APPLICATION OF HOUSE OF QUALITY TOOL INTO THE ANALYSIS OF OPERATIONAL CONCEPT FOR THE FUTURE PERSONAL AIR TRANSPORTATION SYSTEM

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Abstract. The Personal Air Transport Systems (PATS) can be a new standard in the close future. One of the goal of the PPLANE project (FP7 - Personal Plane: Assessment and Validation of Pioneering Concepts for Personal Air Transport Systems) is to define operational concept for the future PATS. Operational concept must take under consideration many aspects regarding not only to the vehicle but it also has to consider the environment problems, safety and security, society acceptance, etc. All together cause, that a big number of variables/parameters must be given to analysis. Paper presents the application of the House of Quality method to select most important features of the future PATS and to assess the operational concept.

1 Introduction

The idea of Operational Concepts is based on the widely accepted assumption that "The personal air vehicle should be analogous to the private car in terms of accessibility and ease of operation, yet delivers the benefits of speed and routing efficiencies that are only possible via direct-to-destination flight", [1]. One can describe Operational Concept as the idea (document) of an effective use of personal plane system which is able to deliver a transportation services being affordable, safe, secure, cost-efficient, environmentally friendly, comfortable, relatively simple, based on modern technology. Such approach causes, that we can obtain a big number of possible concepts, which differ by vehicle type, it's technical characteristics (layout, engines type and number, level of automation, etc.), cost of operation, mission type, ground station, ATM (Air Traffic Management) methods, etc. The basic problem is to analyze and select the most promise configuration. To do this the House of Quality method can be used. It starts from potential customer/user needs and allows to select the most important features of the future Personal Air Transport System.

2 House of Quality – from Customer Needs to Operational Concept

The paper presents how Operational Concept is created from the so-called "CUSTOMER NEEDS". Customer Needs consists of limited number of characteristics which are essential for future Operational Scenarios. One Operational Scenario differ from the other one due to different "customer priorities" – sometimes called "weights". For PPLANE we have defined the so-called "PPLANE System Needs", which consist of a number of characteristics expressed in "language" of specific disciplines, for example aerodynamics, acoustics, communication, maintenance, etc. It expresses "Customer Needs" more precisely via terms used traditionally in these specific disciplines, which sometimes could be not understandable by typical society members, but which are very well identified by engineers involved in these specific disciplines. Typical examples of such PPLANE System Needs are high aerodynamic efficiency (L/D) or high manoeuvrability. Having these PPLANE System Needs defined one has to fill-in the so called House of Quality (HoQ – Fig.1) matrix with the correlation coefficients. This correlation coefficients correspond to the type of dependence between Customer Needs and PPLANE System Needs. They could be defined as integer numbers from the range of 0 to 10 (in some specific cases even the negative integers are valid, for example when there is an strong negative correlation.

