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Integration Axiomatic Design with Quality Function Deployment and Sustainable design for the satisfaction of an airplane tail stakeholders

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Abstract

One of the most important criteria to remain competitive in the marketplace is a suitable product design that satisfy requirements of a diverse range of stakeholders. But, ambiguous, different and general description of customer needs, major technological advance and significant change from traditional requirements (cost, performance etc.) to new requirements such as, economic, environmental, ecological and societal consideration make the design process more complicate. It should be noticed too, while the new requirements have a major effect on the product successfully, the traditional requirement should not be forgotten by designers. Unfortunately, new issues sometimes are deeply coupled with traditional functions, so the current design methodologies are not able to consider them in the product design process. In this regard, the development of new design methods and tools that facilitate design process by consideration new requirements is vital. The Axiomatic Design (AD) approach is one of the most promising design methodology in the field of conceptual design. This method is emerging as a superior method of design, particularly when innovation versus incremental design is needed. This paper focuses on setting up the redesign of the **Beech Baron 58** tail, by using AD method that integrate with Quality Function Deployment (QFD) and Eco-Design concepts.

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Keywords: Axiomatic design (AD), Quality Function Deployment (QFD), Eco-Design, Aircraft tail Design ;

1. Introduction

In the last decade, product design experienced fundamental changes in its concept from focusing on performance, function and durability, to sustainable design criteria such as being environmentally friendly, considering global warming, reducing energy consumption, and conducting end-of-product life cycle management such as reusing, recycling and remanufacturing [1]. In addition, sharing components between similar products, is one of the other new criteria in design process that could reduce the cost of the family of the product by lessening the duplication of effort and minimize waste by utilizing one shared component instead of two or more [2]. Therefore, Sustainability can be incorporated into all phases of the design process such as design for environment, design for resources and energy, design for sustainability [3] and also family product design. Considering this kind of requirements, make able a product or system to work continuously during its life cycle with lowest level of impact in the environment [1]. Although, it should be notice that for both designers and consumers, traditional aspect of design are very important too. In fact, both sustainable and traditional factors should be balanced in the design process in spite of their deep coupling. In the other word, designers should satisfy today's needs (sustainable needs), without limiting the satisfaction of traditional requirements.

To satisfy a diverse range of stakeholders and handle the growing complexity of the product design, many designers are looking outside of new methodologies for conceptual design process. However, the mounting intricacy of the conceptual design phase makes it difficult for even the most experienced engineers to effectively capture and understand the diverse range of customer demands, much less ensure all of their needs are met during preliminary design phase [4]. Aircraft manufacturing, a field with different stakeholders, is even more liable to have trouble capturing the customer demands. Therefore, it is critical to have robust, rigorous, and methodical approaches to early conceptual design of an aircraft for satisfying all of requirements (new and traditional requirements).

A good tool for design complex products is Concurrent Engineering (CE) that allows the designers to adopt some different design theories and methodologies, such as QFD, AD, Design for Manufacture and Assembly (DFMA), Value Engineering (VE) [5] and Sustainable Design in the design process. Newer fields, like manufacturing engineering, have developed a number of methods to improve product design and development projects based on customer requirements.

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Literature has demonstrated that manufacturing New Product Development (NPD) and construction share a number of similarities [Formoso, et al., 2002]. Due to this similarity, methods used in NPD are easily adaptable to the construction industry [4]. Two popular NPD mythologies are QFD and AD that both of them are used in this study. This paper seeks to address an aircraft tail conceptual design process by using a QFD-AD methodology. This method will work well with tail design because the design process of the tail is very iterative. Therefore, suitable identifying of Technical Requirements(TRs) by using QFD and mapping its result to the AD process, could reduce the repetition in the design process. The remainder of this paper will proceed as follows:
Section 2 introduces the AD method briefly, in section 3 and section 4 we define sustainability and QFD and explains how this two concept are beneficial to the conceptual design process by AD approach. Section 5 presents a case study to demonstrate the application of this theory to redesign of the empennage of the **Beech Baron 58** aircraft. Ultimately, Section 6 provides a discussion of the results and a conclusion of the article.

