This appendix documents the findings from a series of meetings with the Ministry of Defense (MoD) of the United Kingdom (UK) and with representatives of shipyards in that country: Vickers Engineering and Shipbuilding Limited (VSEL) and Kvaerner Govan Limited (KGL).

**STRUCTURE OF THE BRITISH AIRCRAFT CARRIER FORCE**

The Royal Navy currently has three Invincible-class (CVS) aircraft carriers in its force structure. These carriers have an approximately 20,600-ton displacement fully loaded and typically carry a complement of seven Sea Harrier FA-2 short take-off/vertical landing (STOVL) aircraft, plus seven anti-submarine warfare (ASW) Sea King HAS-6 and three airborne early warning (AEW)-2 Sea King helicopters. The lead ship in the class was designed and built by VSEL at Barrow-in-Furness, England; the remaining two were built to the VSEL design and blueprints by Swan Hunter Shipbuilders at Wallsend, England. The timelines for these carriers are shown in Table F.1.

<table>
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<tr>
<th>Ship Name</th>
<th>Number</th>
<th>Builder</th>
<th>Date Keel Laid</th>
<th>Date Launched</th>
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<td>R 06</td>
<td>Swan Hunter</td>
<td>7 Oct 1976</td>
<td>1 Dec 1978</td>
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**Table F.1**

Invincible-Class Timelines


1Under surge conditions, the Invincible class can embark 12 Harriers and seven ASW and three AEW Sea King helicopters. Under either normal or surge conditions, approximately 15 of the aircraft and helicopters are positioned on the hangar deck of the ship.
Only two of the three carriers are in operational status at any one time; the third is in a semi-mothball status or in overhaul. This arrangement is due primarily to budget, personnel, and aircraft constraints. For each ship, there is an approximate 10-year cycle between modernization and overhaul.

The British MoD is currently in the initial stages of planning for the next class of carriers; the anticipated delivery is approximately 2012. Therefore, there will be approximately a 20-year gap in the production of aircraft carriers in Great Britain. However, two major issues are currently unfolding in Great Britain that will affect the design and construction of large military ships:

1. The carriers are in the 20,000-ton range, and two other classes of ships (amphibious ships) of roughly the same size have been
   - designed (landing platform–helicopter [LPH] and landing platform–dock [LPD])
   - are under construction (LPH—design start in 1993, to be commissioned in 1998)
   - are about to start construction (LPD).

2. The military shipbuilding environment in Great Britain has undergone major changes so that
   - the traditional MoD carrier knowledge base is quickly becoming less important
   - the lack of continuity in shipyard practices is even less important because commercial practices are inherently quite different.

Therefore, the gap in large ships is not as great as might be inferred from looking at carriers only.

In the following two sections, we discuss these issues in turn. We then detail specific implications these issues have for the two major shipbuilders, VSEL and KGL. We conclude with remarks on carrier-specific considerations.

**LPH AND LPD SHIP CLASSES**

With regard to the first issue that affects design and construction of military ships—size—the British Royal Navy is currently in the process of acquiring LPH and LPD ships of approximately the same size as the CVS class.
Amphibious Helicopter Carrier (LPH)

The amphibious helicopter carrier, designated as a landing platform–helicopter, was originally conceived in the mid-1980s as a replacement for HMS Hermes, to provide the type of amphibious assault required during the Falklands campaign. The primary role of the ship is to carry an embarked military force of up to 800 personnel, 12 medium-support helicopters (currently Sea Kings, but EH-101s in the future), and 6 Lynx helicopters of the UK/Netherlands amphibious force. This force would then be disembarked as part of an amphibious assault. Secondary roles include afloat flight training, limited ASW operations with suitable helicopters, ferrying Sea Harriers, and being a base for anti-terrorist operations. Up to 20 Sea Harriers can be carried, but not supported.

The first competition for the design and build of the LPH (then called the auxiliary support ship [ASS]) was held in 1988. The Invitation to Tender (ITT; similar to a Request for Proposal [RFP] in the United States) included a price guide. Unfortunately, the shipyards bidding to construct the ship either offered a compliant design that was unaffordable or a design with major shortcomings that was affordable.

