AN APPROACH TO IMPROVE AIRFRAME CONCEPTUAL DESIGN PROCESS

Hendri Syamsudin, John P Fielding
Aerospace Engineering Group
Cranfield University, UK MK43 0AL

Keywords: *Airframe, Conceptual Design Process*

Abstract

Designing an airframe is a very complex activity, as it has to meet a list of very stringent requirements to satisfy customer, airworthiness and company objectives by synergising important aspects that are very often conflicting with each other. The designer must consider the method of fabrication and tooling for each individual component and the operating environment on the part that they design.

The intention to rush into detail design analysis by taking few concepts could result the designer optimising a non-optimum concept. The opportunity to explore more effective structure could be easily missed and or problems found at later stage where the cost to rectify the problem is already un-economical to do.

Conceptual design stage is critical as design decision made during this stage would commit between 60% of total cost. Meanwhile the actual cost spent is around 5% of total development cost.

The paper demonstrates the proposed method to allow better a decision making process during conceptual design stage. It works by structuring the process using best practices in industry and providing the information that would allow the designer to check their design including the critical elements from other disciplines.

The accompanied knowledge based tool helps to reduce the time and effort normally spent to acquire information on critical aspect of aircraft structure. By having this structured information, the designer can interactively question his/her design and make any possible improvements during the 'synthesis' activity. It will help designer to explore their creative thinking in complex product modelling and decision making more effectively.

The generated airframe concepts are then rated based on the product performance, the fabrication and assembly characteristics, and the reliability and in-service requirements. These three major parameters are the most representative of the product to satisfy the customer requirements. The rating result does not necessarily represent the concept chosen. It shows the strong features and weaknesses of certain concepts. The objective is to allow the designer to make decision to carry on with the highest rating or to improve certain concepts based on a certain strong feature. The technique is simple and meaningful for the designer in selecting the concept. More importantly, it gives more responsibility and control for the designer to satisfy the main requirements.

The paper concludes that the approach and accompanying tool enable the designer to systematically exercise the critical aspect on requirements, component functionality and the effects of any design decision on manufacturing and maintenance. The series of check list and rating process helps in establishing sound and economical concept that meet the specified target.

1. Underlying problems

To understand the likely methodology used in the structural design, it is critical to understand the reason of methods adopted by industries.

It includes the understanding of the overall design process and the contribution of each discipline to each stage and the interface between them during conceptual design stage. Integrated product development philosophy is to ensure that essential requirements are considered during the trade studies of structural arrangements include functionality, producibility, and maintainability.

It should be borne in mind that the airlines will have further or different requirement when selecting aircraft for their fleets. To facilitate this, the manufacturer should present trade-off analysis whenever departure from the basic requirements permit advantages in weight, performance or DOC, taking into consideration specific characteristics of the design, such as the size of aircraft, number of engines, engine power, growth potential, range, family concept.

If we look at the last 50 years of commercial aircraft history [1], the concept generated and selected is driven by different factors, such as weight driven, cost driven, and performance driven, etc. Each of these drivers pulled a distinct characteristic to the concept.

Weight is probably the most common driver in airframe design process. Minimum weight is essential for the success of an aircraft and this not just by optimising the main load carrying structure but also by careful attention to detail. An example in Niu's book [2], shows one of the example where by increasing the stringer pitch while increasing the skin thickness (weight) but in overall reducing the weight by reducing the number of fastener and clips. In addition it increases the flutter boundary. The use of light material and associated manufacturing process are required to achieve the weight target. The development of advance aluminium alloy, advance composite, and titanium alloy with super plastic diffusion bonding are the result of this driver.

Cost is becoming more important since the recent crisis and the airlines face a very stiff competition in order to stay in the market. The manufacturer has to produce an aircraft that provides a cheaper operating cost whilst maintaining or improving the existing performance. These balance all relevant aspect of technology, manufacturing to achieve the target.

The cost driven has changed the design and manufacturing relationship. The design objective used to be performance which is translated to minimum weight. Experience has shown that this is not the main factor, as the cost of high performance material which is expensive and difficult to be fabricated and assembled outweigh the weight saving. Experience also shows that the product simplicity, reduce part number, redesign fabrication and assembly sequences, and 'parts availability/off the shelf material' will be the primary ways [3].