2. Axiomatic Design

The Axiomatic Design method establishes a scientific theoretical basis that gives structure to the design process. Axiomatic Design offers perspectives that most conventional algorithmic design approaches fail to achieve. This algorithm is not limited to the product-conceptualizing stage but is extended to include the detailed design and manufacturing process domain too [6]. The axiomatic design has been developed in order to merge the standardized design theory with objective and universal principles [7], that allows the designer to quickly determine what is higher priority and ensures a broader systems view[8]. The result of using this approach is improving the design activities by providing the designer, a theoretical foundation based on logical and rational thought processes and tools [9]. Axiomatic Design could make human designers more creative, reduce the random search process, minimize the iterative trial-and-error process, determine the best designs among those proposed, help the designer to design and represent complex systems such as the Orbital Space Plane logically and explicitly and to endow the computer with creative power through the creation of a scientific base for the design field [9].
At the heart of the axiomatic design approach, there are two fundamental axioms govern the design process and identified by examining the common elements that are always present in good designs. These axioms are:
Axiom 1: The independence axiom maintains the independence of the Functional Requirements (FRs).
The independence axiom requires that the functions of the design be independent of each other [9]. Designers must come up with a design that satisfies the independence axiom in which the FRs are maintained independent and then make the design robust, so that the system range is always in the design range. This, facilitate the elimination of complexity (real complexity) in the design process [10].
Axiom 2: The information axiom minimizes the information content of the design.
This axiom says that the best design alternative among all, is the one that minimizes the information content. It is simple to understand that less necessary information means a high probability of optimization of the task [11]. The information axiom violation and high quantity of information of the design, increases the complexity of the product design too [12]. Therefore, it is necessary to minimize the information content of the design.

The performance, robustness, reliability, and functionality of products and processes are significantly improved when these axioms are satisfied. Conversely, design axioms can be used to analyses why machine and processes are not working well and to solve the problems by coming up with alternate designs [9].

3. Sustainable Design

The concept of sustainable development was first proposed by the world commission on environment and development in 1987. Sustainability can be defined as the ability of a product or system to work continuously during its life cycle with the lowest level of impact to the environment. It encompasses, as show in Figure 1, three elements: environment, economy, and social considerations [1]. Sustainability has been applied to many fields, including engineering, manufacturing and design [3]. The Product design process is one of the most prominent sustainable development field. Sustainable design affects all stages of the product life cycle from extracting the raw material to the end of its life cycle [1]. As an instrument of sustainable development, sustainable design intends to conceive of products, processes, and services that meet the needs of society while striking a balance between economic and environmental interests. Sustainable design decisions would spontaneously self-assemble in the marketplace too. For this to happen, sustainable design would need to create more business value than could be captured by designs not considered sustainable [13].

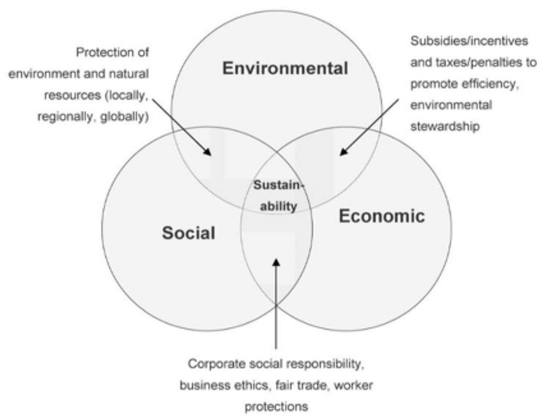

Fig. 1. Sustainability as the intersection of its three key parts[3].

Generally, there are two related problems to bringing sustainability into the conceptual design process. The first problem is that common sustainability criteria are not robust enough to provide a complete picture of sustainability, and sustainability principles are seldom directly applicable for use in requirements specification for a new product. The second is that in an operative design situation, there is little or no time and data available to undertake the work to integrate sustainability [14]. Another difficulty with sustainable criteria (same eco-factors) is that they are generally considered to be coupled with the product functions. As such, they may be relegated to the status of constraint too [15], whereas a very important criteria of AD is that FRs must be define independently. So it is hard to find how to incorporate sustainable issues into the AD methodology. Despite of this problem, in this study, reducing energy consumption, reusing, recycling, using less material, more safety and health for passengers, minimize direct and indirect cost and family design, considered as sustainable design criteria for redesign of the aircraft tail. It is our hope that employ AD with sustainable consideration will help to design a better tail for the Beech Baron 58 Aircraft.

4. Quality Function Deployment

4.1. The Anatomy of QFD

All Quality Function Deployment (QFD) is a very well-known design method, developed in late 1960 in Japan, and used with the aim of translating CNs and wants into technical design requirements by means of the use of a series of matrices, called House of Quality(HoQ), with the objective to satisfy the customers' expectations improving the quality level of the product at the same time [16]. In Figure 2, a modified HoQ that used in this study is shown. In this figure, CNs and the degree of their importance are shown in boxes 1 and 2. Box 3, represent the customer rating for different benchmarks. At this stage in completing HoQ, some similar products are selected as the benchmarks. Understanding how customers, rate the benchmarks can be a tremendous competitive advantage. Eliminating the trial and error process, speeding up the improvements process and increasing the efficiency of the company in developing new ideas are the main advantages to use benchmarking [1]. TRs are listed in the top row, boxes 4 to 8, that split into Non-Functional Requirements (NFRs), Selection Criteria (SCs), FRs, Optimization Criteria (OCs) and Constraints (Cs), whereas in the classical AD does not acknowledge these additional categories or provide any guidance on how to include them in the design process. These cause designers to classify all requirements information as FRs even if much of them are not functional in nature [17]. In box 9, designer shall determine the direction of improvement of TRs. Then, the roof of matrix (box 10), called the correlation matrix, is accomplished to determine the impact of FRs on each other. The correlation of functions can be strongly positive with the symbol of (++), positive with the symbol of (+), negative with the symbol of (-), or strongly negative with the symbol of (–) [1]. Although the relationship of CNs and TRs that is defined as high with the sign Θ, medium with the sign O, or weak with the sign ▲, is shown in box 11. If there is no interaction between a CN and a FR, their corresponding cell will be blank. The QFD will provide the designers with important information, such as the most important FRs to ensure clients satisfaction, and which Cs are most likely to hinder the realization of the project. From this information, designers can determine the most important areas to invest resources. When the QFD is completed, the designer moves to AD to complete the design [4].

