Improving the Efficiency of Aviation Products Design Based on International Standards and Robust Approaches

A Dmitriev$^{1,2}$ and T Mitroshkina$^2$

$^1$Samara National Research University named after academician S.P. Korolev (Samara University), Samara 443086, Russian Federation
$^2$Samara Region State Academy (Nayanova), Samara 443010, Russian Federation

E-mail: dmitriev57@rambler.ru

Abstract. The article considers the possibility of using QFD, robust design and other modern approaches for designing innovative aviation products. As an example, the projected unmanned aerial vehicle and engine, as its key part, are considered. Based on expert evaluation and analysis of benchmarking data, the main consumer requirements for UAV and a small-size gas turbine engine were identified. It is also necessary to pay attention to such general requirements as low noise, low emission of harmful substances (CO and NOx). The use of international standards of the ISO 16355 series as a methodology and basis for improving design efficiency is discussed. The results and conclusions can be applied to various types of aviation products, as well as used in other industries.

1. Introduction
Aviation industry is one of the strategic in Russia. The goal of the state program of the Russian Federation "Aviation Industry Development, 2013-2025" is "to create a highly competitive aviation industry and consolidate its position in the world market as the third manufacturer in terms of production of aviation equipment." High efficiency of the aviation products development based on meeting the requirements of standards and implementation of quality management methods is the most important direction in improving the competitiveness of products and Russian enterprises of the aviation industry.

Implementing the requirements of international standards, as well as applying quality management methods, such as “quality function deployment” (QFD), “failure mode and effect analysis” (FMEA), robust design and others are organizational innovations that aimed is helping organizations develop or improve the basic management system to ensure continuous improvement of the organization [1].

The above fully applies to the design and manufacture of unmanned aerial vehicles. This type of aircraft is used for video monitoring of the terrain in real time, for the tasks of oil and gas production enterprises, pipeline transportation, in power engineering and communications, medicine, for the tasks of the Ministry of Emergency Situations and so on. Due to the high extent and territorial extent of the objects of observation, aerial monitoring is the most effective means of monitoring and remotely collecting data on their condition.

The relevance of the topic of work is that the high efficiency of the development of aviation products and quality management based on robust design methods is the most important direction in improving the competitiveness of products. Otherwise as a result of a superficial approach to customer
requirements, it may ultimately lead to unnecessary costs, and as a result, a decrease in the competitiveness of the manufactured product.

2. Quality function deployment

Quality function deployment (QFD) is a method to assure customer or stakeholder satisfaction and value with new and existing products by designing in, from different levels and different perspectives, the requirements that are most important to the customer or stakeholder. These requirements should be well understood through the use of quantitative and non-quantitative tools and methods to improve confidence of the design and development phases that they are working on the right things. In addition to satisfaction with the product, QFD improves the process by which new products are developed [2].

Reported results of using QFD include improved customer satisfaction with products at time of launch, improved cross-functional communication, systematic and traceable design decisions, efficient use of resources, reduced rework, reduced time-to-market, lower life cycle cost, improved reputation of the organization among its customers or stakeholders.

Since its inception in 1966, QFD has broadened and deepened its methods and tools to respond to the changing business conditions of QFD users, their management, their customers, and their products. Those who have used older QFD models will find these improvements make QFD easier and faster to use. The methods and tools shown and referenced in the standard represent decades of improvements to QFD; the list is neither exhaustive nor exclusive. Users should consider the applicable methods and tools as suggestions, not requirements.

Current Japanese users of QFD concepts include Nissan, Toyota, Komatsu, Nippondenso and Honda. In the United States of America users include Ford, GM, Chrysler, DEC, TI, 3M, HP, AT&T Bell Labs, NovAtel, Xerox, Exxon and Dow.

