continually vary our field of interest (actually our focus, and also our depth-of-field in photography parlance) from the artefact towards the super-system. We can start by forming entry vectors at any level of artefact detail; the SSA approach requires that entry vectors at the macro and the super-system level must also be considered.

This is an essential requirement, for it provides multiple solutions <u>and</u> the structuring for the innovation task at the macro level. There is a separate mechanism to provide structuring at the micro level. The role of both will be explained later.

We also observe that each aircraft was perfectly airworthy till the moment of impact. No external agency interfered to cause a deviation from the norm. Each aircraft was designed and inherently equipped to cope with all conceivable flight conditions.

We form the closed boundary of our system as the aircraft in normal flight. The flow of information generated, and processed, within the aircraft (internally within the system of interest) will be our main area of investigation. We focus on the following information-related sub-systems within the aircraft: (Fig.6)

[Originating source of information] The pitot + static airspeed measuring circuit and transducers.

EV1: Susceptibility to blockage through ingestion or icing.
(a maintenance and design issue)

EV2: Improvements to reliability, fail-safe operation mode.
(a product improvement issue)

[Information interfaces] Flight-crew + flight-instruments.

EV3: Incomplete situational awareness.
(an information management issue)

EV4: The inefficient transfer of vital information.
(an ergonomics issue)

[Processors of information] The flight crew + digital flight controllers

EV5: The inefficient processing of time-critical information.
(a training issue for the flight crew)
(a systems design issue for the digital flight controllers)

EV6: A possible "Inverted Pyramid" syndrome.
(a systems design issue)

Each entry vectors provide us with general direction to approach the problem space. The selection of entry vectors helps us determine the critical issues that will have to be addressed as we traverse the periphery of the problem space from the initial (or given) problem and move towards the super-system. It also enables us to prepare to tap into the available knowledge space (Fig.6 and Fig.16).

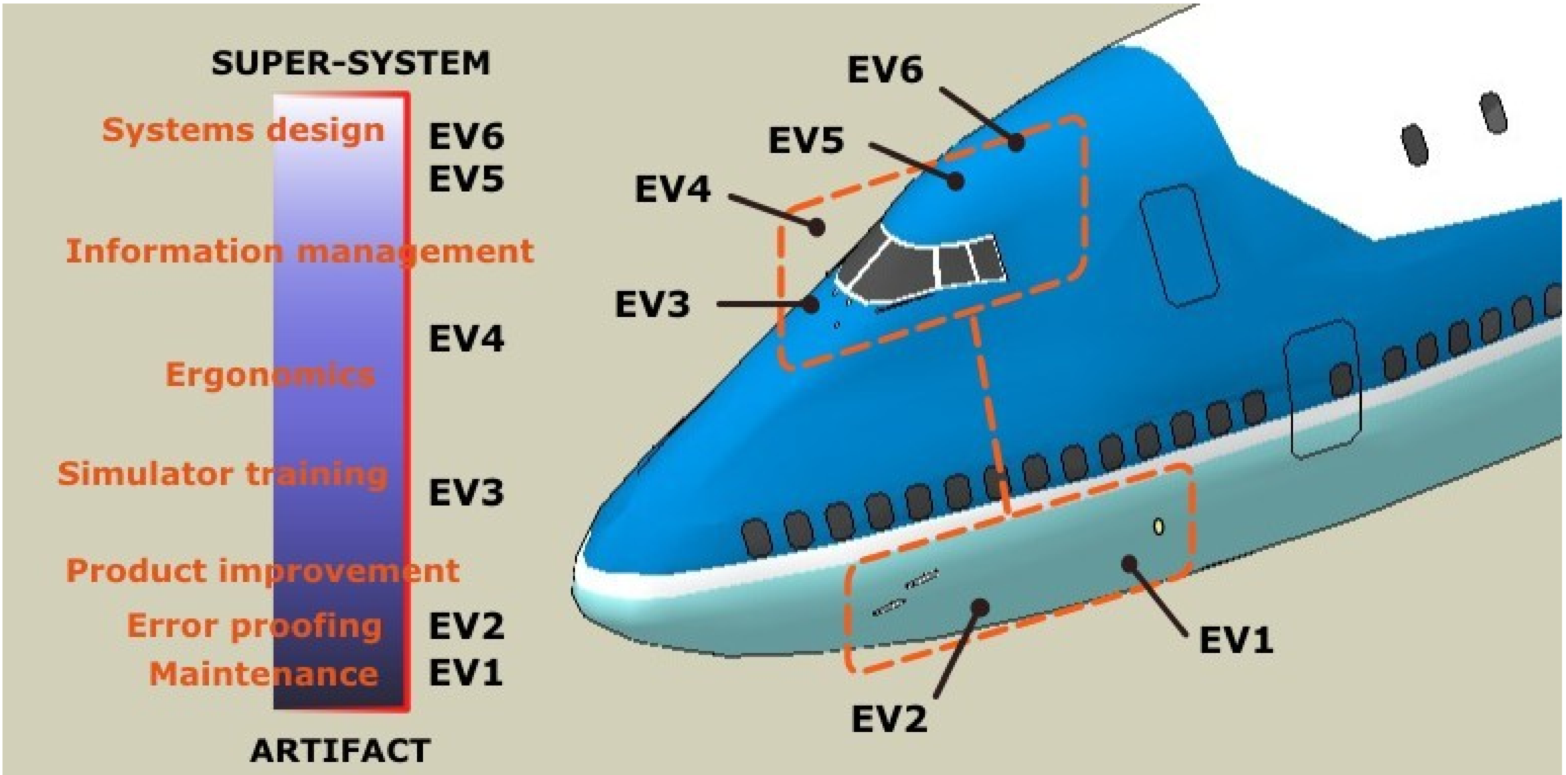

Fig. 6 Entry vectors into the problem space

At the point of entry into the problem space, each entry vector is resolved into four prongs, called Functional Streams, to allow us four levels of subject analysis at the micro- level (see Fig. 7).

The four Functional Streams (FS) explained:

Functional Streams (FS) may be likened to a composite view of the entry vector as seen in a systems engineering context. We are interested in a detailed study of the sub-components and their inter-workings. Our focus, our depth of field, and our cone of view, in photographic parlance, need to be varied from the extreme close-up to the wide-angle lens. These four "lenses" are the four functional streams:

Interface [FS+1]: The field of view is limited to interfacing issues only, and thus involves a limited amount of innovative effort. We consider as an interface the narrow zone where force, material and information interchange occurs between the functional stream (now being the system in question) and the components of its corresponding super-system. Thus the physical components of the pitot + static system would form a functional stream. The interfacing on one end would be the pitot probes on the external surface of the aircraft where the data originates. The other interface would be the visual display of the processed data on the cockpit instruments. This second interface would also include the input of data to the digital flight computers.

Minor [FS+2]: In this second FS, the zone of interest is expanded inwards from the interface zone. We focus on bringing about limited changes within the functional stream to subcomponents adjacent to the interface zone. The reason for using the term "minor" is that the scope of changes allowed is limited to a small portion of the sub-systems within the context of the functional stream.

Major [FS+3]: In the third FS, the zone of interest has been expanded to cover the entirety of the sub-components within the context of the functional stream, with one important exception. Some sub-components must be retained and cannot be modified or replaced for technology or legacy reasons. As the scope of this FS covers the majority of sub-components under review, it is referred to as such.

Evolutionary [FS+4]: At the fourth level, we focus is again the functional stream context in its entirety, and our aim is to provide for it an evolutionary replacement. We may decide to change the form of the material, force and information flows within the FS. For instance, airflow within the pitot + static circuit may be replaced with electronic signals, or the more efficient flow / exchange of electro-optical data.

Paradigm Change [FS+PC]: The fifth level of paradigm change is not discussed here and will be presented with examples at a future opportunity. It is something that occurs as a consequence of the innovative effort stated above, rather than by design.

