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Assessment of an energy-efficient aircraft concept from a techno-economic perspective

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HIGHLIGHTS

- Energy saving of a novel green aircraft concept is compared to conventional technology
- Direct operating cost saving versus conventional technology is estimated
- An investment cost analysis is used to identify the financial benefit of energy saving
- Maximum acquisition price for an attractive investment is estimated
- Scenarios such as emissions taxation improve economic viability

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ABSTRACT

An increase in environmental awareness in both the aviation industry and the wider global setting has led to large bodies of research dedicated to developing more sustainable technology with a lower environmental impact and lower energy usage. The goal of reducing environmental impact has necessitated research into revolutionary new technologies that have the potential to be significantly more energy efficient than their predecessors. However, for innovative technologies in any industry, there is a risk that adoption will be prohibitively expensive for commercial application. It is therefore important to model the economic factors of the new technology or policy at an early stage of development.

This research demonstrates the application of a Techno-economic Environmental Risk Assessment framework that may be used to identify the economic impact of an energy-efficient aircraft concept and the impact that environmental policy would have on the viability of the concept. The framework has been applied to a case study aircraft designed to achieve an energy saving of 60% in comparison to a baseline 2005 entry-into-service aircraft. The model compares the green aircraft concept to a baseline conventional aircraft using a sensitivity analysis of the aircraft direct operating cost to changes in acquisition and maintenance cost.

The research illustrates an economically viable region for the technology. Cost margins are identified where the increase in operating cost due to expensive novel technology is counterbalanced by the reduction in cost resulting from low energy consumption. Viability was found to be closely linked to fuel price, with a low fuel price limiting the viability of energy-efficient aviation technology. In contrast, a change in environmental taxation policy was found to be beneficial, with the introduction of carbon taxation incentivising the use of an environmentally optimised aircraft.

1. Introduction

The aviation industry can be considered a key contributor to today's global economy and has grown continuously since its inception. Modern aircraft – whilst superficially similar – are significantly more energy efficient and produce significantly less environmental pollutants than their predecessors. Despite accounting for only approximately 2% of total global Carbon Dioxide emissions [1], the impact of aviation will become increasingly noticeable as other industries such as power generation and road transport move towards low emission and green technologies. The aviation industry has therefore become increasingly aware of the environmental impact of its growth and now aims for a more sustainable future. Historically, the primary focus of the development of new technology has been on decreasing fuel consumption.

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Nomenclature

BLI	boundary layer ingestion
BWB	blended wing body
CO_2	carbon dioxide
DOC	direct operating cost
ETRW	energy to revenue work ratio
IRR	internal rate of return
LH_2	liquid hydrogen
NO_x	nitrous oxides
NPV	net present value
TERA	techno-economic and environmental risk assessment
WACC	weighted average cost of capital

Symbols

C_n	cash flow
i	inflation
r	discount factor
r_n	nominal rate of return
r_r	real rate of return

Nevertheless, with the current growth of the aviation industry, emissions and energy consumption will continue to increase unless action is taken, particularly in sectors with large air traffic growth such as China [2]. In order to drive the development of greener aviation, The civil aerospace industry has set for itself challenging goals for future aircraft in the mid to long term timeframe. The focus of these goals is to achieve dramatic reductions in the emission of Carbon Dioxide, Nitrous Oxides & noise and to reduce the industry's overall energy consumption. Current development suggests that these targets are unachievable with the typically evolutionary nature of new technology. Revolutionary new technologies and policy changes are therefore required to enable a more sustainable aviation industry. However, the introduction of a change in technologies and policies poses a high risk, particularly in an industry such as aviation where development and certification requires the investment of large sums of time and money.

