The Foothold in the War of Cognition: The Operational Training Infrastructure Enterprise System Model

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ABSTRACT

The Air Force Lifecycle Management Center Simulators Program Office (AFLCMC/WNS) is creating an integrated and maintainable enterprise Model Based Systems Engineering (MBSE) system model for the current simulator enterprise baseline. This system model is essential to fulfilling the Operation Training Infrastructure 2035 Flight Plan and placing the Air Force simulator enterprise on the digital engineering path. The Operational Training Infrastructure (OTI) Enterprise System Model (ESM) contains data for each simulator to the subsystem level, including specifications, interfaces, data flows, and software versions. This system model will transform simulator acquisition into a digital engineering environment informing Request for Proposals (RFPs), Configuration Control Boards (CCBs), engineering design reviews, and verifying Engineering Change Proposals (ECPs). The system model will become a central hub for Government and industry to comprehensively control each Air Force simulator's baseline with requirements, testing, reporting, and simulator architecture all in one easy to navigate model. The OTI ESM will fundamentally change the communication between Government and Industry through the seamless delivery of simulator data through each system model, enhancing acquisition cognition.

ABOUT THE AUTHOR

2d Lt Christopher Reed is a training systems engineer in AFLCMC/WNS. He graduated from Embry-Riddle Aeronautical University with a B.S. in Aerospace Engineering in December 2017 and has been working in AFLCMC/WNS since January 2018. He started his career leading engineering efforts for 44 different simulator devices at four bases in support of AETC, AFSOC, and AFMC. He was then handpicked to work on a $900M project where he quickly learned MBSE to understand and effectively communicate the intricacy of new systems. In recognition, Chris was named the subject matter expert in MBSE for AFLCMC/WNS. The OTI ESM was started by Lt Reed to launch Digital Engineering (DE) in Air Force training systems acquisition.

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BACKGROUND

The United States Air Force (USAF) currently utilizes upwards of 3000 Aircrew and Maintenance Training Devices (ATDs and MTDs) at locations around the globe. The Air Force Lifecycle Management Center Simulators Program Office (AFLCMC/WNS), or the Simulators Program Office (WNS) for short, is charged with maintaining a portfolio of approximately 2380 training devices, of which, more than 900 are flight simulators. Since the Simulators Program Office was founded, engineering and program management has been done through documents. A single action on a single ATD is documented in multiple spreadsheets, a separate collection of engineering design review documents, and multiple separate management plans.

The USAF is in a transition period, where hundreds of new aircraft are being acquired per year with accompanying ATDs included in order to train the pilots. Legacy aircraft are planned to fly for the next 20 years with their accompanying ATDs to continue training pilots. This transition period leads to a rapidly expanding ATD enterprise. The Operational Training Infrastructure (OTI) encompasses the devices within the ATD enterprise that support operational training, along with air vehicle systems that support operational training.

The OTI faces a unique sustainment problem. Every aircraft in the USAF inventory receives periodic upgrades that need to be reflected in the ATDs to stay concurrent for training. The upgrades to an ATD usually require specialized parts that are different from the actual aircraft, and require special software coding to make aircraft software work in a simulated training environment. For example, an altimeter straight from an F-16 will not work if it is plugged into an F-16 simulator cockpit. The F-16 simulator is always on the ground, so the altimeter needs to be stimulated by custom computer inputs, or it needs to be replaced with a simulator specific altimeter. Additionally, the computers and other hardware running the simulations require periodic replacement as technology evolves, known as a tech refresh. A relatively modern simulator built in the early 2000s would have used the new and cutting edge Windows XP as an operating system to host the simulated world for the pilot. Windows XP is no longer supported with security patches, so without a tech refresh, the simulator’s computer systems would be vulnerable to a cyber-attack. Every change in hardware and software on a government owned ATD managed by WNS requires a contract action and a change to the technical baseline. With the constantly expanding OTI, and hundreds of different actions happening every year in WNS, it is increasingly difficult to understand and maintain the technical baseline of each ATD with documents alone.

