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# DOCUMENTING TECHNICAL SPECIFICATIONS DURING THE CONCEPTUALISATION STAGES OF AEROENGINE PRODUCT DEVELOPMENT

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## 1. Introduction

Gas turbine aeroengines are considered to be an extremely complicated product to develop, design and manufacture. Their complexity originates from the large number of components that form the final product as well as the high standards, such as reliability, that these components have to meet in order for the engine to satisfy all the requirements of the main stakeholders. In order to deliver a high quality product, a set of detailed specifications has to be agreed and documented during the conceptualisation stage of product development. This is a critical step since the processes of capturing, structuring and documenting stakeholder requirements provides the foundations for successful design. It is then the task of designers to embody these requirements into the production of a conforming product. This paper provides an illustrative case study of how an aircraft engine original equipment manufacturer (OEM) generates the requirements from its product stakeholders and composes the necessary technical specifications for the design process. A model of the key requirements documents (bodies of information) and the essential relationships between them for aeroengine development is presented.

## 2. Research focus and approach

The accurate representation of a product's requirements from its stakeholders and the associated documentation from the early stages of a project, i.e. conceptualisation stage, is a critical factor for the ultimate acceptance and market success of the product. A focus on the documentation at the conceptualisation stage is very important since it is the information generated at this stage and the associated decision-making that has the greatest impact on the downstream design and manufacturing processes. According to Baya [1996], it is the supporting information handling at the conceptualisation stage that is "very likely to lead to significant betterment of design practice." At the aeroengine OEM, the conceptualisation stage is the first of four main stages of their product definition lifecycle, as is presented in Figure 1, and it is at this stage that the stakeholder requirements are elicitated. From these requirements, the conceptual definition of an aeroengine is generated and documented.

Within the company there are internal procedures that form a basic business process for the documentation and dissemination of requirements and technical specifications to ensure the production of clear, well-written statements of product needs that must be delivered to their customers and end-users. To gain an understanding of the associated documentation a series of questionnaires, company visits and detailed, follow-up, semi-structured interviews were conducted with company personnel

involved with the specification of a specific product family [Kritsilis 2003]. All the interviews were conducted 'face-to-face'. The interviewees were composed of three different groups, namely:

- The project managers who 'own' the documents
- The personnel involved in the 'preparation and generation' of the documents
- The engineers and designers that have to 'work from' the documents

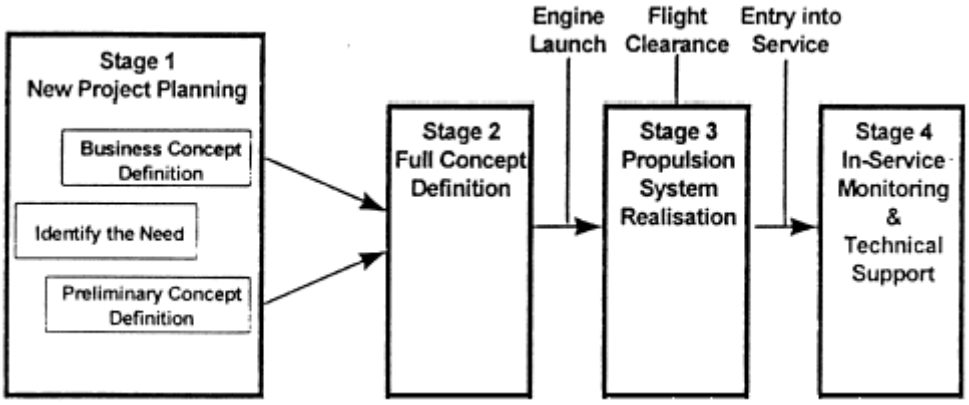


**Figure 1. Propulsion system definition lifecycle [Baird *et al.* 2000]**

## 3. The requirements documentation model

Requirements engineering and management practices were introduced into the aeroengine OEM as a way to produce a clear written statement of the business and technical objectives that have to be delivered through the supply chain. These practices form 'precedent terms of business' for negotiation with stakeholders. Of course, the most important input for aeroengine product development are the requirements raised from the customers, i.e. the airframer and the airlines, concerning the final product. The aim is to ensure that customer requirements are embodied into product designs and satisfied by the finished goods. Additionally, there was also the need to tighten the relationship between the input from the 'commercial side' of the company and its corresponding solution by the 'technical side'. For an aeroengine, requirements can vary enormously from project to project. All these requirements need to be documented in a clear, concise manner and agreed between the customers, the OEM and their suppliers. All the parties work from a number of different documents that provide different types of requirements information and various levels of depth. These documents form the foundations of the product development process and in order to better understand their relationships a requirements documentation model, as shown in Figure 2, has been generated. This model for the technical documentation during the conceptualisation stages of aeroengine product development will now be explained.

