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The technology revolution at sea: a case study of small combatants

Clarke, Stephen M.

Monterey, California. Naval Postgraduate School

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THE TECHNOLOGY REVOLUTION AT SEA: A CASE STUDY OF SMALL COMBATANTS

by

Stephen M. Clarke
Lieutenant, United States Navy
B.S. University of Southern California, 1986

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The U.S. Navy's doctrine "...From the Sea" anticipates that future naval confrontations will likely occur in the littoral regions of the world in support of operations ashore. One of the challenges facing naval forces are corvette or light frigate warships incorporating advanced technologies. In this thesis, a review of the historical developments of these limited displacement warships is presented. World War 2 escorts of the Allied forces formed the backbone of many of the navies which formed after the war. Technological improvements have allowed corvettes and light frigates to develop from being ships of limited capabilities to being the "capital ship" for smaller navies.

It was determined that while more countries, particularly Pacific Rim countries, are producing warships, the number of producers of technologically advanced weapons and sensors is still primarily limited to the countries of Western Europe. The anti-ship missile is expected to continue as the primary weapon, however, its capabilities are going to increase as higher speeds, lower radar cross sections, and passive seekers are incorporated.

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ABSTRACT

The U.S. Navy's doctrine "...From the Sea" anticipates that future naval confrontations will likely occur in the littoral regions of the world in support of operations ashore. One of the challenges facing naval forces are corvette or light frigate warships incorporating advanced technologies. In this thesis, a review of the historical developments of these limited displacement warships is presented. World War 2 escorts of the Allied forces formed the backbone of many of the navies which formed after the war. Technological improvements have allowed corvettes and light frigates to develop from being ships of limited capabilities to being the "capital ship" for smaller navies.

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EXECUTIVE SUMMARY

This thesis traces the origins of corvette and light frigate-size warships since World War II, with emphasis on their technological capabilities. Many of the navies formed after World War II acquired "second-hand" warships from the established "mature" navies. The ships which were made available were small compared to the newest ships entering the inventories of the mature fleets. Because of the level of sophistication available at the time, the larger fleets had little to fear from this horizontal proliferation of naval capabilities. Technological improvements, however, have reduced the size of weapons systems while improving their effectiveness, and this has allowed more military potential to be placed into smaller ships. Many of the smaller navies are currently engaged in vertical proliferation, acquiring ships and supporting equipment with capabilities comparable to the larger fleets.

The introduction of surface-to-surface missiles (SSM) and their incorporation into fast attack craft (FAC) platforms, beginning in the late 1950s, changed the way that ships were evaluated. These small high speed FACs became the smaller nations "equalizer" against the larger cruiser and destroyer platforms of the mature fleets. As effective countermeasures and defensive systems developed, the popularity of FACs waned.

Ships of corvette and light frigate-size are becoming popular with small navies. They generally deploy more military potential than can be placed on a FAC-size platform, and have better seakeeping and endurance. They have been described as the ideal platform for patrolling a countries exclusive economic zone (EEZ).

The first chapter introduces the problem and provides an overview of the questions which will attempt to be answered.

The second chapter traces the acquisition patterns of warships within the developing world since World War II. A broad overview of acquisition patterns is presented, and includes: the post-war period, the introduction of cruise missiles; and the current and projected future trends. In addition, the author defines corvettes and light frigates.

The third chapter traces the history of these light escort vessels, starting with World War II. The major classes of British and American light escorts are compared, and their disposition after the war is followed. The development of these vessels is briefly analyzed through the periods: 1945-1965; 1965-1980; and 1980-Present. An in-depth analysis is done on the Israeli Navy's Sa'ar 5 class of corvettes, since it appears to be the most sophisticated and carry the most military potential of the new warships.

The fourth chapter explores some of the technological innovations which are, or have the potential of being, incorporated into these small warships. Topic include: modular equipment and weapons, offensive and defensive weapons; and techniques for reducing characteristic signatures of the ship.

The fifth chapter looks at the development and availability of electronic systems and command decision systems. Electronic warfare, radar, electro-optic, and integrated command decision systems are reviewed.

Some of the conclusions drawn from the research include:

• The level of sophistication of small warships is increasing, mostly due to the availability of equipment and technology from the Western European countries.

- The number of small fast attack craft in the inventories of smaller navies is expected to remain high, however, many navies will acquire larger corvettes and light frigate-size ships.
- The concept of modular equipment modules and ships built with a "fitted-for-but-not-with" approach will become more prevalent. This will make ships more flexible in their capabilities, and make it more difficult to "know" how a ship is equipped at any given time.

