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Technical paper

Parametric cost analysis and quantitative risk assessment for developing strategies to counter risks in the design and production of medical aircraft in the Russian federation

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Abstract

The objective is to identify potential risks in the aircraft development and to quantify the risks in the process, ultimately to find mitigating strategies. Monte-Carlo simulation for quantitative risk assessment and RAND DAPCA IV to calculate the cost are employed. These results are comprehended and collectively assessed with few assumptions. The assumptions are in due consideration to the local conditions, and thus they reflect in the approximations. These assumptions indicate the impact of the industrial and academic environment of the Russian Federation on the developmental cycle of the aircraft. The estimated financial risk for the development of an air medical ambulance for the Russian Federation is 29%, and the cost for unit production of the medical aircraft is nearly 19 million USD. The suggested strategies can reduce the financial risk to 22% and the cost for unit production of the medical aircraft to nearly 13 million USD.

Keywords: *Aircraft Production Cost Analysis; Monte-Carlo Simulation; Parametric Analysis; Quantitative Risk Assessment; RAND DAPCA IV*

1. Introduction

The Feasibility study[1] assess the existing medical aircraft designs and their services around the world. It also discusses the need for medical aviation in the Russian Federation. An amphibian aircraft with shortened take-off and landing capabilities have been designed using an open-source parametric aircraft geometry tool - Open VSP. (Fig. 1) illustrates the 3D model of the designed medical aircraft as per identified requirements for the Russian Federation. This design has no base cost or historical data- as the configuration & technical requirements are unique to this selected configuration. The fundamental question is how to quantify the budget for this aircraft development and who is accountable for it? Since this is supposed to be a project of public interest and public development, should the government invest in it? If so, how much? On what basis should budget allocations shall be formed? Or should it be the expected market price of the aircraft for potential buyers? If so, how to optimize production costs and incurred project costs? Or should it be based on the expected reduction in the annual budget for health care, economic and industrial investment? If so, how can this amount be quantified? Despite all this, the expected cost of production tends to increase over the period. Moreover, the initial cost is necessary to compare the different strategies and plans for the development of the project[2].

2. Methodology

As long as these questions are not known, the project is uncertain and unpredictable. So, a quantitative risk assessment was performed; by using Monte-Carlo simulation. Monte-Carlo simulation assigns random probabilities to various outcomes. For over 1100 iterations, the simulation is about 95% accurate in prediction.[3] Based on the historical data of long-term civil and aeronautical engineering projects, four risk factors are identified, which will affect the project outcome [4]. Here, each risk factor is independent of the others when it occurs and can have a cascading effect over 6-18 months. However, about the development period of 8-10 years, potential risk factors affecting the development process are identified and illustrated in (Fig. 2). The total weight of the aircraft is 17767 Kg, and the maximum velocity is 156 m/s. RAND DAPCA IV estimates production cost for 100 units per annum in American dollars. This model assumes the design, research, and development, manufacturing, quality control, and material procurement of aircraft in the corporate environment of the U.S.A. Cost

