# Naval Platform Simulation Using the NATO Virtual Ships Standard


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## *ABSTRACT*

*The new NATO Virtual Ships standard is a resource for developing simulations of naval platform systems involving highly coupled multiple entities. The standard focusses on distributed simulations developed using the High Level Architecture; however, much of the content, including modelling of the environment and naval platform systems, is applicable to other simulation frameworks. The Virtual Ships standard has been successfully applied to several naval platform areas, including replenishment at sea, launch and recovery of small water craft, and ship signature management. Experience with naval platform simulation validation has highlighted challenges validating simulations of short duration events, such as replenishment at sea, in random seaways.*

## 1.0 INTRODUCTION

Approximately two decades ago, distributed simulation using the High Level Architecture (HLA) [1, 2] became an area of very active development with application to many military areas. It was envisioned that simulations would need to be "HLA compliant" if they were to be adopted by others. In response to this emerging technology, NATO Subgroup 61 on Virtual Ships, under the Ship Design Capability Group of the Naval Armaments Group, was formed for the purpose of developing standards for facilitating collaborative efforts when applying simulation to naval platforms. Standard development focussed on application of distributed simulation using HLA to naval platforms [3, 4]. This paper describes naval platform simulation using the Virtual Ships standard, including lessons learned.

## 2.0 NAVAL PLATFORM MODELLING AND SIMULATION

Modelling and simulation using digital computers have been widely applied to naval platforms, including ships and submarines, since the 1960s [5]. Most modelling and simulation of naval platforms has focussed on a single entity, such as the motions of a single ship in waves (see Figure 1). Modelling and simulation of naval platforms routinely includes the following:

- Resistance in calm water,
- Maneuvering in calm water,
- Motions in waves,
- Structural strength assessment, including fatigue and ultimate strength.

For modelling hydrodynamic performance, varying levels of fidelity can be used, including simple regression methods based on databases of experimental values, potential flow numerical methods with intermediate fidelity and computational requirements, and detailed computational fluid dynamics including detailed modelling of viscous effects. Similarly, structural analysis can vary from relatively simple beam models to detailed finite element modelling.

Multiple entities are involved in many naval platform operations, including:

- Replenishment at sea,
- Naval helicopter operations,
- Launch and recovery of small water craft.

Figure 2 shows an example of replenishment at sea, which can include fuelling operations and transfer of solid payloads between vessels.

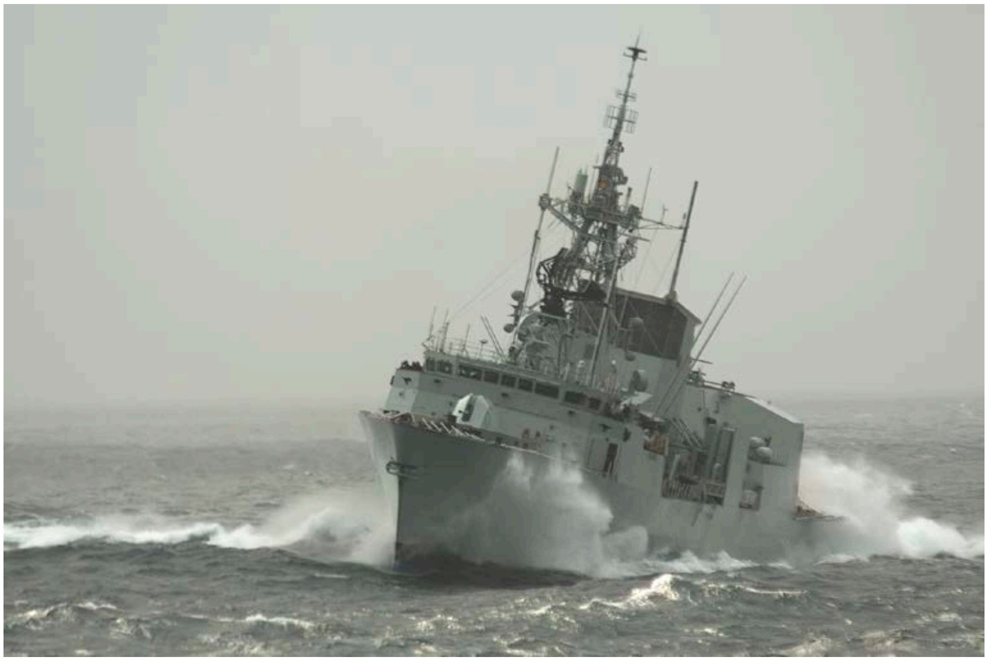

**Figure 1: Canadian Patrol Frigate in waves**
**(http://www.navy-marine.forces.gc.ca/en/multimedia/gallery-ships.page)**

