Chapter 5 – SEA VEHICLES

5.1 INTRODUCTION

Sea vehicle design and building is an extremely complicated process that requires the coordination of many complex phases. Coupled with the fact that there are many different types of sea vehicles—ships, submarines, unmanned undersea vehicles, and undersea weapons and the need to control costs and improve production schedules, shipbuilding companies have recognized the advantages of integrated design, standardization, lean manufacturing and leveraging cross cutting technologies into new designs.

5.1.1 Historical Aspects of Sea Vehicle Production

In commercial applications, sea vehicle production is clearly business and market driven; whereas in military applications, it is solely mission driven. Overall, sea vehicles are designed and built in response to new technologies, world politics, military strategies and of course economic condition. Fundamentally, sea vehicle design focuses on: what the vehicle needs to carry; what powers it; what are the stability and drag requirements; what are the survivability requirements; how does it avoid detection; and what new technologies need to be incorporated. The genesis of military sea vehicle design lies in the desired functions and performance of the vessel against a perceived threat.

Naval sea vehicle design includes analysis of the functional requirements leading to a suite of conceptual solutions ranging from conservative to non-traditional. The design encompasses the incorporation of the latest technology and developmental research that to be integrated into the current and future designs. The design also includes the integration of existing subsystems such as:

- Number and mixture of platforms.
- Inter-relationships with existing defence equipment and facilities.
- Weapon types and combinations.
- Alternative hull form configurations and sizes.

Sea vehicle conceptual designs initially rely on historical expertise as the starting point. From the design databases, algorithms, intuition and estimation along with computer aided modelling are used in advancing these conceptual designs. At the initial stage, the design is detailed enough to provide insight into operational capability, technological risk/engineering complexity, development and lifecycle costs. From these conceptual designs, the process leads to a suite of trade-off studies. At the completion of the initial design phase, a single preferred design configuration is selected. Performance characteristics for the entire ship including subsystems is available that provides an accurate measure of cost. Following the conceptual design and trade studies, detailed design starts and results in a complete engineering definition of the ship to a level of detail sufficient for construction to commence. Testing and acceptance are the remaining phases.

5.1.2 Ship Design Process

The design and analysis of sea vehicle, such as surface ships, is still largely compartmental in nature and propulsion, resistance, manoeuvring and seakeeping are often performed independently [396]. Computational fluid dynamics (CFD) is part of the experimental process that supports the design cycle. Mission requirements often drive the ship design process and CFD codes are used during the very early design stage to calculate and
balance ship characteristics. The commonly used CFD codes are Reynolds Averaged Navier-Stokes (RANS), Large Eddy Simulations (LES), FLUENT, and ship motion prediction programs such as Large Amplitude Motion Program (LAMP) and FREDYN. Such codes allow one to quickly evaluate the design space and perform trade-off studies to achieve the best solution for the required mission. Because of cost and efficiency, the shipbuilder is likely to move to integrated ship design in the future. At the early design phase, CFD computations are very attractive and could be used to study the various hull forms, and in particular the radical new hull forms.

5.1.3 Need for Integration

Similar to the air and land vehicles, the shipbuilding community in the United States and Germany has been engaged in an organized way toward changing the processes involved in designing, manufacturing and maintaining ships for some time. Within the U.S., since the late 1990s, the National Shipbuilding Research Program (NSRP) has established to guide the industry in developing a suite of practices for ship design [397]. The NSRP is a collaboration of U.S. shipyards working with the U.S. Navy to reduce the cost of ship construction and repair by improving shipbuilding industry productivity through advanced technology and processes. In Germany, research into the development of a tool entitled, “Knowledge Lounge as an Instrument for System Integration”, suggests that 70 percent of the ships cost is determined within a few weeks of the first customer inquiry [398]. Committed outlay cost in the world shipbuilding industry is forcing the German shipyards to seek cooperation and standardization to avoid specialized suppliers and the subsequent multiplicity of sub-contractors. Coordination and cooperation amongst the German shipbuilders mirrors the effort within the United States.

As evidence of the NSRP effort, a project called Lean Shipbuilding and Repair has been initiated. The Lean Production concept is based on the Toyota automobile production model developed by the Massachusetts Institute of Technology. Accordingly, the Lean Shipbuilding and Repair Initiative comprises of six areas:

- Shipyard Production Process Technologies — an element focused on process oriented projects designed to gain insight into implementing world class Lean Manufacturing principles.

