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BRAINSTORMING THE CRYOPLANE LAYOUT BY USING THE ITERATIVE AHP-QFD-AHP APPROACH

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Abstract. Most of commercial civil aircraft are derivatives of each other. They start with an aero-structural design based on the mission profile, and what remains is the integration of existing subsystems. This only leaves room for incremental innovation. When a totally new concept has to be worked out, an innovative brainstorming procedure has to be facilitated, leading to a new product definition. This collaborative creative thinking is not an easy task, and analytical design management tools are required. Therefore, an iterative AHP-QFD-AHP approach for brainstorming is implemented into a concurrent engineering environment in the early phases of layout conception. In the case study, the proposed model delivered the product definition of the cryoplane concept successfully, which promises clean operation.

Keywords: AHP, QFD, concurrent engineering, concept development, new product development (NPD), cryoplane.

1. Introduction

On one hand, change is inevitable, so radical technology breakthroughs, which drive towards innovations (Iyer *et al.* 2006), must be managed to maintain sustainability (Tidd *et al.* 2005). Higher requirements and limits of old technologies lead to radical innovation, where totally new products are introduced (Borgianni, Rotini 2012). On the other hand, aircraft design is highly constrained by airworthiness regulations (De Florio 2006), delaying or even preventing the generation of collaborative creative concepts.

In order to cope with the regulations and life-cycle issues, aircraft producers, such as Airbus, implement concurrent engineering techniques (Mas *et al.* 2013). These efforts, however, are mostly introduced within the design gates after the initial product conception that comes after the requirement generation, which is the key for radically new technologies. There are attempts to enable a collaborative environment, such as the Common Parametric Aircraft Configuration Schema (CPACS), as in DLR (2015), or Conceptual Aircraft Vehicle Engineering CAVE in Safavi (2013). Since they assume existing data bases and models, they are suitable for derivative designs. Digital design tools that are increasingly used (Fixson, Marion 2012) do not support innovative new product design (NPD) in the preliminary phases, so it is still a manual task in a concurrent environment (Ucler 2014a).

Considering that most of the failures in new products are front-end related (Florén, Frishammar 2012), the preliminary stage in the NPD should be carried out using a collaborative analytical approach to include all aspects, ensuring consistency as well as improving efficiency and effectiveness (Leenders *et al.* 2007). Supervisory analytical tools might negatively impact creativity, which is fundamental for NPD (Tu, 2009). NPD is driven by the communication structure of the team (Leenders *et al.* 2007), which also supports creativity,

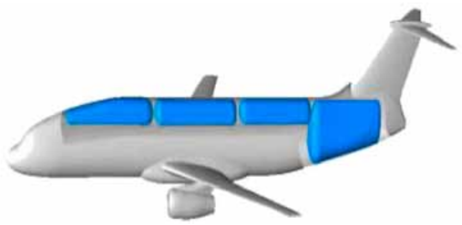

Fig. 1. Traditional cryogenic plane layout in Khandelwal *et al.* (2013)

leading to collaborative conception in the early phases of radical innovation products.

The cryoplane case discussed here is analysed with this motivation to understand the process of creative conception from scratch. Cryoplanes are fuelled by hydrogen (Contreras *et al.* 1997) or natural gas (Ucler 2013), stored cryogenically in a liquefied phase. Since the expanding aviation industry (Mazraati 2010) is associated with increased fuel consumption (ICAO 2010), it represents a high environmental load (Marquart *et al.* 2001; Kivits *et al.* 2010), which contributes to the climate change (Capoccitti *et al.* 2010). Traditional fuel supply is projected to be limited in the future (Kivits *et al.* 2010; DOE 2013), where for liquefied gasses are considered along with synthetic biofuels as a solution (Hendricks *et al.* 2011; ICAO 2009), which are also reducing emissions (Ucler 2013, 2014b). Until now several alternatives have been considered (Daggett *et al.* 2006; Bradley, Droney 2012), including currently ongoing projects of Boeing (O'Neil 2012) and Airbus Germany (Khandelwal *et al.* 2013). Early cryoplane technology demonstrators were built in the US (Contreras *et al.* 1997) and in Russia (AKO 2006). These projects incorporate the adaptation of bulky pressurized tanks into standard aircraft (Fig. 1), where the associated weight and volumetric utilization implications have led to a new concept requirement (Ucler 2013). Consequently, a clean sheet layout definition is targeted here by facilitating brainstorming using the iterative AHP-QFD-AHP approach, as explained in the following section.

