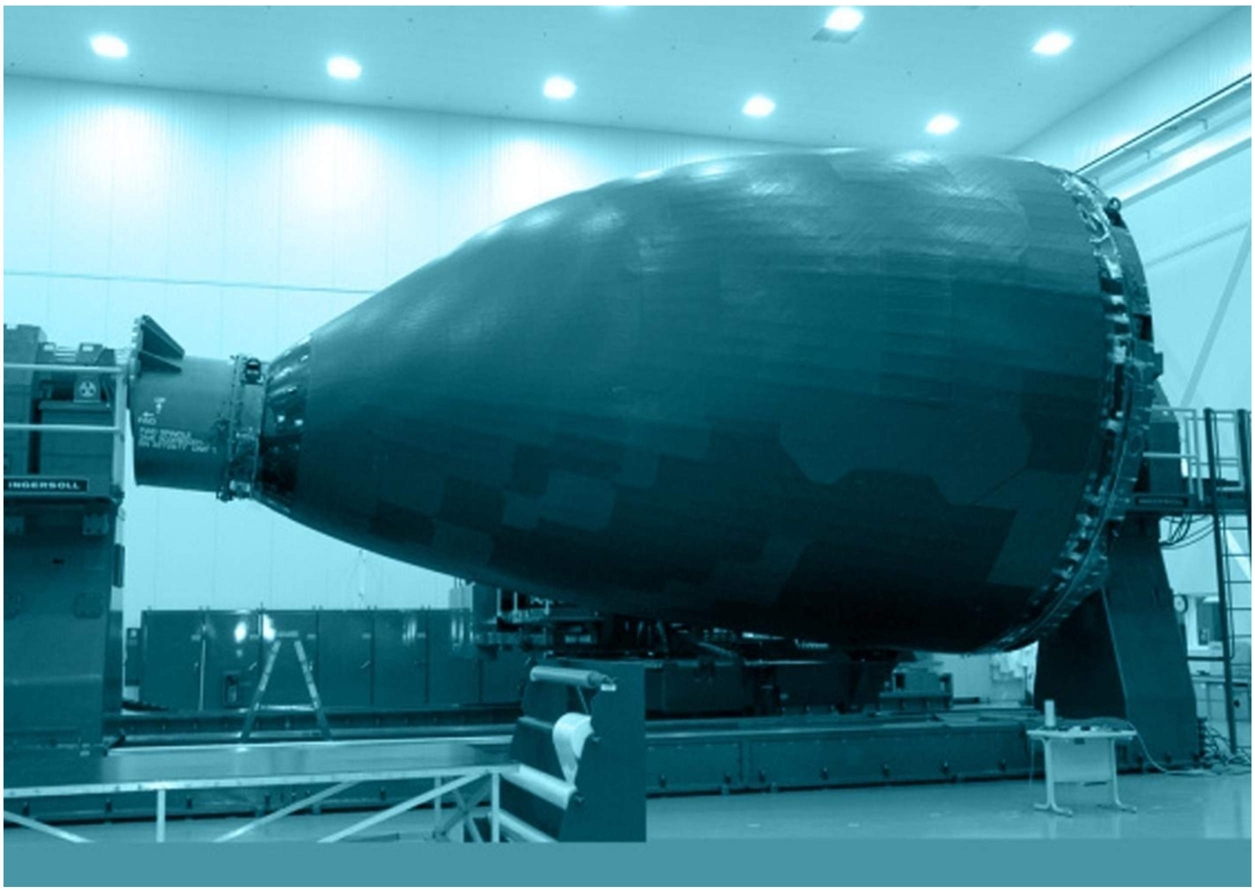
Aviation in a sustainable world Omega

Influence of Implementation of Composite Materials in Civil Aircraft Industry on Reduction of Environmental Pollution and Greenhouse Effect

Main Thematic Area: Technology



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About Omega

Omega is a one-stop-shop providing impartial world-class academic expertise on the environmental issues facing aviation to the wider aviation sector, Government, NGO's and society as a whole. Its aim is independent knowledge transfer work and innovative solutions for a greener aviation future. Omega's areas of expertise include climate change, local air quality, noise, aircraft systems, aircraft operations, alternative fuels, demand, and mitigation policies.

Omega draws together world-class research from nine major UK universities. It is led by Manchester Metropolitan University with Cambridge and Cranfield. Other partners are Leeds, Loughborough, Oxford, Reading, Sheffield and Southampton.

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Executive Summary

The aim of this study was to assess the scale of environmental gains through the use of composite materials in civil aircraft, by quantifying the impact of aircraft composite components on emissions reduction in service and in manufacturing stages. Aircraft fuel emissions are highly dependent on an aircraft's body weight and flight performance, among other parameters. Recently, it has been a trend to introduce advanced composite materials to replace aluminium alloy components and thus contribute to increased strength and reduction of overall weight.

Motivation for the project

The level of fuel use by aircraft and the resultant emissions are highly dependent on the total weight of the aircraft. Over the last 40 years there has been a trend to increase the proportion of advanced composite materials in aircraft construction as shown in Figure 1. These lightweight composites such as carbon fibre reinforced epoxy resin and laminates such as GLARE can replace heavier traditional aluminium alloy components. Not only does the structural integrity of the aircraft remain sound but the overall weight of the aircraft is reduced.

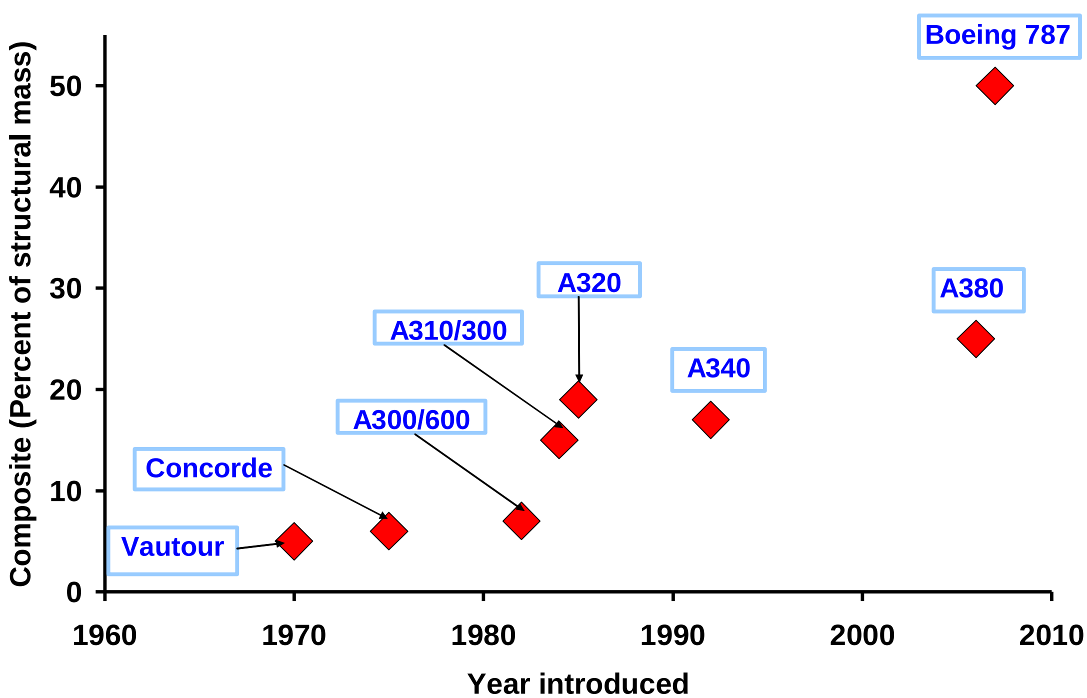


Figure 1 – Increased use of composites in aircraft since 1970

The lightweight composite materials are around 20% lighter than an equivalent aluminium alloy component. However, much larger amounts of fossil fuels are used to supply energy and raw materials for the production of the lightweight composite materials. This is even more pronounced when the extremely efficient recycling of aluminium is taken into account. Recycling aluminium only takes around 5% of the energy required to refine it from ore. In addition, aluminium can be recycled many times without degrading its properties.

