02S-SIW-045

Results and Lessons Learned from a Multi-National HLA Federation Development Supporting Simulation Based Acquisition

Richard Reading
VisiTech, Ltd.
535A East Braddock Rd.
Alexandria, VA 22314
703-622-8529
reading@visitech.com

Magnus Örnfelt
FMV – Defence Materiel Administration
FARTYG
S-115 88 Stockholm, Sweden
00 46 8 782 4759
magnus.ornfelt@fmv.se

Dr. John M. Duncan
Defence Procurement Agency
Abbey Wood, Mall Point 95
Bristol BS34 8JH
United Kingdom
00 44 117 91 35163
stgtc@dpa.mod.uk

Keywords:
HLA, simulation based acquisition, multi-national distributed environment, reusability, interoperability, ship and air vehicles

ABSTRACT: *The NATO/PfP Interoperability and Re-use Study, NIREUS, is a thirteen-nation project to apply the High Level Architecture (HLA) to investigate multinational distributed simulation for system design and acquisition. The NIREUS test case concerns distributed simulation of Vertical Take-Off and Landing (VTOL) air vehicles landing on ships, initially focusing on Maritime Unmanned Air Vehicles (MUAVs). Maritime landing of an air vehicle depends on the capabilities of multiple systems and the ability to orchestrate them together in a complex environment. For small ships in heavy seas, this operation can be particularly dangerous.*

Use of a common simulation framework enables nations to examine operational envelopes cost-effectively and without risk of life. The intention is to address system design and interoperability issues before buying and building hardware, and once hardware is built, to optimize performance of the system-of-systems. Thus, ship and aircraft designs can be improved, and safe landing envelopes can be expanded, meeting the ultimate goal of improving military effectiveness and safety.

In Fall 2001, the NIREUS federation was successfully demonstrated at the integration site in Toulon, France. This paper describes the results of NIREUS federation execution, and discusses lessons learned from this multi-nation federation development. Of specific interest are the different aspects of interoperability and re-use encountered during NIREUS development.

1. NIREUS Overview

The NATO Naval Armaments Group on Ship Design NG6 recognizes the potential of modeling and simulation (M&S) in ship design and wishes to harmonize investment in and development of ship virtual prototypes, allowing wider re-use and interoperability. In November 1997, NG6 established a Specialist Team on Simulation Based Design and Virtual Prototyping (ST-SBDVP) to explore the technologies and processes of SBDVP applied to the acquisition of naval warships, including: product and process behavior, interoperability and re-use of software, and employing common infrastructures for integrated teams. During the course of the Specialist Team's work, a second track was developed, namely, a multi-nation simulation interoperability study entitled the NATO/PfP Interoperability and REUse Study, or NIREUS.

The main objective of NIREUS is to "bridge the gap between theory and practice" by providing a practical case to illustrate the guidance given within the ST- SBDVP's Allied Naval Engineering Publication [1]. The principal goals for NIREUS may be expressed as follows:

- to foster collaboration among NATO member & partner nations in the development and use of complex and rather novel risk reduction technology
- to identify standardization areas and interoperability deficiencies that might occur in the conduct of joint Allied nation federated simulation scenarios
- to introduce ST member nations to the development and execution of a complex simulation federation using the NATO-recommended High Level Architecture (HLA)
- to make substantial advances, via international cooperation, towards a validated simulation of an important and dangerous military operation, which encompasses extremely complex physics.

NIREUS has used as its application test-bed manned and unmanned aircraft landings on warships, focusing on helicopters and unmanned aerial vehicles (UAVs). This application was chosen because of the national interest in this military operation as expressed by every participating nation, and because of the possibility of modeling and simulating this dangerous operation as part of a joint Allied exercise[1]. NIREUS is an experience-base study, and has actually constructed a working multi-national HLA federation.

[1] A total of 13 countries are involved in developing the NIREUS federation. Australia, Bulgaria, Canada, Finland, France, Germany, Italy, Netherlands, Norway, Spain, Sweden, UK and US.