- Systems Technologies — projects designed at developing the automated processing of vendor data, and engineering and design data. Inherent to this area is a project called the Integrated Shipbuilding Environment that has demonstrated the exchange of design and supplier data in various stages of the shipbuilding process.

- Business Process Technologies — designed to focus on cost and cycle time reductions. These projects target an eCommerce and electronic commerce opportunities within the U.S. shipyards. Internet enabled supply will lead to virtual enterprises for source and supply chain integration amongst shipyards that is transparent to the underlying processes and computing environments of the participative companies.

- Product Design and Material Technologies has sponsored a project that has advanced the concept of designing a ship as a hierarchy or pre-engineered volumes. The project was initiated in recognition of an observation that due to the lack of parametric design U.S. commercial ships had significantly greater material and labor content and therefore higher costs than similar designs outside of the U.S.

- Facilities and Tooling is an area designed to improve the workplace organization.

- Crosscut Initiatives represent areas where projects are centered on influencing organizational change toward accepting and sustaining Lean Shipbuilding principles.
The NSRP is an example of systemic change effort under way with the shipbuilding industry. Similar efforts exist within Germany that streamline the shipyard processes to the standardization of supply chain mechanisms to initiatives that will facilitate the workforce’s acceptance of these new Lean processes and the use of the tools inherent to these processes.

There are various sea vehicles — ships, submarines, unmanned undersea vehicles, and undersea weapons. The discussion that follows focuses on the military aspects of the Integration of Tools and Processes for an undersea weapon. The tools and processes that support the development of ships and submarines are much more complex and sensitive, and hence are beyond the scope of this document.

Bibliography


5.2 UNDERSEA WEAPONS

This section provides an overview of the Undersea Weapons Design and Optimization (UWD&O) Science and Technology activities sponsored by the United States Navy-Office of Naval Research (ONR). The objective of the Undersea Weapons Design and Optimization programme is to develop computational tools and simulation-based methodology to optimise undersea weapon system designs with respect to cost and performance requirements. One of the payoffs of the UWD&O process is a “smart product model” that transitions to not only support the acquisition and lifecycle functions but also facilitates the spiral development of new capabilities within the product lifecycle. The smart product model retains the knowledge base that previously resided with the technical experts to ensure that this knowledge is available throughout the entire product lifecycle.

The UWD&O programme focuses on Simulation Based Design (SBD) system architecture and tools development. Design tools such as a virtual prototype design environment, Multidisciplinary Design Optimization (MDO), and cost/performance analyses are emphasized. Cost and performance trade-off studies are conducted by applying the methodology and tools to rapid prototyping of a torpedo upgrade, new capability, or next generation weapon system design. Connectivity is developed for disparate programming languages, Computer Aided Design (CAD) systems, performance models, and external libraries. The design and optimization process involves building the SBD architecture using physics-based models to provide data for process/mechanical/environmental simulations which, in turn, form the basis for the vehicle subsystems and creates a virtual prototype system design that can be used for performance, cost, and quality assessment.

In the following sections, the design tools and integration processes are described, and technical challenges are discussed. The design tools and integration processes developed in this programme have been implemented in the Torpedo Guidance and Control (G&C), Stealth, Warhead, and High-Speed Supercavitating Weapons programmes. Specifically, the design tools and collaborated design environment are presented for the development of torpedo sonar system, virtual acoustic design using active acoustic control technique, new warhead configurations, acquisition and total ownership cost predictions, and high-speed supercavitating weapon simulations in the virtual reality environment.

UWD&O is the infrastructure that is being developed to support the design of various undersea weapons as shown in Fig. 5-1. The weapons include the High-Speed Quick Reaction, Torpedo Defence, Coordinated Attack, Long Range Stealth, and Advanced Weapons. These undersea weapons cover close-in and extended range scenarios, with affordability as the key requirement.

The UWD&O programme is based on the Simulation Based Design (SBD) approach. As shown in Fig. 5-2, SBD spans the design, prototyping, acquisition, and operations of undersea weapons. Specifically, it is used in the simulation-based design and engineering, virtual manufacturing, virtual testing [399], training simulations, operations and logistics simulations, and warfare analyses.