2.1. Standardisation: Transitioning from JIS Q 9025 to ISO 16355

Since the first published article in 1966 [3], QFD has grown from the strong roots of Japanese quality management methods and tools into the Japanese standard JIS Q 9025:2003 [4], which is based on the Comprehensive QFD model developed by Akao and others [5]. W. Edwards Deming said that knowledge comes from "outside" the system [6], and as QFD has extended its influence globally over the past thirty years, so has QFD absorbed best practices from worldwide practitioners. Based on papers and case studies, the ISO 16355 series of standards brings these Japanese and global methods and tools together to update the new product development process so that it better aligns with today's and tomorrow's customers, suppliers, and competitors [7].

These global methods and tools not only strengthen the classical Comprehensive QFD model, they also integrate with modern strategic planning, market and consumer research, voice of customer analysis to uncover unspoken needs, and innovation. Then, after product launch, the ISO 16355 provides guidance for ongoing support and environmental sustainability.

The ISO 16355 includes 8 parts: 1. General principles of QFD; 2. Acquisition of voice of customer/stakeholder (VOC/VOS) – non-quantitative approaches; 3. Acquisition of VOC/VOS – quantitative approaches; 4. Analysis of VOC/VOS; 5. Strategy and Translation of VOC/VOS into engineering solutions and cost planning; 6. Optimization – robust parameter design; 7. Optimization – tolerance design; 8. Commercialization and life cycle. Therefore the greatest attention is given to acquisition and analysis of voice of customer/stakeholder (VOC/VOS).

First part of ISO 16355 “General principles of QFD” describes the QFD process, its purpose, users, and tools. It contains overview and flow of modern QFD and robust design (Comprehensive QFD for quality, technology, cost, and reliability; 4-Phase QFD for auto parts suppliers; Blitz QFD® to fast-track critical customer needs), 25 figures and tables and 125 published references. It is not a management system standard.

So it does not provide requirements or guidelines for organizations to develop and systematically manage their policies, processes, and procedures in order to achieve specific objectives [2]. The contents of first part of ISO 16355 are shown in Figure 1.
Users of this part of ISO 16355 will include all organization functions necessary to assure customer satisfaction, including business planning, marketing, research and development (R&D), engineering, information technology (IT), manufacturing, procurement, quality, production, sales, service, packaging and logistics, support, testing, regulatory, and other phases in organizations.

3. Application of QFD and robust approaches for unmanned aerial vehicles design

International Civil Aviation Organization (ICAO) recognizes many categories of aircraft, among them balloons, gliders, aero planes and rotorcrafts. Aircraft can be land, sea or amphibious. Whether the aircraft is manned or unmanned does not affect its status as an aircraft. Each category of aircraft will potentially have unmanned versions in the future [8]. This point is central to all further issues pertaining to UA and provides the basis for addressing airworthiness, personnel licensing, separation standards, etc. Unmanned aircraft systems (UAS) are a new component of the aviation system, one which ICAO, States and the aerospace industry are working to understand, define and ultimately integrate. These systems are based on cutting-edge developments in aerospace technologies, offering advancements which may open new and improved civil/commercial applications as well as improvements to the safety and efficiency of all civil aviation. The safe integration of UAS into non-segregated airspace will be a long-term activity with many stakeholders adding their expertise on such diverse topics as licensing and medical qualification of UAS crew, technologies for detect and avoid systems, frequency spectrum (including its protection from unintentional or unlawful interference), separation standards from other aircraft, and development of a robust regulatory framework.

3.1. Study of robust methods for designing and improving UAVs

Model of 4-Phase QFD for auto parts suppliers ISO 16355 [2] and previous work experience [1, 9, 10] was used to design a UAV, the purpose of which is to solve civil tasks: monitoring problem areas of
oil companies' main pipelines, inspecting hydraulic structures, identifying unauthorized dumps, monitoring the extraction of natural resources, and more.

The basic requirements of the consumer are: payload > 5 kg, working height from 1000 to 5000 meters, communication distance > 100 km, stable flight capability > 15 hours and flight range > 2000 km. Conducted collection and analysis of consumer requirements with the participation of experts from the Samara National Research University. The method of pairwise comparisons was used to collect and evaluate opinions. The results of assessing the relative importance of the requirements are presented in Table 1 and Figure 2.