### 3.1 Stakeholder requirements

For the documentation of the technical requirements during the initial conceptualisation stages of aeroengine product development, it was found that there are only, basically, four main requirements stakeholders (as depicted in Figure 2): the airframer (customer), the airlines (end-users), the JAA/FAA (regulatory authorities), and the OEM itself (corporate). It is worthy to note that this composition of the main shareholders is complementary to Gershenson and Stauffer's [1999a, 1999b] taxonomies of requirements for the capture process. They recognised four basic requirement types derived from the requirements' source, namely: the end-user, the product producer, technical, and regulatory.

The principal, and considered the most important, requirements stakeholder is the airframer. Their requirements during the conceptualisation stage involve general engineering specifications such as weight, size and engine performance. They do not involve specific engine parts or component specifications. The airframer's needs are documented in the 'Contract Specifications Document'.

This document essentially outlines all the requirements that are placed on the product by the system provider (airframer). The contract specification is owned by the project director in the company's Customer Facing Business Unit (CFBU). During the generation of the contract specifications document a contract may not exist. Instead, the requirements appear in the form of mutual understanding between the OEM and the customer. A contract is the output from the 'Orders Generation Process '.

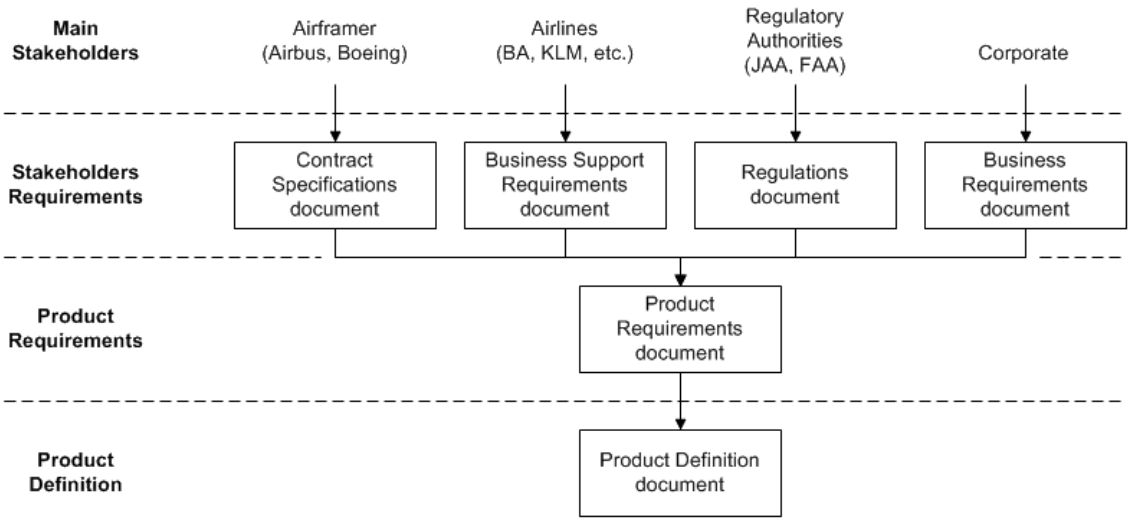


**Figure 2. Requirements documentation model**

Experience is also inputted into the conceptualisation stage through 'lessons learned' from in-service product use which is derived from airline (end-user) feedback. Through the 'Business Support Requirements Document', information is detailed concerning the actual operation of engines, maintenance issues and malfunctions detected resulting from the company's 'Resolve Customer Problems Process'. This document is also owned by the project director and is in effect an input from in-service experience into the new design. It documents details such as modifications to existing products that have been introduced after a product entered service.

