SUSTAINABLE AVIATION - THE WAY AHEAD

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Abstract

Sustainable development is now a well-recognised term, and one that impacts on all sectors of society and industry. For aviation, the difficulty arises in determining exactly what constitutes sustainable aviation, and how it can be achieved.

Sustainable development encompasses three issues; economic growth, ecological responsibility and social progress. Of these, economic growth is well understood, and the need to comply with environmental regulations is easily recognised. Ecological responsibility however, does not end with compliance, and a fuller understanding of this issue and its relevance to aviation is needed. Additionally, social progress is even less well understood and its connection to the aviation industry is still unclear.

A number of tools have been developed to promote the evolution of an environmentally responsible industry, but the most common of these is life cycle analysis (LCA). LCA is most normally used to provide an ' environmental picture' of the impact on the surrounding eco-systems resulting from a product or process. Eco-design (sometimes known as design for environment) is the process or system of design which minimises the overall impact on the environment. LCA, used in partnership with eco-design creates a solid basis for determining the least damaging environmental options for the design, manufacture, use and final disposal of aircraft.

Aviation is a unique industry in that it poses an unusual combination of constraints on design and manufacturing options. The most critical of these is safety - if an engine is not safe, it will not fly. Others include for example, the time lapse between a new design concept and finished saleable product, the length of product life, and where and how the product is used. All these issues combine to form an interesting challenge for the aviation industry.

This paper focuses on the application of life cycle analysis and eco-design to aircraft engines, and aims to show how these concepts can be utilised to reduce environmental impact. In addition, it suggests a program that could be implemented to develop a sustainable aviation industry.

1 Introduction

Since the beginning of the jet age, the environmental impact of new aircraft has been substantially reduced; they are now quieter, cleaner and more efficient than ever before. However, long distance air travel is increasingly popular and global air traffic has grown by approximately 6% per year for the last 30 years.[1] This trend is set to continue, estimates for future air travel growth range between 5 and 8 percent. Air transport contributed US $1,140 billion to the world economy in 1994, and is rising steadily. Over 24 million jobs world-wide are related to air transport and more than one third (in value) of world's manufactured exports are transported by air[2].

There is growing concern over global warming, local noise, air pollution, and new aviation infrastructure development. This is creating a political and social climate, with an increasing desire to control the negative impacts of aviation.

2 Measuring the environmental impact

To develop a complete understanding of the environmental impact of aviation is a mammoth and complex task. It is further complicated by the uncertainty surrounding emissions at altitude, the lack of detailed knowledge of what happens to aircraft, and more especially aircraft engines at the end of their life.

2.1 Life Cycle Analysis (LCA)

LCA is a comprehensive tool, designed to analyse, quantify, understand and improve the environmental impact of products or processes. Based on a simple input/output system, it systematically evaluates the inputs and outputs, creating an 'environmental picture'. This picture is then used to determine the causes of the largest impacts, and subsequently where the greatest improvements can be made.

The major advantage of LCA is that it encompasses the entire life cycle of the product or process, from raw material extraction through to final product disposal.

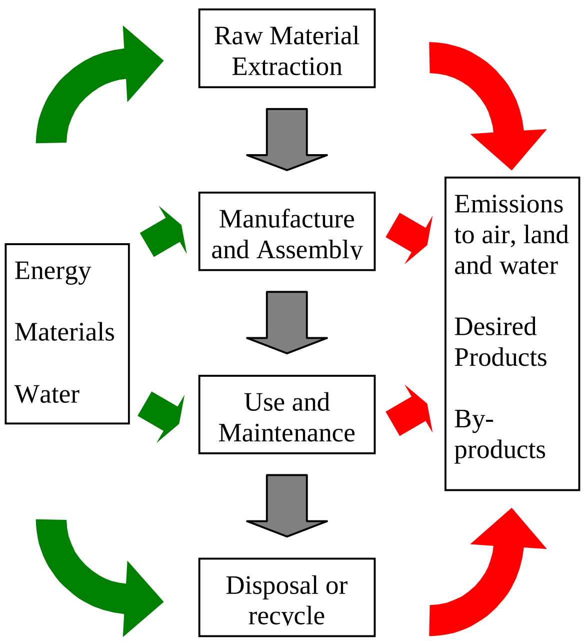

Figure 1: The Life Cycle System

This life cycle concept ensures that minimising the environmental impact of just one stage of the product life does not merely shift the burden to another stage.