The MoD then conducted an Options for Change study (of redesign to meet cost constraints). In spring 1991, cost/capability studies indicated that a worthwhile ship was feasible at an affordable cost. The requirements were revised and a new ITT prepared, the ship’s place in the defense program having been confirmed. The ITT was issued in February 1992, and tenders from VSEL and Swan Hunter Shipbuilders were received the following October. The tender assessment was accelerated in early spring 1993, when the opportunity for a prompt contract award became apparent. VSEL was awarded the design and build contract on May 11, 1993, having made a significantly cheaper best and final offer.

Swan Hunter Shipbuilders protested the award. Their protest led to a National Audit Office (NAO) inquiry into the conduct of the competition. The NAO concluded that the competition had been conducted competently and in a fair manner, and that, given VSEL’s price advantage, the decision to award them the contract was correct. The NAO did make some recommendations for the management of the contract, emphasizing the importance of risk management and the rigorous control of change.

The design and build contract itself is different from contracts in past practice. It is a fixed-price contract and, since VSEL had almost exclusively built submarines (both diesel and nuclear attack, and nuclear ballistic missile submarines) for an extended time, VSEL subcontracted the construction of the
basic hull to the Kvaerner Govan Limited (KGL) shipyard in Glasgow, Scotland. The Kvaerner Govan yard had experience in building large commercial ships but had never constructed a military ship of the size of HMS Ocean. The vessel steamed under its own power in November 1996, from KGL on the Clyde to VSEL in Barrow, where the ship is being outfitted with her military features and combat systems.

Constrained defense budgets caused the MoD to decide to use commercial standards in place of military specifications for the hull construction. However, commercial and military standards and equipment were very carefully considered and combined as needed to maintain naval functionality while controlling construction costs. As a result, the hull meets shock performance requirements. Elsewhere within the ship, systems have been designed to meet levels of military performance. For example, the firefighting system meets the full functionality of a naval system but consists of a mix of commercial and military equipment.

VSEL personnel were positioned at the Govan yard, and the VSEL Barrow facility fabricated some sections of the hull and transported them to the Kvaerner Govan yard. Through this experience, VSEL hoped to regain expertise in the construction of large surface ships.

The hull form of the LPH is based on that of the CVSs and has similar dimensions and displacement. Her main propulsion plant will be medium-speed diesels driving through two reduction gear boxes with fixed-pitch propellers.

The keel for Ocean was laid on May 30, 1994, and the ship was launched on October 11, 1995. Plans call for acceptance from VSEL following her Part IV Trials program (initial Royal Navy trials with crew) in spring 1998, and she will enter operational service in early 1999.

**Landing Platform–Dock (LPD)**

Under the Landing Platform–Dock Replacement (LPD-R) program, the MoD has recently placed a contract to construct two new LPD-class ships, which will replace the Royal Navy’s HMS Intrepid and HMS Fearless. VSEL will design and build these ships at its Barrow facility. The company was the only remaining contender for the contract after a protracted design and competition phase started in 1991, following lengthy studies during the 1980s.

Displacing 13,000 tons, the new LPDs will have a speed of 18 knots, and each will carry 650 troops and 325 crew. They will have a flight deck that can operate two Merlin (EH-101) or Sea King helicopters or a single Chinook, and they will carry eight landing craft, four of which will be capable of landing main battle
tanks. The ships, named HMS Albion and Bulwark, are expected to enter service after 2000, by which time the current LPDs will be almost 40 years old.

Like Ocean, the LPDs will incorporate commercial standards instead of military standards in their hull construction. VSEL designers worked very closely with the MoD to reduce the procurement cost of these new LPDs by approximately one-third of initial cost estimates. The two teams, VSEL and MoD, did so by going through the technical specifications line by line to reduce both risk and cost.

**CHANGES IN MILITARY SHIPBUILDING IN GREAT BRITAIN**

As with construction of Ocean and the LPDs, adoption of commercial practices is one of several major changes that figure in the current military shipbuilding environment in Great Britain. Driven by reduced defense budgets, the MoD military ship acquisition policy is now

- emphasizing competition
- shifting design and production risk from the government to prime contractors and subcontractors
- encouraging adoption of commercial practices, when practical
- allowing contractors more flexibility.

