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ENVIRONMENTAL IMPACT ASSESSMENT OF THE MANUFACTURING OF A COMMERCIAL AIRCRAFT

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ABSTRACT

This paper documents the methodology and presents the results of a comprehensive LCA study of an Airbus A320 commercial airliner to determine the relative environmental impact of its manufacturing phase. The study was conducted in accordance with ISO 14040/44 using SimaPro LCA software, the EcoInvent inventory database and Eco-Indicator 99 weighting method, which allows the analysis to be outputted in a single score representing a number of damage models including damage to human health, ecosystem quality or resource depletion. Results indicate CFRP wings to have the most significant contribution to the overall environmental impact as a proportion to mass.

Keywords: LCA, Aviation, Airliners.

1 INTRODUCTION

The environmental impact of aviation industry is becoming issue of increased significance, with continued social and regulatory pressure placed on aircraft operators and manufacturers to improve their life cycle emissions. Historically, much focus has been placed on the operation phase of the aircraft and the emissions that result. This is understandable due to the length of service and fuel consumed, however the other stages of an aircraft service life are seldom discussed.

Life Cycle Assessment (LCA) is a powerful technique that can be used to assess the environmental impact of products, processes or services throughout their lifecycle from 'cradle through to the grave'. In this study LCA has been utilised to study the environmental impact of the manufacturing phase of a passenger aircraft, in order to derive useful conclusions on the major contributors among materials and assemblies, allowing recommendation for further reduction on the environmental footprint. Among the several subassemblies a number of different materials are used, each subassembly will be examined to establish the areas and materials which have the highest environmental impact.

2 LIFE CYCLE ASSESSMENT

LCA provides a useful methodology that can be followed to assess the environmental impact of a process, product or service from design through to disposal using a holistic approach. The LCA process according to International Organisation for Standardisation (ISO) 14040/14044 (BS, 2006a) and (BS, 2006b) consists of four interdependent phases; goal and scope definition, inventory analysis,

impact assessment and finally interpretation of results. Main assumptions, limitations, and system boundaries should be very carefully set in the initial stages of the study, optimizing resources utilization keeping in mind that due to time and data constraints, it is unfeasible to include every process. The plan for conducting the inventory analysis (LCI) is defined in the goal and scope section and consists of collecting all the data required to complete the study. This can include inputs of energy, materials or raw materials and is typically constructed using a flow model diagram. The purpose of the Life cycle Impact Assessment (LCIA) phase is to evaluate the significance of potential environmental impacts based on the results from the life cycle inventory. Impact categories reflect a particular set of environmental issues such as acidification and climate change. For this particular study, the Eco-Indicator 99 characterization model will be used. Although usually LCA is used for assessing the environmental impact of the whole life cycle, it has been also successfully used for assessing the environmental impact of the manufacturing process only as well (Drakopoulos et al., 2009) and (Salonitis, 2012).

3 LCA IN COMMERCIAL JET AIRLINERS

3.1 Goal of the study

This study aims to perform an environmental impact assessment of the manufacturing phase of commercial jets and hence the popular Airbus A320 aircraft, single aisle narrow body, typically operated on short to medium haul routes, has been selected as a case study. The analysis conducted aims to highlight particular components, materials or processes that significantly affect the overall environmental impact of the aircraft. The increased use of advanced materials such as carbon fibre reinforced plastic (CFRP) have assisted in reducing weight and improving fuel consumption, however the emissions created during production and disposal need further examination to determine if the move from more conventional materials represents a positive environmental output.

SimaPro v7.1.8 software (PRe Consultants, 2008) was used to conduct the analysis, together with the EcoInvent v.2 database (EcoInvent, 2007).