Model Based Systems Engineering (MBSE) Background

MBSE is a method of maintaining the technical baseline of a system at any point in its life cycle, where all of the systems engineering documents and deliverables are created from the system model. The International Council on Systems Engineering (INCOSE) defines MBSE as the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases (INCOSE-TP-2004-004-02). WNS is involved in all phases of the acquisitions lifecycle, MBSE is a unique opportunity to change from document-based engineering while maintaining all capability and traceability. Chapter 1 of Delligatti (2014) outlines the clear advantages of changing from a document-based systems engineering approach to an MBSE approach. The greatest advantage of MBSE is the ability to alter a single element within a model and have the update automatically propagate to every diagram and generated document. This automatic update capability saves countless hours of work in trade analysis and document updates. A mature MBSE system model can inform RFPs, CCBs, engineering design reviews, and verify ECPs by showing the full system design. The time saved greatly increases when MBSE is implemented at an enterprise scale.

THE OTI PUZZLE

The USAF OTI could be interpreted as a 1,000,000-piece jigsaw puzzle called the OTI Puzzle. Each ATD would be collections of dozens of pieces within the OTI Puzzle. The complexity of the puzzle is extreme because the OTI has been acquired over the course of 40+ years. Each ATD has different capabilities and components, sometimes separated by decades of age within one device. The most complex and highest demand ATD is the high-end flight simulator, generally referred to as a Weapon System Trainer, Full Mission Simulator, etc. An individual flight simulator would be hundreds of pieces in the OTI Puzzle. Historically, WNS utilized a document-based approach to organize the puzzle pieces into piles, with multiple documents describing what the pieces look like when put together. However, there are no real connections between the pieces using the document-based approach. If one piece of an ATD is replaced with a newer and better piece, there is no guarantee that all of the documents surrounding the pile of puzzle pieces will be updated correctly, despite the best efforts and intentions of both industry and government workers. Additionally, an exceptional team with full knowledge of the ATD and good lines of communication is the only way to know if all of the requirements for the ATD are still met when a piece of an ATD is changed. WNS has identified MBSE as a solution to assist WNS teams and industry with engineering management of their technical baselines.

As compared to the traditional, document-based engineering management process, MBSE allows a systems engineer to have a complete, consistent, and traceable system design at any level. MBSE ties system requirements, design, physical architecture, cost, risk, and specifications into a concise and understandable digital model. When fully implemented, the OTI Enterprise System Model (ESM) will become the single MBSE model that contains data about the technical baselines of every ATD in WNS, and it represents the first time that all of the pieces in the OTI Puzzle are being put together in one place. A fully assembled OTI Puzzle with the OTI ESM is the foothold in the war of cognition for WNS.

The OTI ESM represents a major shift in how the USAF manages training systems. The OTI ESM enables all stakeholders in the OTI to gain a new level of cognition in order to have accurate communication about ATDs. It represents a first step for WNS into the world of digital engineering. The high-level scope of the OTI ESM can be seen in the OV-1 (Figure 1) below. The broad scope of the OTI ESM is a calculated leap into the world of digital engineering. Leadership in WNS has seen the benefit of MBSE in small-scale projects and they believe WNS is ready to be the first in AFLCMC to embrace MBSE on an enterprise scale.