The NIREUS effort was launched in December of 2000 [2]. Milestone I occurred in October 2001 with ST-SBDVP agreement to a High Level Architecture federation design to meet the objectives [3]. Milestone II was reached in October 2001 with demonstration of the working NIREUS federation to NATO NG6. NIREUS is now transitioning under a full NG6 sub-group, SG61 'Virtual Ships'. Follow-on work is being planned under a formal Memorandum of Understanding (MOU) to proceed to a Milestone III trusted capability for use-case acquisition programs. Applications of the NIREUS simulation capability to other 'virtual ship' problem areas are also being planned under the MOU framework. This paper describes NIREUS progress through Milestone II demonstration of the initial NIREUS federation.

2. NIREUS Milestone II Problem Space

The NIREUS problem space for the Milestone II federation development focused on Vertical Take-Off and Landing (VTOL) air vehicles on warships, particularly focusing on Maritime UAVs (Figure 1). Maritime landing of an air vehicle depends on capabilities of multiple systems and the ability to orchestrate them together in a complex environment, as shown in Figure 2. It is a very difficult and dangerous system-of-systems, operation, especially so for smaller ships in high sea states. It presents challenging physics, engineering, and operational planning problems for which simulation-based exploration holds some advantages. The intent for Simulation Based Acquisition in this application is to address the multiple system design and interoperability issues before buying and building hardware, and, once hardware exists, to optimize the operational performance of the system-of systems safely and cost-effectively.

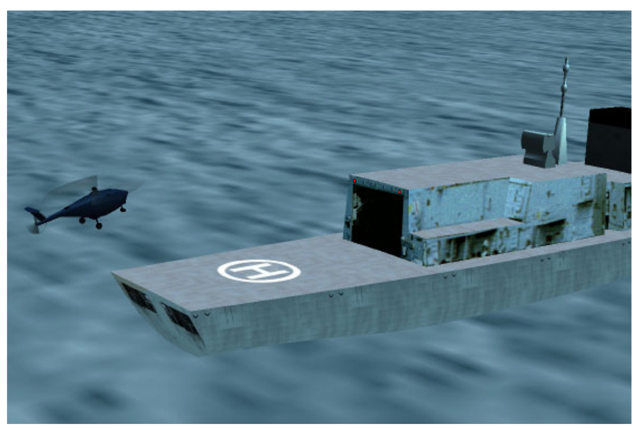

Figure 1. Operational Context

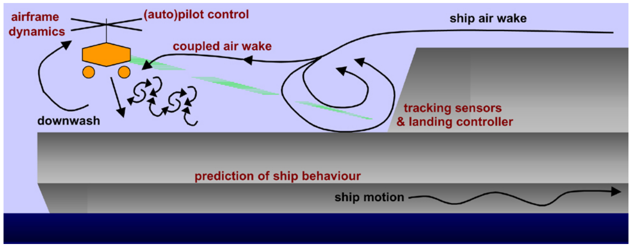

Figure 2. System-of-Systems

To illustrate the system-of-systems nature of the NIREUS problem space, consider the landing paradigm. At high sea states, a safe air vehicle landing may be possible, but only during very tight windows of relatively calm ship motion. The landing process, therefore must have some system to predict the future state of ship motion and indicate when a quiescent period is upcoming. Once a decision to land is made, the air vehicle shall not attempt to follow the sea state induced movements of the landing deck. Rather, the descent path planning should predict the averaged movement of the landing deck. Finally, the air vehicle shall not try to home to the moving landing deck, but rather try to aim at the point where the landing deck is predicted to be at the moment of touchdown. For piloted landings, the latter two requirements are handled intuitively by the pilot, but for automated landings they require systems capabilities for calculations and decision algorithms. Those calculations spawn further requirements for systems capabilities to do things like track the air vehicle during its approach and descent.

From an acquisition perspective, optimal performance of the system-of-systems is best arrived at by assessing and trading the performance of each system capability in the context of the whole. Thus, improvements in air vehicle dynamics can be traded against more reliable prediction algorithms, reduction of ship air wake, or smaller operational envelopes. This leads to optimal investment of finite dollars. These trades are enabled by a common framework that provides a system-of-systems setting into which representations of all of the systems may be placed and operated together. This is not always possible, affordable or safe for physical prototype testing, and in many cases these decisions must be made before one or more of the systems under consideration/acquisition is physically available to test.

