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LEARNING FROM EXPERIENCE

VOLUME III

Lessons from the United Kingdom's *Astute* Submarine Program

Prepared for the United Kingdom's Ministry of Defence

RAND NATIONAL DEFENSE RESEARCH INSTITUTE

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Summary

To design and construct conventional or nuclear-powered submarines, modern navies and shipbuilders need personnel and organizations that possess unique and specialized skills and expertise. These vessels are among the most complex systems that countries produce, and the technical personnel, designers, construction tradesmen, and program managers who work on them represent pools of knowledge that take years to collect and that cannot be replicated or replaced easily or quickly.

In years past, the pace of construction of replacement submarines was quick enough in most countries that key technical and management personnel in submarine programs were able both to work on a stream of successive submarines and to pass their knowledge on to personnel who followed in their footsteps. Individuals who participated in one program gained experience to be leaders or intellectual resources in following programs.

But two events have coalesced in recent years to complicate such transfers of knowledge: Defense budgets have become constrained, and the operational lives of submarines have lengthened as the vessels' production and maintenance procedures have benefited from continuous process improvements and as navies have changed how they operate the vessels. The result is that the pace at which submarines will be replaced is likely to slow, creating significant time gaps between successive programs and far fewer opportunities for veteran personnel to pass on their knowledge to succeeding generations of submarine workers and program managers.

Recognizing the importance of documenting and imparting experiences from past submarine programs, the Director Submarines of

the United Kingdom's Defence Equipment and Support organization asked the RAND Corporation to develop a set of lessons learned from previous submarine programs that could help inform future program managers. The RAND project team focused on the *Astute* program of the United Kingdom. The team derived lessons from previous reports on the *Astute* program[1] and from numerous interviews that the team conducted with past submarine program managers and submarine personnel at BAE Systems Submarine Solution's Barrow yard, which is the shipyard that builds UK nuclear submarines.

RAND's search for lessons also involved reviewing the history of UK nuclear submarines from HMS *Dreadnought* through the start of the *Astute* program; investigating how operational requirements were set for the *Astute* class; exploring the acquisition, contracting, design, and build processes that the *Astute* program employed; and assessing the plans and activities surrounding integrated logistics support for the submarine class.

The lessons that RAND identified are managerial in nature. The project team looked for instructive aspects of how the *Astute* program was managed, issues that affected management decisions, and the outcomes of those decisions. At times, it was difficult for the team to judge the "success" or "failure" of program decisions. Views change during the conduct of a program and are based on the perspective of individuals. The important point is that the decisions were not necessarily "good" or "bad." Rather, they were or were not fully informed by knowledge of the risks and consequences.

In some cases, the RAND team identified lessons that have not really been learned. In other cases, the team identified lessons that have been learned but forgotten (or ignored). Since cost is typically the metric for judging program success, the majority of the lessons focus on controlling program costs.

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[1] For example, see Schank et al., 2005a; Scott, 2002; Willett, 2004; Kincaid, 2002.

The End of the Cold War and Reduced Government Spending

Two events mark the majority of the lessons that the RAND team identified: the end of the Cold War and Whitehall's subsequent decision to reduce both military spending and the government's professional workforce. These resulted in substantial time gaps between the design and build of the *Astute* and its predecessor nuclear submarines—gaps whose ultimate impact on program cost and schedule risk were greatly underestimated by the private sector and the Ministry of Defence (MOD). Both parties also underestimated the impact of the MOD shifting responsibilities to the private sector, which was ill prepared to assume them.

Given these circumstances, the MOD and the private sector made decisions on the *Astute* program without fully understanding their effect. The MOD assumed, for example, that using three-dimensional computer-aided design (3D CAD) software would reduce the labor hours and costs for designing and building the submarine. That assumption proved to be ill founded.

At the same time, it is important to judge the decisions that the government and the private sector made in connection with the *Astute* program in the context of the time they were made. What in hindsight may seem like an ill-advised decision may have actually been appropriate at the time. For example, the significant time gap between the end of the *Vanguard* program and the start of the *Astute* program noted above had adverse impacts on the *Astute* program. The message is not necessarily to avoid gaps but to understand the potential impact of a gap and to incorporate that understanding into the decisionmaking process.

Top-Level Strategic Lessons

Top-level strategic lessons are global in nature and span all programs that design and build new platforms or support the Royal Navy submarine flotilla. They are appropriate for senior management in the

MOD and the Royal Navy, including the Director Submarines. They include the following:

- *Be an intelligent customer who understands the implications of various decisions and an informed customer who knows the status of programs*. Ensure that new processes and new systems are fully analyzed and are not just theoretical ideas.
- *Delineate the roles and responsibilities of the MOD, prime contractor, and subcontractors*.[2] If major responsibilities are shifted from the government to the private sector, ensure that industry is qualified to accept those new responsibilities.
- *Develop knowledgeable and experienced managerial, oversight, and technical support personnel.* Growing future program managers and technical personnel within the MOD and the Royal Navy requires planning and implementation far in advance of any one specific program.
- *Take a long-term, strategic view of the submarine force and the industrial base*.[3] Understand how a specific program impacts the long-term strategic plan for the submarine force and the whole naval flotilla.