By contrast, technologies for recycling composite materials are at an early stage and inevitably the carbon fibres suffer some damage during the process.

During this study, the technique of lifecycle assessment (LCA) was employed to compare the complete lifecycle of materials used in aircraft structures and components. Computer based models were constructed. As illustrated in Figure 2 the LCA can be employed to assess the use of resources and the production and emission of chemicals, some of which are hazardous. LCA can provide detailed information about specific stages in the lifecycle of a chosen material or component or it can include the whole lifecycle. The results of these analyses can be compared with other materials and components. It is essential to be able to get the best comparison between different materials over their complete lifecycle. For this reason, the LCA models are constantly updated to take account of new developments in technology or where more accurate data is developed. For example, recent improvements in recycling of carbon fibre epoxy resin composites and the availability of more detailed information concerning stages of manufacturing of materials.

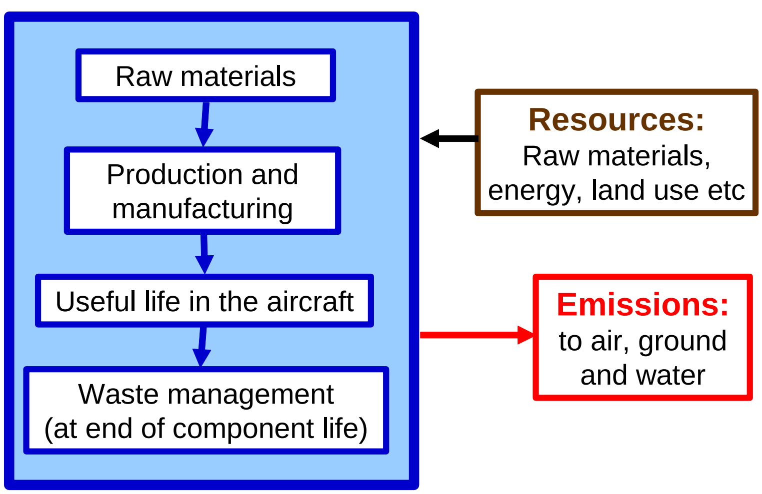


Figure 2 – A simplified representation of the basic processes modelled using LCA.

The time or flight distance that the component is used in the aircraft is very important and LCA can compare the level of fuel use. Although the aluminium uses less energy when its production and disposal is considered, it uses more fuel per mile travelled in the aircraft (as it is heavier than the equivalent component made from a lightweight composite). This is cumulative and after a period of use the aluminium component uses more fuel over its whole lifetime than the lightweight composites.

LCA can compare each phase of the lifecycle or compare the whole lifecycle of the materials. For this project, it was important to get an overall picture of the complete lifetime of the materials to get a truer picture of the potential energy savings offered by the use of lightweight composites.

It is important to make a comparison of the fuel use and emissions produced by various materials. The emissions of carbon dioxide from aviation sources currently amount to between 2 and 3 % of total global emissions. However, with the increase in the volume of air traffic, this is predicted to increase unless improved technologies are developed and used. These technologies include hydrogen based fuels, more efficient engines and use of lightweight advanced composite materials to reduce the weight of the aircraft.

Knowledge Transfer

In addition to exchange of ideas with a wider academic community and Omega partners, the findings of the research project have been presented at meetings involving academic scientists and industrialists:

- "Can Composite Materials Reduce The Carbon Footprint of the Aerospace Industry? A Pilot Study." Alison J Beck, Alma Hodzic, Constantinos Soutis, Chris Wilson Energy and Environment Poster Meeting, University of Sheffield, June2008
- "A Lifecycle Analysis of Energy Use and Emissions from Polymer Composites and Metals for Aerospace Applications," Alison J Beck, Alma Hodzic, Constantinos Soutis, Chris Wilson. Polymer Showcase, York, September 2008.
- "Lightweight Composites and Emissions Reduction", Alison J Beck, Alma Hodzic, Constantinos Soutis, Chris Wilson, Aviation, the Environment & Emissions Trading Conference, 19-20 November 2008, Brussels, Belgium
- "Lifecycle assessment of aerospace materials", Alison J Beck, Alma Hodzic, Constantinos Soutis, Chris Wilson. Abstract accepted by Nova Science Publishers, Inc.

The findings of this short study will also be used to develop LCA models for materials and processes used in industry (not limited to the aerospace industry). The knowledge gained will enhance sustainable projects that are currently run jointly with industry.

Customers of the results of this LCA and how they will they use the information

The aviation industry will be the main beneficiary of the results of this work and the quantified data would be used to manage and plan the utilization of composite aircraft in the future. However, the LCA methodology can readily be developed and adapted to other industrial processes. Industry in general will therefore benefit from the results of this study. The published materials will be disseminated to Airbus who have recently expressed their interest in the results from this study.

In addition academic researchers will benefit from the data arising from the LCA models used in this work. The findings of this short study will be fed into new and more detailed research projects involving LCA in various fields. These will be of interest for projects sponsored by both industry and the government. For example, EPSRC (government sponsored), Carbon Trust (projects sponsored jointly by government and industry).

Examples of possible future research include development of our LCA models to address the following problems:

- Determine the carbon footprints for manufacturing and recycling of a range of materials, processes and specific components.
- Compare different methods of recycling.
- Compare emissions of chemicals and materials such as carbon dioxide, nitrogen and sulphur oxides.
- Comparative studies of the site of emissions. This will be of especial interest to the aviation industry as much of the emissions from aircraft is discharged into the upper atmosphere as opposed to at ground level.

The initial findings of this work will also enhance the training of scientists via future PhD training programmes in many areas including climate friendly technologies, recycling of materials, reduction of carbon emissions.

Although this particular project was motivated by the requirements and interests of the aviation industry, the outcomes are of potential benefit for a range of industrial processes and materials.

Added value delivered by the project

The beauty of the LCA models developed in this work is their ready adaptability to cover a wide range of aerospace materials and components. The ability to adjust and fine tune the models to cope with this ever changing field is vital. For example, as adhesive technologies become more advanced, a particular assembly in an aircraft may use fewer traditional fastenings such as rivets and our LCA models can account for this and other more complex changes.

The adaptability of the LCA models also facilitates their use in industrial fields other than aerospace. They can thus be applied in both industrial and academic settings over a wide range of disciplines.

