ACADEMY

AIRBUS CORPORATE ANSWER TO DISSEMINATE ENVIRONMENTAL MANAGEMENT SYSTEM

Design for Environment

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Design for Environment

Table of Contents

I. What is Design for Environment? 3

II. DfE Success Parameters 4

III. Implementation 6

IV. Examples 17

V. Conclusions 25

I. What is Design for Environment?

The design phase of most products is often determinant for their environmental performance throughout their life cycle, and the majority of a product's environmental impacts will be fixed during this phase A350. The environmental impact of products can be so significantly reduced through an optimised design.

Design for Environment concept (DfE) is a way to systematically consider design performance with respect to environmental, health and safety objectives over the full product or process life cycle. The implementation of DfE into the design process is a key element of the progression towards more sustainable systems, and can lead to incremental improvements or even larger leaps.

The Design for Environment concept (DfE) has been introduced in the 1990's to help designers make better informed choices, and to better appreciate the impact of their decisions on the product environmental performance. There are many aerospace companies to consider and reduce the impacts whenever possible, ranging from customer demands, economic benefits to regulatory pressures and public opinion, depending on the type of impact. The drivers to become more environmentally responsible in product design mainly include the need to comply with legislation and satisfy stakeholders expectations, the search for competitive advantage, and overall, the opportunities to reduce cost and increase values.

DfE practices are intended to develop environmentally compatible products and processes while maintaining or improving price, performance and quality standards.

Airbus is committed to continuously reducing the noise created by its aircraft in flight

II. DfE Success parameters

Supportive Environmental Strategy and Objectives

Companies must have a clear environmental strategy, with defined objectives and priorities to embed environmental considerations in the product creation process. Environmental improvement objectives for the product should be based on relevant internal and external requirements and expectations as recommended by environmental management systems standards. Company policies, regulatory requirements, and key stakeholders' expectations should all be inputs to the product environmental objectives setting process. In particular, customer demands should be given high level of consideration.

Raise Awareness

Raising awareness amongst employees of a company's environmental impacts and objectives and actions to control and reduce them is a key part of an environmental management system. Opportunities should be taken as part of the awareness raising programme to introduce the life cycle thinking concept, the product life cycle impacts, how to reduce these impacts and who can contribute.

Engagement of key actors

Beyond awareness, some key actors in the business must feel fully engaged with the overall design for environment approach to make things happen. These include:

Senior Management

Through top level strategy and policy, senior management should provide full commitment, support and drive the changes required to introduce environmental considerations into design.

Product/Programme Management

When starting a new programme, or reviewing an existing product, any environmental constraints and requirement should be clearly visible and given the relevant priority by the programme manager. Responsibility should be given across design teams to ensure environmental requirements are achieved.

Designers

Designers are key decision makers and select the design options which may reduce or optimize environmental impact. In this respect, their awareness and understanding of the issues are essential, as well as their empowerment to drive changes to minimize environmental impacts. The availability of suitable information to enable the designers to make the right choices is critical.

R&T

Engineers are responsible for innovation and technology - they are key to the development of technological solutions which will allow more environmentally sound designs. Similarly their awareness and understanding of the product environmental impacts and the objectives/constraints to minimize these impacts is paramount.

Appropriate Tools

In order to reduce the environmental impact of a designed product, designers must have suitable information made available for a reasonable expenditure of its time. If they do not feel that it is suitable or reasonable, they will not use the information, nor the method of deriving it.

The tool users must ensure the overall aim of the life cycle approach is fulfilled by knowing when to generate new information or data, revise environmental objectives, balance the pros and cons and seek to achieve compromise.

A characteristic crucial to the effective implementation of these tools is its usability by designers. Tools constitute a crucial means of communication between environmental experts and designers and ensure that the relevant ecological information and data concerning the product is transferred and well interpreted during development.

When developing products, designers have to consider the consequences of their decisions in a number of fields ranging from economy, reliability and ease of change to the environmental impact. In most engineering environments, designers need to be encouraged to integrate environmental aspects by the availability of suitable tools. In short the main requirements should include:

- A simple and easy to use method
- Availability of appropriate data
- Simple results, easy to communicate
- Traceable conclusions

Above all, any tools or information deployed as part of DfE should be fully integrated in exising design process, procedures and manuals. Environment should become a new key parameter to consider in decision-making, alongside technical performance, safety and cost.

III. Implementation

The implementation of Environmental Management System should provide the basic framework needed for a successful introduction of Design for Environment. Environmental policy and objectives should be the guarantee of commitment from senior management. The training programme should ensure a good level of environmental awareness across the key functions and personnel. All critical procedures should be in place to allow the identification of impacts, the maintenance of the environmental management programmes, and support adequate audit and reviewing processes as appropriate.

However, the implementation of DfE requires major focus on the design process and how it can contribute to the reduction of a product environmental impact. The important aspects to analyse and ensure effective integration include:

- Decision-making contexts - When are key decisions made during the design process, by whom and what are the parameters which apply?
- Environmental Objectives and Requirements for an environmentally sound product - What are the constraints ?
- Develop Tools - Which tools do designers need to integrate environmental information and include in decision making and trade-off?
- Organisational Support
- Barriers and obstacles

3.1 Identify Key Decision-Making

Decisions concerning strategic commitments such as environmental performance targets, (e.g, noise, and air, …) emissions release levels, shall require assessments of existing technical research results and tradeoff studies, and a appropriate consultation process with relevant stakeholders. These decisions can only be taken ultimately at the highest level in the organisation since the impact on the product's overall environmental performance during the operational phase will be very significant. In view of current issues associated with aviation, the societal interest and stakeholder engagement in this type of decisions will be high in the aerospace industry.