4.2. The integration of Axiomatic Design and QFD

Needless to say that AD is very creative and applicable approach to design new product. But, before using AD approach, designer should define CNs and their corresponding TRs of the product. One of the methods to launch new products to market, quickly and successfully, that is very fundamental to any customer driven company, is QFD. This method is very effective for new product development since, it identifies customer demands and translate them into product attributes [18]. As a result, AD and QFD approaches could be merge together in order to develop a market competitive product. The two approaches are operated consequently in order to create a design solution that could satisfy all the expectation of customers. On one hand, the QFD analyses, provided to the designers data regarding to competitors and the market expectations that provide a strong background for the development of the solution. The AD approach is focused on the high-level structure of the product so allows the choice of the best technical solution regarding decoupling (Axiom I) and expected performance (Axiom II). The advantage of this approach are the reduction of product cost and better adequacy to the market expectations [19]. In this article, this joint approach will be applied to redesign an airplane tail to help the designer to create a better and more optimum tail.

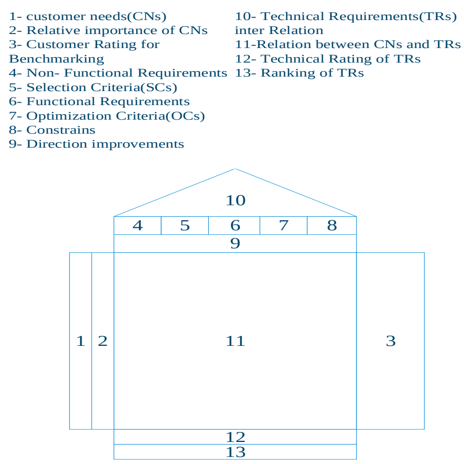

Fig. 2. Different parts of HOQ.

In the following section, the case study is used to demonstrate the application of using AD methodology to redesign the tail of the Baron-G 58. A brief introduction provided in section 5.1 into Baron-G 58 and the specification of its tail. While Section 5.2 demonstrates how the QFD can help the designer to map CNs and sustainable criteria into ranked TRs.

5. Case Study

5.1. Case Study Brief

The Beechcraft Baron that is shown in Figure 3 is a light twin-engine piston aircraft developed by Beechcraft. This airplane is a variant of the Travel Air. The model Baron 58 was developed from the Baron 55, introducing club seating, double aft baggage doors and new gross weight of 5,400 lbs. Depending on the variant, the Baron 58 is fitted with either the continental IO-520 or IO-550 300-hp engine. The Baron 58 can cruise at 200 knots (370 km/h) at 7000 feet (2100 m). The lengthening of the fuselage increased rear baggage space, as well as providing more comfortable six-place seating over the Baron 55 and 56TC [20]. The kind of the tail configuration of this airplane is conventional. This kind of tail is lightweight, efficient, and performs under regular flight conditions. Furthermore, the trim analysis, stability analysis, and control analysis of this configuration is easier than other configurations [21]. The current aircraft tail configuration is generally presented by using traditional methodology of design. We try in this study to demonstrate the advantage of using new methodologies design to create a more suitable empennage for the Baron-G 58.

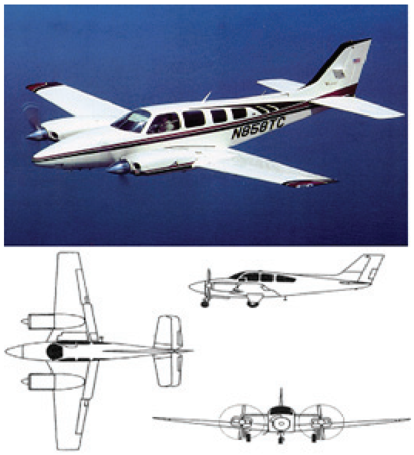

Fig. 3. Baron 58 Airplane.