Figure 1 shows the effect of several stages in committing the cost. Production stage has little effect on cost saving but in other hand any changes during this stage affect to significant amount of cost. In essence making the concept producible is bringing the risk down and eliminates the unnecessary rework during later stage.

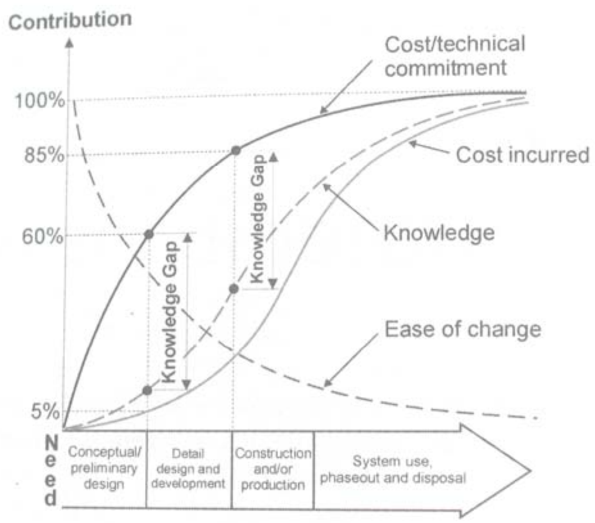

Figure 1: Design cost committed [4]

A good starting point for cost reduction is to provide possible alternatives available in making a design. It is often impossible to determine the best alternative without careful analysis of the probable manufacturing cost. Designing for function, interchangeability, quality, and economy requires a careful study of product quantity, production rate, tolerances, surfaces, finishes, processes, materials, and equipment [5].

The manufacturing problems can be reduced or eliminated by considering the manufacturing and assembly aspect during the conceptual stage. The selection of material for example, would dictate the type or manufacturing process, and tolerances related to it. The size and complexity of product would dictate the manufacturing process and assembly activity. If the above problem could be understood at the very early stage, and with the input from best practices in manufacturing and lesson learned from past experience then the problems could be avoided at minimum cost.

The understanding of company capability and the available technology and supplier would broadened the understanding and also reducing the risk of producing concept(s) that is difficult to manufacture or supplied by vendor.

In addition to the above aspect, the product is also designed to be able to be modified cost effectively to fulfil the future requirements, such as product family. The design team would need to consider whether the change in configuration to accommodate the change in requirement could be produced cost effectively using the available tools and jig and then the product family could be maintained without the need for additional investment for the maintenance.

These consideration lead to the following objective during the development of approach to consider manufacturing for conceptual design stage.

1. the need to design a product that can be manufactured more cost effective, and robust to variation
2. the need to design a product that can be tailored to future requirement or different market without costly modification.

Reliability and Maintainability: The current generation of civil aircraft were designed for at least 20 to 25 years and up to 90 000 flights. These designed service goals are exceeded by many operators of jet and turbo prop. Future types of aircraft are designed for at least the same goals, but structure with higher fatigue life (endurance), higher damage tolerance capability and higher corrosion resistance are required to minimise the maintenance cost and to comply with the requirements of the operator and the enhanced airworthiness regulations [6]. This leads to decision about maintenance practices. Hence much interaction between reliability and maintainability.

The reliability requirement is important aspect in conceptual design. The use of in-depth FMEA and FTA can only be done after detail design is done. If during design work the consideration is given to the probability and of an event occurring and its consequences, then the quality of design work will be improved [7].

Therefore, for the designer it is the principle of risk assessment that is significant rather than the knowledge of a complex analysis method

2. Airframe Synthesis process: Conceptual design stage

The following process as shown in figure 2 is developed to allow most of the above problems to be included in the synthesis process. An effective trade study of the above requirements would ensure minimum iteration time and cost at later design stage.