Given the risk inherent in the development of new technology, it is then useful to forecast the economic impact of a new technology at the early stages of development. Most studies focused on the development of new technology generally assess concepts from a pure performance perspective. However, commercial decisions are made principally and primarily based on economic factors. Goel and Rich [3] highlighted that a significant operating cost difference is the main incentive for adoption of new technology. Historically, high fuel prices have encouraged operators to push for improvements in energy efficiency as the penalty of operating older, less efficient aircraft is high. As fuel costs often contribute in the region of 40% to the operating cost of an aircraft [4], the development of greener technology may run in line with cost reduction goals. As fuel is a significant portion of operating cost, Kristjanpoller and Concha identify that fluctuations in oil price correlate closely with an airline's profitability, where an increase in oil price is followed by an increase in stock price [5]. However, fuel is not the sole operating cost for an aircraft. It is therefore vital to establish the overall economic benefits and commercial viability of new technologies and policies, a type of study rather rarely seen.

Given all these factors, it is vital to have a framework for assessing the economic aspects of a design at the preliminary phase. This combines both technological aspects, in terms of the ability to meet performance targets such as fuel burn, emissions, or noise levels, and the economic viability, in terms of manufacturer and operator costs. This techno-economic perspective is then used to inform design decisions or determine viability. The techno-economic studies by Mavris et al. provide this perspective by presenting novel technology in terms of a metric with a corresponding impact on factors such as performance and cost [6]. Techno-economics can also be used to help determine aviation policies that will encourage investment in an aviation concept. In a study to predict the CO_2 taxation level to encourage investment in new aircraft, Dray et al. [7] highlight the interdependencies of different factors, as a change in policy or the introduction of new technology may have a wider ranging effect. The wider effect of technology infusion was also assessed in a study by Tam et al. [8]. The study highlighted that policy decisions will influence profitability of a novel technology and that there is a wider context that may need to be considered in the course of developing a revolutionary aircraft.

Factors such as maintenance, crew salary and insurance are major contributing factors to an aircraft's operating cost. Edwards et al. present a combined optimisation perspective for reducing the CO_2 emissions of an in-service aircraft using the aircraft Cost Index [9], the ratio between the unit cost of time and fuel. However, they identify that time costs have a more significant impact on cost than fuel-related costs, even once emissions taxation is introduced. A similar conclusion is drawn by Nalianda *et al.* when assessing the economic viability of a novel propulsion system concept [10]. Given the predominance of time and ownership-related costs, a reduction in fuel consumption provided by a change in operation or new technology can be quickly outweighed by rising costs elsewhere. It therefore becomes difficult for an operator to justify investment in the novel energy efficient technology. Newnes identifies that the general expectation is that 70–80% of program costs are committed at the early concept phase [11]. This highlights the importance of identifying the costs and benefits of novel technology at an early stage of development. Without including cost, a highly efficient aircraft may be prohibitively expensive to purchase, discouraging adoption regardless of performance improvements.

Research on revolutionary aircraft concepts predominantly focuses on performance simulation and defining propulsion system or aircraft configurations. As a result, there is limited research that attempts to identify the financial benefit of the energy efficient concepts currently under investigation. It was therefore necessary to develop a way to present performance benefits in a form suitable for a financier's perspective: translation of improved energy efficiency to higher operating cost benefits and a greater return on investment. The goal of the method in the present research is to quantify the financial value of a revolutionary environmentally optimised energy efficient technology. The focus herein is on a case-study of the NASA N3-X conceptual aircraft, developed by Felder et al. [12,13]. Establishing the economic viability of a concept is vital to ensure an environmentally and economically sustainable industry. Two key questions must therefore be answered for the N3-X: What is the financial value of efficiency improvements offered by the novel technologies of the aircraft? Secondly, in what situations or scenarios would the aircraft be financially viable?.

This research will therefore address the techno-economic and environmental risk assessment aspects of a novel aircraft such as the N3-X. The present study aims to demonstrate a method that can present technology benefits in a form suitable for financiers and decision makers of the commercial aviation industry. As there is significant uncertainty in predicting the cost of a novel aircraft, a reverse approach to the economic viability question has been used [10]. Rather than predicting a cost for the aircraft and then assessing financial benefits, maximum cost boundaries can be identified, beyond which there is no longer any financial benefit for an operator to adopt the technology. The core goal of the research is to provide a method that enables the identification of economically viable cost for a new aviation technology and the influence that environmental policy decisions can have over the adoption of green aviation technology. The method may therefore be used to support the selection process between a range of green aviation