Such strategic commitments are eventually translated into the product policy and are cascaded through to the design organisation via project requirements and design.

Product Design Process - Feasibility Phase

Design decisions made at the feasibility stage involving a conceptual step change such as the introduction of laminar flow or an engine noise shielding solution clearly imply a long and complex decision-making process. The technical viability of the solutions considered will need to be validated through extensive technical studies. The introduction of such new technology would have to enhance significantly the main product environmental performance (as mainly the operational phase, the level of noise, emissions released by the aircraft).

Product Design Process - Concept Phase

The concept phase is usually associated with the down-selection of alternative design options, including features such as different structural materials (e.g. metallic versus composite) or system equipment types. These decisions are considered to be well structured with agreed criteria and with articulated preferences based on technical requirements and design standards. The timeframe for decisions is usually much shorter than in the previous phases, however, this will depend on the risk associated with the design options, which is directly linked to the maturity of the technology considered. The decision will in most cases be the outcome of a comparison between alternative design options. The resulting consequences on the product environmental performance may not only affect the operational phase and high profile issues such as greenhouse gas emissions and noise reduction, but also the manufacturing and end-of-life phases through, for example, the reduction of hazardous substances used in the product and the improvement of recyclability. However, there may other internal or external pressures influencing these decisions, especially when introducing advanced technologies for the first time.

Product Design Process - Definition Phase

The selection of fabrication or construction process may also be considered as a routine decision with agreed criteria. Information has to be gathered fast and strict guidelines/procedures have to be followed, routine day-to-day decisions relying on standardised information in predetermined procedures. The timeframe for decisions is likely to be relatively short, as pressure will be increasing as the development programme progresses. The potential improvements on the product environmental performance are likely to be classified as incremental as they should mainly concern the manufacturing phase of the product life cycle. The focus will therefore be on the reduction of local air, water and land pollution through the introduction of environmentally efficient processes (less resources consumption, emissions and waste generation). Even if the overall societal benefits associated with these decisions may be lower, the permits and authorisations under which the manufacturing sites operate will impose legal constraints, which may be instrumental in the decision-making process. In addition, the associated cost savings in terms of energy consumption, materials purchase or waste disposal will be fully visible by the business at this level, and this should clearly and heavily influence the choices.

Design Aspects Technology examples	Life Cycle Impacts - Environmental Requirements		
	Raw Materials, Manufacturing and maintenance	Operation (in flight)	Disposal
Overall Aircraft Configuration Classic Configuration vs Alternative new concept (Noise Shielding, BWB...)	Negligible	- Meet Noise Performance Target (take-off and landing) - Optimise Fuel Burn - Optimisation of Global and Local emissions	Negligible
Associated Design Phases		Strategic/Feasibility Phase	
High Lift Design & General Manoeuvrability High Lift Devices	Negligible	- Meet Noise Performance Target (take-off and landing) - Optimisation of Local emissions	Negligible
Associated Design Phases		Feasibility/Concept Phase	
Navigation Systems	Negligible	- Optimise en route flight path from environmental point of view (minimum impact of emissions on the atmosphere)	Negligible
Associated Design Phases		Feasibility/Concept Phase	
Drag Laminar Flow Fairings Insertion	Negligible	- High speed : Meet fuel consumption performance target and optimise global emissions - Low speed : Meet Noise Performance Target (take-off and landing) and optimise local emissions	Negligible
Associated Design Phases		Feasibility/Concept Phase	
Materials choice Advanced lightweight materials for structural parts	Elimination or Reduction of Hazardous Materials Optimisation of Recycling Potential	Optimisation of Material weight Fuel consumption and global emissions Targets	Optimise Recyclability potential
Associated Design Phases	Feasibility/Concept Phase	Concept Phase	Concept Phase
Systems and Equipment Fuel systems Landing Gear Avionics	Elimination or Reduction of Hazardous Materials (fire suppression, refrigerants, de-icing, brakes, hydraulics, electronic components) Fuel production of power sources	Optimise energy/power sources of APU, Landing Gear and moveables	
Associated Design Phases		Feasibility/Concept Phase	
Components manufacturing processes selection Resin Transfer Moulding	Elimination or reduction of hazardous materials Elimination of solvents based cleaning Increased eco-efficiency and meet key targets for local pollution (Air emissions, Discharge to water, Solid waste, Energy use, Raw material)	Optimisation of Material weight Fuel consumption and global emissions Targets	Avoid creation of special waste due to hazardous material presence
Associated Design Phases	Concept/Definition Phase	Feasibility/Concept Phase	Definition Phase
Assembly Processes selection Adhesive Bonding	Elimination of hazardous materials Increased eco-efficiency and meet key targets (Air emissions, Discharge to water, Solid waste, Energy use, Raw material)	Optimisation of Material weight Fuel consumption and global emissions Targets	Optimise ease of dismantling and disassembly
Associated Design Phases	Concept/Definition	Feasibility/Concept Phase	Definition Phase

3.2 Identify Environmental Requirements and Constraints (see Table above)

The whole life cycle of a product shall be covered in the scope of the Design for Environment process to avoid any transfer of impact from one phase to another.

Significant environmental impacts of a product should be identified through the application of a life cycle assessment (or simplified versions), and requirements and priorities for environmental improvements should be set according to the results of the study.