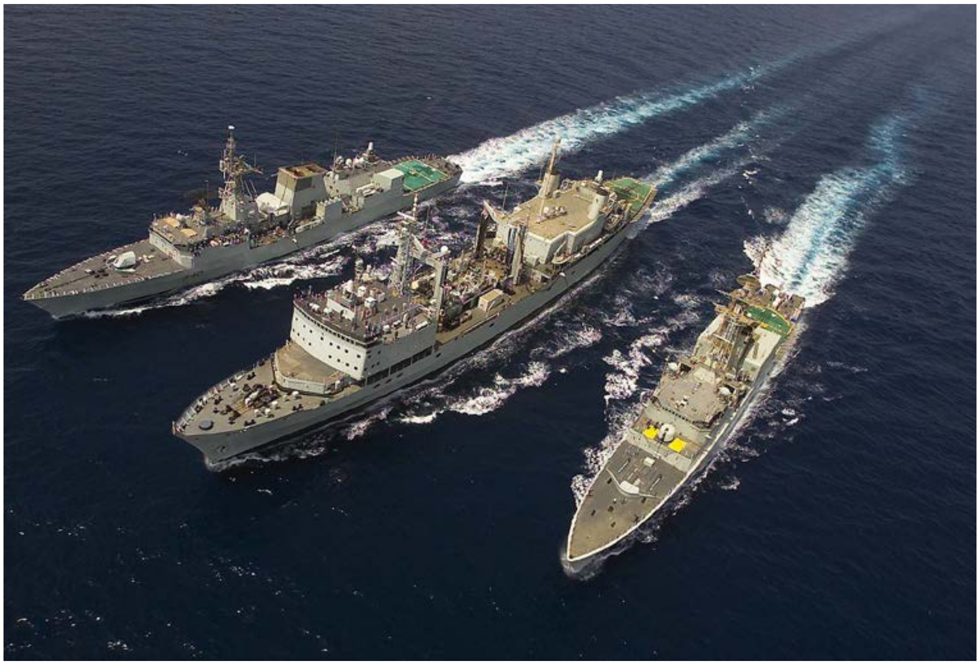

**Figure 2: Canadian ships conducting replenishment operations**
**(*http://www.navy-marine.forces.gc.ca/en/multimedia/gallery-ships.page*)**

Naval operations involving multiple entities require complex engineering and highly competent operational personnel. Fortunately, modelling and simulation can be applied in various ways, including engineering design, operational planning, and staff training.

Naval platform simulation requires domain expertise in several areas, such as:

- Ocean environment, including waves and wind,
- Hydrodynamics, including resistance, maneuvering, and motions in waves,
- Ship structures,
- Marine engineering systems, including power systems,
- Control systems, including rudder and propeller controllers,
- Multibody dynamics, including cranes and collision modelling.

In addition to domain expertise, expertise in areas such as software development, networking, and visualization is required for naval platform simulation.

## 3.0 NATO VIRTUAL SHIP STANDARD

The NATO Virtual Ships standard consists of a brief NATO Standardization Agreement (STANAG) [3] and a substantial Allied Naval Engineering Publication (ANEP) [4]. The technical detail discussed here is fully described in the ANEP. The ANEP focusses on time domain simulation of naval platforms using HLA; however, much of the ANEP content is applicable to general time domain simulation of naval platforms.

The Virtual Ship standard covers the following main areas:

- Virtual Ship federation agreements,
- Virtual Ship reference object model,
- Virtual Ship federation development and execution,
- Virtual Ship repository.

The standard aims to build upon existing best practices by extending them to naval platforms.

### 3.1 Virtual Ship Federation Agreements

The Virtual Ship standard gives detailed guidance on federation management, including initialization, time stepping, and final termination. The standard introduces a Virtual Ship time management scheme, which is intended to improve upon the commonly used runtime infrastructure (RTI) time management scheme. The Virtual Ship time management scheme provides the following new capabilities:

- Ability to specify order of execution of federates;
- Strong support for variable time steps among federates.

