# LONG TERM AIRCRAFT PROJECT AND TECHNOLOGY EVALUATION UNDER THE UNCERTAINTY OF FUTURE SCENARIOS

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Keywords: technology, evaluation, scenarios

### Abstract

To widen the scope of technology evaluation at AIRBUS and to improve the robustness of its results scenario techniques have been used to describe alternative future environments. These scenarios and the uncertainties associated with them have been applied to project and technology assessment methods. This study reveals two different results.

For a classic technology evaluation where the benefit of a technology or set of technologies against a reference project is computed the results are distinguishably different but with reasonable significance. The robustness of this method of evaluation can be considered satisfactory.

Once the scenarios are applied to calculate the benefit of an entire aircraft project over a long period of time, the spread of the result is (as expected) significant. The associated standard deviation when taking into account the uncertainties in each scenario is 1 to 2 times higher. This leads to the conclusion that lifecycle cost-benefit approaches as used in this study to evaluate aircraft project benefit are subject to ambiguity and will need proper interpretation.

## **1** Introduction

The development of new technologies requires long-term investments in terms of time, resources and money. To justify these investments and to guide through the initial steps of the development of either technology or project different methods of life-cycle models are used. These models require information on long-term business development of markets (social and economic environment), future requirements and demands, and the technical characteristics of the technology. All these uncertainty: inputs are subject to the environment conditions of economics and markets, the technical achievements of technology and projects and the model's inherent accuracy.

This paper describes a study carried out recently on the evaluation of an aircraft program and technologies combining methods of scenario analysis, quantitative risk analysis and cost-benefit-analysis for aircraft manufacturer and operator to estimate the influence of uncertainty from different sources and their relative order of magnitude. Three scenarios describe alternative future developments of economic growth, environmental concerns, societal needs, air traffic development and others. The economic environment for each scenario including the bandwidth of its parameters due to uncertainty is used to feed the technology assessment method. The results are set into context and the consequences are discussed.

## **1.1 Technology Evaluation Principles**

The process of technology evaluation at AIRBUS is intended to put the benefit of an individual technology into an overall aircraft context at a comparable basis [1]. To cover the full set of effects associated with it, a costbenefit analysis for manufacturer and operator is computed. Besides the business economic effects the method allows to integrate social, environmental, legislative, macro economic and air traffic management [2] aspects by modeling boundary conditions and trade factors. The process comprises a technical assessment, an economic evaluation and a risk analysis.

The cost-benefit analysis is based on dynamic investment calculation using the methods of Net-Present-Value (NPV) and Internal Rate of Return (IRR) [1]. The results are typically shown in a vector diagram for manufacturer and operator [Fig. 1], either for the absolute benefit of an investment or for the relative change in benefit due to a single technology change. The origin of the diagram is representing the point where the project or program would reach a predefined return on investment.



Fig. 1: Technology Vector

The most desirable quadrant for the results lies in the upper right quadrant. With a hypothetic transfer rate between manufacturer and operator a line can be drawn between the area of net benefit increase and net loss.

The impact the scenarios on the value added by the technology is analyzed in a relative evaluation. For this analysis the absolute economic value of the baseline aircraft is subtracted from the value generated by the aircraft with the technology. These deltas are depicted as technology vectors.

The aircraft project is analyzed regarding its absolute economic value in the different uncertain scenarios. The absolute economic value in this context is a distribution of manufacturer and operator NPV in the benefit diagram. In some of the following diagrams the vector is replaced and only the end point will be shown for clarity.