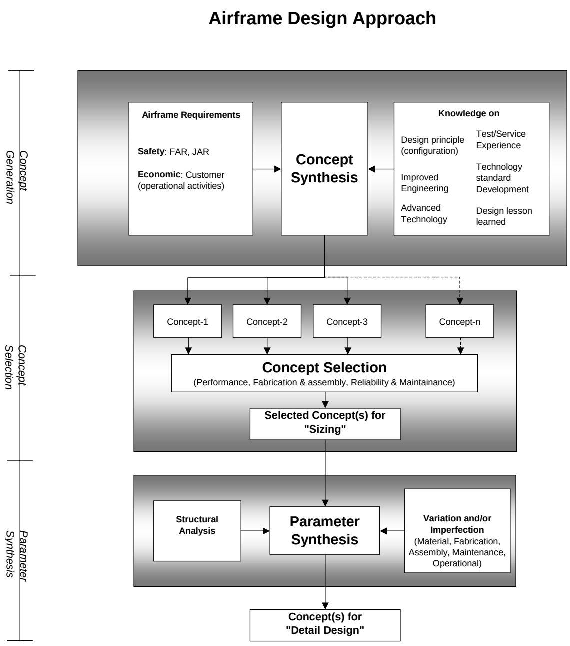

Figure 2 approach for airframe design

The process is started with the synthesis activities and concept exploration. It consists of three major elements, i.e. requirements, synthesis, and product knowledge.

The requirement block provides the technique on how the design specification is consistently maintained throughout the product development process and product breakdown. The lesson learned on failure of the past projects due to wrong set of requirements are provided.

The synthesis block is where the activities of generating concepts performed. It investigates the effects of structural configuration and arrangement toward product performance and economics. Fabrication approaches to reduce manufacturing and assembly cost is highlighted.

The generated concepts illustrate major structural arrangement and major point of interest for assessment of design and manufacturing risk and assessment of life cycle cost.

The critical information to support the synthesis activities is structured based on major parameters, such as configuration, fabrication & assembly, and in-service, to ensure a comprehensive investigation on certain concepts. The accompanied knowledge based tool helps to reduce the time and effort normally spent to acquire those information. By having this structured information, the designer can interactively question his/her design and make any possible improvements during the 'synthesis' activity. This information will help designer to explore their creative thinking in complex product modeling and decision making more effectively.

The generated airframe concepts are then rated based on the product performance, the fabrication and assembly characteristics, and the reliability and in-service requirements. These three major parameters are the most representative of the product to satisfy the customer requirements. The concept with the highest rating does not necessarily represent the concept chosen. It shows the strong features and weaknesses of certain concepts. The objective is to allow the designer to make decision to carry on with the concept with the highest rating or to improve certain concepts based on a certain strong feature. The selection technique is simple and meaningful to support the designer in selecting the concept. More importantly, it gives more responsibility and control for the designer to satisfy the main requirements.

Additional study and development will be performed toward the selected concepts. The candidates would be refined to the point all primary and secondary members are defined, located and roughly sized for the loading and integration requirements of the baseline design space. The design and development efforts for the selected concepts must also include the integration of major manufacturing and process requirements.

In addition it also includes an assessment of major interface and integration requirements of the major system, such as propulsion, landing gear, etc., that affect the design. From these, preferred structural concept shall be developed into more detail design stage.

3. Conceptual design support tool

Airframe design involved several disciplines to ensure a competitive product. During conceptual stage, the information about the product is little whilst the implication of decision is great. Sufficient experience on the airframe design and enough information on relevant disciplines are essential for designer to make good compromise. The use of CAD and FEA are not critical and has little impact on how designer create the concepts. These tools are more useful at later stage.

For airframe analysis there are many well-established and efficient tool to perform detailed calculations of areas such as Static and dynamic analysis of airframe, reliability, damage-tolerance, mechanisms, tooling and fabrication simulation. The aircraft manufacturers have been extensively integrating these to create a seamless analysis tool to reduce the development cost and time to market.

The tools to support synthesis activities at the conceptual stage are much less developed compared to the analysis' tools. This is due to the complexity of the problem of modeling and the way of designers makes judgments. The solution is normally context sensitive and the problems are ill structured so that the computers cannot easily model and simulate them. The method to solve this problem is to use reasoning, decision-making on the basis of special domain knowledge and the designer's experience.

