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Original Article

How to use an Optimization-based Method Capable of Balancing Safety, Reliability, and Weight in an Aircraft Design Process

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ABSTRACT

In order to help decision-makers in the early design phase to improve and make more cost-efficient system safety and reliability baselines of aircraft design concepts, a method (Multi-objective Optimization for Safety and Reliability Trade-off) that is able to handle trade-offs such as system safety, system reliability, and other characteristics, for instance weight and cost, is used. Multi-objective Optimization for Safety and Reliability Trade-off has been developed and implemented at SAAB Aeronautics. The aim of this paper is to demonstrate how the implemented method might work to aid the selection of optimal design alternatives. The method is a three-step method: step 1 involves the modelling of each considered target, step 2 is optimization, and step 3 is the visualization and selection of results (results processing). The analysis is performed within Architecture Design and Preliminary Design steps, according to the company's Product Development Process. The lessons learned regarding the use of the implemented trade-off method in the three cases are presented. The results are a handful of solutions, a basis to aid in the selection of a design alternative. While the implementation of the trade-off method is performed for companies, there is nothing to prevent adapting this method, with minimal modifications, for use in other industrial applications.

1. Introduction

The Product Development Process (PDP) comprises numerous steps or phases, described somewhat differently by different authors, as stated in Unger and Eppinger [15]. Various authors present different models of the design process [2,11,14]. Companies also have their own views of how to proceed in the process, although most processes have great similarities [4]. Staged processes were popular for decades because of their controlled design structures [15]. In this paper, the term "early design phases" means the time span from late in concept development to midway through system level design, as presented in Fig. 1. Aircraft design is a complex process that involves many different disciplines to obtain a holistic

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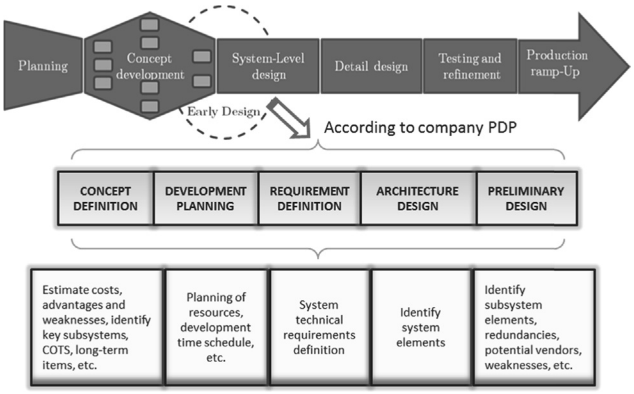

Fig. 1 – Activities performed within early design phases according to the company's Product Development Process (PDP). COTS, XXXX.

approach; many aspects need to be balanced against each other, e.g., safety requirements, reliability goals, and performance specifications. However, while system safety and reliability analyses might begin early in the design [12], with the aim of increasing confidence in the chosen design and avoiding taking decisions regarding design changes at a later stage (which means higher costs). It is in a later phase of the design that most of the system safety and reliability work is done. These analyses use a large range of methods, e.g., Fault Tree Analysis [7,8,12,13,16] and Reliability Block Diagrams [7,8,16]. Typically, targets related to economic performance and those related to safety performance may very well be in conflict, so that the final choice is necessarily a compromise solution [3]. These trade-offs are handled by different optimization techniques. Optimization problems with multiple contradictive targets (the improvement of one target come at the expense of another) are known as multi-objective optimization problems. Finding a single solution in such cases is very difficult, if not impossible. In general, for a problem with m objective functions, the multi-objective formulation can be as follows: minimize/maximize $f_i(x)$ for $i = 1, 2, ..., m$ [1,15]. Many algorithms have been purposed over the years, one of which is the Genetic Algorithm [1,3,9,10,17]. Trade-offs between targets in early design phases might improve the reliability and system safety *baseline* and avoid late changes due to safety or reliability issues. In this paper, the term *baseline* means the preliminary results of system safety and reliability objectives, based on allocated values. One method—Multi-objective Optimization for Safety and Reliability Trade-off (MOSART)—that is able to handle trade-offs such as system safety, system reliability, weight, and cost has been developed by Johansson [4] and implemented at SAAB Aeronautics.

The aim of this paper is to demonstrate how the implemented trade-off method (MOSART) might work in practice to aid the selection of design alternatives.

Aspects considered in this paper concern what can be learned from analyzing system architectures and what can be gained by applying the method. Three cases are considered to highlight those aspects. One case is when the implemented method is tested on a fuel system concept in order to find a balanced combination of vendors for the system's elements. Another case is when several architectures are compared from system safety, reliability, cost, and weight aspects. The last case is to investigate the possibility of finding an optimal solution for the design vector while balancing several safety objectives against the cost and weight objectives, when an additional system safety objective has been introduced.

2. Materials and methods

2.1. Method review

The core of designing is reasoning from function to form. One of the most important tasks of design methodology is to indicate how design processes should be arranged so that they inevitably lead to reliable, effective conclusions and are efficient as well, according Roozenburg and Eekels [11]. According to the company's PDP, the steps shown in Fig. 1 are performed in early design phases. Design problems are always set within certain limits or constraints. One of the most important limits is that of cost [2].

It is in the early phases of the design process that most of the cost is committed. Within the timespan of the design process, knowledge about the problem is gained but the design freedom is lost due to the design decisions made during the process. The characteristics of design evolution with time are illustrated in Fig. 2. A generic objective, or measure of value for the design process (for instance *knowledge* or *freedom*, as well as *cost committed*), is displayed as a random variable with a time-dependent probability distribution. As the design evolves, according to Mavris and DeLaurentis [7], it is desirable to shrink the variability of this objective, as well as shift its mean to more desirable levels (a *lower the better* scenario is depicted in Fig. 2). Nowadays, in other words, it is essential within the design of new products to increase awareness (knowledge) early in the design phases and keep the design decisions (freedom) open as long as possible, and with that

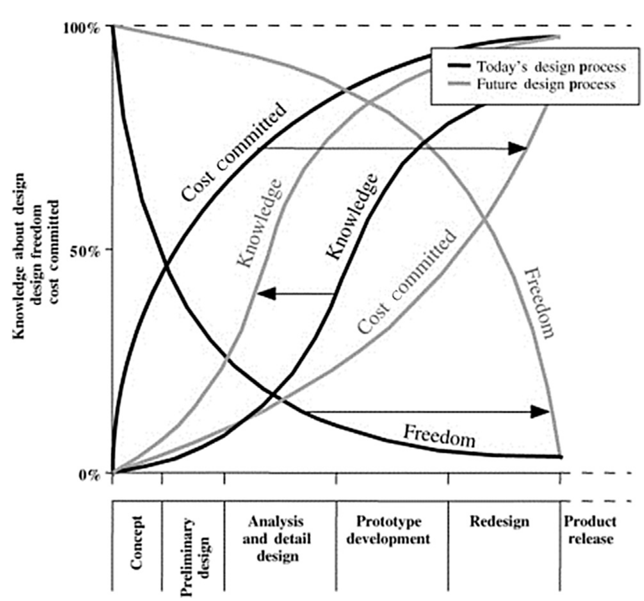

Fig. 2 – Design evolution according to Mavris and DeLaurentis [7].