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Procedia Engineering 131 (2015) 1064 – 1072
Procedia Engineering
www.elsevier.com/locate/procedia

World Conference: TRIZ FUTURE, TF 2011-2014

Modelling the Conceptual Design Process with Hybridization of TRIZ Methodology and Systematic Design Approach

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Abstract

The Theory of Inventive Problem Solving (TRIZ) methodology is known to be very effective in complex problem solving. The method, however, needs enhancements in the safety considerations at the earlier stage of conceptual design. This paper presents a hybridized TRIZ methodology with the work of Pahl and Beitz, Systematic Design Approach (SDA) through an effective modelling. This modelling helps in critical problem solving in conceptual design of aircraft parts. The process is applied to a case study of selected aircraft components with a proposal of a systematic and creative methodology in the conceptual designing process. The implications of this study will help aircraft designers to optimize the aircraft parts design in an effective and creative way.

Peer-review under responsibility of the Scientific Committee of TFC 2011, TFC 2012, TFC 2013 and TFC 2014 – GIC

Keywords: *Conceptual Design, TRIZ, SDA, TRIZ-SDA, Creative and Systematic.*

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doi:10.1016/j.proeng.2015.12.424

1. Introduction

Usually conceptual design activity which involves creative and systematic design approach requires collaboration work from many design tools, experts from design and engineering, plus information on recent and available technologies. Combining these factors, designers can produce a creative design in a controlled and systematic manner, so that the outcome of the design activity is a definitive work and effective design. A conceptual design of an aircraft component, however, requires much greater work effort and time especially on safety constraints apart from other engineering requirements. This research focuses on creative problem solving activity, mainly on the methodology of aircraft parts concept design.

Assuming the reader has the knowledge of the TRIZ process, the aim of this paper is to demonstrate a comprehensive construction and enhancement study of TRIZ. The output of this research is a modelling of hybrid methodology using TRIZ and work of Pahl and Beitz's Systematic Design Approach (SDA) [1].

1.1. Overview of the Problem

Conceptual design, the initial stage of design defined as "the representation of the whole or totality of project artefact, sum of all subsystems" [2], a process of problem identification is essentially through abstraction, function structures, working principles and developing a working structure [1,3]. In the conceptual design stage, systematic approach such as acknowledgement of the origins of the product need to be redesigned in specification documentation [2] that includes details about design requirements planning, and modeling of the problem before initiating a design process. TRIZ is best applicable to the conceptual design process.

Often designers and engineers who are familiar with TRIZ work with a mixture of TRIZ with other problem solving and management tools [4] for further understanding and identifying the essence of a problem, for example: integration of TRIZ with Axiomatic Design [5,6,7,8], Quality Function Deployment (QFD) [9,10,11,12], Design For Manufacture and Assembly (DFMA) [13,14,15,16], Hoshin Kanri [17,18,19] and other design thinking tools. Many integration of TRIZ with other design tools does not embed safety principles, while safety is imperative and critical especially in aircraft design.

In safety-critical aerospace industry, the conceptual design is limited within safety constraints with limitations on manufacturability, flight performance, currently available technology, and regulations set by aviation authorities. It is compulsory to apply safety principles into the beginning process of conceptual design and problem solving.

Combining TRIZ and SDA tools (hereafter referred to as TRIZ-SDA) with a safety approach develops an effective design process which is simple and understandable. Further elaboration of this hybrid methodology design process is through a modeling representation. Development of the modeling will then applied on a case study of an aircraft component.

2. Preliminary Knowledge

2.1. Theory of Inventive Problem Solving (TRIZ)

TRIZ is the Russian acronym of *Teoriya Rescheniya Izobretatelskich Zadach* that means *Theory of Inventive Problem Solving*. The creator of TRIZ, Genrikh Altshuller [20], a Soviet engineer, established a procedure for developing creative problem solving with a unique algorithm that reveals the patterns of innovation while he was working in a patent office, in 1946.