The knowledge based tools is developed to support the process. The information was gathered from established literature, such as journals, working group papers, etc, and combined with material from visits and discussion with experts in industry and academia.

The database is developed electronically and can be accessed on the internet/intranet so that any necessary information, which is not normally available to designer without extensive surveys, will only be clicks away. This database could potentially be useful to retain as much knowledge as possible from the experts. The screen shot of the tool is shown in figure 3. The most challenging task during the tool development was to make the information not overwhelming to the user and adaptable for different product development stage. The result is an intuitive knowledge based tool that can be used in assisting the designer in variety of complex decision making problem during conceptual design.

The knowledge tools are structured based on the following major issues:

- Requirements of Customer's and Airworthiness'
- Configurations from past and current designs
- Material selection
- Fabrication techniques
- Reliability & Maintainability

In addition it contains the glossary and case studies.

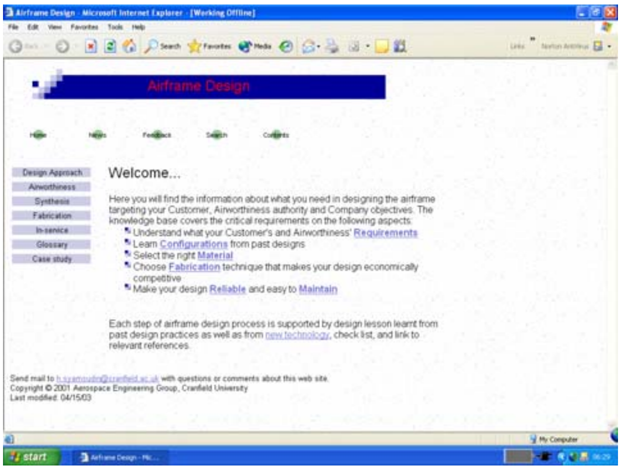

Figure 3. Screen shot of knowledge based tool

4. Wing structure design: Case study

The objective is to demonstrate the proposed approach and tool in the process of designing an airframe of commercial aircraft at conceptual stage. It will illustrate the processes, trade-offs, and decision making techniques necessary to produce a satisfactory airframe design. The advantages and difficulties of the approach then could be drawn for future investigation. Due to a very big area of discussion for the wing design, the discussion in this paper will focus on skin-stringer panel design only.

The aircraft chosen for the case study is the airframe design of wing of a 150-seat twin-engine high technology commercial aircraft designed to compete with the existing competitors [8]. The product must also have commonality with the existing product line and allow future derivatives, i.e. bigger and smaller version, with minimum production and maintenance cost. The following figure shows the wing configuration and the locations of aerodynamics strips.

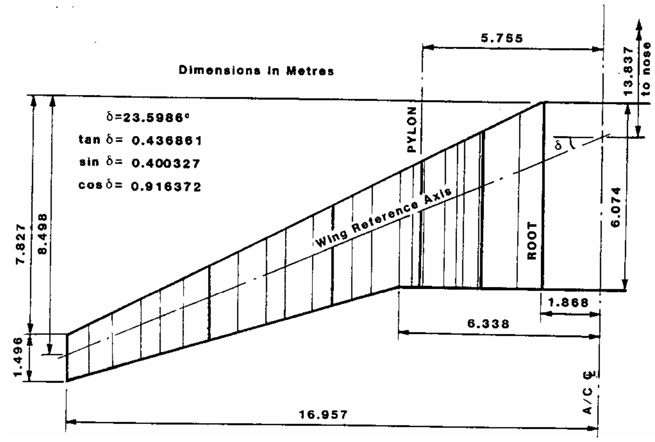

Figure 4. Wing geometry

The aircraft shall be fail-safe and damage tolerant and corrosion protection should be of a very high quality, taking into account worldwide atmospheric conditions. When applying new materials, such as, but not limited to, composites guarantees in terms of practicability and economic shall be given. Before these new materials are used, acceptable methods for inspection and repair by the operator in case of local damage shall have been developed and demonstrated.

