LIFE CYCLE ASSESSMENT OF STRUCTURAL AIRCRAFT MATERIALS

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The main objective of this article is to describe the life cycle of the aircraft components, depending on the materials used. Describe the phases of the life cycle assessment method and the importance of LCA.

K e y w o r d s: life cycle, composite, glare, environment, aviation, aircraft

1 INTRODUCTION

Life cycle thinking reflects the consideration of cradle to grave implications of any actions, and guides the overall approach to dealing with environmental and sustainability issues.

The concept has been considered in decision making in the public and industrial sectors in the USA and Europe. It has been embedded in European Commission Directives on industrial environmental management such as IPPC (Integrated Pollution Prevention Control), and has strongly influenced regulations aimed at the minimisation of consumer product environmental impacts, especially in the electronics sector with the WEEE/ROHS (Directive 2002/96/EC; Directive 2002/95/EC). Voluntary schemes such as the EU Eco-labelling scheme (Regulation 1980/2000/ec) also integrate life cycle considerations in the definition of criteria used in the eco-label award procedure.

Within the scope of sustainable production and consumption, IPP (Integrated Product Policy) advocates “life-cycle thinking”, which mean, that when pollution reduction measures are identified, consideration is given to the entire life cycle of a product, from design to end of life. In this way, appropriate and efficient action can be taken in advance of the problem stages in the life-cycle.

The application of the concept to a product, such as aerospace products, should provide in-depth analysis of the precursors to the product, the production processes and the application and retirement aspects. This comprehensive review of the complete value chain provides a tool for making decisions based on a life cycle view that embeds the driving forces for change. The design phase of most products is decisive for their environmental lifecycle performance, and the majority of a product’s environmental impacts will be determined during this phase.

The main tool supporting the life-cycle thinking concept is Life Cycle Assessment, whose principal aim is to specify the environmental consequences of products and services from cradle to grave. The principles, procedures and methods of LCA are based on the terminology and structure of the ISO Environmental Management Systems, tools and standards on LCA (ISO 14040) and other guidelines published by SETAC or ISO.

2 LIFE CYCLE IN THE AIRCRAFT INDUSTRY

Aviation emissions have come under scrutiny in recent years due to the rapid growth in air transport, which has been increasing at an annual rate of about 5% throughout the last two decades.

The effect of aviation emissions, which consist mainly of carbon dioxide (71%), water vapour (28%) and nitrogen oxides, on the atmosphere is the focus of intense research efforts. It is widely recognised that emission at high altitudes are more environmentally damaging than those at ground level, due to increased interaction with gases in the atmosphere. A parameter used to quantify the effect of aviation emission is the Radiative Forcing (RF) Index, which is a measure of the impact of an agent on the energy balance of the earth’s atmosphere. A positive RF indicates a global warming effect. Aircraft operation involves the emission of (a) directly radiatively active substances, (b) chemical species that produce or destroy radiatively active substances, and (c) substances that trigger the generation of aerosol particles or lead to changes innatural clouds .

Thus, it is important to analyse the life cycle of aircraft systems and structures in as much detail as possible, in order to understand the long-term impact on the human environment and the earth’s ecosystem.

Typically, a Life Cycle Assessment study should follow the requirements of ISO14040 series and include the following four phases:

- Goal and Scope Definition
- Inventory Analysis
- Impact Assessment
- Interpretation

Depending on the complexity of the object of the study, a full Life Cycle Assessment can be a very complex, long and difficult exercise. Streamlining LCA is a practice which has been widely adopted to make this type of exercise more manageable.

Streamlining LCA can be achieved in a number of ways, including:

- Limiting the scope: for example, eliminating life cycle phases deemed not significant, or processes with negligible effect on the environment
- Use of qualitative information
- Removal of upstream and/or downstream components
- Use of specific impact category

In this methodology, the simplification lies in the consideration of a limited scope and the fact that it is based on a combination of qualitative and quantitative approaches to evaluate impacts. Both or only one of the two approaches can be used to determine significant environmental impacts.

LCA composite in the Aviation

In the civil aviation, implementation of composites and hybrid materials is driven largely by the high cost of aviation fuel and the introduction of legislation setting limits on the emission of greenhouse gases during operation.

According to European directive EC 101/2008, from 2012 the aviation sector will be included into the EU ETS emission trading scheme and aircraft operators with flights landing or departing from an EU airport will be required to buy allowances equal to the CO2 emissions for each flight.