Typically, the following principles should be considered:

- Optimise consumption of materials and resources across life cycle
- Reduce emissions (air, water) across life cycle
- Low energy consumption
- Enhance Re-usability and Recycling potential
- Concepts for easy dismantling or recovery at end of life waste disposal should be considered
- Minimization of use of hazardous materials / substances

According to products significant environmental impacts, external requirements, and company's internal policy and objectives, examples of environmental design recommendations can be formulated as follows:

- Minimize the use of hazardous materials
- Reduce the number and types of materials used, rationalise the types of polymeric/resins used and have them compatible to ease recyclability
- Increase the use of recycled materials in product design, including packaging
- Minimize generation of waste at plant level
- Design for disassembly and better recyclability
- Select low energy.

Phase	Proposal	Category
Design phase	Reduce the energy needed to manufacture maintain and use our products	Energy efficiency
Design phase	Avoid or minimise use of hazardous materials or any environmentally unfriendly materials	Hazardous materials
Design phase	Avoid materials that need high energy consumption during raw materials phase and no phase	Energy
Design phase	Design equipment easy to recycle	Waste / Resource
Design phase	Reduce the quantity of materials used in our products and develop materials that induce less environmental impact.	Waste / Resource
Transport	Optimise efficiency transport modes - Optimisation of logistic to ensure a full loaded transport	Emissions
Transport	Minimise quantity of material in a packaging	Waste / Resource
Manufacturing	Reduce and recycle scrap and waste from the manufacturing and by involving the suppliers (request on the contract)	All
Manufacturing	Reduce significant Environmental impacts whenever possible	All
Manufacturing	Involve Engineering when necessary to eliminate environment issues at the source instead of setting up end of pipes treatments	All
Operation	Minimise energy consumption during the operation phase by using lowest energy consuming tecnhologies and tools	All
Operation	Minimise consumables during maintenance operations	All
Operation	Optimise procedure to avoid or minimise the release of some product when not necessary	All
Operation	Optimise life time of product	All
Operation	Optimise operation around the product during its operation phase	All
Operation	Design for easier maintenance and repair through optimal manual maintenance and control of consumables solutions.	All
End of life	Minimise impacts of all possible	All
End of life	Improve possible recycling of parts and materials by putting in place of methodology to optimise the recycling potential during the design phase and avoiding incompatible substances that interfere with the recycling process	All
End of life	Ensure an easy removal of any hazardous material	All

3.3 Develop DfE Tools

A distinction can be made between analysis tools and improvements: analysis tools are used to identify the environmental impact of a product throughout the life cycle, whereas improvements tools facilitate and assist designers to improve the environmental performance of their product.

It is clear that the suitability of the tools will vary according to the product design stage, and, in particular, to the decision contexts in each of these stages. Figure below illustrates the range of DfE tools available and the most suitable phases for their application in the design process.

Analytical Tools

The analytical tool supporting DfE is Life Cycle Assessment and streamlined versions.

Environmental Management System standard requires the application of an environmental analysis methodology to identify the company's significant environmental impact. If the scope of the system includes the product, a life cycle assessment methodology should be developed and applied to the company's range of product to identify key impacts. However the results may not be directly applicable in the design process to influence decisions. Indeed, the usefulness of the technique to practitioners is still very much under debate. Designers often express the need for a practical tool to review tradeoffs between different criteria to support decision-making in the development process. There have been several attempts to make the tool more "user-friendly" through the use of indicators computed by specific software or streamlining techniques.

Some examples are given below:

- Eco-Indicators

The Eco-indicator 99 has been defined as a user friendly tool, compatible with LCA methodologies, which designers can use to simply calculate eco-points for materials and processes. The method is well suited for the comparison of components or assemblies using alternative designs Based on the compilation of indicators. As there is a wide range of life cycle data commercially available for standards materials and processes, limited time and resources would be required to apply the method on a standard component. However, designers are considering more and more advanced lighter materials, specific to aerospace such as GLARE (metallic fibre laminate), for which life cycle information would not necessarily be available commercially. In these cases, a life cycle inventory on a new material or novel technology would need to be performed internally by the business to enable the compilation of a suitable indicator, implying use of considerable time and resources.

- Simplified Life Cycle Assessments (Qualitative or Semi Quantitative Matrixes, Specific Categories, Checklists)

There are numerous examples of such tools developed by industrials or academics, company matrixes. The concept of simplified LCA matrix is flexible and allows organisations to develop a tool according to their own needs and considering their own limitations. It is clear that there are many aspects to consider including the depth and breadth of analysis, valuation, and aggregation. The validity of the method should however be judged on the following criteria:

- All relevant lifecycle phases should be evaluated
- All relevant environmental stressors should be evaluated
- The SLCA should include "LCA's four elements" but these need not necessarily be approached in a quantitative manner refer to the SLCA guideline.

These tools have been developed with the same objective in mind: the application of the life cycle thinking or the Design for Environment concept in product development and design. In the recent years, a number of innovative LCA based methods have been developed involving computer models, to enhance the usefulness of the technique by incorporating new dimensions or capabilities.

Improvement Practices and Tools

Other approaches have also been proposed to support the Design for Environment concept using more simple straightforward tools such as questionnaire or checklist (materials and chemicals lists), design guidelines, or even simple education of the designers. The manual published by UNEP, “a promising approach to sustainable production and consumption”, is a step-by-step plan which allows businesses to initiate and carry out their own ecodesign project, and is based on the traditional, systematic development process.