5.2. Mapping CNs to TRs

The first step of creating a product is obtaining the Voice of Customer (VoC). To this purpose we use QFD tool in this study. Information needed, can be obtained from a range of sources including, but not limited to surveys, interviews, focus groups, and observation. Often customers are ambiguous with their description of needs, and may confuse a physical object for FRs. Customers may also provide vague (subjective) specifications, or provide very general ideas. Affinity trees and diagrams can help clarify and assist in the completion of the list of needs [4]. In this study the CNs that determined for the tail, summarize to easy manufacturing, low direct and indirect cost, competitiveness, efficiency, operational requirements (e.g., pilot view), beauty, low mass, airworthiness (e.g., safety, tail stall, and deep stall), survivability (spin recovery), long life cycle, less material consumption, reusing and recycling. Although, needless to say that the maneuverability and controllability, stability and produce adequate forces and moments to satisfying trim requirement of airplane, are the fundamental requirements of a tail [22]. In addition, Stability and controllability are at odds with each other. These very important requirements of an aircraft are in contrast with each other. In fact, the improvement of controllability in an aircraft has a negative effect on the stability requirement. In the other hand, as the stability features of an aircraft are improved, its controllability features are degraded. [21]. Consequently, designer should determine a borderline between stability and control of an aircraft that defined as handling qualities. Satisfying handling qualities criteria, leads designer to satisfy stability and control requirements too. In Table 1 the CNs and their importance to the user and corresponding TRs are determined by designer. The higher-level TRs where further decomposed into the Cs, NFRs, FRs, SCs and OCs. Each of these five is then further decomposed into high-level TRs for the QFD. In the displayed QFD

Table 1. CNs and corresponding TRs.

Non-Functional Requirements	**Constrains**
Easy manufacturing(8) Operational requirements (8) Beauty(7)	Efficiency(9) Low mass(8) Low cost(8.5)
Optimization Criteria	**Selection Criteria**
Longer life cycle(8) Less material consumption(8)	More reusing components(8) More recycling(8)
CNs for Horizontal Tail(HT)	**Equal FRs for Horizontal Tail(HT)**
Stability and controllability(9) Airworthiness(9) Trim(9)	To satisfy longitudinal flying qualities Be out of dangerous flow To generate forces satisfying FAR 23.161.c
CNs for Vertical Tail(VT)	**Equal FRs for Vertical Tail(VT)**
Stability and controllability(9) Survivability(9) Trim(9)	To satisfy directional flying qualities To satisfy spin recovery requirements To generate forces satisfying FAR 23.161.b

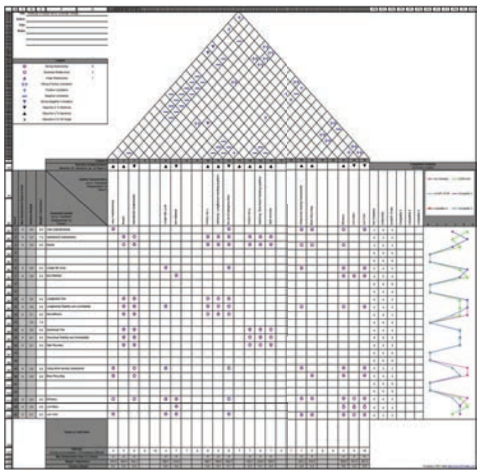

Fig. 4. QFD for Baron 58 tail redesign.

in Figure 4 only the high-level CNs and TRs are used. The reasons to approach this from a high-level instead of leaf level (lowest level) view is twofold: improve clarity and eliminate unintentional bias towards high-level elements that have more leaf-elements [4]. In Figure 4, columns 1 to 3, 6 and 7, 10 to 16, 19 and 20 and 23 to 25 represent Non-Functional Requirements, Optimization Criteria, Functional Requirements, Selection Criteria and Constraints, respectively. This QFD also provides a benchmark analysis of 2 different existing airplanes. Specific information was not available for some aspects of this airplane, so ratings are based on literature about each of them. AVANTI-P180 and CARAVAN are two suitable aircraft for benchmark analysis. Using these different airplane as benchmarks helps to recognize where opportunities exist, and can help designers to better understand how other designers address, or don't address, the VoC [4].

5.3. Decomposition process of TRs

The process of creating a design architecture often follows a process of decomposition, in which a top-level concept of the systems required functions is broken down into sub-functions, and at the same time the most abstract version of its physical form is broken down into subsystems capable of performing the sub -functions. From this definition, decomposition can be viewed from two perspectives [23]:

- As the deployment and refinement of the high-level functions performed by the technical system. This is called functional decomposition.
- As the break-down of the means, or design solutions, for providing the functions. This is often called physical decomposition.