I. INTRODUCTION

In June 1988, the U.S. Navy completed a study entitled Navy 21. It included the views of 188 experts on the implications of advancing technology for naval operations in the twenty-first century. At the time the study was conducted the Soviet Union was still considered to be this country's greatest political and military adversary, yet it also predicted that Third-World countries equipped with sophisticated weapons were becoming an increasingly prominent threat. Some of the technology "drivers" of future naval forces were predicted to include: stealth and counter-stealth technologies integrated with electronic warfare capabilities, advanced communications technologies, ship technologies, including changes in power plant and power transmission systems, internal hull design, and major concept variations in hull form. [Ref. 1:pp. 6,7,29,31]

The Cold War is over, and the United States is confronted with fundamental questions concerning its role in the new world order. Finding the answers to these questions is made all the more difficult by a domestic environment that presses for economic change, especially a "peace dividend." The threat from the former Soviet Union has diminished considerably and this has led to the current debate on the purpose, roles and missions of the U.S. military establishment.

The United States government has reacted to the changing events and threats throughout the world, as well as to the concerns of its people, by proposing a new national security strategy. [Ref. 2] The naval service has followed suit with the publication, in September 1992, of a White Paper, "... From the Sea." This policy document defines a new direction for the naval service, by emphasizing a shift away from the Navy's post-World War II focus on global threats to a new, flexible force able to deal with regional challenges and opportunities. Future conflicts are expected to be joint or combined operations with naval units operating in the littoral in support of operations ashore. The shift to littoral warfare brings into focus new challenges and threats. It portends, among other things, a reduction in battle space, congested shipping routes, advanced ships and submarines, and technologically sophisticated weapons systems.

Since World War II, the proliferation of naval hardware among developing navies has been primarily horizontal, as new states have created new navies. These newly established navies were initially equipped primarily with surplus ships from the major naval powers that displayed roughly comparable levels of technological sophistication. Recently, however, there has been more vertical proliferation, as the capabilities of existing navies are enhanced, as their roles multiply, and as they develop their own ambitions and momentum. These enhanced capabilities include modern diesel-electric submarines, more sophisticated warships, first-rate electronics, and effective command and control systems. In addition to the increasing number of countries acquiring advanced warships and weapons a growing number of countries is able to produce these advanced systems indigenously.

The ending of East-West tensions has made the possibility that the superpowers and their allies will fight each other at sea less likely, although not impossible. More likely is the possibility of superpower and allied navies, functioning as a coalition, engaging in some form of conflict with 'Third-World' navies. The surface combatants which the U.S. Navy might face in future littoral engagements will likely be smaller than its own, yet with technological capabilities that will stress much larger combatants. The "capital" ship for littoral warfare will likely be the corvette. A report by the Center for Naval Analysis claimed, in 1991, how: ".... the ideal generic surface combatant for extensive Exclusive Economic Zone (EEZ) defensive requirements would be a large corvette (FFL) or frigate (FF) size ship." The report went on to describe the typical weapons load-out for such a platform:

- surface-to-surface missiles (range 50 to 100 nmi);
- a multimission helicopter for ASW, surface surveillance, antisurface strike (with a short-range antiship missile);
- a medium-caliber (e.g., 76-mm) dual-purpose gun;
- a self-defense high-velocity gun;
- a sonar; and
- ASW torpedoes or barrage weapons.

This combatant would have:

- a maximum sustained endurance of 800 nmi at 25 knots, and
- a maximum cruising endurance of 2,000 nmi at 18 knots. [Ref. 3:p. 4]

A review of major surface warships currently under construction or on order reveals that the United States and most of the NATO nations continue to order the largest vessels, in terms of displacement. Most of the rest of the world's navies acquire warships of light frigate-size and smaller. [Ref. 4:p. 853-855] These smaller ships are able to devote a larger percentage of their volume to warfighting and less to sustainability by limiting their area of operations.

Countries such as India, Brazil, Israel, Thailand, Morocco, and Italy, to name a few, are producing or purchasing ships within this category. Looking at some of these smaller platforms under construction indicates that advanced technologies, including stealthy profiles, low probability of intercept (LPI) sensors, satellite communications, advanced weapons suites, and quieter and more economical power plants are being incorporated into smaller hulls.

Many countries which previously built their navies around large numbers of missile-armed fast attack craft (FAC) have come to realize the inherent limitations of these platforms. Similarly, countries which could previously afford large, powerful escort vessels are seeking economical alternatives. The current trend in warship procurement seems to be centered around a multi-mission escort vessel of "Corvette" or "Light Frigate" size. These versatile vessels are becoming the "capital ships" of the world's smaller navies.