2. QFD, AHP, AHP-QFD and the iterative AHP-QFD-AHP method

As a total quality management tool (Terninko 1997), Quality Function Deployment (QFD) is a common structured technique (Tidd *et al.* 2005) for NPD within the concurrent engineering environment. It can be applied across organizational boundaries (Ho, Lin 2012) in conceptual design, where the results of the QFD are computed by weighting factors given as inputs in advance (Bhattacharya *et al.* 2005). Generally the QFD consists of the house of quality (HOQ) including a matrix with the main requirements in the rows (the whats) and the technical requirements to meet them in the columns (the hows), where the matrix is populated with the appropriate relationships (Ucler *et al.* 2006). Moreover, the roof of the HOQ gives the dependencies of the technical requirements. An importance rating is associated to each row, i.e. each main requirement. Therefore, when the QFD matrix *Q* is created for *n* main requirements and *m* technical requirements, $\vec{a}$ is the input as the importance rating vector of the main requirements; whereas $\vec{b}$ is the output of the HOQ and represents the associated weight of the technical requirements. Mathematically it can be expressed as follows:

$$\vec{b} = \begin{pmatrix} b_1 \\ \vdots \\ b_m \end{pmatrix} = Q^T\vec{a} = \begin{pmatrix} q_{11} & \cdots & q_{1m} \\ \vdots & \ddots & \vdots \\ q_{n1} & \cdots & q_{nm} \end{pmatrix}^T \times \begin{pmatrix} a_1 \\ \vdots \\ a_n \end{pmatrix}.$$

The input values in $\vec{a}$ might be inconsistent or might not represent all participants' opinions. When the determination of $\vec{a}$ is done using AHP, it is called the AHP-QFD method, where trade-offs and inconsistencies can be easily incorporated (Bhattacharya *et al.* 2005; Dai, Blackhurst 2012). Among other applications the AHP-QFD is used in for NPD and associated selection problems (Hsiao 2002; Kwong, Bai 2002; Ayag 2005; Liu 2011).

AHP was first introduced in (Saaty 1977) and (Saaty 1980), and it includes all the factors necessary in the decision process in a structured manner by means of problem decomposition into a hierarchy tree with several levels. Pairwise comparisons are then stored in (n x n) square matrices for each level. The comparison scale in AHP can be linear, inverse linear or balanced (Ishizaka, Labib 2011). For practicality, Saaty's linear index as in (Saaty 1990) is used here (Table 1), and the pairwise comparison logic is applied within one level only.

The comparison matrix A includes the members a_{xy} with $x = 1,2,\ldots, n \wedge y = 1,2,\ldots,n$ with the inverse values for $a_{xy} = 1/a_{yx}$. The matrix diagonal is populated with $a_{xy} = 1$ with $x = y = 1,2,\ldots,n$. According to Saaty (1990), the relative weights of criteria and the importance rating of the main requirements in this context can be computed by calculating the normalized eigenvector $\vec{a}$ of the AHP matrix A. $\vec{a}$ can be determined iteratively for the positive reciprocal near consistent matrix A. When the AHP composition is made within a team, this iteration can be used for systematicquestioning for

Table 1. Comparison Scale according to (Saaty 1990)

Verbal Expression	Comparison Factor	Inverse Factor
Equal	1	1
Moderate	3	1/3
Strong	5	1/5
Very Strong	7	1/7
Extreme	9	1/9

inconsistencies in the weighting of the QFD input, leading the experts towards creativity via radical innovative NPD. Therefore λ is the maximum principle eigenvalue (λ_{max}) for the given $A\vec{a} = \lambda\vec{a}$. This can be solved easily on numerical basis. Therefore, first matrix A is to be squared delivering A', and then all values in row i in A' are summed up to give a_i of $\vec{a}$ for all i = 1 to n. Afterwards A' is set as A, and the computation can continue until $\vec{a}$ converges. Since A reflects expert opinions, there can be small errors in the judgment, so the consistency ratio (CR) has to be checked as well (below). According to (Saaty 1990), the consistency index (CI) can deliver the CR, which will be 0.1, wherefore the RI values can be taken from (Alonso, Lamata 2006), as given in Table 2, and the calculation is as follows:

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \text{ and } CR = \frac{CI}{RI} < 0.1 .$$

As an extension, fuzzy AHP is also used for alternative evaluations in NPD (Ayag 2005), where, instead of crisp values, fuzzy weightings are used. Consequently, the fuzzy AHP-QFD method was used for the facility location selection (Kumar, Kumanan 2011), supplier selection (Jovanović, Delibašić 2014) or logistics outsourcing (Ho *et al*. 2012). Since the AHP-QFD approach will deliver a suitable tool to be used on-the-fly during concept development meetings, the computational expensive fuzzy AHP application is not preferred. Also, the fuzzy extent analysis reducing computational efforts in the AHP is not preferred (Chang 1996; Buyukozkan *et al*. 2004; Bozbura *et al*. 2007; Yücenur *et al*. 2011), since it is proven to be incorrect (Yan *et al*. 2012) and misleading (Wang *et al*. 2008), so the standard AHP-QFD approach is used.

In fact, the inconsistency during the AHP-QFD session is analysed here, because it drives the iterations and leads to the questioning of the status quo. This is further increased by incorporating a post QFD evaluation using a stand-alone AHP assessment of the technical requirements (hows) to determine variations from $\vec{b}$, the output of the QFD work, i.e. an iterative AHP-QFD-AHP process, is proposed. Therefore, the *(m x m)* pairwise comparison matrix is populated for *m* technical requirements from the HOQ, and $\vec{b}'$ is computed using the AHP. Consequently, $\vec{b}'$ is compared with $\vec{b}$. It is expected that these two should be more or less inline with each other. The goal, therefore, is not to create perfectly matching results, but to highlight the inconsistencies again, to drive a review of the requirements and questioning of earlier stages. First of all, the AHP-QFD-AHP shall lead to the questioning of the defined weights,

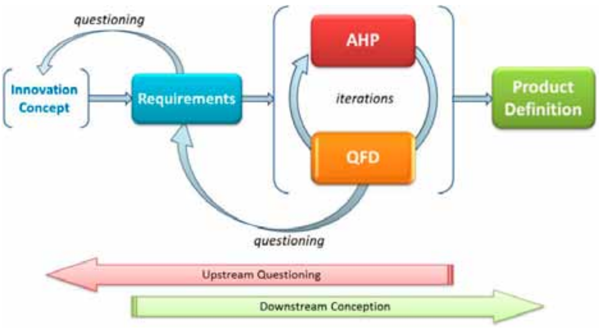

Fig. 2. The iterative AHP-QFD-AHP process

Table 2. RI (n) values from various authors (Alonso, Lamata 2006)

	Author								
	Oak Ridge	Wharton	Golden Wang	Lane, Verdini	Forman	Noble	Tumala, Wan	Aguaron et al	Alonso, Lamata
Matrices	n = 100	n = 500	n = 1000	n = 2500		n = 500		n = 100000	n = 100000
3	0.382	0.58	0.5799	0.52	0.5233	0.49	0.500	0.525	0.5245
4	0.946	0.90	0.8921	0.87	0.8860	0.82	0.834	0.882	0.8815
5	1.220	1.12	1.1159	1.10	1.1098	1.03	1.046	1.115	1.1086
6	1.032	1.24	1.2358	1.25	1.2539	1.16	1.178	1.252	1.2479
7	1.468	1.32	1.3322	1.34	1.3451	1.25	1.267	1.341	1.3417
8	1.402	1.41	1.3952	1.40		1.31	1.326	1.404	1.4056
9	1.350	1.45	1.4537	1.45		1.36	1.369	1.452	1.4499
10	1.464	1.49	1.4882	1.49		1.39	1.406	1.484	1.4854
11	1.576	1.51	1.5117			1.42	1.433	1.513	1.5141
12	1.476		1.5356	1.54		1.44	1.456	1.535	1.5365
13	1.564		1.5571			1.46	1.474	1.555	1.5551
14	1.568		1.5714	1.57		1.48	1.491	1.570	1.5713
15	1.586		1.5831			1.49	1.501	1.583	1.5838

then to the upstream questioning of the requirements, and, finally, to the questioning of the desired innovation concept (Fig. 2). In creative brainstorming everything is ensured by forced participation, communication and structured creativity within the group.