In response, UK defense industries are restructuring and combining their business units.

**The MoD Acquisition Policy**

**Emphasizing Competition.** Using competition to drive down procurement costs is a major theme throughout the MoD, and military shipbuilding is no exception. With the MoD’s strong push for competition, the move toward commercial practices, the desire to have a prime contractor responsible for the entire ship design and construction, and the introduction of two large electronics-oriented organizations into military-ship construction, the traditional business model of military-ship acquisition is changing very rapidly.

As a result, partnerships of organizations, including some organizations with no shipbuilding experience, are now competing for new-ship construction.² For example, GEC, a large electronics, power systems, and telecommunications

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²These partnerships are also being used in the United States, specifically for the LPD-17 program.
conglomerate,3 teamed with a manufacturer of offshore oil rigs and a group of former MoD submarine engineers to bid against VSEL and other competitors on the Batch 2 Trafalgar submarine program. British Aerospace (BA) has also entered into competitions for new shipbuilding contracts. Owing to limited budgets, the MoD has strongly advocated competition and typically awards new contracts to the lowest bidder, conditional on the winning bidder’s having sound plans for the design and construction program.

While the MoD would be willing to extend the logic of competition and use of commercial practices to have a foreign yard build the hull, politics would probably prohibit such a practice. Yet, in the LPH contract, discussed above, MoD did entertain a bid from Norway for a brief time.

**Shifting Design and Production Risk to Prime and Subcontractors.** The MoD is also shifting program risk to the prime contractor in any new-construction program. Many of the design and engineering functions are migrating from the MoD to the prime contractors. The use of modern computer software, including computer-assisted design (CAD) and virtual-reality systems, is helping both the MoD and the contractor examine various design alternatives before any actual production takes place. The assumption is that these advanced modeling skills will allow the MoD and the contractors to “do it right” during construction of the lead ship instead of having the lead ship serve as something of a learning experience for follow-on ships in the class.

One drawback of this new approach is the lack of adequate tools to estimate cost and schedule implications of various design options. The use of commercial products and standards is a new practice, and sufficient data do not exist to construct adequate cost and schedule estimates. Further, since the shipyards will have actual construction cost data but are not contractually obligated to provide those data to the MoD, the MoD may never have sufficient data to build good cost-estimating models. In many ways, the MoD is relying on experience in the commercial marketplace and on faith that “commercial is good enough” for many functions on board a military ship.

These changes are evident in the contract award and construction of the new LPH, HMS Ocean. Previously, the MoD would have performed analyses of the requirements, initial concept, and feasibility and collaborate on the project-definition phase with the shipyard. For Ocean, VSEL participated heavily in the concept and feasibility analysis and performed the majority of the project-definition function. In fact, VSEL was fully responsible for the complete design

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3GEC has acquired VSEL and has formed a GEC Marine Division composed of VSEL, Yarrow Shipbuilders Limited, and the National Nuclear Corporation. Therefore, VSEL is now part of GEC, a competitor in the original bidding for the Batch 2 Trafalgar (nuclear-submarine) program.
of the LPH from concept to detailed design. Also, for prior ships, the MoD would have performed the test and acceptance function once the ship was constructed. For Ocean, VSEL will perform that function. In this current shipbuilding environment, the MoD does very little design work, allowing the prime contractor or shipyard to perform the design function.

Also very different from past practices is the contract for Ocean, which is fixed price. The contractor is encouraged to take full advantage of the cost reductions associated with commercial standards and practices as long as those commercial standards do not jeopardize the military operational missions or the safety of military personnel.

Since VSEL had been building exclusively submarines and, hence, has been out of the surface-ship business for many years (see the “Implications for Shipbuilders” section on VSEL) and has had little current commercial experience, it decided to subcontract the hull building (steel erection) to Kvaerner Govan in nearby Glasgow. The MoD is working closely with VSEL and, through them, with KGL, on the hull build.

MoD officials indicated that the process is still very much in flux, but that they are trying to make good business decisions, banking on the rationale that if something is good enough to be commercial grade, it cannot be overlooked. Of course, when commercial is not sufficient to meet their needs, they permit a “MILSPEC” item or process.