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[2] At a minimum, the MOD should assume the following responsibilities: Set operational requirements for the new submarine by working with industry, the Royal Navy, and other stakeholders; assess safety and technical issues in accordance with the MOD's policy that safety risks should be as low as reasonably practicable; oversee and monitor the design process to ensure requirements and standards are met and, when necessary, provide concessions to those requirements; oversee and monitor the build process to ensure that the submarines are delivered on schedule and at projected cost; ensure submarine construction quality and acceptability by developing a testing, commissioning, and acceptance process that ensures that the submarines have been delivered to design intent; and ensure through-life submarine safety and maintenance and post-delivery control of design intent.

[3] A big contributor to the problems faced by the *Astute* program was the substantial time gap between the design and build of the *Vanguard* class and the start of the *Astute* program. This led to a situation in which submarine design and build skills atrophied in the United Kingdom, resulting in a costlier and lengthier *Astute* procurement effort. The issue is not that the gap should have been avoided, but that the MOD neither anticipated the impact of the gap nor factored into the cost and schedule estimates the need to rebuild industrial base capability.

Setting Operational Requirements

Decisions made very early regarding the desired operational performance of the new submarine influence the technology risk for the program and its likelihood of success. The operational requirements for the platform are translated to performance specifications that lead to technology choices to achieve the desired performance. The operational requirements, especially the desired operational availability, also affect integrated logistics support (ILS) planning. Important lessons here include the following:

- *Clearly state operational requirements as a mix of key performance requirements and technical standards*. Have the discipline to avoid changing requirements unless there is a clear need for the change, and ensure that there is a sound understanding of the impact on cost and schedule of requirements changes.
- *Involve all appropriate organizations when setting operational requirements.* Engineers, designers, operators, maintainers, and technical experts in various areas should all be involved early and throughout a new program.
- *Understand the current state of technology as it applies to the program and how the platform's operational requirements impact technology risks and costs*. Understand the relationship among operational requirements, available technologies, potential new technologies, costs, and risks.
- *Understand that operational requirements also must specify how to test for the achievement of that requirement.* Although it is often difficult to plan tests early in a program, it is necessary to ensure all parties agree on the processes to measure how the performance of the platform meets operational capability objectives. Incremental testing of equipment before it becomes part of a system and before that system is inserted into the hull should be encouraged.

Establishing an Acquisition and Contracting Environment

Establishing an open and fair acquisition and contract environment is another important aspect of any program. Good decisions here—what organizations will be involved in designing and building the new submarine, the type of contract, the specifics within the contract (including incentives), the decisionmaking process to employ when issues arise, and the payment schedule—will resonate throughout the life of the program. The *Astute* program originally felt that competition was possible. But when the industry consolidated and competition was no longer possible, it may have been warranted to consider revising the original request for proposals. Key lessons for establishing an effective acquisition and contracting environment include the following:

- *Consider a single design/build contract for the first-of-class*. Having a single qualified firm complete the detailed design and build a submarine helps to integrate the two processes and reduces confusion and misinterpretations.[4]
- *Use a contract structure with provisions to handle program risks.* While the government can try to place all risk on a contractor through use of a fixed-price contract, the government ultimately holds all program risk. It is far better to structure a contract that holds the contractor responsible for risks under its control (labor rates, productivity, materiel costs, etc.) and holds the government responsible for risks beyond the contractor's control (inflation, changing requirements, changes in law, etc.).
- *Develop realistic cost and schedule estimates.* Costs must be realistic and based on the best knowledge and information available. The aim of all parties should be to establish as much as possible a realistic cost estimate and not to drive for cost reduction where it cannot be justified.
- *Make informed decisions on which equipment will be furnished by the government and which by contractors.* These decisions are based

[4] The *Astute* program probably made the right decision in having a single prime contractor; the problem during its early stages stemmed from the inexperience of the prime contractor and the lack of integration between the design and build teams.

on many factors; one of the most important is which party, the MOD or the prime contractor, is better positioned to manage the subcontractors and the integration of that equipment into the submarine.[5]

- *Develop a timely decisionmaking process to minimize and manage changes.* Changes invariably occur during any program. They may crop up in the desired performance of the platform; in the systems and equipment used to achieve performance; in the schedule; or in the responsibilities of the organizations involved in designing, building, and testing the platform. Changes may affect cost, schedule, or capability. Management structures must be in place to deal with any of the contract changes that are proposed during the program.
- *Establish an agreed-upon tracking mechanism and payment schedule*.[6] Ensure that the tracking system is properly designed and used to produce outputs that are helpful in managing the program.
- *Include an adequate contingency pool*. Whereas a complex project would normally have a contingency fund on the order of 10 to 15 percent or more, the *Astute* contract's contingency fund was approximately 5 percent.

