Feature Modelling as a New Architectural Approach for the Accelerated Integration and Early-Stage Development of Hybrid-Electric Propulsion, MEA and MEE Architectures

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Abstract
This paper presents a feature modelling philosophy and the developed tool, which can be used to support the conceptual design of future generation aircraft electrical architectures. The proposed feature model has been developed in FeatureIDE and consists of four sequential modelling stages, which are programmed to automatically narrow the selection of feasible design options in order to accelerate the complete system specification and documentation. The paper illustrates the feature modelling process, which starts from the identification of high-level aircraft and engine characteristics, considers medium-level electrical architecture layout options, before finally considering the detailed low-level characteristics of individual components.

Introduction

One of the key challenges associated with the successful deployment of a future generation More-Electric Aircraft (MEA) [1] and More-Electric Engine (MEE) designs is to properly identify and manage variabilities, uncertainties and commonalities through the available design and integration options that emerge at different development stages. As a consequence, a number of software tools and models are required for new tightly-coupled inter-disciplinary architectural approaches to accelerate the design and integration of optimal systems configurations.

If one examines the available literature on modelling aircraft electrical architectures [2-5], it becomes apparent that existing models are based on various assumptions and limitations and therefore it becomes difficult to rapidly construct and evaluate different architectures and configurations from a detailed conceptual perspective without creating one's own customized modelling tools.

This paper addresses this gap by presenting the first descriptive rather than analytical approach towards the modelling of aircraft conceptual design characteristics. A descriptive modelling approach allows a consistent management of the requirements and assumptions by addressing the relationships between them in a logical flow that is based on the principles of the feature modelling philosophy.

By doing so, a user can rapidly determine an optimal set of requirements and assumptions at the initial development stage of an aircraft. Consequently, this should accelerate the optimal design and help identifying the most promising electrical architectures.

Feature Modelling as a Design Philosophy for Conceptual Studies

According to [6], feature models were first introduced in the Feature-Oriented Domain Analysis (FODA) method by Kang et al. [7]. FODA is a domain analysis method that became part of Model-Based Systems Engineering (MBSE), where feature modelling has been commonly applied to identify and capture variabilities within reusable software packages. Existing software tools that are available for feature modelling include: FeatureIDE [8], Xfeature [9], SPLOT [10] and others.

In this paper, instead of software products, the feature modelling approach has been proposed to effectively manage available design options of aircraft electrical systems. Fig. 1 illustrates a basic example feature diagram of aircraft distribution network, which allows selection of network type, number of distribution channels and operating voltage levels.

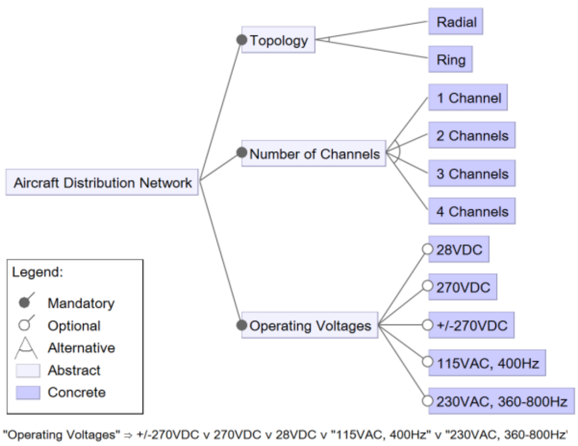

Fig. 1: Example feature diagram (FeatureIDE) of aircraft distribution network with an equivalent single conditional logic statement for 'Operating Voltages' group.

All the defined three groups of features are set as mandatory and are therefore required for selection by the tool user. Features related to ”topology” and ”channels number” selections are combined using a logic operator ’Alternative’. After the selection takes place, this operator automatically de-selects the remaining features. Features related to operating voltage levels are set optional, yet a logic constraint Fig. 1 is defined so that at least a single feature from this group is required to be selected. In accordance with this, some features will be automatically selected based on previously defined comditions.

Types of Feature Models

In feature modelling philosophy, a feature is used to define a desirable characteristic property or behaviour of a product that is required by one or more stakeholders.

In order to select from various features, a model is required that defines the features of a product and relationships between them. In accordance with Fig. 1, two types of feature models can serve this purpose:

- *Product Line Feature Model:* defines the organisation, variability (and commonality) and interrelationships between set of features that defines two or more products in a product line.
- *Product Feature Model:* defines unique set of features that collectively define all the desired properties and behaviour of a system (product).

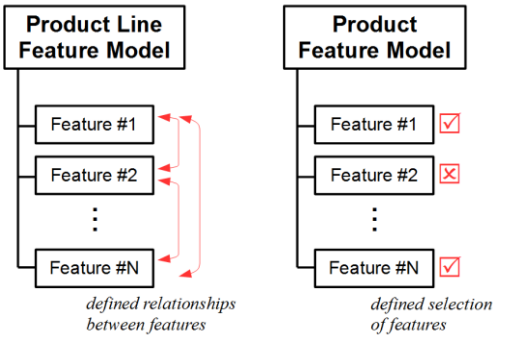

Fig. 2: Schematic representations of product line feature model (left) and product feature model (right).