Since the ship will be “built in a computer” (CAD/CAM), and since the building yard will own the computer model, the building yard will be the logistics and maintenance yard for the life of the ship—unless the MoD pays for the model and its transfer to another facility, which is unlikely—so the competition to build may turn out to be (de facto) a competition for cradle-to-grave support.

While this approach is very conducive to cost as an independent variable (CAIV) application, other conditions may force a return to more-traditional practices. There were no competitive bids for the LPD. The only bid (VSEL) was too high for the MoD. To reduce the total cost, the MoD and the yard, together, analyzed each cost item to see what could be done. The contractor had provided a cost that included risk money, because it had been asked to translate a short, “functional” specification (for example, “be able to fight 5 fires at once”) to a “build” specification (“so many pumps,” “this kind of pipe,” etc.). MoD opted to move away from a functional specification and agreed with the builder on a design that would prove adequate. Consequently, contractor risk is reduced and the price drops. By this method, the MoD took out 33 percent of the cost, but, in some areas, had to become involved with the detailed (build) specifications rather than staying with the functional or performance specifications.
Encouraging Adoption of Commercial Practices. The MoD is aware of the risks involved with this new way of doing business and is being careful to make sound military decisions within the fiscal constraints. The move to commercial standards and practices (which has an analog in U.S. acquisition reform initiatives, which encourage “commercial-off-the-shelf” [COTS] products when appropriate) is being monitored closely. The basic assumption is that commercial products must work to remain competitive in the civilian marketplace. However, usually no data have been available for measuring the reliability of the commercial systems, especially in a military environment, and there is always the chance that commercial suppliers may go out of business, potentially creating logistics problems for the military users (this is also a potential problem with suppliers of military products).

The MoD estimates that the new computer design technologies (CAD/CAM), combined with a strong effort to simplify the ship and with “going commercial,” results in about a 33-percent reduction in man-hours to build, because the ship is built right the first time. It also believes that while the shipbuilders think they are being efficient, or are becoming more so, there is still more efficiency to be gained. An internal VSEL study suggested that personnel were actually working less than half the time, and waiting the rest. But the core capability of shipyard personnel is integration; and a time-and-motion analysis of people in the yard may not capture the essence of the job.

The MoD is aware that commercial suppliers may go out of business and not be there for the long-term logistics. They hope that other options will arise to help them fix problems if and when such problems arise.

Allowing Contractors More Flexibility. MoD pointed out that, contrary to the Naval Sea Systems Command (NAVSEA) practice of “affordability through commonality” (i.e., economies of scale), the number of ships in the Royal Navy is not sufficient to justify such an approach. As well, because MoD is using a greatly diverse supplier base to foster competition, although ships of the same class would be unlikely to have different equipment, different suppliers could provide similar equipment across ship classes (for example, laundry or compressors). And although the MoD does give the prime contractor flexibility in selecting equipment, builders of follow-on ships in a class must bear the full cost of introducing any new equipment into the design and construction of the ship.

MoD has paid special attention to simplifying the ship design so that “going commercial” provides the biggest benefit.

These two issues have had implications for both major shipbuilders. We discuss those implications for VSEL and Kvaerner Govan in the next two sections.
IMPLICATIONS FOR SHIPBUILDERS—VSEL’s EXPERIENCE

Prior to being nationalized in the 1980s, VSEL employed 14,000 to 15,000 people in producing surface ships, submarines (nuclear-powered and conventional), and other major items (for example, guns and locomotives). When it was nationalized by the government, VSEL was directed to divest its surface-ship capabilities and concentrate on building submarines. To implement this objective, they built a land-level facility (similar to those at Electric Boat and Newport News Shipbuilding), optimized their production methods for submarines, started modular construction, and ensured that their land-level facility was set up in an efficient way to reduce cost.

A few years later, they were privatized and were asked to compete in the broader shipbuilding world. “Going commercial” was a key part of the competition. VSEL is undergoing major changes in trying to adapt to the new world. Now employing only about 5,300 people, VSEL finds that the overhead of the land-level facility and of maintaining a nuclear license makes it difficult for it to be competitive in the current environment. VSEL is working with the MoD to allocate that overhead to a special account so that it can compete for other contracts. The overhead for the nuclear-license part may be considered by the MoD, but the huge land-level-facility part is still under discussion.