Future knowledge requirements in the area of composites

- Investigate the potential of renewable materials and composites based on plant fibres and other natural materials to be used for aerospace and other applications.
- LCA could provide useful information about the true impact on the environment of composite produced from renewable raw materials. It could also consider the use of renewable materials and compare this to traditional fossil fuel based materials. Renewable materials based on raw materials of plant origin can also use fossil fuel (if artificial fertilisers are used). They can also have an undesirable impact on food production and cause environmental damage as has been the case with bio-fuels.
- Collection and calculation of comprehensive data for lifecycle inventory (LCI) for specific phases in the production of composite materials. At present much of this data is considered proprietary.
- Use of LCA to evaluate in detail, novel processes for recycling carbon fibre epoxy resin composite materials. For example, pyrolysis and milling is beginning to be used industrially to recycle carbon fibre epoxy resin composites. Any potentially hazardous bi-products or undesirable aspects of the process need to be understood alongside the advantages that an effective recycling system for this material offers.

- Detailed investigations using LCA to study all aspects of recycling aircraft materials and assess the viability of a range of materials.

1.0 Introduction

Over the few months of this academic research project we have investigated and compared energy use and production of emissions when various aerospace materials are used in aircraft. Computer-based models were prepared to compare lightweight composites with the traditional heavier aluminium over their whole lifetime which is termed a "lifecycle assessment". This included raw materials, production, useful life in the aircraft and disposal at the end of the material's useful life. The information provided by this work is independent of industrial influence and so provides an objective view of potential savings in energy and emissions.

Lightweight composite materials such as carbon fibre-reinforced epoxy resins and glass-fibre reinforced laminates are increasingly finding application in aircraft to replace traditional heavier metal structures. In commercial aircraft, this is driven largely by the high cost of aviation fuel and the introduction of legislation setting limits on the emission of greenhouse gases. Already the Airbus A380 is constructed of around 25% composites while the Boeing 787 "Dreamliner" uses about twice this amount[1] . Composites are especially adept at achieving overall weight reduction but also facilitate the construction of novel aerodynamic aircraft shapes such as the blended wing-body thus providing additional routes to improved fuel efficiency.

Laminates such as GLARE[2, 3, 4] can typically produce weight savings of between 10 and 15 % with carbon fibre epoxy resin composites saving around 20% compared to a typical aluminium alloy. The carbon fibre epoxy resin composite could in some cases reduce the weight of a component by up to 40 % compared to aluminium. As the fuel consumption of an aircraft is strongly affected by its total weight so the fuel used during flights can be significantly reduced by increasing the proportion of composites used in the aircraft structure.

[1] Soutis, C. Progress in Aerospace Sciences, 41, 143-151, 2005. "Fibre reinforced composites in aircraft construction".

[2] GLARE is a hybrid GLAss-REinforced fibre metal laminate, which has many similar structural properties to Al alloy but is 10 -15% less dense. It is a laminate made up of layers of Al alloy (Grade 2024-T3, *ca* 0.2 mm thick foil) and glass fibre reinforced epoxy adhesive (ca 0.25 mm) layers.

[3] Vermeeren CAJR, Applied Composite Materials, 10(4-5), 189-205, 2003. "An historic overview of the development of fibre metal laminates"

[4] F.C. Campbell, "Manufacturing Technology for Aerospace Structural Materials", Elsevier, Oxford, 2006.

However, the production, manufacture and final disposal of high performance composites and similar materials for use in aircraft requires considerably more energy than metal components such as aluminium alloys. For example, aluminium can be recycled at about one 20th the energy that it takes to refine it from ores. This energy saving, when aluminium is recycled, provides a significant reduction in the energy use of aluminium over its whole lifetime. This illustrates that it is vital to consider the energy and raw materials used and waste products produced at all stages of the lifetime of the material. A more accurate view of the total savings in aviation fuel use and emissions achieved by using the lighter materials can be obtained.

Lifecycle assessment (LCA) has been employed to ascertain the effect on the environment in terms of fossil fuel use and emissions of potentially hazardous products when different aerospace materials are used. Aluminium alloy (AlCuZnMg, aerospace grade 7075), the laminate GLARE (which is used by Airbus and consists of layers of glass fibre-reinforced epoxy resin sandwiched between aluminium foil), and carbon fibre reinforced epoxy resin composites were chosen for comparison. The choice of these materials had the additional advantage of facilitating the evaluation of the software and currently available data bases for the LCA. The LCA takes into account all the stages of the material lifetime: raw materials, production and manufacturing, useful life in the aircraft and waste management at the end of the component life.

The evaluation of lightweight aerospace materials is vital with the predicted future increase in aviation emissions unless improved technologies are implemented, as illustrated in Figure 3.

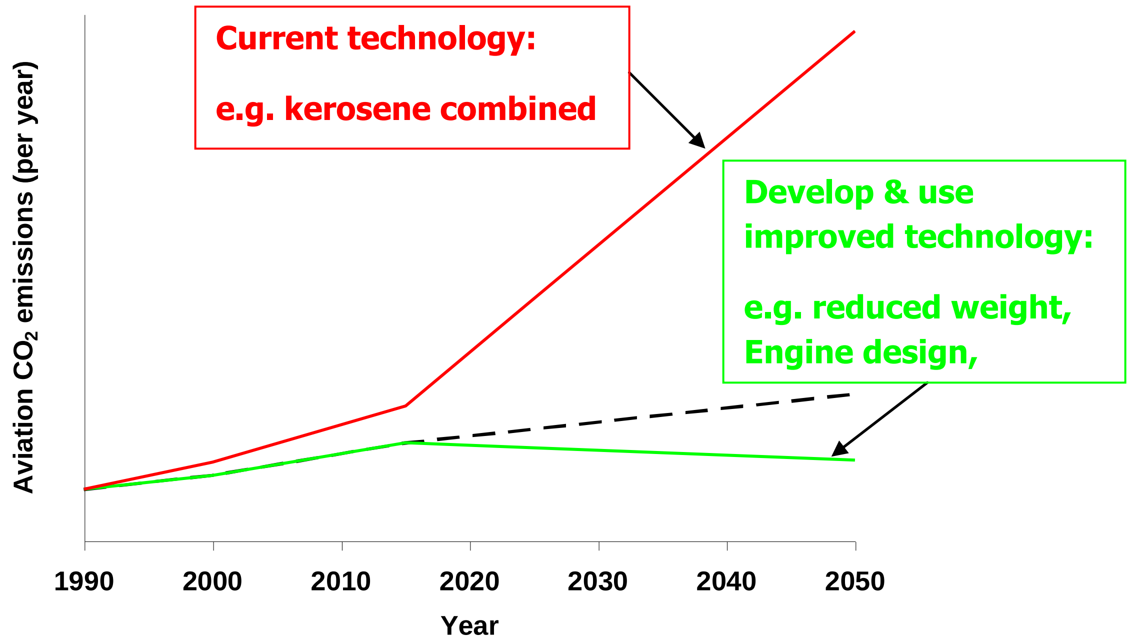


Figure 3 – Predicted trends in emissions of carbon dioxide from aviation sources, After J Penner et al, "Aviation and the Global Atmosphere" [5]

The results of our LCA modelling contain data concerning the use and production of literally hundreds of chemicals and raw materials. The exact number of items depends on the particular material and the nature of the processes involved in its overall lifetime. The huge amount of data that is concealed within the LCA model provides a challenge to present it in a meaningful way. For the purposes of this short study, items of current interest have been extracted from the LCA model for further analysis, airborne emissions of substances which influence climate change (known as radiatively active substances[6]) such as carbon dioxide, sulphur and nitrogen oxides and particulates have been initially selected. However, if another type of emission was considered particularly

[5] J. Penner, J.H. Ellis, N.R.P. Harris, D.H. Lister, "Aviation and the Global Atmosphere" http://www.grida.no/publications/other/ipcc_sr/?src=/climate/ipcc/aviation/064.htm

[6] K. Takeda, A. L. Takeda, Bryant, J. Clegg, The Aeronautical Journal, 112, 493, 2008, "Systematic review of the impact of emissions from aviation on current and future climate."

important this data could be analysed at a later date. For example, the emission of volatile organic chemicals or individual named chemicals such as benzene could be studied.