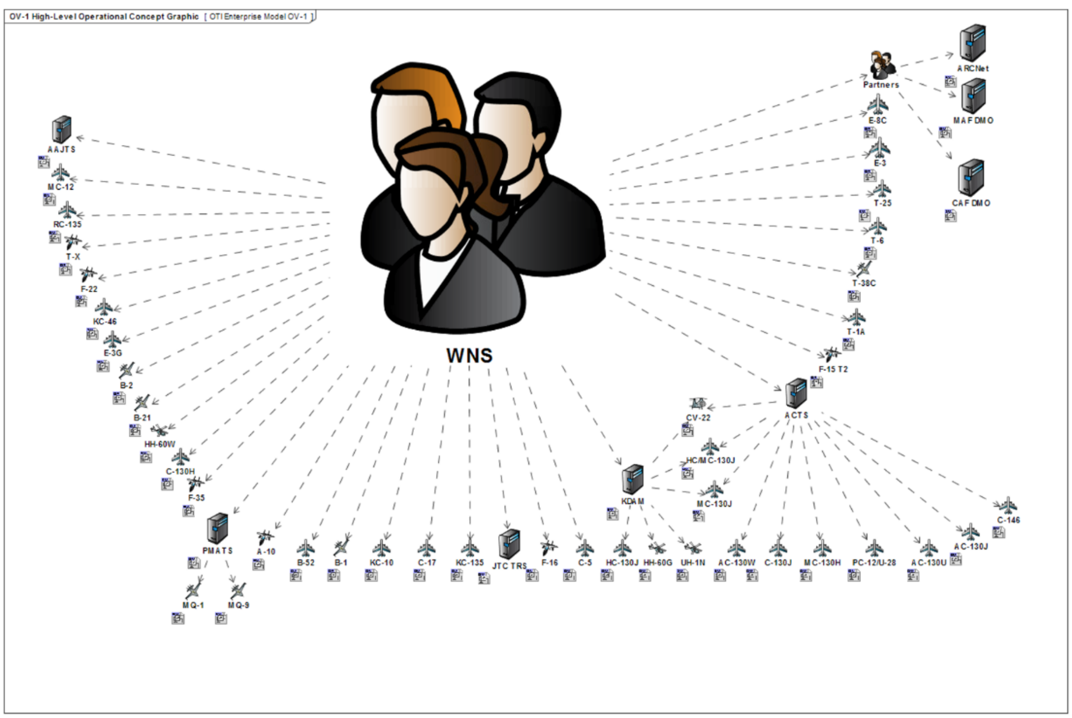

Figure 1. OV-1 High Level Operational Concept Graphic

Puzzle Framework

The first thing most people do when they solve a jigsaw puzzle is build the outside frame, because the outer pieces are easier to identify and connect to each other. We have done the same thing with the OTI Puzzle. The OTI ESM framework is set up with a numbering system and style guide with component library. This combination allows for quick reference architecture, seamless model building, and future expansion.

Numbering System

The numbering system decomposes the OTI enterprise down to each ATD with three high level categories:

1 – WNS training devices
2 – WNS simulator networks
3 – Foreign Military Sales (FMS) through WNS

The numbering system then sorts these categories with a X.Y.Z decomposition:

X is the sub-program (WNS multi-platform programs)
Y is the platform
Z is the device number

As seen in Figure 2, the CAF DMO simulator network sub-program is numbered 2-2 and the WNS T-6 Simulator platform is numbered 1-5.21. Each platform list expands to show locations of each simulator and their device numbers.