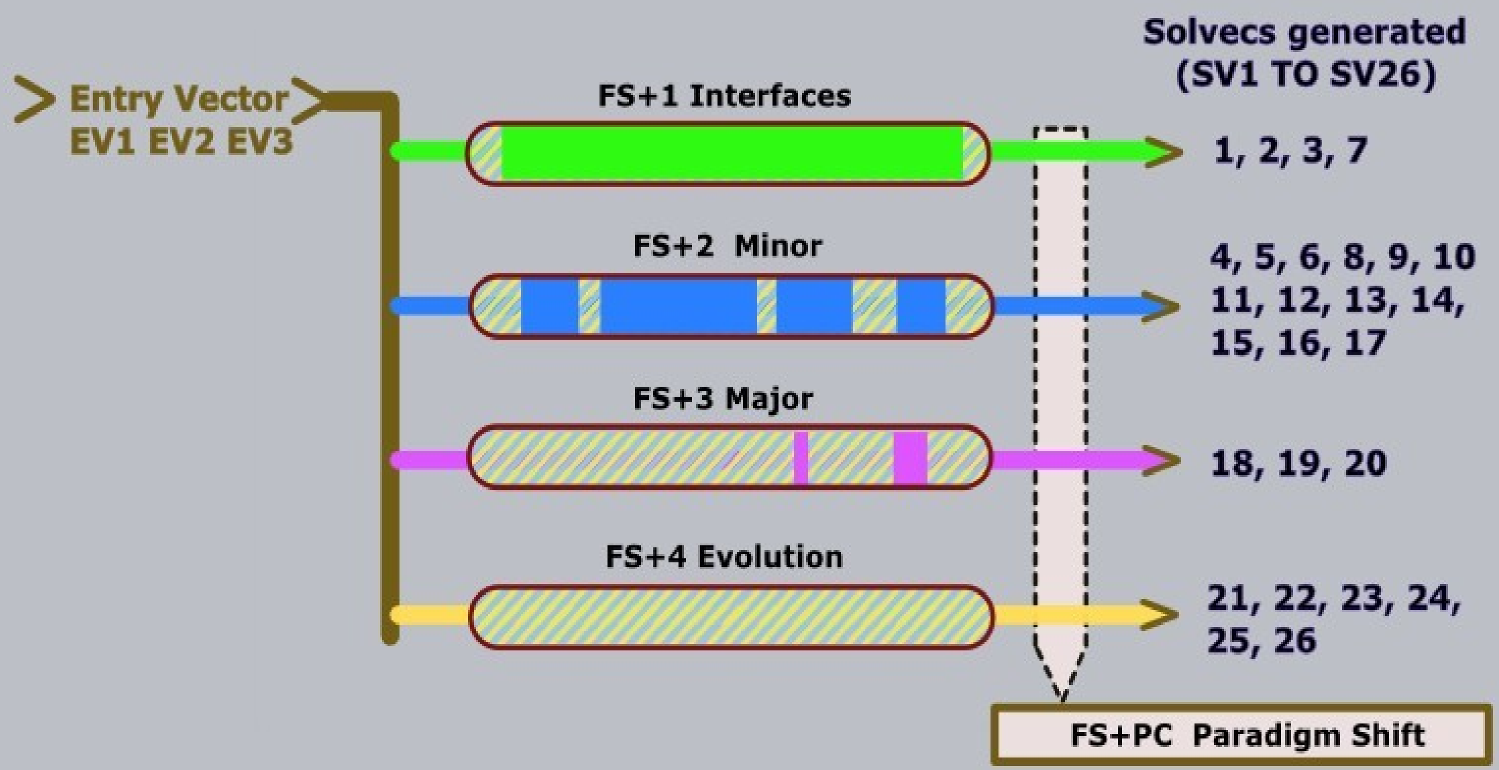

Fig. 7 Functional Streams and generated Solvecs

Paradigm Change [FS+PC] (cont'd): It is rare that the basis for paradigm change can be identified at the earliest stages, without going, at least partly, through the innovation process. Certainly, this includes the problem definition and refinement stages.

Functional Streams Applied:

By processing the functional streams, we can generate solution vectors (**solvecs**) as is shown in Table 1. It should be noted that these solvecs are generated for the static ports. Not every possible solvec combination is described. A few examples from Table 1 will be used to illustrate the output of the SSA approach:

EV-1 Eliminate susceptibility to blockage:

FS+1 (change limited to system interface)

- **SV1**: Directed light source located within static port.
- **SV2**: Detect magnetic substrate of special covering tape.
- **SV3**: Detect conductivity of special covering tape.

FS+2 (minor changes to system)

- **SV4**: Detect presence of covering tape by acoustic sensor within port.
- **SV5:** Detect presence of covering tape by ambient / reflected light sensor
- **SV6**: Detect presence of covering tape by air pressure release sensor.

EV-2 Improvements to reliability / product development:

FS+2 (minor changes to system)

- **SV9**: Use ram air with pebbled surface around port opening.
- **SV10**: Use ram air with easy peel-off paint around port opening.
- **SV11**: Use ram air with detachable skin panel around port opening.
- **SV12**: Use ram air with heated skin paned around port opening.
- **SV13**: Use air pressure pulse within port to clear obstruction.
- **SV14**: Built-in swing away covers over port.
- **SV15**: Built-in sliding metal skin panel over port.
- **SV16**: Built-in retractable metal skin panel over port.
- **SV17**: Special water repellent baffle installed over port.

FS+3 (major changes to system)

- **SV18**: Nose wheel landing gear door extension to block port when landing gear L/G down.
- **SV19**: UHF antenna on L/G door to block port when L/G down.
- **SV20**: Re-locate air pressure transducers to exterior surface of aircraft.

FS+4 (evolutionary change to system)

- **SV21**: Use special polymer external panels to register dynamic air pressure.
- **SV22**: Instrument external metal skin panels to register dynamic air pressure.
- **SV23**: Use ionised air pulsing to measure air flow.
- **SV24**: Use array of ionised air sensors to measure 3D air-flow patterns.
- **SV25**: Use ground mapping radar with digital terrain matching.
- **SV26**: Use Ground Positioning Satellite GPS system at all altitudes.

EV-3 Incomplete situational awareness.

FS+1 (change limited to system interface)

- **SV7**: Flight computer does not allow engine start if tape auto-detected.

FS+2 (minor changes to system)

- **SV8**: Flight computer does not allow engine start if special covers not removed and stowed into cover-receptacles within landing gear doors.

EV-4 Inefficient transfer of information.

Solvecs (SV) generated but not discussed here.

EV-5 Lagging (slow) processing of information.

Solvecs (SV) generated but not discussed here.

EV-6 "Inverted Pyramid" syndrome.

Solvecs (SV) generated but not discussed here.

Table 1: Solution Vectors generated for Entry Vectors EV1, EV2, and EV3.

	EV-1 Susceptibility to blockage	EV-2 Improvements to reliability	EV-3 Absence of critical information	EV-4 Inefficient transfer of information	EV-5 Rapid processing of information	EV-6 Inverted pyramid syndrome
FS+1 Interface	S1 S2 S3		S6			
FS+2 Minor	S4 S5 S6	S9 S10 S11 S12 S13 S14 S15 S16 S17	S7			
FS+3 Major		S18 S19 S20				
FS+4 Evolutio n		S21 S22 S23 S24 S25 S26				

Brief discussion of the solution vectors / solvecs (SV):

We will now briefly consider the third component of the SSA approach - the solvecs that were generated and are listed in Table 1. The terms "Solution Vector", "Solvec", and "SV", are all identical in meaning and equally refer to the output of the Super System Augmented (SSA) approach.

SV1: Passive assistance to detection. This is a simple, passive, solvec to detect, at night-time, the presence of any obstruction or tape covering the static ports. A low intensity laser source located in the static port emits a beam that is directed downwards, at an angle, at the tarmac. Ground personnel can detect the presence of beam, or its intensity, visually or with a hand-held sensor even in complete darkness, irrespective of the height of the static ports above ground. Any type of tape or material obstructing the ports can be detected.