The proposed feature modelling approach offers a consistent method to support the development of integrated MEA, MEE and even hybrid-electric propulsion system architectures by:

- Allowing an engineer to logically store their specialist knowledge about a product in a model that can be shared.
- Understanding commonality and managing variability within the scope of multiple products, which is essential for developing reuse.
- Identifying and organising this commonality and variability.

Requirements and Knowledge Capture with a Developed Feature Model

This section describes the selected modelling strategy for creating a consistent feature model, which can be reused to generate different electrical architectures in a consistent manner and in accordance with stakeholder requirements.

The top level structure of the proposed feature model is shown in Fig. 3 and consists of four main stages respresented by feature containers, which aid the grouping of feature groups into a logical hierarchical order. Each container therefore consists of feature groups, which are the collection of features that have some relationship with each other and represent points where a design may vary.

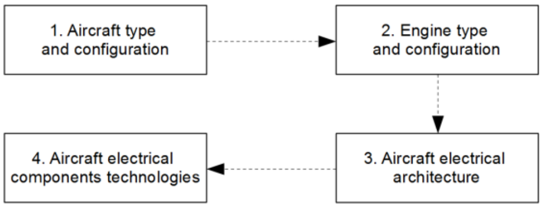

Fig. 3: Four sequential modelling stages of the developed feature model for MEA

The features not only can be set selected as optional or mandatory based on specific stakeholder requirements, but also each feature within a model can have a logic relationship with other features through the use of ’Feature Constraints’. As a result, single or multiple selected or eliminated features may either require or prohibit selection of the remaining specific features.

Fig. 4 illustrates the feature diagram of the modelled features along with feature groups within the ’Aircraft Type and Configuration’ container.

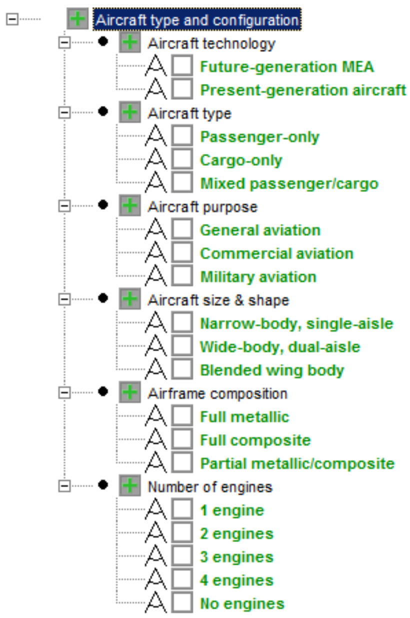

Fig. 4: Tree structure of a modelling stage 1: Aircraft type and configuration.

In this modelling stage, a design team selects general characteristics of aircraft, such as: technology, type, size, number of engines, etc.

Once the general aircraft design options have been selected, a next step involves selection of features related to engine design and propulsion type, including different hybrid-electric propulsion configurations from [11].

At this phase, a generated product feature model allows identification of aircraft propulsion and engine starting functions, and which of those functions need to be managed and performed by components that are driven electrically. The selection of ”No engines” option from the previous container implies the selection of ”All-electric” feature. Consequentially, the selection of ”All-electric” propulsion type results in automated selection of the following features from Fig. 5: ”No engine”, ”No engine location” and ”No engine starting”.

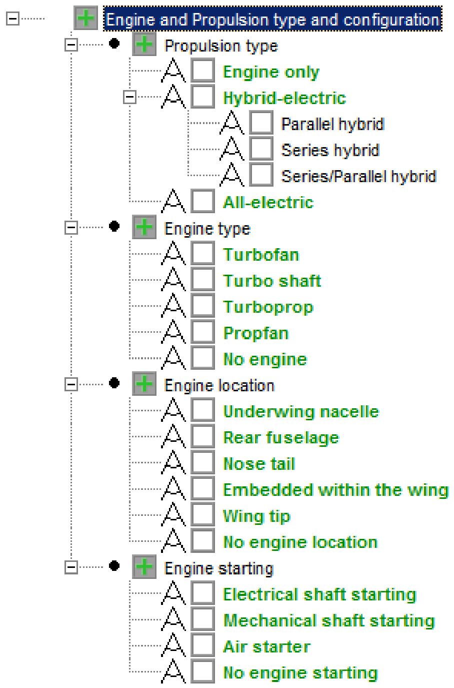

Fig. 5: Tree structure of a modelling stage 2: Engine and Propulsion type and configuration.

After selecting desirable design options in first two containers, the next container involves modelling of an electrical architecture that would accommodate the demand of electrical power. In this stage, a selection of: electrical sources, power distribution network and electrical loads takes place. Fig. 6 illustrates the structure of a modelled container with the available feature groups and their associated features.

After this point, a completed product feature model allows drawing an example scheme from Fig. 7 with all identified electrical supplies on one side, electrical loads on the other side, and the available options for the power distribution in the middle. Consequentially, the constructed scheme can be used to support drawing of the single-line diagram of electrical architecture that would include detailed interconnection arrangements.