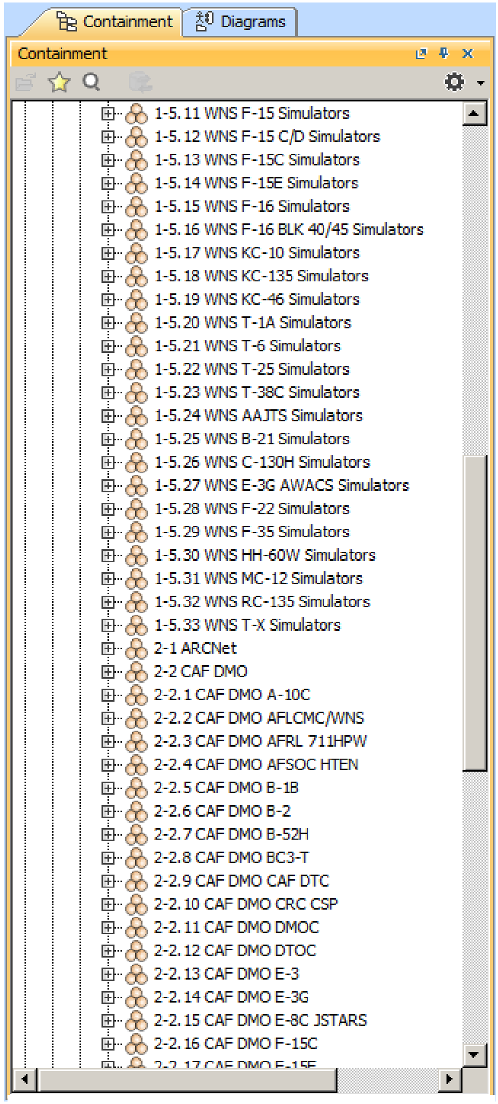

Figure 2. OTI ESM Numbering System

This numbering system is important for configuration control and baseline traceability. Each platform's ATD baseline needs to be traced to the actual ATD, and this numbering system allows for concise traceability while also allowing maximum variance. The three number decomposition was chosen because WNS has some programs that sustain the same aircraft platforms. The main example of this overlap is with the C-130J platform. There are two sub-programs and a WNS platform program sustaining different C-130J simulators, so the sub-program number was added as an additional identifier. The OTI ESM is also capable of growing to accommodate the expanding ATD enterprise. For example, if another ATD platform was added to the WNS portfolio, the numbering system is able to expand with 1-5.34. Additionally, if a new ATD or network is made and needs to be added to the portfolio, it can simply be done by adding an additional X number if it is a new sub-program, Y number if it is a new platform, or a new Z if it is a new ATD.

Questions about a piece or collection of pieces in the OTI Puzzle can be quickly answered by knowing where in the puzzle the piece(s) exist and how they connect to other pieces. The numbering system allows anybody with model access and general MBSE knowledge to home in on answers at any level, and enables cognizant communication between all stakeholders involved with the question. If the AFLCMC/WNS Senior Materiel Leader (SML) asks a question about the operating systems in every WNS KC-10 simulator, they would have the answer in hours rather than days. The WNS KC-10 team would be able to communicate with the SML, using their baseline models with the 1-5.17 numbering as reference, about not only what operating systems are present, but also what hardware is hosting each operating system. All of this communication would occur immediately upon receiving the question with the OTI ESM. Whereas the past method of document based engineering required hours of research and communication between the program team and the contractors maintaining the devices just to come up with the data to answer the question. Awareness of all of the connected pieces to the KC-10 operating systems through the OTI ESM allows IPTs to answer high-level questions with a level of cognition that could resolve the issue that spawned the question the first time. Overall, the OTI Puzzle is effectively organized and the framework is made by this numbering system.

Style Guide

Creating a cohesive enterprise model at a scale comparable to the OTI ESM with hundreds of technical baselines modeled by different engineers is only possible if there are rules for what a technical baseline model should look like. The OTI ESM style guide is a comprehensive reference for WNS and industry engineers to use when creating MBSE models for the OTI ESM. Regular practice in the Air Force is to make an Air Force Instruction (AFI) or standards document that directs Airmen on how to do something. However, WNS is embracing digital engineering and using an alternate route for the style guide by creating it in the OTI ESM with the MBSE tool.

The OTI ESM is a hybrid of the Department of Defense Architecture Framework (DoDAF) modeling language common in the USAF, and Systems Modeling Language (SysML) that is prevalent in industry. The high-level enterprise modeling is done in DoDAF, while the individual ATD technical baselines are modeled in SysML. The style guide consists of a SysML Package named “Style Guide” in the containment tree that includes all of the stereotypes, example diagrams, and a common component library for the ATD baseline models. The containment of the style guide is depicted in Figure 3.

The style guide acts as an informal instruction book to assemble the OTI Puzzle that enables flexibility for the disparate ATD technical baselines to model their as-is architecture without worrying about every name and data set for every block. The ATD Baseline Package Structure is the starting point for WNS engineers to use for their models. The baseline models should match how the ATDs are currently, but only the most important subsystems will have stereotyped and detailed specifications to start. Using this process, each technical baseline model is built at a reasonable initial scale so that the OTI ESM can be operational in a realistic timeframe. Standardization of naming conventions and ontology will begin once the OTI Puzzle has been fully assembled and the big picture can finally be viewed and analyzed. Additional detailed modeling and specifications will also be added to the OTI ESM through maintenance processes described within the Puzzle Strategy.

