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International Naval Technology Transfer: Lessons Learned from the Spanish and Chilean Shipbuilding Experience

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Preface & Acknowledgements

Welcome to our Ninth Annual Acquisition Research Symposium! This event is the highlight of the year for the Acquisition Research Program (ARP) here at the Naval Postgraduate School (NPS) because it showcases the findings of recently completed research projects—and that research activity has been prolific! Since the ARP's founding in 2003, over 800 original research reports have been added to the acquisition body of knowledge. We continue to add to that library, located online at www.acquisitionresearch.net, at a rate of roughly 140 reports per year. This activity has engaged researchers at over 60 universities and other institutions, greatly enhancing the diversity of thought brought to bear on the business activities of the DoD.

We generate this level of activity in three ways. First, we solicit research topics from academia and other institutions through an annual Broad Agency Announcement, sponsored by the USD(AT&L). Second, we issue an annual internal call for proposals to seek NPS faculty research supporting the interests of our program sponsors. Finally, we serve as a "broker" to market specific research topics identified by our sponsors to NPS graduate students. This three-pronged approach provides for a rich and broad diversity of scholarly rigor mixed with a good blend of practitioner experience in the field of acquisition. We are grateful to those of you who have contributed to our research program in the past and hope this symposium will spark even more participation.

We encourage you to be active participants at the symposium. Indeed, active participation has been the hallmark of previous symposia. We purposely limit attendance to 350 people to encourage just that. In addition, this forum is unique in its effort to bring scholars and practitioners together around acquisition research that is both relevant in application and rigorous in method. Seldom will you get the opportunity to interact with so many top DoD acquisition officials and acquisition researchers. We encourage dialogue both in the formal panel sessions and in the many opportunities we make available at meals, breaks, and the day-ending socials. Many of our researchers use these occasions to establish new teaming arrangements for future research work. In the words of one senior government official, "I would not miss this symposium for the world as it is the best forum I've found for catching up on acquisition issues and learning from the great presenters."

We expect affordability to be a major focus at this year's event. It is a central tenet of the DoD's Better Buying Power initiatives, and budget projections indicate it will continue to be important as the nation works its way out of the recession. This suggests that research with a focus on affordability will be of great interest to the DoD leadership in the year to come. Whether you're a practitioner or scholar, we invite you to participate in that research.

We gratefully acknowledge the ongoing support and leadership of our sponsors, whose foresight and vision have assured the continuing success of the ARP:

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We also thank the Naval Postgraduate School Foundation and acknowledge its generous contributions in support of this symposium.

James B. Greene Jr.
Rear Admiral, U.S. Navy (Ret.)

Keith F. Snider, PhD
Associate Professor

Panel 12. Revitalizing the Ship Design and Shipbuilding Process

Wednesday, May 16, 2012	
3:30 p.m. – 5:00 p.m.	**Chair: Robert "Bob" G. Keane Jr.,** President, Ship Design USA, Inc. ***International Naval Technology Transfer: Lessons Learned from the Spanish and Chilean Shipbuilding Experience*** Larrie Ferreiro, *Defense Acquisition University* ***Total Ship Design Process Modeling*** David A. Helgerson, *CSC Advanced Marine Center* Seth Cooper, *NAVSEA05C* Gilbert Goddin, *Naval Surface Warfare Center, Dahlgren* Gene Allen, *Naval Surface Warfare Center, Carderock Division* Daniel Billingsley, *Grey Ghost, LLC* Sean Gallagher, *Naval Surface Warfare Center, Carderock Division* ***Revitalization of Naval Surface Warfare Center Excellence in Early Stage Combat System Engineering*** Ashby Hall, Terence Sheehan, and Mark Williams *Naval Surface Warfare Center, Dahlgren*

Robert "Bob" G. Keane Jr.—Mr. Keane is the president of Ship Design USA, Inc. Prior to starting his own consulting firm, Mr. Keane worked at the Advanced Marine Center of CSC and at the Naval Sea Systems Command (NAVSEA) for 35 years. Mr. Keane was a member of the Senior Executive Service (SES) for 21 years. He last served as executive director of the Surface Ship Design and Systems Engineering Group in NAVSEA. He also served as director of the Total Ship Systems Directorate (Code 20) at the Naval Surface Warfare Center Carderock Division (NSWCCD). Mr. Keane previously held senior leadership positions in NAVSEA as chief naval architect and deputy director, Surface Ship Design and Systems Engineering Group; technical director, Ship Design Group; director, Ship Survivability Sub-Group; director, Naval Architecture Sub-Group; director, Hull Form Design, Stability and Hydrodynamics Division; head, Hull Equipment Branch; and as a ship arrangements design specialist.

Mr. Keane is widely recognized as an expert in naval ship design, is a plank holder in the Navy's Center for Innovation in Ship Design at NSWCCD, and has fostered the professional development of engineers and scientists in government and industry. He received his Bachelor of Engineering Science in mechanical engineering from Johns Hopkins University, his Master of Science in Engineering in ship hydrodynamics from Stevens Institute of Technology, and his Master of Science in Engineering in naval architecture and marine engineering from the University of Michigan.

Mr. Keane is currently serving as chair of the American Society of Naval Engineers (ASNE) and Society of Naval Architects and Marine Engineers (SNAME) Joint Ship Design Committee, as a member of the ASNE-SNAME Joint Education Committee, as a member of the SNAME Technical & Research Steering Committee, and ex-officio member of the ASNE-SNAME Strategic Alliance Committee and he is a current member of the ASNE National Council. He recently served as chair of the highly successful ASNE-SNAME International Electric Ship Design Symposium (ESDS) in February 2009, and has served as chair of the ASNE Flagship Section, chair of the SNAME Chesapeake Section, president of the Association of Scientists and Engineers (ASE) of NAVSEA, regional vice president of SNAME, and president of the D.C. Council of Engineering and Architectural

Societies. He has held numerous other leadership positions in these societies, and has published frequently in the *Naval Engineers Journal* and *Journal of Ship Production*.