3. The cryoplane application

A cryoplane is a radical innovation. It represents a big deviation from existing solutions. Therefore, all aspects of operation have to be considered. As a result, the referred concurrent engineering team involved three different groups: flight operations (OPS), represented by commercial pilots; ground management (MNG), represented by civil aviation professionals; engineering (ENG), represented by maintenance, aeronautical design and cryogenics engineers. After the introduction of the concept, all parties were asked what they consider could be important for such a new generation aircraft fuelled with alternative cryogenic fuels. As detailed in (Ucler 2014c), the potential main requirements (whats) were developed and a common list was created:

1. Low weight;
2. Max. safety;
3. High efficiency;
4. High range;
5. High robustness;
6. Low noise;
7. Low volume;
8. Fast bunkering;
9. Long life;
10. Low price;
11. Odourless;
12. Easy to learn.

Due to the input of a cryogenics engineer, the quality of being odourless was eliminated, since one of the prerequisites of such a pressurized cryogenic system is tightness, automatically implying odourless. The learning objective was also eliminated, since it is too early for a conceptual design. Consequently, the AHP matrix was populated as a (10×10) square matrix from the first 10 requirements, and the related pairwise comparisons were assigned in consensus.

In the first iteration high range was overrated in comparison with high efficiency, leading to an inconsistency. This resulted in a reconsideration, arguing that efficiency and range are bonded to each other by optimum cruising speed and the requested mission profile. Moreover, the importance of safety was obvious, so it was scored as extreme against low weight as an aviation reflex. However, during the iterations it was slightly downgraded for this application based on statistical data. It was also noted that the mission profile of the cryoplane has to be considered. Accordingly, a lower speed profile with a higher volume utilization and higher wing thickness was also mutually agreed on in the third iteration. In addition to that, the efficiency and price relationship was also iterated. Pilots defined price as the run cost, whereas the remaining members looked at the whole life cycle cost. Nevertheless, both parties agreed that some compromises can be made given a reduction in the price. This led to a contradiction in the comparison of price with range and efficiency. Consequently, it has been accepted that the price shall include the procurement price of the system, but not the operation costs and the matrix was updated again accordingly. As a result, the final eigenvector $\vec{a}$ indicating the weightings was computed (Fig. 3) after three iterations with Δ_{max} = %0.0001. The consistency ratio of the matrix was determined as CR = 0.076 < 0.1 with CI = 0.1105, and the AHP matrix A was found to be consistent.

Subsequently, $\vec{a}$ was used as the input for the QFD work, where the HOQ was modelled based on the excel templates given in (QFD … 2007). The work group determined the associated technical requirements populating the HOQ (Fig. 4).

After the scoring and computations in the HOQ, the relative weights of the technical requirements were computed as $\vec{b}$. In order to enable an onsite AHP

10 x 10 AHP Matrix

$$
\begin{array}{rc}
 & \begin{array}{cccccccccc} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 \end{array} \\
\begin{array}{rr}
\text{Low Weight} & 1 \\
\text{Max. Safety} & 2 \\
\text{High Range} & 3 \\
\text{High Efficiency} & 4 \\
\text{High Robustness} & 5 \\
\text{Low Noise} & 6 \\
\text{Low Volume} & 7 \\
\text{Fast Bunkering} & 8 \\
\text{Long Life} & 9 \\
\text{Low Price} & 10
\end{array} &
\begin{pmatrix}
1 & 1/7 & 1/3 & 1 & 1/3 & 1 & 1 & 1 & 1/5 & 3 \\
7 & 1 & 5 & 7 & 3 & 9 & 9 & 9 & 3 & 7 \\
3 & 1/5 & 1 & 1 & 1/5 & 3 & 5 & 7 & 1 & 5 \\
1 & 1/7 & 1 & 1 & 1/3 & 1 & 1 & 5 & 1 & 3 \\
3 & 1/3 & 5 & 3 & 1 & 5 & 5 & 7 & 3 & 9 \\
1 & 1/9 & 1/3 & 1 & 1/5 & 1 & 1 & 1 & 1/3 & 1 \\
1 & 1/9 & 1/5 & 1 & 1/5 & 1 & 1 & 1 & 1/3 & 3 \\
1 & 1/9 & 1/7 & 1/5 & 1/7 & 1 & 1 & 1 & 1 & 1 \\
5 & 1/3 & 1 & 1 & 1/3 & 3 & 3 & 1 & 1 & 3 \\
1/3 & 1/7 & 1/5 & 1/3 & 1/9 & 1 & 1/3 & 1 & 1/3 & 1
\end{pmatrix}
\end{array}
$$