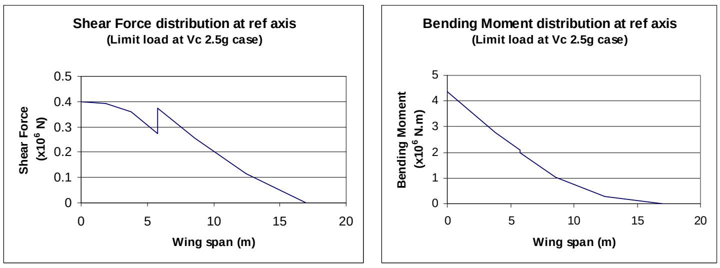

Figure 5 Design wing load distribution

Please note that UB90 aircraft is fitted with LAF or GLA which reduces the wing loads in gust to a magnitude similar to that of maneuvers loads.

Table 1. Airworthiness requirements to be justified in the case study [9]:

JAR Part 25	**Remark**
25.601	Structural principle
25.603	Materials
25.605	Fabrication methods
25.609	Protection of structure
25.611	Accessibility provision

The information on the airworthiness requirement is available electronically in design tool.

4.1 Structural principle

The product breakdown structure of wing box is shown in figure 6. For some non-conventional wing configuration, the product breakdown structure might be different.

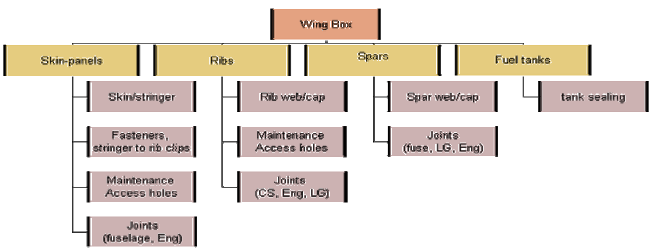

Figure 6 Product breakdown structure

The structure design features incorporates the latest approach to design and damage tolerant structures according to the current airworthiness requirements.

Various form of configuration for the main wing box are possible based on the utilisation of vertical webs and outer skin to form a box beam. For this type of airplane when the load intensity is moderate to high, it becomes practical to use the upper and lower skins between the spar to provide the main reaction to the spanwise bending. Thus the skins are constructed to carry the end load by supporting their area with spanwise stringers [11]. Upper and lower skin-stringer panel design is governed by the load type, i.e. compressive buckling load on the upper, and fatigue tensile dominant in the lower panel. Access panel will be required on the skin panel for maintenance purposes.

To improve the damage tolerant of structure, the skin panel construction is divided into a number of spanwise planks joined by cracking stopping butt straps.

The design of skin-stringer panel is supported by the tools by providing some practical information of typical constructions available. Several skin-stringer panel configurations are included in the concepts design. The supporting information on typical configuration is shown as follows:

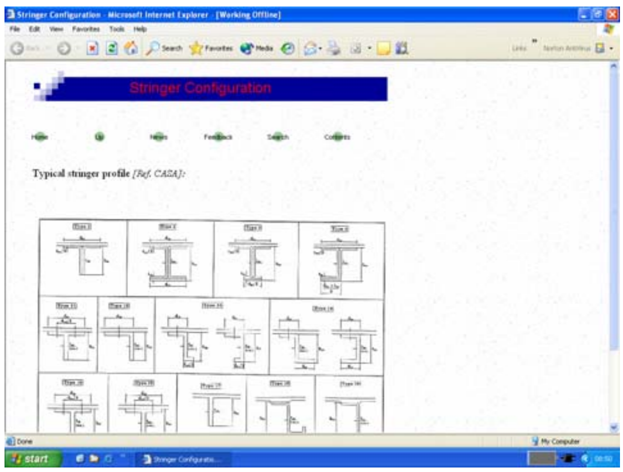

Figure 7. Typical stringer profile commonly used in transport aircraft

In which, practical information on the application of skin-stringer configuration on current aircraft configurations as shown in the following table are provided as quick guidelines during conceptual stage.