The aim of this type of method is to point to key issues such type and characteristics of materials used, energy consumption of manufacturing processes, ease of dismantling or transportation requirements. The designer is then encouraged to think about these aspects and use common sense to select design options with less environmental impact, for example, favouring light materials and less resource intensive manufacturing processes. Corporate policies and legislative influences can also lead to the definition of key design for environmental strategies. These would be supported by specific “improvement tools” as described below:

- Product Life Extension
- Material Life Extension
- Materials Selection and Reduced Intensity
- Process Efficiency
- Efficient Distribution
- Improved management Practices

Analysis tools such as LCA assist the incorporation of environmental issues by showing what the environmental issues are and the priorities that need to be addressed. DfE practices that are problem solvers are necessary once environmental priorities have been identified. Due to the breadth of environmental issues, a range of improvement practices are required to offer specific advice, the best known are listed below:

- Design for recycling
- Design for disassembly
- Design for remanufacture
- Hazardous material minimisation
- Design for energy efficiency
- Compliance with regulations and standards

In most DfE programmes, these improvement practices would consist of design manuals developed to inform and guide the decisions of design staff. These manuals provide the rationale for undertaking DfE initiatives including corporate policies and legislative influence.

For successful implementation, potential tool users require proper understanding of the tool objectives and methods, as well as adequate environmental knowledge, in particular of the organisation's policy and strategy, and legislative influences in the matter. Design for Environment shall be implement at each level of design actors and shall not be included as a specific way to work but in a normal way to design aircraft, like safety.

The training should outline the common DfE objectives for all actors in order to ensure synergy within the company. The inclusion of DfE principles in design guidelines is essential to ensure successful implementation.

Examples of DfE improvements tools include:

Simple qualitative information for key compliance issues such as hazardous substances

List of prohibited substances: A listing of substances banned by legal regulations that are applicable to aircraft industry.

List of hazardous substances: List of substances which, from a point of view of industrial safety and health and environmental protection, may represent some hazards and shall therefore be avoided or replaced. Generally, those are substances subject to strict legal restrictions or for which legal restrictions or even prohibitions are to be expected in the near future.

Practical guidance for eco-efficiency improvement: Procedure integrated in the design process

3.4 Organisational issues

Beyond the introduction of environmental analysis tools in the design process, the integration of environmental aspects in product development must also consider organisational, communication, and management issues, as well as other product-related activities such as research, procurement, and supply chain management, as guided by ISO14062.

General Aspects

Adopting environmentally responsible design practices is likely to involve significant changes in organisational values, practices and procedures, breaking entrenched habits of thought and practice to take on board new ways of thinking. It is clear that the implementation of changes to enhance environmental improvements needs to be organised in stages with a careful examination of potential issues linked to the organisational structure and technical decision-making. In particular, the appointment of the right individuals in key positions need to be addressed.

For example environmental managers and experts need to be appointed in aircraft programme development teams. They should be assigned responsibilities and accountabilities to ensure all environmental requirements are met and drive the realisation of improvements through effective intervention in decision-making process.

Ideally, environmental functions and competencies for product design and development should be organised and structured in all relevant disciplines supporting the Product development team in particular research, core engineering, quality, procurement and manufacturing. This multidisciplinary approach is important to ensure all relevant business functions are involved and committed to environmental improvements throughout the process. Communication, management considerations are detailed in paragraph below.

Communication issues

A communication strategy is an integral part of the process of incorporating environmental aspects into product design and development. This should address both internal and external communication (ISO14062).

The synergy of objectives and the effective communication/discussion related to environmental issues between different functions as mentioned above, are essential to ensure consistency in the approach. Effective internal communication must be supported by top level policy, training and reports providing information on product and site environmental impacts, such as external reports communicated to all key stakeholders. Training and education is essential to reinforce environmental awareness amongst all personnel.

Management considerations

The process of integrating environmental aspects into product design needs top level management support to have a significant effect on an organisation's product development activities. In particular, the allocation of sufficient financial and human resources and time for the tasks involved in integrating environmental aspects into product design and development is essential, and would support the organisational issues detailed above.

Management should also take part actively in the definition of environmental vision, policy, objectives and targets for product environmental performance, which then be cascaded in top level product requirements for consideration by the aircraft development team.

Research and Technology

The research and technology group has the important role to steer technology and concept research and development, and to bring capabilities and possible solutions for future product which will respond to the challenges ahead. In essence, new technologies should enhance the aircraft performance in many ways. In particular, in terms of safety, efficiency, cost, reliability and, of course, environment. Obviously, one key challenge concerns the very long timescale involved, as there could easily be a decade between the time when research work on a technology commences and the time when it is fully integrated and operational in the product. The maturity of a technology is an essential criterion for its selection in the design process and years of development may be required to reach a suitable maturity level for optimum integration in the product.

In aircraft design, we can distinguish the high level concept research, which is undertaken by the same competent group completing the feasibility studies (future projects), and the detailed technological research, undertaken by key competency groups such as aerodynamics, structures, systems and equipment.