TRIZ recommends changing a specific problem into a simplified, generic problem (Fig. 1) and finding solutions by identifying the main function of the problem and its contradiction. After identification of both main function and contradiction of a problem, it is then reformulated into a parameter according to the TRIZ *39 Parameters* (39-P) and then brought forward to the TRIZ *Contradiction Matrix.*

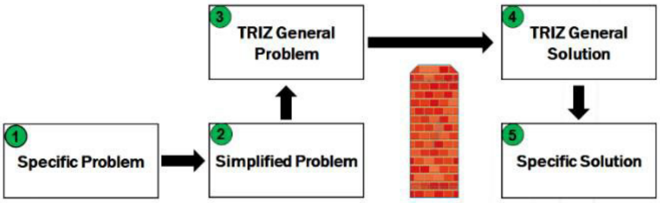

Fig. 1: TRIZ basic steps of problem solution.

The selected inventive principle as general solution is then expanded and detailed out into a specific solution finding process. Analysis of the problem and analytic use of TRIZ happens while transforming from the first box to the fourth, on the way to the fifth box, thinking by analogy develops specific solution [21].

2.2. Pahl and Beitz work of Systematic Design Approach (SDA)

Most engineering design terms and resources stem from the engineering design work of Pahl and Beitz *Systematic Design Approach* (SDA) methodology, referring VDI2221 [22] and VDI2222 [23]. SDA is a systematic embodiment design process, developed by German professors, Gerhard Pahl and Wolfgang Beitz in the 1970ies. The first book on engineering design by them was published in German in 1977 and their first English version of the book published in 1984. The SDA has a tool called *function structure*, intended to comprehensively represent the product design space and a functional basis, a list of functions and terms used to create functional models in order to avoid bias when searching for a solution. SDA, although efficient in functional process but deficient in customer interface and aesthetic [24].

General objective of embodiment design is fulfilling of technical function, economic feasibility, individual and environmental safety, which sum up to three primary rules: clarity, simplicity and safety. This research adopted SDA's conceptual design framework (CDF) and safety principles.

3. TRIZ-SDA Conceptual Design Framework (CDF): A Hybrid of TRIZ with SDA

TRIZ-SDA makes a more firm methodology. Fundamental understanding of conceptual design, safety and problem solving resulted to a systematic yet simple optimization process simultaneously changing the perspective of creative problem solving as a whole. In further elaboration, TRIZ-SDA embed TRIZ tools inside SDA CDF (Fig. 2). Several green boxes in the CDF indicates replacement of current SDA process tools with TRIZ-SDA procedures.

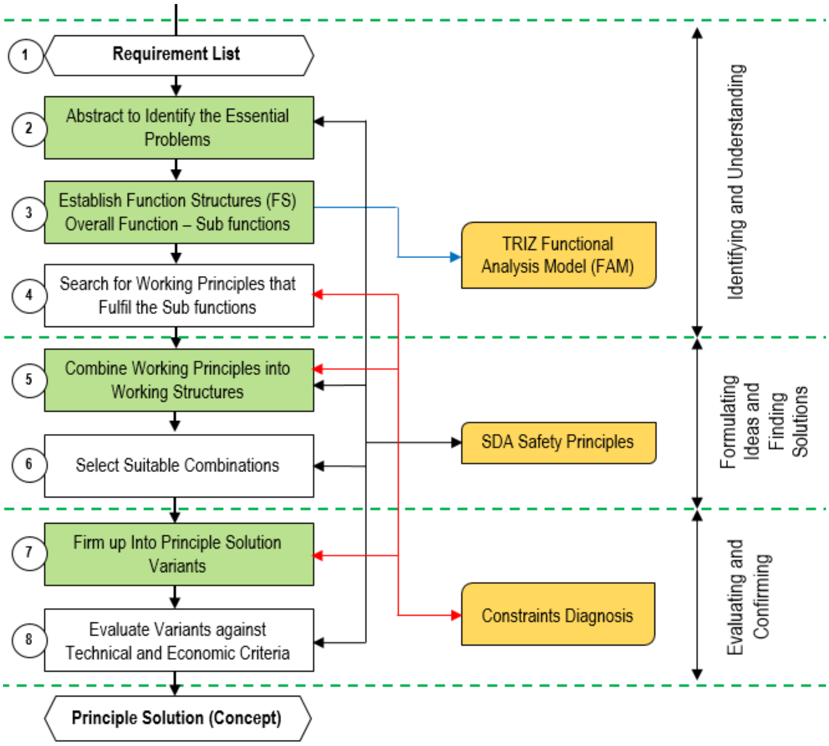

Fig. 2. SDA Conceptual Design Framework (CDF) with TRIZ-SDA. The uncoloured boxes represent existing SDA CDF process and green boxes represent TRIZ-SDA process. There are three major approaches of TRIZ- SDA: *TRIZ FAM*, *SDA Safety Principles* and *Constraints Diagnosis*.

