Developing a Current Capability Design for Manufacture Framework in the Aerospace Industry

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Abstract
During progressive product design and development in the aerospace industry, a lack of effective communication between the sequential functions of design, manufacturing and assembly often causes delays and setbacks whereby production capabilities are unable to realise design intent in high-complexity product models. As a result, there is a need to formalise the progressive release of an engineering model to production functions during New Product Introduction (NPI) via defining key stages of definition maturity and information requirements through a structured process. This paper describes the development of a framework to facilitate optimal 'design for manufacture' based on current manufacturing capabilities within the aerospace industry.

Keywords:
Design for Manufacture and Assembly, Process Capability Analysis, Aerospace Industry

1 INTRODUCTION

Due to the high complexity and sensitivity of aircraft engine design, a progressive design release process is followed over a period of time during the introduction of a new product. The nature of staged product definition is built around resource planning to allow long lead-time activities such as material sourcing and machining acquisition to take place before the design is finalised. Design and manufacturing functions need to communicate and negotiate on a multitude of design factors to ensure that the product can be manufactured to the desired specifications under strict quality control. This is a key Design for Manufacture and Assembly (DfMA) principle.

It has been identified that up to 80% of product costs are defined during early concept design [1]. Despite this statistic, the design function within manufacturing organisations often sits largely unconnected to sequential functions throughout the duration of a design definition. There is often a lack of formal buy-off procedures, with manufacturing and assembly functions frequently missing a quantitative means of conveying their capabilities to design via statistical analysis and key performance indicators.

Consequently, up to 50% of development effort can be wasted simply correcting product designs that have been sent back as unworkable from the manufacturing and assembly functions [2].

This research paper defines a framework to facilitate optimal 'design for manufacture' based on current manufacturing capabilities within the aerospace industry. This framework takes the form of a progressive definition release process route-map to guide integrated product teams through the efficient release of a product master model from design to the manufacturing and assembly functions.

The remainder of this paper is structured as follows. Section 2 provides an overview of research related to the topic area; Section 3 describes the research methodology followed to undertake the study. Section 4 provides a description of the produced framework, which is validated and concluded in sections 5 and 6.

2 RELATED RESEARCH

The historical approach to engineering design and product development has largely been via a series of sequential stages [3]. Firstly, a need for a new or adapted product is identified and an initial design is formulated. This is then passed to manufacturing and assembly who have the responsibility to make and build the product. It is then released onto the market, where its in-service performance, lifespan and success are determined.

This linear method encountered many problems due to lack of upstream communication of requirements from manufacturing and assembly to design [4]. The concurrent engineering tool of DfA (Design for Assembly) was first proposed following the undertaking of a number of studies into assembly constraints caused by inefficient product design [5]. Such considerations were bought into the manufacturing domain with the proposal of DfM (Design for Manufacture) techniques that promoted part reduction, simplification and the formulation of manufacturing rules for design [6].

These methodologies incorporate manufacturing and assembly capabilities into the very earliest stages of concept design, ensuring that products are designed in such a way that they can be optimally manufactured. The topic area has expanded to include various other dimensions within the product design stage such as maintainability, quality and lifecycle management (DfMt, DfQ and DfLC) [7].

The need for the implementation of 'matrix management' for the successful facilitation of DfM methodologies is constantly emphasized [8]. This moves companies away from a vertical business layout towards a matrix layout that as well continuing to foster functional specialists also promotes cross-functional integrated product teams. This concept of integrated functional teamwork emphasises the importance of the communication of knowledge and information between different functional departments working on creating, developing and maintaining a quality product.

In addition to sources of explicit knowledge such as operating manuals, product drawings and written company procedures, employees each possess substantial tacit knowledge about their work as a result of training and experience, enabling them to fulfill their responsibilities. Substantial research effort that has been pursued into knowledge based systems in the facilitation of capturing and representing tacit knowledge related to both the product being designed and its manufacturing environment [9]. This knowledge can then be categorised in line with the larger DfM framework according to the defined separate product and manufacturing hierarchies.