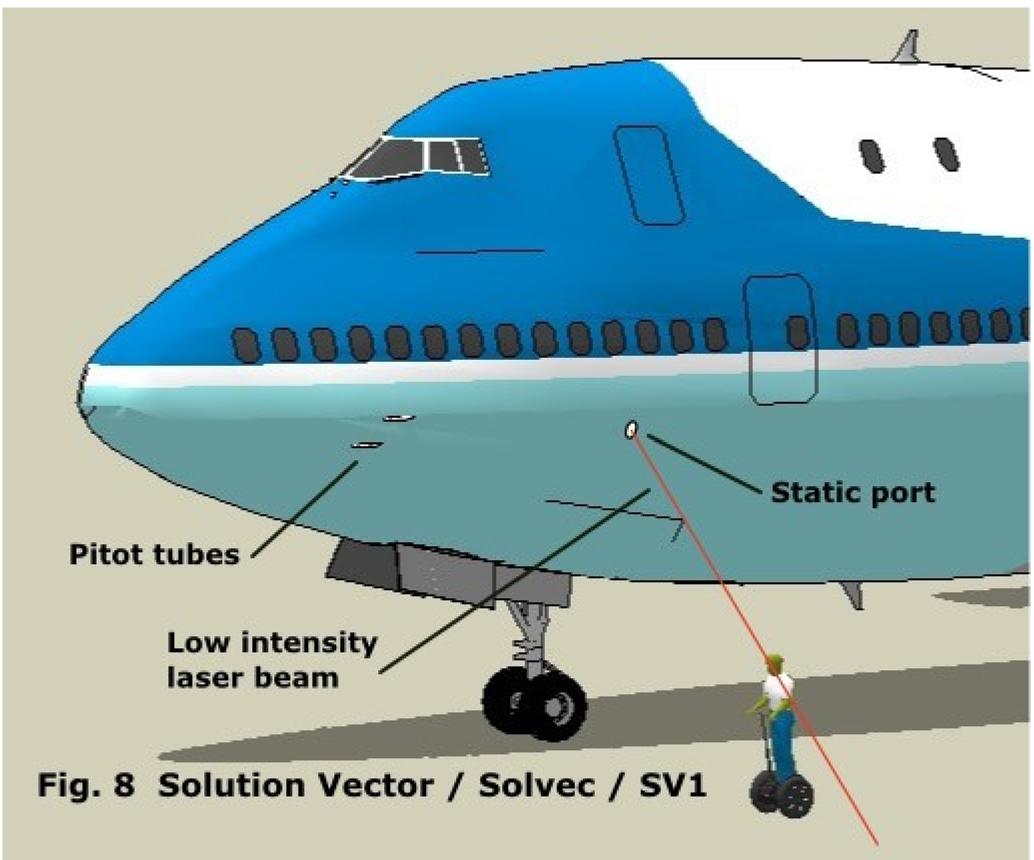

Fig. 8 Solution Vector / Solvec / SV1

SV2, SV3: Auto-detection of special tapes. These are the active versions of **SV1**, where the static port is equipped with the means of checking the conductivity or magnetic substrate of special covering tape. The sensors would be located flush with the exterior surface of the aircraft, in the proximity of the static ports. The limitation here is that only specially fabricated tape with magnetic or conducting substrates or properties can be auto-detected.

SV4, SV5: Auto-detection of all types of tapes. These solvecs are the active version of **SV1** for the detection of tape using the principle of reflected acoustic pulse or a reflected light beam off the obstruction. The emitter and receiver are located within a fairing inside the static ports.

SV6: Auto-detection by low pressure air pulse. This solvec relies on monitoring the rate of decay of a low-pressure air pulse within the circuit. The main advantage is that by using solenoids to isolate the sensitive instrument transducers, this solvec can check both paths of the pitot + static circuit independently for blockages. The pitot and static sides can be isolated and checked at any time on the ground.

SV9, SV10, SV11, SV12; Auto removal of tape during flight. The detection of an obstruction is not as useful as the means of automatically removing such an obstruction during flight. TRIZ suggests that we consider using freely available resources first, and try to achieve solutions where the desired result is achieved in and of itself. To remove a tape covering the static port, we can use ram air effect of the passing air stream. To break the adhesive bond we may consider a pebbled stainless plate forming the exterior of the static port as in **SV9**. The use of easy peel off, low adhesion paint, as in **SV10**, could be another option; as would a detachable cover plate as in **SV11**. **SV12** suggests application of additional energy to break adhesion.

SV13: Auto-removal of obstructions by high pressure pulse. The above four solvecs address the issue of tape removal off the static port, which is a highly unlikely event to recur. What is more probable is the partial obstruction of the circuit due to foreign object ingestion, wasp activity, or by icing, etc. **SV6** provided us with the concept of detecting blockages using an air pressure pulse. In **SV13** we intensify this concept by using high pressure pulse, possibly generated by combustion gases, for the clearance of internal or taped over obstructions, followed by compressed air release to clear the system. The outstanding advantages of this solvec are: are:

1. Detection, clearance, and verification is done automatically by the same solvec.
2. There is no need to modify the pitot tube or static port geometry, at the exterior or interface level.
3. The concept is well suited for retro-fit to existing systems.
4. A preventative purge cycle may become routine as the aircraft leaves the apron and taxies to the runway.

SV14, SV15, SV16: Retractable covers. This set of solvecs emerge from the problem space with a view to automate the placement and removal of covers on the static ports. Using the TRIZ philosophy of first utilising available resources, **SV14** and **SV15** rely on air-flow to actuate the covers. Basically, simple, spring-loaded mechanism keeps the ports covered until the force of the air-flow is sufficient to shift the covers. **SV14** suggests a sliding arrangement, while **SV15** is based on a rotating / pivoting arrangement. The method of operation utilises a free resource, the high speed air-flow past the static ports. The aerofoil converts the energy of the air stream into an opening torque. The cover can be locked in the open and the closed positions. A limitation of this solvec is that it will not deploy at very low speeds, while the aircraft is taxiing. This is not critical, as other more precise methods are available during this phase. **SV16** provides a pivoting cover arrangement, with an independent actuator, that can be deployed upon engine start while the aircraft is stationary.

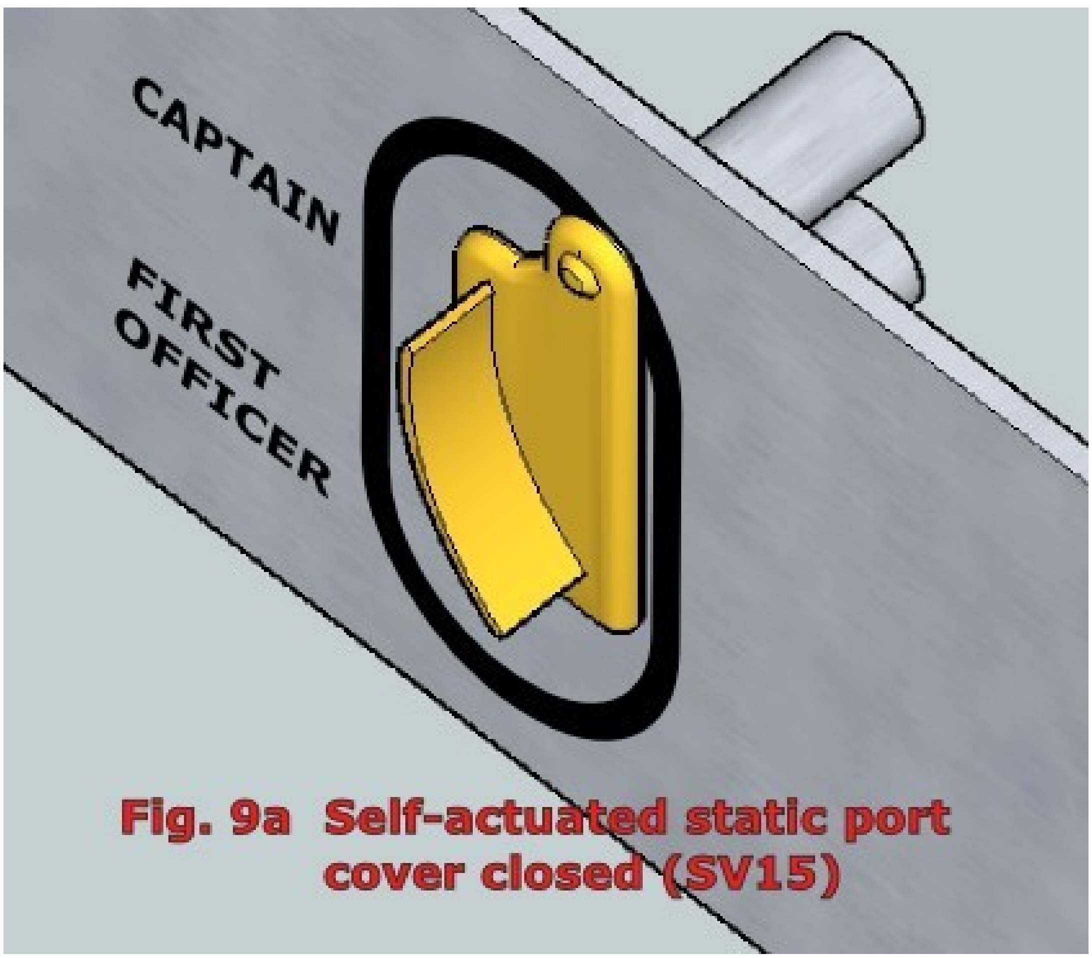

Fig. 9a Self-actuated static port cover closed (SV15)

