Quality function deployment as a tool of risk management at early stages of an unmanned aircraft design

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Abstract. This paper is devoted to quality management of a high-tech product at the design stage. The object of study is a multipurpose High Altitude Long Endurance Unmanned Aerial Vehicle (HALE UAV). Quality management is supposed to be implemented through such a tool as quality function deployment (QFD). The article provides a detailed description of this method and gives an example of its use at the stage of conceptual design of a HALE UAV.

1. Introduction
The process of design is one of the most complicated types of engineering creativity. Sometimes it can be extremely difficult for a manufacturer to produce a product of such a high quality that it could not only satisfy, but anticipate customer requirements. Solving of this problem can be simplified by use of quality design tools [22]. Quality function deployment (QFD) is one of such tools that helps to identify the correlation between customer requirements, product characteristics and the features of its design. The most common QFD model today is the four-level one, however only the first level of QFD was considered in this work [13,20,24].

2. UAV: purposes and the features of design
The design of UAVs in many ways is similar to the design of manned aircraft, but the absence of the crew gives the developer additional opportunities. There are no cabin with all its controls, no life support system and no catapult in UAV and the higher overloads are permissible in this case [1,2,14].

As a base for this study the characteristics of the S-62 UAV were chosen. The information about this project of the Sukhoi Design Bureau has appeared in the Internet several years ago. There is some information about its characteristics in the open access [3,4,5]. It is known that S-62 is a multi-purpose aircraft that can be used both as a part of research and civil aviation, and as a part of the Air Force. There it is unknown at what stage the development of the S-62 is now. Perhaps the information about it was classified due to its military potential. Perhaps work on this project was temporarily suspended. However, the S-62 is extremely interesting both in terms of use and development [15-18,23].

3. QFD approach
The term QFD is a method that allows to deploy the customer requirements into performance characteristics, performance characteristics - into part characteristics, part characteristics into manufacturing process and manufacturing process - into control tools [6,7,19]. QFD should be used since the conceptual design stage, because the decisions made at this stage provides about 70% of the project’s success with minimal costs [8,9,21].

Figure 1 shows the structure of the main QFD tool - the House of Quality, which received such a name for its shape.
4 QFD application

4.1 What are the customers’ needs?
Gathering the information about customer requirements is probably the most difficult part of QFD analysis. Understanding and correct interpretation of the customers’ needs and wishes is extremely important, because it is the voice of the customers that should determine the final configuration of the product.

After the requirements are determined, it is necessary to evaluate their importance. There are various methods of evaluation [10, 11, 12]. To rank the requirements in this work a pairwise comparison matrix was used. The results are presented in the first two columns of Table 1. The most important parameters are viewing angle, endurance and range.

4.2 What competitors offer?
To create a product of a high quality it is necessary to base not on the customers’ desires only, but on the capabilities of competitors as well. An effective means to assess the market situation, to determine the strengths and the weaknesses of the project, and therefore to choose the direction of improvement is benchmarking.

During the benchmarking, a comparison of three UAVs was made: the Russian S-62, the American RQ-4 Global Hawk Block 40 and the Chinese CASC Rainbow CH-5. The results of benchmarking are shown in Table 1. The first two columns correspond to the Table 1, the following five reflect the grade of performance of the characteristics of different aircraft on a five-point scale. The following symbols are used: ○ - S-62; ◊ - Global Hawk; □ - CH-5. Based on these estimates, target values were determined. The improvement ratio is equal to the ratio of the target value to the current one. The importance of each indicator was calculated by multiplying the values of importance and the improvement ratio. The relative weight is calculated as a percentage per each requirement.

It should be noted that the cost in this work was considered as a complex value which includes the costs of manufacturing and maintenance of an unmanned aircraft. This parameter was not evaluated during benchmarking, since there is no information about the cost of the S-62. However, since the cost of production and maintenance of foreign analogues are usually estimated as high, we can assume that our aircraft will also be expensive, therefore the improvement ratio for this indicator is assumed to be 1.25.
The results of benchmarking let us to conclude that the most important characteristics are endurance and range. The viewing angle moves to second place, since in this characteristic the S-62 exceed its competitors.