# **1.2 Scenarios and Risk Analysis**

Three different types of uncertainty can be distinguished [3, p. 30]:

- The uncertainty of technical data like technologies performance parameters
- The uncertainty of the environment parameters that a technology or aircraft program will face in the future, for example the economic conditions of different scenarios
- The calculations' inherent uncertainty. As the methods for technology evaluation in the early stages of the design phase are based on simplified models they are a source of uncertainty themselves

The first type of uncertainty in the context of technology evaluation and conceptual aircraft design at Airbus was investigated in a thesis carried out in 2003 [3]. Numerous other works addressed technical uncertainty: Greens theory demonstrates the calculation of uncertainties in aircraft performance using NASA's Flight Optimization System (FLOPS). He incorporated the uncertainty of technological input parameters with Monte Carlo and Method of Moments [4]. Largent assessed technology programs modeling the uncertainty of development performance and costs of technologies with Monte Carlo [5, p. 2]. Kirby demonstrates the selection of adequate combinations of technology with uncertain performance [6], [7] using Monte Carlo Simulation. Although economic uncertainty was addressed as well [8], [9] the focus of probabilistic modelling is observed in the area of technological uncertainty.

This study was carried out to investigate the influence of the more external economic factors and boundary conditions on the validity and robustness of the technology and project evaluation process.

#### 2 Scenarios and Modeling of Uncertainties

#### 2.1 Three Scenario Storylines

The three scenarios that were used to test the sensitivity of the project and technology evaluation results to the uncertainty of the future development of economic conditions were taken from an AIRBUS scenario project.

The Trend scenario is oriented along the assumptions that are taken into account for the AIRBUS Global Market Forecast. It assumes a sound economic growth without major crisis and disruptive events and a continuous strong growth of air transport.

The Green scenario reflects rising concerns on environmental issues with legislation in place that taxes emissions and energy use. This impacts the economic growth, the cost structure of manufacturer and operator and the willingness to travel. As the development of the implementation of political measures may differ between Europe and the rest of the world, a European sub-scenario has been used.

A pessimistic, constrained scenario describes a cool-down of growth rates due to political and economic tensions including concerns about the access to energy and limited international trade.

### **2.2 Uncertain Parameters**

As the creation of these scenarios was making use of a metric oriented approach already in the description of the parameters [10] with some bandwidth the notion of uncertainty is already implemented here. Some of the economic conditions varied in this study were directly derived from the scenario storyboards, some had to be translated into the inputs of the cost-benefit-analysis.

Main focus was put on the general economic conditions:

- Gross Domestic Product (GDP) growth as an indicator for prosperity, travel propensity and disposable income influencing the air traffic demand
- Production cost: labor and material
- Operation cost: labor
- Production volume

- Interest rate for capital cost
- Revenues: ticket price
- Fuel price including environmental taxes for the green scenario
- Landing fees and navigation charges including also effects of local noise and emission taxation

In the case of the translation of factors major concern was not a transformation of the absolute values but it was taken care that the bandwidths or uncertainties were handled in a consistent way.

#### **2.3 Escalation Factors and Bandwidths**

The process of scenario analysis does not only lead to images of possible future also environments but describes the development that leads there [11, p. 12]. That in turn means that the scenario is not described only through the future state of its parameters but also through their evolution in time. Based on initial values of the relevant parameters the time dependent development of the economic environment is modeled with escalation factors. They are the annual growth rates for each environmental parameter [Fig.2].



Fig. 2: Uncertainty of economic conditions modeled by a variation of the escalation factor

For this study the modeling of the uncertainty was limited to a variation of the escalation factors. A variation in time series, e.g. by a disruptive event in one of the scenarios, was not taken into account.

# **3 Method of Risk Analysis and Implementation**

The transfer of different scenarios into technology evaluation was done by modifying the economic condition and its evolution in time. This time dependent development with uncertain, that is, statistically distributed escalation factors, was used to model the scenarios inherent uncertainties.

#### **3.1 Monte-Carlo Analysis**

The probabilistic analysis and evaluation were done using an Excel based method in combination with a Monte Carlo simulation; a discrete-event simulation based on probabilistically selected input variables. This means numerically exercising the Excel model for the inputs in question to analyze their effects on the output [12, p. 5 - 6].

The probabilistic cost benefit analysis results in a population of vectors in a NPV diagram [Fig. 3].