At concept research level, advanced or innovative aircraft configurations such as the flying truck, pro active green, or the challenging flying wing may be investigated with a view to establishing key criteria and technological requirements for airworthiness. The technological research will focus on the component or systems level, looking at new materials and fabrication technologies, or new systems, etc. Although the technologies investigated will not impact the product performance until their selection by the product design teams, the consideration and evaluation of environmental parameters is essential at this early stage. Indeed, the environmental benefits associated with certain technologies or concepts can be used to influence further development and even support decision making in the later. The difficulties of assessing the true environmental impacts of the technologies at this stage lie with the following aspects:

- Visibilibity of major environmental problems in the long term: climate change versus ecotoxicity?
- Assessments are likely to be generic and not applied to components with specific design data and manufacture conditions
- As new technologies, only experimental data for environmental input/output can be used to perform the assessment

However, one key advantage at this stage is the long timeframe for development which should allow for opportunity to ensure consideration of environmental aspects. The same types of tools in particular those recommended for the concept phase, are likely to be suitable at this stage to compile environmental information such as inputs (water, energy, materials) and outputs (emissions, waste) on the technologies, especially for materials and manufacturing processes, as once again, life cycle information should be considered bearing in mind the limitations listed above.

Supply Chain Management

Supply chain management covers interaction with suppliers, subcontractors, carriers, etc. These interactions are likely to vary upstream and downstream, depending on the influence the organisation can have on the supply chain. As a complex product, a large proportion of aircraft parts and items are designed, manufactured and procured for the Original Equipment Manufacturer. In this respect, the supply chain plays an important role in overall product performance, and the following actions are examples of good practices to be implemented to control, monitor and improve supply chain impacts (ISO14062):

- Increase environmental awareness among supplier and customers (e.g. distribution of company environmental policy and strategy with environmental report)
- Assess supplier's performance (questionnaire targeting aspects such as existence of environmental policy and organisation, formal systems to ensure legal compliance, certification to recognised EMS such as ISO14001 and EMAS), encourage the uptake of best practices (especially for SMEs)
- Formulate specific requirements in technical specifications and contract documents, such as avoidance of certain materials and requests for detailed information on the chemical composition, for example, of major hazardous items
- Involve suppliers in environmental programmes such as research programmes for replacement of hazardous chemicals such as chromates, or metals such as cadmium, beryllium or lead

To succeed in the implementation of DfE, the organization within the company will be a key factor. It will ensure there is a single policy and will set up common objectives and targets. The SPOEMS approach is important to federate site and product objectives and to show the single common path to be followed, and also to set a common pace for the company.

Moreover, the company commits itself to the continuous improvement of its products, which can increase the DfE.

Integration in a complex organization will therefore be done progressively, to obtain new competences and knowledge from the actors for an environmental friendly design. The continuous development of internal competences and the product shall be performed with the same level of commitment:

- Environmental awareness among supplier and customers
  (e.g. distribution of company environmental policy and strategy with environmental report)

3.5 Barriers/Obstacles

The structural inertia inherent to a large and complex organisation designing safety-critical systems will almost inevitably lead to a lengthy process of change. This process can only be accelerated by tougher regulations and more apparent financial incentives for environmental actions. This would strengthen the business commitment, and certainly facilitate the progressive greening of the organisation, as has been the case in other industries such as fast-moving consumer goods, electronics, and to some extent the automotive industry.

Basically, the recognition of the importance of environmental issues in financial and commercial terms, and the willingness to take positive action towards protection, must be present in the organisation to overcome change barriers. However, it is clear that the implementation of changes to enhance environmental improvements will need to be organised in stages, with careful examination of potential issues linked to the organisational structure and technical decision-making. In particular, the synergy of objectives and effective communication/discussion related to environmental issues between different functions, as well as the appointment of the right individuals in key positions, will have to be addressed. Obviously, the uptake of DfE tools and techniques will only be possible if these can be completely integrated in existing design practices, with minimal disruption to the designers. These also need to be adapted to adequately support the achievement of the environmental objectives determined by the business.

IV. Examples

4.1 Incremental Improvements

Environmental incremental improvements in the product mostly concern the manufacturing/maintenance processes. They will therefore mainly influence the manufacturing and assembly phases, and to some extent the end of life with regards to dismantling and ease of disassembly. For aerospace products, these are not considered as dominant from a global point of view as the operational phase, especially considering the length of aircraft life in service and the key stakeholder requirements associated with aircraft operational environmental parameters.

The potential for environmental improvements should therefore focus on the reduction of air, water and land pollution on local sites through the introduction of environmentally efficient processes with optimised energy and resource consumption requirements, as well as minimum waste generation potential. The introduction of criteria to improve dismantling and recycling of assemblies and parts at the end of life can also constitute an environmental improvement.

The aim of this type of approach is to point to key issues such as the EHS characteristics of materials used, the energy consumption of manufacturing processes, air and water pollution associated with the manufacturing, ease of dismantling or transportation requirements. The designer or decision-maker is then encouraged to think about these aspects and use his judgment to select options which will improve and optimise the environmental impact of the process, for example by favouring less resource-intensive or hazardous-materials-free manufacturing processes.

Current corporate and legislative concerns, likely to act as the main incentives for environmental improvements in this type of decision context, include:

- Reduction of hazardous materials usage, as a result of various regulatory incentives and stakeholder expectations
- Eco-efficiency of manufacturing technologies for reduced environmental cost (low resource consumption, reduced local pollution, waste minimisation)
- Compliance with operational permit conditions for local sites in terms of air emissions, water discharge and waste disposal

These can be completed by more global environmental considerations so that the product can anticipate future concerns for the business, such as:

- Sustainability of aircraft materials
- Ease of dismantling or disassembly of the aircraft and its parts
- Optimised re-use and recycling of aircraft parts and materials

Customised checklists are likely to constitute the most suitable tools in this context. For example, materials on the black or grey lists, or basic checks on process eco-efficiency or material recyclability and dismantling issues are likely to be straightforward tools for engineers to integrate in their working practices at this stage of the project. Since trade-offs involving environmental aspects are unlikely, as the design is almost finalized, environmental optimisation of selected manufacturing processes with customised checklists integrated into standard procedures or manuals appears to be an appropriate solution.