In Axiomatic Design, decomposition is achieved by zigzagging back and forth between at least two adjacent design domains, depending on the scope of the design process. By use of this zigzagging method, hierarchies for FRs, DPs, and Process Variables(PVs) are created in each design domain [23]. After determination of CNs and their corresponding TRs, the redesign of the airplane tail system was done by using the AD zigzag methodology. As can be seen in the QFD, the high-level FRs and their design parameters selected to fulfil each of these FRs for **Horizontal tail**, are:

- FR1= To generate forces and moments for longitudinal trim according to FAR 23.161.c.
- FR2= To satisfy flying qualities for the mission flight phase adequately (Level 1 for longitudinal handling requirements).
- FR3= Be out of dangerous flow (wing vortex, wake etc.).

- DP1= Suitable sizing of HT.
- DP2= Suitable sizing of HT.
- DP3= Adequate configuration selection for HT.

and for **Vertical tail** are:

- FR1= To generate forces and moments for directional trim according to FAR 23.161.b.
- FR2= To satisfy flying qualities for the mission flight phase adequately (Level 1 for directional handling requirements).
- FR3= To satisfy spin recovery requirements.

- DP1= Suitable sizing of VT.
- DP2= Suitable sizing of VT.
- DP3= Adequate configuration selection for VT.

The selected DPs may also change depending on designers point of view and experiences. During the AD design process, the conceptual design should start to take form in the designers mind. Each continuous step of the zigzag process and expansion of the Design Matrix (DM) will further develop the shelter form. A design matrix needs to be formulated for each level of the decomposition to avoid violating the Independence Axiom [4]. Equation 1 shows the DM for level 1 of the decomposition process for both HT and VT. This equation demonstrates that the selected DPs for level 1 satisfy the independence axiom.

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} x & 0 & 0 \\ 0 & x & 0 \\ 0 & 0 & x \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix} \quad (1)$$

5.4. Generation of sub-FRs

Generation of sub-FRs is not as simple as identifying a set of sub-FRs which produces the parent FR. This is because the set of sub-FRs must take into account the other factors which impinge on FR creation. Some of this factors are parent DP, parent-level constrains, and the parent-level DM. The designer could consider the following guideline for generation sub-FRs.

Guideline1:

To develop a sufficient set of sub-FRs, all potential sources of sub-FRs at a level should be considered. These include, parent FR, parent DP, parent-level Cs, parent-level DM (as a source of either potential Cs or sub-FRs), and the set of CNs [24].

Guideline2:

A good order to consider these sources is first to define sub-FRs based on knowledge of the parent DP. Second, define additional sub-FRs in accordance with the parent-level FRs and Cs. Finally, consider the parent DM and CNs [24].

According to this two guideline, designer could continue the decomposition process. Equation 1 shows that the design is uncoupled at the highest level and the independence axiom is not violated. Next, each of the FRs will be further decomposed. For brevity, only FR_2's decomposition for VT will be shown, however, the other FRs will follow a similar decomposition format. FR_2 was chosen because it decomposes to more leaf than other FRs.

Handling Qualities satisfaction is one of the most important requirements for an airplane. This criterion is responsible for two very important functions: longitudinal and directional stability and controllability. Hence, designer define two sub-FRs for FR_2 of VT. This two sub-FRs and their corresponding DPs are:

- $FR_{2.1}$= To generate adequate stability.
- $FR_{2.2}$= To generate adequate controllability.

- $DP_{2.1}$= Satisfying directional static and dynamic stability adequately.
- $DP_{2.2}$= Using adequate rudder for controlling airplane in OEI (One Engine Inoperative) state.

Again this can be mapped into a Design Matrix to ensure that the independent axiom in the second level of the design is not violated. The DM below demonstrate this result.

$$\left\{ \begin{array}{c} FR_{2.1} \\ FR_{2.2} \end{array} \right\} = \left[\begin{array}{cc} x & 0 \\ 0 & x \end{array} \right] \left\{ \begin{array}{c} DP_{2.1} \\ DP_{2.2} \end{array} \right\} \quad (2)$$

Since the independence axiom is not violated in this layer, the third level of decomposition can be created by following the Zigzag process. First $FR_{2.1}$ is decomposed into:

- $FR_{2.1.1}$= To satisfy directional static stability requirement.
- $FR_{2.1.2}$= To satisfy directional dynamic stability requirement.

- $DP_{2.1.1}$= Positive rate of change of yawing moment coefficient with respect to sideslip angle ($0.05 < C_{n\beta} < 0.41$).
- $DP_{2.1.2}$= Damping of roll and Dutch roll mods.

$$\left\{ \begin{array}{c} FR_{2.1.1} \\ FR_{2.1.2} \end{array} \right\} = \left[\begin{array}{cc} x & 0 \\ 0 & x \end{array} \right] \left\{ \begin{array}{c} DP_{2.1.1} \\ DP_{2.1.2} \end{array} \right\} \quad (3)$$

And $FR_{2.2}$ is broken down into:

- $FR_{2.2.1}$= To produce enough force for controlling airplane in OEI state.
- $Dp_{2.2.1}$= Sufficient ruder deflection.

