Chapter 2
Requirements, Development and Certification Process

Abstract The airframe material selection is decisive to determine target weights as well as manufacturing and operating cost of aircraft components. It is a prerequisite for production planning and long lead time items. In addition, it is key for identifying any material-related certification risks and for establishing the certification process planning and means of compliance. It is therefore very important to freeze the material decision for components well before a new aircraft is offered to the market. This chapter starts with a discussion of the development process of new aircraft and the definition of the basic milestones. Fundamental aircraft requirements of operators, authorities and airframe manufacturers influencing the material decision are highlighted, and the requirement cascade is introduced. The functional analysis method as part of the design process is explained followed by the description of the general procedure of the structure stressing and certification process. Special emphasis is put on the description of the "no crack growth" concept of CFRP structures.

Keywords Development of new aircraft • Top level aircraft requirements • Aircraft design goals • Requirement cascade • Design process VDI 2221 • Functional analysis • Design service goal • Limit load • Ultimate load • Safety factor • Reserve factor • Design load cases • Structure stressing • Certification process • Damage tolerance • Crack growth • No crack growth concept • Safe life • Fail safe • Impact • Compression after impact

Development Process and Requirement Cascade

Although graphs similar to the one shown in Fig. 2.1 have been and still are discussed in many textbooks, it cannot be stressed enough how important it is to use the early phase of a new aircraft development in order to carefully examine and smartly define product requirements. As the freedom of choice is still relatively high in the concept phase, large efforts have to be undertaken in order to trade different concepts and to find the best compromise to cope with operator, regulator (authorities) and manufacturer requirements. Towards the end of the concept phase more than 2/3 of the manufacturing costs are already fixed, and the freedom of choice rapidly decreases during the definition phase, when manufacturing drawings

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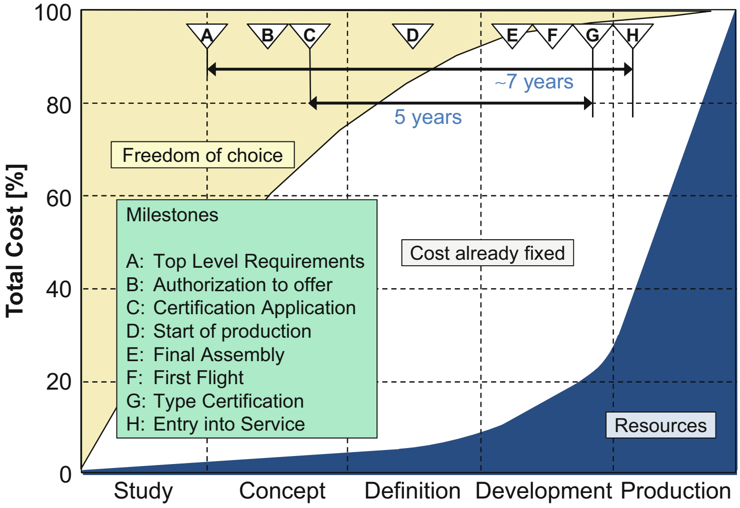

Fig. 2.1 Development phases and cost allocation

are being generated for all parts. In practice, this is also the time in which deltas are detected by detailed weight analysis based on CAD-models and supporting FEM-calculations, often indicating a weight above the target. Changes from the originally selected material to a lighter one (in order to reduce weight) are very difficult in such a late stage of the development process. Material qualification is a very time consuming and expensive process, and material changes can also impact production technology, for which long lead time items (tooling, manufacturing facilities etc.) are needed.

Providing a high amount of engineering resources as well as expensive test material and test equipment is necessary when developing a new civil transportation aircraft for commercial operation. It also requires the provision of a high amount of capital: The total development cost of a new transportation aircraft can add up to 10 billion euros. In order to limit the financial risk linked to this investment, aircraft manufacturers have a high interest in selling their new aircraft long before the first plane is tested and certified. In fact, the "authorisation to offer", signing contract orders with airline operators, usually takes place during the concept phase, some 7 years before entry into service, Fig. 2.1. The customer (the airline) buys a product that only exists on paper, and the seller (the aircraft manufacturer) guarantees a certain product performance without having defined, built or tested real design solutions for the aircraft. Hence, the risk of failing to meet important product requirements, probably resulting in price deductions, penalties or even order cancellation, must and can only be reduced by the intensity and quality of early concept studies and trades. This requires highly skilled experts.

The three main parties defining the most important requirements are the regulator (i.e. the government authorities, in Europe the European Aviation Safety Agency EASA, and in the U.S. the Federal Aviation Administration FAA), the operator (airlines) and the aircraft manufacturer, Fig. 2.2. The type certification of a new aircraft is provided by the regulator, and aircraft manufacturers are obliged to demonstrate that their new aircraft complies with all applicable rules. Safety standards are set by the authorities, as well as environmental standards. The manufacturer's goal is providing an attractive and successful product to the market; minimising manufacturing cost is a key requirement. In consequence, manufacturers are interested in using existing infrastructure and existing resources as much as possible. The operator is seeking product attractiveness for passengers (or freight) at minimum total cost of ownership; a low purchase price, low fuel and maintenance cost, high passenger comfort, maximum payload, range flexibility, cabin flexibility, superior take-off, landing and manoeuvring performance, a long service life (high resale value) and many more advantages are desired in particular. These requirements of regulators, operators and manufacturers can easily conflict with each other. The lightest material, enabling very low airframe mass and low fuel consumption, will very likely also be the most expensive material, leading to high manufacturing cost, to give only one example. High safety standards—a must for every airframe design—can also be a matter of high operating cost when affecting maintenance or repair. After all, a new aircraft, having to fulfil regulatory requirements for its certification, will always be the best compromise between operator and manufacturer requirements. This also means that requirements—most likely increasing downwards along the requirement cascade—are prone to changes and adaptions throughout the complete development process.

In order to capture, document and elaborate requirements, guide the design, validate design solutions and verify hardware (i.e. performing tests, demonstrating that requirements are fulfilled), all requirements are carefully recorded and organised in a cascade, Fig. 2.3.