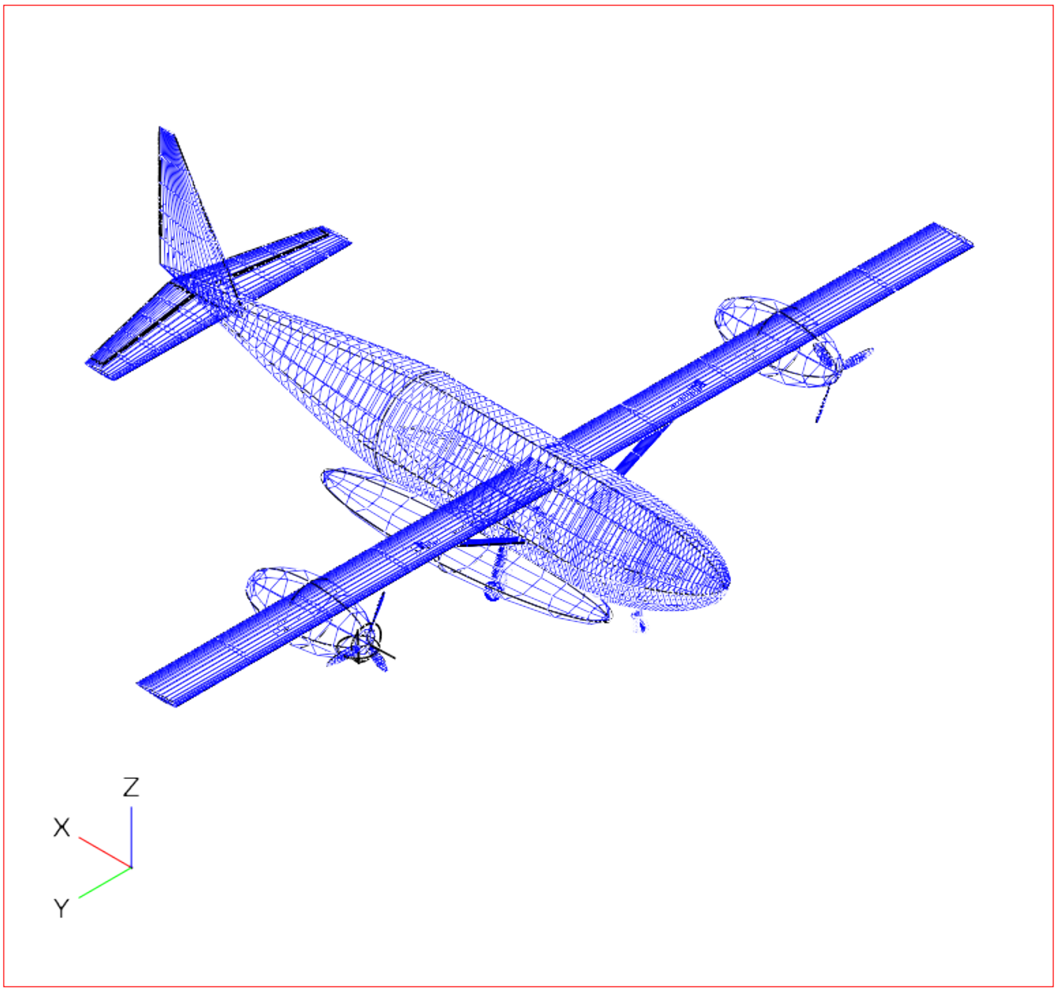

Figure 1: 3D model of the aircraft

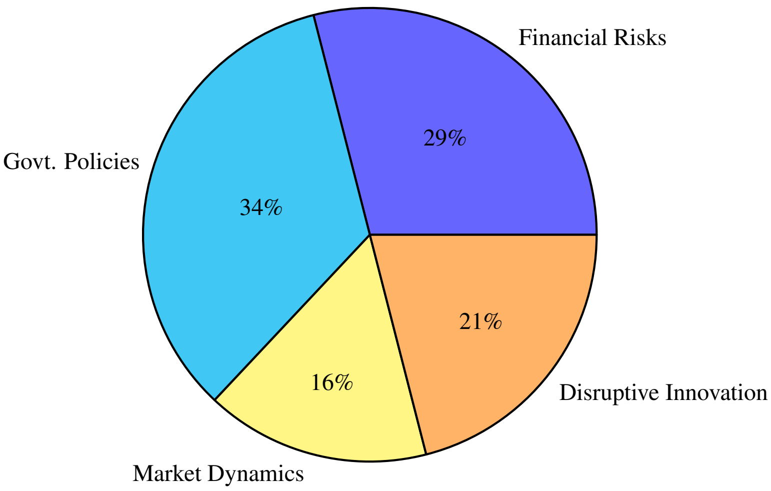

Figure 2: Various risk factors and their probability based on Monte-Carlo simulation

for the engine and avionics are assumed to be part of the acquisition cost. RAND DAPCA IV model is developed based on 1986 market conditions of the U.S.A [5]. This model will use English units of measurement, and the cost will be in US dollars [6]. All mechanical components of the aircraft are assumed to be manufactured with the inclusion of the airframe, landing gear, hydraulics, floats, fasteners, etc. The costs of engines and avionics are acquisition costs [6, 5]. It requires corrections regarding total labor hours, raw material costs, development time, and wages [7]. Here, the industrial inflation factor is substituted as a correction factor to calculate how many times the estimation has parametrically deviated from the initial approximation [8, 9]).

$$Cm_0 = Cm_{TEX} + Cm_{TOOL} + Cm_{PROD} + Cm_{QC} + Cm_{DEV} + Cm_{TEST} + Cm_{MAT} + Cm_{ENG} + Cm_{AVI} \quad (1)$$

Where,
Cm_0 - Cost for the aircraft development and production; Cm_{TEX} - Engineering costs; Cm_{TOOL}- Tooling costs; Cm_{PROD}- Cost of production; Cm_{QC}- Quality management costs; Cm_{DEV} -Development support cost; Cm_{TEST} - Cost of testing and certification; Cm_{MAT} -cost of materials for production; Cm_{ENG}- cost of engines; Cm_{AVI}-Cost of avionics

