VMAP enabling interoperability in integrated CAE simulation workflows

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1 Introduction

With the progress in CAE simulation leading to more complicated and integrated workflows, data control and transfer becomes essential. This is extremely important in the manufacturing industry where complicated simulation workflows are necessary in tracking material changes throughout the manufacturing proclete software interoperability. Additionally, VMAP provides a library of IO routines to help engineers speed-up the creation of their workflows thereby removing the emphasis for considering data formats. This enables easier and more flexible data transfer, use of different software for different simulations and the creation of re-useable processes that can be easily adapted to include more or different data. Moreover, this enables software interoperability for post-processing and data manipulation and processing.

VMAP is cost-free, and is supported by the international VMAP Standards Community comprising independent software vendors (ISVs), developers, academia and other entities and provides the CAE industry with a focus group to provide guidance, collaborate, evolve and maintain VMAP.

This paper describes the VMAP standard and IO libraries, example of its successful implementation via various use cases. The important roles of the VMAP Standards Community are also described.

2 The VMAP Standard

VMAP is defined as a vendor neutral standard for CAE data-storage to enhance interoperability in virtual engineering workflows.

The data standard is based on HDF5, a widely accepted implementation platform for many IO related applications. The data formats currently included in the release version 0.5 relate to geometry and discretization, coordinate and unit systems, result and state variables, parameters for (material) models as well as meta-and user-defined data. The list is under continual enhancement.

Many ISVs, both large and small players, will implement the VMAP Standard directly within their software to extract the maximum speed and efficiency, shown schematically in Fig.1:

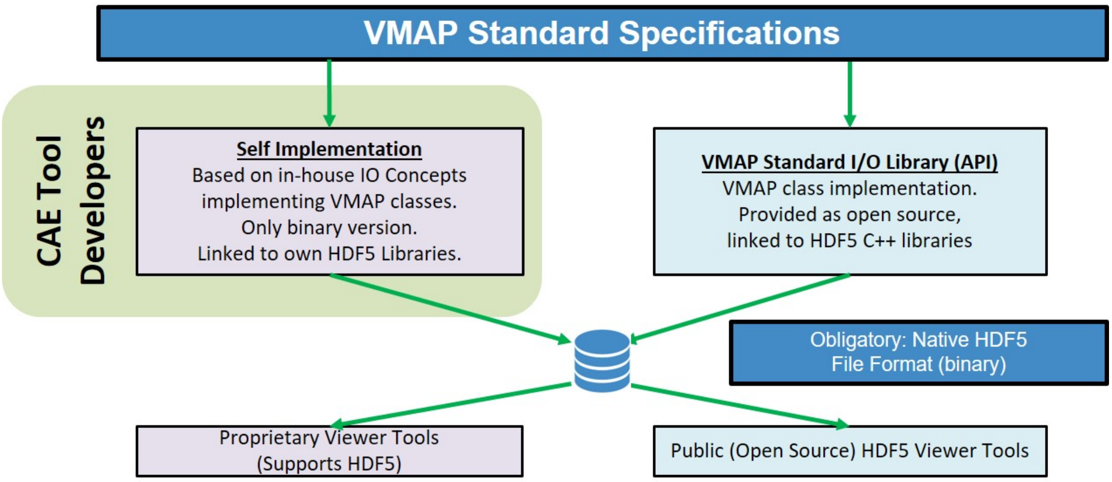


Fig.1: Figure 1: VMAP Standard implementation, either within ISV software or utilising the supplied IO software library.

However, all data defined within the standard, can be written or read using the IO software library provided as part of the VMAP Standard, also shown schematically in Fig.1:. This enables engineers to utilise VMAP without having any knowledge of the standardised data formats. The freely available SWIG wrapper tool can be utilised to bind the VMAP IO software library into software written in any other programming or script language, see Fig.2:. As such, the VMAP IO library is universally available.