Mr. Keane has received many honorary awards including the Secretary of the Navy Distinguished Civilian Service Award, Department of the Navy Superior and Meritorious Civilian Service Awards, SNAME David W. Taylor Medal, ASE Silver Medal, ASE Professional Achievement Award, SNAME Distinguished Service Award, two SNAME Elmer Hann Awards for Best Paper, ASE John Niedermair Award for Best Paper, and election as a Fellow of SNAME. Mr. Keane and his wife, Judy, have three sons and four grandchildren. [keanerg@comcast.net]

International Naval Technology Transfer: Lessons Learned from the Spanish and Chilean Shipbuilding Experience

Larrie Ferreiro—Dr. Ferreiro is the director of research at the Defense Acquisition University, and executive editor of the *Defense Acquisition Research Journal*. He has been a naval architect in the U.S. Navy, U.S. Coast Guard, the French Navy, and the British Navy. He is a professor of complex systems engineering at the Catholic University in Washington, DC, and at George Mason University in Fairfax, VA. He is the author and editor of several award-winning books, notably *Ships and Science*, about the history of naval architecture; *Measure of the Earth*, about an 18th-century scientific expedition to the equator, and *Technology of the Ships of Trafalgar*, about the vessels that fought in the most important naval battle of modern history.

Abstract

In 2007 the Spanish shipbuilder Navantia won the contract to rebuild the Australian navy with high-end destroyers and amphibious ships. The same year, the Chilean shipyard ASMAR won the contract to build an advanced Icelandic Coast Guard Vessel. Both shipyards just a few years before had been importing design and construction technologies from abroad; now in a rapid evolution of capability, they had become net technology exporters. A similar process had occurred at the turn of the 20th century, when United States and Japan rapidly built up their own shipbuilding capabilities using knowledge primarily derived from British shipbuilders, who at the time were known as “naval architects to the world.” This paper uses the examples of Spain and Chile to demonstrate how modern naval shipbuilders can rapidly evolve from net importers of technology to net exporters with the assistance of foreign technology transfer, and lays out the systematic way this process may occur. It then derives lessons for other navies (including the U.S. Navy) as they rebuild their fleets to meet new global missions in the face of dwindling resources.

Introduction

On June 20, 2007, the Spanish shipbuilder Navantia made a clean sweep of the global competition to rebuild much of the Australian Navy, landing a total of $11 billion in contracts for three Air Warfare Destroyers and a pair of amphibious ships on the same day (Uhlmann, 2007). Coming on the heels of a major export contract to Norway (five air-defense destroyers) and one to Thailand (an aircraft carrier), this was a wake-up call to the world’s naval industries: Spain, which just 20 years earlier was still importing design and construction expertise, was now not only equipping its own navy with advanced destroyers, amphibious ships, and aircraft carriers; it had become shipbuilder to the world for these same high-value warships. In the same year, the Chilean shipbuilder ASMAR (Astilleros y Maestranzas de la Armada) began construction of an advanced Icelandic Coast Guard Vessel, after winning the contract in the face of stiff competition worldwide (“ASMAR Construirá Patrullero,” 2006). ASMAR had recently won export contracts for building complex vessels, such as an Icelandic oceanographic research ship and a patrol ship for Mauritius, after decades of repair work and the occasional fishing vessel; so on a smaller scale, Chile, while building up its own naval fleet with new offshore patrol ships, was now also following in Spain’s footsteps, constructing complex military vessels for the world market.

What is happening today in Spain and Chile echoes the process of technology transfer that occurred in nations such as the United States and Japan that were building and rebuilding their navies during the late 19th and early 20th centuries: first, import of engineering expertise, often beginning with direct purchase of ships built in a foreign yard; next, accumulation of experience by designing and building vessels locally under a license or government agreement from a foreign shipyard; and finally, the creation and construction of indigenous warships to meet navy requirements. The difference between Japan and the United States of yesteryear, and Spain and Chile of today, is that while the former navies used that expertise almost exclusively to build up their own fleets, the latter have rapidly expanded their capabilities beyond their own navies and into the growing naval export market. In other words, both Spain and Chile have gone from being a net technology importer to a net exporter of naval shipbuilding technology and expertise in almost the blink of an eye. The purpose of this paper is to chart this rapid progress, and to derive lessons for other navies (including the U.S. Navy) as they rebuild their fleets to meet new global missions in the face of dwindling resources.

International Technology Transfer in the Naval Industries: The Historical Context

Long before the word *globalization* entered the modern lexicon, shipbuilding was a global enterprise. At the Battle of Trafalgar in 1805, for example, the Spanish flagship *Santísima Trinidad* was designed by a constructor of Irish descent, Matthew Mullan, and built by other English-speaking artisans who themselves had been recruited from British shipyards. Other Spanish ships at Trafalgar were actually designed by a French constructor, François Gautier, who had been recruited to harmonize the allied fleets of France and Spain. Both France and Spain made extensive use of copper sheathing to protect their ships, a technology originally developed in Britain but rapidly extended into other countries through both industrial agreements and espionage. Finally, more than half of Britain's fleet at Trafalgar consisted of 74-gun ships that owed their design to captured French warships (Ferreiro, 2007).

Technology transfer was the critical feature in the rapid expansion of the Industrial Revolution around the globe during the 19th century. This was nowhere more evident than in ship design and construction, and in particular the experience of British shipbuilders. The two critical technologies of the period—metal hulls (first iron, then steel) and steam propulsion—originated in Great Britain, but were quickly adopted almost everywhere. British constructors were known as "the naval architects of the world," both for building vessels for other countries, as well as for teaching other nations how to do so (Matsumoto, 1999, p. 76). Then, as now, economics governed the majority of technology transfer cases, with both sides expecting a reasonable profit at minimal risk. British ships dominated world trade, and both ship-owners and shipbuilders from many maritime nations, rather than attempting to compete toe-to-toe with indigenous technology, chose to buy or build British vessels. A common pattern emerged during the late 1800s: a British shipyard would at first sell its ships to a foreign ship-owner or shipyard. These sales were followed by industrial visits to the British yard by foreign dignitaries and engineers alike, often leading to commercial agreements in which British designs, materials, and often workers were directly imported into a foreign shipyard; in some cases these workers came on a temporary basis, in others as permanent expatriates. The foreign shipyard would work closely with the British engineers to introduce the latest innovations, at the same time gradually substituting their local expertise, material, and labor. British shipbuilders, with full order-books, did not view this as harmful competition, but rather saw increased profits via direct sales of ships and materiel, as well as licensing fees (Ville, 1991). This pattern of technology transfer was even more prevalent in the naval industries, that is, the design and construction of warship hulls and machinery, where both political considerations and profit played equal roles. Two examples stand out: the reconstruction of the U.S. Navy post–Civil War, from 1880–1900, and the buildup of the Japanese Navy from 1865–1912. These will serve as a backdrop to the more recent experience of the Spanish and Chilean Navies.