Subcontracting to Redevelop Full Capability

To redevelop full shipbuilding capability, VSEL has expanded into the surface-ship world—a reason it bid on the LPH contract and subcontracted with Kvaerner Govan for the hull. VSEL is carefully monitoring that process to learn how to rebuild surface ships and how to be efficient in a commercial environment. It has subcontracted some simple steel-erection work from KGL to its own Barrow yard so that it can apply the lessons learned. While this learning process is going on, VSEL considers its efforts (and losses or meager profits) an investment in the future of the company. On the subcontract to KGL, it is not making much (if any) profit but has learned enough to feel that it can now be competitive in surface-ship commercial practices.

Over the years, the yard layout has been optimized for submarines. With the new surface-ship contracts, getting a ship of the planned size through the yard and to the water requires tearing down parts of buildings in town and working with the city to widen public streets to move large sections of the hull. Modifying the yard was not economical for a single ship, but, with the winning of the contract for the two LPDs, the modifications to the yard and public streets will be made.
VSEL’s primary strength is in performing ship integration. For more-complex surface ships and for submarines, VSEL believes that it has unique skills that will help it succeed in the long run. However, to get to the “long run,” it needs to survive by doing all jobs (even at little or no profit) that contribute to its long-term strategy of becoming a full-capability yard that can handle both military and commercial work. VSEL believes that it is accomplishing its goal: Despite subcontracting with Kvaerner for the steel erection of the LPH, it considers itself ready to build the LPD on its own.

**Competition Versus Core Capability**

Emphasizing on several occasions that competition is fine and that it is willing to compete, but realizing that a company must really know the product in order for competition to be fruitful for the MoD, VSEL clarified its knowledge by discussing the LPD design (provided by a design firm) it was asked to build. There were several problems, most significant being the lack of design margin necessary to account for changes and growth during the life of the ship. The design team obviously lacked experience and sufficient knowledge to question the MoD’s intentions. As a result, VSEL had to make several modifications (with MoD’s participation) before it could provide a cost bid. The implication was that competition for its own sake and a bid by a new entrant in the field may be interesting, but that, in the long run, you have to pay the real cost of what you are buying.

We discussed the bidding war on Arleigh Burke-class destroyers (DDGs). VSEL managers indicated that they were concerned that too much emphasis on competition was driving them in that direction, but that MoD may not fully understand all the adverse implications.

VSEL has embraced the concept of competition. While learning how to work in a more commercial environment and willing to optimize costs by subcontracting extensively in most areas, it wants to maintain integration and outfitting as a core capability. It is burdened by the overhead items from its nationalized days but is working on fixes with the MoD. Facilities modifications to accommodate the new type of work are going to be expensive.

Skilled personnel flow to and from VSEL much as engineers flow, with contracts, into and out of aerospace companies in the United States. Therefore, maintaining specific skills is not as critical as it once was. And geographical separation of the various yards is not as great in the United Kingdom as it is in the United States.

VSEL was not perceived to be big enough to be a prime contractor to the MoD. But with its acquisition by GEC, it is again viewed as a major competitor for
new-ship construction. VSEL still considers the yard to have the key ingredient—integration skill—but welcomes the combat-system expertise that GEC brings.

It appears that taking the direction to specialize in submarines (during the nationalized period) was quite damaging and that going back to a broad-based-capabilities yard is both difficult and mandatory. VSEL has identified no “silver bullets” to aid in reaching its goal. It appears that hard-nosed business decisions are the operating principle. VSEL’s relationships with its owners (GEC) and customers (the MoD at the moment) will be unfolding—reaching agreement on core competencies and realizing the benefits of competition.

**IMPLICATIONS FOR SHIPBUILDERS—KVAERNER GOVAN’s EXPERIENCE**

The Kvaerner Govan Limited shipyard is situated on the south bank of the River Clyde in Glasgow, Scotland. The yard itself has been in existence for well over a century and was acquired in 1988 by Kvaerner Govan, a large, diverse Norwegian company with interests in energy, pulp and paper, engineering, and shipbuilding.