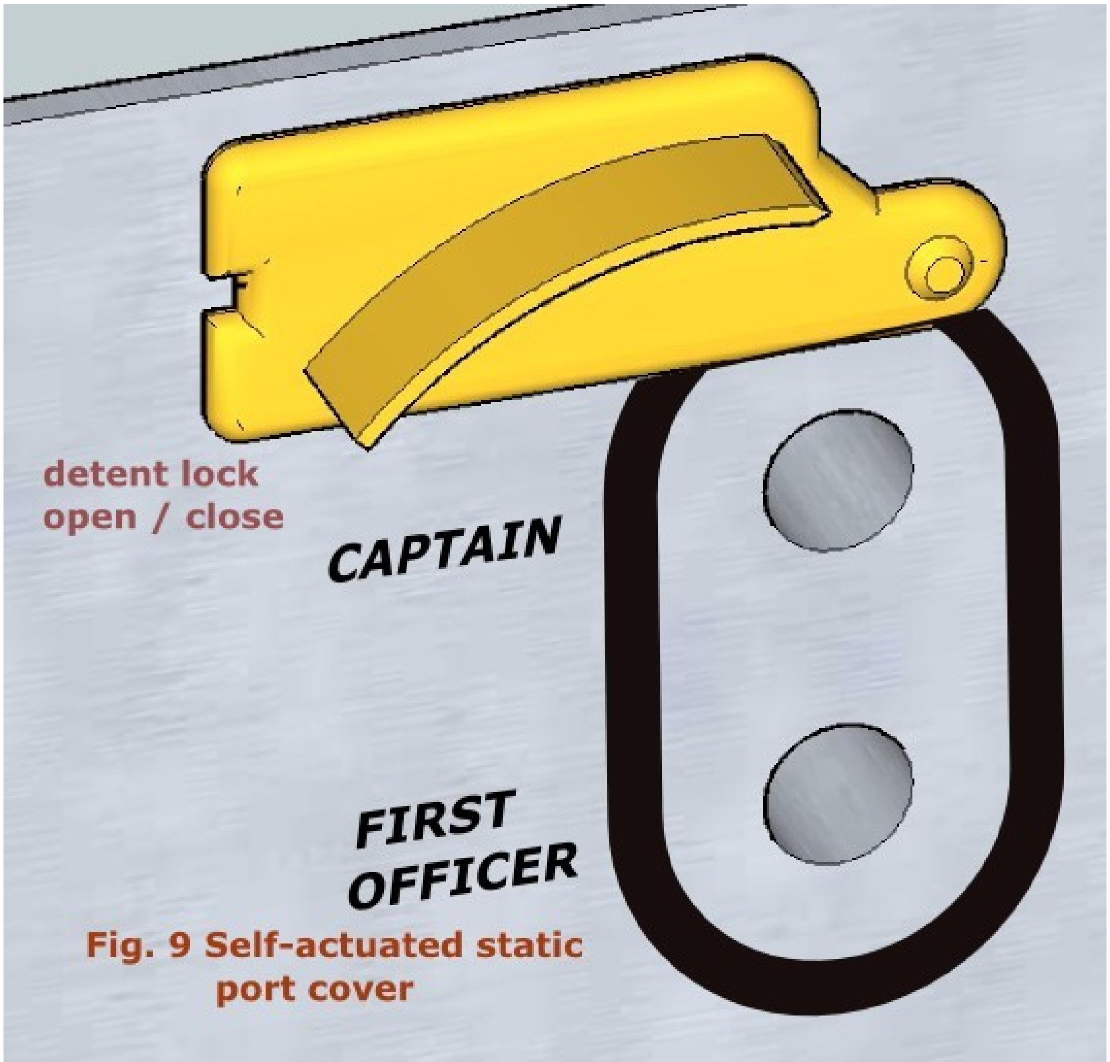

Fig. 9 Self-actuated static port cover

Fig 1a Wreckage showing taped ports of N52AW

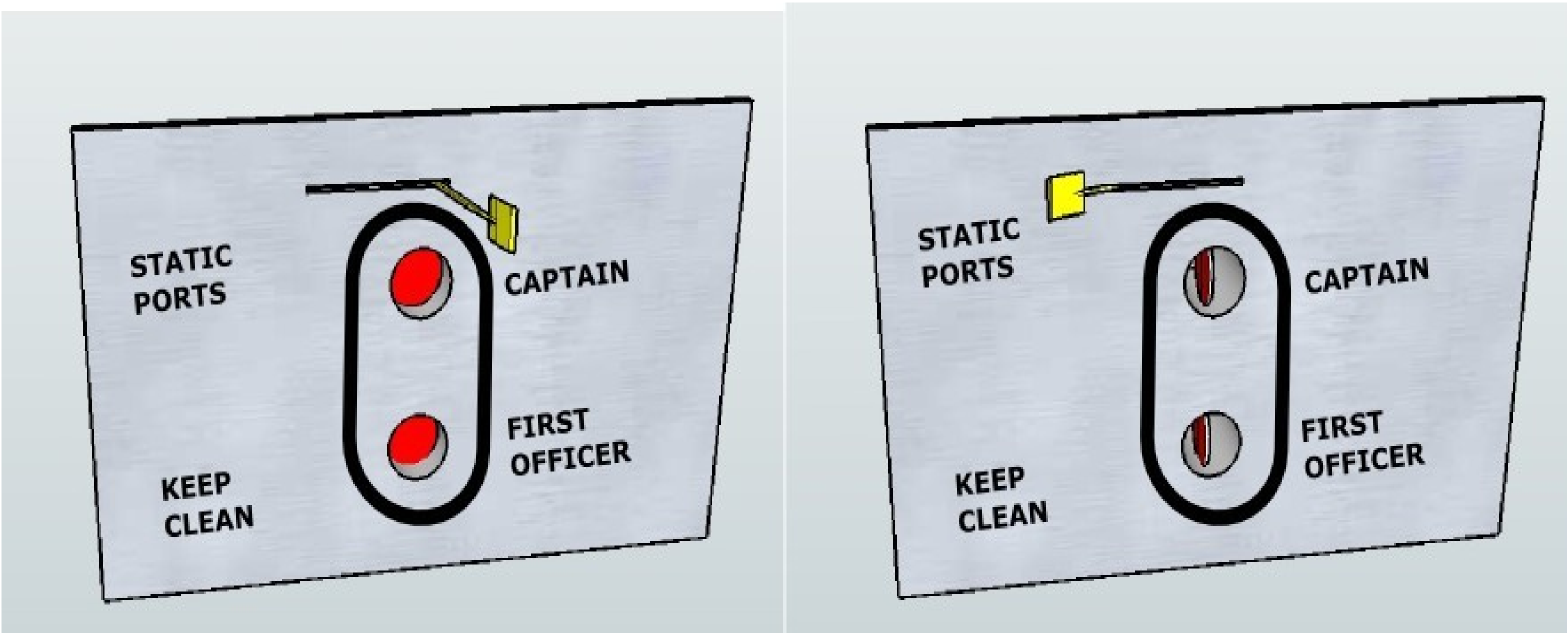

Fig. 10 Self-actuated static port cover (SV14, SV15)

SV17: Ingestion resistant covers: Within this direction a number of solvecs can be generated, all designed to reduce foreign object ingestion and allow relatively free passage to air.

Using TRIZ tools such as smart little people (SLP), and by the modification of geometry, we can develop simple static solutions to provide the desired ingestion resistance. Any such modification at the entry and exit to the pitot + static circuit will require re-calibration of the probe data, which is more convenient in the new digital format as compared with the older analogue versions. Possibilities within this solvec include water repellent baffle covers over the static port, wire-gauze netting covers, thin criss-crossing wires with high voltage capacitative charge, slow burn pyrotechnic filling in pitot probe housing, etc.

SV18, SV19: Re-location of static ports near L/G doors: This series of solvecs are the result of using the FS+3 functional stream which mandates a major change to the existing system. The internal tubing of the pitot + static circuit and location of the transducers has to be re-routed inside the front of the aircraft. The advantage of this solvec, from the TRIZ viewpoint, is that existing resources are being utilised to perform additional functions.