The importance of considering the structure and organisation of such knowledge feed-in is highlighted [10] to ensure that the range of knowledge input is filtered and fed in at the correct process planning stage for optimal effect. General, top-level awareness of whole process capabilities and factory capacities is used in the early, holistic views of concept assessment, whereas specific shop floor and machine level performance awareness is required for specific feature manufacturing analysis.

The Foundation of Manufacturing-Committee of the National Academy of Engineering stress how "world-class manufacturers recognise the importance of metrics in helping to define the goals and performance expectations for the organization. They adopt or develop appropriate metrics to interpret and describe quantitatively the criteria used to measure the effectiveness of the manufacturing system and its many interrelated components" [11].

This quote emphasises the integral role and importance of good quality capability data and measurement information in producing quantitative performance records and metrics to drive an organisation's strategic planning and success. Within any manufacturing process, a vast amount of measurement data is collected in order to monitor and control the process and product, ensuring quality and stability. Statistical Process Control (SPC) can be used to analyse this data, measuring process capability through numerical and graphical analysis.

However, there often lacks an inter-relation between the establishment and promotion of a new DfMA framework and the significance of quantified process capability analysis. There is a necessity for a clear definition of what manufacturing and assembly knowledge is required throughout each stage of concept and component design within the aerospace industry. This paper describes a proposed methodology to formalise capability transfers as standard within a design and buy-off process.

3 RESEARCH METHODOLOGY

A qualitative research methodology was adopted throughout the study, using the primary tools of semi-structured interviewing and subjective observations to collect and analyse information from which to draw conclusions and build a solution.

As opposed to traditional research methods where by a theory is built up and then applied to contextual application, this framework was developed directly around the requirements and problem statement of the case study company. Given the breadth of information gathered, this could then be built up to form a generic methodology, the principles of which are wholly transferable to wider application.

To assess current practice and identify the requirements from the solution framework, a series of thirty hour-long interviews and workshops were undertaken with a total of 34 employees. Participating interviewees included senior representatives from central design, assembly and manufacturing functions in addition to teams from specific component manufacturing plants. Semi-structured questionnaires examined and scrutinised examples of previous design releases, gauging the roles and requirements from each stage in the progressive model release process:

- What are the key stages and milestones of design release?
- What individuals and functions are involved at each stage?
- What methods and media of communication are adopted?
- How are manufacturing capabilities communicated and used?
- How are lessons learnt captured and used?
- What are the major causes of setbacks or delays within current practice?
- What resource management and production planning tasks are directly coupled to the design buy-off?

The progressive release route-map was constructed and populated with information through the further use of ten hour-long interviews and workshops. These were carried out through three contrasting case-study component plants chosen in order to collect unbiased and broad company information set, and the focus was on understanding the reasons behind inefficiencies and problems with current practice and finding solutions that would overcome this and shorten lead-times and design iterations. Studying such contrasting components, each with different methods of manufacture, machining and production lead-times, aided not only in highlighting all of the different considerations required to produce a generic framework, but also in exposing variation in procedures of progressive model release and capability process control followed within different facilities.

4 THE PROGRESSIVE MODEL RELEASE FRAMEWORK

The formulated framework has the form of an interactive process route-map as part of the case study company's production system intranet 'How to' guides, imbedding best practice into company operating procedures. The process (Figure 1) consists of five principle activities (large ovals), and is hypertext-enabled, whereby clicking on each stage takes the user through to sequential layers of information and links to associated documentation.

Each activity consists of a series of interactive steps that are broken down into further levels of information. At the end of each activity, a 'Gate Checklist' poses a series of questions to the user to ensure that all requirements specified in completing that activity have been met before progression to the next stage.