Specification of execution order of federates is required due to some federates being dependent on data (e.g., forces influencing accelerations) produced by other federates. Efficient support of variable time steps is required because some entities have motions that vary relatively slowly, which other entities have motions that can vary rapidly. For example, a time step size of 0.1 s can be sufficiently small for simulating the motions of a naval destroyer or other large vessel. In contrast, a time step size of the order of 0.001 s can be required for simulating the motion of small craft attached to a crane cable that experiences snap loading.

### 3.2 Virtual Ship Reference Object Model

Significant effort was devoted to developing the Virtual Ship reference object model, which is based on Version 2.0 of the Real-Time Platform Reference Federation Object Model (RPR FOM) [6]. The Virtual Ships FOM extends the RPR FOM to include the following entities required for simulation of naval platforms:

- Ocean environmental models, including seaway, wind, and currents;
- Ship appendages, including rudders, propellers, and stabilizer fins;
- Ship mechanical systems, including winches and cables;
- Forces that can arise from various sources, including aerodynamic, hydrodynamic, and cable forces.

The Virtual Ships standard includes specification of coordinate systems to be used with the Virtual Ships FOM. These coordinate system specifications have proven to be highly useful when developing naval platform simulations. The Virtual Ships coordinate systems remove the need for further deliberation, contribute to the reliability of software components, and simplify re-use and interoperability.

### 3.3 Virtual Ship Federation Development and Execution

The Virtual Ship standard includes direction regarding federation development and execution. HLA standards for the Federation Development and Execution Process (FEDEP) [7] and verification and validation [8] provide the foundations for this direction. The Virtual Ships standard adds direction in several areas, including coordination with shipbuilding projects and updating of simulation repositories.

### 3.4 Virtual Ship Repository

The Virtual Ship standard promotes usage of a NATO Virtual Ship Repository, including standardized templates. The proposed repository has not yet been established as an active entity. The authors of this paper have witnessed several attempts to develop simulation software repositories; however, successful implementation and ongoing maintenance of software repositories appears to be challenging. In practice, ongoing interaction among Virtual Ships practitioners appears to be the most successful approach for promoting active sharing and collaboration for simulation software.

## 4.0 EXAMPLE SIMULATIONS

This section describes simulations of replenishment at sea and launch and recovery of small craft that have been developed using the Virtual Ship standard. The Virtual Ship standard was also applied to a ship signature management simulator, which is described in a separate paper [9].

### 4.1 International Replenishment at Sea Simulation

An international replenishment at sea simulation was developed by the defence departments of Canada, France, Germany, Italy, and the United Kingdom. Additional details have been presented in separate publications giving an overview [10] and details of validation using model tests for a tanker and destroyer [11]. The international participants were actively involved in development of the Virtual Ships standard. The collaborative replenishment at sea simulation provided an excellent opportunity for applying and refining the Virtual Ships standard during its development.

The replenishment at sea simulation focussed on the modelling of ship motions in a seaway and the transfer of a solid payload between ships using replenishment gear. The simulation was intended for evaluating the essential capabilities for safe replenishment at sea operations:

- Maneuvering controllability of ships,
- Seakeeping performance in waves,
- Ability of replenishment gear to accommodate changes in relative locations between replenishment points on supply ship and receiving ship,
- Ensuring that transferred payload maintains a safe elevation above the ocean surface.

The simulation consists of a High Level Architecture federation with the following federates:

- Seaway,
- Motions of lead ship,
- Helm for lead ship,
- Motions of following ship,
- Helm for following ship,
- Hydrodynamic interactions between ships,
- Replenishment gear,
- Execution manager,
- Data logger,
- Visualizer.

The simulation was designed such that existing ship motion software could be integrated as federates. The seaway models waves, with multiple wave components used to model realistic seaways. The helm federates monitor ship motions from the ship motion federates and provide command rudder deflection and propeller RPM inputs to the ship motion federates. For replenishment at sea operations, the lead ship is typically the bigger of the two ships. The hydrodynamic interaction federate monitors motions of the two ships and evaluates the hydrodynamic interaction forces that influence ship motions. The replenishment gear federate models several details, including tension forces which are applied to ships and the motion of the solid payload as it is transferred between ships. The execution manager controls initialization, time stepping, and termination of the federation. The data logger and visualizer passively monitor data from other federates.