The fundamental purpose of this thesis is to examine several questions. One, what are the current and projected surface threats to the U.S. Navy operating in the so-called littoral regions of the world? Two, what types of technologies are being or are capable of being integrated into these surface ships? And three, how is the world market for these technologies changing?

A. SCOPE OF THE STUDY

While examining the threat to U.S. naval operations posed by technologically advanced warships of corvette or light frigate-size, this thesis addresses the technologies associated with weapons, hull design, electronic sensors, and command and control systems which are currently, or have the potential of, being incorporated into platforms of this size.

Anti-ship missile-equipped platforms are the principal focus of interest. Gun and/or torpedo-armed Fast Attack Craft (FAC) and Fast Patrol Boats (FPB) are looked at in the context of their wide distribution and inherent limitations. For the purpose of this thesis, the term Corvette refers to an anti-ship missile-equipped warship of between 600-1,500 tons, full load displacement. A Light Frigate refers to an anti-ship missile equipped warship of between 1,500-2,500 tons, full load displacement.

This thesis also examines the trends in warship acquisition among the newly developed countries after World War II, from the introduction of anti-ship cruise missiles in the 1960s to the present. A review of corvette and frigate-size vessels in the U.S. and British navies during and since World War II is included for historical perspective.

B. METHODOLOGICAL APPROACH

The approach used in this thesis is to first examine the material development of Third World navies since World War II, including the role the anti-ship cruise missile has had in this development. An in-depth examination of the past, current, and future capabilities of corvette/light frigate-size warships is next. The main focus is on weapons, sensors, electronic support measure/electronic countermeasure (ESM/ECM) systems, command and control systems, and signature management techniques. The purpose is to determine the extent of development and proliferation of technological sophistication in regards to these systems.

II. WARSHIP ACQUISITION IN THE DEVELOPING WORLD

The navies of the United States and her allies have, since World War II, developed forces and strategies with the primary goal of containing the Soviet threat. These forces have primarily been large in terms of ship displacements, and powerful in terms of capabilities. While the superpowers focused on countering each other, many other countries established and expanded their naval capabilities. This chapter will explore the establishment of these infant navies, the effect of the introduction of anti-ship cruise missiles, and future acquisition trends.

A. POST WORLD WAR II

The period of de-colonization after World War II was accompanied by a horizontal proliferation of naval capabilities. Naval technology trickled downward as newly independent nations took advantage of the huge surplus of warships that became available after the war. The United States, Great Britain, and the Soviet Union transferred large numbers of combatants through low-cost sales, leases, or outright donation. Additionally, a portion of the surviving fleets of the defeated Axis powers was distributed to other nations. As a result, between 1947 and 1960, some 1,230 naval ships and submarines were handed over to 55 nations. [Ref. 5:pp. 172-203] The United States was by far the largest provider of surplus vessels, reportedly selling, leasing, or transferring 611 ships and submarines during the 13 year period. [Ref. 5:pp. 172-203] The Soviet Union transferred 322 vessels, Great Britain and France, 167 and 42, respectively. [Ref. 5:pp. 172-203] Many of these vessels that became the backbone of the new navies were wartime U.S. destroyers (DD) and destroyer escorts (DE), and British corvettes and frigates.