# **3.2 Application of Scenario Dependent Parameters**

The technology evaluation method is funded on an economical environment that is not defined as a constant situation. Based on



Fig 3: Schematic population of evaluation vectors in uncertain scenarios

initial values of the relevant parameters the time

dependent development the economic projection was modeled with escalation factors. Each "story" represented by a specific set of the economic conditions and according escalation factors can be regarded as one economic scenario for technology evaluation.

For the interpretation of the scenarios with respect to the quantitative evaluation it is essential to define a starting point. At this point the scenario data and the input data to the evaluation have to fit together. The trend scenario was chosen to constitute this starting point. This means that all scenario-based economic conditions for the other scenarios are deflections from the trend scenario.

The interrelation between the scenario parameters and the escalation factors is identified through an influence analysis. The escalation factors' range developed here is as broad as the one of the corresponding scenario parameters.

escalation factor For each several parameters were identified as influential. Within these the mere qualitative ones gave information to decide qualitatively whether the escalation factor is higher or lower than in the trend scenario. The same approach was used for the scenario storyboards. Those corresponding parameters that were scenario given as bandwidths then defined the escalation factors mean values and bandwidths.

To perform the probabilistic analysis of the scenarios uncertainties the escalation factors were varied via Monte Carlo simulation.

# **3.3 Correlations and Interdependence of Parameters**

In the approaches of scenario analysis the parameters are generally regarded not to develop independently [11, p. 33 - 41], [13, p. 41 - 50] but in a causally interconnected manner. For a statistical analysis this has to be addressed using a correlation of the input variables.

The correlation coefficients in this study were obtained by calculating the similarity between the parameters. This similarity is based on the relationship that is derived with a Delphi based Influence Matrix and the Cross Impact Matrix raw data from the underlying scenario process. It was calculated by comparing the sets of scenario parameters that influence each escalation factor.

#### **4 Scenario Based Evaluation**

For this study two major evaluation approaches were made. First the whole aircraft program was evaluated with respect to the potential value it generates in the different scenarios and the uncertainty of these results. Second the effects of mere technologies under these conditions were analyzed.

#### 4.1 Major Results

The benefit of an overall aircraft program reacts very sensitive on the significant economic changes that take place between and within the uncertain scenarios. Hence the result populations for the aircraft's project expected benefit in the scenarios are very broadly distributed. Fig. 4 shows the result populations of the absolute NPV of an aircraft project under uncertainties in the four scenario situations mentioned above. The positions of the deterministic scenario results without uncertainties are depicted with the black crosses and the scenario names.

The NPV populations range for manufacturer and operator are in the order of magnitude of fifteen times the expected NPV in the average Trend scenario (without uncertainty assumed). The population's standard deviations are in the order of magnitude of three times the expected NPV in the discrete Trend scenario.

Despite the broadly distributed populations it is possible to distinguish between the different scenarios. Although they do overlap significantly their mean values differ by at least the half standard deviation in either manufacturer or operator NPV.

The evaluation of technologies leads to a significantly more robust outcome. The result distributions are very narrow with a range of



Fig. 4: Result population of an aircraft project evaluation under uncertain scenarios

around 1/8 of the mean value and a standard deviation of around 1/45 of the mean value.

Although the populations do overlap they can be distinguished very good as they differ by three to five times the standard deviation.

#### **4.2 Influence of Parameter Bandwidth on** Aircraft Program Assessment

Two different kinds of variations have to be distinguished. The first is observed between the discrete scenarios (the mean values of the populations). Here the main drivers are the escalation factors that model the different developments and the significant differences in the amount of sold aircraft. The second variation takes place within each scenario. It is driven through the mere inherent uncertainty for each scenario. It is key to note that this inherent uncertainties impact is greater than the impact of different scenarios.

This demonstrates the enormous influence of the environment on the economic benefit. In fact the result populations range within one uncertain scenario is one order of magnitude greater than the desired benefit.

With the method of this study sensitivity and risk assessment can be performed on the basis of the acquired data.