Table 1. UAV customer requirements table.

| #  | UAV customer requirements                                         | Weight, % |
|----|------------------------------------------------------------------|-----------|
| 1  | Maximum communication range (over 100 km)                       | 13,0      |
| 2  | The ability to control a long distance                          | 12,5      |
| 3  | Flight range (more than 1920 km)                               | 11,8      |
| 4  | The possibility of stable flight (more than 15 hours)           | 11,3      |
| 5  | Maximum area of observation of the device with good image quality | 10,9      |
| 6  | Reusability                                                      | 9,1       |
| 7  | Maximum payload (more than 5kg)                                | 8,9       |
| 8  | Working height (from 1000 to 5000 m)                            | 7,4       |
| 9  | The minimum mass of the UAV (30 kg)                             | 7,1       |
| 10 | The ability to quickly move                                     | 3,4       |
| 11 | Low cost                                                         | 2,8       |
| 12 | Fast assembly / disassembly and easy transportation             | 1,7       |

Thus, the most significant indicators are the maximum communication range, the ability to control at a long distance and the flight range. It is these parameters determine the radius of action of the aircraft, the area available to its review directly depends on them, which is very important both for military intelligence and for scientific observations. The most important requirements taking into
account the results of benchmarking are the maximum communication range and the ability to control at a long distance.

At the first phase of QFD, the requirements of consumers using the house of quality (HoQ) were transferred to the flight performance of the UAV: Maximum take-off weight, Mass of payload, Relative payload ratio, Cruising speed, Maximum flight speed, Radius of action, Video transmission distance, Flight duration hour, Practical ceiling, Limit wind speed at the surface of the Earth at the start, Guaranteed resource, Viewing angle, Camera rotation angle, Deployment time.

| #  | UAV Flight performance                        | Weight, % |
|----|---------------------------------------------|-----------|
| 1  | Radius of action                            | 14,05     |
| 2  | Maximum take-off weight                      | 12,63     |
| 3  | Video transmission distance                  | 12,36     |
| 4  | Mass of payload                             | 9,55      |
| 5  | Cruising speed                              | 8,33      |
| 6  | Maximum flight speed                        | 8,33      |
| 7  | Practical ceiling                           | 7,95      |
| 8  | Viewing angle                               | 5,81      |
| 9  | Camera rotation angle                        | 5,81      |
| 10 | Flight duration                              | 5,56      |
| 11 | Guaranteed resource                          | 5,13      |
| 12 | Deployment time                              | 2,41      |
| 13 | Relative payload ratio                       | 1,10      |
| 14 | Limit wind speed at the surface of the Earth at the start | 0,98 |

Figure 3. Pareto diagram for UAV Flight performance weight.

The flight performance characteristics that are most important for the implementation of customer requirements are Radius of action, Maximum take-off weight, Video transmission distance.

Then the technical characteristics of the UAV units are considered: Glider, Transceiver with rheostat-contactor control system, Target load, Power load, Energy sources. As a result of building a
House of Quality and FMEA, the most important characteristics of the components of an unmanned aerial vehicle have been identified, which need to be improved in the first place: telemetry and autopilot transceiver (weight 20.52%); opto-electronic system (weight 15.70%); relative thickness of the airframe shell (weight 12.98%).

Using methods Taguchi and experiments conducted in the universal software system ANSYS product Discovery Live, carried out parametric design of UAVs. As a result of the robust design, the optimal configuration of control factors (UAV take-off mass; wing span; wing area) was found, at which the signal-to-noise ratio takes the maximum value.

3.2. QFD to improve and study the small-size gas turbine UAV’s engine

Additionally, the possibility of implementing QFD to improve and study the small-sized gas turbine engine of an unmanned aerial vehicle was considered.

A gas turbine engine is a type of heat engine that operates according to a certain principle. The principle of operation of the engine is to convert gas energy into mechanical work. The gas is compressed and heated before starting. A distinctive feature of a gas turbine engine from a piston engine is that all processes occur in a stream of moving gas.

As an object of study of this work, the TJ100 small-sized turbojet engine, which is a sub-type of small-sized gas turbine engines, was chosen. This small jet engine was developed for light aircraft, for example for light and ultra light sport aircraft, gliders equipped with an auxiliary engine, manned vehicles of the experimental category and various UAVs.