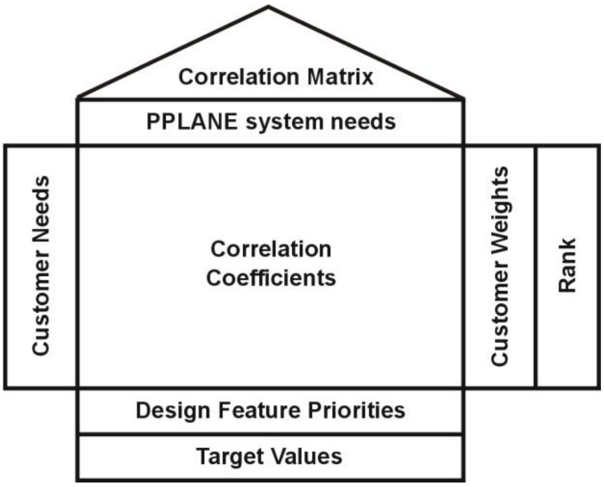

Fig. 1 – The structure of the House of Quality

Correlation coefficient could be defined in other way, for example as normalized values, i.e. 0.1, 0.3, 0.6, 0.9. However, in one of the following steps the so-called "Design Feature Priorities" computed by user are then normalized (i.e. all Design Feature Priorities are divided by the sum of all Design Feature Priorities values). So, it does not matter, if the Correlation Keys are dimensional or dimensionless – in fact only their relative ratios are important.
In many successful applications of HoQ approach there were used more than one tier of relations between customer needs and system features. The example of such approach to find the design features of multi-role combat aircraft is presented in [2]. It is a typical "Bottom-up approach" - from customer needs (Ministry of Defence) to Design Features. In the case of PPLANE project we are looking for a similar scenario; from Society Needs (long term goals expressed in the low risk of accident, society acceptance, low cost, high simplicity of piloting etc) to features of the PPLANE system (platform with pilot on-board + Ground Control Station + specific expectations from society). Such defined system, i.e. platform with pilot on-board + GCS + specific expectations from society represent the Operational Scenario. The important feature of such an approach is that we are able to create different Operational scenarios changing the Customer Needs (by changing of their weights). If we do not change the PPLANE system features, we don't need to change the correlation keys. In this way we can also asses what design features are the most important for selected customer needs. Of course, many depends on the selection of parameters defining the Tier_1 and the Tier_2 PPLANE system features and on the estimated correlation coefficients as well. To check the correctness of these values the roof of House of Quality – Correlation Matrix could be used. Fig. 2 presents example of correlation matrix. Small value denotes, that design features are strongly correlated, what means, that customer needs depend on these features in the similar way. The big value means, that design features are independent from customer needs point of view. For example, on the Fig. 2 the distance (in Euclidean sense) between "High L/D" and "low minimum drag" is equal to zero, what is foreseeable and "Low control overshooting" is almost independent on "Low W_strucutre/W_TO".

	1	2	3	4	5	6	7	8	9	10			
1	0	10	0	11	14	10	5	8	9	11	1	16	High L/D
2		0	10	6	6	7	12	8	8	10	2	22	High CLmax
3			0	11	14	10	5	8	9	11	3	16	Low minimum drag
4				0	4	4	12	8	10	10	4	16	Low turn radius
5					0	7	15	11	12	12	5	21	Small control overshooting
6						0	11	7	9	9	6	15	High excess of power
7							0	10	11	11	7	13	Low W_structure/W_TO
8								0	4	8	8	6	Highly reliable materials
9									0	9	9	12	Low part count
10										0	10	15	High MTBCF both of plane & GCS

Fig. 2 – Correlation matrix (example)

3 PPLANE Operational Concept

The so-called Operational Concept includes generally four main areas (Fig.3): Platform, Ground Control Station, Take-off and Landing site and Mission. The most important features of these parts have to be set following the Customer Needs via necessary Technologies.

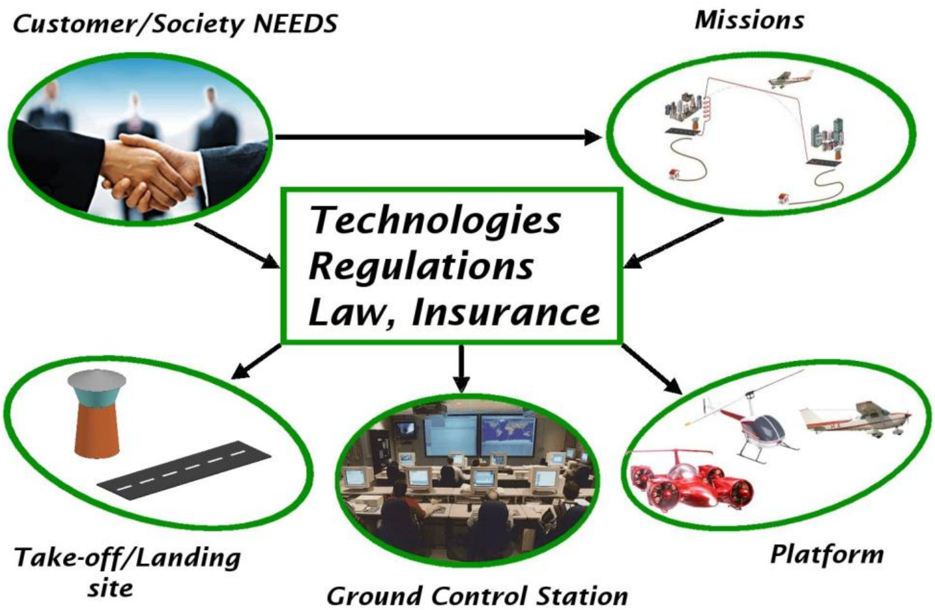

Fig.3 – Relations between Customer Needs, Take-off and landing site, Ground Control Station, Platform and Mission

