AAML

Avionics Architecture
Modelling Language

Executive Summary Report

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ABSTRACT:

This Executive Summary Report provides a general description of the AAML (Avionics Architecture Modelling Language) study.

The work described in this report was done under ESA Contract. Responsibility for the contents resides in the author or organisation that prepared it.

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1. INTRODUCTION

The AAML (Avionics Architecture Modelling Language) study was aimed at advancing the avionics engineering practices towards a model-based approach by:

- identifying and prioritizing the analyses of interest that shall be performed based on an avionics architecture model,
- specifying the modelling language features necessary to support the identified analyses, and
- prototyping a software tool to demonstrate the automation of the selected analyses based on a modelling language compliant with the defined specification.

This study was also an occasion to bring further the achievements of the activities related to the definition of the ESA On-board Software Reference Architecture (OSRA), as well as a helpful step in starting to bridge the currently different system and software design paradigms (or at least making the two communities closer regarding the use of model-based design and abstract reasoning for specifying their respective domain concepts).

The study was led by GMV Aerospace and Defence (GMV), which has long experience in the development of on-board software, and counted on the participation of Thales Alenia Space France (TAS-F), which has extensive experience in the development of satellite systems. Both companies provided to this study a significant and valuable background resulting from their participation in previous ESA activities around model-based technologies.

The work was decomposed into three main tasks to achieve each of the three objectives pointed out above:

1) Specification of avionics relevant analyses.

2) Specification of modelling language features.

3) Demonstration and prototyping.

2. SPECIFICATION OF AVIONICS RELEVANT ANALYSES

The avionics architecture is the backbone and brain of a spacecraft. It encompasses all intelligence, data transmission systems (including commanding and monitoring) and power distribution, and as such, requires a vast variety of analyses to design a spacecraft.

Provided that usually not all the information required for the design of a satellite is available at the beginning of a project, the design process typically follows an incremental approach. As presented in Figure 1: , the design of the satellite avionics starts with iterations between initial versions of the design model and some coarse-grained analyses to converge on a first baseline definition of the system. Then, the solution is refined with a loop between fine-grained analysis and more and more detailed versions of the design model, including additional information coming from the equipment integration and testing.

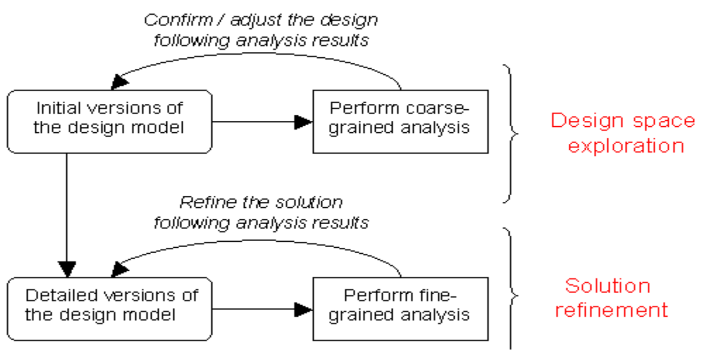

Figure 1: Design with models with use of coarse- and fine-grained analysis

The set of avionic analyses that support this process cover most of the phases of the life cycle, warranting the coherence of the developments from the equipment level up to the satellite level and ensuring the compliance between higher-level requirements and their breakdown to equipment level.

In the AAML study we identified the following set of relevant avionics analyses (all of them applicable at both coarse- and fine-grained levels) which allowed us to map the relevant analyses with the main satellite functions.

1) **Satellite mode definition, RAMS, FDIR and autonomy concept analysis,** that includes, between others, the description of the satellite modes and their transitions in compliance with autonomy requirements and equipment failure modes, the definition of the safe mode policy, or the identification of functions to be directly controlled and monitored from the OBC via hardwired links.
2) **Design consistency and correctness checks,** that include the verification of the flow-down of requirements through the mission product tree and the verification of the correctness of the satellite design (test & validation phases).
3) **Commandability and Observability analysis,** that deals with the access capabilities to on-board resources in various modes, the visibility of on-board autonomous actions, the OBCP/Patch/Mission Time-Line management & storage, the use and tailoring of the Packet Utilization Standard (PUS) on the space/ground link, the definition of the used protocols (ECSS/CFDP/DTN/PUS/Others) and the security policy.
4) **Bus/Network load & latency analysis,** that includes the identification of on-board entities requiring a high throughput interface, the identification of on-board entities requiring a dedicated bus interface, the verification of control-loop performances and the estimation of the throughput on communication buses.
5) **Space/ground communication analysis,** that consists of the Platform and Payload Radio Frequency (RF) system sizing, including coding schemes, RF power and RF network design.
6) **Avionic resources analysis,** that includes the identification of the cross-strapping policy between I/O unit and equipment, the decentralization needs for I/Os (several RTUs on main buses, sensor buses) and the platform-to-payload communication needs.
7) **On-board functions and performance analysis,** that deals with the central computer sizing (processing budget) and the On-board storage capacity and access methods.
8) **Power and mass analysis,** that includes the identification of the power supply characteristics (bus voltage and power loss duration), the identification of units to be permanently powered (FCL) and power consumption of units per modes or per phases, and the mass characteristics of the satellite, taking into account propellant consumption.