$$
\text{with} \quad \vec{a} = \begin{pmatrix} \text{Low Weight} \\ \text{Max. Safety} \\ \text{High Range} \\ \text{High Efficiency} \\ \text{High Robustness} \\ \text{Low Noise} \\ \text{Low Volume} \\ \text{Fast Bunkering} \\ \text{Long Life} \\ \text{Low Price} \end{pmatrix} = \begin{pmatrix} 0{,}043 \\ 0{,}342 \\ 0{,}108 \\ 0{,}069 \\ 0{,}212 \\ 0{,}036 \\ 0{,}039 \\ 0{,}034 \\ 0{,}092 \\ 0{,}025 \end{pmatrix}
$$

Fig. 3. The AHP Matrix with the associated pairwise comparisons

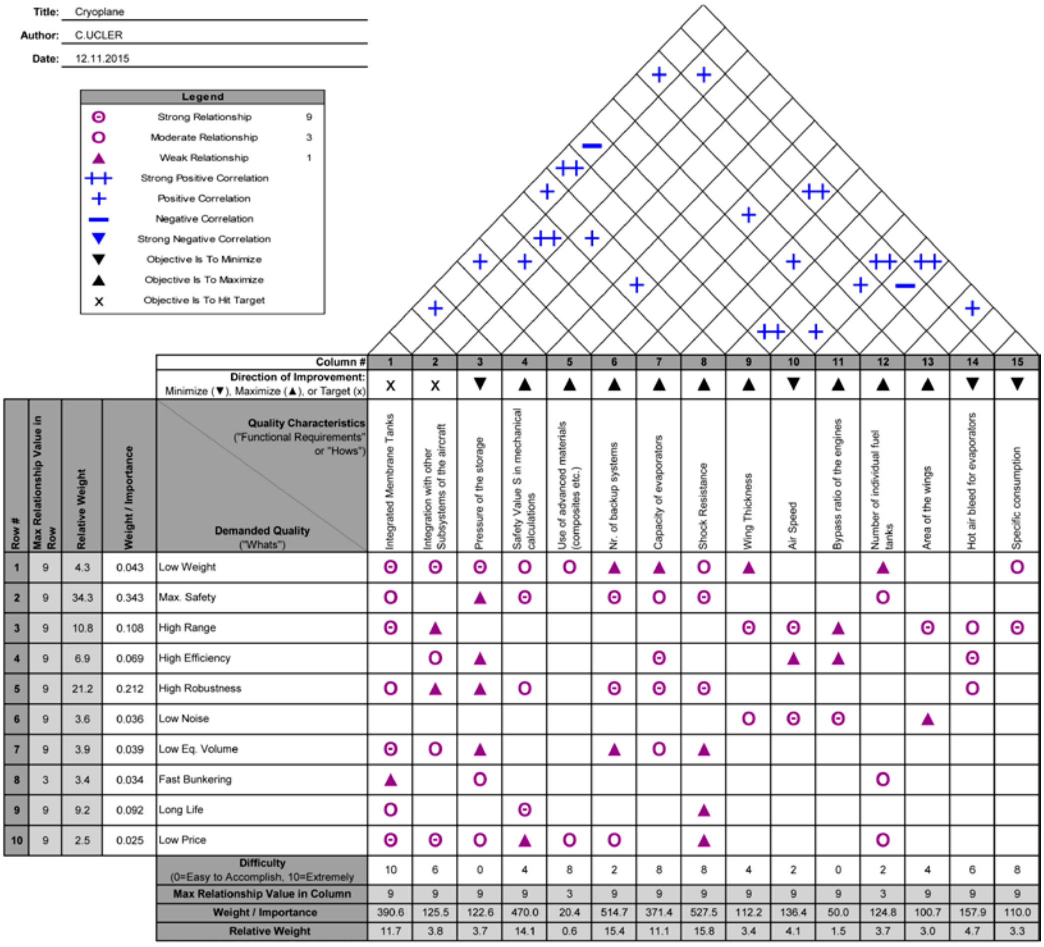

Fig. 4. The HOQ for the Cryoplane

Table 3. Weight factors and associated ranking of technical requirements in the first iteration