After the Civil War the U.S. Navy scrapped or sold most of its warships, so that by 1880 it had effectively been reduced to a coastwise fleet. In terms of numbers and capabilities, it fell behind all European powers and even navies of South America. From 1881–1883 the Navy and Congress put together a plan to rebuild its capabilities, beginning with a set of steel vessels called the ABCD ships for their names *Atlanta*, *Boston*, *Chicago* (all cruisers), and the dispatch vessel *Dolphin*. By this time several U.S. naval officers had graduated from the constructors' course at the Britain's Royal Naval College in Greenwich, and were intimately familiar with the design and construction of British warships. The U.S. Navy bought the plans and specifications for the *Leander*-class protected cruisers and closely hewed to them when designing the ABC cruisers. The contracts were let to the John Roach shipyard in Delaware, who initially bought compound engines from the British firm Randolph and Elder before producing his own under license. During the 1880s and 1890s, the U.S. Navy spent many thousands of dollars to obtain plans and specifications for other British cruisers and engines, and to send its naval officers to be trained at the Royal Naval College. However, it did not import British constructors or engineers to work at U.S. facilities. By 1900, the Navy had developed its own ship model testing facilities at the Washington Navy Yard, based on Britain's Haslar tank, and its own naval constructor's course at MIT that closely hewed to the Greenwich model (Bennett, 1896, pp. 773–794; Thiesen, 1999; Ville, 1991, p. 79).

Japan's Meji Restoration saw enormous technological changes as the country clawed its way from the 16th century all the way to the 20th in just a few years. Shipbuilding was one of the most important industries to be literally built from the ground up, starting with naval constructors from France (notably François Léonce Verny and Emile Bertin) who from 1865–1885 created Japan's first modern warship fleet (Dedet, 1993). By the mid-1880s, however, Japan firmly fixed its sights on the British model. In particular, the Mitsubishi Nagasaki shipyard carefully crafted a long-term strategy to import naval technologies from the UK. In addition to sending engineers overseas to learn at British schools and factories, it recruited a number of skilled workers on both short-term and long-term contracts, who were placed in charge of key facilities. However, as their Japanese subordinates gained skill and experience, they gradually took over these positions. Mitsubishi imported plans, materiel, and machinery for designing, testing, and constructing ships and equipment; for example, steam turbines were imported from the Charles Parsons Company in 1907, until the yard was able to build a turbine manufacturing facility under license. In 1907–1908 it also imported materiel and know-how to create its own testing tank. By the eve of the First World War, just two generations after it had begun from scratch, Japan had a well-developed, autonomous capability to design, test, and construct its own warships (Fukasaku, 1992, 1995; Matsumoto, 1999; Matsumoto & Sinclair, 1994).

Military technology transfer must always be regarded in the wider political and economic frameworks, and the cases discussed in this paper are no different (Anthony, 1990). In the above examples of the United States and Japan, the principal goal of the receiving nation was to build or rebuild its fleet; the development of a shipbuilding export capability was a minor or nonexistent consideration on the national scale, and few of the commercial shipyards built warships for export. In the following cases of Spain and Chile, the goal of creating a warship export capability will be seen as integral to the political and economic policies of sustaining the national naval infrastructure.

Evolution of Technology Transfer in Spanish Naval Shipbuilding, 1890–2010

Throughout the 19th century, Spain's warships were either bought directly from other nations (primarily Britain and to a lesser extent France), or constructed in the three government-owned naval shipyards of El Ferrol, La Carraca (in Cádiz), and Cartagena. In

1887 the Squadron Law authorized the construction of a new generation of modern warships, and allowed a consortium of British and Spanish firms to form a private company, Astilleros del Nervión in Bilbao, for the express purpose of constructing some of them. In the manner of the Spanish yards at the time of Trafalgar, Astilleros del Nervión had a mixture of Spanish and British technical personnel, though it was the latter who were in overall charge. Three *Infanta María Teresa*–class cruisers, basically an enlarged version of the British *Orlando* class, were laid down in 1889 and completed four years later, not much longer than British yards required. That capability did not transfer to the government yards, for three similar cruisers laid down in those yards at the same time were still not complete a decade later in time for the Spanish–American War (1898), which ravaged the Spanish fleet and eliminated its last remaining colonies.

In 1909, after an extensive international competition, the Sociedad Española de Construcción Naval (SECN), known as "La Naval," was created by a consortium of British shipyards (Vickers, Armstrong, and John Brown) to rebuild the fleet to Spain's new needs. According to the terms of the contract, they leased the facilities of the three government shipyards, in effect privatizing their operations, and extensively modernized them. Over the course of 20 years the SECN built numerous warships generally based on British designs (e.g., the *España* class was a reduced *Dreadnought*). Once again, the British were unquestionably in charge of the operation; most of the design and manufacturing expertise, as well as all of the senior personnel, came from Britain (large expatriate communities grew up around the shipyards, including a British School at El Ferrol). The downside of this arrangement was that very little of that technical expertise was transferred to Spanish engineers and shipbuilders (Houpt & Ortiz-Villajos, 1988; Lozano Courtier, 1997; Ramírez Gabarrús, 1980).