From time to time it is discovered that a chemical, previously considered to present no risks to human health or to adversely affect the environment, is actually hazardous. This could be that it adversely affects the climate or causes global warming or perhaps that it is toxic to global environment in other ways. As another example, chemicals that were previously thought to be harmless are often found to be carcinogenic or otherwise damaging to human health.

Emissions of particulate materials, for example, can affect both the environment, contributing to climate change and are hazardous to human health. Particulate materials can be particularly damaging to human health if they are produced in the lower part of the atmosphere, around airports for example. When such particulate matter is produced in the atmosphere during flight of aircraft, they become radiatively active and affect global warming. Similarly, aircraft contrails (consisting of mainly water) are thought to be radiatively active and thus influence climate change.

At the present time there is a lot of uncertainty about the effect on climate change caused by water emitted by aircraft.[6] This illustrates the potential of our LCA model as it contains information on many materials and emissions that are likely to be of great importance in the future.

1.1 Future Applications of LCA

The computer-based models developed in the course of this work are described for three of the most commonly used aerospace materials. However, these are readily applied to many other materials of interest to aerospace engineers and designers. For example, there are literally hundreds of aluminium alloys plus a range of titanium alloys etc that could be modelled using our system. Examples of different aluminium alloys of especial interest are those that include a range of proportions of lithium. They are lighter weight (i.e. they have a lower density depending on the exact composition and in particular the lithium content) than many aluminium alloys. As an example, these alloys are used to construct the fuselage of the Bombardier C-series aircraft.[7] The lithium-containing aluminium alloys are certainly lighter than other aluminium alloys but remain heavier than composite materials. The lithium-containing aluminium alloys have

[7] http://www.bombardier.com/en/aerospace/products/commercial-aircraft/technology?docID=0901260d800091f1

the added complication as they have to be segregated from all other forms of aluminium at the end of their useful life. This is because their high lithium content could lead to explosions if they are recycled using the same processing technology as conventional aluminium. The beauty of lifecycle analysis however is that it considers all stages of the lifecycle and it can pinpoint potential difficulties with materials and give a truer comparison of their advantages and disadvantages.

It is generally accepted[8] that LCA models have to be continuously improved and updated in line with developments in materials, recycling technology, and improvements to the databases. This is typified by the recent developments in recycling technology for carbon-fibre epoxy resin composites and glass-fibre reinforced polymer composites.[9] Currently these types of composite materials are largely consigned to landfill or incineration after they are stripped from the aircraft at the end of its life. An efficient system for recycling these fibre-reinforced composite materials would markedly improve their impact on the environment during their complete lifetime. Companies are now recycling carbon fibre reinforced composites[10] although the recovered fibres are currently of lower quality and would not be approved for aerospace use.

Another aspect of aircraft construction that is always being improved and developed is the use of advanced adhesive systems. This is especially applicable to fibre-reinforced polymer composites. The use of adhesive technology can significantly reduce the number of rivets used to secure a particular component such as the tailfin. This has the effect, not only of reducing the use of expensive titanium based rivets but can increase the speed of aircraft construction and the weight saved could also be significant.

The use of "green" composite materials that use biomaterials to produce the fibres and resin matrix should be investigated in future. These materials are often termed biocomposites and they have the advantage of being biodegradable[11] and currently initial studies are suggesting that the products of the biodegradation of biocomposites are innocuous in the environment.[12] However, the natural fibres do not have the

[8] H. Baumann, A.-M. Tillman, "The Hitchhiker's Guide to LCA", Studentlitteratur, Sweden, 2004

[9] A. M. Cunliffe, N. Jones, P. T. Williams, Journal of Analytical And Applied Pyrolysis, 70(2), 315-338, 2003 Title: Recycling of fibre-reinforced polymeric waste by pyrolysis: thermo-gravimetric and bench-scale investigations

[10] Milled Carbon Products Ltd, West Bromwich, UK. http://www.milledcarbon.com/

[11] A. K. Mohanty, M. Misra, G. Hinrichsen, Macromolecular Materials And Engineering, 276(3-4), 1-24, 2000, "Biofibres, biodegradable polymers and biocomposites: An overview"

[12] E. Rudnik, N. Milanov, G. Matuschek, A. Kettrup, Chemosphere, 70(2), 337-340, 2007. "Ecotoxicity of biocomposites based on renewable feedstock - Preliminary studies"

consistent quality of carbon fibres produced from poly(acrylonitrile fibres) and they may have to undergo complex processing involving the use of solvents and other hazardous chemicals[13]. In the future these materials could be developed to meet aerospace specifications and LCA studies of a range of biocomposites would assist in determining their overall benefits and disadvantages.

These are examples of how our LCA models could be adapted to address questions vital to the efficient use of aerospace materials. The LCA models that we have developed during the course of this research project have the advantage that they can readily be adapted as will be required to cope with the constantly changing world of aerospace composites.

2.0 The Concept of lifecycle analysis

The complete lifecycle of aerospace materials (advanced composites and aluminium alloy) has been investigated to assess and compare the total emissions produced and determine the quantities of raw materials such as fossil fuels that are used. The stages of the material's lifecycle that were examined were broadly:

- raw materials
- production
- useful life in the aircraft
- disposal at the end of the material's useful life

However, the details used to model these processes have been especially tailored to reflect the particular nature of the production and other stages of the lifetime of each individual material.

[13] A. K. Mohanty, M. Misra, L. T. Drzal, Composite Interfaces, 8(5), Special Issue: SI, 313-343, 2001. "Surface modifications of natural fibers and performance of the resulting biocomposites: An overview"

3.0 Method

3.1 Lifecycle assessment (LCA) software and database

SimaPro 7.1 software was used in combination with ecoinvent database to carry out LCA for aerospace materials (Pré Consultants, NL). The ecoinvent data v2.0 contains international industrial life cycle inventory data on energy supply, resource extraction, material supply, chemicals, metals, agriculture, waste management services, and transport services. Eco-indicator 99 (E) V2.05 Europe EI 99 E/E was used for calculation of single score data.

4.0 Results and discussion

Initially a general understanding of the lifecycle of the material was developed. This is illustrated in Figure 4 for a carbon fibre epoxy resin composite material.