An example to demonstrate the benefits of life cycle thinking can be seen in the development of turbine blades. The original turbine blades for engines were made using standard materials and processing routes, with relatively low associated environmental impacts. During engine use, these blades could not withstand particularly high temperatures, thus the efficiency of the engine was low. As a result, fuel consumption was high. In contrast, modern turbine blades are made from unique materials and require an extremely complex manufacturing route with considerably higher environmental impact than the earlier blades. They can withstand much higher temperature, and thus the efficiency of the engines has been increased. As a result, fuel burn decreased. If the environmental impact of the turbine blade had been determined purely by examining the manufacturing stage, the older blades would clearly be the best option. However, looking at the full life cycle, the reduction in fuel burn, enabled by the design of newer blades, generates a saving far in excess of the increased impact generated at the manufacturing stage.

The information generated by a full LCA study provides a number of opportunities.

2.1.1 Benchmarking and Reporting

Benchmarking of products is the first step in managing environmental impact. LCA provides comprehensive data covering the whole life cycle, and aids the creation of relevant and useful indicators. These indicators can then by used for reporting, either internally or externally, for example, through a company environmental report. Recent developments in some countries have indicated that environmental reporting will become essential for all companies, not just for those wishing to maintain high environmental credibility. The UK government has developed a number of 'sustainability' indicators, and are pushing for these to be used in measurement and reporting.

Benchmarking of products and processes is also of use for Environmental Management Systems such as ISO 14001, or EMAS.

Although ISO 14001 does not specifically require an LCA to be carried out, the principle of continuous improvement will eventually give rise to the need for a comprehensive evaluation of products and processes - essentially a life cycle inventory.

2.1.2 Development Opportunities

A comprehensive LCA clearly highlights development opportunities. These may be within the influence of the system, and can therefore be developed using existing resources. Alternatively, an LCA may indicate long-term opportunities, which need to be developed in collaboration with outside sources. A good example of this would be a link-up between aero-engine manufacturers and fuel producers, to develop a fuel with lower environmental impact during combustion.

2.1.3 'Cherry-Picking' Opportunities

LCA can highlight areas of the product life cycle, directly under the influence of the company conducting the LCA, which can be easily improved. This is commonly called cherry picking, and is a relatively easy way to reduce environmental impact. Examples of common cherry picking include implementing energy saving schemes, or recycling schemes. These opportunities focus on the general results of a life cycle, rather than specific areas of concern. The schemes can also involve minor changes to the product processes, but generally do not involve improvements that physically change the products.

3 Improving Environmental Impact

Measurement of the environmental impact of a product is both necessary and useful, but of more benefit is the ability to produce a product for which the environmental impact has already been considered and minimised at the design stage.

LCA is effective at determining the environmental impact of products that already exist, and for identifying the causes of the greatest environmental impact. However, attempting to apply this to products which do not yet exist is extremely difficult, quantities need to be estimated and not all environmental consequences can be foreseen. The concept of Design for Environment (DfE), is an attempt to apply the principles of LCA, at a design stage. It can be applied both to products which have a highly defined manufacturing processes and yet require environmental improvement, and perhaps more importantly, to those not yet in existence.

3.1 Design for Environment

DfE is defined as the 'systematic consideration of design performance with respect to environmental, health and safety objectives over the full product <u>*and*</u> process life cycle'. Nearly 80% of product characteristics are defined by the end of the design process. It is thus necessary that the environment needs to be considered alongside the more traditional trade-offs of performance and cost. Perhaps more importantly, it must be seen as being of equal standing.

DfE can be applied on different levels, from small changes, resulting from the cherry-picking activities of an LCA, through to the radical concept changes, such as the re-evaluation of the purpose of a product i.e. the provision of the same service but by a different method. The lower levels of DfE are generally applied to products or processes already in existence. 'Pure DfE', the re-evaluation of the service that a product provides, is generally applied to situations where there are no existing design or manufacturing constraints.

An example of re-evaluation of a product is Interface Carpets. They have ceased to 'sell' carpets, they are now moving towards leasing floor coverings, taking responsibility for ensuring that the floor coverings are replaced as necessary. By replacing only that carpet which needs replacing, and by developing to a new carpet material which produces 99.7% less waste, Interface have achieved a 97% reduction in the net flow of materials and embodied energy. As far as the customer is concerned, there are only positive benefits to this change of business practice.

DfE can be broadly split into three levels, each level requiring greater freedom from constraints.