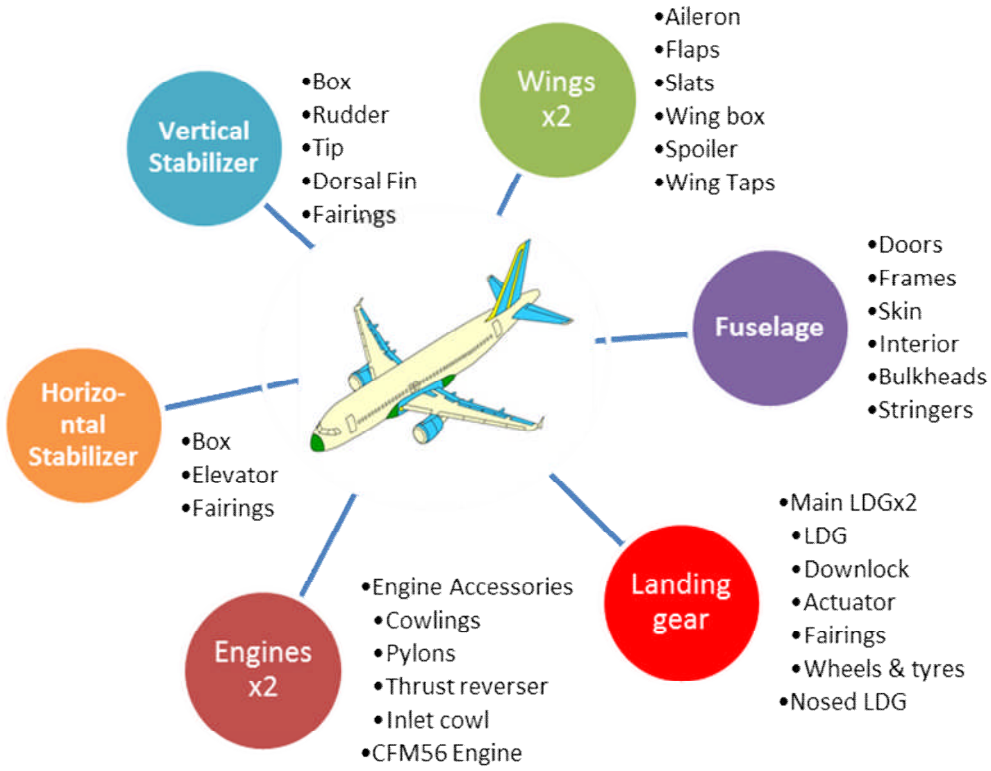


Figure 1: Subassemblies considered for the purposes of the present study

3.2 System Boundaries and Limitations

This study considers the complete life of an aircraft over a 20-year service life. The LCA was modelled in second order, ignoring capital goods involved during production. An average large commercial aircraft will consist of millions of parts and components (Scott, 2009), which would be unfeasible to model due to time and data constraints. Therefore the A320 has been separated into major structural components which can be divided into separate sub-assemblies. For the purpose of this study, 6 assemblies and 75 sub-assemblies have been considered (figure 1). The major structural components of the A320 are manufactured in several plants located European wide and then transported to the final assembly line in Toulouse, France. Transportation, excluding the engines, has been considered in the overall LCA, with average distances calculated from each manufacturing base to Toulouse. Disposal was also included for the aircraft involving recycling, incineration and landfill, data of which is discussed in the following sections.

Limitations of the study constitute the fact that aircraft systems and internal components have not been considered as they are often manufactured by third parties thus limiting the availability of accurate data. Manufacturing processes involved in the production of the A320 may also vary from the processes established in the Ecoinvent database. However methods continually evolve, with processes today varying from those during the infancy of the A320.

3.3 Life Cycle Inventory Analysis

The sub-assemblies of the A320 consist of a number of different materials and corresponding masses. With the scarcity of data containing precise mass and material compositions, a number of educated assumptions had to be made. The Operational Empty Weight (OEW) of the A320 is 41,244kg (Airbus, 2005), which includes the weight of the structure, power plant, furnishing, systems and all other operators' items such as life vests and engine oil. All systems aboard the A320 have been neglected from the study and have been assumed to account for 10% of the overall OEW. Each CFM56-5B engine has a basic dry weight of 2,380kg therefore the structural mass excluding engines is 34,420 kg. Table 1 summarises the assumptions relating to the mass of each assembly while Table 2 includes the proportional content of each major material in the A320 structure.