When developing unmanned aerial vehicles, it is necessary to ensure that the product conforms to all the conditions of the customer’s technical specification. First of all, this applies to aircraft engines, the requirements for which can be divided: into general and to a specific type of engine installed on a specific UAV. General requirements for small-size gas turbine engine UAV include [10]:

1. Safety requirements: engine safety; stable operation of the power plant; stable performance.
2. Destination requirements: ensuring thrust on take-off mode; ensuring thrust in cruising flight conditions; ensuring specific fuel consumption in cruising flight conditions.
3. Design requirements: compliance with restrictions on size; compliance with weight limits; modularity.
4. Technical requirements: high reliability; high durability.
5. Operational requirements: high maintainability; ease of maintenance and repair.
6. Production and technological requirements: ease of manufacture and assembly; use of available materials.
7. Special Requirements: low noise; low emission of harmful substances (CO and NOx).
8. Technical and economic requirements: low cost of manufacturing a serial sample; low operating and maintenance costs.

Based on expert evaluation and analysis of benchmarking data, the main consumer requirements for a small-size gas turbine engine were identified: stable operation of the power plant, provision of thrust in take-off mode, provision of thrust in cruising flight conditions, provision of specific fuel consumption in cruising flight conditions, use of available materials, low cost of manufacturing. It is also necessary to pay attention to such general requirements as low noise, low emission of harmful substances (CO and NOx).

According to the results of QFD for the design of a small-size gas turbine engine, priority technical characteristics were determined (engine weight; total mass of the power plant and fuel consumed during the flight; engine thrust in take-off mode; hourly fuel consumption in the engine), as well as the most important indicators of the efficiency of engine components (full engine recovery ratio in the input device; full engine recovery ratio in the combustion chamber; nozzle speed ratio; ent complete combustion of the fuel in the combustion chamber).
4. Conclusion

The paper presents examples of the implementation of QFD in the development of UAVs and small-sized gas turbine engines of UAVs. The use of QFD in the development of innovative aviation products requires the involvement of experts and knowledge of statistical methods and robust design approach. An additional advantage is the possibility of conducting experiments using mathematical and virtual models in information systems, for example, ANSYS Discovery Live. The ISO 16355 series of standards are not standards for management systems and do not contain ready-made procedures for implementation. At the same time, the application of the tools given in the ISO 16355 series of standards allows the company to increase the efficiency of design and development of innovative products and processes.

References

[1] Dmitriev A Y 2016 Robastnoye proyektirovaniye i tekhnologicheskaya podgotovka proizvodstva izdeliy aviatsionnoy tekhniki (Samara: Samara University) [In Rus]
[2] ISO 16355-1:2015 2015 Applications of statistical and related methods to new technology and product development process - Part 1: General principles and perspectives of Quality Function Deployment (QFD) (International Standards Organization, Geneva, Switzerland)
[3] Glenn Mazur 2017 Transitioning from JIS Q 9025 to ISO 16355 International Symposium on QFD (ISQFD)
[4] Oshiumi K 1966 Perfecting Quality Assurance System in Plants Quality Control, pp 62-67.
[5] Japanese Industrial Standard 2003 JIS Q 9023:2003(E) Performance improvement of management systems – Guidelines for managemant by policy (Japanese Standards Association)
[6] Akao Y. and Mazur G H 2003 The leading edge in QFD: past, present and future International Journal of Quality & Reliability Management 20(1) 20-35
[7] Deming W E 1994 The New Economics (Cambridge, MA: MIT-Center for Advanced Educational Services) p 92.
[8] ICAO Cir 328 AN/190 2011 Unmanned Aircraft Systems (UAS) (International Civil Aviation Organization)
[9] Dmitriev A, Mitroshkina T and Rogachev G 2017 Structural and Parametric Analysis of Robust Design Quality of Complex Technical Systems ITM Web Conferences 10 01001
[10] Dmitriev A and Mitroshkina T 2016 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 ITM Web of Conferences 6 02005