There was considerable deliberation regarding design of the simulation, in part because of the inexperience of partners in the development of a distributed simulation for naval platforms. For example, decisions were required regarding whether detailed seaway data, including wave elevations and wave kinematics, would be evaluated by the seaway federate and shared via the runtime infrastructure at each time step. Ultimately, a federation design was adopted that involved minimal sharing of data among federates. For seaway modelling, the seaway federate shared wave component properties (amplitude, direction, frequency, wavelength, and phase) upon initialization of the federation, with other federates (e.g., ship motion, visualizer) having their own local seaway models for computing required parameters at each time step. Experience developing and executing the simulation indicated that this federation design with minimal sharing of data among federates was successful.

Validation was conducted using specially designed model tests for a tanker and a destroyer [11]. The model tests were conducted in both calm water and in random head seas, representing realistic operational conditions. The tanker model was free in heave and pitch but otherwise restrained, with forward motion provided by a towing carriage. The destroyer model was free running, with propeller and rudder controllers used to maintain position relative to the tanker. Some of the model tests included modelling of replenishment gear tension between ships using a weight and pulley system. The model experiments were very useful for validating the simulation, including the ship motion, helm, and hydrodynamic interaction federates. So far, no detailed validation that includes operational replenishment gear has been conducted.

## 4.2 Simulation of Launch and Recovery of Rigid-hulled Inflatable Boat

Recent efforts in Canada have simulated launch and recovery of rigid-hulled inflatable boats from ships [12]. The simulation was intended for evaluating essential capabilities for safe launch and recovery operations:

- Stability against capsize of the small boat, including while being attached to the crane, bow line, and tag lines,
- Directional stability of the small boat,
- Seakeeping performance of the small boat,
- Load capacity of the crane,
- Clearance of the ship launch and recovery location above the ocean surface.

Simulation development efforts have benefited from various aspects of the Virtual Ships standard; however, the simulations were developed as a single multi-threaded executable program rather than as a High Level Architecture federation. Simulation components include the following:

- Seaway,
- Motions of parent ship,
- Motions of rigid-hulled inflatable boat,
- Crane, including winch and cable,
- Collision detection and force modelling.

Figure 3 shows dedicated model tests that were conducted to obtain validation data for ship and boat motions during launch and recovery. These data will be used for ongoing validation efforts.