3. Results and Discussion

The aircraft weighs 38973.26 lbs (17767 Kg), the maximum velocity of the designed aircraft is 303.24 knots (156 m/s), and six aircrafts are submitted, for airworthiness regulatory authority as prototypes for testing and certification. The parametric costs of the aircraft development, acquisition, certification and production costs are tabulated in table.1. The estimated cost of research, development, production, quality control, and certification per unit aircraft is $ 16626199.76 (16 million USD). The estimated unit cost of the aircraft is in 1987 in the American industry. The inflationary factor indicates that in the period 1986-2020 in the United States there are multiple increases in the cost of various goods. Thus, the cost of manufacturing the proposed aircraft per unit is $ 19951439.71 (19 million dollars). Manufacturing costs have dropped over the past 40 years thanks to automation, experience, and increased understanding, which has reduced the frequency of errors and failures in manufacturing [2, 8]. Besides, over the past four decades, labour wages and the cost of raw materials have increased significantly throughout the world [10]. The Dornier 328 Jet Bada currently worth $ 13-15 million and weighs about 15 (15,200) tons. Compared to the proposed aircraft, which weighs 17.7 tons (17,678 kg) and has an estimated production cost of $ 19 million. The cost of production for Dornier aircraft is $ 987 per kilogram if the material is aluminium. Likewise, the proposed aircraft costs $ 1,128.7 per kilogram. There is a 14% variance in the results.

S.No.	Type of Cost	Cost in USD	% cost
1	Engineering costs	$333420892.9	20%
2	Tooling costs	$239146072.7	14%
3	Cost of production	$633643656.1	38%
4	Quality management costs	$76212234.19	5%
5	Development support cost	$59669294.99	4%
6	Testing and certification cost	$36411924.43	2%
7	Cost for materials	$196281540.62	12%
8	Cost of engines	$ 9887814.91	1%
9	Cost of avionics	$77946544.72	5%
10	Total cost	$1,66,26,19,975.6	

Table 1: Parametric cost estimation of the amphibian medical aircraft

However, this may seem like a reasonable estimate of the cost of production, it is not very accurate as this model did not take automation, supply chain management, and digital manufacturing into account in the estimation [7, 6]. This estimate was made on the assumption of average wages and working hours for aircraft development and production . If there were disruptive innovations, marketing strategies, acquisition strategies, concessions from governments could have a big impact on actual costs. Let us assume that the change in the cost of aircraft production by 14% per kg is due to these factors.

As a thumb rule, American-made aircraft is 40-50% more expensive than Russian-made aircraft. Such an approximation is valid for military aircraft. However, it depends on market leverage, defence agreements, and cooperation with other countries. Russian industry is less dependent on imports of raw materials, and the cost of skilled labour is cheaper in Russia than in America. So, from this, one can make a relative approximation, such that the proposed aircraft will cost 11% more than the Dornier 328 Jet-Bada if produced in America. The cost estimate did not take into account the political influence and the impact of foreign trade policy on the final cost of aircraft, along with the costs incurred.

Thus, the final estimate of the cost of production per unit kg is $ 903 per kilogram. Therefore, the estimated unit cost of the aircraft for a unit, which when produced in the Russian aviation industry, will amount to $ 16073400 ($ 16 million).

The aircraft must be cost-effective to purchase and operate, as it must complement the cost of organizing and maintaining facilities in the health sector. Meanwhile, a low-cost product provides a competitive edge to compete in the marketplace.

The quantitative risk assessment of the project for the four risk factors considers the following possibilities, which will potentially contribute to the failure of the project.

- **Financial risks:** The project planning should consider the lack of grants, the delay in approvals, which will significantly affect the results. Availability of funding, allotment of budget to each department is holistic in nature for an aerospace project. Delay or insufficient allocations to one department can have a cascading effect [4]. To overcome this a stable financial support and funding are necessary for the project to accomplish its tasks. Aerospace companies allocate 60-80% of the annual budget for R&D works. The delivery of R&D to a certain degree is unpredictable. Thus, the project is estimated to have 29% of the risk due to finances.
- **Public policy and regulations:** This risk factor has the highest contribution of 34% probability towards failure. The government of the state is bound to change at regular intervals. The project's development cycle is for 8-10 years. The development cycle of the project is two consecutive terms of a government or more governments. Even if the same government resumes the second term, the government's priorities might change depending on socio-economic, political, climatic, trade, and foreign affairs. This aspect of risk involves various external parameters. They can't be monitored or controlled by the internal environment of the project [11].
- **Market dynamics:** The objective of the project is to reduce the financial burden on the public healthcare sector. Simultaneously, to generate revenue in the global civil aviation market. If other countries or competing companies can provide cheaper aircraft, this will ultimately affect the project [4]. Countries like China, which has good manufacturing capabilities to produce aircraft, or American companies like Boeing, which have a long supply chain and efficient talent acquisition system, material procurement, and stable

finances, can develop similar aircraft in a shorter period compared to others. This risk accounts for 16% of the total probability of failure. It is an unknown-unknown and an external factor.