### Table 1. Evaluation of customer requirements' importance and benchmarking

| Customer requirement                               | Importance | Point | Target Improvement Ratio | Absolute Importance | Relative Importance |
|----------------------------------------------------|------------|-------|--------------------------|---------------------|---------------------|
| Endurance: 24 h / 3,500 nm                         | 19.00      | □     | 1.25                     | 23.75               | 14.91               |
| Range: 3,500 nm                                    | 19.00      | ○     | 1.25                     | 23.75               | 14.91               |
| Cruise altitude: from 59,000 to 65,600 ft          | 16.50      | ◊    | 1.00                     | 16.50               | 10.36               |
| Payload: 800 to 1200 kg                            | 9.67       | □     | 1.25                     | 12.09               | 7.59                |
| Maximum speed: 310.7 mph                           | 17.50      | ○     | 1.25                     | 21.88               | 13.73               |
| Take off and landing: 2,000 × 200 ft²              | 5.92       | ○     | 1.00                     | 5.92                | 3.72                |
| Viewing angle: 360°                                | 22.00      | ◊    | 1.00                     | 22.00               | 13.81               |
| Working temperature range: -58 ° F to +122 ° F     | 14.33      | ◊    | 1.00                     | 14.33               | 8.99                |
| Turnaround time: maximum 1 hour                    | 4.33       | □     | 1.00                     | 4.33                | 2.72                |
| Cost: low                                          | 11.83      | ○□   | 1.25                     | 14.79               | 9.28                |

4.3 Performance characteristics of the UAV

Customer requirements were deployed into performance characteristics of the aircraft. First of all it was necessary to evaluate correlation between the technical characteristics of the product in order to understand how changes in some characteristics may affect to others. The result of the analysis of the relationship between performance characteristics is presented in Table 3. The directions of the improvements are indicated by arrows: ↑ - if an improvement implies an increase in the value of this characteristic, and ↓ - if a decrease. The tightness of the bounds was assessed according to the scale shown in Table 2.
Table 3. The tightness of the bounds and the directions of the improvements of the performance characteristics

4.4 The results of QFD
It is necessary to determine the tightness of the bounds between the customer requirements and performance characteristics of the aircraft. After that the priority of each characteristic should be calculated. The results of the calculations are presented in Table 4.

Table 5 is a matrix diagram, the rows of which correspond to the requirements, and the columns - to the characteristics. Each requirement-characteristic pair was assigned in accordance with Table 3, then the coefficients were multiplied by the relative importance of the relevant requirements calculated on the basis of benchmarking, and summarized by the relevant columns, which resulted in the absolute values of the priority of each characteristic. Relative priority was found as percentage of the absolute one.
Table 4. The results of QFD