It is widely recognised that the fuel consumption of an aircraft is strongly affected by its total weight and that the fuel used during aircraft operation can be significantly reduced by increasing the proportion of lightweight composites in its structure. On the other hand, disposal of composite parts at their end-of-life is often more problematic than in the case of metals. Composites are not only more costly and energy intensive to produce than metals, but also notoriously difficult to recycle. Whilst the End of life Vehicles (ELVs) Directive 2000/53/EC places a significant burden on the automotive vehicle manufacturers, with recycling and recovery targets of respectively 85% and 95% by 2015, no such legislation applies to the civil aerospace industry. However, there is growing concern in the industry that a similar directive may be introduced. It is therefore clear that the overall environmental benefits of replacing metals with composites are not directly evident, and a full cradle-to-grave life cycle assessment needs to be performed in order to rank different aerospace materials in terms of their environmental impact, as stated by the 'product stewardship principles for the aerospace sector' proposed by the Advisory Council for Aeronautics Research in Europe. This paper aims to establish whether the increase in efficiency gained by using lightweight composite materials is significant enough to justify the additional emissions produced during the manufacturing and disposal stages compared with those of aluminium, and further to investigate after how many hours of flying time do composites and GLARE become the more environmentally friendly choice. In the aerospace industry, LCAs are being performed to assess various ways of reducing the environmental impact such as new materials, alternative fuels, improved aerodynamic design etc. In particular, the present debate is on the use of composite materials for primary airframe structures instead of the more conventional heavier aluminium.
An initial study from Beck et al. Provided insights into the different levels of hazardous emissions arising from the manufacturing of Al, CFRP and GLARE hybrid laminates in aerospace industry.

However, due to confidentiality reasons and to he difficulty in obtaining data from industry, such study was limited to examining flat plates of equal size made of different materials rather than actual aircraft components. Moreover, no other similar investigations are currently available in the literature. The present work extend Beck's study by first examining flat plates of Al, GLARE and CFRP taking into account the typical weight savings of these materials, and subsequently presents a more detailed analysis on an actual component , whereby a structural steel tube was replaced with a tubular CFRP component. Although in the case of metals the specific energy [MJ/kg] needed to manufacture a component is fairly independent of its shape, size and shaping technology (typically, for aluminium the energy required for shaping the component is very low compared to the energy used to produce the material itself), in the case of composites the curing and shaping processes are simultaneous, and the specific energy requirement for the component is substantially influenced by processing conditions, such as curing temperature and time, type of autoclave used, degree of packing of the autoclave and so on. Those processing conditions can in turn be related to the geometry and dimension of the part, but also to many other factors, which are more specificto the manufacturing site.

Therefore, in order to compare the LCA performance of composites and metals in aerospace, it was necessary to examine real size components.

Future aircraft Composite built, A350

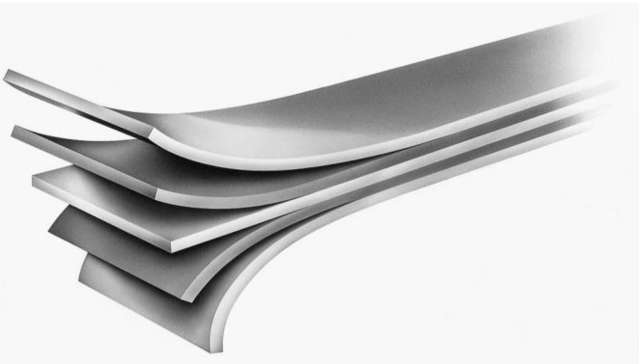
Glare

GLARE (GLAss-REinforced" Fibre Metal Laminate) is a laminated material consisting of thin (0.13 mm) layers of aluminium sheet (typically more than 70% in volume) and unidirectional glass fibre layers embedded in an adhesive system. The layers are laid up and subsequently autoclaved.

Due to its relatively limited use in the industry, interest in recycling of the Al layers in the hybrid system has been limited. Moreover, thermal recycling of GLARE might not be environmentally sound, being a very energy intensive process.

The Ecoinvent database contains data on the emissions related to the production of GLARE sheets. It was assumed that no substantial emission would arise from manufacturing of the flat panel of the required dimension starting from these sheets.

The disposal scenario for both CFRP and GLARE is landfill, as there is no commercial recycling route available at this stage.



3 CONCLUSSION

A life cycle assessment (LCA) of CFRP, GLARE and Aluminium 2024 plates used as aircraft panels was performed to determine potential emissions savings of lightweight composites over the life of the component. It was shown that, despite being more energy intensive to manufacture and more difficult to dispose of, CFRP and GLARE can lead to substantial decrease in the overall environmental impact when used in aerospace due to the high fuel consumption during air transport.

The break-even distances above which CFRP and GLARE start showing a net reduction of environmental damage compared to Aluminium 2024 were respectively 70 000 and 240 000 km. Subsequently, a case study was presented on LCA of a CFRP component, which replaced a steel tube, and analysed in several different applications. Real manufacturing data were used and showed in this case a more dramatic reduction in the overall environmental impact by using the composite component.

In this case, the break even for replacing a steel component with CFRP was achieved after 3 600 km, corresponding to approximately 5 h of air transport. Lightweight composite structures and hybrid composites produce dramatic positive effect on the total emissions savings when used in the aviation transport. Fossil fuel consumption and the subsequent CO2 emissions are most significantly reduced. Other aspects such as carcinogens and ozone layer depletion require more hours in service to show benefits from the implementation of lightweight structures. Other transport scenarios have shown also to benefit from the implementation of lightweight structures, however they require more hours in operation to realise such environmental benefits, due to their already lower effective emissions compared to the air transport.

The areas to further investigate would be the environmental effect of different disposal scenarios of composites in the environment, and their optimised, automatic manufacturing methods.

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