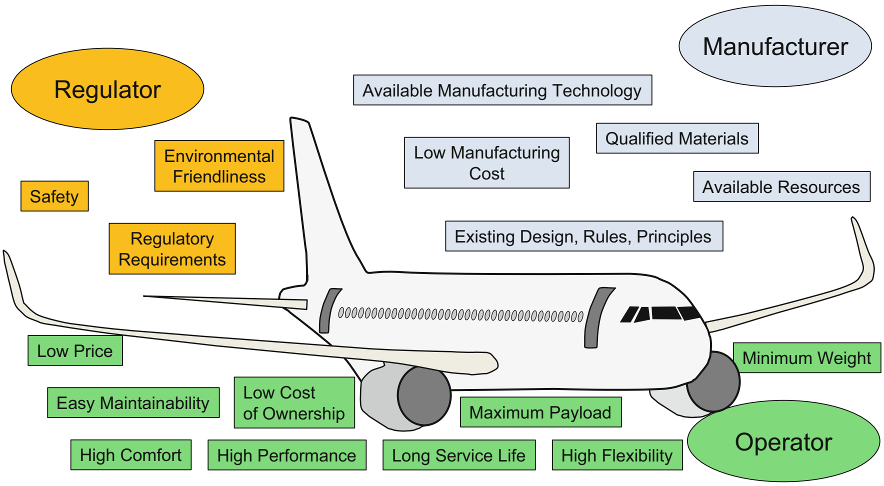

Fig. 2.2 Typical design goals of regulator (authorities), manufacturer and operator

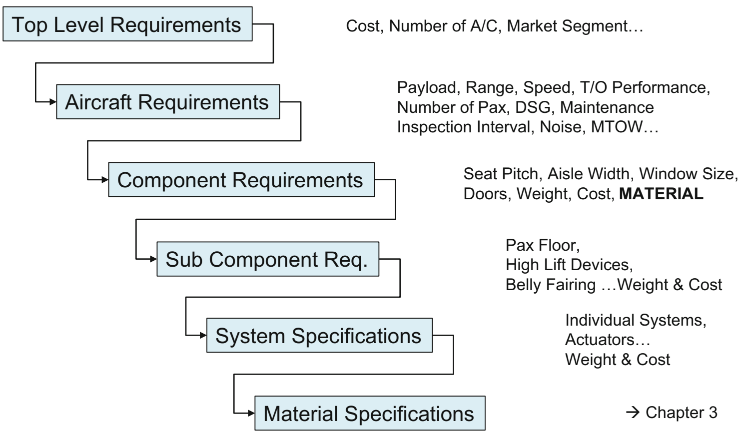

Fig. 2.3 Requirement cascade

The requirement cascade usually starts with top level requirements. These include the market segment (i.e. short range, medium range or long range aircraft), the number of aircraft to be produced, the cost etc. . . The aircraft requirements (see milestone A in Fig. 2.1, at which these requirements should be frozen) define for example the payload (number of passengers, weight or freight), range, speed, take-off and landing performance, design service goal (number of flights, total flight hours, years of service), maintenance, inspection intervals, noise etc. . . Any aircraft can be divided into its large components: wing, fuselage, tail plane, landing gear, engines. Examples for typical component requirements for a fuselage are diameter, length, seat pitch, aisle width, window size, doors etc. . . Weight and cost targets are defined on aircraft as well as on component and sub component level, down to individual parts. Material requirements can already be defined on component level, too, as the choice of material has a high impact on total aircraft cost as well as on development and production effort. Components can be divided into sub components. Typical sub components for the fuselage are the passenger floor, the cargo floor, the belly fairing etc. . . The requirement cascade continues with specifications for individual parts or systems. Finally, requirements for materials are a matter of the material qualification process, as discussed in Chap. 3.

The compilation, definition and documentation of requirements are extremely important. Many delays, unexpected high development costs, problems of industrial production ramp up, failures to meet contracted performance guarantees etc. are directly linked to missing, incorrect or conflicting requirements. Other complications may include non-functional yet solution-oriented requirement definitions, inadequate monitoring processes of design stages by validating intermediate design solutions, carefully analysing the fulfilment of requirements by the proposed solution, etc. . .

Design Process According to VDI 2221

An appropriate method for a structured design process is defined by VDI guideline 2221 [1] (VDI = Verein Deutscher Ingenieure), Fig. 2.4.

One of the most important steps is the precise definition of functions. In order to guarantee a thorough understanding of the product requirements at the very beginning of its development, functional analysis must be organised involving experts from all disciplines (structure, systems, aerodynamics). Functional analysis enable to think in terms of functions and not in terms of solutions. The precise definition of functions also helps understanding and identifying the root cause of unwanted intermediate product features (i.e. in case it is discovered that a design solution for a given part would lead to too much weight or cost) and consequently adapting the design solution, or challenging (and potentially changing) a requirement in order to meet more important requirements from superior levels of the requirement cascade. A good example for a purely functional requirement is: “The floor must be able to carry payload (maximum load 32 t)”. A bad example (as it is already solution oriented) in this context would be: “The floor structure is an aluminium honeycomb design capable to withstand a maximum load of 32 t”.

The basic procedure for a functional analysis is described in Fig. 2.5.

After a description of the product (step 1), the functions are systematically analysed (step 2) by a team of experts from different disciplines. Step 3 is the hierarchical organisation of the different functions, while step 4 characterises all functions. The final step prioritises these functions. An example is illustrated in

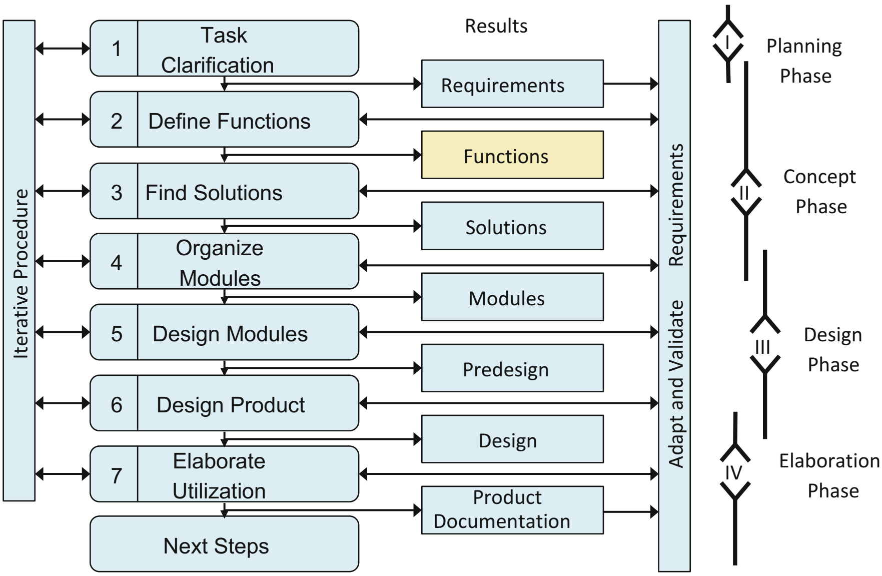

Fig. 2.4 Design process according to VDI 2221 [1]