Nr. (j)	Technical Requirement	Relative Weight ($\mathbf{b}_j$)	Ranking	Updated Comparison Value ($\mathbf{b}'_j$)	Post AHP Weight ($\mathbf{b}''_j$)	Post AHP Rank	Delta
1.	Integrated Membrane Tanks	11.71	4	*13.28*	*3.16*	9	–76%
2.	Integration with other Subsystems	3.76	8	*4.26*	*9.05*	4	112%
3.	Pressure of the storage	3.68	10	*4.17*	*3.72*	8	–11%
4.	Safety Value S in mechanical calculations	14.10	3	*15.98*	*16.25*	3	2%
5.	Use of advanced materials	0.61	15	–	–	–	–
6.	Nr. of backup systems	15.43	2	*17.49*	*7.58*	5	–57%
7.	Capacity of evaporators	11.14	5	*12.63*	*17.86*	2	41%
8.	Shock Resistance	15.82	1	*17.93*	*19.53*	1	9%
9.	Wing Thickness	3.36	11	–	–	–	–
10.	Air Speed	4.09	7	*4.64*	*4.91*	6	6%
11.	Bypass ratio of the engines	1.50	14	–	–	–	–
12.	Number of individual fuel tanks	3.74	9	*4.24*	*4.26*	7	0%
13.	Area of the wings	3.02	13	–	–	–	–
14.	Hot air bleed for evaporators	4.74	6	*5.37*	*13.68*	10	155%
15.	Specific consumption	3.30	12	–	–	–	–
		Sum = 100		Sum = 100			

Post QFD AHP Matrix

		1	2	3	4	5	6	7	8	9	10	Normalized Principal Eigenvector
Integrated Membrane Tanks	1	1	1/5	1	1/3	1/5	1/7	1/7	1	1	1/3	3,16%
Integration with other Subsystems of the aircraft	2	5	1	3	1	1	1/5	1/5	3	3	1/3	9,05%
Pressure of the storage	3	1	1/3	1	1/5	1	1/3	1/3	1/3	1/3	1/3	3,72%
Safety Value S in mechanical calculations	4	3	1	5	1	5	1	1	3	5	1	16,25%
Nr. of backup systems	5	5	1	1	1/5	1	1/3	1/3	1	3	1	7,58%
Capacity of evaporators	6	7	5	3	1	3	1	1	3	3	1	17,86%
Shock Resistance	7	7	5	3	1	3	1	1	5	5	1	19,53%
Air Speed	8	1	1/3	3	1/3	1	1/3	1/5	1	1	1/3	4,91%
Number of individual fuel tanks	9	1	1/3	3	1/5	1/3	1/3	1/5	1	1	1/3	4,25%
Hot air bleed for evaporators	10	3	3	3	1	1	1	1	3	3	1	13,68%

Fig. 5. The Post QFD AHP Computation

assessment, a rank reduction was done, eliminating technical requirements after the 10th rank. The weighting of the requirements from 11 to 15 was distributed to the other requirements depending on their importance per QFD. This new set is called $\vec{b}'$. Subsequently, the post QFD weights were computed by running an AHP for the *(10x10)* matrix of technical requirements delivering $\vec{b}''$ (Fig. 5). The difference between $\vec{b}'$ and $\vec{b}''$ is designated as Delta (Table 3).

Since the post AHP computation of the technical requirements was found to be consistent with CR = 0.073, the QFD inputs were questioned in line with the AHP-QFD-AHP methodology. Therefore, the AHP ranking was used to visualize the data easier. The target of the comparison was clearly not to achieve totally similar results in the QFD and post AHP. Questioning the status quo, it was seen that hot air bleed for evaporators was underestimated in the first line. This was explained by the QFD score for high range and its associated weight / importance. This was also noticed in the roof of the HOQ, showing a strong correlation with the air speed and with the thickness of the wings. It was also seen that the capacity of the evaporators had to be weighted more, which led to the idea that supplementary heat sources shall be incorporated to enhance the fuel conditioning process. This statement was also supported with the higher post AHP ranking of integration with other subsystems of the aircraft. The last significant deviation obtained by post AHP was that the integrated membrane tanks were weighted less than initially anticipated.