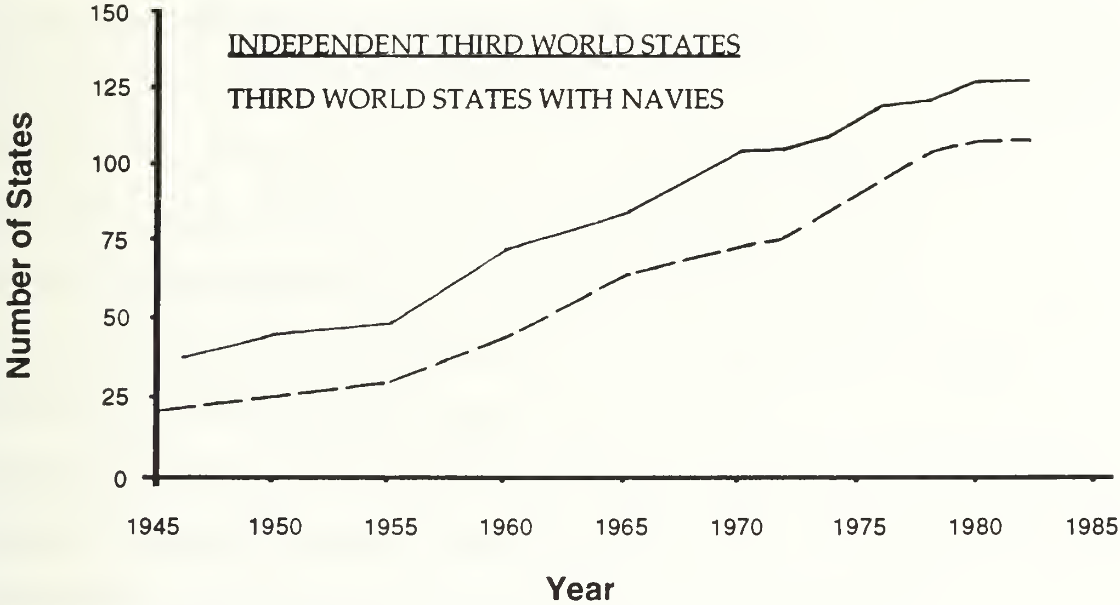
1. Infant Navies

The disintegration of colonial empires after World War II produced a host of newly independent states. Although not quite as urgent a task as the establishment of a land-based militia, most of them regarded the establishment of a navy as a necessary concomitant of national sovereignty. Figure 1 documents the growth of independent Third-World states and relates it to the growth of Third-World states with navies.

During the first 20 years or so after World War II the level of technological capability of most warships in the inventories of the developing countries was limited compared with that of the navies of the United States and her allies. Additionally, most warship construction was still limited to very few countries, notably Great Britain, the United States, France, the Soviet Union, Italy, and West Germany.

2. The Introduction of Cruise Missiles

The introduction of compact cruise missiles into the Soviet fleet in the late 1950s set the stage for a new phase in naval development that particularly benefited the nascent navies of the Third World. The anti-ship missile became the "poor man's" counter to the heavily armed aircraft carriers and cruisers of the mature fleets. Capable of being fitted into small displacement hulls, the weapon drastically changed the manner by which a warship's offensive potential was



Sources and Methodology: Chronological growth of Third-World independent states was derived from successive issues of *Europa Yearbook*. Chronological growth of Third-World states with navies was derived from successive issues of *Jane's Fighting Ships*. Third-World states have qualified for listing in *Jane's* when some kind of formal naval organisational structure is established and when at least a modicum of naval vessels is acquired, such as several patrol craft.

Source: Morris, M.A., Expansion of Third World Navies, p. 7

Figure 1: Growth of Third-World States and Navies

calculated, in much the same way as the introduction of the torpedo had done nearly one century before. Traditionally, a combatant's firepower had been equated to its displacement -- the heavier a ship, the greater its firepower. Now, small high-speed craft were given the wherewithal to cripple or sink much larger (and more expensive) warships, from greater ranges than had been possible with torpedoes.

a. *Early Developments*

After World War II, the Soviets undertook an intensive program of missile development with the intention of creating a range of weapons across the tactical and strategic spectrum. In the late 1950s, this program began to yield useful results in the field of surface-to-surface anti-ship missiles (SSMs), and the first Soviet cruise missile was placed in service some four years before its Western equivalents. The first such type to reach operational status was the SS-N-1 Scrubber, which entered service in 1958. [Ref. 6:p. 15] Its large size limited its service to destroyer-size platforms, however.

b. *Introduction of Styx Missiles*

The first practical weapon in terms of size was the considerably smaller SS-N-2 Styx. It can truly be said to have revolutionized naval warfare. Spanning 2.75m (9ft 0.25in) and measuring 6.3m (20ft 8in) in length, the Styx weighed 3,000kg (6,614lb) with a 500kg (1,102lb) high-explosive warhead. It had a theoretical maximum range of 85km (52.8 miles) at a speed of 1,100km/h (684mph). [Ref. 6:p. 16] The full range could only be usefully employed if mid-course updating of the guidance package were provided by a supporting platform within radar range of the missile and target (an unlikely contingency in this period). Therefore, the effective range was 37km (23 miles), i.e., horizon-range. A cruise altitude of up to 300m (985ft) was preset prior to launch and the missile flew under the control of an autopilot with an active radar taking over during the terminal phase of the attack. [Ref. 6:p. 16]

c. *Early Platforms*

The Soviets converted simple torpedo craft into launch platforms for the SS-N-2 missiles, with a total of about 100 Komar class vessels being produced. The Komars, at almost 27 meters in length and 75 tons (full load displacement), carried just two SS-N-2A Styx SSMs. [Ref. 6:p. 79] Of these, some 78 were later transferred to the navies of satellite and client countries. China produced another 110-plus copies, and named it the Hegu class. [Ref. 6:pp. 79-80] Even as the first of the Komars entered service, the Soviets were building an improved successor, known as the Osa class. These craft were the first purpose-built missile armed FACs with double the missile armament of the Komars and a considerably more seaworthy hull design. [Ref. 6:p. 122] The first unit of this class was laid down in 1959 or 1960 and entered service in 1961. Production continued up to 1970 and amounted to some 289 craft (175 Osa I and 114 Osa II, excluding more than 100 built in China as the Huangfeng class. [Ref. 6:pp. 120-122] These vessels served in all four of the Soviet fleets, but over a period of years many were transferred to the navies of satellite, allied and client states.