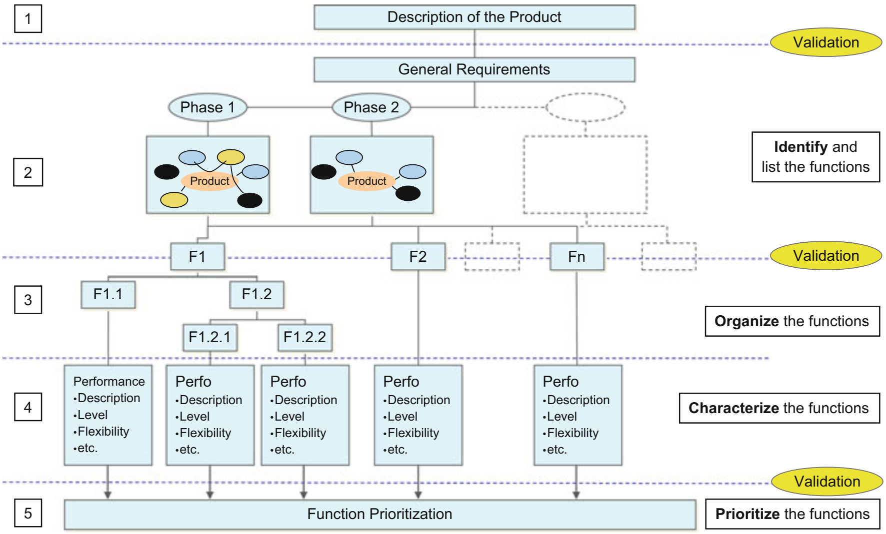

Fig. 2.5 Functional analysis process

Fig. 2.6. The product to be designed is depicted in the centre (step 1), surrounded by all elements that could interfere with the product throughout its complete life span. This requires the analysis to be individualised for all phases: assembly, handling, transport, test, operation, maintenance and disassembly + recycling.

In step 2, any important interaction between the surrounding elements and the product has to be analysed and recorded in a purely functional manner, i.e. as free of existing or new design solutions as possible. Some possible examples are given in Fig. 2.7. Once the functions are identified, they are organised within functional tree architecture (step 3) in order to facilitate the reading and understanding, and to identify sub or lower level functions, Fig. 2.8.

Step 4 deals with the characterisation of each individual sub (or lower level) function. Characterisation means that quantifiable criteria have to be defined, enabling designers to implement these characteristics in models and drawings, and enabling engineers to validate that requirements have been properly considered. Tables as shown in Table 2.1 can be used to record these criteria as well as to provide references to documents. They can also be used to record the result of step 5 of the functional analysis, the prioritisation. For this purpose, flexibility levels can be assigned to each criterion: F_0 could be used to indicate that the criterion is a must, F_1 could indicate flexibility, F_2 could indicate that the relevant criterion is just something “nice to have”. In practice, if at some stage of the design it turns out that the predefined solution is violating individual requirements, it is often a chief engineer’s decision whether a redesign is necessary to fully meet the requirement or if criteria for requirements are adapted.

In order to transfer functional requirements into design drawings, following the principal procedure described in Fig. 2.4, different design solutions for the

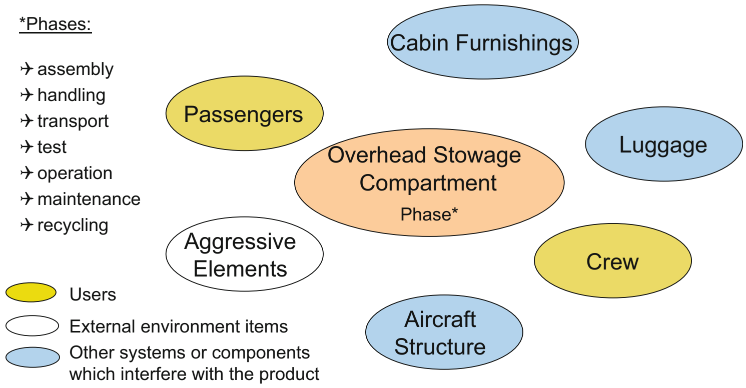

Fig. 2.6 Functional analysis example

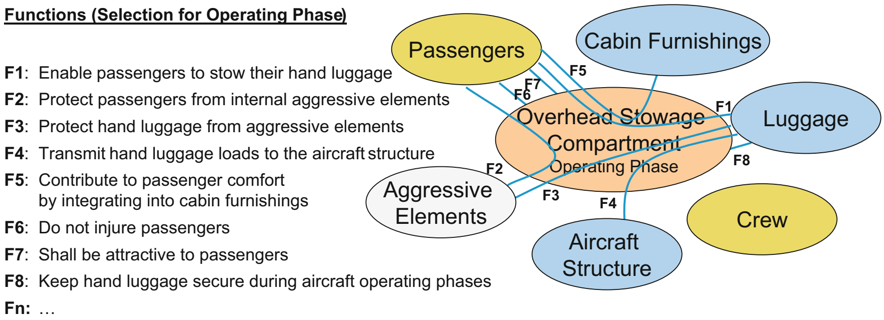

Fig. 2.7 Selection of possible functional requirements for the operating phase

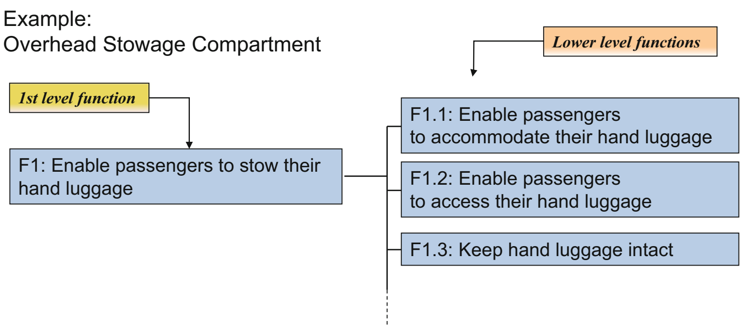

Fig. 2.8 Functional tree

functions can be traded, selected and combined by means of morphological boxes. The process is described in [2].