Also, in compliance with Nam Suh's Axiomatic Design [10] principles, we are gaining a third functionality from two entirely unrelated elements without suffering functional interference at any point.

The ventral UHF antennas are not used while on the ground as the dorsal antennas are better positioned (see photo Fig. 1). During this period we utilise the ventral antenna as a static port cover. Once the aircraft is airborne, the nose L/G doors close over the retracted landing gear, the UHF antenna resumes its designed function, and the static port cover materially disappears. A physical contradiction has been resolved on a change of condition, as per classical TRIZ thinking.

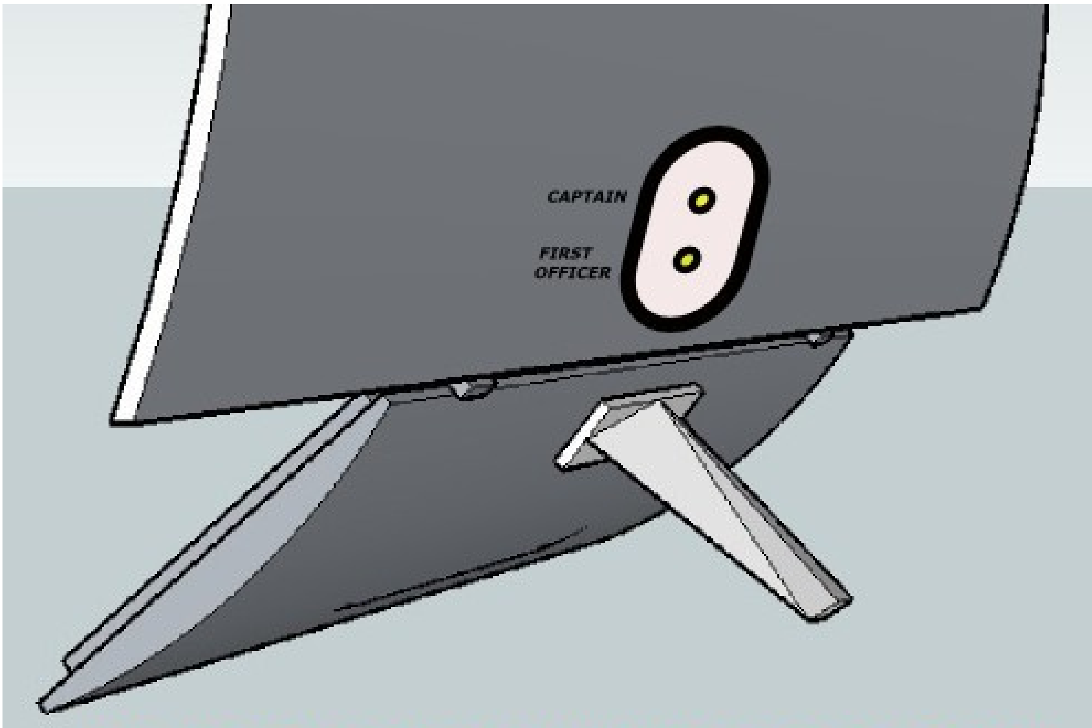

Fig. 11a Repositioning UHF antenna on L/G door

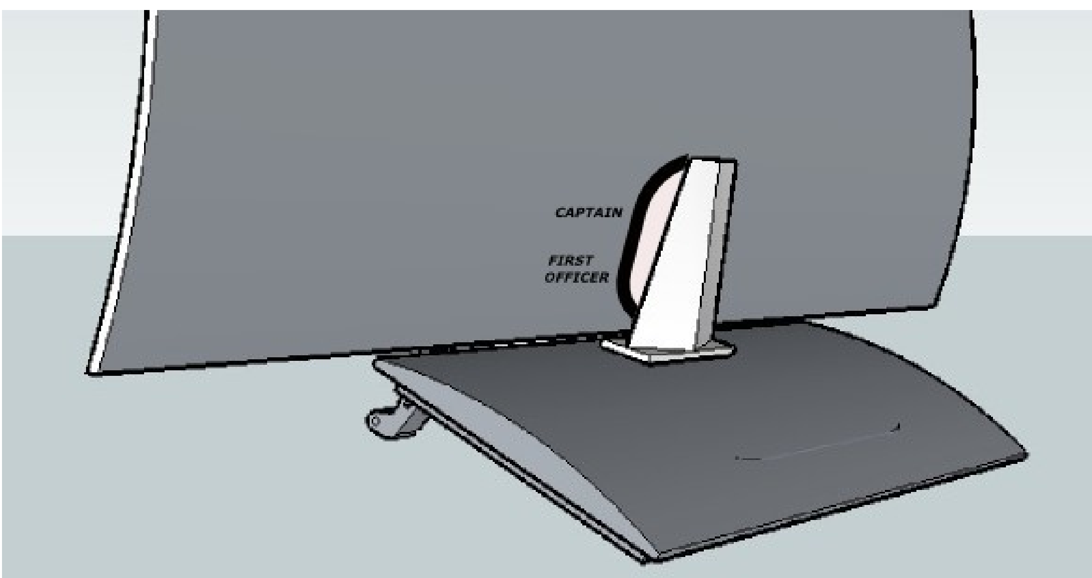

Fig. 11b UHF antenna as static port cover (SV19)

SV20: Eliminate tubing from the pitot + static circuit: This is also an example of the FS+3 functional stream. The major change in this case is that modified versions of pressure transducers are relocated to the exterior of the aircraft. The objective is to directly obtain air pressure and dynamic air pressure data from the ambient air flow. As a result the pitot tubes, the static ports and all the internal tubing can be dispensed with and are removed.

From a TRIZ viewpoint, this is a superior solvec since the problems of tubing blockage are also eliminated with the tubing. A limitation of this solvec is the adverse influence of rain, snow, etc. on the data obtained. Again, TRIZ offers systematic innovation principles such as scaling the probes (within practical limits) to the extremes of size, sensitivity, cost, etc., to generate new concepts. We are also advised to look into segmentation, nesting, prior action, dynamics etc. Again, conceptualisation of a new solution is no substitute for the engineering of the solution through rigorous R&D and physical testing past failure.

> **Note:**
> **SV21** to **SV26** are all examples of the fourth functional stream, **FS+4,** where we consider evolutionary change that encompasses the entire system in question. We try to develop solvecs that will provided the desired functionality by completely replacing the present technology. From an innovation perspective, these are solvecs of a higher order. The only solvecs superior are those originating from the fifth **FS+PC** (paradigm change) functional stream, in which evolutionary change is propagated to the super-system, and is deployed from a higher, heretofore unknown, vista. The outcome of **FS+PC** will span, and possibly eliminate several lower level components within the encompassing super-system.

SV21, SV22: Dynamic pressure sensing: This solvec applies TRIZ principles to **SV20**, to reduce extraneous components by trimming, and by merging desired properties within structural components. **SV21** directs us to use special polymer panels mounted flush with the exterior skin to register dynamic air pressure. The polymer panel can serve as a diaphragm to convert air pressure directly into air-data, or through the intermediary of a fluid membrane cell. **SV22** suggests that the metal skin panels be directly instrumented with strain gages to convert deflection under air pressure into a pressure reading. In this solvec, a segment of the external aluminium alloy skin of the aircraft is instrumented to provide deflection data under the dynamic air pressure. This relationship should be linearly elastic throughout all conceivable flight parameters. Using simple neural networks, self-calibration of data would be possible. **SV22** also provides the possibility of measuring low static pressure with a sealed double walled skin panel, as shown in Figs. 12A, 12b, and 12c.

The elegance of **SV22** lies in the fact that the skin panels are made to perform two entirely separate and unrelated tasks, simultaneously, and without functional interference. In this manner, **SV22** maintains the independence of functional requirements, and also decouples the functional elements. In this, the solvec meets the first principle of Axiomatic Design.

These series of solvecs also remove the need for pitot probes, static ports and associated internal tubing of the circuit. The original basis for launching the innovation exercise has been eliminated by using functional streams, as we begin to migrate towards solvecs for the super-system. The reservations stated in **SV20** will still apply.

SV23, SV24: Using scientific phenomena / effects: This set of solvecs suggest using known scientific phenomena and effects to measure air-flow. The idea is to develop a solution based on solid-state devices which are:

1. Extremely rugged, reliable and contamination resistant.
2. Not affected by moisture or rain
3. Are at the early stages of a new technology “S-curve”.