The Component Library SysML package within the style guide contains common components with desired specification fields for ATDs. Every item in the component library is tailored to include the desired specification fields for the specific component. For example, a hardware component will have specification fields for vendor and manufacturer by default, while specific components can be expanded to include power use, heat generation, weight, size, cost, etc. as appropriate. Additionally, color can be assigned to the component to make it easier to identify in a diagram. For example, all hardware components exist as warm colors and software types exist as cool colors. That way, at a glance, it is clear what the diagram consists of and which hardware is hosting software.

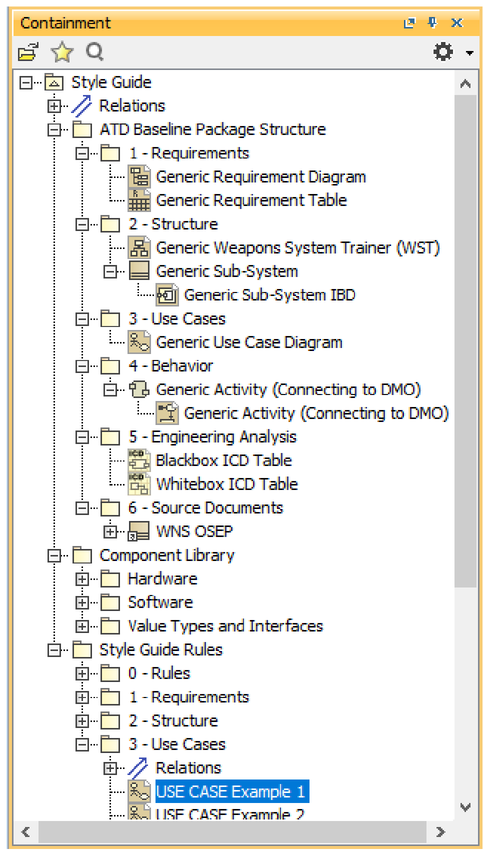

Figure 3. Style Guide Containment

The overall goal of the style guide is to have an expandable and flexible guide for modelers contributing to the OTI ESM to utilize when modeling their ATDs. The style guide is intended to be a “living document”, which can become more or less restrictive as concerns are brought up by engineers working on the models or by the users of the models. Rule sets can be added to the style guide to highlight and warn of any model elements in the OTI ESM that do not follow the style guide practices. However, adding unnecessary rule sets early would hurt innovation and limit what a creative modeler could add. Currently, the style guide consists of SysML Stereotype blocks and SysML generic ATD diagrams. This guide visually depicts where a new ATD model should start and what information should be included in multiple types of blocks and interfaces. An example of how the style guide informs the creation of use case diagrams can be seen in Figure 4.