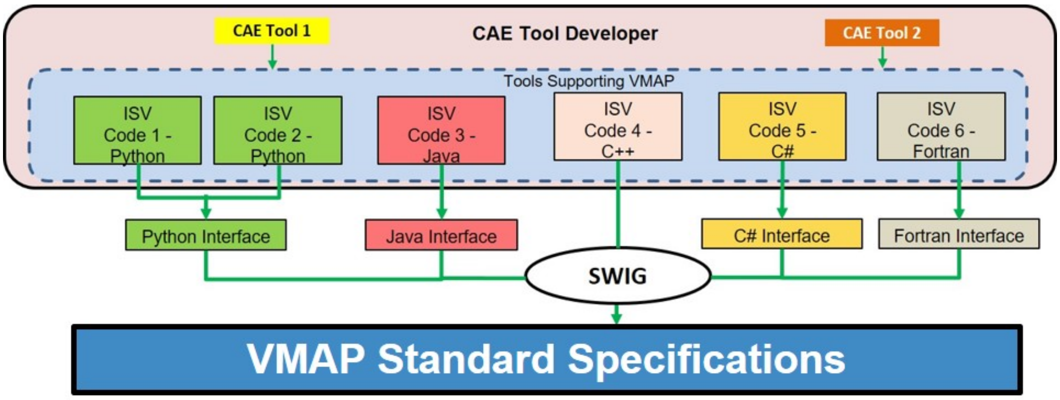


Fig.2: Figure 2: VMAP Standard implementation with other programming/scripting languages via the SWIG wrapper

To aid users and implementers a series of simple test cases are supplied within the release pack so that implementations can be quickly verified.

In summary, the complete VMAP Standard release includes:
1. defined VMAP Standard (document),
2. use case descriptions and background information (document),
3. IO software library (software),
4. a set of test cases to verify any implementation (files),
5. contact information for the VMAP Standards Community (document).

Fig.3:shows a few ontology levels in VMAP. The green text represents a group, blue text represents datasets and red text represents attributes, all containing further details about a model. The HDF5 format stores the data in a similar format with groups, datasets and attributes.

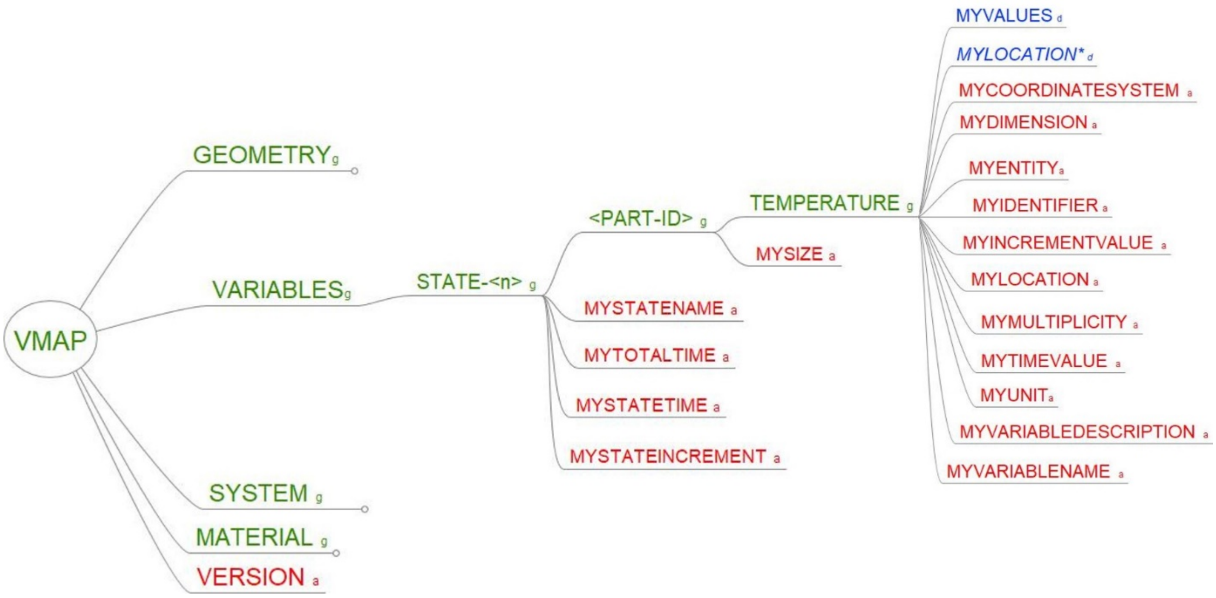


Fig.3: The VMAP Group

As can be seen in the ontology, VMAP is capable of storing dynamic time based analyses. The VMAP library can also offer the possibility to store multiple process simulation steps in the same VMAP file, useful for SMEs who do not wish to invest further in DBMS systems.

3 COTS Software Implementations

To date the VMAP Standard has been implemented in many Commercial-Off-The-Shelf (COTS) software. This list, shown in the table on the right, is growing with discussions continuing with other groups regarding the VMAP implementation and creation of use cases defined by themselves (not listed).