A transformation from an existing technology towards a new technology is in keeping with TRIZ philosophy. One of the markers for a change-over is when the existing technology base is unable to cope with the rapidly growing demands being placed on it. Pitot + static systems were certainly around in the 1930's, if not earlier. The performance requirements of the new digital flight systems have evolved so rapidly that a technology over-load is indicated (inverted pyramid syndrome).

There are known techniques to measure air flow, such as small turbines, hot-wire anemometers, etc. A new method of detecting a ping or pulse some distance downstream needs to be developed. In **SV23**, the emitter / antenna is located at the nose of the aircraft, while the receivers are located aft along the fuselage.. Depending on the speed of the aircraft, the time for a pulse of say, ionised air, will vary and can be measured. Laser-interferometry may be adapted for this purpose. The solvec only provides us with a direction in which to proceed. It will require substantial amount of R&D before a workable solutions emerge.

SV24 suggests using a phased array of emitters and sensors along the exterior to obtain 3D air-flow patterns about the aircraft. Thus components of roll, pitch, yaw, drift, angle of attack, etc., may be derived differentially from the data obtained (Fig. 13).

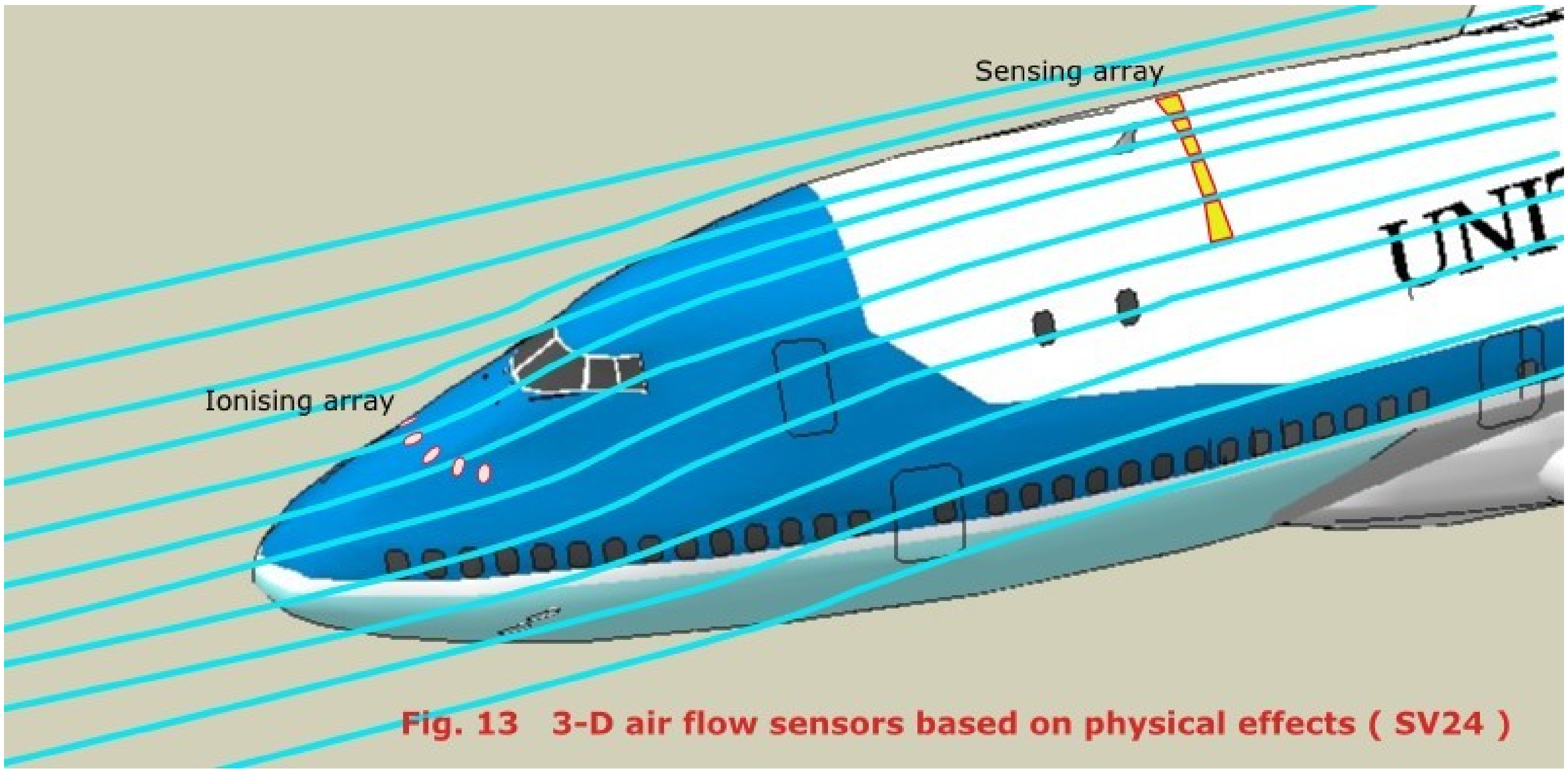

Fig. 13 3-D air flow sensors based on physical effects (SV24)

Note:
The the following two solvecs propose extending the use of navigation technologies developed for defence purposes towards civil aviation.

SV25: Ground mapping radar with terrain following: Most military aircraft use ground mapping radar as a means of high speed navigation at low levels. Versions suited to civil aviation can provide additional situational awareness to the flight crew to support standard navigational aids. Several airline disasters have resulted from confusion in the cockpit caused by poor ground communications, bad weather, pilot fatigue, ill-timed or undetected malfunction of ground navigation aides, etc. Terrain following can provide a separate 3D reference to the aircraft's position viz-a-viz the environs, especially in mountainous regions during landing. Naturally, ground mapping is of little use over large bodies of water except for altitude indication.

SV26: GPS monitoring of aircraft position and attitude: GPS technology is commonplace, and is continually evolving at a phenomenal pace. This is a key resource, widely available at an acceptable cost. As per TRIZ thinking, we are obliged to consider all such resources in coming up with innovative ideas for the task in question.

Until 2000, a policy of selective availability meant that high end GPS systems were reserved for the use of the US military; while civilian applications were provided a degraded signal with resolutions of around 100 M. These days, after a change of policy, all GPS, and specifically Global Navigation Satellite System (GNSS) have resolutions of 10-20M or better, and differential or augmented systems have resolutions of 1-2M. Specialised systems, such as by John Deere for agricultural use, that combine GNSS and ground based wireless navigation signals have resolution approaching 0.01M.

With newer GPS systems being planned, such as the European Galileo, the Russian GLONASS, the Chinese Beidou, and the next generation USA GPS4, we can expect signals of much better resolution. Local augmentation of the signal by land based stations, and /or by dedicated regional satellites, will further improve the resolution.