3. NIREUS Multi-National HLA Federation

The NIREUS Milestone II federation simulates the final approach and vertical landing of an unmanned air vehicle on various nations' ships in various operational conditions. The NIREUS federation design implemented for Milestone II is given in Figure 3 (for further discussion of the NIREUS design, scenario, and conceptual model, see ref [4]).

The NIREUS federation was developed by an active partnership of all 13 nations. The flags shown on the federates in Figure 3 indicate nations that actually undertook implementation of software code for the federation. As can be seen, a total of 8 nations wrote software for the federation. Multiple flags indicate multiple nations worked together to construct the federate. Significantly, a total of 6 federates were in themselves multinational collaborations.

The color coding of the federates refers to sub-teams within NIREUS responsible for specific areas of expertise (e.g., blue for ships, yellow for air vehicles and air wakes). Those nations that were not writing sourcecode participated actively within these expert teams. Regarding those nations listed on the Run-time Infrastructure (RTI) bus: Germany was responsible for leading federation integration & testing, The Netherlands supported integration efforts and wrote support software (e.g., a test harness for stub testing federates prior to federation integration), and the federation ran on an RTI developed by the U.S. Defense Modeling and Simulation Office. The federation was integrated on a local area network at a single site in Toulon, France.

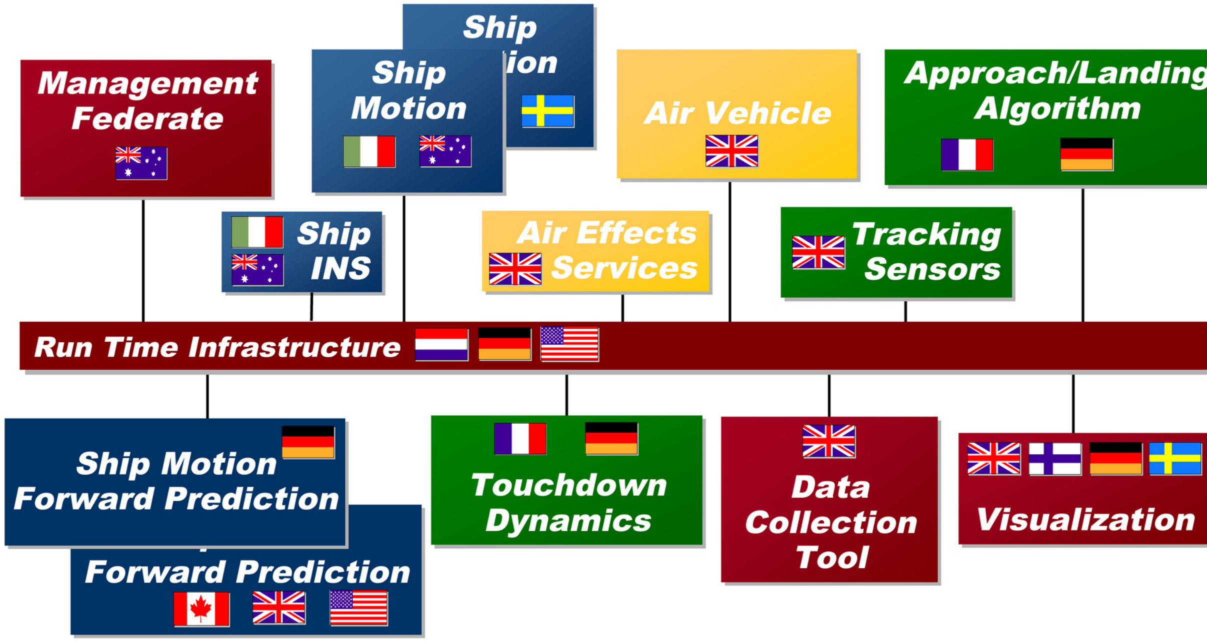

Figure 3. NIREUS Federation Design

NIREUS scenario progression was controlled by a management federate provided by the Australian Virtual Ship Execution Manager [5]. An XML script was used to drive VSEM initialization of the federation, wherein ship type, air vehicle type, scenario geometry, landing criteria, and natural environment conditions were variable selections at runtime.