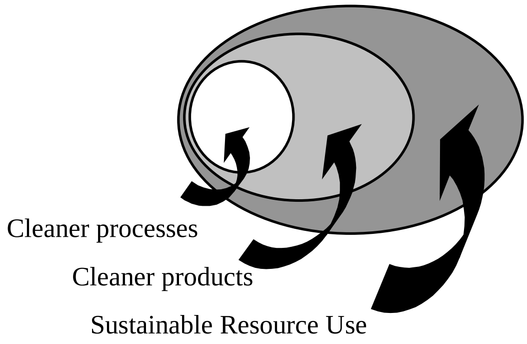

Figure 2: Design for Environment Concepts[3]

3.1.1 Cleaner Processes

This is the simplest level of design for environment, and often results from the LCA study. At this level, there is little freedom to redesign the product or process, and existing environmental effects, rather than the causes, are addressed. This might be more easily recognised as 'end-of-pipe' solutions. Examples include changing a material with a high hazardous or toxic rating to one with a lower impact, or moving from a single use cleaning system to a recycled system.

DfE at this level can be tied in with company wide targets, for example, a reduction in solvent use, or increase in materials recycled. Such targets and objectives should be set in a way that ensures that they are addressed by standard design procedures and objectives.

3.1.2 Cleaner Products

At this, the second level of DfE, the entire life cycle is considered, and there is more freedom to modify materials and processes. The emphasis is on removing the cause of the impact, rather than just alleviating its effects.

At this level it is harder to provide rules for the designers to follow. For example, material A may be classed as non-toxic, but requires a more energy intensive processing route than material B. Material B, in contrast, is considered to be more toxic, but requires less energy to process. Which material should be chosen? The solution will depend on the relative importance of the environmental impact categories, and company values. Most normally, a few key issues are highlighted by the company, from which guidelines are derived thus allowing these issues to be addressed.

To function fully at this level, DfE needs to be seamlessly incorporated into the standard design considerations that already exist. This entails understanding the issues of concern to the company, and developing a methodology to integrate the measurement of these issues into the existing trade-off systems.

3.1.3 Sustainable Resource Use

This is the highest level of DfE application, and is most normally applied to new design, where there are no constraints to design and manufacture, rather than to existing products. The underlying goals of DfE, that products should be non-toxic, recyclable or compostable, and any energy required should be from renewable sources, are applied.

To fully implement these principles, a new way of thinking is necessary: a shift from producing products to providing a service. This opens up the potential for aftermarket business, and provides producers with a route to reclaiming their products at end of life, to recapture the value held within the materials and/or the design.

4 Rolls-Royce and the environment

At Rolls-Royce, we have undertaken an LCA study of a state-of-the-art aero engine. This study has confirmed our understanding of the stages of an engine life which create the greatest environmental impact. Further analysis of this data will identify areas of the life cycle, directly under the control of Rolls-Royce, where environmental impact can be significantly improved.

Alongside that initiative, we have investigated and implemented DfE principles to out product range. We have categorised DfE into three groups, which broadly agree with those defined above; component modification, system modification and new product concept.

4.1 Cleaner Processes / Component Modification

At Rolls-Royce, we have instigated a 'Materials Selector', a process by which the health and safety implications of a material are catalogued, and scored. Designers are required to consult the selector, and to pick the material with the best rating available whilst still meeting the design requirements. An environmental aspect is currently under development and will be added to the selector in the near future.

Within the next year we will incorporate these issues into standard design procedures to ensure compliance.

In addition, we also have company targets to reduce waste, increase recycling and reduce energy consumption.

4.2 Cleaner Products / System Modification

Many Rolls-Royce products are designed for future development and modification. The product can be separated into 'modules', which have the potential for improvement, rather than individual components. This ensures our designs have sufficient flexibility to incorporate module upgrades as they are developed.

Module improvements have up to now tended to focus on improving the environmental performance of the engine during use. The best example of this is what is called the 'Phase 5 combustor'. This new combustor, awarded the 1998 Queens Award for Environmental achievement, has resulted in reductions of NOx emissions of around 40% for the RB211 aero-engine. The same combustor, fitted to the state-of-the-art Trent 800 engine, has a NOx production rate of only 58ppm of total air flow at take-off, about 70% of the current landing and take-off cycle regulation standard.

4.3 Sustainable Resource Use / New Engine Concept

This is a much harder concept. Aircraft engines have significant design constraints, and must be considered as a 'component' of an aircraft. New engine designs must therefore be optimised alongside the airframe.