These privatized yards had mixed success in jump-starting the Spanish shipbuilding industry and aiding its shipping sector. Although equipment manufacture (e.g., turbine and diesel engines, electrical systems) rapidly spread into the merchant shipbuilding sector, the overreliance on British technical support—even shipbuilding steel came from Britain—crippled any real innovation. Spain's dependence on foreign sources for science and engineering was widely rationalized with a quote from the Spanish writer Miguel de Unamuno: *¡Que inventen ellos! Let others (i.e., foreigners) invent it!* (Unamuno, 2007, p. 296). The phrase gained wide currency, a self-portrayal of the Spanish as somehow lacking the scientific acumen of other (European) nations, and being merely passive adopters of new technologies.

The events of the next few decades seemed to reinforce this negative image of Spanish technical expertise. In 1939, at the end of the Spanish Civil war and the beginning of both World War II and Francisco Franco's regime, the SECN was reorganized out of the warship business, with the three shipyards restored to government control as British workers returned home to a nation newly at war. Without British help, naval shipbuilding limped along under the Instituto Nacional de Industria (INI, a government-owned holding company) and its subsidiary Empresa Nacional Bazán de Construcciones Navales Militares (Bazán, the newly-nationalized consortium of the three government shipyards); only a handful of small warships—mostly outdated destroyers and minesweepers, and no capital ships—were constructed during World War II and the years immediately following (Alvarez-Maldonado Muela, 1997, pp. 37–43; Molas-Gallart, 1995, pp. 46–47). Instead, Spain turned to Germany for technical assistance and technology transfer in submarine construction, both during the war and afterwards. This arrangement was driven principally by national political considerations, because Spain shared a "special relationship" with Germany through much of World War II, and was generally ostracized by other nations afterwards because of that relationship. This arrangement, however, was largely unsuccessful at the technical level, due to the fact that Spanish shipyards balked at the obsolete designs being offered by Germany, and German engineers who came to Madrid found Spanish technical and managerial capabilities to be sorely lacking (Presas i Puig, 2005, 2007, 2008).

This all changed in 1953, when Cold War realities pushed aside prior political considerations, and resulted in the signature of the Pact of Madrid by Spain and the USA. Among other things, the Pact provided for mutual defense, for U.S. military aid to Spain, and for the construction of bases in Spain that could be used by the USA (notably Rota). The advantages for Spain were clear: its navy was in a sorry state, with capital ships over 30 years old; even its most modern vessels were based on outdated designs. For the USA, it meant having an allied navy to lend a hand against the newly-ascendant Soviet Union, strong in minesweeping and antisubmarine warfare (ASW), which could bolster the eastern Atlantic and Mediterranean approaches. Over the next decade the United States transferred 26 ASW destroyers and minesweepers, transferred over $42 million (worth about $340 million in 2012 dollars) to modernize equipment on 40 other ships, for example, guns, fire control, and so forth, mostly using American gear, and provided extensive training for officers and the sailors (Whitaker, 1961).

For its next upgrade, Spain originally intended to build British *Leander* class frigates, but political complications between the two nations ended that effort. In November 1964 the Spanish Ministry of Defense approved the construction of guided-missile ships to be built under U.S. license at the Bazán El Ferrol shipyard. In May 1966 the support agreement, NOBS 4078, was signed between the two countries for what became known as the DEG7 *Baleares* class, based on the DE1052 *Knox* class ASW destroyer, but modified to have an anti-air warfare (AAW) missile system in place of helicopter facilities. The U.S. Navy established a small Resident Shipbuilding Liaison Office (RESHIPLO) on-site at El Ferrol, headed by a U.S. Navy commander, to administer the day-to-day workings of the support agreement (Alvarez-Maldonado Muela, 1997, pp. 106–107; Blackman, 1970, p. 272; Fernandez Gonzalez, 2009; Luengo-Romero, 2009; Ramírez Gabarrús, 1980, pp. 192–195; Saylor, 2009). The *Baleares* project proved to be a turning point in Spain’s ability to build modern warships.

The Bazán approach to technology transfer was completely unlike the pattern established at the SECN in the 1920s and 1930s, where the majority of the technical expertise came in the form of foreign personnel. Instead, it resembled more the Mitsubishi strategy which specifically emphasized the gradual development of home-grown skills. The first task was to define what was already available, and what was still needed, to construct such advanced warships in the El Ferrol yard. To do this, the RESHIPLO assisted Bazán in obtaining licenses for the design and construction of the ship and major equipment, and bringing representatives of the various U.S. industries. Bazán by then was building large tankers (up to 75,000 deadweight tonnes) for the international market, so they had excellent steel fabrication facilities. However, they lacked adequate capability to fabricate large aluminum plates for the DEG7 deckhouse, and needed additional facilities for weapon systems integration and to machine the high-speed reduction gears. Bazán invested some 500 million *pesetas* (equivalent to $48 million in 2012 dollars) to upgrade its facilities, as well as developing a complete training system for its technical personnel. For example, U.S. Navy personnel oversaw the establishment of a welding school to teach the specific techniques needed to weld the comparatively thin plates and close frames for warship; but this was a “train-the–trainers” arrangement, where a handful of Americans taught the welding techniques to senior shipyard welders, who then trained other workers.

The U.S. Navy hired the design firm Gibbs & Cox Inc. (G&C) as ship design agents for the DEG7 hull and machinery, and Sperry for the combat systems. G&C long had a special relationship with the U.S. Navy as its preferred design agent (i.e., it provided the designs that shipyards would then build), and it was at the time handling the detailed design work for the DE1052 class. G&C redesigned the ship to accommodate the Spanish requirements, at the same time translating the plans into metric units (and into Spanish). Sperry established a training and integration facility in New York for the combat systems, which trained Spanish personnel at the same site where the combat systems were integrated and tested, before those systems were disassembled and shipped to Spain. Other engineers were sent for training to U.S. shipyards and factories where the DE1052 and its components were constructed. In 1969 the RESHIPLO was moved back to the Washington, DC, region to manage the contracts, but there were now over 100 U.S. personnel from various companies (e.g., G&C, Sperry, Foster-Wheeler for the propulsion machinery, etc.) on-site at El Ferrol, mainly devoted to quality assurance which was still not up to U.S. standards.