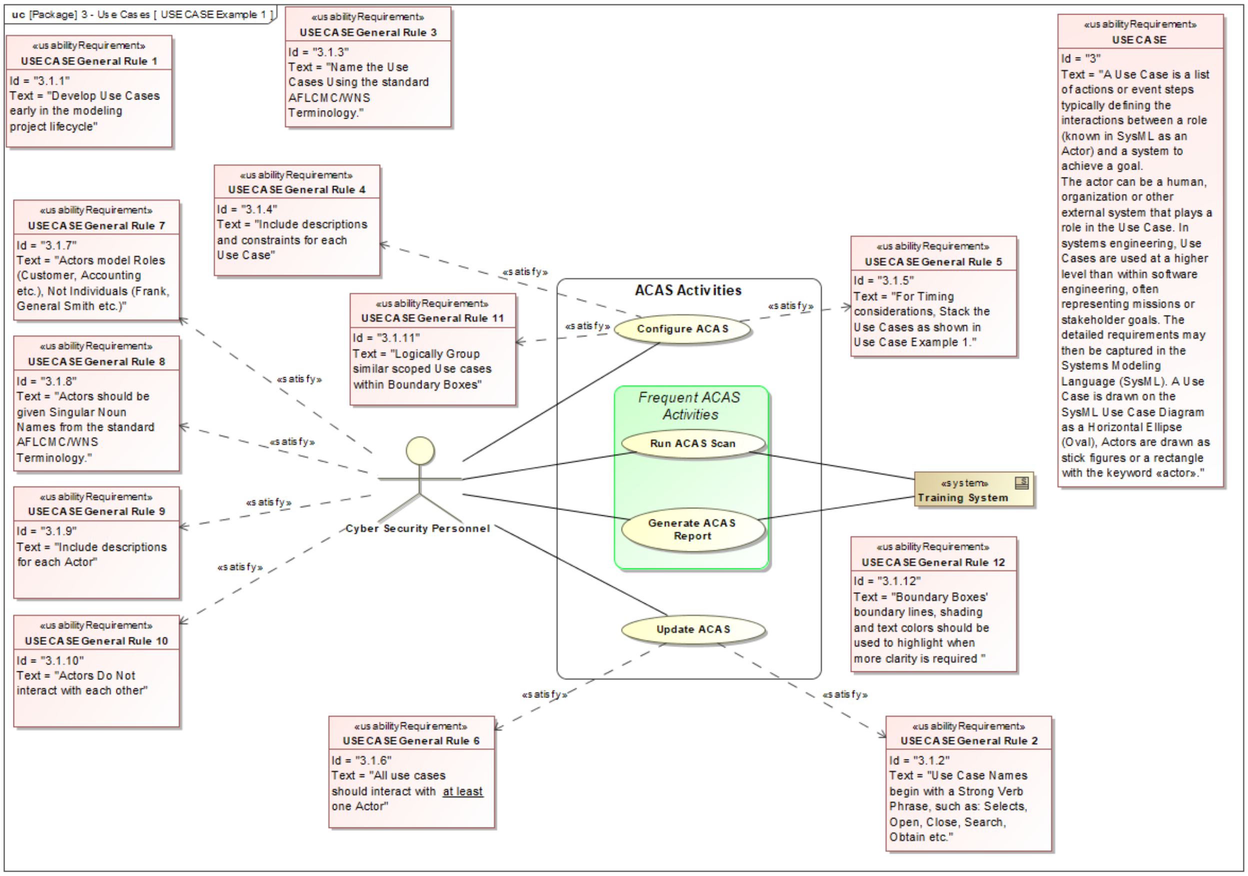

Figure 4. Style Guide Use Case Example

Each rule within the OTI ESM style guide is labeled as a usability requirement and is numbered to the parent package and diagram example number. The numbering of each rule allows the requirements table within the "0 - Rules" package (Figure 3) to become the meat of a formal, document-based style guide if desired. Using requirements within SysML allows the rules within the style guide to be traceable to elements within each example diagram. As seen in Figure 4, many of the rules are directly satisfied by elements within the diagram. However, drawing a line to every example of each rule would become overwhelming for any user of the style guide. To maintain full traceability, the remaining requirement connections are made in a separate requirements matrix within the rules package. Overall, the style guide enables the OTI ESM to exist as a cohesive enterprise model and is the backbone of the WNS modeling strategy.

Puzzle Strategy

The numbering system and style guide create a strong framework to the OTI Puzzle; however, a sound strategy to fill-in the million-piece puzzle is essential. The WNS strategy employs training, delegation, support, integration, and maintenance. This strategy will result in a completed ESM with a balance of speed and accuracy. WNS explored many options for completing the OTI ESM. Overall, keeping reference modeling in-house and contracting for detailed modeling provided the best opportunity to create the architecture of the ATD technical baselines. The knowledge base in WNS and clear lines of communication to the people maintaining the simulators enables the OTI ESM to be completed with the desired speed and accuracy at a high level. Additional levels of detail will be added over time through some of the hundreds of contract actions in WNS. To create a WNS knowledge base and gain experience with MBSE, WNS has launched a custom tailored MBSE training program for program engineers.

Training

The custom training course that will bring WNS into the digital engineering future is a collaborative effort with the Air Force Institute of Technology (AFIT). The goal is to train up to 100 engineers in MBSE to become competent modelers for their technical baselines. AFIT is also introducing the rest of WNS to MBSE through a two-hour wrap up course, combined as part of the engineers' classes. This short course introduces how MBSE is useful for WNS, how to navigate MBSE tools and diagrams, general DoDAF and SysML familiarization, and general import/export features of MBSE. The course is taught with an Object-Oriented Systems Engineering Method (OOSEM) because most of the devices in the OTI are in the sustainment phase of their lifecycle. OOSEM is ideal for modeling already-developed physical systems, Friedenthal (2011).