| Importance | Weight | Wing loading | Aerodynamic quality | Lift coefficient | Drag coefficient | Stability | Trust-to-weight ratio | Specific fuel consumption | Tensile strength | Cost of transportation | Cost of manufacturing | Average repair time | Mean time between failures |
|------------|--------|--------------|---------------------|------------------|------------------|-----------|----------------------|--------------------------|----------------|-----------------------|-----------------------|---------------------|-----------------------------|
| Endurance  | 14.91  | O            | O                   | O                | O                | O         | O                    | 14.00                    | O              | O                     | O                     | O                  |                               |
| Range      | 14.91  | O            | O                   | O                | O                | O         | O                    | 14.00                    | O              | O                     | O                     | O                  |                               |
| Cruise     | 10.36  | O            | O                   | O                | O                | O         | O                    | 10.36                    | O              | O                     | O                     | O                  |                               |
| altitude   |        |              |                     |                  |                  |           |                      |                          |                |                        |                        |                    |                               |
| Payload    | 7.59   | O            | O                   | O                | O                | O         | O                    | 7.59                     | O              | O                     | O                     | O                  |                               |
| Maximum    | 13.73  | O            | O                   | O                | O                | O         | O                    | 13.73                    | O              | O                     | O                     | O                  |                               |
| speed      |        |              |                     |                  |                  |           |                      |                          |                |                        |                        |                    |                               |
| Take off   | 3.72   | Δ            | O                   | O                | O                | O         | O                    | 3.72                     | O              | O                     | O                     | O                  |                               |
| and landing|        |              |                     |                  |                  |           |                      |                          |                |                        |                        |                    |                               |
| Viewing    | 13.81  | Δ            | O                   | O                | O                | O         | O                    | 13.81                    | O              | O                     | O                     | O                  |                               |
| angle      |        |              |                     |                  |                  |           |                      |                          |                |                        |                        |                    |                               |
| Working    | 8.99   | Δ            | O                   | O                | O                | O         | O                    | 8.99                     | O              | O                     | O                     | O                  |                               |
| temperature|        |              |                     |                  |                  |           |                      |                          |                |                        |                        |                    |                               |
| Turnaround | 2.72   | Δ            | O                   | O                | O                | O         | O                    | 2.72                     | O              | O                     | O                     | O                  |                               |
| time       |        |              |                     |                  |                  |           |                      |                          |                |                        |                        |                    |                               |
| Cost       | 9.28   | O            | O                   | O                | O                | O         | O                    | 9.28                     | O              | O                     | O                     | O                  |                               |
| Absolute   |        |              |                     |                  |                  |           |                      |                          |                |                        |                        |                    |                               |
| priority    |        |              |                     |                  |                  |           |                      |                          |                |                        |                        |                    |                               |
| value       |        |              |                     |                  |                  |           |                      |                          |                |                        |                        |                    |                               |
| Relative   | 19.73  | 415.94       | 119.85              | 156.96           | 164.46           | 340.65    | 157.12               | 40.74                    | 195.66         | 180.57                | 192.28                | 2108.18            |                               |
| priority    | 5.68   | 7.45         | 7.80                | 16.16            | 7.45             | 1.73      | 4.67                 | 2.36                     | 9.28           | 8.57                  | 9.12                  | 100.00             |                               |
| value       | 4.88   | 5.74         | 5.80                | 13.04            | 4.85             | 1.36      | 3.67                 | 2.06                     | 9.28           | 8.57                  | 9.12                  | 100.00             |                               |
| Total       |        |              |                     |                  |                  |           |                      |                          |                |                        |                        |                    |                               |

QFD analysis allows us to conclude that the weight of the aircraft has the highest priority among the analyzed characteristics. An analysis of correlation between generalized performance characteristics showed that reducing the weight of an aircraft contributes to the improvement of aerodynamic characteristics: wing loads, lift coefficient and aerodynamic quality — which in its turn contributes to an increase in endurance and range of the flight. Also, according to the results of QFD, attention should be paid to the drag coefficient. This parameter is also associated with many customer requirements, and by reducing its value, it is possible to improve the quality of the UAV significantly.