Software implementation was a mixture of new source code and re-use of existing models. Interestingly, there was a good balance between software re-use for internal models, vice software re-use for RTI interface layers. That is, some federates (e.g., touchdown dynamics) used legacy models inside, but had newly-written code to interface to the RTI, whereas other federates (e.g., ship motion) had newly-written internal models but re-used legacy RTI interface software.

Evidence of NIREUS design re-use and commonality is noted in Figure 3 in the Ship Motion and Ship Motion Forward Prediction federates, which are depicted as layered federates. In each of these cases, a baseline federate was selected for the federation; these are shown as the top layer federates. However, in each of these cases a nation or set of nations took it upon themselves to use the NIREUS federation design information to implement an alternative federate that could be interchanged into the federation in lieu of the baseline federate. Both additional federates were successfully integrated and included in the Milestone II execution.

The alternative federates enhanced the NIREUS capability in different ways. In the case of the ship motion forward prediction federate, the alternative federate used different algorithms to designate upcoming calm ship motion periods, demonstrating rapid-reuse of the NIREUS framework to explore alternative design approaches to meeting a system requirements. In the case of the ship motion federate (Figure 4), additional functionality to integrate a helmsman-in-the-loop was included in the Swedish implementation, allowing NIREUS to further explore operational scenarios with ship maneuvering. Further, the Swedish federate included additional functionality to calculate ship motion data at runtime. This allows ship description data to be directly input to the federate and enables the federate software to exercise multiple aspects of performance in early-stage ship design. The same federate could conceivably be re-used for multiple federation implementations for various applications from early design to tactics development and training, over the life of the ship.

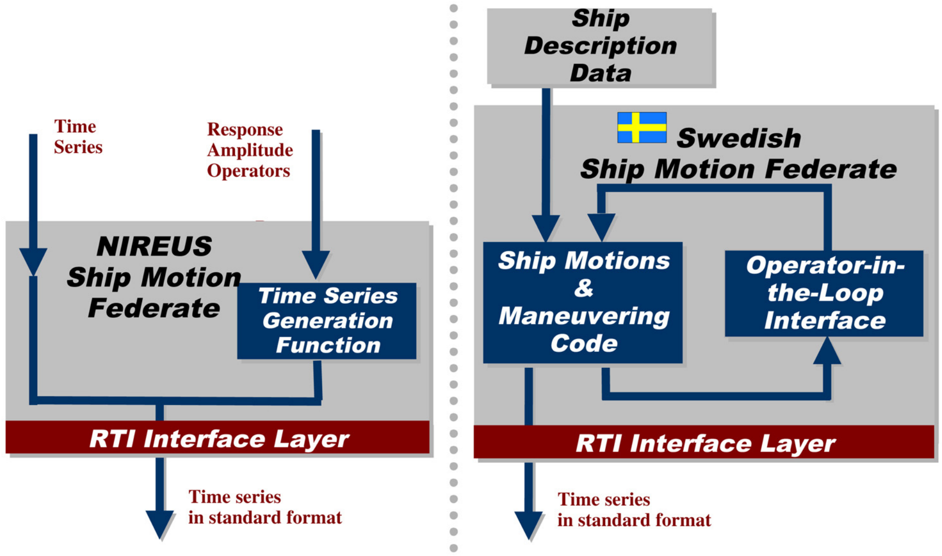

Figure 4. Federate Interchange in the NIREUS Framework

4. NIREUS Federation Execution

The NIREUS federation was successfully executed and demonstrated in October 2001 for the NATO NG6 at the integration site in Toulon, France [6]. A follow-on demonstration for the NATO Naval Armaments Group is planned for June 2002 at NATO headquarters in Brussels, Belgium.