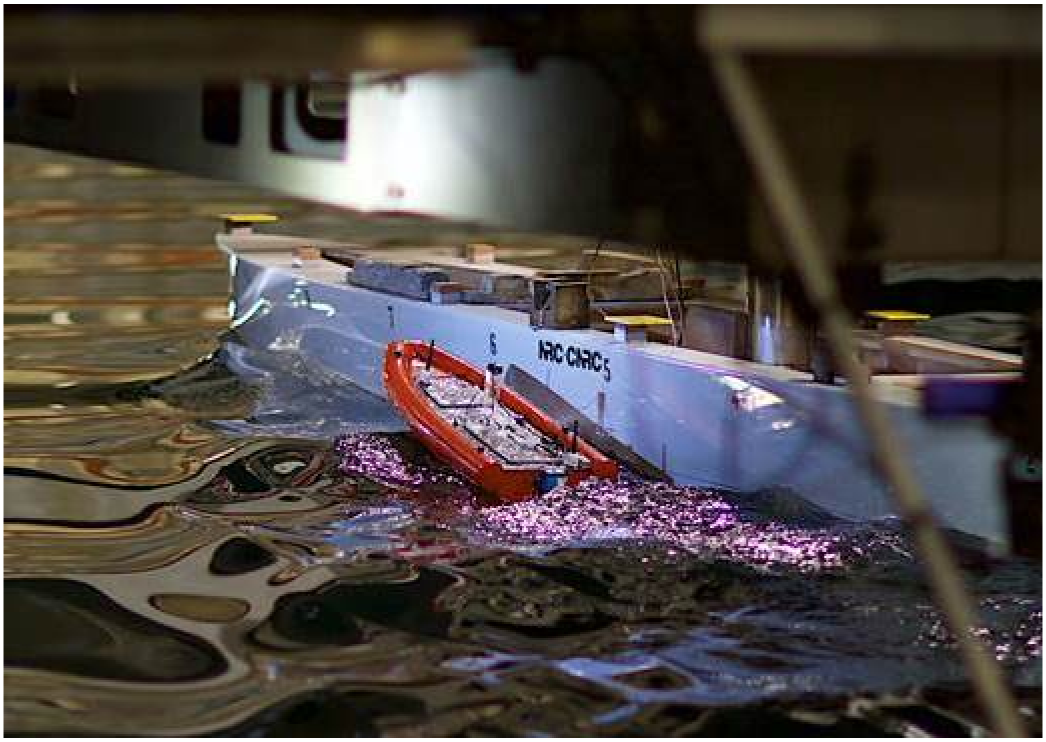

**Figure 3: Model tests of rigid-hulled inflatable boat alongside ship during launch and recovery**

## 5.0 SUMMARY OF LESSONS LEARNED

This section summarizes several key lessons that have been learned during simulation of naval platforms using the Virtual Ship standard.

### 5.1 Importance of Using Multi-disciplinary Teams

Naval platform simulation requires expertise in several domains related to the physics and control of naval platform systems. In addition, expertise is required in various aspects of simulation development, including the High Level Architecture. Consequently, multi-disciplinary teams are essential for efficient development of naval platform simulations.

### 5.2 Usefulness of Virtual Ships Standard

The NATO Virtual Ships standard [3, 4] has been very useful for developing naval platform simulations. For simulation using HLA, it provides constructive direction regarding how HLA can be applied to naval platforms. Content regarding coordinate systems and modelling of forces and motions is very applicable regardless of the simulation framework (i.e. HLA or other) that is chosen.

### 5.3 Application of High Level Architecture to Naval Platforms

Experience has shown that HLA can be applied successfully to time domain simulation of naval platforms. Only a subset of the total HLA capabilities has been required to date for simulation of naval platforms. The Virtual Ships standard provides very useful direction regarding key components of HLA for naval platform simulation.

While providing an impressive range of capabilities for distributed simulation, HLA is challenging to learn and to apply effectively. Programmers of a federation require significant training and common understanding of federation agreements.

Experience has shown that effective simulations of naval platforms can be developed without using HLA. Computer workstations with many processors are readily available, and multi-threading is now widely supported by programming languages.

### 5.4 Initial Development of High Level Architecture Prototype Federation

The international replenishment at sea federation included federates developed by several different organizations in multiple countries. Prior to development of the full federation, a prototype federation was developed with data sharing and time stepping of prototype federates, which produced representative data. The prototype federation was very useful for refining the federation design. Furthermore, the prototype federates served as templates to developers of the fully functioning federates.

### 5.5 Initial Verification and Validation of Simulation Components

The development of a successful federation was highly dependent on initial verification and validation of simulation components prior to integration into the federation. This initial verification and validation ensured that individual components were working correctly, and provided advance knowledge of areas in which federation fidelity could be expected to be weaker. Working with well tested components greatly simplifies verification and validation of the final federation.

### 5.6 Challenges Validating Transient Events during Naval Platform Operations

Traditionally, validation of naval platform simulation software [13] has assumed stationarity of ship response statistical properties over a specified time duration, with 20 minutes to 3 hours representing typical durations. Validation has focussed on quantities such as root-mean-square (RMS) response or zero-crossing period, which can easily be compared between simulations and observations from model tests or sea trials. This approach has limited value when validating simulation of transient events of short duration, such as replenishment at sea and launch and recovery. One possible way forward is to evaluate portions of a federation using deterministic approaches. For example, replenishment gear simulation components could be evaluated deterministically using experimentally observed motion time series of the supply ship and receiving ship. This approach would enable direct comparisons of replenishment gear time series from experiments and simulations.

## 6.0 CONCLUSION

The new NATO Virtual Ships standard can be used to develop simulations of naval platform systems. While originally intended for building distributed simulations using the High Level Architecture, many aspects of the standard are very useful for simulations that don't use HLA. The standard has formed the basis for simulations in several areas, including replenishment at sea, launch and recovery of small water craft, and ship signature management. Many naval platform operations to be simulated involve transient events, presenting challenges for validation during operation in random seaways.

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