Software	Platform(s)	Integration Type	VMAP import	VMAP export
4a FIBREMAP	Windows	Integrated	v 0.5.2	v 0.5.2
4a MICROMEC	Windows	Integrated	(under development)	(under development)
4a VALIMAT	Windows	Integrated	(under development)	(under development)
ANSYS Mechanical	Windows, Linux	External Wrapper	v 0.5.0	v 0.5.0
Autodesk FUSION 360 Platform	Windows	Integrated	(technical evaluation)	(technical evaluation)
Autodesk Moldflow	Windows, Linux	External Wrapper	(under development)	v 0.5.0
Beta CAE Ansa	Windows, Linux	Integrated	v 0.4.0	v 0.4.0
Beta CAE Epilysis	Windows, Linux	Integrated	(under development)	(under development)
Beta CAE Metapost	Windows, Linux	Integrated	(under development)	(under development)
Convergent Compro	Windows, Linux	External Wrapper	v 0.5.2	v 0.5.2
Convergent Raven	Windows, Linux	Integrated	v 0.5.2	v 0.5.2
DYNAmore Envyo	Windows, Linux	Integrated	v 0.5.2	v 0.5.2
ESI Visual Environment	Windows, Linux	External Wrapper	v 0.4.0	v 0.4.0
e-Xstream Digimat	Windows	Integrated	v 0.4.0	v 0.4.0
Forge (Transvalor)	Windows, Linux	Integrated	v 0.4.0	v 0.4.0
inuTech Diffpack	Windows	External Wrapper	v 0.5.0	v 0.5.0
inuTech OOT	Windows	External Wrapper	(under development)	(under development)
Magmasoft	Windows, Linux	Integrated	v 0.4.0	v 0.4.0
MpCCI Mapper (SCAI)	Windows, Linux	Integrated	v 0.5.2	v 0.5.2
MSC Marc	Windows, Linux	External Wrapper	v 0.5.1	v 0.5.1
OOFEM	Windows, Linux	Integrated	v 0.5.2	v 0.5.2
OpenFOAM	Linux	External Wrapper	v 0.5.2	v 0.5.2
Simcon CADMould	Windows	Integrated	v 0.5.0	v 0.5.0
Simulia Abaqus	Windows, Linux	External Wrapper	v 0.5.2	v 0.5.2

Legend: Existing tool available
Tool development in progress
Tool in initial development or technical evaluation stage

Fig.4: VMAP Standard ISV implementations: The latest release is version 0.5.2 (15 October 2020). All release versions prior to release 0.4.0 are compatible.

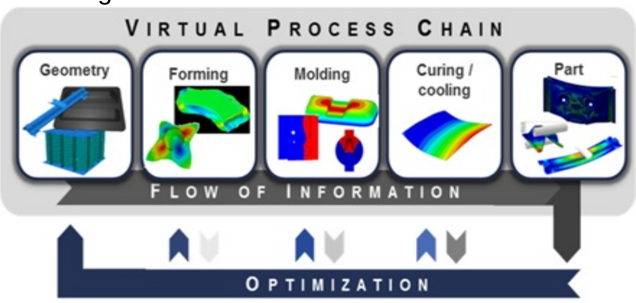
4 Use Cases

The VMAP Standard has been verified by many industrial use cases; some examples are shown in Figure 5. All these use cases include complex simulation processes requiring the tracking of material information throughout the process to ensure the correct component design with its desirable characteristics and to accurately design the manufacturing process details. Use cases that are being created in collaboration with entities external to the project are not defined here.

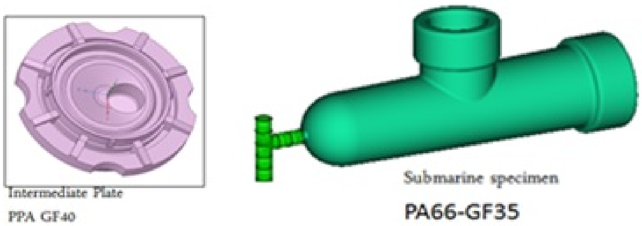
- **Blow Forming**: The blow moulding use case (4 simulation stages, 4 softwares) shows the detailed prediction of shrinkage and warpage of plastic bottles and containers. The product range of extrusion blow-moulded plastic parts ranges from thin-walled packaging products like bottles or cans, to highly stressed technical parts like fuel tanks or intermediate bulk containers (IBC).
  The process simulations provide information, for example, about the wall thickness distribution and the shrinkage and warpage, which significantly

influences the product properties of the final part. Therefore, all the information regarding the process history (e.g. temperatures, residual stresses, or wall thickness) needs to be stored and transferred between the different simulation steps. In combination with advanced material models, this integrated simulation approach makes it possible to predict the product properties of blow moulded parts with a very high accuracy.
More accurate simulation methods enable higher product performance of blow moulded plastic parts with less material consumption and shorter design/manufacture cycle times. Due to standardization and automation of the CAE workflow, time consuming data transfer between the different simulation stages can be avoided. This case is representative for many blow moulded components as the material interfaces can easily be expanded.