5. Conclusion

An example of QFD use at the stage of conceptual design of a multi-purpose HALE UAV flight is given in this paper. QFD showed that the priority for improvements is to increase the duration and range of the flight. The use of QFD at the design stage of a UAV allows to take into account a variety of aspects that influence to its quality, to reduce the cost of an experimental batch manufacturing and the cost of the product development.
References
[1] Karimov A Kh Features of designing unmanned aircraft systems of a new generation 2011 Proceedings of the MAI: Electronic Journal 47 [In Rus]
[2] Dmitriev A Ya and Mitroshkina T A Improving the efficiency of aviation products design based on international standards and robust approaches 2019 IOP Conference Series: Materials Science and Engineering
[3] Brener B A, Drobyshhevsky A V and Silkin A.T. Universal drones 2003 Independent Military Review: Internet version of the newspaper [In Rus]
[4] Gelmiza N K Unmanned aircraft: maximum capacity 2002 Science and Life: Internet version of the journal 6 [In Rus]
[5] Udalov S O S-62 Sukhoi KB 2015 Russian Pulse: Electronic Journal [In Rus]
[6] Adler Yu P No matter how much you deploy, you still have to structure 2002 Methods of quality management 4 11-13 [In Rus]
[7] Tan R K W Quality function deployment as a conception aircraft design tool (Naval postgraduate school: Monterey, California) p 102
[8] Vashukov Yu A 2012 Technology of rocket and aerospace structures made of composite materials (Samara State Aerospace University named after academician S P Korolev: Samara) p 185 [In Rus]
[9] Bossert J L 1991 Quality function deployment: a practitioner’s approach (ASQC Quality Press) p 127
[10] Dmitriev A Ya, Vashukov Yu A and Mitroshkina T A 2016 Robust design and technological preparation of the manufacturing of aviation equipment (Samara: Samara University) p 76 [In Rus]
[11] Dmitriev A Ya and Mitroshkina T A The ontological model and the hybrid expert system for products and processes quality identification involving the approach based on system analysis and quality function deployment 2016 ITM Web of Conferences 6 02005
[12] Dmitriev A, Mitroshkina T and Rogachev G Structural and parametric analysis of robust design quality of complex technical systems 2017 ITM Web of Conferences 10 01001
[13] Aytasova A S, Karpenko P A, Solopova N A 2019 Development the risk management system of processes in the enterprise. Proceedings of the 2019 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering, ElConRus 2019, art. no. 8657147, pp. 1357-1360. DOI: 10.1109/ElConRus.2019.8657147
[14] Pogarskaia T, Churilova M, Petukhova M, Petukhov E 2019 Simulation and optimization of aircraft assembly process using supercomputer technologies. Communications in Computer and Information Science, 965, pp. 367-378. DOI: 10.1007/978-3-030-58074-4_31
[15] Zaitseva N, Lupuleac S, Petukhova M, Churilova M, Pogarskaia T, Stefanova M 2018 High Performance Computing for Aircraft Assembly Optimization. Proceedings - 2018 Global Smart Industry Conference, GloSIC 2018. DOI: 10.1109/GloSIC.2018.8570136
[16] Lupuleac S, Zaitseva N, Stefanova M, Berezin S, Shinder J, Petukhova M, Bonhomme E 2019 Simulation of the Wing-to-Fuselage Assembly Process. Journal of Manufacturing Science and Engineering, Transactions of the ASME, 141 (6). DOI: 10.1115/1.4043365
[17] Rostova O, Shirokova S, Sokolitsyna N 2019 Management of project for automation of investment control at industrial enterprise. IOP Conference Series: Materials Science and Engineering, 497 (1). DOI: 10.1088/1757-899X/497/1/012017
[18] Krasyuk I, Kirillova T, Bakharev V, Lyamin, B 2019 Life cycle management in network retail enterprise based on introduction of innovations. IOP Conference Series: Materials Science and Engineering, 497 (1). DOI: 10.1088/1757-899X/497/1/012125
[19] Klochkov Y, Klochkova E, Didenko N, Frolova E, Vlasova N 2018 Development of methodology for assessing risk of loss of a consumer through the fault of an outsourcer. 2017 International Conference on Infocom Technologies and Unmanned Systems: Trends and Future Directions, ICTUS 2017, 2018-January, pp. 719-724. DOI: 10.1109/ICTUS.2017.8286101
[20] Polteva T, Antipov D, Klassen N 2019 The Improvement of the Market Risk Management Mechanism at the Automotive Industry Enterprises. Proceedings - 2019 Amity International Conference on Artificial Intelligence, AICAI 2019, pp. 1005-1014. DOI: 10.1109/AICAI.2019.8701324

[21] Rostova, O, Shirokova S, Sokolitsyna N 2019 Management of project for automation of investment control at industrial enterprise. IOP Conference Series: Materials Science and Engineering, 497 (1). DOI: 10.1088/1757-899X/497/1/012017

[22] Borovkova V, Borovkova V, Boikova U, Testina Y 2019. Improving efficiency of company risk management system monitoring. IOP Conference Series: Materials Science and Engineering, 497 (1). DOI: 10.1088/1757-899X/497/1/012055

[23] Dvas G V, Dubolazova Y A 2018 Risk assessment and risk management of innovative activity of the enterprise. Proceedings of the 31st International Business Information Management Association Conference, IBIMA 2018, pp. 5650-5653

[24] Levina A I, Borremans A D, Burmistrov A N 2018 Features of enterprise architecture designing of infrastructure-intensive companies. Proceedings of the 31st International Business Information Management Association Conference, IBIMA 2018. pp. 4643-4651.