Designing and Building the Submarine

It is important to get all the right organizations—designers, builders, operators, maintainers, and the technical community—involved

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[5] The assignment of Rolls-Royce as subcontractor to the prime contractor rather than its typical role as prime contractor to the MOD caused some friction during the initial stages of the *Astute* program. Rolls-Royce has numerous contracts with the MOD to support submarines already in service, and the MOD is Rolls-Royce's most predominant customer. Rolls-Royce has longer-term contracts and more revenues from these other sources than it receives by providing the nuclear steam-raising plant (NSRP) to BAE Systems for the *Astute* class.

[6] During its first several years, the *Astute* program had no effective mechanisms to track progress on the submarine's design and build. This made it impossible for the MOD and prime contractor to recognize problems that were growing in the program. At the same time, the program's payment clauses were tied to production metrics such as length of installed pipe or electrical cable that proved to be counterproductive: the shipyard installed pipe and cable before the design was complete that it subsequently had to rip out and re-install.

throughout a program, to understand how operational requirements impact design and construction, and to plan for the appropriate testing of the systems and platform to ensure that requirements are met. To some degree, lessons for the design and build process overlap the lessons that emerged from the earlier stages of the submarine program. These design and build lessons include the following:

- *Involve builders, maintainers, operators, and the technical community in the design process*. Design/build should go further than merely involving builders in the design process. It is important to think of the design team as a collaboration of submarine designers and engineers with inputs from those who must build to the design, operate the submarine, and maintain it. This collaboration should extend throughout the duration of the design program. However, throughout the design/build process, it is important to keep in mind that the cost-effectiveness of the submarine's post-delivery or ILS period is the true design and construction target.
- *Specify and manage adequate design margins.* Without adequate margins, it may not be possible to modernize and upgrade equipment.
- *Design for removal and replacement of equipment.* Adequate access paths and removal hatches should be included in the design, so as to facilitate removing and replacing damaged or obsolete equipment. For command, control, communications, computing, and intelligence (C4I) equipment, modularity and interoperability should be incorporated into the design.
- *Complete the majority of the design drawings before the start of construction.* It is far better to delay construction to ensure that the design is largely complete than risk the costly rework and changes typically resulting from an immature design. A good rule of thumb is to have 3D CAD electronic product models approximately 80 percent or more complete when construction begins.
- *Develop an integrated master plan for design and build.* A program should have an overall integrated schedule detailing the tasks, milestones, and products produced during the design and build

of the submarine. This integrated master plan shows the order of tasks and events and the interrelationships between them.
- *Track progress during the design and build process.* A properly designed and utilized project tracking system will help to predict program cost and schedule status.
- *Ensure sufficient oversight at the design and build organization.* The program should have a strong presence at the shipyard to provide on-site construction oversight for deviations from design, ensure compliance to quality and testing procedures, and keep the MOD aware of the challenges that the program faces.[7] MOD representatives on-site should be experienced in both technical and managerial aspects of delivering a submarine program and also have some decisionmaking capability in order to facilitate concessions and deviations that have only a minor impact on cost, schedule, or performance.
- *Conduct a thorough and adequate test program.* Develop the test program during system design and update it during the conduct of the program.

Establishing an Integrated Logistics Support Plan

Operating and supporting new submarines after they enter service account for the vast majority of their total ownership costs. Therefore, it is imperative to establish an ILS plan for the new submarines. Important lessons here include the following:

- *Establish a strategic plan for ILS during the design phase.* Such a plan must be put in place early in the program. Personnel from

[7] At the beginning of the *Astute* program, MOD oversight at the Barrow shipyard was greatly reduced as part of the movement to control Government spending. This lack of on-site presence blinded the MOD to the design and construction problems that were emerging during the early years of the program. The MOD has since increased its presence at Barrow to approximately 30 people (from a low of two naval officers and two civilians) in order to have more visibility and inputs into the build program.

organizations responsible for maintaining the submarine should be involved in the design process. Additionally, the submarine's concept of operations must take account of the fact that the vessel will require time for preventive and corrective maintenance and for equipment modernizations.

- *Maintain adequate funding to develop and execute the ILS plan.* Resist reducing ILS planning funds when problems arise in other portions of the program.