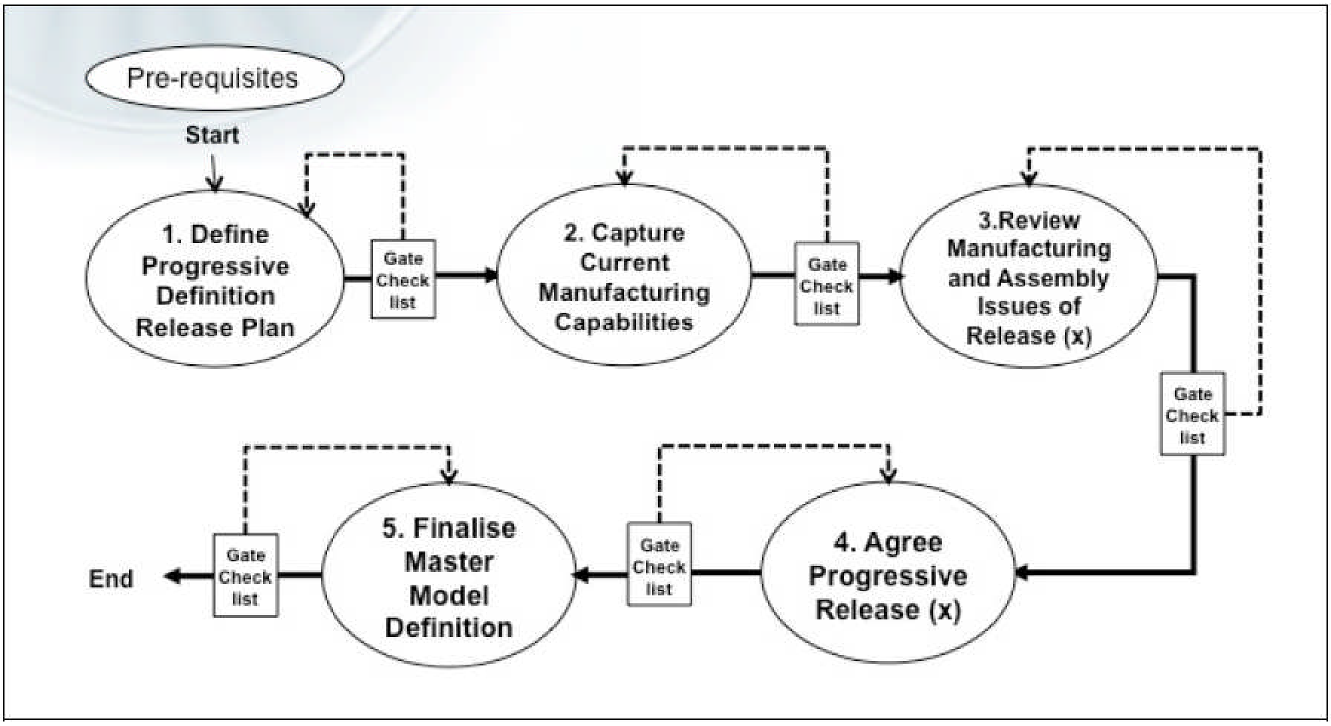

Figure 1: Top-level interactive route map

During data gathering, IDEF0 modelling was used to structure and organise all the information to be included within the process route-map. Traditionally intended for functional modelling, IDEF0 is frequently used to pictorially represent an ordered process due to its ability to accurately portray complex processes at different levels of detail and granularity.

Each function or activity is represented by a box, which can be dissected to reveal all the sub-activities contained within. The whole activity, 'Facilitate an Effective Manufacturing Design Buy-off', is displayed in Figure 2. The primary input to the process, the release of a concept design, is represented coming in form the left. Emerging from the right are the outputs resulting from the process taking place. These are a Master Model ready for production and a feature acceptance log and issue database completed during the buy-off process. The constraints (coming down from the top) and mechanisms (coming up from the bottom) respectively govern and facilitate the progression of the process.

The main process is broken down into five principle activities (Figure 3). These activities are discussed in detail in [12]. The first activity, 'Define Progressive Definition Release Plan', addresses the foundations required from which to carry out an efficient model release process. It supports the establishment of an integrated product team to create a plan for the progressive release of a model, defining specific stages of release based on the constraints of manufacturing scheduling requirements and product introduction milestones.

The second activity (Figure 4) describes how to create an enumerate capability forecast for each feature or requirement on a model through a translation of qualitative knowledge and capability performance data.