Figure 5 lists the 10 ships included in the NIREUS ship library at the time of demonstration. Ship models consisted of ship geometry, ship motion, and ship air wake (where available) representations. As can be seen, a broad set of nations provided ship models to the NIREUS framework. The NIREUS ship library contains a variety of ship types and ship sizes, including one with a fore, rather than aft, landing deck. This allowed NIREUS to examine landing operations across a swath of ship capabilities and constraints. Further, the NIREUS ship library contains ships at differing stages of the acquisition cycle, from early concept design through in-service modifications. To provide consistent outputs for the demonstration, a generic UAV model for a helicopter-type airframe with three-point landing gear was used for the demonstration scenarios.

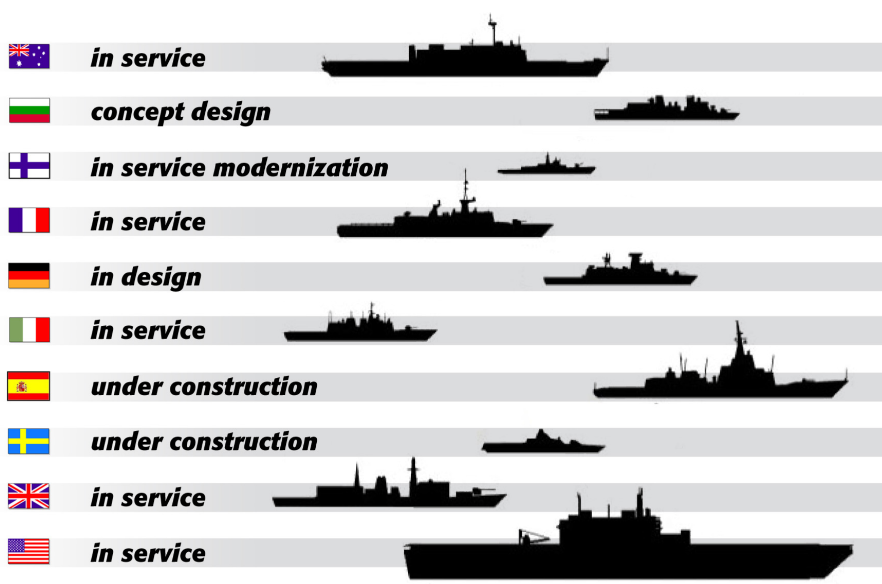

Figure 5. NIREUS Ship Library

NIREUS federation execution demonstrated aspects of MUAV operation on multiple nations' ships in varied operational conditions, from calm seas with light winds to very intense scenarios. As a whole, the set of NIREUS scenarios demonstrated the viability of a simulation environment like NIREUS to enable naval staff to analyze different operational procedures during ship design. For the more challenging scenarios (e.g., landing on a corvette in sea state 6) the NIREUS execution certainly enabled analysis in a safe environment of operational procedures for complex and potentially hazardous activities. Operational constraints such as safe landing criteria were varied to explore definitions of Measures of Effectiveness for VTOL operations. In certain scenarios, NIREUS permitted the bursting of the operational envelope without crashing very expensive MUAVs or causing damage to actual ships.

The success or failure of a landing was obvious in some cases (e.g., landing on a large deck ship in sea state 1 condition). In many cases, however, the end-state success of a landing operation would ultimately be determined by offline engineering analysis of data collected during execution, like that given in Figure 6. The NIREUS federation was built upon best-available physics-based simulations producing engineering-level data, to create a framework suitable for validation and use in design and acquisition decisions. As stated earlier, the intent is to support system-of-systems prototyping in a virtual environment, safely and sometimes before physical prototype.

Figure 6. Landing gear z-axis displacements and stresses, corvette with a generic UAV in sea state 3.

5. Lessons Learned

The NIREUS Milestone II federation execution culminates the efforts of:

- 13 NATO, PfP nations, and Australia participating in design and development
- 10 nations providing ship models to the federation
- 8 different nations writing software to a common architecture
- 6 simulations constructed by multinational collaboration
- 2 pairs of interchangeable federate simulations built by nations to a common interface definition

NIREUS represents unprecedented multinational simulation interoperability. As such, much of the NIREUS experience to-date has been concerned with the challenges of operating in a multi-national environment outside the formal auspices of an MOU [4]. Yet, it is believed that the NIREUS lessons learned are applicable to any cross-organizational or cross-discipline distributed simulation effort.