The UWD&O system architecture (as depicted in Fig. 5-3) consists of four major components: multi-user access server, design tools, simulation environment, and lifecycle factors. The multi-user access server is the project data manager that communicates and interacts with the other three components. The design tool consists of analytical and numerical models, computer codes, and technology object library that supports product design and development. The simulation environment provides performance simulation and virtual training, testing, and tactics evaluation. The lifecycle factors component deals with logistics modelling, cost modelling and analyses, and manufacturing process modelling.
Figure 5-1: Impacts of undersea weapon design and optimization.

Figure 5-2: Simulation Based Design (SBD) vision.
5.2.1 Technical Challenges

Affordable Science and Technology (S&T) product development, acquisition, and support for future undersea weaponry requires a software driven simulation based design process that provides: 1) improved (reduced time and cost) product development, 2) accurate cost and benefit estimate of new technologies to meet future warfighting needs, and 3) efficient transition of technology to the end users. The UWD&O programme develops the infrastructure that supports the development of undersea weapons in torpedo guidance and control, warhead, propulsion, stealth, and torpedo defence technologies, as well as advanced weapons system concepts such as the high-speed supercavitating weapons. This programme establishes a modelling and simulation environment that integrates the Navy’s S&T with Engineering Development efforts in undersea weaponry. The goal of the UWD&O project is to develop a system that determines the design that gives optimal performance with a minimal Total Ownership Cost (TOC).

Some of the key technical challenges and S&T issues include:

- Interface of the various design tools and computer codes.
- Connectivity of multi-users in a collaborative design environment.
- Affordable, and optimized designs.
- Uncertainty in design variables and operation.
- Accurate cost estimates.
- Effective visualization of large amounts of data.
5.2.2 Collaborative and Distributive Design Environment

The UWD&O programme focuses on the development of system architecture and design tools for the collaborative and distributive design environment. Design tools such as a virtual prototype design, Multidisciplinary Design Optimization (MDO), and cost/performance analyses are emphasized. Cost and performance trade-off studies are conducted by applying the methodology and tools to rapid prototyping of a torpedo upgrade, a new capability, or a new weapon system design. Figure 5-4 illustrates the virtual prototyping of a torpedo. Given overall system attributes in speed, depth and range, the designers can select the subsystems in power, guidance and control, propulsor, hydrodynamics, shell and structures, and payload. Cost analyses and simulated engagements are then performed to determine the optimal design.

Connectivity needs to be developed for disparate programming languages, Computer Aided Design (CAD) systems, performance models, external libraries, and users. Boyars et al. [400] identified connectivity among designers and users as one of the key requirements for the collaborative and distributive design environment. The design and optimization process involves building the SBD architecture using physics-based models to provide data for process/mechanical/environmental simulations, which, in turn, forms the basis for the vehicle subsystems, and creates a virtual prototype system design that can be used for performance, cost, and quality assessment. As an example, a web based collaborative and distributive design environment was used to design a torpedo sonar array (Fig. 5-5). Engineering analyses and design were performed by geographically dispersed designers/users.
5.2.3 Multidisciplinary Optimization

Multidisciplinary Design Optimization (MDO) helps the users and designers to gain the understanding of the interaction among the various components to make effective and efficient trade-off decisions. Kusmik [401] used MDO, and Belegundu et al. [402] used attributed-based MDO to design undersea vehicles. Further Alyanak, et al. [403] used MDO to determine the optimal arrangement of stiffeners in a High-Speed Supercavitating Weapon. MDO seeks the rapid convergence on an optimal system-level design using the various models, simulation tools, and information management systems. Considering the conflicting requirement of the various sub systems and components, such optimization is indeed very complicated. Research efforts in interval programming, probabilistic methods, and meta-models with nonlinear strategies are under way to develop effective and fast algorithms for optimization. Multi-objective MDO is being used for a new warhead design (Fig. 5-6). Given the design requirements, and objectives and constraints, the optimizer interacts with the warhead server, torpedo shell analyser and lethality evaluator to produce the optimal warhead design. In this optimization, warhead lethality, radiated noise, and probability of kill (P_k), and cost are considered simultaneously.

In the electric propulsion design and analysis, thermal and structural analyses are performed simultaneously to optimise motor design. As shown in Fig. 5-7, thermal analysis and finite element analysis are integrated in the motor design.