Table 2.1 Typical results of function characterisation (selection of examples, figures not to be taken for design)

Criteria	Level	Reference	Flexibility	Means of control
Volume of overhead stowage compartment	170 $dm^3 \pm 5\,\%$ or 56 dm^3 per passenger	Master geometry	F2	Design review
Shape of overhead stowage compartment	Parallelpiped constant thickness max. 25 cm	Master geometry	F0	Design review

Load Cases and Stressing

An important part of defining and refining design schemes is stressing. External loads are needed for calculating internal structural stresses and for sizing thicknesses (or to re-arrange the topology) for minimum weight accordingly. It is necessary at this stage to define some important terms:

- *Design Service Goal* (DSG) is an important aircraft requirement. It is the planned life time of the aircraft. The figure is provided in flight cycles (FC), years or flight hours (FH), and relevant for design an certification
- *Limit Load* (LL) is the maximum load to be expected by the airframe throughout the complete service life (DSG)
- *Safety Factor* (SF) is a factor applied for airframe design (usually 1.5)
- *Ultimate Load* (UL) is the product of LL and SF
- *Reserve Factor* (RF) is the relationship of structure strength (sustained load) and ultimate load. It should be $\geq$1.0.

The design service goal depends on the type of aircraft and the main missions it is designed for. The A320 was originally designed for a design service goal of 20 years or 48,000 flight cycles. The A380 was designed for only 19,000 flight cycles; however, the typical duration of a flight is much longer compared to the A320. The design service goal is not a life limit: Life extension is possible by means of adequate fatigue test results and positive in-service experience. Special maintenance programs are defined in case of a life extension. The design service goal is an important input for the assumption of load cycles that have to be taken into account for stressing purposes.

Steady load conditions and incremental loads of different phases have to be analysed. The most important phases are "on ground" and "in flight", Fig. 2.9, but there are other phases which can also be very important for structure design: During manufacturing or assembly, tool drops on structural parts can cause large impact energies and have to be taken into account for design and stressing. Ground load cases can be linked to braking, turning, freight loading and unloading operations etc. and have to take into account worst case conditions (i.e. temperature influences, media influences etc.). Typical flight load cases occur during manoeuvring and during gusts, but cabin pressurisation is also an important case. Accidental damages

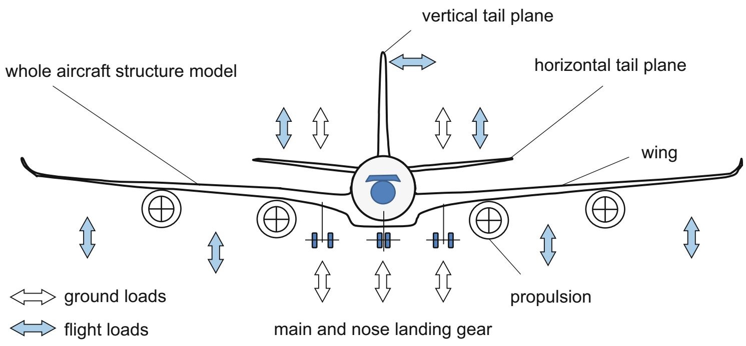

Fig. 2.9 Aircraft model and loads

and the resulting loads must also be assessed (for example depressurisation of the cabin or a tyre burst with broken parts impacting the fuselage).

To support aircraft manufacturers and to make sure that all important and safety relevant load cases are properly taken into account, the regulators (authorities) provide a catalogue of requirements applicable for certification. In Europe, this is the Certification Specification [3], in the United States it is the Federal Aviation Requirements (FAR 25) [4]. As the regulations defined by the authorities are also prone to updates and changes, the applicable set of requirements is fixed at the point in time when the aircraft manufacturer officially applies for the certification of a new type of aircraft being developed. This is usually linked to the milestone "authorisation to offer", Fig. 2.1, and the following board decision of the aircraft manufacturer to launch the programme or not, depending on the number of aircraft sold to the first customers. From this point in time, a maximum of a 5 years period is allowed to demonstrate that all requirements can be fulfilled for the type certification.

The general procedure for structure stressing and certification is:

(1) Definition of the aircraft geometry and its outer loft
(2) Generation of an aircraft finite element model
(3) External loading of the model with all relevant cases
as defined by the rules of the authorities, including safety factor application
(4) Calculation of forces, displacements and internal stresses/strains
(5) Comparison of sustainable stresses (depending on material allowables under the given temperature and media influences, wall thicknesses, topology, etc.) to internal stresses. This is supported by tests. Manufacturing and in-service damages have to be taken into account.
(6) Calculation of reserve factors
(7) Re-design for minimum structural weight

As the shape and mass of the aircraft are prone to changes during the development and are both influencing the loads, load loops can be necessary and lead to a redesign of parts, Fig. 2.10.

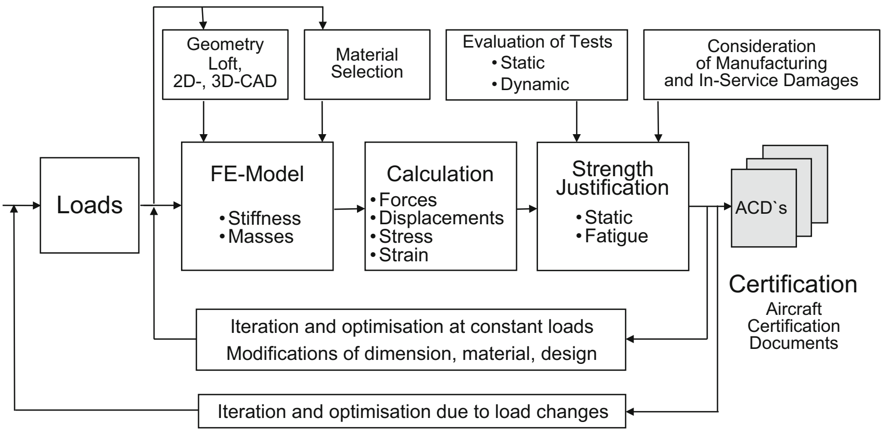

Fig. 2.10 General procedure of stressing and certification process

The goal of a thorough analysis is to calculate all relevant load cases for the part being designed, and to find out which load case is the most relevant one, i.e. leading to the maximum internal stresses and thus defining the dimensions of the part. Figure 2.11 illustrates some design load cases and resulting stresses.