Finally, $FR_{2.1.2}$ is broken down into two sub-FRs:

- $FR_{2.1.2.1}$= To damp roll mode.
- $FR_{2.1.2.2}$= To damp Dutch roll mode.

- $DP_{2.1.2.1}$= Determination adequate roll mode time constant ($T_r < 1.4s$).
- $DP_{2.1.2.2}$= Determination adequate value for damping ratio (ξ_d) and frequency of oscillation(ω_d): $\xi_d > 0.08$ and $\omega_d > 0.4$.

Since other FRs follows a similar decomposition format, we shows the sub-FRs and their corresponding DPs without any access explanation.

- $FR_{1.1}$= Determine VT parameters.

- $DP_{1.1}$= Using suitable technique for sizing the tail.

and

- $FR_{3.1}$= Design adequate rudder for satisfying spine recovery requirements.
  - $FR_{3.1.1}$= Determine rudder area (S_R).
  - $FR_{3.1.2}$= Determine rudder chord (C_R).
  - $FR_{3.1.3}$= Determine rudder span (b_R).
  - $FR_{3.1.4}$= Determine maximum rudder deflection ($\delta_R max$).
- $DP_{3.1}$=Selection suitable rudder design technique.
  - $DP_{3.1.1}$= Selection adequate value for ratio ($\frac{S_R}{S_v}$).
  - $DP_{3.1.2}$= Selection adequate value for ratio ($\frac{C_R}{C_v}$).
  - $DP_{3.1.3}$= Selection adequate value for ratio ($\frac{b_R}{b_v}$).
  - $DP_{3.1.4}$= Determination adequate value for ($C_{n\delta R}$).

A FR does not need to be further decomposed if its target object is different than the target object of its parent FR. However, a DP must still be selected to satisfy this kind of FR. At each point in the decomposition at which the target object changes between parent and child, a new target object has been introduced into the decomposition [24]. The complete sets sub-FRs and sub-DPs for HT, placed along the different levels of the design hierarchy, are:

- FR_1= To generate forces and moments for longitudinal trim according to FAR 23.161.c.
  - $FR_{1.1}$=Determine HT parameters.
- FR_2= To satisfy flying qualities for the mission flight phase adequately (Level 1 for Longitudinal handling requirements).
  - $FR_{2.1}$= To generate adequate stability.
  - $FR_{2.1.1}$= To Satisfy longitudinal static stability requirement.
  - $FR_{2.1.2}$= To Satisfy longitudinal dynamic stability requirement.
  - $FR_{2.1.2.1}$= To damp long period mode.
  - $FR_{2.1.2.2}$= To damp short period mode.
  - $FR_{2.2}$=To generate adequate longitudinal controllability.
  - $FR_{2.2.1}$=To produce enough force for controlling airplane in take-off phase.
- FR_3= Be out of dangerous flow (wing vortex, wake etc.).
  - $FR_{3.1}$= To avoid horizontal tail stall.
  - $FR_{3.1.1}$=To Consider adequate location of the horizontal tail relative to the wing.
  - $FR_{3.1.2}$=To reduce dangerous flows.
- DP_1=Suitable sizing of HT.
  - $DP_{1.1}$=Using suitable technique to determine HT parameters.
- DP_2=Suitable sizing of HT.
  - $DP_{2.1}$=Adequate longitudinal static and dynamic stability.
  - $DP_{2.1.1}$=($-1.5 < C_{m\alpha} < -0.3$).
  - $DP_{2.1.2}$= Damping short period and long period modes.
  - $DP_{2.1.2.1}$= $\xi_{ph} > 0.04$.
  - $DP_{2.1.2.2}$= $.3 < \xi_{ph} < 2$.
  - $DP_{2.2}$=Using adequate elevator for controlling airplane take off phase.
  - $DP_{2.2.1}$=Sufficient elevator deflection.
- DP_3=Adequate configuration Selection for HT.
  - $DP_{3.1}$=
    * Considering adequate location of the horizontal tail relative to the wing.
    * Reducing dangerous flow influence.

    .
  - $DP_{3.1.1}$= Suitable Configuration Selection for the tail .
  - $DP_{3.1.2}$= Using adequate instrument.

After all the leaf-levels in the different branches of the design hierarchy have been reached, and by using Described axiomatic decomposition method, the final full design matrix for both HT and VT was constructed in Figure 5 and Figure 6, to confirm the consistency of the lowest-level design decisions, in terms of the DM elements. The designer could use this DMs to identify coupling between the FRs and try to reduce the iterative in the conceptual design process of the tail.

				DP1	DP2				DP3	
					DP2.1			DP2.2	DP3.1	
				DP1.1	DP2.1.1	DP2.1.2		DP2.2.1	DP3.1.1	DP3.1.2
						DP2.1.2.1	DP2.1.2.2			
FR1	FR1.1			X	0	0	0	0	0	0
FR2	FR2.1	FR2.1.1		X	X	0	0	0	0	0
		FR2.1.2	FR2.1.2.1	0	X	X	0	0	0	0
			FR2.1.2.2	0	0	0	X	0	0	0
	FR2.2	FR2.2.1		0	X	0	0	X	0	0
FR3	FR3.1	FR3.1.1		0	0	0	0	0	X	0
		FR3.1.2		X	X	X	0	X	0	X

Fig. 5. Final DM for HT.