Communication processes in an international coalition merit very careful consideration. To enable this communication, adherence to an agreed project organization structure with associated authority is of benefit. Further, the development effort needs process guidance (e.g., HLA FEDEP) that fosters collaboration and negotiation. Simulation interoperability is very much about people interoperability and common understanding of requirements and definitions. Early system engineering process phases will contain critical agreements that will smooth or stall later work. The early stage requirements and design negotiations may be frustrating and slow at times, but are well worth the effort. It follows that the effort to document the agreements and write detailed design specifications pays back at implementation time. Certainly, this documentation enabled the rapid-reuse of the NIREUS framework seen in the alternative ship motion & ship motion forward prediction federates.

The NIREUS team members hailed from multiple nations and therefore spoke different native languages. Yet, the NIREUS team also hailed from multiple expertise areas, and therefore spoke different *technical* languages. Interestingly, communication gaps caused by the latter often superceded those caused by the former. Similarly factional issues within NIREUS rose and fell along technical boundaries rather than national boundaries. For the success of NIREUS a balance of domain experts, software developers, and HLA practitioners proved invaluable.

Finally, the benefits/constraints of legacy code should be considered fully at the outset. NIREUS relied on heavy technology reuse to achieve a working federation within two years. However, some components (ship motion, air effects services) were collaboratively designed and newly written both to enable all nations to contribute models to NIREUS and to promote broader re-use in future applications.

5.1 Network-Centric Development

NIREUS also represents a unique and interesting form of cooperating when nations find themselves faced with a not unusual situation in defense material acquisition. This situation is characterized by the following dichotomy:

- There is strong and widespread, national and international, interest and belief in a particular system.

However,

- there are no formal defense strategic decisions,
- there is no program authority,
- funding is tenuous, and
- some doubts may exist regarding technology and feasibility.

As the situation exists today, MUAVs embody this dilemma, and represent a good use case for cooperative development.

NIREUS is an example of addressing this problem using "network-centric" technology development. The absence of formalized requirements means limited resources in funding. This has the follow-on effect that it is difficult to establish formal bilateral or multinational agreements such as MOUs. Yet, it is obviously possible to form a network, or a study group, that can work under a more simple form of cooperation in the spirit of a Gentleman's agreement. Every nation or participant contributes what they can, in the form of labor, loaned hardware, or legacy technology. The first result is essentially a demonstration that provides proof-of-concept. After the demonstration everyone take their piece of technology, software or hardware home again. Anyone who liked what was demonstrated will have the freedom to acquire it. Some nations may decide they want to continue the development, perhaps leading to a joint acquisition. Others may decide that it would be more cost effective to continue alone. In any case, the risk in initial technology development has been mitigated by leveraging the contributions of the other nations in the network. Thus, network-centric development permits nations to explore high risk, high payoff technologies quickly and cost-effectively, before moving forward to more formal internal or international program arrangements.

5.2 Re-Use and Interoperability

The NIREUS effort has revealed several layers to both re-use and interoperability. Regarding interoperability, the obvious top layer is simulation interoperability. 13 nations came together and managed to get software communicating in a substantive way. Enabling the technical interchange and cooperative development is a layer of people-interoperability and cross-domain expertise collaboration. Beyond individuals is the extent to which multi-national collaboration has been achieved, leading finally to the potential for representation of joint Allied military operations.

Similarly, there are multiple layers of re-use for NIREUS. The FEDEP products describing NIREUS can be re-used, tailored, and modified (e.g., conceptual model, federation design, FOM). The NIREUS framework as a whole can be re-used and built upon. Certainly, the developed federates represent software that can be re-used by the individual nations. More so, each participating nation leaves with HLA development experience that can be re-used for other applications. Finally, NATO and the participating nations have garnered multi-nation simulation interoperability experience that can be re-used to reduce risk in future like efforts.