To do this we have defined eleven customer/society needs. They are:

1. High Simplicity of PPLANE Use
2. Low Risk of Accident
3. Low Risk of Hijacking/Terror Abuse
4. Low noise and Pollution Signiture
5. Low Cost
6. Easy Access to Small Landing Site
7. Society acceptance

8. Short Door-to-Door Time
9. Low weather sensitivity
10. Long Range
11. Low impact of Human factors

PPLANE system design features must correspond to Customer Needs and expressed as technical measures coming from different disciplines (topics), as aerodynamics, acoustics, engine technologies and others. The number of these technical measures must be balanced to avoid any artificial domination of one disciple over the second one. For example, if we put 10 parameters corresponding to Flight Control System and only one corresponding to maintenance that for sure the Flight Control related issues will dominate over the maintenance issues. In the PPLANE scheme of HoQ procedure one has introduced the following groups of specific disciplines:

1. Aerodynamics:
   a. High aerodynamic efficiency L/D
   b. Low minimum drag CDmin
   c. High CLmax

2. Flight Dynamics and Control
   a. Low turn radius
   b. Small control overshooting
   c. High power access

3. Efficient structure and materials
   a. Low $W_{STRUCTURE}/W_{TO,max}$
   b. Highly reliable materials and loading structure
   c. Low part count

4. Advanced communication technology
   a. High MTBCF in communication
   b. Digital wide band signal
   c. Highly efficient GCS

5. High level of automation of platform and GCS
   a. High level of automation: plane and GCS
   b. High level of fault tolerance
   c. High situational awareness

6. Modern power unit technology
   a. Low SFC
   b. Long design life-time
   c. High Available Power per unit weight of engine + fuel + battery

7. Modern pro-green technologies
   a. Low CO_2
   b. Low NO_x
   c. Low community noise

8. Efficient economics
   a. Low MMH/FH
   b. Short Time of availability the PATS on demand
   c. Elastic model of insurance

9. Society acceptance measures
    a. Lowest Fear and nuisance level
    b. High Reduction of road congestion
    c. High knowledge about flying

To cover the mentioned areas we have defined 29 system features. It allows to build Tier I HoQ with defined correlations coefficients (Fig.4). Changing the customer weights values one can obtain (exclude) operational concept features needed to satisfy general customer needs or exclusively one of them (by setting sufficient customer weight to one and zero for others).

No.	System features / Customer needs	Customer weights	1 High L/D	2 High CLmax	3 Low minimum drag	4 Low turn radius	24 Short Time of availability the PATS on demand	25 Low cost, wide-spread inssurance	26 Lowest Society Fear and nuisance level	27 High Reduction of road congestion	28 High Society knowledge about flying	29 Low experienced pilot
1	High Simplicity of PPLANE Use	0				3	3	3		3	3	9
2	Low Risk of Accident	0		6		3					1	3
3	Low Risk of Hijacking/Terror Abuse	0										
4	Low noise and Pollution Signiture	0	3	3	3	3			9	6		
5	Low Cost	0	6	3	6		3	6		3		6
6	Easy Access to Small Landing Site	1		9		9			6			
7	Society acceptance	0							9	6	9	
8	Short Door-to-Door Time	0	1	3	1	1	6			1		
9	Low weather sensitivity	0								3		3
10	Long Range	0	9	1	6					3		
11	Low impact of human factors	0						3				9
	Priorities	63	0	9	0	9	0	0	6	0	0	0
	Computed priorities	63	0	9	0	9	0	0	6	0	0	0
	Normed values	1	0.00000	0.14286	0.00000	0.14286	0.00000	0.00000	0.09524	0.00000	0.00000	0.00000