Each training course is held for four full days. To alleviate difficulty associated with leaving work for four days, the AFIT MBSE classes are offered in three-day blocks with one follow on day to evaluate models that were assigned as homework. This arrangement allows the WNS engineers to learn the basics of how to use MBSE tools to model their ATD technical baselines without interruptions for the first three days. Then, the homework to model one ATD technical baseline is assigned. The WNS engineers can then work on modeling their baseline around their main duties. Once the baseline is modeled, the WNS engineer can then attend any of the follow-on evaluation days to get feedback on their model and ask questions about more advanced modeling techniques that they may want to implement. This flexibility in schedule allows WNS engineers to attend the class without worrying about timing conflicts.

There are many advantages to collaborating with AFIT to train WNS in MBSE. First, the class is taught with access to a MBSE tool so the engineers get hands-on experience with MBSE while following the instructor's lessons. Hands-on learning is critical for retention of MBSE knowledge and resolves any questions immediately. Second, the AFIT instructors have customized the MBSE class to be simulator specific. The customization makes MBSE application to WNS extremely clear. In class, hands-on examples all are based on a generic simulator with a concept of operation, requirements, and a generic component library. These examples prepare the WNS engineers to model their own ATD technical baselines and they get immediate experience in MBSE by modeling one baseline as homework. Finally, AFIT is part of the USAF team, so there is already a strong connection between the instructors and WNS personnel.

Delegation

In order to assemble this 1,000,000-piece puzzle, it is critical to give the pieces representing each ATD to the people who know them best. Each Integrated Program Team (IPT) in WNS is tasked with maintaining training using their devices; therefore, the IPT is best suited for modeling the right level of complexity for their ATDs. As discussed in the training section above, engineers from each IPT will attend the custom AFIT MBSE class and learn how to model their ATD technical baselines. Once the WNS engineers have been trained, they will be tasked with modeling their ATD technical baselines. The style guide SysML Package is provided to each IPT to act as a starting point to generate their models.

There are three main advantages to assigning the baseline modeling to each IPT. First, as stated above, the IPT has knowledge and expertise with their ATDs to know the intricacies of each baseline. Second, each IPT has a maintenance and training support team that is either government or contractor for each ATD. The lines of communication to each ATD support team is strongest from the IPT, so the IPT has the ability to gather information to fill gaps in knowledge quickly. The IPT can then populate their baseline models with reduced effort. The final advantage is that each IPT in WNS will gain a much better understanding of their own devices by putting their puzzle pieces together in MBSE. This better understanding is the foothold to winning the war of cognition for the IPTs in WNS.

An alternate route that each WNS IPT may choose to utilize when modeling their technical baselines is to buy an already existing model that their Contractor Logistics Support (CLS) team may already have. Some CLS teams have made MBSE models to aid in their maintenance of the ATDs, but have had no need to send the model to WNS because WNS had never previously required MBSE to be delivered under the contract. These models would have to be re-formatted to match the WNS style guide, but the data itself would contain a deeper level of information than what WNS engineers could create. The advantage to having more data would be apparent when an Engineering Change Proposal (ECP) could be quickly evaluated to an ATD baseline with all affected components and requirements.

Support

The WNS MBSE strategy recognizes that expert support is required to implement MBSE properly. WNS deployed a team of MBSE advisors to help provide support to each IPT modeling their ATD technical baselines. These advisors have a diverse set of experience with MBSE and each provide valuable input to the OTI ESM. Their role as an MBSE support team is to provide support to the IPT first, but they are capable of modeling the ATD technical baselines if an IPT requires their help. Some advisors are assigned to large sub-programs as designated assistants, and the other advisors float to help IPTs in need. Overall, the MBSE support team have availability to help IPTs quickly, while also learning about the various technical baselines. The MBSE support team is the equivalent of having puzzle creators assist with assembling the OTI Puzzle.