Table 1: Assembly masses used in study

A320 Assembly	**Total Assembly Mass (kg)**
Wings (x2)	13713
Fuselage	11755
CFM56-5B (x2)	7052
Main Landing Gear	3918
Horizontal Stabiliser	1175
Vertical Stabiliser	1175
Nose Landing Gear	392
Total	**39,181**

Table 2: Material composition data for the A320, excluding engines

Structural Material	**Percentage Composition**	**Approximate Mass (kg)**
Aluminium	68%	23,405
Composites	15%	5163
Steel	9%	3098
Titanium	6%	2065
Miscellaneous	2%	689
Total		**34,420**

(Rendigs and Knuwer, 2010)

Composite materials are expected to be the most important for this analysis due to the fact that they are more energy intensive to manufacture and with challenges relating to disposal (Suzuki, 2005), therefore their LCA impact during production is expected to be significant. The major composite constituent is CFRP, of which the content in each assembly has been modelled based on data available (Airbus, 2005), and accounts for 99% (1163 kg) of the horizontal stabilizer, 96% (1128 kg) of the vertical one, 9% of the engines (635kg), 8% (1097kg) of the wings and 7% (82 kg) of the fuselage (Figure 2).

Material profiles for CFRP are not currently available in any LCI databases. Therefore a custom entry was modelled, data for which were obtained from (Duflou, 2009) and (Suzuki, 2005).

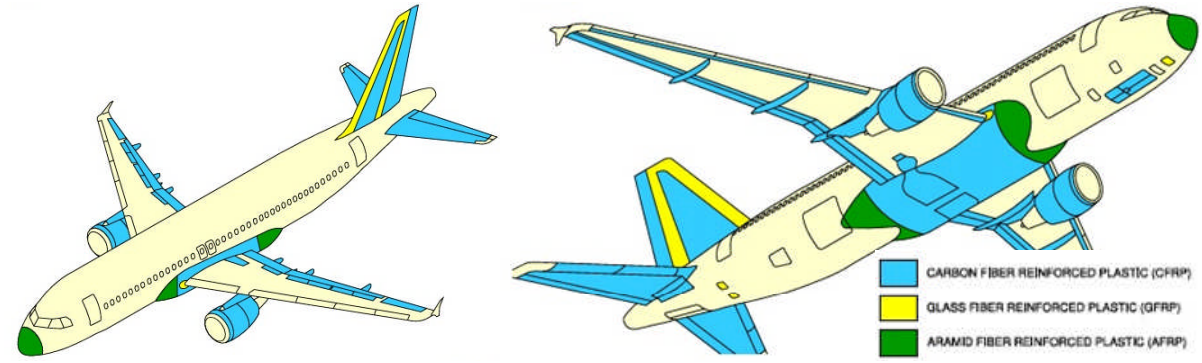


Figure 2: Location of composite materials on External Surfaces of A320 (Airbus, 2005)

As previously mentioned the assemblies of the A320 are manufactured at separate locations and transported to the Final Assembly Line (FAL) in Toulouse. Manufacturing locations are split across several European countries, with differing methods of transport used. The transportation of each sub-assembly has been considered from production to final assembly. The total estimated transportation used to relocate all assemblies and sub-assemblies to the FAL has been calculated to $1.67x10^4$ tn.km via airfreight and $1.37x10^4$ tn.km via road transport.

4 RESULTS AND DISCUSSION

Manufacturing has been shown to represent a small impact in the overall lifecycle (Howe et al., 2013), however manufacturing phase is significant and will be examined in more detail. The modelling of the manufacturing phase has been conducted using the Eco-Indicator 99 (H) method, which aggregates each process impact into a single score.

Carbon dioxide (CO_2) emissions is of particular interest to manufacturers operating within the European Union, due to regulatory obligations under the EU emissions trading system (ETS). The ETS scheme provides annual 'carbon credits' to all emitting companies, with those exceeding their allowance having to purchase additional credits. The overall impact of each assembly over the manufacturing phase is displayed in Figure 3, with the CO_2 emission proportions also displayed. It can be observed that the wing assembly and engines have the highest environmental impacts and together represent nearly two thirds of the total emission score. The impact compares similarly to the mass of the wing (35% of total mass) with a 32% impact. However, the fuselage although similar in mass to the wing is significantly lower with a 19.3% total impact contribution. The horizontal stabilizer assembly also shows a similar trend to that of the wing.