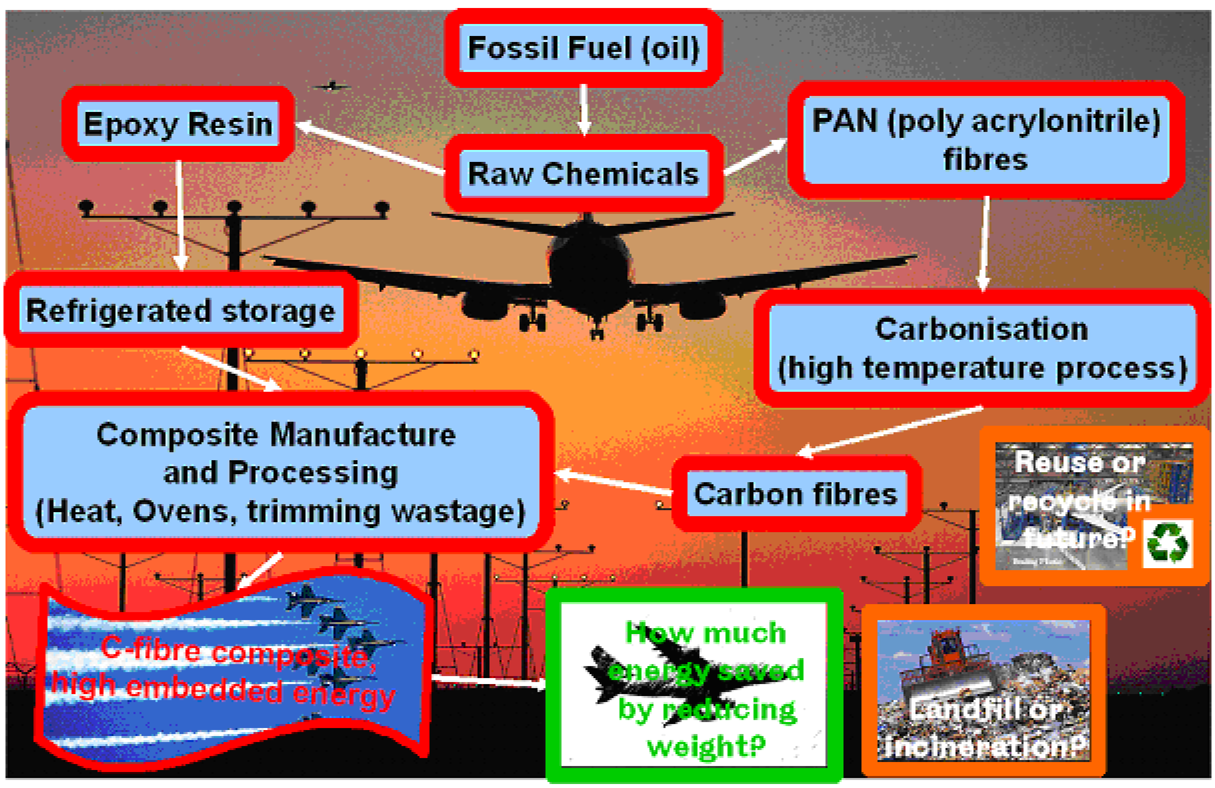


Figure 4 – Schematic diagram showing the important stages in the lifecycle of carbon fibre epoxy resin composites.

This is of course, greatly simplified and the LCA model itself contains detailed information from the material and process databases. However, Figure 4 highlights the areas in the manufacture of carbon fibre epoxy resin composites that use large quantities of energy (largely from fossils fuel sources). Additional amounts of fossil fuel are used to produce the raw chemicals required to manufacture the carbon fibre epoxy resin composite. The main two ingredients of carbon fibre epoxy resin composites are epoxy resin and carbon fibres and they are both produced from fossil fuel (oil).

Considering the epoxy resin first, this is produced as a liquid and it has to be stored under refrigeration[14]. This cold storage is necessary as the liquid epoxy resin has a tendency to react and become more viscous with time. The refrigerated storage merely slows down this reaction and even with refrigeration the liquid epoxy resin has a limited life. However, the process of refrigeration consumes energy which contributes to the overall energy use of the carbon fibre epoxy resin composite. The carbon fibre component begins its life as poly(acrylonitrile) fibres, again originating from fossil fuel. The poly(acrylonitrile) fibres then undergo a high temperature carbonisation process. So, considerable amounts of energy are needed. This is carried out in the absence of air. The carbon fibres are then woven into the form required for the component under manufacture; they are effectively mixed with the liquid epoxy resin to form a material known as "pre-preg". At this stage, the uncured pre-preg is trimmed and at the trimmings should be minimised by effective composite design.[15] The component is then heated under pressure (autoclaved) to cure the epoxy resin and form the durable, solid carbon fibre epoxy resin component. Other methods of curing have been reported such as using beams of electrons or radiation[16] and electrical resistance[17] and these could be compared in future LCA studies. The processes and material stages of the LCA model for aluminium, carbon-fibre epoxy resin composite and GLARE are illustrated in Figures 5 to 7.

[14] J. M. Sands, B. K. Fink, S. H. McKnight, C. H. Newton, J. W. Gillespie Jr., G. R. Palmese, Journal Clean Products and Processes, 2(4), 228-235, 2001. "Environmental issues for polymer matrix composites and structural adhesives"

[15] C. Ward, K. Potter, SECIO 08, SAMPE Europe International Conference, 543-548, 2008. "Understanding composites design & manufacturing for minimisation of scrap generation: the first steps to efficient use"

[16] A. Singh, Nuclear Instruments & Methods In Physics Research Section B-Beam Interactions With Materials And Atoms, 185, 50-54, 2001. "Radiation processing of carbon fibre-reinforced advanced composites"

[17] C. Joseph, C. Viney, Composites Science and Tech., 60, 315, 2000. "Electrical resistance curing of carbon fibre/epoxy composites"