An aeroengine has to be designed and tested in accordance with regulations set by the airworthiness authorities. The Federal Aviation Administration (FAA) and the Joint Aviation Authorities (JAA) are the main two sources of regulations with which the engine has to comply, if it is to be certified and eventually placed into service. To achieve certification approval for a product, it is necessary to demonstrate compliance with the requirements of the applicable regulatory authority. It is the responsibility of the Airworthiness Department in the OEM to maintain a register of applicable regulations and make them available to the integrated program development team.

Finally, a set of requirements are also generated from the company itself. During conceptualisation, the OEM will develop a number of concepts for possible engine solutions and create a 'Business Requirements Document'. This document actually encapsulates the requirements and specifications created over the years and re-uses experience gained from previous projects together with company research and development. The commercial information section of the business requirements document is essential as it reflects the operating profile of all potential customers for the product. This enables accurate generation of technical concepts to meet these requirements. Essentially this document is the statement of what the company requires from a product technically and commercially.

During the conceptualisation process, regular reviews and workshops are held between the main stakeholders in order to access the current state of the product, recognise changes in specifications and to investigate methods for these changes to be implemented. With regard to the actual documentation, each document has an owner who is responsible for maintaining a live document, i.e. always reflecting the most up to date information. It is essential that, should a change be made in one document, the

implications related to it be reviewed and updated in all the others. It is the responsibility of the document owners to communicate changes in their documents to the other owners.

### 3.2 Product requirements

The requirements of the main stakeholders are encapsulated into a top-level design specification called the 'Product Requirements Document' (Figure 2). This serves as a manual for the designers since it essentially provides an overall summary at the whole product level. It includes all the expectations of the main stakeholders of a project, as well as the regulations set by the airworthiness authorities that dictate the acceptance levels for certain requirements. The document details:

- Technical specifications (performance, size, weight, life, reliability)
- Costs (development cost targets, production unit cost targets)
- Timescales (development and production program, key delivery dates)
- Quantities (numbers of units and associated timings)
- Policy (company, business group or project policy)
- Quality (quality system and processes to be used)
- Reporting (frequency of program reviews, report contents and formats)

### 3.3 Product definition

After a number of iterations and meetings between the stakeholders of a project, the 'Product Requirements Document' is translated into the 'Product Definition Document'. This is the detailed specification involving the definition of the different engine systems together with any new requirements that the stakeholders introduced during the previous levels. The relationship between the product requirements document and the product definition document is very important since it reflects the relationship between the requirements that must be met by the finished product and the product's definition. The engine leader owns this document, which includes the:

- Gas turbine's mechanical definition
- Gas turbine's general arrangement
- Gas turbine assembly and strip instructions
- System concept
- System schematics
- Performance bids
- Basic cycle data
- Technical electrical specification

### 3.4 Documentation dissemination

Products are often built up in a top-down manner and this is reflected in the product specification and the product structure [Schachinger & Johannesson 2000]. This is true for the aeroengine OEM who as a corporate entity works at the engine (system) level downwards by being divided into smaller businesses each looking into one of the engine's subsystems: fan, compressor, combustor, turbine. "Requirements pass down this chain and ultimately products pass up it" [Baird *et al*. 2000]. After the creation of the 'Product Definition Document', requirements are decomposed into the engine's subsystems, as illustrated in Figure 3, and disseminated through the respective functional design groups in the form of 'Subsystems Requirements Documents'. This is effectively a cascade from the whole product to the individual subsystems. As each Subsystems Requirements Document is created, a 'Working Relationship Document' will also be produced for each sub-system to record the program interfaces (including escalation routes) between that specific sub-system and the others necessary for the collective development of the engine.

At the subsystems level, the subsystem requirements are divided into 'work packages'. Managers have to break down these packages into component parts. As with the relationship between the product requirements and associated product definition, during all the levels of breakdown, the

requirements are matched by a corresponding definition at the same level of breakdown. For example the subsystems definition documents are generated in response to the requirements in the respective subsystems requirements documentation (Figure 3).