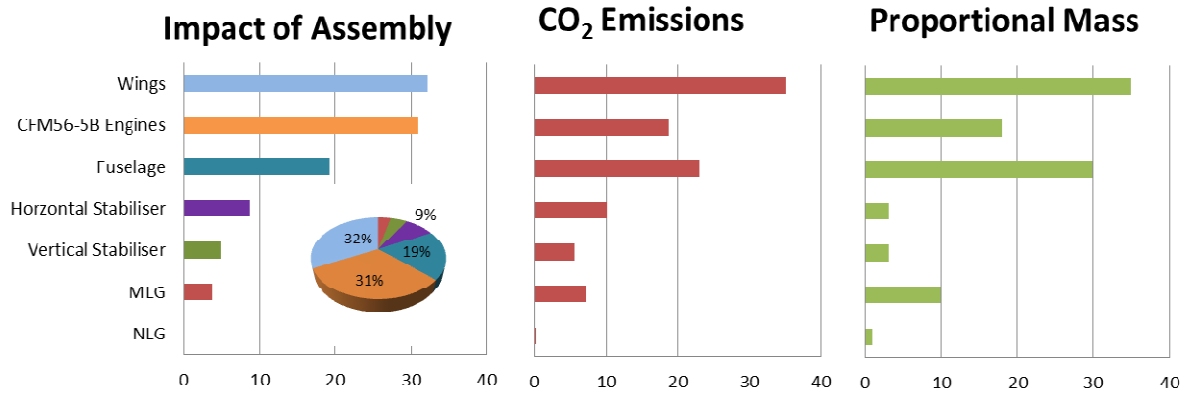


Figure 3: CO_2 Emitted (estimated using Eco-indicator 99 (H), Category Climate Change), Total Impact (%) and Proportional Mass (in kg) per Assembly

The overriding factor for this increase in environmental impact is the choice of material. The use of CFRP represents almost half of the total process contribution (45.4%) compared to only 18.4% for aluminium alloy, despite aluminium representing nearly 70% of the total material content. Assemblies such as the fuselage which are predominately aluminium have a relatively low impact to mass proportion. However assemblies using higher levels of composite material such as the horizontal stabilizer show the opposite trend with the total impact significantly higher than the proportional mass. The impact of the power plant assembly is one of the highest environmental contributors, despite being almost half the mass of the wing assembly. This can again be attributed to the high levels of CFRP, titanium and nickel when compared to aluminium.

To better quantify the overall impact of composite parts in the manufacturing lifecycle all CFRP was replaced with its aluminium. CFRP is predominately used in aircraft manufacturing due to significant weight reductions of more than 25% (Achternbosch et. Al., 2002). Therefore the alternative A320 model without CFRP has been modelled as 30% heavier to standardise the results. Figure 4, illustrates the impact of CFRP, when used instead of conventional materials, converting all the LCI data into a single score for each impact factor. The environmental significance of CFRP is highlighted by the vertical and horizontal stabilizer assemblies; both conventionally contain over 90% composite material; however the replacement to aluminium improves the environmental efficiency of both by over 80%.