Considered the largest merchant shipbuilder in the UK, KGL has about 1,500 employees and broad experience in designing and constructing a large variety of vessels, such as bulk carriers, product tankers, container ships, and cruise ferries. In recent years, KGL has built only merchant ships and has specialized in the “high end” of shipbuilding: relatively complex ships such as chemical tankers and liquid-gas carriers. It is currently building a missile-transport tracking-and-command ship for a sea-launched missile program that can place commercial satellites in orbit.

KGL constructed the hull and installed the propulsion and auxiliary propulsion equipment on the LPH, under a subcontract from VSEL. It made maximum use of commercial standards and practices to save construction costs. Once the hull and machinery were completed, the ship transited under its own power from Glasgow to the VSEL yard at Barrow-in-Furness for final outfitting with military features, installation and test of the combat system, and final trials. The completion letter was signed on November 25, 1996, and the ship is now at VSEL.

**Overview**

As a corporate policy, KGL would never enter a warship contract itself; however, it did undertake the subcontract from VSEL. KGL was concerned that a stan-
standard government contract would inundate and burden it with paper, inspection requirements, documentation, and the like. The negotiations with VSEL produced a one-volume specification, instead of the multiple volumes MoD imposed upon VSEL. All contact contractually was to be between KGL and VSEL, with no official contact between MoD and KGL. MoD and VSEL had a team of some eight overseers on-site throughout the construction period, acting as Supervisor of Shipbuilding/owner’s representative.

The conceptual design of the ship was performed by VSEL and was provided as a package to KGL as part of the contract proposal. KGL would accept no classified drawings, and none was required, except for the hull lines and general arrangements. These drawings were kept in a safe and used only for reference. The detailed design was performed by KGL.

The hull and machinery were constructed and installed to the extent practical in accordance with rules for commercial shipbuilding laid down by Lloyd’s Register of Shipping, the UK’s classification-society counterpart of the American Bureau of Shipping (ABS). The configuration of the LPH, with large cut-out sections in its hull for aircraft elevators and landing craft, required a modification of the Lloyd’s classification and certification process. The structure conformed to Lloyd’s rules up to the tank tops; above the tank tops, Lloyd’s Register accepted the results of finite-element analyses, as long as the local stresses and stress distribution met acceptable standards. A formal certification was not issued; instead, Lloyd’s provided a letter stating that the ship, as modified, met its rules.

Wherever practical, commercial equipment and practices were utilized. The majority of construction cost savings can be attributed to “commercialization.”

**Subcontracting**

Seventy percent of the hull, mechanical, and electrical (HM&E) work was done by KGL; the remaining 30 percent was contracted out. Turnkey operations were called for in the following areas:

- Hull thermal insulation
- Heating, ventilation, and air conditioning (HVAC)
- Firefighting systems
- Remote operating valves.

Electrical-power and distribution systems were contracted out but were not turnkey. Similarly, the laundry was not turnkey. KGL agreed that more turnkey operations were desirable and, indeed, was moving in that direction.
Commercial Instead of Military Specifications and Standards

Lloyd’s Register of Shipping (LR) rules, which govern commercial-ship hull and machinery, were imposed, but MoD modified them to suit military requirements. Some of the rules and modifications are as follows:

• LR requires navigational lights to have dimmers; MoD did not want dimmers.
• LR allows interrupted welding of stiffeners; MoD required continuous welding.
• LR allowed thicker plates but fewer stiffeners. This was accepted by MoD and resulted in less deformation of the structure (“hungry horse” look) and a flatter flight deck.

MoD required an International Maritime Organization (IMO) “certificate” for the sewage system, but IMO has established no such certification. MoD requirements for piping were not as stringent as those the tanker buyers and operators imposed on KGL for chemical tankers.

Military specifications for electrical cabling were beyond commercial practices for redundancy and watertight integrity. As a result, KGL underestimated the man-hours required to pull the cables. MoD was not in favor of commercial standards for firefighting systems and made several changes during construction.