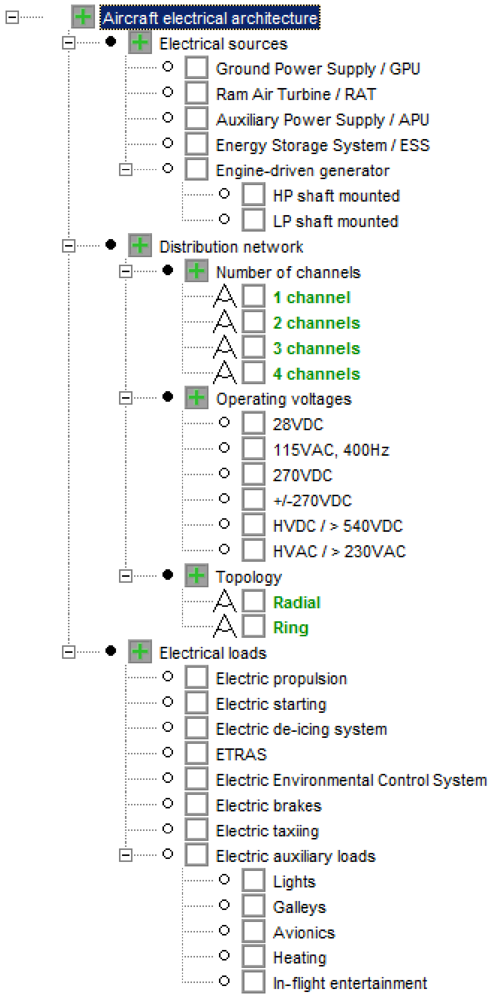

Fig. 6: Tree structure of a modelling stage 3: Aircraft Electrical Architecture.

Finally, a more detailed design specification can be obtained by completing the last container, which includes selection of component types for each previously selected source and load.

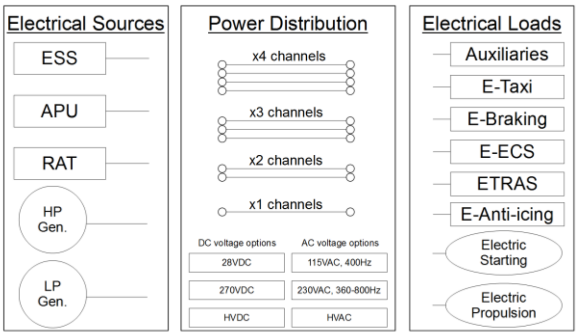

Fig. 7: Example illustrative requirements capture on electrical sources, power distribution and electrical loads.

The structure diagram of a final container: 'Aircraft Electrical Component Technologies' has been shown in Fig. 8. In this container, the developed feature model allows specification of the technologies for electrical machines, power electronics converters, contactors and energy storage system (ESS).

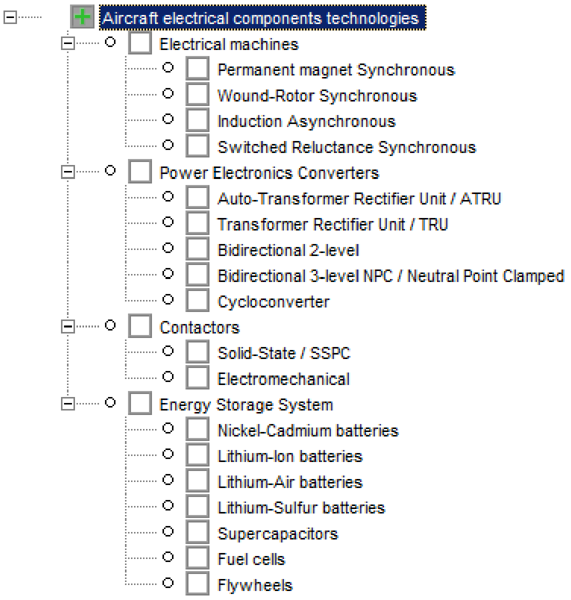

Fig. 8: Tree structure of a modelling stage 4: Aircraft Electrical Components Technologies.

Among electrical machine variants, the presented feature model allows identification of whether a permanent magnet, rotor-wound, induction or switched-reluctance designs will be utilised. For power electronics converters that can be used either as rectifiers or as inverters, the developed model allows selection among five different design options. The selection of contactors can be either solid-state or electromechanical. Finally, the developed feature model allows specification of ESS that can be made of different battery types, supercapacitors and/or fuel cells.

Conclusions

This paper has illustrated based on tree structures how feature modelling can be utilized to support conceptual design studies of aircraft electrical architectures.

By providing a logical order for how architecture design should be approached and capturing the impact of certain design selections, the developed product model has the potential to conveniently capture and store essential specification and knowledge required for detailed design of future generation aircraft electrical systems. The feature model final output relates to the complexity level and number of the selectable features. However, the presented level of complexity allows detailed high-level specification of the electrical system connection arrangements, as well as detailed low-level specification of the utilized component designs and technologies.

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