The hybrid process integrates three major approaches:

- TRIZ Functional Analysis Model (FAM)
- Use of SDA safety principles, and
- Continuous diagnosis of constraints.

3.1. TRIZ Functional Analysis Model (FAM)

The identification of problem and contradictions starts with a focus on the proper FAM shown in Fig.3. Different from the SDA function structure which emphasizes signal, energy and material as the three flows passing a component system boundary, the FAM uses component functions in three levels of system. They are system, sub-system and super-system; super-system being the unrelated component that have influence or impact on the component overall system.

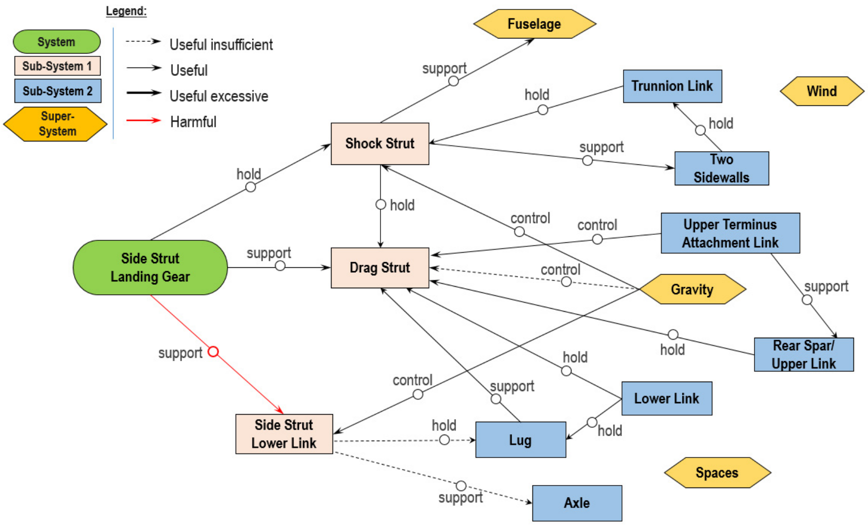

Fig. 3. Functional Analysis Model (FAM) of *Side Strut* component of landing gear [25]. A sub-system 1: *Shock Strut* shows harmful indication with increase loads to *Side Strut Lower Link* component, and gives multiple inefficiency to related sub components. Super-system *gravity* is the core element in designing landing gear.

3.2. Use of SDA Safety Principles

The evaluations on safety occurs at several steps in the CDF. The earliest implementation of safety occurs in box 2, the abstraction process where designers construct conceptual safe design. At box 5, 6 and 8, safety approach here are more to re-check and firming-up the safety concept. TRIZ-SDA safety approach is to have three principles of:

- *Direct Safety* – system or component actively involved in the performance of a particular task. Every component can be optimally designed in accordance with its task.
- *Indirect Safety* – when direct safety proved inadequate, a protective mediator or help for safety is applied.
- *Warnings* – indicate changes and causes of safety failures. Remember TRIZ generalizes a problem before it proceeds to the specific one. The safety approach, in this research context, also goes through a generalization process before going into the specific safety solution.

3.3. Continuous Diagnosis of Constraints

Constraints must be embedded in design process and continuously diagnosed to ensure the design does not violate constraint requirements. The appropriate terms for the continuous diagnose is the *constrained satisfaction* constrained-based approach. There are variety of engineering constraints in the design of Landing Gear, for example, in terms of internal constraints: it is closely related to the hydraulic mechanism, multiple strut and arm, mechanism associated with the tire axle and small supportive components, incorporated in the overall system of landing gear. The external constraining conditions of landing gear are: the moving passage of landing gear, wind resistance, runway surface and weather factors that affect landing gear solid grip and stable landing performance. Then, identification of constraints surrounding the designed component such as: balance and stability, door clearance, movements, gear positioning, tyre sizing, weight assessment, kinematic attachments, materials, coatings, crash-worthiness, structure and topology constraints. The goal is to reduce or eliminate unwanted constraints, or turning them into benefits.