Especially in the early phase of the development process these findings are very important for the selection of "the right material at the right place".

The basic structural certification approach is based on analysis validated by testing . Each critical loading condition is analysed in order to demonstrate compliance with strength and deformation requirements. A "test pyramid" is used to provide results at different levels of the design and development stage, and to verify that the structure fulfils all requirements, Fig. 2.12. The pyramid will be discussed in Chap. 5.

Damage Tolerance Requirements: The "No Crack Growth" Concept of CFRP

The applicable rules for relevant load cases, safety factors etc. defined by the authorities can only reflect the latest best available technology ("state of the art"). Since the new aircraft can contain new technology such as forward looking gust sensors and active load alleviation systems, structural health monitoring systems, new types of engines, unconventional wing architecture etc., it is necessary to assess any kind of certification risk already before the "authorisation to offer" and to discuss possible mitigation technologies with the authorities. It is also necessary to agree with the authorities on special analysis and tests to be carried to demonstrate that all risks have been properly assessed and can be mitigated by adequate design solutions or additional precautions.

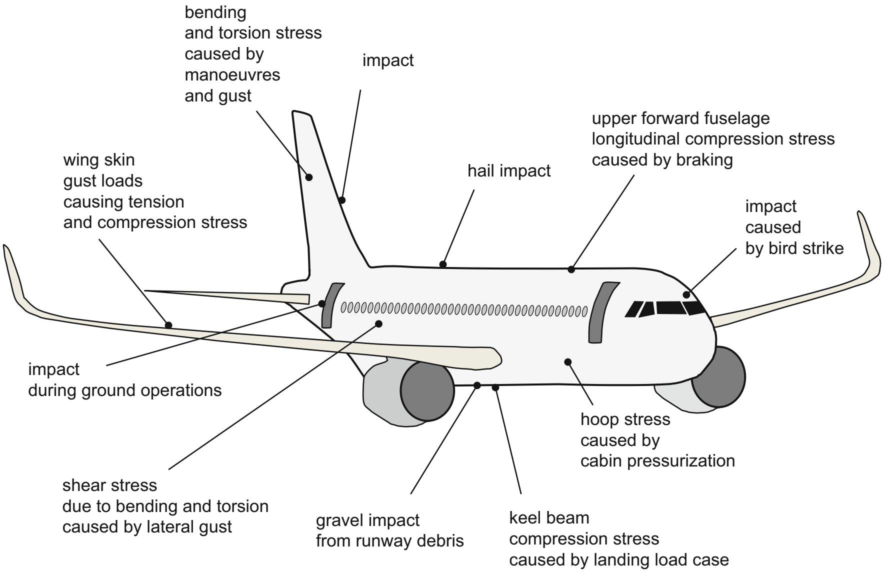

Fig. 2.11 Examples for design load cases and resulting stresses

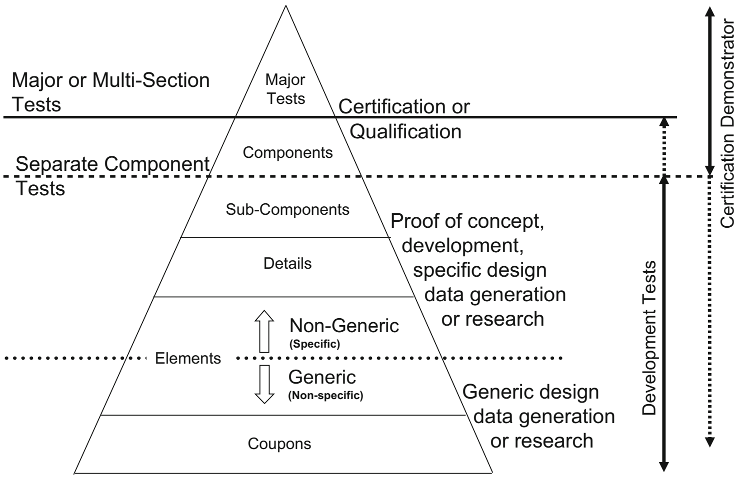

Fig. 2.12 Test pyramid (see Chap. 5)

Safety requirements have been revised and improved continuously [5]. Very important steps were

- Introduction of "safe life" requirements in the 1940s
- "Fail safe" requirements in the 1950s
- "Damage tolerance" requirements in the 1970s

"*Safe life*" means that the structure has a safe, limited lifetime. Analytical and experimental verifications with appropriate safety factors have to be demonstrated.

"*Fail safe*" means that different load paths are available. In case one load path fails, the remaining load path can sustain the load.

"*Damage tolerance*" means the capability of a damaged structure to sustain the loads until the damage is detected and repaired during a scheduled inspection (or if the damage leads to a non-critical loss of a function).

The damage tolerance requirements were revised following in-service incidents. A famous incident in 1954 was the explosive fuselage decompression of the De Havilland Comet 1 (DH 106-1, G-ALYP) on the 10th of January after only 1286 pressurised flights and less than 2 years of service, and the disintegration of a second Comet 1 on the 8th of April in the same year. An intensive investigation revealed metal fatigue as the main cause of these accidents [5]. As a consequence, the authorities demanded a certification either by fatigue evaluation of the airframe ("safe life" approach) or by a "fail safe" design, demonstrating that after failure of a single principal structural element catastrophic failure would not be probable.

Incidents in the 1970s (loss of an AVRO 748 in Argentina 1976, Dan Air B707 crash in Zambia 1977), the damage tolerance concept was included into the fatigue evaluation of the structure by the FAA [5].

Another very famous incident was Aloah Airlines flight 243 on April 23rd, 1988. A 19 year old Boeing 737 with 35,500 flight hours experienced a fuselage panel failure in 24,000 ft. The pilot managed to land with 94 survivors and only 1 fatality (a crew member). The result of the following examination by the National Transportation Safety Board revealed corrosion and multiple fatigue cracks, and the subsequent failure of riveted fuselage panel joints as the key origin of the incident (Fig. 2.13).