On this basis, a questionnaire containing approximately 25 questions was compiled as an example to assess performance against the above 3 criteria for the following design features:

Materials

The characteristics of the materials selected, in terms of their toxicity, density, recyclability, scarcity and potential for re-use, as well as their variety and easy identification for end of life are the main aspects evaluated as part of the questionnaire.

Assembly Techniques - Construction

Optimisation of the variety of materials/components used, and compliance with maintenance/ dismantling/disassembly requirements are the focus of the analysis in this section.

Manufacturing Processes

The efficiency of the process in terms of energy and resource consumption, recyclability of the manufacturing tool and the optimal use of the semi-finished products are the key aspects to be characterised through the questions raised.

The questionnaire was applied to a component of the wingbox, Upper Cover: Stringers + Skin, to compare the environmental efficiency of two manufacturing solutions. This example was selected because it illustrates two very different manufacturing processes also involving a change of structural material, which will facilitate the identification of variations in environmental impacts.

Case Study: Manufacture of Upper Cover (Skin and Stringers), wingbox component.

Solution 1

Materials: Carbon Fibre Reinforced Plastics
Manufacture: Pre-preg, Lay Up, Autoclave
Assembly: Co-curing

Solution 2

Materials: Aluminium 7150
Manufacture: Machining + Degreasing + Surface treatment (blasting, anodising, pickling, painting)
Assembly: fastening

A. Design Criteria

	Solution 1	Solution 2	
1	No	No	Are standard semi-finished products used whose shape closely resembles the final contour, leaving no unused areas that will become scrap?
2	Yes	Yes	Has the variety of materials in use been optimised?
3	No	Yes	Can the materials used in composite/assembled structures still be separated?
4	Yes	No	Can the materials used be identified easily? (Guideline for Identification)
5	No	Yes	Can the materials in use be recycled or disposed of without problems?
6	No	No	Can recycled materials be reused for the product design process?
7	Yes	Yes	Have the materials / bulk materials been checked for their inclusion on the list of prohibited and restricted substances as defined within Airbus?
8	No	Yes	Can the materials / bulk materials used be stored indefinitely?
9	No	No	Has the combination of surface protection and component materials been optimised by skilfully selecting the materials?
10	Yes	No	Do the surface protection systems and sealants used contain any additives that are on the black or grey list?
11	Yes	Yes	Is the quality level of the surface protection as high as necessary and as low as possible?
12	N/A	N/A	Can supplies such as hydraulic fluids, oils, etc. be purified?

B. Constructions

	Solution 1	Solution 2	
1	Yes	Yes	Has the variety of materials employed been optimised?
2	N/A	N/A	Has the variety of components employed been optimised?
3	Yes	Yes	Have the number and variety of fasteners employed been optimised?
4	Yes		Has the variety of bulk materials (bonding agents) employed been optimised?
5	No	No	Has the construction been adapted to assembly/disassembly requirements?
6	Yes	No	Has the construction been adapted to maintenance requirements? (e.g. quickly removable non-permanent joints, simple exchange of parts subject to wear, etc.)
7	No	Yes	Is the construction easy to repair?
8	No	No	Have materials containing hazardous substances been classified into groups?

C. Manufacturing Process

	Solution 1	Solution 2	
1	Yes	Yes	Has the use of the semi-finished products been optimised during development of the process? (as little scrap as possible, length/width, fibre orientation)
2	No	No	Has the energy with the smallest impact on the environment been selected for the manufacturing process?
3	No	No	Are the tools required for the process recyclable?
4	No	No	Are only environmentally friendly bulk materials used for the manufacturing process?
5	No	No	Have the manufacturing processes been represented in a simulation and have they been optimised?

4.2 Technological Change

At the concept stage, design activities are broken down into subsystems, assemblies and parts. The parameters defining the environmental performance of these subsystems should be adapted, bearing in mind that key operational parameters such as noise level, CO_2 or NO_x emissions cannot easily be decentralised into subcomponents, except notably for engines. However, a change in technology at assembly or part level can have significant impact on the aircraft's overall environmental performance, for example through weight reduction when introducing a lighter material. To illustrate this, it was calculated that the use of carbon fibre reinforced plastics instead of traditional alloys on primary aircraft structures could lead to 20% weight savings, which can be translated into 9% fuel burn reduction and equivalent cuts in CO_2 and SO_2 emissions.