Fig.4 – Tier I HoQ to exclude features important for „Easy Access to Small landing Site”

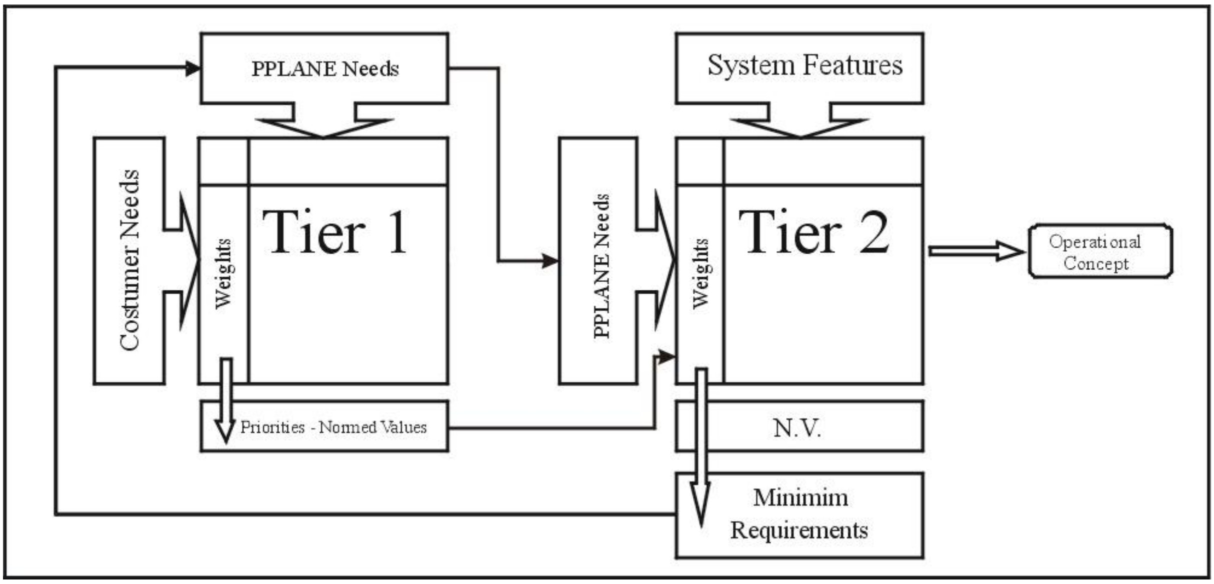

Fig.5 – Two tiers HoQ scheme [4]

The system features selected in Tier I and obtained normed values are the needs (so-called PPLANE needs) in Tier II (Fig.5) with normed values as weights. Selected system features (about 40 in analyzed case) with the computed priorities (Fig.6) allow to define the Operational Concept.

No.	Desing feature	Priority value
1	Fixed wing	0.02550
2	Rotary wing	0.04989
3	Swing wing	0.05543
4	Advanced Diesel engine	0.01330
5	Advanced Hybrid engine	0.00665
6	Advanced Electric Power Unit	0.01330
7	Twin engine	0.00000
8	High Passenger capacity (>4)	0.00333
9	Reliable Recovery Systems in hazardous states of flights	0.01774
10	High Aspect Ratio	0.00333
11	Low Wetted Area	0.02328
12	Fuel Efficient Design	0.01996
13	On-board Auxiliary Power Unit	0.04324
14	Very Efficient high lift system	0.07650
15	User-friendly expert system on-board	0.06319
16	User-friendly expert system at GCS	0.06319
17	Reliable Collision avoidance system	0.06319
18	Redundancy of all essential system	0.03991
19	Elastic model of Ownership and insurance	0.05987
20	On-board diagnostic system in flight & mulfuction software and hardware	0.04989
21	Pre-flight automatic diagnostic system	0.03659
22	Signal encoding	0.02661
23	Modern system of education about flying addressed to society	0.00000
24	Simple Mechanical Design	0.00665
25	Efficient anti-icing, de-icing systems	0.05654
26	New generation PPLANE oriented transponder system	0.02993
27	New generation PPLANE oriented autopilot (to be used from taxi run, through entire flight till touch-down and taxi)	0.04656
28	Wide-band digital system of communication (including data link)	0.03326
29	High propulsive efficiency (specific trust)	0.01330
30	Low NOx combustion engine	0.00000
31	Light weight materials	0.01330
32	Light weight (smart) structure	0.00665
33	Low noise design (configuration)	0.01330
34	Quiet passenger cabin	0.00665
35	CO2 neutral fuel engine (bio-fuels ?)	0.00000
36	Efficient pilot identification system based on-biotechnology	0.01996