Several examples of the re-use envisioned by NIREUS have already been realized. Within the NIREUS framework, common data "plugs" have been used by multiple nations to provide interchangeable system models (e.g., NIREUS ship library). More strongly, common federate "plugs" have been used by multiple nations to provide interchangeable federates (e.g., Swedish ship motion federate). NIREUS technology (e.g., FOM, Air Effects Services federate) has also been used by other programs, specifically the Joint U.S./U.K. Distributed Simulation (JUDS) Program.

5.3 VV&A

The ST-SBDVP firmly set forth VV&A as an important topic to be addressed within NIREUS, and a separate sub-team within NIREUS was established for VV&A. Three primary VV&A products were agreed:

- V&V of conceptual model and federation design.
- Verification of interim demonstration federation.
- VV&A planning guidance for follow-on NIREUS development.

A pragmatic approach was taken for VV&A activities for the NIREUS Milestone II federation development, wherein the basic validation tenet was fitness for purpose relative to SBDVP goals. The basic purpose of the NIREUS effort was the demonstration of technology application to a real engineering problem. In that respect the conceptual model was deemed valid. Further, the VV&A team determined the federation design and models could form the basis of a design tool. However, additional V&V commensurate with Milestone III work was recommended before NIREUS is applied in earnest within acquisition programs. Of course, future validation for specific applications would be mapped against specific accreditation requirements for use in decision-making.

6. Way forward

The NIREUS study has successfully developed an HLA federation to demonstrate multinational collaboration and simulation interoperability on an unprecedented scale. In so doing, NIREUS has provided practical insight into application of SBDVP technology into complex system-of-systems problem spaces. NIREUS demonstrates that simulation interoperability can enable systems interoperability. Additionally, the NIREUS effort has revealed multiple layers of re-use and interoperability for NATO and the participating nations.
NG6/SG-61 will continue to raise the level of awareness of the benefits, costs, and risks of modeling & simulation for surface ship systems acquisition. Based on the success of NIREUS, further work is being planned to improve and expand the NIREUS framework under NG6/SG-61 and a formal MOU. Future work may include examination of other ship mission areas, such as ship combat systems, as well as validation of NIREUS for application in use case acquisition programs.

Common architectures, such as HLA and NIREUS, should be exploited to enable multinational collaboration, simulation reuse, faster/cheaper new simulation development, improved system designs, and major contributions to improved military operations.

References

[1] Allied Naval Engineering Publication on Simulation Based Design and Virtual Prototyping, December 2000.

[2] "NIREUS Study Document", December 1999, Specialist Team on Simulation Based Design & Virtual Prototyping, NATO Naval Armaments Group 6.

[3] "NATO/PfP Interoperability and Re-Use Study Milestone I Report", October 2000, Specialist Team on Simulation Based Design & Virtual Prototyping, NATO Naval Armaments Group 6.

[4] White, S. & Reading, R. "NATO/PfP HLA Federation of VTOL Operations Supporting Simulation Based Acquisition", paper 01E-SIW-034, June 2001.

[5] "Virtual Ship Environment Manager", J. Best, Australian Defence Ministry, November 2000.

[6] NIREUS Milestone II Demonstration and Briefing, Toulon, France, October 2001.

Author Biographies

RICHARD A. READING is a senior engineer with VisiTech, Ltd. He is currently serving as the NIREUS International Project Team Leader. He is also providing technical leadership and support to HLA federation developments for U.S. Navy ship combat system testing, as well as other multi-national efforts applied to systems acquisition. Mr. Reading served as the system engineer for the Navy PEO Theater Surface Combatants HLA Pilot Program. Previously, he spent over ten years at the Naval Research Laboratory developing hardware and software simulations for surface ship electronic warfare systems development.

MAGNUS ÖRNFELT is a senior manager in Naval Systems Engineering in support of naval ship acquisition for the Swedish Defence Materiel Administration. He is the Swedish representative to the NATO NG6 Virtual Ship Sub-Group 61. He was a member of the NIREUS Study Executive Steering Group and the Swedish representative to the NATO Specialist Team for Simulation Based Acquisition and Virtual Prototyping. Mr. Örnfelt is also the chairman of a NATO specialist team on ship maneuverability.