The MBSE advisors have also helped to develop the style guide to standardize the modeling done by each IPT so that the completed ATD baseline models can be incorporated into the OTI ESM seamlessly. The advisor team will constantly update the style guide as holes are found. Using the advisors as an intermediary between the OTI ESM and the IPTs ensures that integration into the OTI ESM continues to improve.

Integration

Once the IPT has a completed a baseline model for their ATD, which resembles their pieces being assembled into a complete puzzle chunk, their model will be incorporated into the OTI ESM. It will be the job of the MBSE advisors to ensure compliance to the style guide and proper integration to the OTI ESM. As each assembled chunk is added to the OTI Puzzle, the overall picture of the OTI will become more complete and clear. At the same time, each chunk added will reveal new areas of the style guide to improve. Once all of the baseline models are integrated, the OTI puzzle will be considered complete, and the OTI ESM will be considered ready for full WNS use. However, the integration process will take at least a year and many changes occur to various technical baselines within a year. An enterprise model populated with data from up to a year ago would be useless unless there is some kind of model maintenance to keep concurrency.

Maintenance

As described in the background, WNS completes hundreds of contract actions per year. Many of these actions affect the technical baselines of various ATDs. The OTI ESM needs to have proper configuration control and permissions to allow the right people to update their technical baselines once the ATD model has been integrated. WNS is evaluating a solution using a cloud-based model host that will be located at Wright-Patterson Air Force Base with proper access permissions to prevent unauthorized sharing of proprietary or competitive information. With this solution, WNS engineers will be able to work with their IPT and ATD support teams to keep the MBSE baseline concurrent. The MBSE support team is the overall custodian of the model, and the MBSE support team lead is the final approval authority for changes to system models within the OTI ESM. The WNS Chief Engineer is the approval authority for enterprise wide changes to the OTI ESM.

The maintenance of the OTI ESM would be similar to replacing an old piece of the OTI Puzzle with a shiny, new piece. The numbering system and style guide ensure that the correct puzzle piece is replaced with a piece that matches the OTI Puzzle format. The long-term goal of OTI ESM maintenance is to bring the OTI to a common model architecture and ontology, where the components of each ATD are traced to other similar components. Knowledge of similar components reduces the likelihood of obsolescence emergencies shutting down training for extended periods on an ATD. As an example, if WNS received the requirement to upgrade the visual system of a WNS F-15 simulator to continue operational training, the OTI ESM 1-5.11.Z system model could be used to confirm that the visual system change is possible. Then, the system model acts as an additional verification method for the baseline configuration change, showing the difference to the full system before the actual parts are changed. Finally, the system model would be validated with the completed F-15 simulator modification and updated into the OTI ESM as the new baseline for that device.

CONCLUSION

The OTI ESM represents a cultural shift in how engineering is done within AFLCMC/WNS, and it will become the foothold for a new era of cognition in WNS. Every ATD baseline will be maintained in the enterprise model, and the same documents that are required for high-level Air Force management will require much less time to update and verify. At the time of writing this paper, the OTI ESM is still in its early stages with WNS MBSE training starting in July and integration efforts following shortly after. The completed framework with the numbering system and style guide feed into the custom MBSE training and create course modules with clear purpose toward the OTI ESM. Training WNS personnel in MBSE through AFIT is an effective way to prepare WNS to complete the OTI ESM. The inherent knowledge of ATDs in WNS combined with MBSE training will allow the OTI ESM to be populated with the best available data in a reasonable amount of time. The OTI ESM can be a powerful tool for WNS if properly created and utilized. The steps taken and the steps planned have sound justification and inspire confidence for a completed OTI ESM.

ACKNOWLEDGEMENTS

I would like to thank my WNS teammates that inspired me to launch the OTI ESM and supported me through the organizational barriers that are always present with change. A special thank you to Lei, Skip, Carlton, and Kevin for introducing me to MBSE and helping me to realize the potential of MBSE. I would also like to thank Dr. Colombi for being so willing to teach MBSE to my teammates in the program office.

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