4. Effective Modelling on Case Study

At the start of this study, all 40 Inventive Principles (40-IP) of TRIZ are examined for any potential safety-related input. For example, *Periodic Action*, the nineteenth principle of 40-IP, is compatible with *Redundancy principle* which means a safety approach in the form of parallel risk sanctions. So far, the principle number *11-Beforehand Cushioning* is a principle specifically for safety. The compatibility arrangements between TRIZ 40-IP with SDA safety principles are clustered according to its similarity, related actions, or both. The clusters are shown in Table 1.

Table 1. Principles similarity between TRIZ 40-IP and SDA safety principles.

SDA Safety Principles	TRIZ 40-IP Similarity	Remarks
Direct Safety; Safe-Life	3, 6, 8, 9, 11, 14, 17, 20, 22, 25, 28, 31, 36, 37, 40	Operate without breakdown or malfunction throughout lifecycle
Direct Safety; Fail-Safe	2, 3, 5, 6, 8, 10, 11, 12, 16, 19, 32	Signal of any impairment from main function.
Direct Safety; Redundancy	1, 2, 3, 5, 7, 10, 11, 15, 19, 23, 26, 34, 38	Superfluity or excess. Allow transmission losses, hence safeguard the system
Indirect Safety	9, 11, 13, 16, 18, 24, 30, 32, 39	Use of special protective systems and protective devices (when direct safety inadequate).
Warnings	1, 2, 9, 11, 15, 19, 21, 23, 24, 27, 32	Pointing out dangers and indication of the danger area.

4.1. TRIZ Applications

Each of 40-IP will provide inspiration for safety solutions. The research continues to identify each 39-P compatibility with SDA safety principles and any possible direction towards safety which may strengthen the 40-IP towards safety solution. The FAM builds an in-depth understanding of a product characteristics and its functions performances.

Fig. 4 shows the model of Engineering Contradiction (EC) of TRIZ, inspired from binary model from Orloff's modern TRIZ [26]. First EC formulation is between improving parameter: *27-Reliability,* assuming the shock strut (sub-system of side strut) component design is reliable in terms of geometric and material used for moving mechanism, and worsening parameter is: *01-Weight of Moving Object,* assuming that the component weight is inefficient. From the EC formulation, a few solution principles suitable for new concept design are selected. They are:

- *Principle 3-Local Quality* - suggests that every part linked to the main system of a component should fulfill its function under the best possible conditions,
- *Principle 8-Anti-Weight* - suggests countering the weight of the problem, merging it with other components/objects that can provide lift of weight or compensating the weight by interaction with the environment, and
- *Principle 10-Preliminary Action* - suggests ideas related to an action made before a particular procedure is started.

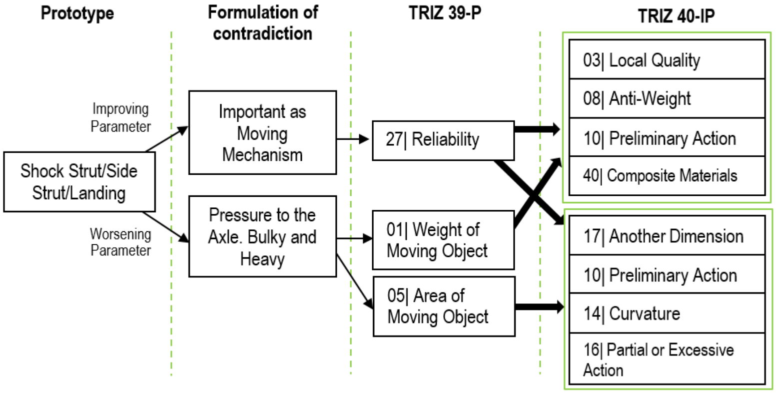

Fig. 4. Engineering Contradiction (EC) model of the landing gear side strut design. Shown here two EC formulations between TRIZ parameter 27 with 01, and 27 with 05.