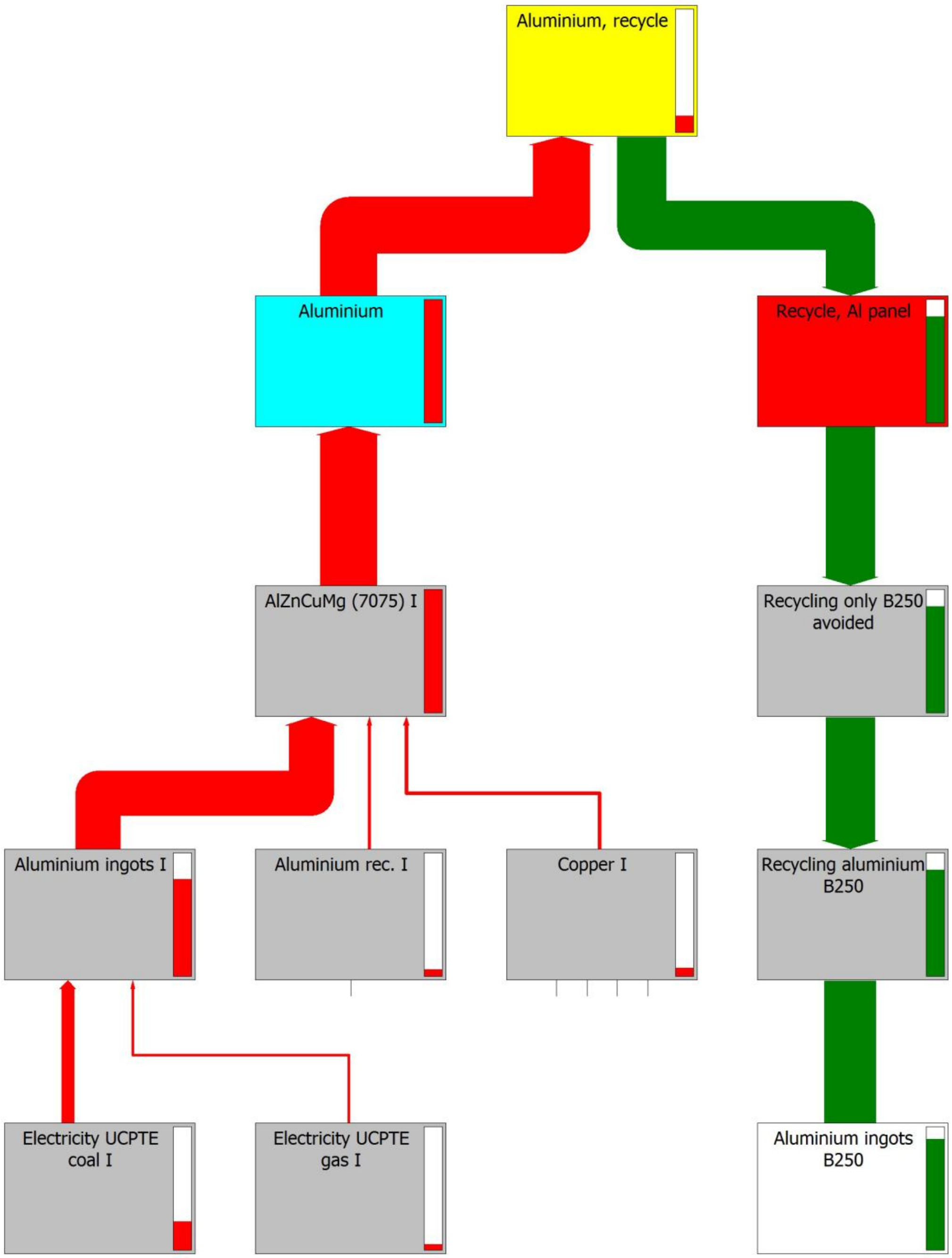


Figure 5 – Flow chart showing the materials and process stages for an aluminium panel (17 out of 182 are shown).

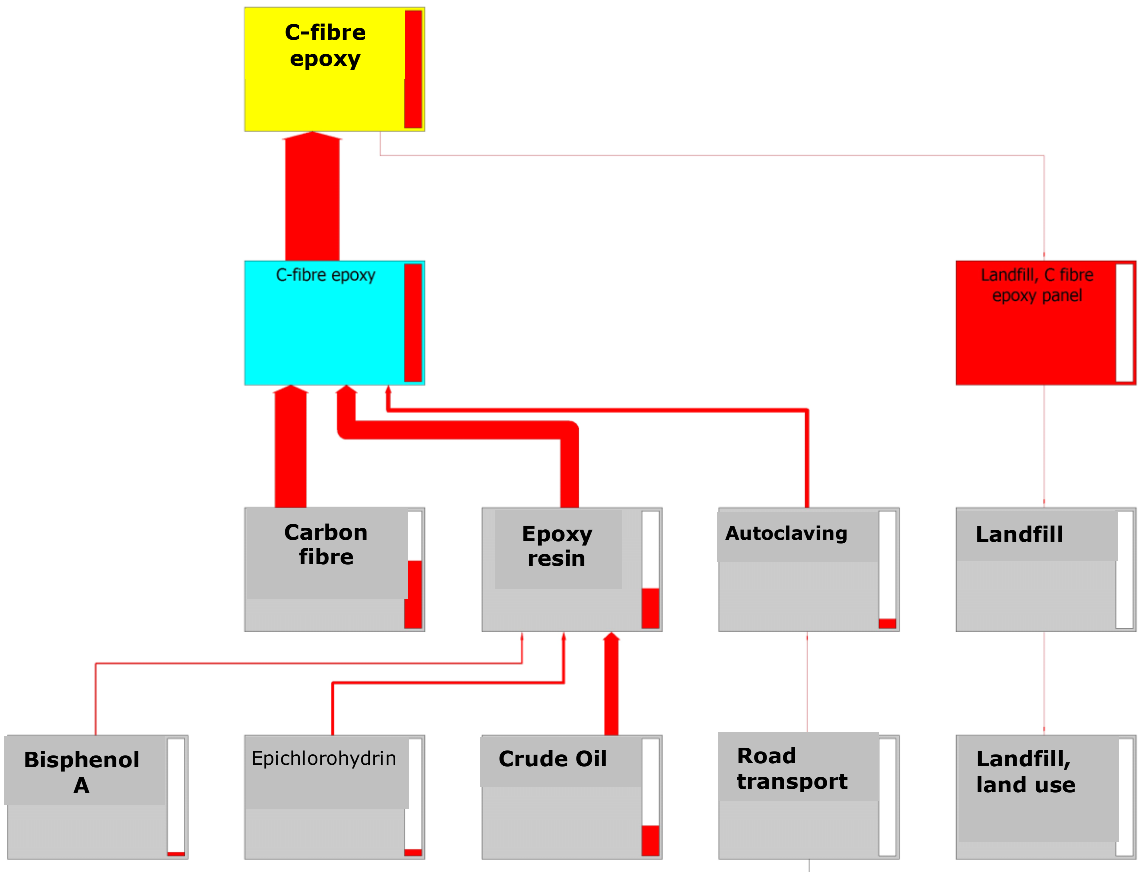


Figure 6 – Flow chart showing the materials and process stages for an carbon fibre epoxy resin composite panel (12 out of 14 are shown).

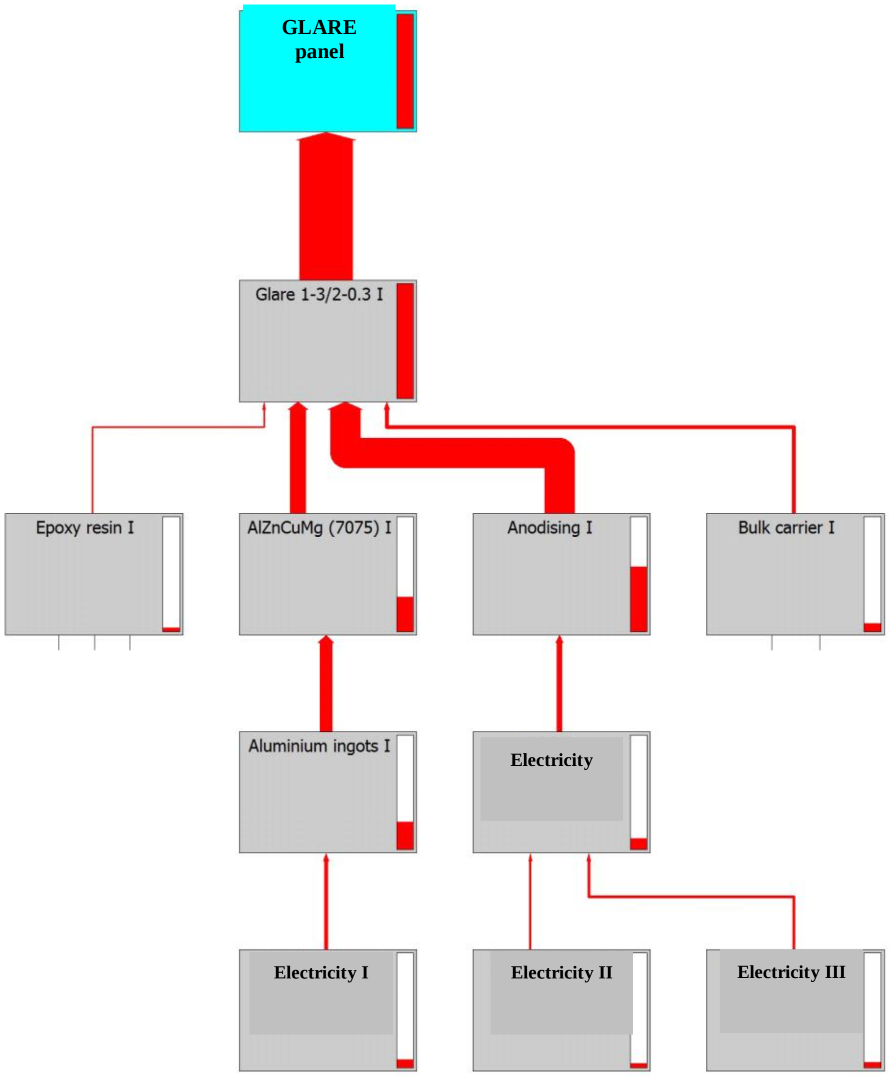


Figure 7 – Flow chart showing the materials and process stages for an GLARE panel (12 out of 236 are shown).