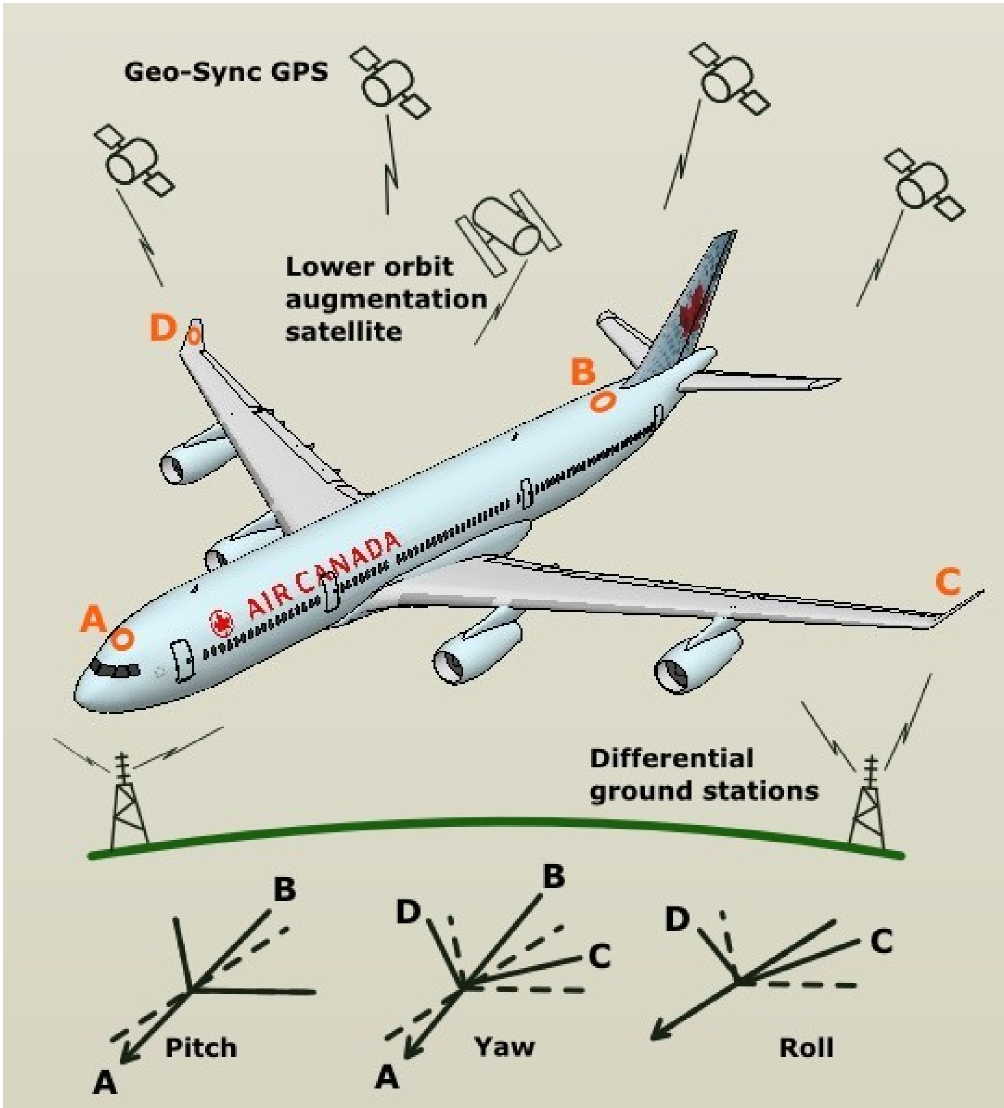

Fig. 14 Augmented GNSS Aircraft position, velocity and attitude data. (SV26)

SV26 proposes an arrangement of 4 receiving stations on the aircraft as shown in Fig.14. This would provide not only position, altitude and velocity information, but also the roll, pitch and yaw components of the aircraft's attitude. The goal would be improve flight safety, and to fly continually optimised profiles, with dynamic updates based on weather conditions, so as to conserve flight time and fuel consumption.

Note:

The following two solvecs follow from EV3, incomplete situational awareness, and provide timely feedback to the flight-crew prior to take-off.

SV7: No engine start if port obstruction auto-detected**:** The entry vector EV3 is directed at improving situational awareness in the cockpit. The ideal final result is not to have a problem in the first place. Solvecs **SV2, SV3, SV4, SV5**, and **SV6** deal with the auto-detection of a blocked condition. This information can be used by the on board flight computers to prevent engine start, unless the situation is corrected by the ground engineers.

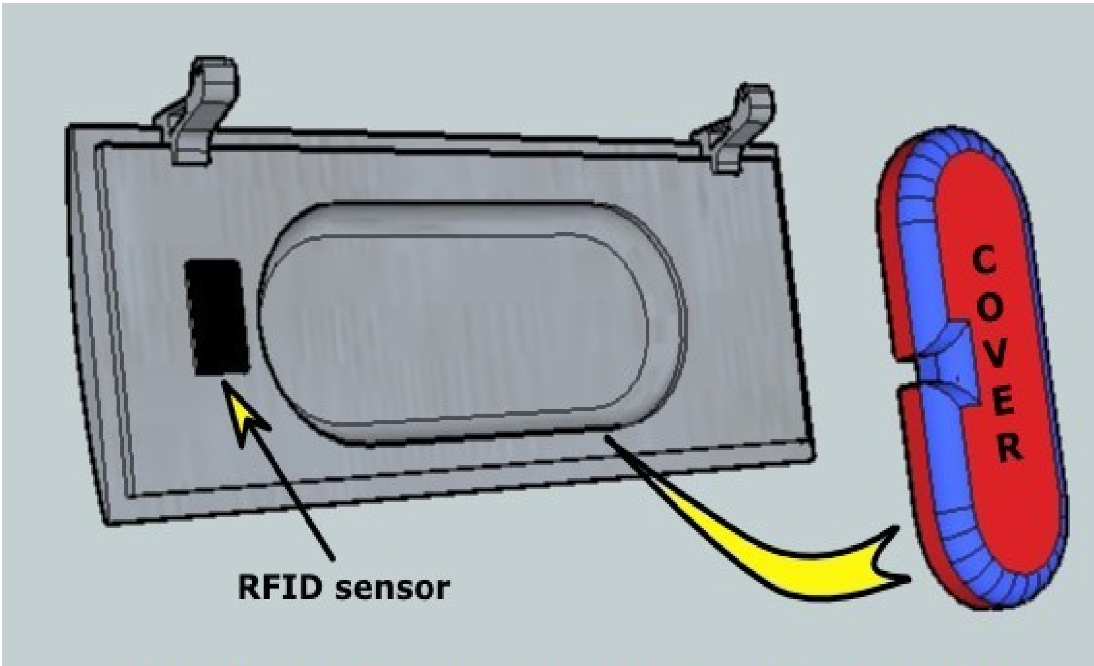

Fig. 15 Static port cover stowage L/G door (SV8)

SV8: Engine start only on proper cover stowage**:** This solvec is also based on EV3, yet employs an entirely different approach. Airbus airliners come equipped with dedicated port covers. There is a slight chance that these covers may be left on inadvertently, at night time or in poor light / weather. The stowage space proposed within the front landing gear (L/G) door can be wired to indicate that a cover has been properly secured and is thus no longer on the ports. The engine start sequence can then be activated (Fig. 15).

There remains the possibility that ground crew may have a number of spare covers, which they could use for a quick work-around as a pit crew to minimise turn-around time on ground. If the original cover was left on say at night-time, and a spare placed into the L/G door receptacle, we would be back to the original problem.

By tagging each cover with an RFID chip, and having a sensor built into the receptacle space, **SV8** ensures that the possibility of error or mischief is greatly reduced. The covers cannot be switched or swapped, they travel with the aircraft, **SV8** requires no modification of the pitot + static circuit, its components or its interfaces.

The solvec retains the low cost characteristic of the manual Airbus solution, and employs just the right amount of automation in transparently linking the super-system (the aircraft and its flight crew) with a minor sub-component (the cover).

The SSA Approach v. the TRIZ Systems Thinking Operator:

The TRIZ systems thinking operator, also termed the multi-screen, or 9-boxes tool, provides the TRIZ user with a systems perspective to any inventive problem solving task.

Systems thinking operator requires us to look at the super- and sub- systems of the item under review. It suggests considering the past, present, and future states of each of these, giving us nine views regarding the task at hand. Further enhancements are possible using the basic operator as a template [8]. Often this tool, or a customised version, is used in a tabular format to collect pertinent information regarding the problem and as a means of overcoming psychological inertia. Compared with this TRIZ tool, the SSA approach offers clear advantages:

Advantages of the Super Stream Augmented (SSA) approach:

<u>As a process structuring tool:</u> SSA provides a structuring exoskeleton to the innovation effort. As in the detailed example in this article, we select the entry vectors (EV) to determine the course of the program. The choice of the EVs determines the immediate, the intermediate, and the longer term expectations from the exercise. For each of the EVs, we know that at least four (4) functional streams will have to be developed for each EV. As shown in Fig.16, entry vectors (EV) are the vehicle for innovation planning at the macro-level, while functional streams (FS) perform the primary task of innovation-in-the-small; at the micro, detail level.