There is the potential to move existing engine design towards sustainable development. Such ideas include modifying the engine to burn bio-derived fuel, and the electric engine. In this development, three locally optimised systems incorporating pneumatics, hydraulics and electrics, are replaced by one globally optimised system of electrics. The result should be a lighter, more efficient engine.

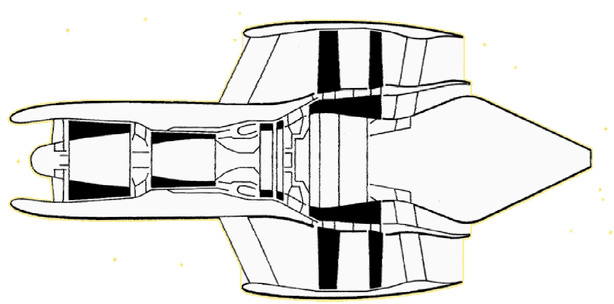

Figure 3: Aft-fan engine design

Changes to airframes can drive changes to engine design, for example, a blended wing body airframe could employ a different nacelle/engine configuration as the aircraft body would shield noise from the ground. Modified airframe shapes, combined with the current underlying principles of jet engines would allow for designs incorporating aft fans and ducted fan engines.

A long-term concept is solar aircraft or hybrid solar/kerosene aircraft, where the main source of power is harnessed through solar panels on the airframe wings and possibly body. An example of this has been built, but considerable development is needed before it could be considered as a viable alternative to kerosene powered air transport.[4]

Perhaps the most radical concept in air travel is the suggestion of 'Up and Over' flights, whereby the 'plane' leaves the atmosphere and re-enters when the earth has rotated below to the correct location. One newspaper article has suggested that by this method the journey time between London and Sydney could be reduced to 75minutes[5].

The sustainable impacts of the ventures given above have yet to be fully evaluated, thus their development cannot be guaranteed. Only those developments that meet the requirements of sustainability should be taken further.

5 Sustainable Aviation

Rolls-Royce, like many manufacturing companies, is from moving from a position of concentrating on the environmental aspects of its business towards the more inclusive concept of sustainable development. This means developing a comprehensive picture of the effect our products have on society, the environment and the economy, alongside developing our design philosophy to create a product range that fits with the concepts of sustainable development.

Perhaps one method of viewing the concept of sustainable development, would be to consider not 'What is sustainable aviation?', but rather 'What role does aviation have in a sustainable society?'

This question cannot be answered easily: indeed, the industry is hampered by the lack of a clear and accepted definition of what this means. The first step in achieving an aviation industry that has a valued part in a sustainable society is to hold a meaningful and constructive dialogue with all stakeholders. This needs to include NGO's and those who are involved in the 'creation' and 'definition' of a sustainable society. Once this has been accepted, then the industry as a whole can move towards achieving this goal. This is particularly important for aviation, a highly integrated industry that is constrained almost exclusively from the top down. The picture of 'sustainable aviation' is further complicated by the length of service of its products: it is anticipated that the world 30-40 years hence could be very different from that of today, with very different priorities. One aspect that will not change however, is that of safety, which will always remain the number one priority.

Notwithstanding the bigger picture, the application of LCA and DfE allow the minimisation of environmental effects to continue. These techniques show the areas giving the greatest cause for concern for the aviation industry as it stands today. In addition, and perhaps more importantly, these techniques will indicate where future development needs to be concentrated.

6 Conclusions

Given the fact that most of the environmental impact of an engine derives from its use[6], the environmental issues of aircraft to date has centred on three main topics; noise, fuel burn and NOx formation. These three impacts are the basis for the environmental consideration of all engines. However, engine design is now heading towards a trade-off situation, where any dramatic improvements in one will lead to detrimental effects in the others.

A second area for concern and conflict results from local effects versus global effects. Climate change is very much a global effect and one that is causing significant concern at the present time. But global issues cannot and should not be the entire story: local issues can also play a large part. Around airports, for example, NOx is considered to be a significant impact. Many manufacturing processes produce by-products and toxic wastes, odours etc. which reduce the quality of life for those living nearby. This is extremely relevant to Rolls-Royce, who is in the business of producing power, be it on land, sea or in the air.

As the understanding of sustainable development, and the positive impacts of aviation, such as employment and a provider of a transport service, are better understood, the integrated philosophy of people, planet and profit becomes more clearly defined. The most important lesson to be learned from the recent economic past is that concentrating on one aspect, to the exclusion of the others leads us to a system that is not sustainable, or indeed desirable.

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