Due to the high-level of design and feature carryover for new products, an extensive awareness of manufacturing capability can be established before the model is first released by studying past manufacturing data from the related component family. Components are frequently grouped together based on similarity or relation of features, promoting not only standardisation and organisation of parts but also data and information reuse across parts where appropriate. By identifying the component family, top-level methods of manufacture, specifications and operation listings can be identified in the first step of planning production and analysing capability.

Statistical Process Control data (SPC) and Key Performance Indicators (KPI) are key mechanisms used to assess current manufacturing capability levels, analysed to give an indication of present performance levels and highlight any potential capability issues. Process capability indices (PCIs) form an effective means of summarising process performance relative to a set of specification limits, proving effective tools for both process capability analysis and quality assurance. The primary indices used are the Cp and Cpk indices. The Cp index is a measure of the precision of a given process; the Cpk index is a measure of the distribution of points relative to the design specification limits. Other KPIs such as non-conformance rates and percentage of scrap also provide effective indications of capability.

Figure 2: IDEF0 mapping detailing the top-level process activity

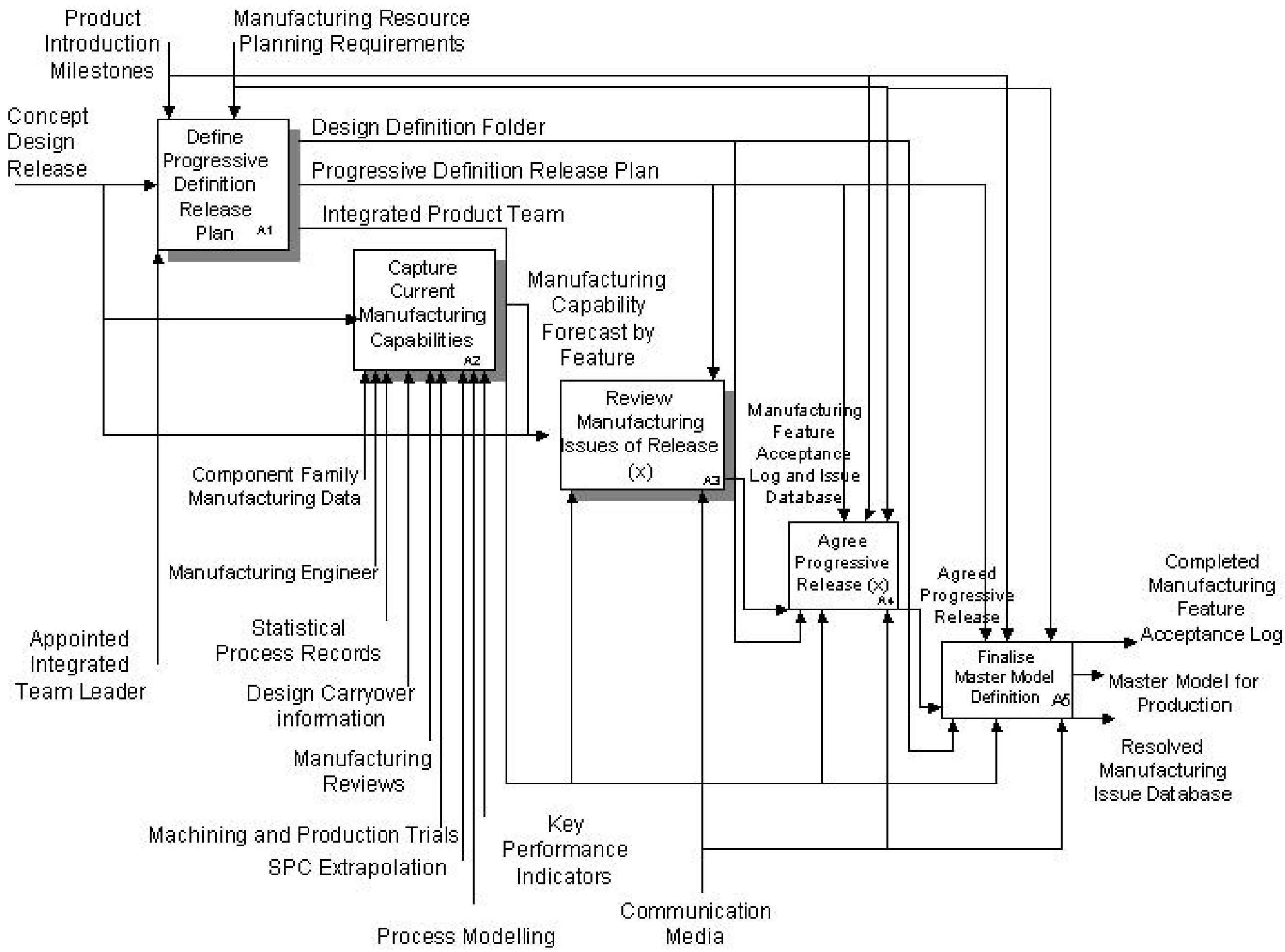

Figure 3: IDEF0 mapping detailing the five primary process activities

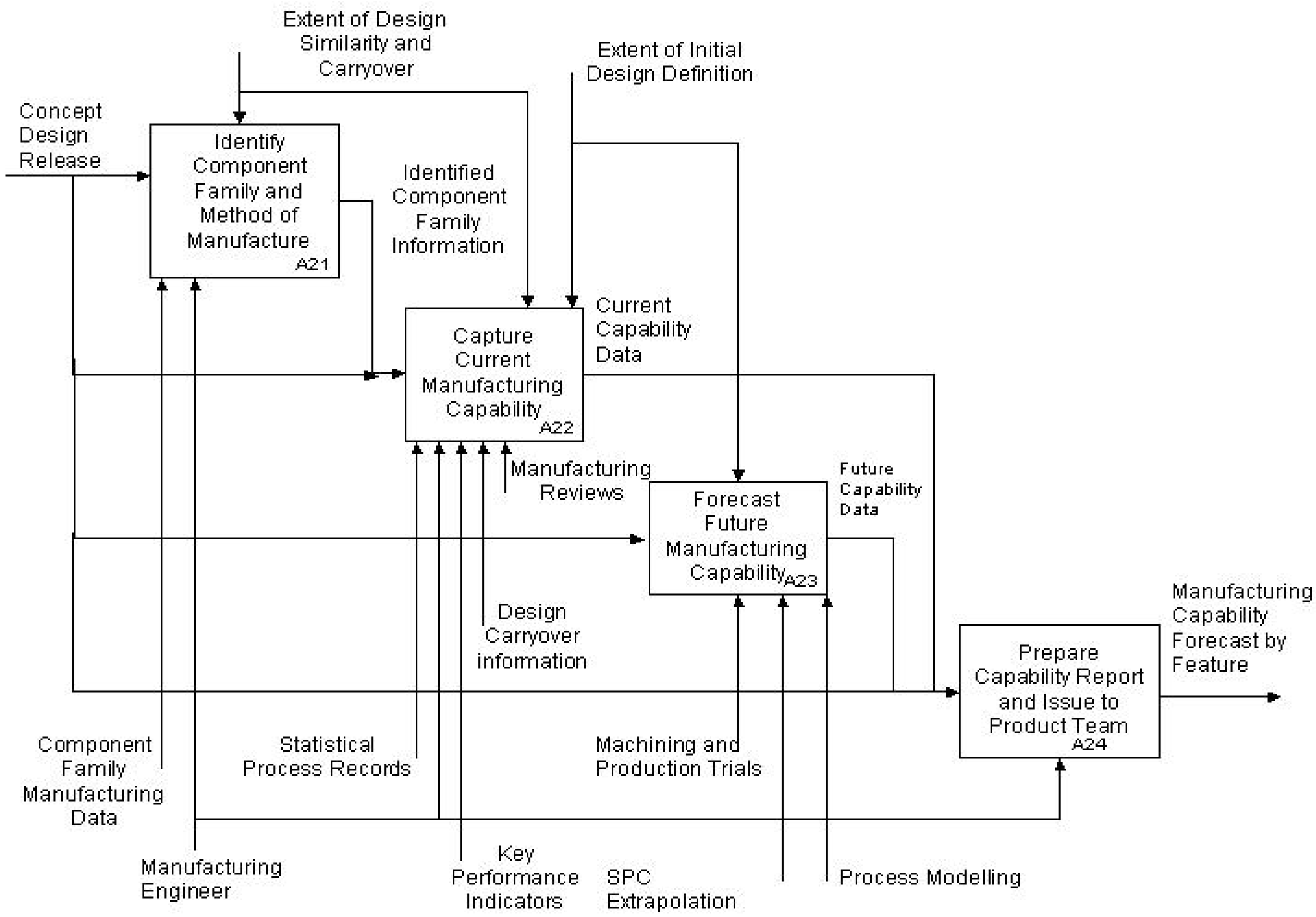

Figure 4: IDEF0 mapping detailing the sub-process activities within stage 2: 'Capture current manufacturing capabilities'

Predicting future manufacturing capability is also important, proving especially relevant for new or changed manufacturing methods where existing capability knowledge is sparse. This can be collected through the use of machining trials, process modelling and computational predictions and then incorporated into the forecast. Qualitative, tacit knowledge concerning efficient manufacturing practice can