d. *First Kill*

The destructive potential of these small high speed craft was demonstrated before the world on 21 October 1967, when the Israeli destroyer *Eilat* was hit and sunk by Styx missiles launched from two Komar-class craft of the Egyptian navy. This was the first occasion in which a ship-launched SSM had sunk another warship. [Ref. 7:p. 181] The result was the 'missile-fever' of the late

1960s. For nations with large navies, this was a dangerous threat which they were illprepared to handle. For poorer nations, it provided a tremendous opportunity to upset the traditional naval balance. By 1971, many navies, including those of Norway, Sweden, Germany, Denmark, Israel, Italy, Greece, Algeria, China, Malaysia, Brunei, Cuba, Egypt, Finland, East Germany, Indonesia, Poland, Romania, Yugoslavia, Syria, and Libya had fleets of these small cruise missile boats. [Ref. 8:p. 133]

e. *Overall Effort*

Since the Styx, cruise missiles have been developed by a number of nations other than the Soviet Union, notably the United States, France, Israel, Italy, Norway, and China. They have been exported in huge numbers throughout the world, are capable of being launched from ships, submarines, planes, and trucks, and can be configured to attack targets at sea or on land. Table 1 lists the estimated total numbers of sea launched SSMs imported by selected countries as of 1991.

TABLE 1: INVENTORIES OF IMPORTED SEA LAUNCHED SSMs HELD BY SELECTED COUNTRIES

Eastern Mediterranean		
Egypt	300	Styx, Harpoon, Otomat
Greece	250	Exocet, Harpoon, Penguin
Israel	150	Gabriel*, Harpoon, Sub-Harpoon
Libya	300	Styx, Otomat
Syria	300	Styx
Tunisia	100	Styx, Exocet
Turkey	200	Harpoon, Penguin
Arabian Gulf and Western Indian Ocean		
Bahrain	50	Exocet
India	250	Styx
Iran	200	Styx, Exocet (Harpoon or Sea Killer?)
Iraq and Kuwait	400	Styx, Exocet
Oman	80	Exocet
Pakistan	100	Styx, Harpoon, Sub-Harpoon
Qatar	50	Exocet
Saudi Arabia	400	Harpoon, Otomat
United Arab Emirates	100	Exocet
Yemen	100	Styx
Northwestern Pacific		
China	100	Styx*, Exocet*
Japan	1,000	Harpoon, Sub-Harpoon
North Korea	300	Styx
South Korea	300	Exocet, Harpoon
Taiwan	1,000	Gabriel*, Harpoon, Otomat

Note: Numbers are approximate and may include orders not yet filled.
An asterisk (*) indicates that a country can produce the missile domestically.

[Source: Stockholm International Peace Research Institute Database.], Cited in Arnett, E.H., *Sea Launched Cruise Missiles and U.S. Security*, (Praeger Publishers, 1991), p. 98

B. CURRENT AND PROJECTED TRENDS

1. The World Since 1989

Since 1989, political and military tensions between the superpowers have eased. Many of the West's developed nations have begun reducing their naval strength to meet perceived peacetime needs. If the trend that followed World War II is repeated, some ships from these navies will be transferred to the navies of less affluent nations. This will result in a further diffusion of naval power. At the same time, many of the long-time "recipient" nations are electing to purchase new ships, designed and built to their individual requirements, rather than to continuing to "make-do" with hand-me-downs that, though cheaper, have commonly proved ill-suited to local circumstances.