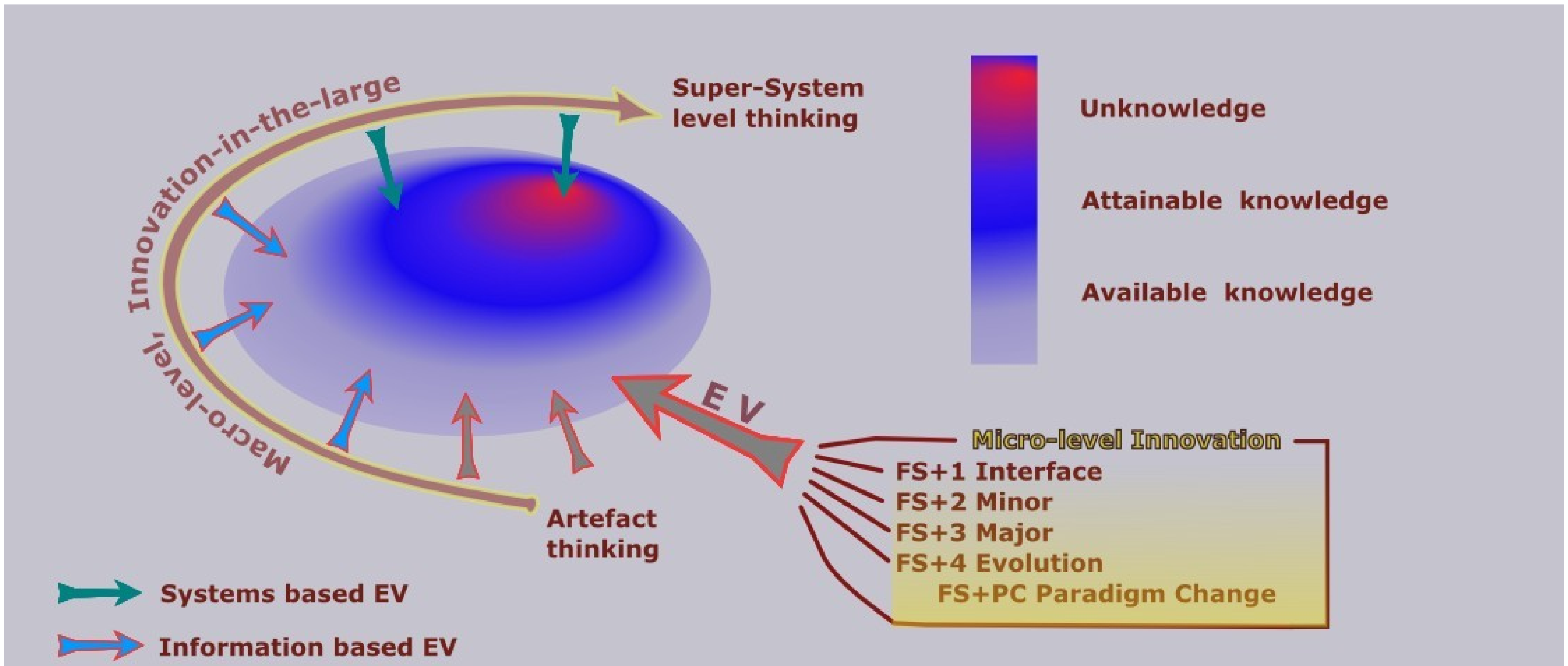

Fig. 16 Problem space, entry vectors, functional streams

For assumption modelling: Entry vectors provide an explicit and unambiguous record of the assumptions formed at the start of the innovation program, as well as during its execution. There is no analogous tool in TRIZ.

As a momentum building and directing tool: Establishing momentum early in the innovation exercise, and feeding it off the early successes is absolutely crucial [2]. It is also vital to give the right direction to this momentum. There is little purpose in expending valuable resources in developing concepts that will be by-passed or made redundant by other solvecs.

For example, in the set below:

[SV1, SV2, SV3, SV4, SV5, SV9, SV10, SV11, SV12]

can be by-passed by gains in this set of solvecs:

[SV21, SV22, SV23, SV24]

which, in turn, can be supplanted by advances in this set:

[SV25, SV26]

It stands to reason that **SV25** and **SV26** should be given the highest developmental priority, unless there are valid technology, policy, or other reasons for delay. In this case, the momentum should be re-directed towards the middle set of solvecs above.

For Innovation-in-the-large / small: This is an important concept which needs some elaboration. Innovation in the small is the isolation of our focus and its concentration on an artefact, a product or a process. Here we deploy our inventory of innovation tools and expect to come up with a good solution. We may need to drill down from the system level to the sub-system level to the component, the function, and finally the parameter level. This may need to be repeated until a satisfactory outcome is reached. An exceptional solution may approach the ideal final result (IFR) in delivering the desired outcome at minimal cost.

The concept of innovation-in-the-large is quite different in that our goal is to is to generate not one but several solvecs (minimum 4 in a solvec set). From these, we rank solvecs based on a criteria which can include:

1. Number of solvecs in the set that will be made redundant by this solvec.
2. Position of the solvec on the technology S-curve. To introduce a new technology curve, or to be placed at the early stages of an existing curve is preferable.
3. Other issues, such as developmental costs, environmental issues, government policy, international collaborations, etc. can enter at this stage when

evaluating the entire solvec set. Note that these issues are not considered earlier.

The reader may agree that achieving an IFR on a solvec that will be supplanted at the innovation-in-the-large stage is not an ideal outcome. We can observe this with **SV19** and **SV22,** both of which individually approach high IFR, but are not as technologically efficient when compared with **SV26**.

For dynamic evaluation and serendipity: The SSA approach encourages the generation of multiple solutions, each of which may be in varying degrees of completeness at any given point in time. A mature innovation program in an organisation is one that has several projects completed or are in the pipeline. We can take a snapshot in time of the solvecs in any program, and make exit / entry decisions based on the degree of their completeness. Additionally, the visibility of multiple solvecs promotes aspects of serendipity, by further ideation, merging of functions, etc.

For enrichment of innovation vocabulary: In a submission to the Review of the Australian National Innovation System, it was noted that: "We also do not possess a precise vocabulary to classify aspects of innovation – a generic term that is freely and interchangeably used to describe the mindset, the capability, the process, its outcome, and the reasoning involved." [3]

In the SSA approach, we present the entry vector as a composite of the assumptions and the prior knowledge about the problem space. The solvecs are the output of the innovation exercise, being the in-process form of an innovation. Solvecs form the in-process inventory of the innovative organisation, and can be in varying states of completeness and readiness for commercial gain. A vibrant innovative organisation must have a substantial inventory of solvecs. A depletion of the solvec inventory should cause alarm.

Conclusion:

The primary goals for this article have been:

1. To provide sufficient information on an issue of current interest, so that it can serve as the test-bed for further development of innovation techniques. It is essential that the topic is from the open domain, that supporting information is usually unrestricted, and that the resulting innovations are assigned to Common Good. It is so that other contributors do not feel constrained by confidentiality agreements.

2. The proposed Super Stream Augmented approach provides a structuring methodology based on systems engineering principles to support the rich inventory of tools and techniques available in TRIZ.

3. In the current economic climate, when much is expected of innovation, SSA can also serve to highlight the synergy and serendipity aspects of the process. Using innovation-in-the-large concepts we are able to use an alternate metric for measuring the progress of the innovative effort.

4. The concept of the Solvec has been proposed as a representation of the intermediate, in-process form of an innovation.

Directions for further research:

1. The obvious direction for further research would be in the continuation of the case study, so that solvecs for EV4, EV5, and EV6 can be developed and presented. The author plans to present his own work in a follow-up to this article at a future date. In the interim, the interested reader may wish to employ the functional stream approach in this or any other task. As a hint, it may be mentioned that the aircraft disasters mentioned above were caused by the flight crew losing situational awareness at a critical time.

2. The second area of research may be in further testing the SSA approach, and in discovering its limitations. Any new approach that complements, supplants or entirely by-passes the proposed methodology would be a desirable addition to the larger field of Innovation Sciences.

3. A third area is in developing an enhanced vocabulary of innovation terms [3]. We need finer granularity to be able to bring the various components and stages of the innovation process in sharper focus. At present the limited vocabulary in the field of innovation causes key aspects to become indistinguishable in a diffused haze. Developed bodies of science must have, out of necessity, sophisticated vocabularies.

Utilising free resources:

The author has used SketchUp7 components from the Google 3D Warehouse in some illustrations, GIMP and Inkscape 0.46 for all art-work, and OpenOffice.org 3.0 as a complete productivity suite replacement for MS Office. These are all open source resources of exceptional quality. In TRIZ terms, they represent an Ideal Final Result, in that the desired functionality is achieved at the lowest cost.

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Fig. 3 Lutz Schonfeld, Wikimedia Commons.

About the Author:

Shahid Saleem A. Arshad earned his Masters and PhD industrial engineering / CIM from Purdue University, USA. His verifiable record of industrial innovation begins with his senior design project at the Macklanburg Duncan Co. in Oklahoma City in 1979. He has experience in industry as well as in research. Presently he is based in Sydney, Australia, and is active in the field of applied industrial innovation.