Work progressed slowly as the Bazán personnel developed the skills, techniques, and quality control practices required to construct advanced warships. Most of this knowledge transfer took place with the production personnel (welders, shipfitters, machinists, etc.); by contrast, the design and engineering personnel were much less involved in the process, as those tasks were primarily left to G&C. By 1976, Bazán had successfully delivered 5 ships (now redesignated as frigates, the F70 class), which played an important role in the NATO naval force structure when Spain entered the organization in 1982.

The *Baleares* program was part of a larger agenda of industrial internationalization begun in the 1960s by the Spanish government, which included building *Delfin* class submarines and AMX 30 tanks under license from France, *João Coutinho* class corvettes (for Portugal) in cooperation with the German shipyard Blohm und Voss, and F-5 fighters under license from the USA, all with the express purpose of ramping up manufacturing capability and training the production work force (Castillo Masete, 1990, p. 118; Molas-Gallart, 1990, pp. 353–354). After the death of Franco in 1975, a new Ministry of Defense was created, which merged the formerly separate ministries of Navy, Army, and Air Force. Within the new MoD, an organization called DGAM (Dirección General de Armamento y Material), modeled upon the highly centralized French Délégation Géneral pour l'Armement, was created to coordinate armament procurement and budgeting, allowing for the creation of a uniform defense industrial policy (Molas-Gallart, 1995, pp. 95–96; Ramírez Gabarrús, 1980).

One of the first coordinated procurements, which actually had its roots in the creation of DGAM, was the combination of AV-8 Harrier VSTOL fighters (designated Matador in Spain) with a new-generation aircraft carrier. The Spanish Navy had many difficulties operating a small group of AV-8s from the antiquated (WWII-era) carrier *Dédalo*, and decided it needed a new carrier expressly built for this purpose. At the same time, the U.S. Navy was considering building a fleet of small ASW carriers, designated the Sea Control Ship (SCS) that carried AV-8s and helicopters, to work in conjunction with the FFG7 *Perry*-class ASW frigates then in development. The Spanish Navy saw the SCS as a potential replacement for *Dédalo*, and in 1973 under the NOBS 4078 agreement, pursued a joint program with the U.S. Navy to design and construct the carrier. However, in 1974 the U.S. Congress refused to fund the SCS, effectively killing the U.S. participation, though the Spanish continued to study the concept (also briefly examining a French helicopter carrier, the PH75) and develop a proposal for a new carrier. In 1977 Spain formally approved construction of the small carrier (initially designated the PA11, it became the R11 *Principe de Asturias*), in conjunction with the construction of three (eventually six) *Perry*-class frigates (known as the F81 *Santa María*-class), both designed and built under license from the USA. Once again, the U.S. design agent Gibbs & Cox Inc. was to be the critical intermediary in the transfer of technical knowledge (Blackman, 1970, pp. 496, 498; Fernandez Gonzalez, 2009; Luengo-Romero, 2009; Molas-Gallart, 1995, p. 125; Ramírez Gabarrús, 1980, pp. 221–226; Saylor, 2009).

The already well-established working relationship between G&C and Bazán greatly facilitated the ramp-up for the two new programs. The SCS project had initially been designed by the U.S. Navy's technical bureau NAVSHIPS (Naval Ship Systems Command), but the 50-odd concept drawings were completed by G&C. Under NOBS 4078, G&C (in close cooperation with Bazán engineers) created the 1,667 detailed design drawings and complete technical specifications needed to construct the vessel. The R11 had several notable modifications from the original SCS. First, it was fitted with a ski-jump to provide a launch boost for the VSTOL fighters, a concept originally invented by the British Navy but at the time not yet operational on its carriers *Invincible* or *Hermes*, so its inclusion was a bit of a leap of faith. Second, the vessel's military capabilities in terms of shock resistance, magnetic signature, and damage control were improved over the original design. Finally, the Spanish Navy selected the indigenous close-in-weapon system Meroka over the American Vulcan/Phalanx, which had to be integrated into the combat system. Spanish engineers worked closely with G&C and Sperry during the entire design and construction, learning valuable lessons on how to carry out and manage the overall process. After keel-laying in 1979, the hull construction took a reasonable 31 months until launch; but installation of propulsion and combat systems was agonizingly slow due to numerous design modifications, so that the vessel was delivered, not as planned in 1983, but rather in 1988, eleven years after keel-laying.

The F81 frigate program was approved in the same 1977 budget authorization as the aircraft carrier, though the resources needed for the carrier design and construction briefly interrupted the otherwise steady flow of design and construction. The first of class, *Santa María*, was laid down in 1982 and completed in four years; the sixth ship took just two years from keel-laying to commissioning. The frigates and the carrier both had gas-turbine propulsion plants, a technological leap from the steam plant of the F70. Bazán built several elements under license (e.g., the turbine enclosures and the reduction gear housing) which further advanced the state of the industry. As with the R11, Spanish engineers participated in the detailed design and construction, including integrating the weapons systems into the platform. G&C was heavily involved not merely in the design of the ships, but also in the formation of the Spanish engineers' training and skill development, including structural design, shock resistance, weight control, stability and hydrodynamics. At the height of the collaboration in the mid-1980s, almost half of G&C was in some way working on the two Spanish Navy programs.

It should be noted that both shipbuilding programs were actually just a small subset of a much wider effort by Spain during the 1980s to boost its military-industrial capability through foreign technology transfer, via industrial offsets and licensed production. The Foreign Military Sales (FMS) contracts for the frigates amounted to $227 million, while for the carrier it was $165 million. By contrast, the ASW helicopters and systems for the frigates were $230 million, while the Matadors for the carrier were $369 million; and even these paled in comparison to the F-18 fighter contracts, worth over $2.5 billion, each helping to develop a particular, strategically important niche of Spanish industry (JUSMAAG, 1987).