2. Limitations of FAC's and FPB's

The FAC and more lightly armed and slower Fast Patrol Boats (FPB) have become the centerpiece of many of the smaller navies. Yet, since the missile fever of 20 years ago, it has been recognized that these vessels have several important limitations, including:

- the complexity of combat systems, per ton of displacement, makes these vessels very expensive to operate and maintain;
- because of their limited payload, FACs and FPBs cannot be multi-mission ships, most being limited to a surface strike role;
- because of their relatively small size, they have a generally poor seakeeping capability;

• because of poor seakeeping, small crew size, and propulsion plants which cannot be operated at low power for long periods, these platforms have poor endurance;

• they have very poor survivability against modern anti-ship weapons, which have very high hit probabilities;

• because of their complex systems, and the need for highly skilled manpower and unique test equipment, they are often difficult to operate and maintain; and

• limited or non-existent long-range detection capabilities greatly limits the effective range of anti-ship missiles. [Ref. 9:p. 10]

These limitations and the ability of the large anti-ship missile armed combatants of the mature fleets to out-range the smaller FACs and FPBs by utilizing shipboard helicopters have prompted a decline in the number of missile-armed FACs entering service: from 112 between 1982-86 down to only 33 during the period 1987-92. [Ref. 10:p. 27]

As Michael Morris points out in Expansion of Third World Navies, the corvette is the next logical acquisition for a navy which is interested in expanding its capabilities beyond FACs without purchasing larger and more expensive frigate-size hulls. "Corvettes", writes Morris, "having larger hulls and more weapon systems than FACs, have greater range, sea-keeping and combat capabilities." [Ref. 11:p. 40] They are an excellent choice for Morris' Rank 3 (inshore territorial defense) navies because of their flexibility and cost effectiveness. Additionally, they provide a low-end capability for larger navies interested in procuring a "high-low" mix of capabilities.

3. Defining Corvettes and Frigates

Ship classifications are made based on size or displacement, the type or size of armament, and sometimes, based on intended mission(s). It is quite common for different countries and professional publications to classify the same vessel quite differently. The Glossary of Naval Ship Types (GNST) is the Department of Defense (DoD) standard for classifying and typing non-U.S. naval ships and craft. According to the GNST, a corvette (FFL) is defined as:

> "A surface warship less capable than a frigate but more capable than a patrol combatant (e.g., generally between 1,000 and 1,500 metric tons, full load displacement). Capable of limited operations on the open ocean, but primarily designed to operate nearer the littoral than frigates. Distinguished from Patrol Ships (PS) by sustained speed capability greater than 20 knots."

The editor of *Jane's Fighting Ships*, an industry and military standard, defined a corvette in 1975 as a major surface ship with a full load displacement of between 500 and 1,100 metric tons. [Ref. 12:p. 105] Other respected military references have similar definitions, although none are exactly the same. The GNST, for example defines a frigate (FF) as:

> "A surface warship generally with weapons and associated sensors, optimized for one principal warfare discipline. Frigate capabilities in other warfare roles are primarily for self-defense purposes, although there are modern warships described as "general-purpose frigates" which can function in many ways as destroyers. Should have sufficient endurance and seaworthiness to enable open-ocean deployments. In the absence of information to the contrary, this requirement is assumed to be met if full load displacement (FLD) is equal to or greater than 1,500 metric tons. To distinguish from PS, must be capable of sustained speeds of over 20 knots. Currently, frigates vary from 1,500 to over 5,000 metric tons FLD."

Because of the sophistication and size of modern weapons and sensors, frigate- size vessels can have multi-mission capabilities. Generally, however, larger vessels are more likely than smaller vessels to be configured for multi-mission operations.

The definitions which will be utilized for the remainder of this paper will be:[1]

Corvette: a warship armed with anti-ship missiles, whose full load displacement is between 600-1,500 tons. Must be capable of sustained speeds of over 20 knots.

Light Frigate: a warship armed with anti-ship missiles, whose full load displacement is between 1,500-2,500 tons. Must be capable of sustained speeds of over 20 knots.

4. Current Warship Programs

A snapshot look at the types and sizes of major surface warships on order as of August, 1991 reveals that so called light frigates and corvettes predominate outside NATO. These countries include Argentina (two-1,680 ton frigates), Brazil (three-1,966 ton frigates), India (six-1,350 ton corvettes), Israel (three-1,275 ton corvettes), Italy (two-1,285 ton corvettes), Morocco (two-2,000 ton frigates), South Africa (six-2,000 ton frigates), and Thailand (four-1,900 ton frigates, two-2,000 ton frigates). [Ref. 4:pp. 853-855] The vessels on order appear to be a compromise between the larger, more expensive destroyer-type designs that are the core of the fleets of the mature navies, and the smaller less capable FAC/FPB designs that predominated among the emerging navies during the 1970s. These vessels will serve as the flagships for many of the smallest navies in

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[1] The dividing line of 1,500 tons between corvettes and light frigates was chosen arbitrarily. The author's interest is in warships between FAC-size and Western frigate-size.

which they are acquired, and will provide an economical patrol/escort capability for the larger navies.