LCA models are often represented as shown in figures 5 to 7 and it illustrates the complexity and quantity of the information available. Figure 7, shows 12 out of 236 processes that are included in the model. This further illustrates that it is necessary to judiciously choose which information available from the LCA model should be used to answer specific questions. In this work the airborne emissions and use of fossil fuel are analysed.

Figure 8 is shown as it illustrates the single score impact of a range of emissions and effects on the environment. The single score is a method of comparing many different items each having different units. However, according to ISO 14042, this type of representation must be treated with caution as it is subjective. The impact factors can differ according to the software that is used for the calculation. This must be made clear to anyone who views this type of representation.[8] In this work Eco-indicator 99 (E) was employed and it is reported in the literature that this is an acceptable method of calculating impact factors.[18, 19]

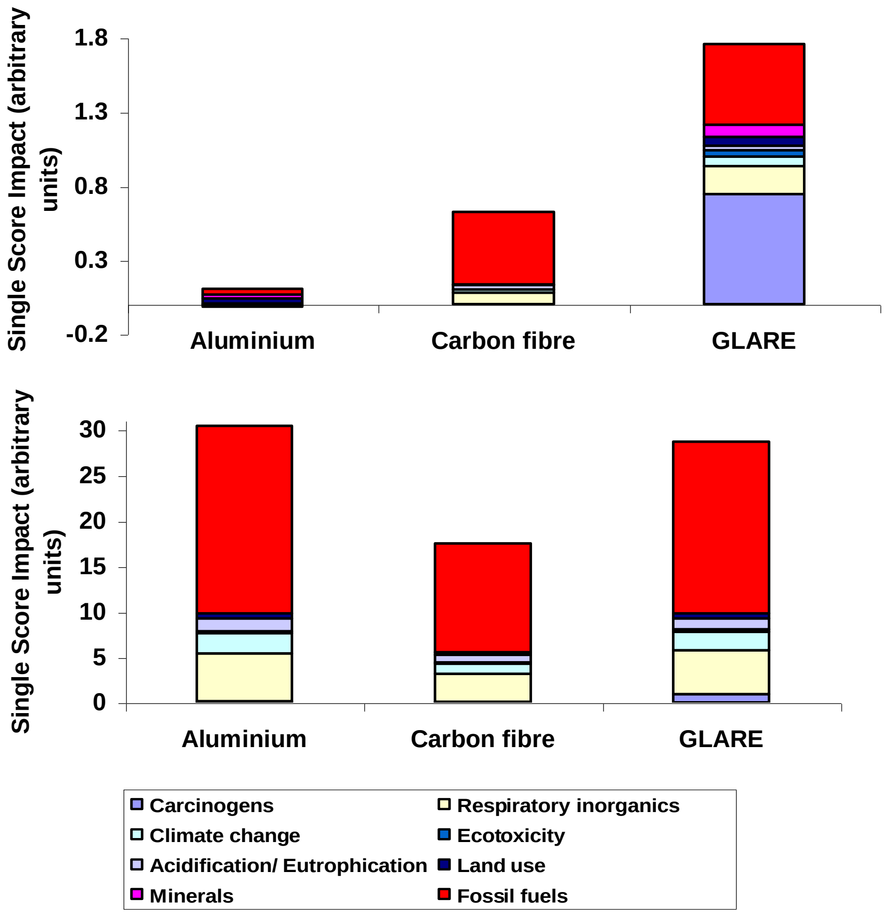


Figure 8 – Single score impact to compare the effect of the different materials on various parts of the environment.

[18] L. C. Dreyer, A. L. Niemann, M. Z. Hauschild, International Journal Of Life Cycle Assessment, 8(4), 191-200, 2003. "Comparison of three different LCIA methods: EDIP97, CML2001 and Eco-indicator 99 - Does it matter which one you choose?"

[19] O. Jolliet, M. Margni, R. Charles, S. Humbert, J. Payet, G. Rebitzer, R. Rosenbaum, International Journal Of Life Cycle Assessment, 8(6), 324-330, 2003. "IMPACT 2002+: A new life cycle impact assessment methodology"

The data available from the LCA model may be grouped according to use of raw material and emissions to the air, water and ground. There is a large amount of numerical information available for further processing. However, it would be too unwieldy to present the full amount of data. Airborne emissions of radiatively active chemicals and materials such as particulates are shown in Table 1. This shows the level of emissions for production and disposal only. The aluminium almost always has lower emissions which is a result of the savings gained from the extremely efficient recycling of aluminium.

Table 1- Comparison of selected airborne emissions for aluminium, glare and carbon fibre epoxy resin composite panels. The production and disposal stages are included.

Substance	Unit	Aluminium	Carbon fibre epoxy resin composite	GLARE
Ammonia	g	0.01	12.61	0.04
Carbon monoxide	g	-16.85	15.89	45.55
Cyanide	g	0.00	26.70	0.00
Hydrocarbons, unspecified	g	0.86	10.32	3.72
Hydrogen chloride	g	0.36	0.11	1.42
Methane	g	-1.11	3.61	25.25
Nitrogen dioxide	g	0.64	1.04	0.54
Nitrogen oxides	g	0.93	19.94	44.58
NMVOC, non-methane volatile organic compounds, unspecified origin	g	-10.10	0.05	1.94
Particulates, > 10 um	g	8.94	0.01	11.71
Particulates, SPM	g	0.32	3.31	0.59
Sulfur dioxide	g	68.08	0.94	82.47
Sulfur oxides	g	-56.72	12.10	1.27
VOC, volatile organic compounds	g	0.50	x	3.65
water	g	x	25.20	0.00
Carbon dioxide	kg	1.13	4.69	12.79

Table 2 shows further detail on the sizes of particulates emitted into the atmosphere for the production and disposal stages only. The GLARE produces the greatest level of emissions for these stages. However, as the materials are used in the aircraft the heavier aluminium uses more fuel to travel the same distance and over time in use the aluminium finally produces the highest level of emissions.

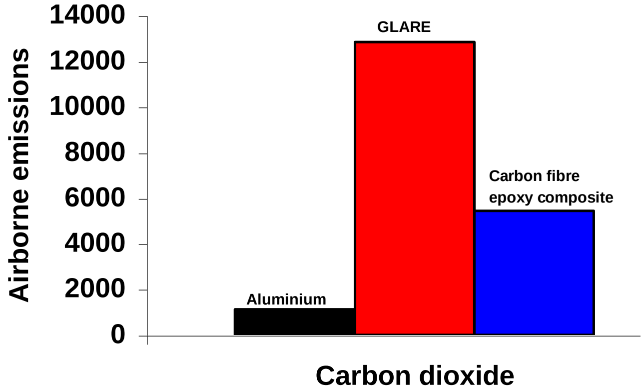
Table 2- Comparison of airborne emissions of particulates for aluminium, glare and carbon fibre epoxy resin composite panels. The production and disposal stages are included.