- **Composites for Lightweight Vehicles:** The lightweight vehicle composites use case (4 simulation stages, 5 softwares) shows an application of the continuous virtual process chain to a practical-oriented automotive structural part. An automated and accelerated workflow for product verification including both manufacture process and product design is available.
  Mapping of results from solid to shell mesh is the most crucial point here and this has been achieved with a VMAP standardized data storage format. Most common variables include fibre orientation, volume & density.
  Standardization of the data format will facilitate a complete CAE workflow for high-performance composites in relevant structural automotive applications.



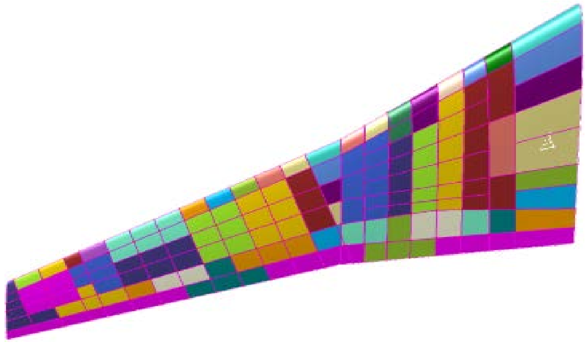
- **Injection-Moulding:** This includes four sub cases: Impact, Foaming, Fatigue and Creep. These 4 plastic moulding use cases (2 to 4 simulation stages, 3 to 6 softwares) show the engineering potential of low-cost materials available for lightweight and safety applications. Short- & Long-Fibre Reinforced Thermoplastics are used and fibre orientation including weld lines are transferred from an injection moulding simulation to a structural simulation, the main issue being the mapping of fibre orientation and other parameters.
  With a completely integrated simulation process higher product performance with reduced product development times can be achieved.



- **Additive Manufacturing (AM)**: The additive manufacturing use for plastic components and parts case (4 simulation stages, 4 softwares) demonstrates the needs and capabilities for AM in plastics. The product performance of additively manufactured parts is highly influenced by the process conditions. Therefore, the whole process history needs to be transferred between several simulation stages also involving different solvers and meshes. The main challenge is the transfer of time dependent boundary conditions from printer to simulation. This can be carried out effectively with the standardized VMAP data storage format.
  A standardized format will help reduce efforts & cost during product development times.

- **Hybrid Modelling of Consumer Products**: The consumer lifestyle use case explores the complex improvement of the production processes and the performance of shaver products. The goal is to have a complete virtual process chain which, prior to VMAP, not been possible. Now, with using VMAP the teams are working on developing a virtual process chain which will enable seamless virtual product development.

- **Composites in Aerospace**: The aerospace composites use case (5 simulation stages, 6 softwares) shows how standardized information can be passed between all the relevant simulation modules for the different phases of commercial aeronautics product development program utilizing the autoclave manufacturing process. The computational fluid dynamics simulation requires a different mesh and boundary conditions than for the thermo-chemical simulation, saturated flow, and stress/deformation simulations. So far, VMAP has been developed with a focus on structural simulation, however, it is possible to store and transfer data from and to other analyses types. Developing the standardized material models to enable process simulation will significantly accelerate and optimize the many simulation steps of an aerospace composite component development program.



5 VMAP Standards Community

The VMAP Standard Community (VMAP SC) supports and promotes the complete VMAP Standard. Current members comprise ISVs, developers, academia and other entities committed to evolve VMAP into a truly international standard used by the CAE sector. At the date of writing the VMAP SC is being legalized as a not-for-profit association with a founder group of at least 15 entities (the legal statutes are currently being revised by the tax office) and membership will be open to any entity using, involved and working with VMAP.

During 2020, the last year of the project, the VMAP International Conference on CAE Interoperability was held with 25 presentations and about 120 attendees (see vmap.eu.com/vmap-conference-2020/).

All VMAP Standards Community information can be found on the website vmap.eu.com/community.

6 Acknowledgements

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