				DP1	DP2				DP3			
					DP2.1			DP2.2	DP3.1			
				DP1.1	DP2.1.1	DP2.1.2		DP2.2.1	DP3.1.1	DP3.1.2	DP3.1.3	DP3.1.4
						DP2.1.2.1	DP2.1.2.2					
FR1	FR1.1			X	0	0	0	0	0	0	0	0
FR2	FR2.1	FR2.1.1		X	X	0	0	0	0	0	0	0
		FR2.1.2	FR2.1.2.1	0	0	X	0	0	0	0	0	0
			FR2.1.2.2	0	X	0	X	0	0	0	0	0
	FR2.2	FR2.2.1		0	0	0	0	X	0	0	0	0
FR3	FR3.1	FR3.1.1		0	0	0	0	0	X	0	0	0
		FR3.1.2		0	0	0	0	0	0	X	0	0
		FR3.1.3		0	0	0	0	0	0	0	X	0
		FR3.1.4		0	0	0	0	X	0	0	X	X

Fig. 6. Final DM for VT.

5.5. *Discussion and result of the case study*

This case study presented contributed to illustrate the applicability of the Axiomatic Design method that integrate with QFD and sustainable design. The main findings from this Study are summarized next:

- The designers want to minimize the amount of resources (in terms of time, manpower, money, etc.) needed to produce a design. To do that they need to minimize repetition of the design process. This benefit is similarly provided by the design axioms that defined in AD theory. The design axioms reduce the amount of unnecessary repetition in the design process [24].
- The integration of AD and QFD, make easier the determination of both traditional and sustainable attributes of a product in the design process.
- The designer should decompose the TRs into the Cs, NFRs, FRs, SCs and OCs correctly, and create a parallel classification for the information (Figure 7) to reduce coupling between FRs in the decomposition process.

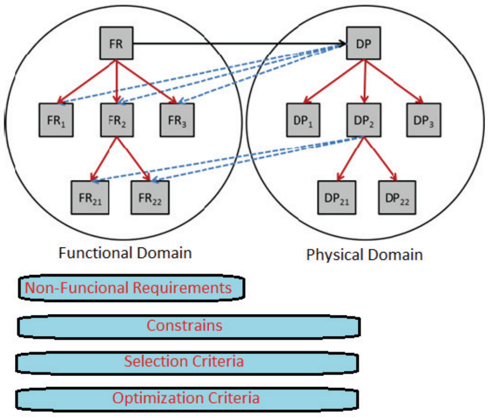

Fig. 7. Expanded requirements categories for AD[25].

- The final full design matrices (Figure 5 Figure 6), demonstrate that design decisions led to a decoupled design that is very important for designers, since it indicated which FRs influence on the others, before beginning of the sizing process of the tail.

6. Conclusions

While many design ideas for airplane tails have been proposed, none of them have been able to completely use by designers. This is because they are unable to adequately meet the stakeholder requirements. In this paper, the Axiomatic Design method was applied to the preliminary conceptual design of **Beech Barons G 58** tail, in order to derive a better configurations. The method is integrated with two proven design methodologies, QFD and Sustainability. QFD is a very well-known design method that is used to translating the VoC to the designers and sustainability is a concept that utilized to reduce the impact of product design to the environments. AD has developed wide acceptance due to its ability to improve creativity, minimize the iterative process, and quickly optimize for the best solution [4]. The CNs and Sustainable considerations are mapped into the FRs and DPs based on the Axiomatic rules by QFD to identify the minimum set of independent FRs. The result is two DM that are shown correlations between FRs and DPs. In both of the DMs the Independence Axiom is satisfying.

Further research will be done to design the new configuration in detail and compare the result with the current configuration. The designer should estimate exactly, how much of the iterative process could be reducing by using the result of AD approach(DMs). As a result of this paper, it is very important that designer could select the best configuration for the tail in the beginning of the design process and this is possible by introduce an approach based on the second axiom of Axiomatic Design and QFD. Using Eco-Design and sustainable criteria and other kind of Technical Requirements such as SCs, OCs, Non-FRs and constrain could make the structure of this approach.