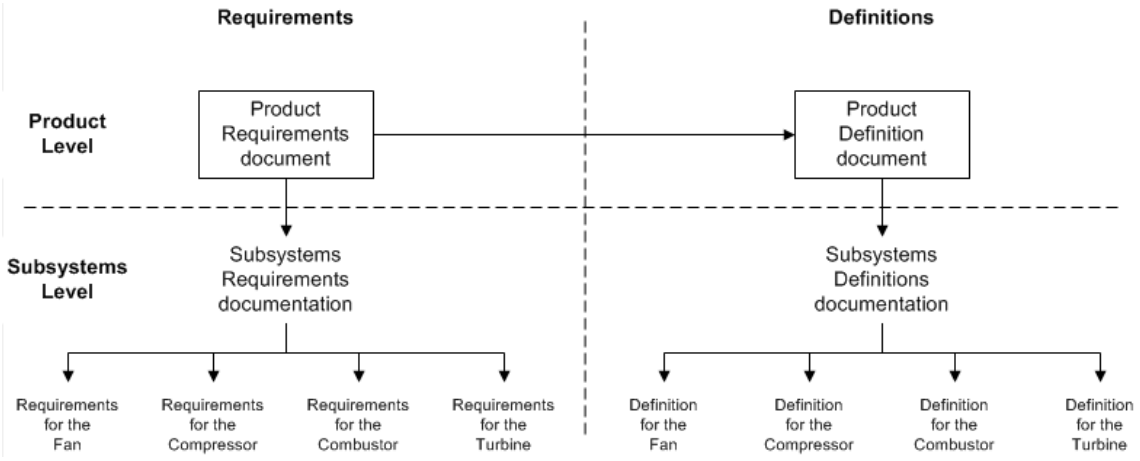


**Figure 3. Documentation dissemination**

## 4. Key observations and bottlenecks

Requirements engineering and management at the aeroengine OEM are generally performed in a document-centred environment. The management of requirements is through the use of non-automated practices. Documentation is achieved through written requirements that the stakeholders agree upon. The communication of these documents is achieved basically through e-mail, both within the company and between the external parties, since the company's intranet serves as the main means of communication. This does however offer the means to establish traceability, although somewhat primitive. Traceability is the links from the original needs and specification through the project lifecycle to the completed and acceptance product [Thomson 2001].

There are bottlenecks in the processes due to the current use and dissemination of the documents. This is basically due to the lack of a central database or repository. For example, engineers working on specific engine components usually store the associated requirements and specifications on their personal computers. However, this can lead to problems and delays when changes have been made at a higher level and this needs to be propagated to all the necessary parties. Some engineers can be working with different versions and it is also time consuming to check and compare updates to different versions stored on personal computers. Moreover, lack of a main database causes delays in requirements confinement and tracking. It is very common in a project team for one of its members to look up a specification for reviewing or alteration purposes. It is then difficult to trace when certain changes were made and to identify the associated rationale for the change. Additionally, it is very time consuming to identify which teams are impacted by a change and thus need to be informed/issued with an update.

With regard to the content and use of the documents, engineers and designers report that 'poor specifications' from the stakeholders and their translation between product/subsystem requirements to product/subsystem definitions causes problems. This is observable in the form of incorrect and insufficient information. Sometimes the engineers and designers have to enter the process of guessing 'what is really wanted'. A principal reason for such a problem is the use of different terminology for requirements/definitions explanation. This derives from the company's organisational practices where different 'internal businesses' tend to create their own methods of 'getting things done' together with the use of their own jargon for describing features and attributes of the product. However, the company is addressing this currently by working towards the creation of a 'common ontology'. This involves the convergence of the different representations and languages to a common format.

## 5. Conclusions

The documentation of product requirements and associated specifications is achieved at the aeroengine OEM through manual processes via written representations. During the initial conceptualisation stages of aeroengine development, it was found that there are four main requirements stakeholders: the airframer, the airlines, the JAA/FAA and the company itself. The requirements of each of these entities is recorded in separate documents. These are then encapsulated into a top-level design specification that serves as a manual for the designers. This is translated, from the requirements of the product, to the definition of the product in order to provide the detailed specification of the engine. Both the global product requirements and associated definitions are then decomposed for the engine's subsystems and disseminated through the respective functional design groups. The major problem with the documentation process are the delays when trying to propagate a requirement change through the company. This is basically due to the lack of a central repository. With regard to the documents, the main problem is the perceived incorrect and insufficient information resulting from the use of different terminologies for requirements/definitions representation.

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