4. Discussion

It was shown that the usage of an iterative AHP-QFD-AHP supports the product conception in two ways: iterative questioning of the weighting of the main requirements and upstream questioning by post AHP. The iterations for the AHP computation of the importance vector $\vec{a}$ for the HOQ enabled all experts to understand the correct definitions associated to the requirements in the same way and to have an overview of the other dimensions' perceptions. Since all representatives had to achieve a consensus in the pairwise comparisons, concurrency was forced with this information exchange. This led to an understanding of the real requirements, e.g. in the first line it was determined that the requirements for the preparation of conditioned gas as fuel are more important for cryoplanes rather than ordinary aeronautical constraints. This was reflected in different aspects, such as the hot air bleed for evaporators, capacity of the evaporators, and the integration with other systems, which were rated higher in post AHP. This in fact resulted in a number of the back-up systems being estimated as a less important factor in the comparison. Indeed, later literature analysis indicated a patent of Airbus facilitating the air conditioning system as a heat source for the cryogenic system and vice versa (Airbus 2012). In short, this method allowed including unpredicted aspects during the session, indicating a cognitive collaboration.

This led to the requirement for the engine to be incorporated in the cryoplane preliminary design. It was shown that the cryoplane development is not a standard system integration job, where existing subsystems can be integrated, but is a radical innovative product with the need of building the aircraft around the cryogenic system. As a result, this indicated the basic research areas as well as supporting technology road mapping.

Apart from this, the interconnections in the roof of the HOQ were questioned within the iterations. This came up analytically when questioning the flight envelope. Parameters such as consumption, manoeuvrability, and flight envelope were looked at in detail. In fact, these details were not included in the HOQ at first, but the questioning process of post AHP accomplished a creative thinking session where a totally new concept was preferred – a lower speed jet or turboprop aircraft with thicker wings incorporating the available volume in the wings. Furthermore, a radical blended wing body concept was proposed during the sessions, where the pressurized tanks can support the fuselage in an integrated manner. This is an untraditional approach and a highly creative outcome. Moreover, the integration of heat from sources such as engine exhaust, air conditioning or possible usage in combination with fuel cells was proposed, which again indicates innovation.

The interrelationships between the technical requirements as indicated in the roof of the HOQ have to be mentioned as well. During the case study they were not included in the AHP evaluation. In fact, a good design has the minimum interaction among its variables with the least information (Park 2007), but for sophisticated products, it is unavoidable. Therefore, analytical network processes (ANP) could be used to include interrelationships (Yücenur *et al.* 2011). However, since the post AHP here is just a tool to drive the questioning rather than to provide a basis for weighting, a classical AHP is used for simplicity. Nevertheless, it should be noted that it is worth to have further research on the interrelationships and how they can be incorporated into this method.

In summary, the design envelope of a cryoplane was determined, and a product concept was drawn successfully making use of the extended iterative AHP-QFD-AHP approach. It was noticed that the limited set of requirements using this method lead to further requirements during the application. These new requirements were not used to extend the QFD matrix, but they were noticed as creative outcomes of the brainstorming session.

5. Conclusions

An iterative AHP-QFD-AHP approach providing an analytical approach for collaborative creativity and leading to innovative product conception is proposed. This proposed methodology differs from standard AHP-QFD applications in two basic elements. First of all, the AHP application for the determination of QFD weights of the Hows is not post processing questionnaire data, but includes a team of experts to generate the assessment together in an iterative session. Second, there is a post AHP application to review and to check the output of the QFD. As a result, this methodology is used as a real time tool involving the participants in an upstream questioning process, increasing the participation, and hence evaluating different dimensions, which leads to creativity in the downstream product conception.

Consequently, the extended iterative AHP-QFD-AHP approach can be used in front-end product conception, where high levels of innovation are required. This was demonstrated here with the cryoplane concept development work, which resulted in an environmentally green, lower speed aircraft built around the cryogenic system, using it as an integrated part in both fuselage and subsystems. The main challenge is identified as the conditioning of the cryogenic fuel.

Future work can examine the correlation levels of the post AHP and the QFD outcome in existing AHP-QFD applications to evaluate mathematical correlation models. The interrelationships on the roof of the HOQ were used in the comparison process only qualitatively; therefore, quantitative models involving the roof could be developed as well.

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