With the completion of these three programs—F70, F81, and R11—the Spanish naval shipbuilding industry had rapidly learned how to create detailed designs, manufacture components such as hull and machinery, and integrate complex systems. The final step towards technological self-sufficiency was the ability to autonomously create complete, integrated designs starting with customer requirements. Although the first steps had been taken in the 1970s with the *Descubierta*-class corvettes, a significant leap in capability was made with Spain's participation in the NATO Naval Frigate Replacement 1990 (NFR90) program. NFR90 was conceived in 1979 as a means of creating a common weapons and sensors platform intended to replace aging units in eight NATO navies: Britain, Canada, France, Germany, Italy, the Netherlands, Spain, and the United States. In 1983 a common set of requirements was developed, and the following year the company Internationale Schiffs–Studien–Gesellschaft (ISS) was established in Hamburg to carry out feasibility designs. Spain began as a decidedly junior partner during the three-year feasibility/definition phase, in both the figurative and literal sense: a large number of young engineers from Bazán and the Spanish Navy cut their teeth on this program, working side-by-side with experienced naval architects, marine engineers, and combat systems engineers from other nations on early-stage concepts, trade-off studies, systems engineering, and systems integration activities: all critical aspects of the process to create a feasible design concept from user needs. The Spanish team quickly rose from being junior partner to leader; in 1989, a senior Bazán engineer was appointed to head the second phase of the design effort; but several months later, the program abruptly ended as one nation after another pulled out (Schütz, 1990; "Un Ingeniero de Bazán," 1989).

The abrupt cancellation of NFR90 led various nations to collaborate on new frigate designs. Spain briefly collaborated with Germany and the Netherlands on a derivative design, but Spain soon pulled out in favor of creating a completely indigenous design. By now, the experience of NFR90, as well as the establishment of a solid Research and Development (R&D) base (e.g., the creation of the Bazán 80/82 series of hull forms in collaboration with El Pardo ship model basin), had given the government-owned shipyard the technical confidence to conceive, design, and build highly-complex naval ships without external assistance. The Plan Altamar, conceived at the end of the Cold War from 1989–1990, called for a number of large, capable vessels to form a self-sufficient combat group to carry out operations at large distances and over extended periods—a distinct break from Spain's previous role as a specialized cog in the overall NATO fleet. The first vessels conceived were six F100 air-defense frigates, the progeny of the NFR90 program, based upon the U.S. Aegis destroyer DDG 51 and built to strict military standards for shock, survivability, and so forth. Although the combat systems came from Lockheed Martin, the ships design and integration was performed entirely by Bazán. The first vessel, F101 *Alvaro de Bazán*, was ordered in 1997, laid down in 2000, and delivered in 2002.

The next vessels in the Plan Altamar were logistics/replenishment vessels, required to sustain the combat group while forward deployed, and amphibious landing ships, which carry troops and equipment for deployment ashore. Spain (Bazán) collaborated with the Netherlands (Nevesbu, the design agency) from 1991–1994 to develop both types of ships. The jointly-developed replenishment vessels became the *Amsterdam* and *Patiño* classes, both delivered in 1995. In 1998 both navies delivered their amphibious landing vessels, *Rotterdam* and *Galicia*. Spain was a co-equal in the engineering of both ship classes, a remarkable leap of capability given that they were junior partners in the R-11, F80, and NFR90 programs just a decade earlier. Minehunters and submarines rounded out the plan's capabilities. Since that time, a completely new vessel, the Buque de Proyección Estratégica (equivalent to an LHD) L61 *Juan Carlos I* has been launched. At 28,000 tonnes and €360 million ($500 million), it is the largest and most expensive vessel in the Spanish Navy (Armada Española, 2011; Campbell-Cruz, 1997; Lok, 1989).

The accumulated experience of designing and building complex warships, both in cooperation with other nations as well as autonomously, quickly led Bazán to enter the export market. Its first major export contract was obtained in 1992 for the construction of the VSTOL aircraft carrier *Chakri Naruebet* for the Royal Thai Navy. This was a major accomplishment for the Spanish industry, coming as it did on the heels of the Thai Navy's cancellation of a project with the German shipyard Bremer Vulcan, long a major force in the naval warship export market, and winning ahead of competing bids from French and Italian shipbuilders. Bazán based its design on the recently delivered *Principe de Asturias*, with major modifications to the propulsion, aviation, and combat systems, but squeezed into a hull 2/3 the size. The vessel was delivered in 1997, just three years after keel-laying. From start to finish, this was a completely indigenous effort, and marked Spain's entry as a major player in the world naval export market (Saunders, 2007, p. 773; Saylor, 2009).

One of the reasons for Bazán's strong showing was its steady improvement in design and construction methods during the 1990s. Much of this was home-grown, although there was some interaction with the Spain's state-owned merchant-shipbuilding enterprise, Astilleros Espanoles S.A. (AESA), which also had shown steady improvements in productivity in the face of overcapacity and increased competition (Cerezo & Sánchez-Jaúregui, 1995; Houpt & Ortiz-Villajos,1988). In December 2000 the Spanish government sought to improve the overall competitiveness of the shipbuilding enterprise by merging Bazán and AESA into a single company, Izar, having both military and commercial capabilities. Interestingly, with the emergence of high-level requirements in commercial vessels for noise reduction, high speed, and integration of complex systems, there was as much flow of technical knowledge from the military to the commercial sectors as in the other direction (Ferreiro, 2004). That merger was annulled soon after, when the European Commission found it to be in breach of regulations; in 2005 Izar spun off the military yards in El Ferrol, Cádiz, and Cartagena to form the new company Navantia.

The ability to mix commercial and military shipbuilding practices was a strong factor in Norway's selection of Bazán (soon to be Izar) over other competitors, including the German shipbuilder Blohm und Voss and a consortium of Norwegian shipbuilders, to build five Aegis frigates. The F310 *Fridtjof Nansen* class is based on the F100 design, even though at the time the first Spanish ship was not yet in commission, but with hull and machinery systems to a mix of commercial and military standards. Izar laid the keel of the first vessel in 2003 and delivered it in 2006, with more frigates following every year until 2011. This rapid pace was maintained even while the shipyard was constructing F100s; in other words, the shipyard effectively managed the side-by-side construction of two classes of ships, one built to mixed commercial/military standards and the other to purely military standards, with little or no difficulty in configuration control (Ferreiro, 2004; Saunders, 2007, p. 544).