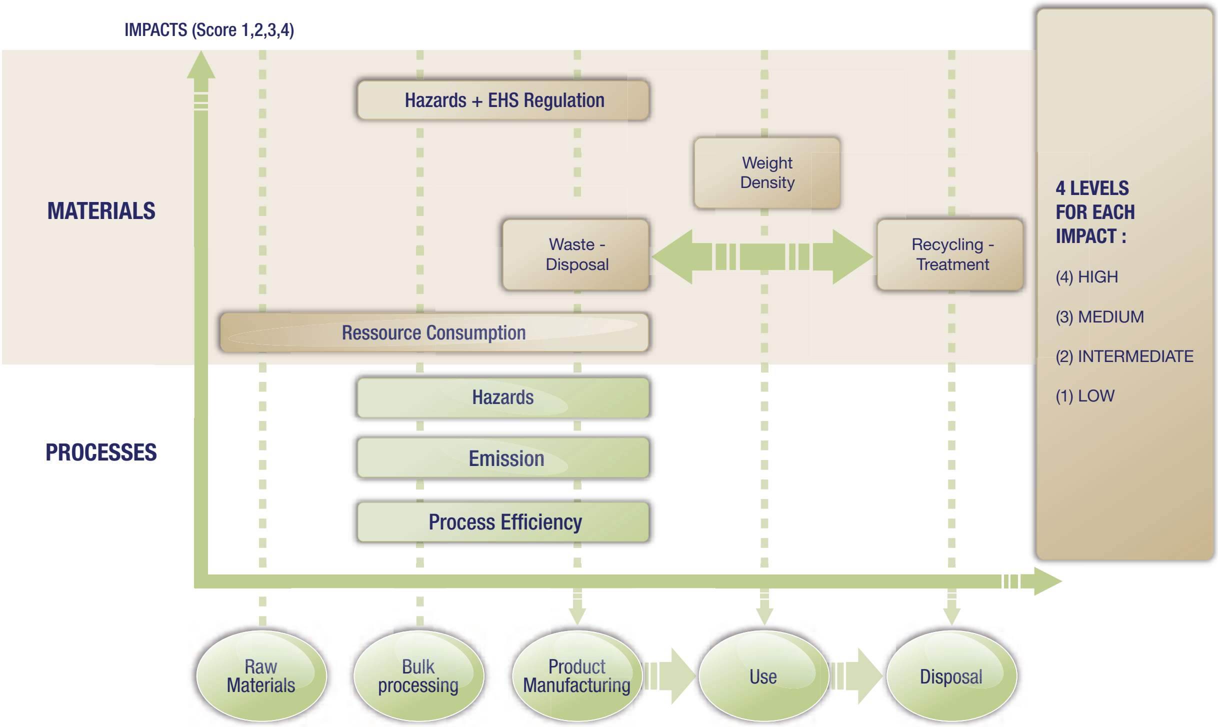
The design methods employed by engineers during the concept stage have a strong procedural element - most technical aspects and associated requirements are documented in manuals, handbook or procedures, from bolting policies to aerodynamic requirements and materials corrosive and protective treatment. When trade-offs or compromises between criteria have to be reached, this normally occurs through design reviews where figures and facts are presented and discussed in a semi-structured way. In this respect, there is a need to provide information that meets the following requirements:

- Specific requirement: checklists (restrictions on particular materials or substances, guidance on type of energy media, etc), or more top level: optimised life cycle performance or end of life aspects.
- Tool included in procedural documentation supporting the design process.
- Information in a format which lends itself to discussion (e.g. the weakness of an indicator is that it is not very transparent)

The most suitable tools for providing information include design procedures with checklists, life cycle matrices or tables with a metrics system that allow the environmental options to be ranked:

- Detailed Checklists
- LCA indicators
- LCA Matrix or Tables

A semi-quantitative LCA matrix-based methodology is illustrated in the Figure below. As a first step, life-cycle data for the relevant parameters associated with materials is compiled and analysed. This analysis is complemented by the evaluation of the major environmental impacts of associated manufacturing processes, according to the criteria defined in the Table below. This tool serves to capture key environmental aspects for materials and processes used in the design of structural parts and assemblies on a life-cycle basis, without the need for extensive quantitative data. The matrix-based format also facilitates a quick comparison of evaluations between technologies.



Proposed Environmental Indicators Based on DfE Criteria	Overview of Data Requirements
1. Toxicity (Human Health and Environment)	Hazardous Constituents - Intrinsic toxic properties (risk phrases) - EHS regulatory/classification aspects
2. Resource Efficiency - Material Usage - Energy Consumption	Materials availability Materials sourcing Energy/Resources usage in - Raw Materials extraction - Materials manufacture / forming / shaping
3. Disposal (Options) - Landfill - Recyclability potential - Re-use potential (lower grade for alternative use or same grade for similar use)	Amount and Quality of Waste materials in - Production - Manufacturing Processing Options for component at EOL
4. Density - Component Weight reduction -> fuel savings and reduction in emissions	Density of Materials

Overview of data requirements for Materials Indicators

Environmental Indicators Based on DfE criteria	Overview of Data Requirements
1.Toxicity HSE - Chemical Hazards - Physical Hazards	Intrinsic toxic properties and EHS regulatory aspects of Hazardous Materials in - Process Materials (aircraft) - Process Consumables (non-aircraft)
2. Process Efficiency - Energy Efficiency - Resource Efficiency	Process Energy sources and requirements Process Materials and Consumables usage/quantities (cycle time)
3. Emissions (pollution) - Air Pollution - Water pollution - Waste generation	Discharges to Air - description + quantities (regulatory impact) Discharges to Water - description + quantities (regulatory impact) Waste generation - description + quantities (regulatory impact)

Overview of data requirements for Process indicators

Below are presented the main characteristic of the two materials.

Functional unit: Production, Use and Disposal of 1 kg material.

Toxicity	☺ Intermediate (2)
Resource efficiency	☺ Intermediate (2)
Disposal	☺ Low (1)
Density	☹ Medium (3)

Table 1

Customised LCA matrix - Aluminium Alloy 7051

Typical Carbon Fibre Reinforced Plastics (Pre-Preg)

Toxicity	☹ Medium (3)
Resource efficiency	☹ Medium (3)
Disposal	☹ Medium (3)
Density	☺ Low (1)

Table 2

Customised LCA matrix - Carbon Fibre Reinforced Plastics - PrePreg 977-2 (50% to 60% resin, 50% to 60% carbon fibres).