3. DEFINITION OF THE MODELLING LANGUAGE

In order to support modelling and analysis of the avionics system, in the AAML study we specified a modelling process that is based on three levels of definition:

1) The avionics functional definition.
2) The avionics logical architecture definition.
3) The avionics physical architecture definition.

The **avionics functional definition** is used to design the avionics system as a set of avionics functions that communicate each other exchanging data. The avionics functional architecture is a representation of what the avionics system has to accomplish for its users. It permits to identify the boundaries of the system, consolidate its requirements, model functional data exchanges and start to model the system behaviour.

The **avionics logical architecture definition** is a representation of how the system will be logically structured so as to fulfil the requirements and expectations of the users. In this level the first analyses and exploration of the design space will be performed.

The **avionics physical architecture definition** instead is concerned with how the system platform will be concretely developed and built using physical components, such as processors, sensors and actuators.

The three previous levels are complemented by an orthogonal level of definition where the corresponding non-functional properties are specified.

The main idea behind this process was to provide the means to manage the different phases of conception and implementation of the avionics system as a sequence of subsequent refinements of the avionics definition. A transition from an upper level to a lower level can be considered as a sort of "contractual refinement" in which the assumptions of the upper level (in forms of functional or non-functional requirements) are realized by the lower level of definition: the properties of the lower level are a response to needs and requirements of the higher level. They shall ostensibly show their compliance to the assumptions of the higher level or they will be subject to analysis for confirmation. The model allows architects to trace architectural decisions during the model refinement iterations and defines several rules for the refinement/deployment process. These rules are aimed to guarantee the global consistency of the model and establish the concrete ways in which entities of the higher levels may be related to those of the lower levels.

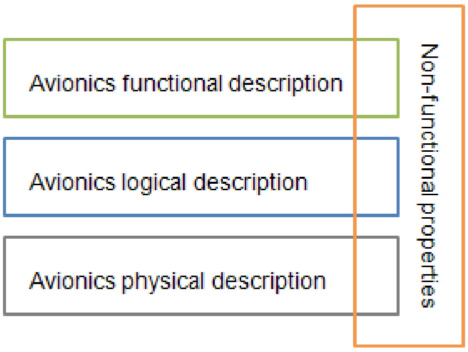

Figure 1: Avionics definition levels

The most noteworthy characteristics of the AAML modelling language are listed here below:

- The avionics analyses are performed based only on the information extracted from the AAML model entities. These entities capture the avionics architecture and the associated non-functional properties needed to perform such analyses. This way, the model represents a single source of input for the various analyses, guaranteeing overall consistency.
- The language supports most of the developments across the different project phases and allows expressing in the model the concepts of the avionics architecture, keeping the best possible compromise between abstraction and precision.
- The language also supports the possibility of first providing a coarse-grained specification of the model entities and their non-functional properties, which can then be refined to introduce more details in the suitable project phase. This allows the user to perform an early coarse-grained analysis to obtain an initial set of analyses results, which is of great value for the so called "design space exploration". Although these initial results may be just indicative or conservative, they are very useful for helping the user taking early sufficiently founded design decisions.
- The language accommodates a component-based design to allow developing a common library of COTS models for various COTS architectural elements (e.g., buses, devices).

4. DEMONSTRATION AND PROTOTYPING

A prototype implementation of the Avionics Architecture Modelling Language (AAML) meta-model and the associated editor was developed. A sub-set of the relevant analyses (namely, the **bus load and data latency**, **commandability and observability** and **on-board functions and performance** analyses) was also selected for prototype implementation. This implementation also included the corresponding graphical user interface that enables the user to execute the analyses.

This toolset was developed as a set of Eclipse plug-ins that configures a design and analysis environment integrated into the Eclipse platform (see

Figure **1: AAML design and analysis environment**).