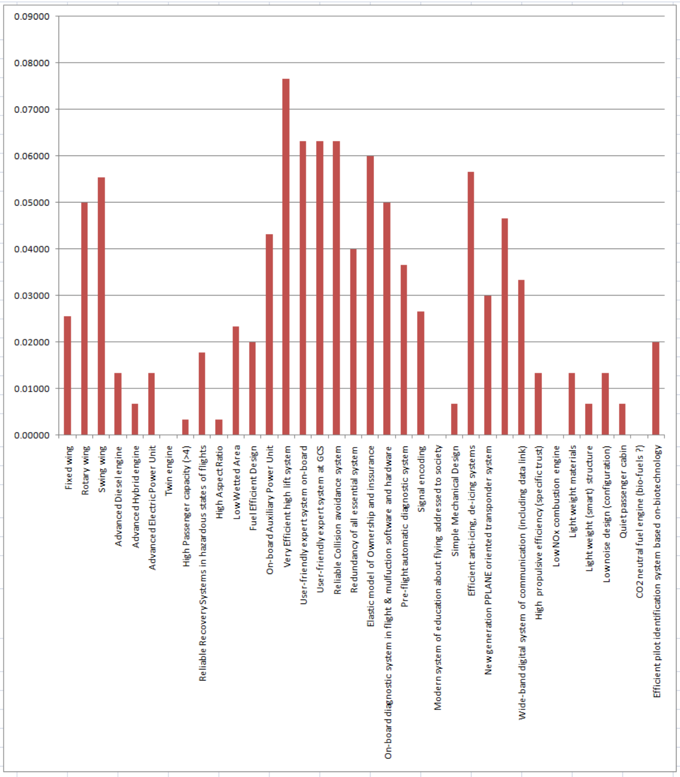

Fig.6 – Example of Tier II results – System features with computer priorities

4 Concluding remarks

Following the components of Fig.3 (1. Platform; 2. Ground Control Station; 3. Take-off and landing Site; 4. Mission and; 5. group consisting of Technologies, Regulations, Law and Insurance) we have divided Technical Features (in other word Technical Characteristics) into just 5 groups,. These Technical Features (Technical Characteristics) consists of 46 parameters, which describe an Operational Concept. The analysis presented above allowed to select four concepts:

Operational Concept #1 - called "FW,D,PA", where FW means Fixed Wing configuration; D- Diesel engine and PA – Partly Automated).

Operational Concept #2 - (called "FW,D,FA", where FW means Fixed Wing configuration; D- Diesel engine and FA – Fully Automated).

Operational Concept #3 - (called "FW,E,PA", where FW means Fixed Wing configuration; E- Electric engine and PA – Partly Automated).

Operational Concept #4 - (called "R,D,PA", where R means Rotary configuration; D- Diesel engine and PA – Partly Automated)

Of course this brief description doesn't define completely all technical features but only shows the basic differences. However, vehicle configuration, propulsion type and level of automation allow to define details of operational Concept.

Acknowledgment

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References

[1] C. deTallec: PPlane Air Transport System preliminary architecture concepts. PPLANE Internal report, Oct.2009;

[2] Randall J. Stiles, John J. Bertin, Ray Whitford, Steven A. Brandt: Introduction to Aeronautics: A Design Perspective (AIAA Education Series - 1997)

[3] PPLANE – the Personal Plane Project. Assessment and Validation of Pioneering Concepts for Personal Air Transport Systems. Grant agreement no.: 233805, Annex 1, June 30 2009;

[4] Fabrizio Giulietti, Report on the Definition of Operational and Technical Parameters and on Requirements of PPLANE vehicles. Internal report, May 2010.