Navantia's clean sweep of the global competition to rebuild Australia's navy, mentioned at the beginning of this paper, had its roots starting in 2003, during the lead-up to Australia's 10-year Defence Capability Plan (DCP) 2006–2016. The Navy was in the process of revitalizing its shipbuilding and sustainment capabilities, having recently completed (with New Zealand) the construction of 10 ANZAC under license from Blohm und Voss. Under the new DCP, the Australian Navy would further expand its indigenous shipbuilding capabilities to include the management, integration and sustainment of highly complex warships, *viz.* three Air Warfare Destroyers (AWDs) and a pair of LHD-type amphibious ships (Markowski et al., 2008).

In fact, Australia was going through the exact situation Spain had found itself in during the 1980s when it was still building frigates under license, although at the time these parallels were not always obvious. In fact, the early round of bidding for the AWDs seemed to favor Blohm und Voss over their rivals Navantia and Gibbs & Cox Inc. Blohm und Voss, apart from its success with ANZAC, was by far the leading warship exporter in the world, with over 50 ships built or licensed around the world. In 2005, however, the Defence Minister announced that Gibbs & Cox Inc., with their modified DDG 51 concept, was the "preferred designer," even though the competition was still open ("American Firm Chosen," 2005). At the same time, the competition for the amphibious ship program was heating up between the French naval shipbuilder ARMARIS and its proposal based on the recently commissioned *Mistral* class, and Navantia's proposal based on *Juan Carlos I*, which was not even launched. However, on June 21, 2007, the Royal Australian Navy selected both of Navantia's proposals, which involved the shipbuilder teaming with the local defense industry leader Tenix; the AWD *Hobart* class would be built entirely in Australia, while the LHD *Canberra* class would be primarily constructed at El Ferrol, but integrated in Australia (Davies, 2007; Uhlmann, 2007).

It is not too great a leap to state that Gibbs & Cox Inc. had been the mentor to Navantia/Bazán, guiding them through the arduous process of ship design and construction; now, in perhaps a poignant moment, that student had become a master and a mentor to others. The two firms, however, maintain an excellent relationship. Navantia today continues to look further afield for export opportunities, building on its relationship with Norway to provide replenishment ships that will keep its frigates forward-deployed, and is also looking to reequip a resurgent Indian Navy with modern destroyers ("La Armada Noruega," 2009; Raghuvanshi, 2009).

Evolution of Technology Transfer in Chilean Naval Shipbuilding, 1960–2010

The history of Chile's naval shipbuilding industry is both shorter and narrower than that of Spain, but it represents a snapshot of a similar but accelerated pattern of an industry advancing towards national autonomy while simultaneously becoming a global force in the naval export market. Since its inception, the Chilean navy has been almost entirely composed of foreign-built and secondhand vessels. Indeed, during Chile's war for independence from Spain in 1817, its first naval commander-in-chief was former British naval officer Thomas Cochrane, who fought aboard the Russian-built frigate *O'Higgins* which had been captured from Spain. Its ties with Britain remained strong throughout the 19th century; most of its ships, including the famous vessels *Esmeralda* and *Blanco Encalada*, were built in Britain, and many of its officers, engineers and sailors were British-born. This pattern continued through the first half of the 20th century, with Chilean officers visiting British industries and attending its universities, and vessels such as the battleship *Almirante Latorre* being built in its shipyards (Corbalan, 1994; Roth, 2009; Scheina, 1987; Urrutia, 2008).

The United States saw a brief rise in influence across Latin America after World War II. It established naval missions throughout the region, and in 1947 led a coalition of nations to sign the Rio Treaty which established a common defense framework for the Western hemisphere. As part of this framework, the USA sold or leased warships at low cost to several nations including Chile, for example, the ex-*Brooklyn* class cruisers *O'Higgins* and *Prat*, as well as gradually replacing many British-built destroyers with U.S. ones. These transfers came at a price; under the U.S.-led strategy, the Chilean and other Latin American navies were assigned the ASW mission against potential Soviet forces. This was not a mission for which the Latin navies were either prepared or particularly enthusiastic. Through most of the Cold War, Chile and its neighbors participated in joint ASW exercises such as

UNITAS, but their ships and equipment became increasingly outdated as the U.S. restricted the transfer of more modern equipment. Dissatisfaction with this state of affairs, coupled with U.S. sanctions against Chile during the Allende and Pinochet regimes and the general friction that ensued after the Falklands (Malvinas) War, greatly reduced the U.S. influence in the region. Although the situation improved markedly after the end of the Cold War, the Chilean navy longer depended on one or two allies to supply its ships and equipment; in its recent naval buildup, Chile has acquired modern warships from Britain, France, Israel, Netherlands, and the United States, in support of its modern naval strategy that has de-emphasized ASW in favor of a “three vector” strategy: the defense of maritime sovereignty, enforcement of maritime laws, and participation in international operations (Revista Vigia, 2008).

In fact, Chile had long been moving, albeit quite slowly, to develop an indigenous capability to repair, modernize, and eventually rebuild its own fleet. Chile’s extensive Pacific shoreline, and its position at the entrance of the Magellan Straits, made it a natural site for shipyards, which have existed in Valparaiso, Valdivia, Talcahuano, and Punta Arenas since the early 1800s. Originally, naval shipyard activity was almost entirely devoted to the repair and maintenance of Chile’s foreign-built warships. With assistance from Britain, Germany, and France, these facilities were gradually modernized with the installation of fixed and floating drydocks (the first of which opened in 1896), heavy cranes, and workshops, although these improvements did not keep pace with the increasing technical complexity of the warships they serviced. Unlike the Spanish paradigm, the naval shipyards were never operated directly by foreign-owned companies.