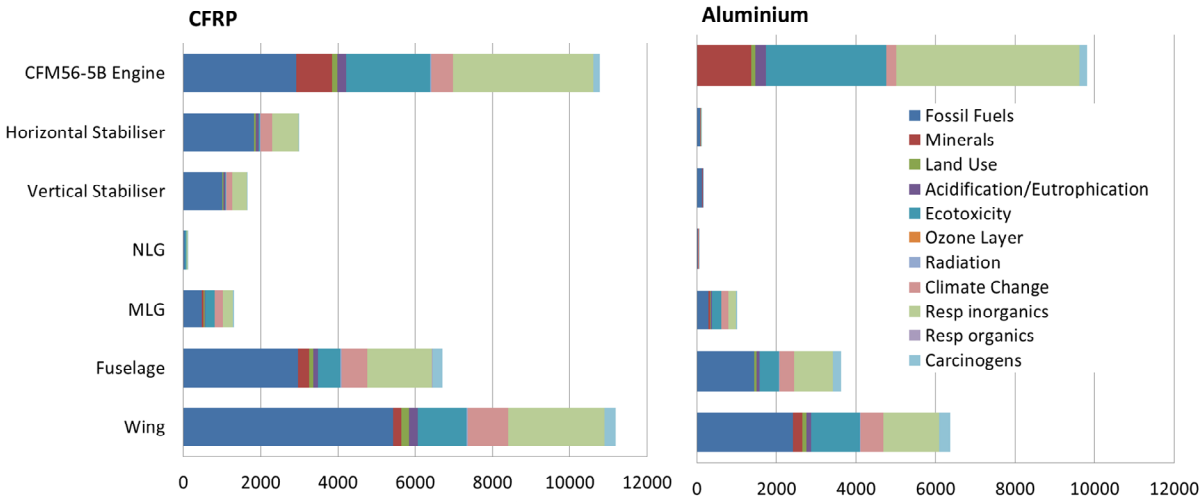


Figure 4: Comparison between an actual A320 and A320 without CFRP (Weighting, Single Score)

Classification, characterisation, normalisation and weighting are key steps of life cycle impact assessment aiming to represent in a single score a series of environmental impacts representing endpoints. In this study the Eco-Indicator 99 method has been employed. Figure 5 presents normalised results for the Eco-Indicator categories of the manufacturing phase of the A320 relating to the impact categories. Fossil fuel depletion is the most significant contributor to the overall impact followed by respiratory inorganics, with wings and engine component to contribute more to the impact of the assembly.

5 CONCLUSIONS

This paper examined the environmental performance of the manufacturing phase of a commercial passenger jet predominantly based on masses of materials and basic processes. Results show that fabrication of CFRP components have the greatest impact to the overall results illustrating that although this material allows mass optimization, the same trend is not followed for environmental impact. In the scarcity of relevant studies, this paper illustrates the need for more analytical analysis of the manufacturing process also taking into account further aspects of the prefabrication and assembly of components.

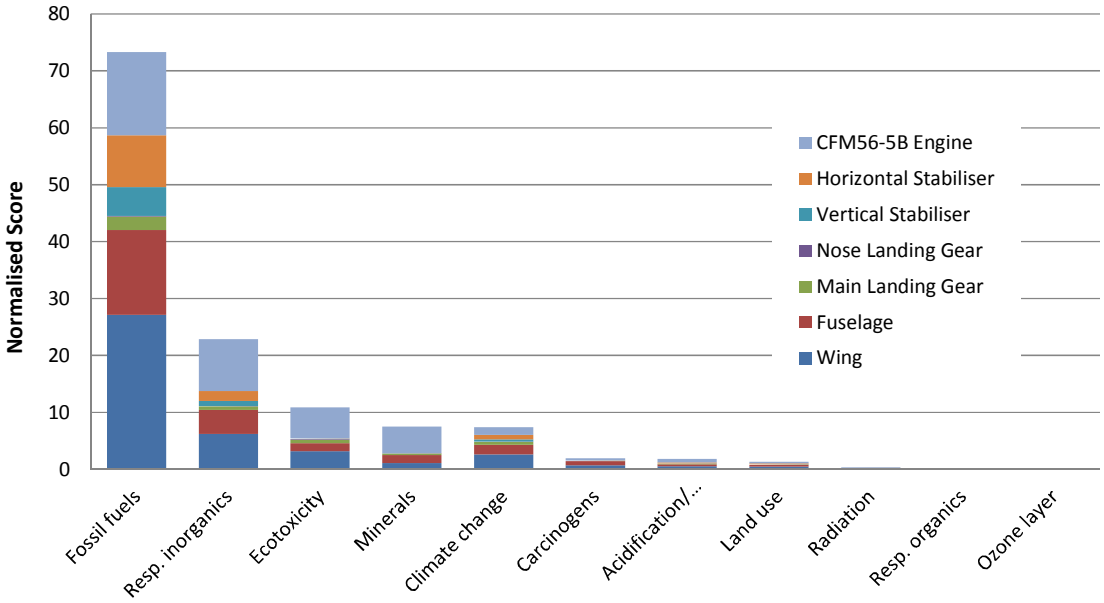


Figure 5: Normalised results for the Eco-Indicator categories of the manufacturing phase of the A320 relating to the impact categories

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