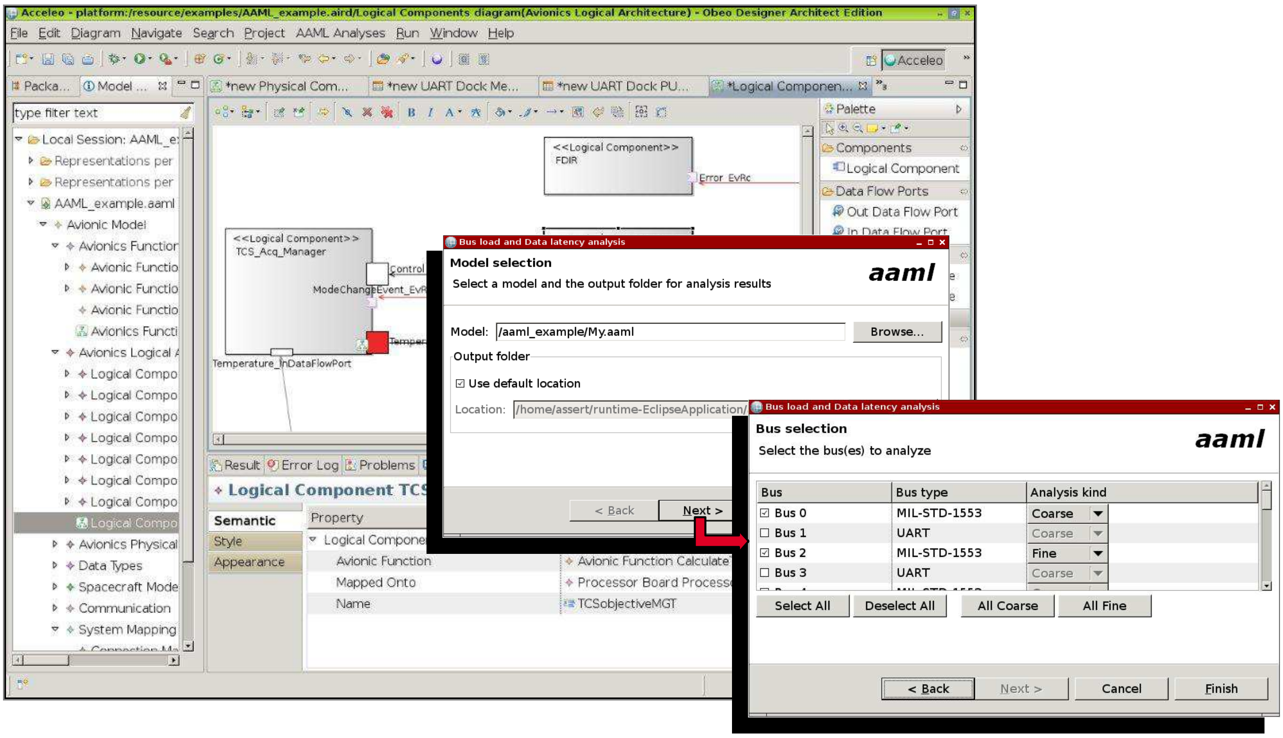

Figure 1: AAML design and analysis environment

The main capabilities of the AAML toolset are:

- Creation/modification of AAML models through the modelling graphical editor. The toolset allows editing the model by means of different kinds of diagrams and tables and provides a customized palette for each of them.
- Configuration of avionics analyses from a graphical user interface based on Eclipse wizards. These wizards guide the user on configuring the specific analysis before executing it. In particular, they allow the user to:
  - o select the input model,
  - o select the location where the analysis results will be stored,
  - o select the specific model elements to be analysed, and
  - o select the kind of analysis (coarse- or fine-grained) to be performed (per model element).
- Storage of the last configuration, to speed up the analysis process when the corresponding analysis is performed several (consecutive) times under the same configuration.

- Execution of avionics analyses based strictly on the model contents. The AAML toolset provides the following outputs after performing the analysis of a given model:
  - A file containing the analysis results, as for example the bus load in the case of the Bus/Network load and latency analysis.
  - A file containing debug information, where the user may examine which model elements/properties were used for computing the analysis results.
- Identification of model inconsistencies. The toolset identifies when the model presents inconsistencies or there is missing information and informs the user about it, by means of a series of output error/warning messages.

The evaluation of the AAML modelling language and the toolset was performed using a use case model based on the Sentinel-3 mission satellites. Sentinel-3 is an Earth Observation mission primarily devoted to support services related to the marine environment.

The opportunity of using Sentinel-3 as the use case for this study allowed exercising various analyses at avionics level based on a real case with a classical complexity level, as well as ensuring that the approach proposed in the study was compatible with the vision on the On-Board Software Reference Architecture (OSRA). The use case aimed at being rich enough to evaluate all the aspects of the approach.

During the analysis iterations feedback and recommendation on the tooling implementation were provided. The use case covered all the activities which are inside the scope of AAML study, and demonstrated at full extent the main capabilities of the AAML modelling language and methodology.

The evaluation results showed that both the AAML modelling language and the toolset were suitable for capturing the avionics architecture and conducting the corresponding analyses, which were the main goals they had to achieve. Moreover, the analysis results provided by the tool were proved very useful to confirm or modify the system design.

Finally, some soft spots and open points regarding the modelling language and the toolset were identified, as well as the potential improvements that are feasible to be made in the short term. Further work would also include the addition of new features to support the set of avionics analyses that were not selected for implementation in the scope of this study.

5. CONCLUSIONS

The main achievements of this study are:

- a catalogue and complete description of all the analysis of interest for avionics design in the different phases of development, their input and expected results;
- the initial definition of the AAML language for modelling an avionics system and specifying all the necessary information to be used as input for the analysis;
- the AAML toolset, including an implementation of the avionics modelling language and the three selected avionics analyses; and
- the modelling of the use case using the aforesaid toolset.

According to the evaluation results, the usefulness of the model-based approach was sufficiently demonstrated, and it can be concluded that this study was a successful first step towards an industrial model-based methodology for avionics design.

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