To prevent this kind of failure, a mandatory design process for damage tolerant structures was introduced:

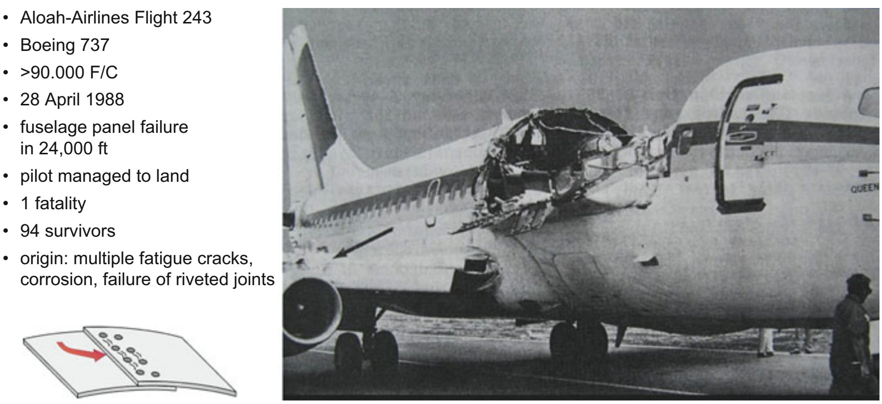

Fig. 2.13 Aloah Airlines Flight 243, image source see [6]

(1) Identification of structure critical elements
(2) Definition of the types of damages to be encountered
(3) Assessment of damage initiation time, propagation rate, critical size
(4) Definition of minimum detectable size
(5) Definition of inspection threshold, inspection interval, access and inspection method

Especially after the ALOAH accident, the authorities insisted on including manufacturing defects as a damage source. This has led to more safety, but also to additional development efforts as well as additional maintenance efforts (and costs!) in particular for conventional aluminium airframe structures.

The growth of a crack within an aluminium sheet is schematically depicted in Fig. 2.14. At a certain time (after a certain number of flight cycles), the crack reaches a length which reduces the residual strength of the structure to limit load. It has to be ensured by appropriate design (i.e. the selection of the right material, the sizing to an adequate thickness), that a crack detected during an inspection will not reach its critical length before the next scheduled inspection, Fig. 2.15. The length of the inspection interval also depends on the minimum detectable crack length. Typical values for the minimum detectable crack length (Visual Special Detailed Inspection VSDI) are between 35 mm and 70 mm, depending on light conditions and surface. Using special test equipment (High Frequency Eddy Currents HFEC), applied by specially trained and qualified personnel only, it is possible to detect very small cracks down to 1 mm length.

For CFRP, the “no crack growth” concept can be applied. If the maximum strain of a dynamically loaded CFRP structure is limited to a certain value (depending on the type of material typically to 0.4 %), cracks (delamination) within the structure,

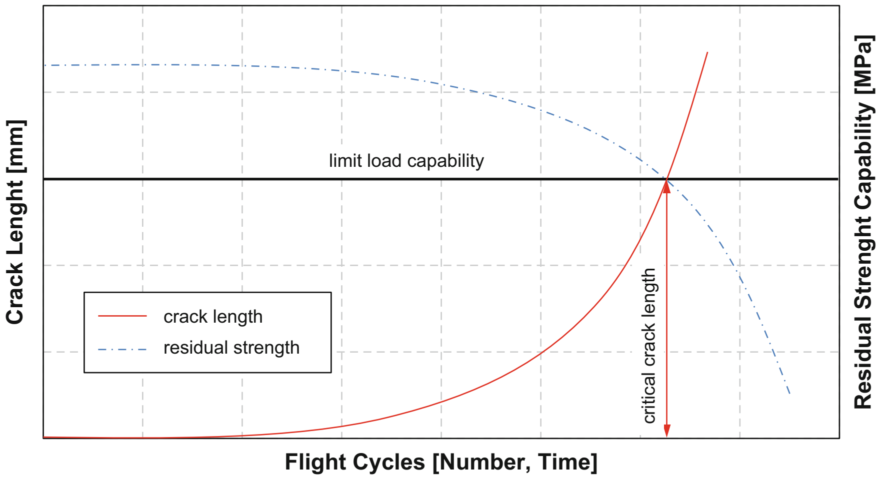

Fig. 2.14 Crack growth within aluminium sheet and residual strength capability

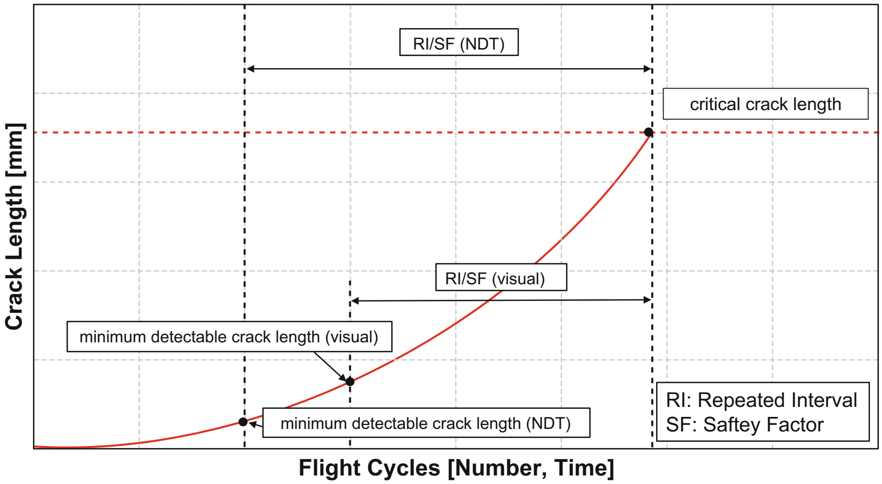

Fig. 2.15 Crack growth and inspection interval for an aluminium skin

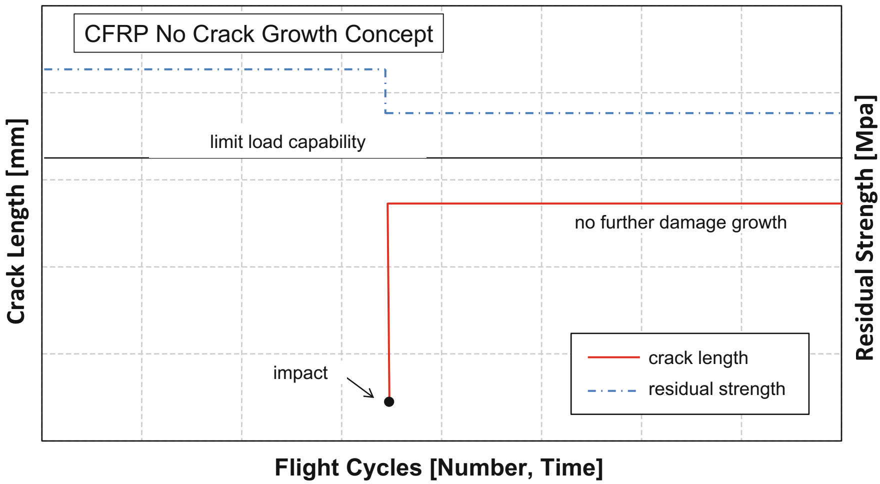

Fig. 2.16 Crack growth (usually delamination size growth) and residual strength capability of a CFRP sheet

as they can be caused by impact events, for example, will not grow. Figure 2.16 also refers to [7].