be gleaned from individuals involved in the product realisation through the utilisation of effective manufacturing review meetings. The framework defines specific feature acceptance logs and issue trackers, the adherence to which are incorporated into the stage-gates so that progression is not permitted until they are adequately fulfilled.

Manufacturing and process capabilities are typically manifested through assigning tolerances to all manufacturable design parameters. A tolerance is the permissible range that the quantity may vary from that specified without detrimentally impacting functionality or performance of the product. Tolerance allocation is of significant importance for the functionality of mechanical products and the manufacturing cost of the parts.

From a design point of view, the definition of tolerances is based around the criticality of the feature and the resulting affect that a variation would have on its resulting performance. The more critical or sensitive a feature, the tighter the tolerance band shall be. Conversely, from a manufacturing standpoint, tolerances reflect the capability of the manufacturing process in achieving the nominal value. These are dependant on the ability of the machines, cost, production and measurement processes used to create the feature, and there will always be an unavoidable degree of statistical variability due to common cause variation in factors such as material quality, machining stability and environmental conditions.Stage 2 culminates in the creation of a specific capability forecast for every feature on the drawing. Through the definition of an achievable manufacturing tolerance band in the early stages of a product concept, the designers are explicitly aware of the exact production capabilities before entering into detailed design, preventing later iterations and enabling a more informed and data-driven buy-off for each specific feature.

Activities 3 through 5 detail the specific company procedures and standard practices to follow in negotiating and agreeing each design specification. Reviewing the model for release and assessing the manufacturing capability on a feature-by-feature basis ensures that the final master model cannot be fixed until all drawing features are accepted by the production functions and all concerns have been resolved.