By 1953 the Chilean navy was looking for a way to breathe new life into its increasingly moribund naval industrial sector, and entertained numerous proposals from abroad to update its facilities. After much internal debate, in 1960 the government created the state-owned enterprise Astilleros y Maestranzas de la Armada (ASMAR), incorporating the naval shipyards at Talcahuano, Valparaiso, and Punta Arenas. Although the shipyard’s principal mission was to service the vessels of the Chilean navy, it actively sought other business opportunities in the repair and modernization of other navies (e.g., Ecuador and Peru) as well as the construction and repair of fishing vessels and other commercial vessels, which helped maintain employment and augment shipyard skill levels. In the early 1970s the government once again invited proposals from around the world to modernize ASMAR’s facilities, but the fiscal crisis of 1973 and subsequent military coup put the brakes on this project. Within a few years, however, the country began a program of investing 10% of sales from the state copper company CODELCO into the military, divided equally between the three services. As the naval budget began to rise, so too did investment in ASMAR’s facilities and expertise in modern naval systems, as the shipyard performed ever-more-complex overhaul and modernization tasks such as the conversion of two ex-British missile cruisers into light helicopter carriers (Fritz, 2005; Roman, 2009).

In 1977 ASMAR began its foray into constructing complex military-type ships, initially for the Chilean navy. The first vessels, three *Maipo* amphibious (LST) vessels, were built to the plans of the French DCN-designed *Batral*, and delivered from 1982 to 1985. This was followed by a Canadian-designed cargo/troopship *Aquiles*, delivered in 1988. In 2004 ASMAR teamed with the German shipyard Fassmer to create an offshore patrol vessel (OPV) program of up to four ships that would provide sea and airborne capabilities for all three maritime vectors. The *Piloto Pardo* class was designed by Fassmer based on previous patrol vessels, but enlarged and possessing greater military capability to meet Chile’s needs. The German yard provided design and engineering support, but the entire fabrication, construction, and systems integration of this complex vessel was carried out by

ASMAR engineers. Two ships have already been delivered, with another two projected for the future. The same design is being used by Chile's neighbors, Argentina and Colombia, for their naval patrol programs (Swinford, 2008; Quezada, 2008).

At the end of the Cold War, with the naval export market beginning to increase and broaden, ASMAR took the step of constructing military-type vessels for other nations. In 1992 it teamed with the Western Canada Marine Group (WCMG) to offer an OPV to the Mauritius Coast Guard, which beat out competition from ten other shipyards. Using plans developed by Polar Design Associates of Canada, ASMAR worked under the supervision of WCMG to build the stealthy vessel (i.e., lower radar cross-section, acoustic silencing), which required a high quality of workmanship to meet the operational specifications. In 1998 ASMAR competed against 13 other shipyards worldwide to build the Icelandic oceanographic research vessel *Arni Fridriksson*, using plans developed by an Icelandic design firm. Once again ASMAR had to perform high-quality, complex work due to the exacting acoustic silencing requirements similar to those of a naval vessel. This successful project led ASMAR in 2006 to bid for another Iceland project, a 4,000 tonne OPV for the Icelandic Coast Guard to be built under license from STX Canada Marine (whose parent company had by now bought up several of ASMAR's former partners, including WCMG and Rolls Royce-Ulstein, which had originally provided the design for the OPV, similar to the Norwegian Coast Guard's *Harstad*). ASMAR won the bid in 2009 and constructed the ICGV *Thor* at the Talcahuano shipyard, which despite enormous damage from the 2010 earthquake and tsunami, was delivered to the Icelandic Coast Guard in 2011 ("Canadian/Chilean Bid," 1996; Fritz, 2005, pp. 187–197; Icelandic Coast Guard, 2011).

In summary, the Chilean naval shipbuilding capability embodied in the state-owned company ASMAR is now at approximately the same stage (but at a smaller scale) as its Spanish homologue Navantia was during the 1980s: via a series of international partnerships providing shipbuilding technology transfer, it has developed the autonomous capability to build complex warships for both indigenous use as well as for export. For the time being, AMAR intends to continue maintaining and modernizing its foreign-built fleet, and partnering with other designers to create new coastal and offshore patrol vessels (Vega, 2008). It remains to be seen if and how ASMAR will develop and maintain a capability (including access to a solid R&D base) for the early-stage conception, design, and integration of complex military vessels for the Chilean navy as well as for export abroad, which would give the nation full autonomy for its warship building industry.

Conclusions and Lessons for Naval Shipbuilders

The experiences of Navantia and ASMAR show how a modern naval shipbuilder can rapidly evolve from a net importer of technology to a net exporter, with the assistance of foreign technology transfer. Beginning with the Navy's direct purchase of foreign warships, the shipyard can develop familiarity with complex naval systems to build up its engineering expertise; next, it can accumulate design and build expertise with the construction of vessels under a license or government agreement from a foreign shipyard; and finally, participating with partner yards in early-stage conception, design, and integration process in order to have a complete end-to-end warship building capability. This process is little changed from when the United States and Japan rapidly evolved their own naval capabilities at the beginning of the 20th century. The difference between then and now is that the naval warship export market, which has opened considerably since the end of the Cold War, has greatly improved the potential for both business partners as well as customers, which helps build the business case for these investments. Once again, as the examples of the Spanish and Chilean shipyards have shown, it is possible to rapidly take a leading position in that market while still partnering with other yards for design support (as shown by ASMAR), or having a fully fledged conceive–design–build capability (Navantia).

The recent experience of a U.S. shipbuilder shows how such international technology transfer may improve its market position. In January 2009 the Italian state-owned shipbuilder Fincantieri acquired Marinette Marine, a Wisconsin-based private shipyard currently building the Littoral Combat Ship (LCS). The Italian yard is bringing to Marinette its experience, know-how, and capital equipment to increase shipbuilding automation, streamline production processes, and rationalize its build and launch techniques, with the goal of decreasing shipbuilding costs by one-fifth. As of February 2012, the labor-hours required to construct an LCS have decreased 30% (Kington, 2009; Phelps, 2012). One of the long-term goals is to offer the LCS for export, an ambition which has been thwarted in the past due to large program cost overruns.

¿Que inventen ellos? In the case of naval shipbuilding, it is often true that others (i.e., foreigners) *have* already invented it. The experience of Navantia and ASMAR have shown that it matters less who *invents* it, but rather how others can *adapt* it to become their own. It is by following this process that Spain and Chile have so quickly become shipbuilders to the world.

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