This CFRP design means a key advantage over classic aluminium designs, as it reduces the maintenance effort for the operating airline. Reduced maintenance time means less time in the hangar and more time to transport payload and create revenue.

As there are several impact events that can occur during aircraft service, Fig. 2.17, but even already during manufacturing and assembly of the aircraft, it

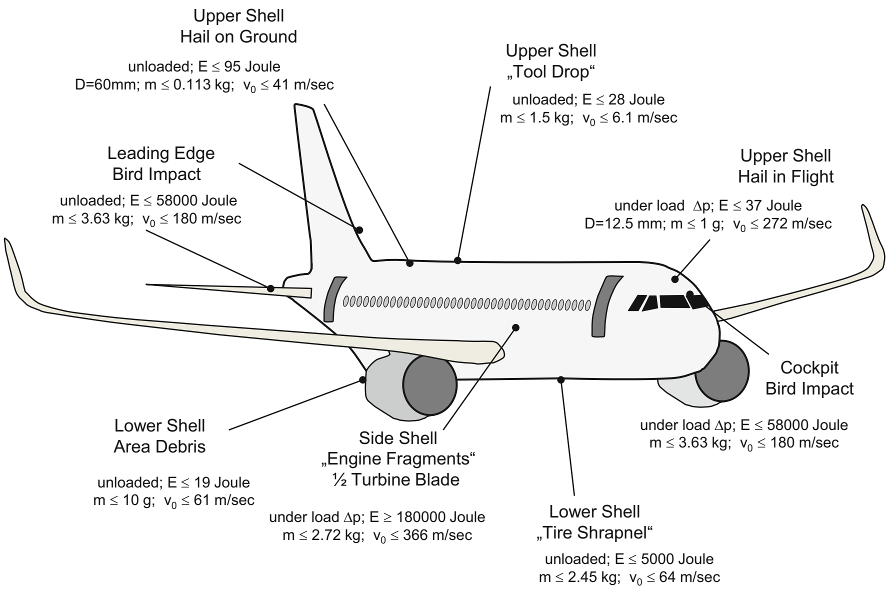

Fig. 2.17 Impact events (examples only, not to be taken for design, based on [8] and [9])

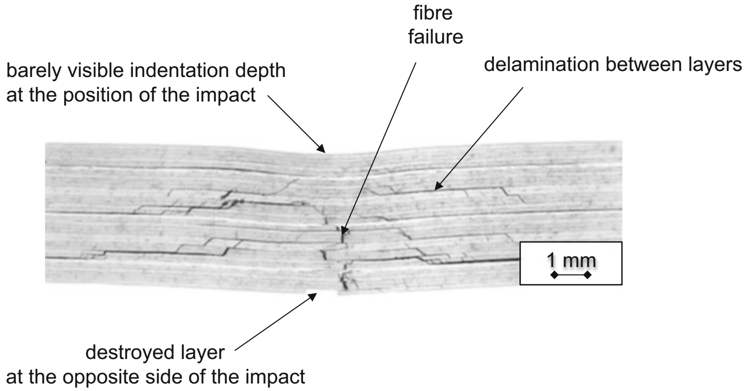

Fig. 2.18 Barely visible CFRP impact damage. The structure looks intact and faultless from above, although it contains severe damages inside

is necessary to take these impacts into account during the structure development, and to verify the “no crack growth concept” for CFRP by analysis and test.

Since impact events are also possible for CFRP, where damage occurs within the laminate structure (matrix failure, delamination, fibre failure) while no damage is visible from the outside, Fig. 2.18, it is necessary to design the structure in a way that provides ultimate load capability for these cases.

This damage tolerant CFRP-design, considering not only manufacturing imperfections but also impact damages below the visibility threshold, will allow a

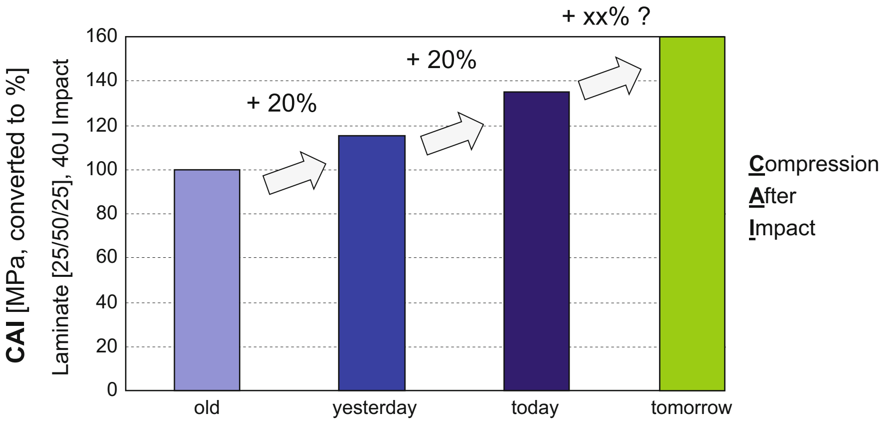

Fig. 2.19 Compression after impact strength, comparison of "old" 125 °C curing epoxy systems and new, toughened 180 °C curing prepreg materials

"maintenance friendly" aircraft structure in service and limit repair efforts of the operator: Impact damage that cannot be detected from the outside will not require any repair for the complete design service goal, see Chap. 6. On the other hand, this customer-friendly requirement of robustness can also come with a price in terms of weight, as a minimum wall thickness is necessary to cope with probable impact events. CFRP material manufacturers have constantly and successfully improved impact damage tolerance by toughening the epoxy resin, Fig. 2.19, and see also Chap. 3.

However, attempts to improve the impact damage tolerance by z-reinforcements, i.e. out-of-plane reinforcements such as pins, special yarns etc., have not been widely introduced into series applications so far, as these reinforcements degrade in-plane material properties with negative effects on the part weight.