The objective of the High-Speed Supercavitating Weapons programme is to develop vehicle guidance, control, and manoeuvring capabilities for quick-reaction and delivery weapons. Vehicle guidance deals with acoustic sensors, signal processing, waveform design, homing techniques and the controller that are used to guide the weapon to the target. Vehicle control deals with the control and manoeuvring of the high-speed weapon, with emphasis on stabilizing the Supercavitating bubble cavity and optimising the bubble shape for drag reduction.
In the development of the Supercavitating Weapons, MDO is used to optimise the vehicle guidance and control. A detailed description of the technical challenges and research efforts in hydromechanics and control has been documented by Ng [404] Vehicle control approach and control algorithms development are provided by Kirschner et al. [405].

![Diagram](image)

**Figure 5-6: Multi-objective multidisciplinary design optimization for warhead.**

### 5.2.4 Cost Analysis

Total Ownership Cost (TOC) has become one of the critical criteria in the weapon system acquisition process. TOC consists of costs from: 1) research and development, 2) production and manufacturing, 3) operation and maintenance, and 4) disposal. There are commercial parametric cost estimating software and cost models, e.g., PRICE, Galorath’s System Estimation and Evaluation of Resources (SEER), for cost analyses [406]. Typical cost estimation requires inputs such as design, schedule, and deployment information. The outputs of cost estimation consist of total programme cost, cost by phase, cost by type, and cost by category. The cost by category includes drafting, design, system engineering, project management, prototype, production, tooling and test equipment, general and administrative, and overhead. Maintenance cost is one of the most challenging cost estimations, in particular when there is a lack of repair records or historical cost data.
5.2.5 Virtual Design Environment

Recently, substantial progress has been made in virtual reality and scientific visualization to translate large amounts of data to visual representation. Aukstakalnis and Blatner [407] defined Virtual Reality as “a way for humans to visualize, manipulate and interact with computers and extremely complex data.” The virtual design environment provides visualization techniques so that designers can see design changes and their impact on the overall system. Virtual reality and collaborative design environment are used for the development of advanced undersea weapons. Specific interests and focus are on torpedo stealth, warhead design, and high-speed supercavitating weapons. For example, the Virtual Reality Laboratory at the University of Maryland is developing the active noise and vibration control techniques [408] for stealth torpedo using this approach (Fig. 5-8). Numerical results from the finite element model of the torpedo shell are displayed in the virtual environment. The animated structural noise radiation can be heard using the sound system and the vibration of the shell can be felt with the touch glove.
With the virtual environment, designers can select a range of subsystem technologies to assemble a conceptual design. This virtual prototyping capability dramatically reduces development time and total ownership cost. The virtual environment provides simulation and modelling capabilities, as well as evaluation of realistic operational scenarios. The immersive visualization facilities at the Penn State University/Applied Research Laboratory, Virginia Tech, University of Maryland, and Georgia Tech are utilized together with basic and applied research related to Supercavitation physics, torpedo silencing and warheads to develop a unique integrated design environment. The four virtual reality sites are connected to form a collaborative design cluster among UWD&O team members. The capability to visualize real-time simulations of the High-Speed Supercavitating Weapons has been demonstrated at the Penn State University’s Applied Research Laboratory. Modelling and simulation capabilities are augmented with the capability to generate immersive simulations from a synthesis of individual subsystem designs. Collaborative design architecture, multidisciplinary optimization scheme, cost analysis tools and other relevant subsystem synthesis methods are incorporated into this virtual design environment. The advanced weapon designs are evaluated in operational scenarios modelled using the concept of operations requirements from the operational Naval community. Standard protocols are utilized so that the conceptual designs can be evaluated in warfare simulation involving real players. This virtual design environment provides a faster, more effective, and affordable design space to develop undersea weaponry to meet future threats.

5.2.6 Implementation of Undersea Weapon Design and Optimization

The Naval Undersea Warfare Center (NUWC) Division Newport has implemented the UWD&O tools and integration process to develop the ONR Swampworks prototype next generation torpedo [409]. The Swampworks prototype torpedo is compact, and contains advanced arrays to increase its guidance and control capabilities. It is powered by a propulsion system designed to maintain performance over a wide range of missions while maintaining vehicle stealth and effectiveness. The UWD&O process was initiated with a warfare analysis to establish requirements for future threats.
Using the design space tools, a preliminary assessment of design alternatives was performed. The parametric design tools enable quick selection of the propulsion and sonar systems. Software development was also performed in the UWD&O environment to allow real time evaluation of the embedded software’s capability on the new weapon system. Software was developed in an open architecture to facilitate upgrades and performance trade-offs.