5. What the future holds

FAC have steadily increased in size, so that vessels of 450-500 tons, or more, are not uncommon. Most, however, remain limited in their capabilities, being designed and equipped primarily as surface strike platforms. The limitations of the standard FAC-size hull will accommodate only so much additional weight and space, particularly weight placed up high. The solution for many navies is to "upgrade" to corvette and light frigate-size vessels, which can provide most of the capabilities of larger frigates hulls. Their greater displacement allows additional offensive and defensive weapons, expanded EW equipment, a comprehensive command and control suite, and helicopter facilities. They are able to carry war-making capabilities not much different from those found on larger vessels by sacrificing range and endurance. Ships of this size have nevertheless the kind of endurance that is sufficient in peacetime to underwrite the vastly expanded claims to national control that have come with the establishment of EEZs. In war, they could act as a squadron leader for smaller FACs, or conduct local anti-submarine or surface strike missions.

The next chapter will trace the history and development of these light warships, from World War II till the present. It is important to understand how these ships of modest capabilities, produced in large numbers, were utilized both during the war and since. The chapter will conclude with a comparison of some of the latest corvette/light frigate designs, and a review of the most heavily armed current warship, the Sa'ar 5 class, in this category.

III. HISTORY OF CORVETTES/LIGHT FRIGATES

Corvette and light frigate-size vessels have undergone significant changes since World War II. Advancements in weapon capabilities and the development of sophisticated electronic systems have allowed ships of limited displacement to develop into the "capital ships" of smaller navies. This chapter will trace the history of these vessels of limited size from World War II to the present in order to understand how technology has affected their roles, missions, and capabilities.

A. WORLD WAR II

The requirement to convoy large amounts of material and personnel across the Atlantic and Pacific during World War II necessitated the building of many patrol and escort vessels. These ships were primarily built by the British, Canadians, and Americans. They performed a variety of functions during and after the war years besides their primary role as escorts. These included assault and anti-submarine operations, as well as radar picket and personnel transport duties. [Ref. 13]

1. British Corvettes and Frigates

The British government ordered a total of about 700 escort vessels between 1939 and 1945. Two corvette and two frigate designs were built, including the Flower and Castle classes of corvettes, and the River and Loch classes of frigates. These vessels, primarily built by shipbuilders not usually engaged in warship construction, were designed to first-class mercantile standards. This ensured that large numbers could be built cheaply by merchant shipyards, thus freeing the traditional naval builders to concentrate on "conventional" warships. They were principally armed with depth charges for use against submarines, and with various small and medium caliber guns for use against aircraft and small surface targets.

In addition to their own designs, the British ordered, under the Lend-Lease program, over 300 U.S.-built destroyer escorts (DEs). Seventy-eight American DEs, including 32 Evarts class and 46 Buckley class, were completed and transferred during the course of the war and became known in the British Navy as the Captain class. [Ref. 13:p. 7]

Table 2 lists the leading particulars of the four classes of British-built escorts used during World War II. Table 3 shows the disposition of many of these ships after the war. The data on the Captain class of ships is contained in Table 4, along with that for the other American-built DEs. These ships and their American counterparts became the building blocks for the new post-war navies.

TABLE 2: WORLD WAR 2 BRITISH ESCORTS

Item	Corvettes		Frigates	
	Flower Class	Castle Class	River Class	Loch Class
Length, B.P.	190 ft.	225 ft.	283 ft.	286 ft.
Beam, molded	33 ft.	36 ft. 6 in.	36 ft. 6 in.	38 ft. 6 in.
Depth molded to upper deck	17 ft. 6 in.	17 ft. 6 in.	17 ft. 6 in.	17 ft. 9 in.
Load displacement, tons	1,170	1,580	1,865	2,260
Oil fuel storage, tons	200	480	440	724
Propelling machinery H.P.	2,750	2,750	5,500	5,500
Speed, knots	16	16.5	20.5	19.5

Source: Baker, R., and others, Selected Papers on British Warship Design in WWII: From the Transaction of the Royal Institution of Naval Architects, 1983, p. 85.

2. U.S. Escorts

Shortly after the European war started in 1939, the U.S. Navy recognized the British Navy's shortage of ocean escorts. Fearing that the United States, too, might be drawn into the conflict, the Navy established its own need for vessels of this type. In addition to the 300 escorts ordered by the British Navy by the spring of 1942, hundreds more were laid down for the U.S. Navy. Ultimately, over 1,000 DEs were ordered, with over 550 completed. [Ref. 13:p. 6] Of these, some 475 were commissioned into the U.S. Navy, including 94 that were used as fast troop transports (APDs). [Ref. 13: p. 6]

The U.S. built six main DE classes. Their respective numbers and specifications are listed in Table 4. It can be seen that the differences between classes, other than in main propulsion, were largely confined to main and close armament.