Figure 2.20 shows the detectability (dent depth) of an impact versus the impact energy [10]. For realistic energy levels and below the detectability threshold, the structure must sustain ultimate load, following the concept of robustness. An impact event is assessed as realistic if it occurs once within 10^5 flight hours. The detectability threshold for a visual inspection of a CFRP airframe structure is typically about 0.1 mm dent depth. Up to extremely improbable impact events with high impact energies and an occurrence of one event within 10^9 flight hours (for comparison, the design service goal of A320 was 48,000 flight cycles; for typical 2 h flight missions this means less than 100,000 flight hours) and up to large visible impact damages, at least limit load must be sustained.

The size of "large" visible impact damages is defined by certification specification requirements, in case of new technologies and associated risks it has to be agreed with the authorities for the relevant structural parts. For a "thin" CFRP part, the detectability threshold is already reached at relatively low energy levels with a

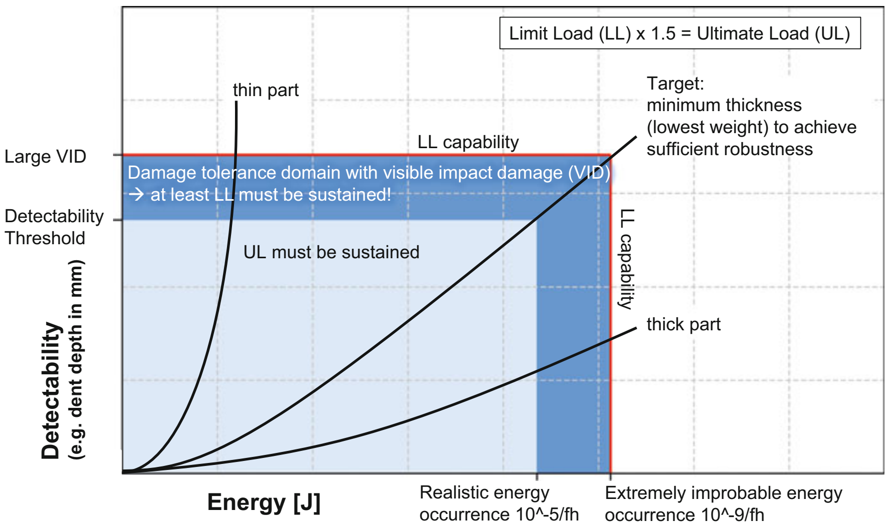

Fig. 2.20 Detectability of impact damages versus impact energy [10]

high probability of occurrence. This kind of light weight design would require frequent repair and is not favourable from an airline operator point of view. A "thick" part would never reach the detectability threshold (and thus never require any repair), but this over fulfilment of robustness would lead to a heavy design solutions. The optimum solution is the thickness that is just achieving enough robustness and sustains the loads for damages caused by the relevant impact events.

Certification Concept

A possible testing concept supporting fatigue and damage tolerance demonstration and complying with the applicable rules defined by the authorities within the certification specification document can be:

(1) The CFRP part is manufactured with a specially qualified material (Chap. 3) and a specially qualified process (Chap. 4). The maximum allowable manufacturing defects (porosities, delamination, etc.) and the maximum allowable (non-visible) impact damages are artificially introduced to the CFRP part.
(2) Dynamic loads are applied to the part, simulating a complete design service goal ("fatigue phase"). A load elevation factor is used and applied in order to compensate for any material strength reduction due to temperature and humidity. The factor depends on the type of material.
(3) The static ultimate load is applied, and the part must not fail.
(4) Visible and large impact damages are introduced to the part.

(5) Dynamic loads are applied for another design service goal (or a portion), and for this "damage tolerance phase" a load elevation factor is applied again to compensate for any material strength reduction due to temperature and humidity.
(6) A final test is made to determine the residual strength of the part, which should be above limit load.

Questions

1. How long does the aircraft development process typically take from the definition of top level requirements and the concept phase until the delivery of the first aircraft to the customer?
2. Why it is important to evaluate requirements (and possible solutions) of a new aircraft project at the beginning? What exactly needs to be assessed?
3. Which three parties play the most important role for requirements and the specification of a new aircraft?
4. What are typical general requirements for the development of commercial aircraft concerning manufacturers, operators and authorities?
5. Why are requirements from manufacturers, operators and authorities often conflicting? Examples?
6. Into which phases can the design process in accordance with VDI 2221 be divided?
7. During which phase of an aircraft product and component development would perform a functional analysis? Why?
8. In which phase of the development process of a new aircraft would you trade different materials? Why?
9. What is a functional analysis?
10. How is a functional analysis performed?
11. What is the benefit of a functional analysis?
12. What is a typical "design service goal" of a commercial aircraft?
13. Which typical structure loads do you know?
14. Where can you find certification relevant requirements for the aircraft structure ?
15. What are the typical phases of the certification process?
16. How do you principally proof, that the structure meets all safety and certification requirements?
17. How can you provide structural verification?
18. What advantage does the so-called pyramid test provide, and how it is structured?
19. What is "Limit Load", what is "Ultimate Load"?
20. What is a structure safety factor?
21. What is a structure reserve factor?

22. Why and how did the safety requirements for commercial aircraft increase over the past decades?
23. Prepare a simplified flow chart with the main steps of structure stressing and certification.
24. Is it reasonable to assume that load carrying CFRP structures which were damaged by impact show crack growth during aircraft operation?
25. Which typical impact damages must be considered when designing CFRP structures?

Exercise: Simplified Functional Analysis

1. Prepare a bubble diagram (see Fig. 2.6) to identify important functions of a passenger floor structure. Put the floor structure bubble in the centre and include all relevant elements in surrounding bubbles that might interfere with this structure throughout the complete lifetime. Distinguish at least the following phases: Assembly, Operation, Maintenance, Recycling.
2. Define the most important functions by reflecting the interfaces between the passenger floor structure and the interfering elements.
3. Define and describe the functions more precisely by means of a table with the following six columns: Phase (for all the phases stated in (1), Function, Criteria, Level (try to quantify each criterion), Flexibility ("must have" or "nice to have"), Means of Control (planned validation and verification). If a distinct criterion cannot be attributed to a single function, the function must be split further into its sub-functions.
4. Try to identify the most cost and weight driving functions, and provide some rationale.

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