The Advanced Weapons Elevator Digital Twin

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The *Ford* Class aircraft carrier design is required to meet many new and challenging requirements relative to earlier designs. Among these is a reduced time to prepare and launch a plane, which requires a sharp increase in the rate at which weapons can be moved throughout the ship.

To meet this requirement, electrically driven linear motors are used to raise and lower the elevators transporting weapons, thus the term 'Advanced Weapons Elevators' (AWE). As this is just one of many new technologies on the ship, competing concerns for other systems resulted in the AWE design not being fully prototyped before construction of the ship began. Integration issues encountered during the early build phase resulted in the need for a method to address problems without interfering with the shipboard test program. A land-based engineering test site (LBETS) was planned for future work but would not be available in time to support construction.

To facilitate shipboard testing and to allow a comprehensive understanding of the design, Newport News Shipbuilding (NNS) developed an integrated domain of model-based systems, energized hardware, contract requirements, environmental elements, shipboard code, augmented reality and additive manufacturing collectively referred to as a Digital Twin.

The term Digital Twin both benefits from and is constrained by the lack of a clearly accepted, industry-wide definition. While various disciplines have utilized emerging design tools and environments to realize the improvements available from digital technologies, few have 'closed the loop' and developed configuration managed products such that the end design is supported in a manner commensurate with the technology it utilizes to meet requirements. NNS is working with government and industry partners to reach agreements on definitions and processes to facilitate the delivery of the best products to meet our customer requirements.

The AWE Digital Twin begins first with requirements and then moves into a functional domain utilizing products within the MATLAB/Simulink environment. As this was developed in reaction to design issues (as opposed to concurrent with system development), the method of tracking functions against requirements was performed manually in most cases.

An early question was how to integrate a functional, partially physics based model of the controls and power train of the elevators with the geometry of the design (modeled or as-built). The answer to this was co-simulation. The physical elevator build was based on a product model and NNS research led to the understanding of compatibility between design and engineering tools. Via co-simulation, elements of a system best suited for functional or physics based tools can reside in a software package such as MATLAB while design and geometry aspects can reside in a software package such as SimCenter 3D or AutoDesk Inventor. Environmental aspects such as sea state forces can reside in either, depending upon modeler preference. This essentially lets us use the product model geometry as a digital prototype under the control of modeled or ‘wrapped’ system control software and modeled powertrain hardware.

As-built geometry and flexible structure (such as the elevator trunk and/or the moving platform) are achievable in this domain and obviously require significant attention to detail and special skills. NNS experience to date has shown that careful judgment must be applied when selecting which behaviors to implement in this manner, as not all are necessary – and general industry experience supports this approach.

The next phase of the AWE Digital Twin began once the systems on the ship became operational and hardware/software issues were encountered. This resulted in the addition of a second part to the effort – real time hardware in the loop. In this paradigm, the MATLAB/Simulink models are operated on real time processors while connected to shipboard code with some parts of the system existing in physical form. Control signals leave the model and interface to the operating hardware with feedback from the physical equipment returning to the model for integrated system operation. Visualization in this paradigm was initially difficult but – after working with specialized personnel - the geometry files were transferred to a dedicated system and projected via augmented reality. Motion calculated by the model and driven by physical hardware performance translates to an immersive, real time environment and data is sent back. Some instances of system hardware have been created via additive manufacturing and integrated into the real time, physical domain as well. Sea state forces remain present and are calculated real time and applied digitally, as well as out to the hardware control signals. Data from the ship can also drive the visualization tool allowing a shore side engineer to ‘see’ the shipboard events. This effort now operates in conjunction with the LBETS at Naval Surface Warfare Center Philadelphia to provide integrated digital and physical system support.

Future use of this approach for specifying, modeling, testing and integrating systems can benefit from lessons learned during this effort. In some instances the AWE engineering community worked exclusively by model – there was no written transcription into or out of the modeling domain – and this significantly improved turnaround time for understanding problems and implementing solutions. Operating in this manner will not happen incidentally; government and industry members must develop the proper environments, train personnel and create processes to facilitate the work which will consume resources but will provide benefits, and in a modern engineering world ensure relevance.

In summary, the AWE Digital Twin is a product that allows detailed analyses, real time operations, immersive visualizations, hardware integration, training and testing that supports but does not interfere with a shipboard construction process. In the end, the results are compared to requirements as would be done in a physical system – the fundamentals remain the same.