Commercial ships employ far more automation than that specified by MoD. KGL believes it could actually have installed more to commercial standards for the same price, or even cheaper. MoD did allow limited use of commercial pipe and fittings in the sewage system; more cost savings could have resulted from wider usage. MoD specified the use of sheet metal (light-gauge steel) for berths and lockers instead of commercially utilized wooden laminate.

Material and Equipment Procurement

KGL was able to purchase material and equipment far cheaper than MoD could, even for the very same item. Military specifications caused suppliers to charge twice as much as for making the same item to commercial specifications.

VSEL selected 1970s’ model Pielstick engines, probably because those engines were already installed in other Royal Navy ships and, therefore, offered an overall lower cost than did other engine alternatives. KGL stated that it could have purchased a current model of Wartsilla engines at a much lower cost.
Manual, remotely operated valves, specified by MoD, are not in common commercial usage; they have been replaced by electro-mechanical control valves. Consequently, only one manufacturer could be found to supply the valves, and his price had to be accepted.

**Life-Cycle Costs**

A current-model Wartsilla diesel engine, which is cheaper to purchase than the specified Pielstick, is also 20 percent more fuel-efficient and would result in a direct 20-percent savings in fuel costs over the life of the ship. Additionally, the Wartsilla engines are supported by parts and service worldwide. The older engines would be more difficult and more expensive to support.

Paint systems for tanks are available commercially and, if applied to ballast tanks, would last for the life of the ship. Although KGL has installed such paint systems on the chemical tankers it has recently constructed, it was apparent to KGL that the effects of corrosion were far more important to its commercial customers than they were to MoD.

More-extensive use of automation would require less crew. An integrated bridge with full control of the ship is a good example.

The heating, ventilation, and air-conditioning system for HMS Ocean was designed to maintain environmental conditions for electronics and computing equipment, but applied to the whole ship. KGL felt that a more balanced design would save not only operating costs but acquisition costs as well.

**Lessons Learned**

KGL learned several lessons as it constructed HMS Ocean and reported them during our discussion:

1. Much tighter change control is necessary to minimize disruption and unreimbursed costs. This is difficult at times, especially when there are three parties involved—MoD, VSEL, and KGL—with communication often being two-way instead of three-way. Many of the changes were initiated by VSEL, not necessarily by the MoD. The MoD’s change control on the prime contract with VSEL was, for the most part, very tight.

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4A paint system is more than just a can of paint. Applications are designed and built on what is being painted.

5MoD may be moving toward greater recognition of life-cycle costs. New auxiliary-oiler contracts have higher paint-life requirements and specify an integrated bridge.
2. It is difficult to work to two standards in one shipyard. Even for HMS Ocean, with its large portion of commercial standards and specifications, KGL found that it could not readily and easily exchange workers from HMS Ocean to commercial projects. This is also a problem for U.S. yards engaged in naval and commercial ship construction.

3. KGL is headed toward using more and more subcontractors who will be performing operations with well-defined boundaries in a turnkey fashion.

4. KGL subcontracted the design of the electrical-power generation and distribution system to Siemens and the installation to a Norwegian company. In retrospect, KGL stated that the installation would have been far more efficient if Siemens had done the entire job. In the future, KGL intends to have electrical work done entirely by one subcontractor on all complex projects.

5. The preponderance of cost savings by constructing to essentially commercial standards in a commercial yard came from steel fabrication and erection and from cheaper procurement of material and equipment. A savings of 30 to 40 percent would appear to be valid.

CONCLUDING THOUGHTS

With regard to technologies or systems that may require special attention—catapults, side protection, compartmentation, or movement of weapons to the aircraft—MoD does not believe that any of these are sufficiently special to cause concern. MoD cites the availability of carrier-specific technologies, such as aircraft launch and recovery; industry efforts, primarily from the United States; and the possibility of customizing these technologies to meet its requirements for future aircraft carriers. The intellectual design ideas for other technologies can be studied and implemented without the in-depth knowledge required for such aircraft-specific technologies as launch and recovery.

In actuality, the changing shipbuilding environment in the UK and the evolving new design and production technologies may override any negative effects resulting from the size of the gap between design and production of aircraft-capable ships.