A menu driven motor design tool was used to assess electric and thermal propulsion candidate systems. The design tool seamlessly interacts with thermal, structural and electromagnetic models to provide rapid assessment of system feasibility. The two models together predicted the unsteady torque generated by the engine and transmitted directly into the propulsor. The design baseline was also used to predict the structural transfer functions of the housing, mounts and couplings. A third model, the Vehicle Acoustic Signature Tool (VAST) provides an acoustic model of the system that takes the unsteady vibration information and the transfer functions and predicts the in-water radiated noise signature.

Embedded optimization was used to tune component properties to achieve enhanced performance. If a design does not meet all of the requirements, a set of achievable design characteristics is returned to the warfare analysis assessment tools to evaluate the impact of relaxing specific requirements. If no design evolves to meet the minimum goals for the weapon, a design concept is developed that will enable the seamless integration of new processors and hardware. Successful implementation requires a product model and database that are sophisticated and persistent for the weapon’s total lifecycle. Preplanning a spiral development path that introduces enhanced capabilities as they evolve ensures that the weapon system remains technologically state-of-the-art. The Swampworks torpedo described here is a spiral evolution of the Common Broadband Advanced Sonar System (CBASS) torpedo and will evolve to the next generation sonar array through these processes.

**5.2.7 Conclusions and Future S&T Directions**

Simulation Based Design (SBD) is an effective approach for system design and product development. The UWD&O environment provides the foundation for timely, information-based engineering and programmatic decision-making.

Future S&T directions should focus on Multidisciplinary Design Optimization, cost analysis, and virtual environment for simulation. Specifically, the following areas should be of great interests:

- Efficient optimization schemes.
- Fast convergence algorithms.
- Accurate cost analyses.
- Representation and interaction with large amounts of digital data in the virtual environment.
- Interfacing design tools and computer codes.

**Bibliography**


5.3 STATE-OF-THE-ART TOOLS

The United States Navy Hydrodynamic/Hydroacoustic Technology Center (H/HTC) is the depository for state-of-the-art design tools for all naval platforms and systems. Founded by Defense Advanced Research Project Agency (DARPA) in 1988, the H/HTC is located at the Carderock Division of the Naval Surface Warfare Center (NSWC), and is managed by the Naval Sea Systems Command (NAVSEA 05H). Through the maintenance and operation of the state-of-the-art computational facilities, and the development and employment of collaborative engineering tools, the H/HTC acts as an enabling node linking a geographically distributed network of scientists and engineers highly skilled in hydrodynamics and its various sub-disciplines. As such, the H/HTC infrastructure and support staff provides the tools and the environment to foster research related to hydrodynamic and hydroacoustic design and engineering [410].

5.3.1 Hardware Resources

The H/HTC operates two computer networks, one for classified and one for unclassified data processing. The primary processing resource on each network is a 24-processor SGI Origin 3400 compute server, with the unclassified network further supported by a 16-processor SGI Origin 2400 compute server, and a 14-node Beowulf Cluster. The servers are networked with a cluster of SGI and Windows-based engineering workstations and a shared file system with hierarchical storage provided by a StorageTek L700 Robotic Storage System.

5.3.2 Software Resources

The software available at the H/HTC is driven by the needs of the hydrodynamic and hydroacoustic user community. Sources for software are commercial vendors, universities and government agencies. In addition to a number of tools developed at the H/HTC, the following application software is available to the H/HTC users:

5.3.2.1 Geometry Definition and Grid Generation

The following software and computer codes support the geometry definition and grid generation for the sea vehicles of interest:

- GRIDGEN: Grid generation.
- IDEAS: General geometry definition.
- FASTSHIP: Geometry definition and grid generation.

5.3.2.2 Computational Fluid Dynamics

The following software and computer codes support fluid dynamic (hydrodynamic) calculations for sea vehicles:

- UNCLE: Reynolds Averaged Navier-Stokes (RANS) code with steady and unsteady flow capabilities.
- VSAERO: Aerodynamic flow calculation.
- CFDSHIP-IOWA: CFD code developed by Iowa State University for ships.
- USAAERO: Aerodynamic flow calculation.
In addition, the Computational Fluid Dynamics (CFD) Group at NSWC has state-of-the-art computational tools for the analysis and interpretation of complex fluid dynamics. Specifically, the flows include: incompressible and compressible flows, free surface flows, turbulence, combustion, chemical reacting flows, flow with heat transfer, and multi-phase flows. Ranging from model scale to full scale, CFD analyses are used to identify and understand flow physics affecting the performance of surface ships, submarines, and their subsystems such as propellers, pumps and impellers. These analyses support new designs, as well as modifications to existing design, in many applications of sea vehicles.