Supporting Comments

Toxicity

Carbon fibre and resin have a relatively high score, mostly due to the associated risk phrases which include toxic, dangerous for the environment, and some mutagenic resins.

Resources Efficiency

The production of composite materials (carbon fibre and resin) requires high energy levels compared to already energy-intensive aluminium. 1 kg of composite requires 6 times energy more than for 1 kg of aluminium.

Disposal

The recyclable potential of aluminium is much higher than for composite materials. Aluminium can be easily recycled in existing dedicated facilities. For example, aluminium swarf produced on manufacturing sites can be sold to metal smelter companies. Currently, composite scrap is difficult to recycle, and is either land-filled or incinerated. The main issue is the non homogeneity of materials which are made of a matrix (polymer, epoxy) and fibre (glass, carbon, aramid, etc.). Some composite materials used in aircraft parts (floors, nacelles), such as honeycomb structures, are even more difficult to treat as they are made of many different types of materials, such as plastics, adhesives, glues, cardboard. Although technologies such as pyrolysis have been developed, when the fibres can be recovered, the low volumes generated have often prevented their implementation in a commercial environment, so far. Grinding is now increasingly used as a first step in treatment, the materials are then used in the steel industry as filler or incinerated. Considering the long life cycle of the product, there are obvious uncertainties and data gaps with respect to the viability of these techniques at the end of life.

Density

Composite materials have a much lower density than typical Aluminium alloys, thus offering the potential to design much lighter parts.

V. Conclusions

As a result of different types of pressures and incentives, each relevant decision context in aircraft design brings its own specific implementation of different levels of environmental improvements. These can only be successfully achieved if two conditions are met:

1. The incentives for improved environmental performance are clearly visible for the business, and have been appropriately translated into design requirements, through specific targets or objectives or the application of key procedures.

Whether the incentives are of a regulatory nature, derived from customer requirements or the results of company policy or commitments, they must form part of the design requirements at the onset of the programme, so they can be considered throughout the process in a timely manner. Based on examples of decisions, which have led to environmental improvements, these incentives need to be very clear and visible by all parties concerned by the decision, to enable trade-offs with other key parameters, if and when required.

When the decision concerns strategic improvements such as the reduction of noise levels to comply with specific airport standards, then trade-offs are possible with key performance parameters such as fuel burn and operating cost. However, in other cases, environmental improvements can only be achieved if there is no detrimental effect on safety, technical performance and cost. Searches for substitutes for chemicals such as sealants and paints containing hazardous substances are good examples of this. Alternative environmentally-friendly design solutions are developed and qualified to the same standard to ensure no compromise is made in terms of safety and technical performance. In these cases, although long-term cost is reduced, design changes and associated research, development, certification and industrialisation activities will have cost implications which need to be justified by design requirements.

2. The information on the environmental performance of the design options should be transparent, relevant and in the right form, so that it can easily be integrated as a parameter in the relevant decision-making process and support potential improvements.

As a result, the application of life-cycle thinking in decision-making needs to be guided by appropriate tools and methods. Due to the complexity of the aircraft, composed of thousands of parts, and the massive supply chain implications, the full data requirements of standard LCA methods are just too great to be manageable. The specificities of the aerospace sector need to be reflected in the tool customisation exercise, in particular limitations in terms of detailed data availability, uncertainties due to a long life cycle and characteristics of the design process decision-making.

In the later phases of the design process, design solutions are almost completely finalized. However, the optimisation of aircraft part manufacturing processes can lead to incremental environmental improvements during production activities, as well as maintenance and end-of-life phases, thanks to the support of checklists, design guidelines focussing on materials compliance with toxicity and recyclability requirements, and eco-efficiency criteria to optimise the use of energy and resources and minimise the generation of waste.

During the concept phase, key decisions such as the selection of aircraft structural materials can affect the local and global impacts of the product in various life-cycle phases. Whilst contributing to fuel burn reduction, reduced noise nuisance and reduced impact on local and global air quality, weight savings achieved through the use of advanced lightweight composite technologies may also worsen the environmental performance of manufacturing sites by lowering the overall efficiency of the materials and energy and reducing the possibility of recycling scrap. This type of decision is a clear example of where there is a need to integrate life cycle techniques to ensure no arbitrary shift of the environmental burden from one phase to the other. Streamlined LCA methods, such as matrices using simple metrics for key parameters, will enable designers to see the environmental impacts of different design options and to appreciate the significance and variation of these impacts for the different scenarios. As a result, fair balance and trade-offs can be identified and adjustments made in the design definition process to optimise life cycle impacts, whenever possible.

In addition to the design functions, DfE should be integrated in research technology projects, where there is more time available to support the compilation of relevant environmental data for specific technologies. Relevant information should be collected from suppliers, such as the presence of hazardous substances in bought items, to ensure that the entire business plays its role in the integration of environmental considerations in product development.

Abbreviation

DfE: Design for Environment

LCA: Life Cycle Analysis

EMAS: Eco Management and Audit Scheme

EMS: Environmental Management System

SLCA: Streamlined Life Cycle Assessment

SPOEMS: Site and Product Oriented Environmental Management System

UNEP: United Nations Environmental Program

SME: Small and Medium Enterprise

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