		Aluminium	Carbon fibre epoxy resin composite	GLARE
Particulates, < 2.5 um	g	x	7.4 x 10-3	19 x 10-3
Particulates, > 10 um	g	8.9	0.01	11.7
Particulates, > 2.5 um, and < 10um	g	x	4.1 x 10-3	7.6 x 10-3

The LCA model includes energy used in various ways such as transport and use of electricity, refining and production of raw materials and finally takes into account energy use (or savings) due to the disposal method employed. Information concerning emissions (to air, ground or water) can also be extracted from the results of the LCA model. Items of particular interest to this work are fuel use and airborne emissions of substances that can influence climate change. However, data concerning use of other raw materials and different emissions is contained within the LCA model and can be interpreted further in future.

As an example of the sort of information that the LCA model can provides, Figure 9 compares the emissions of carbon dioxide produced by aluminium alloy, GLARE and carbon fibre epoxy resin composite. For production and disposal only (Figure 9 (a)), the aluminium clearly produces less carbon dioxide. However, with a period of use in a typical aircraft, the heavier aluminium overtakes the lighter composite materials to produce more carbon dioxide overall.

(a)



(b)

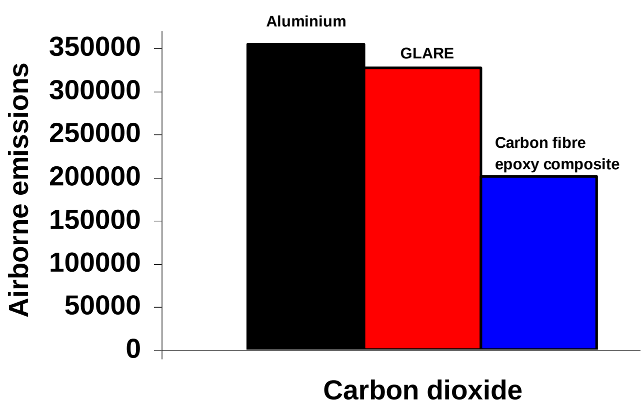


Figure 9 – Comparison of airborne emissions of carbon dioxide (a) production and disposal only and (b) after use in the aircraft.

LCA has great utility in providing engineers with data that allows them to predict at what stage in their lifetime, the lighter materials begin to show a overall benefit, for example in terms of fuel use. Figure 10 illustrates how LCA can show when the materials "break-even".

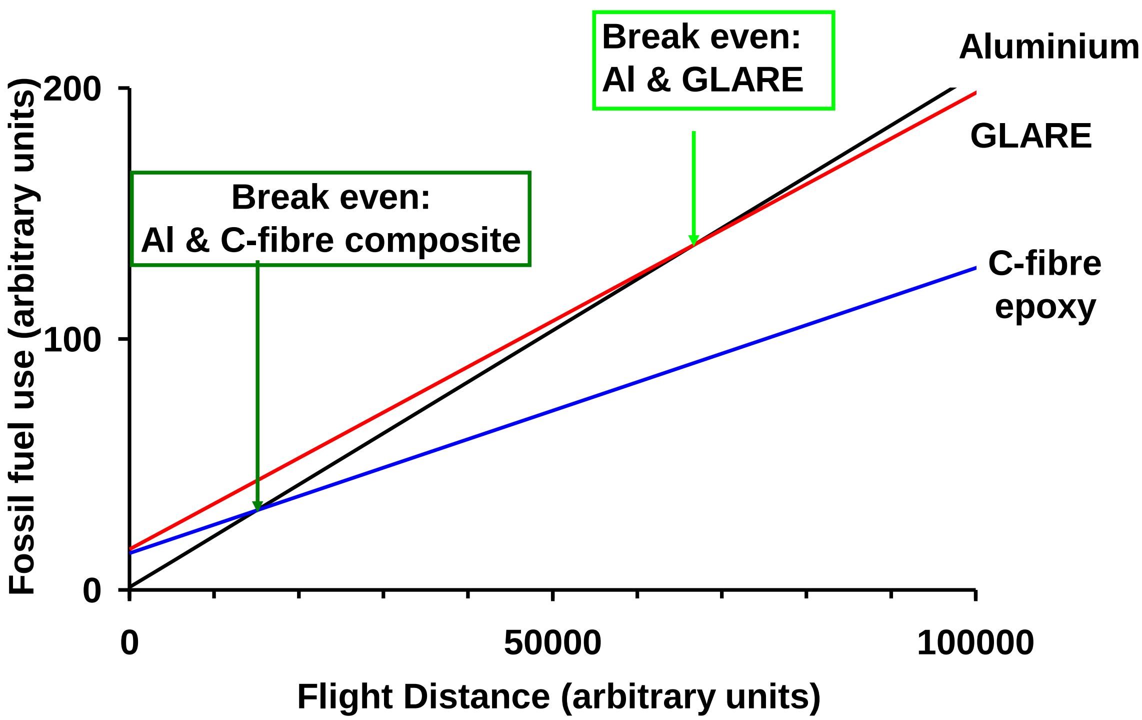


Figure 10 – Schematic of "Break-even" in terms of fuel use for aluminium, GLARE and carbon-fibre epoxy resin composite.

5.0 Conclusions

LCA has been used to model and compare the energy use and emissions of aerospace materials: carbon fibre epoxy resin composite, GLARE and aluminium. This has shown that the production and disposal of aluminium (100 % recycled) uses less resources and produces lower emissions that either GLARE or carbon fibre composite materials. However, once the material is used as a component in the aircraft, the heavier aluminium uses more fuel. As flight time increases, so there is a cumulative saving of aircraft fuel when the lighter materials are used in components.

The model requires further work to fine tune energy requirements at various stages of the composite lifecycle. For example, the exact form of a component will affect the energy used in manufacture, especially at the stage where the component is autoclaved.[20]

The model used for LCA has highlighted areas for improvement in the production of composites such as reducing trimming wastage.

It would also be desirable to improve the recycling processes and the amount of composites that are currently recycled. However, unlike aluminium, which can be recycled over and over again, composites degrade to a certain extent on recycling.

6.0 Dissemination of findings

- "Can Composite Materials Reduce The Carbon Footprint of the Aerospace Industry? A Pilot Study." Alison J Beck, Alma Hodzic, Constantinos Soutis, Chris Wilson Energy and Environment Poster Meeting, University of Sheffield, June2008
- "A Lifecycle Analysis of Energy Use and Emissions from Polymer Composites and Metals for Aerospace Applications," Alison J Beck, Alma Hodzic, Constantinos Soutis, Chris Wilson. Polymer Showcase, York, September 2008.
- "Lightweight Composites and Emissions Reduction", Alison J Beck, Alma Hodzic, Constantinos Soutis, Chris Wilson, Aviation, the Environment & Emissions Trading Conference, 19-20 November 2008, Brussels, Belgium
- "Lifecycle assessment of aerospace materials", Alison J Beck, Alma Hodzic, Constantinos Soutis, Chris Wilson. Abstract accepted by Nova Science Publishers, Inc.

[20] Autoclaving (heating under pressure) of carbon fibre epoxy composites uses a considerable amount of energy during the production process.

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