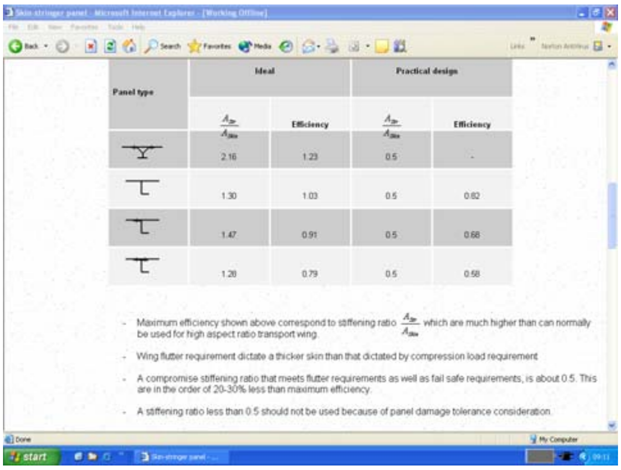

Figure 8. Practical design on typical skin-stringer panel (Data extracted from [2])

4.2 Material

The selection of material is driven by the characteristic of the material to resist the load type acting on the upper and lower panel, stress corrosion and damage tolerant characteristic. Data on material used by current airplane are most valuable as starting point due to its proven and well known characteristics during operational. The tool provided information on the type of material used by several current aircrafts. It contains the information on some of the progress achieved by the Industries in the application of new material for their new generation aircraft.

4.3 Fabrication methods

The assessment of manufacturing and assembly for the above concepts are assisted through a series of check list as shown in figure 9. The check list is generic in nature and therefore could be applied to different part of aircraft structure. The lower skin panel is curvature required by the aerodynamic profile definition. The construction is achieved using combination of incremental forming by mechanical press and compound forming by shot peening. The top and lower skin are machined and where possible pocketed to save weight.

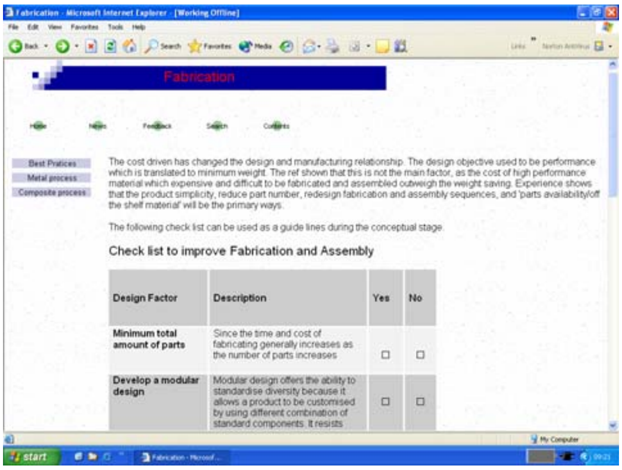

Figure 9. Check list to improve fabrication and assembly

4.4 Maintenance

Maintenance cost of airframe is largely depending on the direct labour cost 45% of total cost and 30% for material and subcontract. It is quite different compared to engine where labour constitute just 9% of the total cost where 52% is for the material and subcontract. The effect of component modularity and ease of inspection on the engine design and the high cost of high performance material contributes to this distribution. Therefore to minimise the maintenance cost of the airframe is to reduce/minimise/change the labour cost whilst keeping the cost for material and subcontracts the same or less. The effect of ease of inspection and repair shall be the subject of investigation.

There are three major structural damages on an aircraft, i.e. fatigue, environmental damage, and accidental damage. International air transport survey estimates that 36-40% of damage to aircraft is from ramp and maintenance damage, sometimes called friendly foreign object damage. The interfaces areas on aircraft structure with servicing and other equipment are especially prone to damage and require special attention to the use of robust material and protection. Potential solution and rating for maintainability aspect therefore can be classified into three major area, i.e. protection, inspection, and repair. The guideline for assessment of the concept maintainability during design stage is shown from the following screen shot:

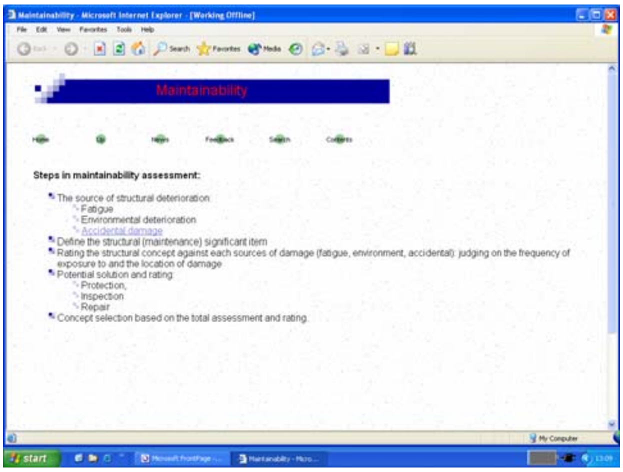

Figure 10. Maintainability assessment

Design rating technique is used to assess the strength and weaknesses of the concepts in which the designer has the freedom to either choose the highest overall rating or to choose less rating which has a strong unique feature and then make an improvement over the weaker area of the concept.

4.4.1 Protection of Structure

Utilising the information of the design tool, based on the past and current aircraft data, protection against corrosion is done for the entire structure by a range of protective treatment. Specific consideration is given to areas of high contamination and high condensation, where anodic corrosion between different material could occur. Aluminium material is treated with Alodine or Chromic acid. Non-corrosion steel is either cadmium plated or adequately protected. In areas which are subject to contamination by aggressive fluids are primed and painted with primer and top coat which are resistant to the fluid. To avoid water accumulation, the drain holes are provided in the critical areas.

4.4.2 Accessibility provision

The wing access holes are provided in skin panel and must be large enough for a man to go through so that the inside can inspected and resealed if necessary. On shallow wing section, the access has to be in the lower surface so that the maintenance people can work in acceptable way although they can not climb in completely. Apart from the sealing problems associated with the lower access panel, it is primarily a tension skin and so introduces stress concentration in area where crack propagation is a major consideration [11]. To this problem, man hole doors are machined elements, non load carrying except for some load carrying door in outer wing. Non load carrying door consist of inner sealed door and outer door shaped to wing profile.

5. Conclusion

The above discussion shows that the experience of designer on different aspect of airframe design is most important aspect to make the right decision during conceptual design stage. The use of the approach and accompanying tool enable the designer to systematically exercise the critical aspect on requirements, component functionality and the effects of any design decision on manufacturing and maintenance. The series of check list and rating process helps in establishing sound and economical concept that meet the specified target.

The process and tool are quite general in essence it could be used together with existing technique and tools used by Academia and Industries. The HTML format makes the use of information in the tool can be very easily accessible from any computer platform.

So far, the quick analysis software, such as loading analysis, sizing, etc, have not been integrated with the design support tool, which bring this task available for future work.

Reference:

[1]. Jupp, J.A. - British Aerospace Airbus Limited, ***Driving down product introduction costs - The "Airbus Experience"***, The Royal Aeronautical Society, Directing and managing cost-effective design, 27 January 1998, London, UK

[2]. Niu, Michael C.Y., ***Airframe Design***, Conmilit Press Ltd, Hong Kong, 1991, ISBN 9 627 12809 0

[3]. ImechE, ***The manufacturing challenge in Aerospace***, ImechE seminar publication, 1997, ISBN 1 86058 111 0

[4]. Swift, K.G.; Booker, J.D, ***Process Selection***, Butterworth Heinemann, 2nd Ed, 2003, ISBN 0 7506 5437 6

[5]. SME, ***Design For Manufacture Handbook***

[6]. Schmidt, H.-J; Schmidt-Brandecker, B; Tober, G; ***Design of modern aircraft structure and the role of NDI***, appeared in ECNDT, June 1998 www.NDT.net/article/ecndt98/aero/001/001.htm

[7]. ***UB90 Design Project***, Bristol University, UK, 1990.

[8]. Thompson, Graham, ***Improving Maintainability and Reliability through Design***, Professional Engineering Publishing Limited, UK, 1999, ISBN 1 86058 135 8

[9]. JAA, ***Joint Aviation Requirements***.

[10]. McGuire, Jack; Varanasi, Rao; ***Boeing structural design and technology improvements***, appeared in Airliner, Apr-Jun 1996, p.12-19

[11]. College of Aeronautics, Introduction to Aircraft Structural Layout – Part 2, Cranfield University lecture notes, DaeT 9564, 1995