Second EC formulation is between improving parameter *27-Reliability* and worsening parameter *05-Area of Moving Object,* assumed as the shapes and size of the movable component interfere with other parts through surface contact. The contradiction model suggests solution principles and selected one principle. It is:

- *Principle 17-Another Dimension* - suggests increasing the freedom of an object: instead of movements in a straight line use movement outside the line, use construction in several layers or use lateral and other surfaces.

5. Analysis and Discussion

Combining all the inventive principles recommended from the EC model, principle 10, 3, 8 and 17, and referring to Table 1, the safety principles that are mostly recommended are Safe-life and Fail-safe. Safe-life principle is the most recommended which means the component side strut design must be a component that is designed to function with no potential of breakdown. The side strut must use durable material and be shaped so that it will not deform, additionally protect other surrounding components. The second suggestion is the side strut design must comply with the Fail-safe principle, which, when any part of the side strut broke down, an alternative safety action is quickly replaced to maintain the landing gear performance. Here are the generic suggestions pertaining to safety in each TRIZ principles selected:

- Principle 3-Local Quality
  - Fail-safe and Redundancy - The side strut design uses surrounding component's safety functions, as a redundancy safety procedure during its operation. This means, any suitable parts linked to the side strut works as a second safety component, third and so forth, if side strut experiences failure.
- Principle 8-Anti-Weight
  - Safe-life and Fail-safe - Suggests merging with other components to avoid failures that leads to malfunctioning of the side strut. It means two solution approaches: one is to physically design a combination of side strut with other parts so that the durability of the parts doubled. Another one, both parts, side strut and neighbouring part's function (non-physical) merged for safety increase.
- Principle 10-Preliminary Action
  - Safe-life and Fail-safe - These two safety principles suggest alternative safety occurs before the main function of the side strut begin, as a preliminary safety procedures, to make sure the side strut main function is working without any potential failure (eg: pressure check, temperature of runway), and
- Principle 17-Another Dimension
  - Safe-life - Recommends new safety features in a different dimension, may be in the form of different characteristics of the material, different geometric design instead of straight line shape. The safety features need to be a prior action, as important as the main function of side strut.

From the given generic ideas of safety approach, they are then clustered within TRIZ Separation Principle table, for Physical Contradiction (PC) problem solution, to identify which safety approach is suitable in which area of focus.

The side strut component also contain PC on loads distribution as its manipulative variables. The side strut needs to be in "main working position" for higher side loads of the aircraft to withstand the static weight loads when the landing gear taxiing. The side strut then needs to be in "not main working position" when the aircraft experience vertical loads and drag loads. The solution for this PC clearly consist of Separation in Time or Separation in Condition, as shown in Table 2. From here, safety solution referring to Table 1 can be applied to suit both side strut working positions. Principle 10-Preliminary Action seems to be the best inventive principle for side strut design solution.

Table 2. The solution ideas compatibility with TRIZ Separation Principles.

Principle	**Separation in Space**	**Separation in Time**	**Separation in Condition**	**Separation in System Level**
3	√		√	
8	√			√
10		√	√	
17	√		√	√

The TRIZ-SDA values fundamentals of each TRIZ and SDA methodology, prioritizes each step with suitability of side strut component concept design. In normality, designers usually applies changes on material of the components as a solution, but changes on topology and geometric design also gives promising efficient design and still maintains the performance and durability of the component.

The prospect of this study is to strengthen the field of problem-solving in conceptual design in a substantial way. Two key contributions in the area of conceptual design methodology arise: firstly the theoretical contribution: exploring the theory of inventive problem solving and understanding of the safety principles in design. This modelling by means of hybrid methodology is useful in the conceptual design of a complex object in particular. Secondly the methodological contribution: the overall objective is to propose a systematic and creative approach on conceptual design and for developing a safe design.

6. Conclusions

In conclusions, TRIZ-SDA increases efficiency on safety and creativity in the conceptual design process. The model will lead to the ability of identifying various levels of component functions and safety understanding that will be a novel contribution to the engineering design and inventive problem solving.

Acknowledgements

The author would like to thank for all the opportunity given for conducting this research to Advance Manufacturing Research Centre (AMRC) with Boeing, The University of Sheffield (TUoS), Universiti Putra Malaysia (UPM), and the Ministry of Higher Education (MOHE), Malaysia for providing FRGS fund.

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