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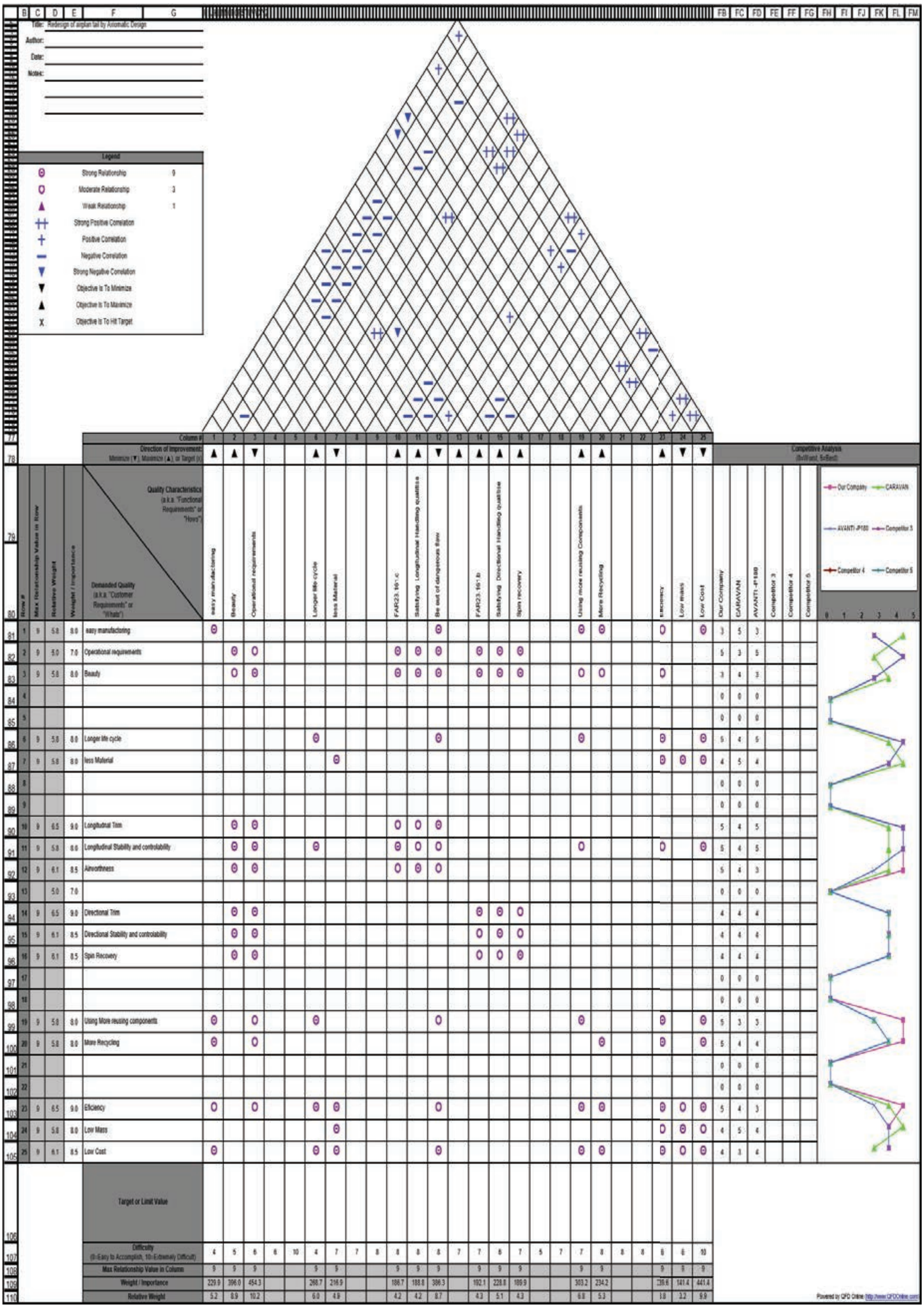
Title: Redesign of airplan tail by Axiomatic Design
Author:
Date:
Notes:
Legend
Strong Relationship 9
Moderate Relationship 3
Weak Relationship 1
Strong Positive Correlation
Positive Correlation
Negative Correlation
Strong Negative Correlation
Objective Is To Minimize
Objective Is To Maximize
Objective Is To Hit Target
Column #
Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)
Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")
Demanded Quality (a.k.a. "Customer Requirements" or "Whats")
Row #
Max Relationship Value in Row
Relative Weight
Weight / Importance
easy manufacturing
Beauty
Operational requirements
Longer life cycle
less Material
FAR23.161-c
Satisfying Longitudinal Handling qualities
Be out of dangerous flaw
FAR23.161-b
Satisfying Directional Handling qualities
Spin recovery
Using more reusing Components
More Recycling
Efficiency
Low mass
Low Cost
Our Company
CARAVAN
AVANTI -P180
Competitor 3
Competitor 4
Competitor 5
Competitive Analysis (0=Worst, 5=Best)
Operational requirements
Longitudinal Trim
Longitudinal Stability and controlability
Airworthiness
Directional Trim
Directional Stability and controlability
Spin Recovery
Using More reusing components
More Recycling
Low Mass
Target or Limit Value
Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)
Max Relationship Value in Column
Weight / Importance
Relative Weight
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