5.3.2.3 Visualization

The following software and computer codes support post processing and visualization of flow calculations:

- TECPLOT: General post processing code for plotting and visualization.
- FIELDVIEW: Graphical visualization for flow.
- FIELDMASTER: Post processing code for visualization.
- SUBTRACE: Visualization for vehicle maneuvering.

5.3.2.4 Structural Finite Element

- ABAQUS: General finite element code.
- NASTRAN: General finite element code.
- SARA2D and SARA 3D: 2-dimensional and 3-dimensional structural acoustic codes.
- LS-DYNA: Finite element code.
- USA: Underwater explosion and analysis.

5.3.2.5 Collaboration

- TEAMROOM: Software supports collaboration.
- TEAMSTATION VTC: Supports video teleconference.

5.3.2.6 Advanced Visualization

An SGI Onyx2 Infinite Reality visualization system is accessible on the classified network. This system, coupled with a Fakespace 3D BOOM (Binocular Omni-Orientation Monitor) and Ascension Motion Tracking System, enables engineers to view large complex computational models in an immersive "virtual" space.

5.3.2.7 Collaborative Technologies

TeamRoom, developed by the H/HTC, is a powerful, secure, web-based tool for team collaboration built around "good teaming" concepts. By creating a shared context for teamwork, TeamRoom offers advantages, both for the individuals on the team and for the team as a whole, over "sending" technologies such as e-mail. TeamRoom’s web accessibility also makes it possible to support geographically distributed teams. TeamRoom are used for raising and discussing issues and concerns, creating collaborative product: memos, presentations, other deliverables, brainstorming, preparation for meetings, tracking meeting agendas and action items, project management, document review, and as a team library and knowledge base.
For real-time collaboration, the H/HTC offers a video teleconferencing (VTC) facility that uses the latest technology to provide audio, video, and data conferencing (concurrent application, whiteboard, and file sharing).

Bibliography

5.4 ISSUES RELATED TO UNDERSEA WEAPONS

Some of the remaining S&T issues related to undersea weapons are:

- Interface of the various design tools and computer codes: connectivity among design tools and codes due to disparate program languages and data formats.
- Connectivity of multi-users in a collaborative design environment: interaction and integration of users in collaborative design environment.
- Affordable, and optimized designs: cost effective design optimization.
- Efficient optimization schemes: effective optimization techniques.
- Fast convergence algorithms: to speed up the convergence of iterations.
- Uncertainty in design variables and operation: accounted for uncertainty in design variables and parameters such as operations, materials, and configuration.
- Accurate cost analyses and estimates: good cost estimates and prediction for design trade-off studies.
- Representation and interaction with large amounts of digital data in the virtual environment: ability to present large amount of out data for visualization of trends and making design decision.
5.5 SUMMARY

Sea Vehicle design, building and maintenance is an extremely complicated process that requires the coordination of many complex phases. Coupled with the fact that there are many different types of Sea Vehicles and the need to control costs and improve production schedules, shipbuilding companies have recognized and seen the advantages of integrated design, standardization, lean manufacturing and leveraging cross cutting technologies into new designs.

The Sea Vehicle section was limited in scope due to the sensitive matters associated with the naval platforms and systems. However, as was previously stated, there are various sea vehicles — ships, submarines, unmanned undersea vehicles, and undersea weapons. The Sea Vehicle section focuses on the military aspects of the Integration of Tools and Processes for an Undersea weapon. The tools and processes that support the development of ships and submarines are much more complex and sensitive, and hence are beyond the scope of this document. To this end, this section discusses the Undersea Weapons Design and Optimization (UWD&O) Science and Technology activities sponsored by the United States Navy — Office of Naval Research (ONR). The objective of the Undersea Weapons Design and Optimization program is to develop computational tools and simulation-based methodology to optimise undersea weapon system designs with respect to cost and performance requirements. One of the payoffs of the UWD&O process is a “smart product model” that transitions to not only support the acquisition and life-cycle functions but also facilitates the spiral development of new capabilities within the product life cycle. The smart product model retains the knowledge base that previously resided with the technical experts to ensure that this knowledge is available throughout the entire product life cycle.

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