5 VALIDATION AND INTEGRATION

The validation process has passed through a number of stages during the framework development. For final validation, the ten principle contacts (senior manufacturing and design engineers) involved with the research were revisited with the completed route-map and the process was dissected step-by-step to ensure agreement and make any final changes. Validation was undertaken with both the functional representatives (to secure integration with company procedure) and also with the specific component introduction teams (to ensure usability and case applicability).

This research project, the subset of a larger initiative, coincides with one of the key milestones in the product introduction of the latest company engine project. The finalised framework was carried forward upon completion for implementation within a series of both design buy-off workshops and product definition meetings as part of a continuous improvement initiative.

6 CONCLUSIONS

The developed progressive definition and release framework promotes the incorporation of process capability knowledge during the design and definition of a product. Adherence to the process route-map ensures that no engineering model is released that cannot be realised by manufacturing and assembly functions.

This research amalgamated DfMA principles and process capability knowledge into the creation of a tangible process to facilitate the release of an engineering model for production. This framework was founded on an analysis of the current practice of product definition and development across the aerospace and automotive sectors and promotes the identification of (1) the major stages and activities within the progressive release of a model in order to support manufacturing production planning, (2) the individuals and functions involved within each activity and their requirements and roles in supporting the evolving model, and (3) the capability data and information required to optimally carry out each activity through informed design.

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