- **Disruptive innovation in other fields:** The development of proposed aircraft is necessary to substitute the vacuum in the public health sector as the demographics of the country are diverse. Thus construction, maintenance, and operations of hospitals become non-viable, and the expenses don't justify. Disruptive innovations in the fields of construction, telemedicine, logistics, and management can make this project unrealistic and eventually leads to the decommissioning of the project [12]. This accounts for a 21% total probability of failure. It is also an unknown-unknown and an external factor of risk.

4. Recommendations for Risk Mitigation

The section 3 shows that the main risks are financial risks and public policies. These are external risk factors that are subjectable to mitigation. While the other two risk factors, namely market dynamics and breakthrough innovations in other sectors, are generally not manageable in the project's internal environment or related processes. Often, this process combines risks and opportunities. The goal is to expose the organization to the ideal risk while exploring the maximum possibilities. All known-unknowns and unknown-unknowns are converted to known-known risks using the following strategies. When working with unknowns-unknown, which were unable to quantify are accepted and assigned in the course of work accordingly.
The following strategies and policies are for reducing or diverting the impact of risks that needs mitigation.

- **Strategies for Mitigating Financial Risks:** Reducing the budget of the proposed project to develop an indigenous amphibian medical aircraft can reduce these risks. It is necessary to maintain the optimal level of the project budget and time delay. If one controls the budget; and delivery time during the project development process, this will affect the quality. The cost estimation shows that the design and development costs represent 24 percent of the total estimated cost. These design and development costs comprise employee wages and the cost of maintenance of facilities. Hence, the initial phases of R&D, design, and development have to be transferable to Academic institutions. It can almost reduce costs by 10-12 percent of the total cost. It also improves the quality and training of students to transfer benefits and risks among various stakeholders.
  Materials, manufacturing, avionics, and tooling costs account for almost 69 percent of the cost for the project. The use of commercial off-the-shelf components, i.e., components, avionics, and systems, which are already developed for other aircraft and are readily available on the market for the detailed airframe design, can reduce production costs for procurement and acquisition. Incorporation of DFMA (Design for manufacturing and Assembly) guidelines in the detailed design phase can reduce these costs by 7-13%. (Airbus and Boeing transport aircraft use of already certified and approved components, which reduces development costs, and as production quantity increases, the cost per unit will decrease. According to Internet sources, the expected decrease in expenditure is about 10-15 percent. It will indirectly influence certification and testing costs as well.) Thus, it will reduce the expected cost of the aircraft to $ 13 million, and as the budget reduces to 20-23 percent, the probability of financial risk decreases to 22 percent from 29 percent.
- **Strategies for mitigating risks due to Public policy and regulations:** The risks associated with public policy often manifest themselves in the form of delays with bureaucratic processes, changing governments, and their priorities. As a result, it contributes to increased salary pays and incurred costs which manifests into financial risk. Thus, it is necessary to integrate legal and ethical standards into the development process and to have different priorities throughout the development process. For example, the project area extends to various disciplines such as healthcare, education, industrial training, research, economics, and the market. It also affects employment, the availability of skilled labour, and the exploitation of resources.
  Project management should shift its focus to different areas, from academic research in the early stages of design to industrial policy and compliance in the later stages. In the event of any sudden changes from government regulations or changes in priorities, the focus keeps resources pooled and prevents the project from stalling. Include the governing bodies as partners in the project and significantly reduce the level of risk. Quantifying the reduced risk at this stage is vague without some additional references or an understanding of how this process might end. However, based on the expert's view, it is arbitrarily assumed as 2-5 %. Enabling these strategies reduces the risk probability by 5% and increases the success probability by 2%.

5. Conclusion

The assessment of risks was just a quantitative estimation based on Monte-Carlo simulations and empirical formulas. These values need further qualitative assessment. However, it is beyond the scope of this work. Experts from different disciplines and fields should collaborate and develop a framework based on a model of collective decision-making.
The most important conclusion of this work is that there is a need for air medical ambulance in the Russian Federation. The amphibian medical aircraft with shortened take-off and landing capabilities can overcome shortcomings of existing designs of air medical ambulances across the globe. Despite that, there is a potential market for the proposed aircraft. Developing the aircraft within Russia's scientific system can reduce the cost from 19 million dollars for unit aircraft to 13 million dollars per unit aircraft. The quantitative methods employed to evaluate risks and project cost generates a quantifiable approximation.

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