A risk assessment for the different scenarios has to be seen in the context of the assumptions that were elaborated during the scenario process. Therefore its validity is strictly confined to the scenarios examples.

The sensitivity analysis [Fig. 5] allows to identify the escalation factors that have the highest influence on the economic value of the aircraft or the technology. Sensitivity analysis helps to determine the aspects of the economic environment that are responsible for the highest uncertainty and therefore inhabit the highest risk for the analyzed project.

# **4.3 Influence of Parameter Bandwidth on Technology Assessment**

The influence of the scenario-implied uncertainty on the technology assessment, the mere benefit generated through the application of the technology, is by far not as large as it is on an aircraft program. In contrast to an aircraft



Fig. 5: Sensitivities for aircraft program manufacturer and for aircraft operation

program assessment the range and standard deviation of the result distributions of the technology delta assessment are significantly smaller than the mean values [Fig. 6].

technologies' effects The are approximately one order of magnitude lower than that of a scenario. Nevertheless its influence can be high enough to have a noticeable effect of the result population in an uncertain scenario. It exerts a positive influence on the result population by generating an offset for manufacturer and operator benefit. Although noticeable the technologies influence is significantly lower than the range and the standard deviation of the result population caused by the scenario-inhibited uncertainty.



Fig. 6: Technology impact relative to a single scenario uncertainty

It became apparent that the relative change of the benefit due to the insertion of a technology is not necessarily highly dependent of the scenario. Fig. 7 shows the result of an improvement of a technology normalized with the result of the overall aircraft project, that is the delta of each aircraft benefit vector between the scenario dependent aircraft benefit and the technology impact.



Fig. 7: Relative normalized delta benefit of a technology in different scenarios

This demonstrates the high stability of the delta method for technology evaluation. Moreover it shows that even for highly uncertain conditions the benefit that will be generated by the application of a technology can be predicted with high accuracy. It can be shown that the economic uncertainty lies in the same order of magnitude as the mere technical uncertainty.

### **5** Conclusions

The evaluation of absolute benefit of an aircraft project must be regarded as a rough estimation resulting in a widely distributed output. This is due to the high level of uncertainty that is inherent in prediction exercises at the beginning of or even before the start of long-term projects like an aircraft program. Unless the dynamic behavior of all actors – manufacturer, operator, markets and society – can be better taken into account the straightforward implementation of scenarios and

their inherent uncertainty will not lead to statistically significant results.

Although the different scenarios outputs do overlap, they are significantly different and can be differentiated. Still, the distinct scenarios allow an analysis of the strengths or weaknesses of an aircraft program approach under changing boundary conditions.

technologies' А economic impact compared with the one exerted by the scenarios is of minor order of magnitude. Yet it can lead to a reduction of the risk that is unveiled with the proposed method. The mere technology related benefit is affected significantly but not severely by the uncertainty of the scenarios. They are significant for each scenario. In an exemplary comparison with technological uncertainty the bandwidths turned out to be approximately of the same order of magnitude. In addition to solving the addressed problem, it proves the Airbus evaluation tool to be a robust approach to technology evaluation.

One general criticism on scenario analysis concerns this study as well: The input to this integration process and the large part of its execution is based on the assumptions and intuition of individual beings. Therefore the result produced cannot be accepted as axiomatic truths.

The result populations are the mere visualization and quantification of the consequences that arise from the conditions that are derived in the scenario process. Moreover the applied approach does not take all aspects of scenario analysis into account. It constitutes a straightforward evaluation process that does not simulate strategic reactions on the different developments that take place in each scenario.

Two aspects in the scope of this study are regarded to be interesting areas of further research. In order to use the scenario parameters' distributions a set of translation functions is necessary. They can be used to directly derive a set of distributed escalation factors that covers the full funnel elaborated with a scenario process.

In a second more technical study the structure of economic risk propagation in an aircraft program could be examined. Using the method elaborated in this study the model is to be examined where and how the uncertainties exert their influence. This knowledge in turn can support the decision-making process during the design phase with valuable information.

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