TABLE 3: TRANSFERS OF BRITISH AND CANADIAN ESCORTS TO OTHER NAVIES

Nation	Designation	Ships	Year of Transfer
Argentina	River class	1	1948
Chile	River class	2	1946
Chile	Flower class	3	1946
China	Castle class	2	1947
China	Flower class	3	1949
Egypt	Flower class	2	1948-49
Egypt	River class	3	1947-48
Iran	Loch class	1	1948-49
Ireland	Flower class	3	1945-46
Israel	Flower class	2	1949-50
Israel	River class	4	1949-51
Italy	Flower class	1	1949
Malaysia	Loch class	1	1962-64
New Zealand	Loch class	6	1947-49
Norway	River class	3	1956
Peru	River class	2	1947
Portugal	River class	2	1948-49
Taiwan	Castle class	2	1947-51

Source: Anthony, I., The Naval Arms Trade, Appendix 1.

Class	Evarts	Buckley	Edsall	Bostwick	John C. Butler	Rudderow
Total Ordered	105	85	152	120	285	268
Total Completed	97	85	152	76	74	81
Dimensions						
Displacement-standard, tons	1140	1400	1200	1240	1350	1450
full load, tons	1360	1720	1490	1520	1660	1780
Length(oa), ft.	289.5	306	306	306	306	306
Breadth, ft.	35	37	37	37	37	37
Main Gunnery						
Main Gunnery	3 x 3"/50	3 x 3"/50	3 x 3"/50	3 x 3"/50	2 x 5"/38	2 x 5"/38
Close range gunnery	4 x 1.1" or 2 x 40 mm 9 x 20 mm	4 x 1.1" or 2 x 40 mm 8 x 20 mm	2 x 40 mm 8 x 20 mm	6 x 40 mm 8 x 20 mm	10 x 40 mm 6 x 20 mm	10 x 40 mm 6 x 20 mm
Anti-submarine Weapons						
Hedgehog	Yes	Yes	Yes	Yes	Yes	Yes
D.C. throwers	8	8	8	8	8	8
D.C. rails	2	2	2	2	2	2
T.T's (21")	0	3	3	3	Nil	Nil
Complement	198	220	220	220	220	220
Main Propulsion						
Type	diesel electric	turbo electric	geared diesel	diesel electric	turbo electric	turbo electric
Horse-power	BHP 6,000	SHP 12,000	BHP 6,000	BHP 6,000	SHP 12,000	SHP 12,000
Engines	G.M.	G.E.	F.M.	G.M.	Westinghouse or G.E.	G.E.
Speed, knots	21	24	21	21	24	24

Note: Depth Charge (D.C.), Torpedo Tubes (T.T.'s)

Source: Elliott, P., *American Destroyer Escorts of World War II*, Almark Publishing Co., 1974.

TABLE 4: AMERICAN DESTROYER ESCORTS (DE) OF WORLD WAR II

B. POST-WAR PERIOD

1. Conversions

After the war, many DEs underwent experimental alterations or full conversions. Produced were Radar Picket Ships (DERs), Amphibious Control Ships (DECs), Floating Power Stations, Experimental Destroyer Escorts (EDEs), and Destroyer Escort Anti-Submarine (DE(A/S)). This wide range of reconfigurations pointed the way to the many different arms "packages" that could be built into a small, well designed surface ship.[1]

2. Transfers of World War II Escorts

In addition to the 78 U.S. DEs sent to the British Navy, 12 others, six each to France and Brazil, were transferred during the war. After the war a further 81 DEs were transferred to 18 other navies. Table 5 lists the countries, numbers, and years of transfer. These vessels, along with other reserve ships from both the American and British fleets, became the backbone of many smaller navies. At the time, they were a bargain on many counts for the following reasons:

- acquisition cost was very low or none;
- the ships provided a multi-mission capability, with weapons and sensors that were state-of-the-art at the time;
- seakeeping qualities were adequate;
- survivability against existing anti-ship weapons, i.e. guns, was reasonable; and

[1]For additional details on DE conversions refer to *Destroyer Escorts*, p. 15-48.

- maintenance and operation were relatively easy thanks to standardized spare parts and a minimum of electronics requiring specialized personnel training and test equipment.

As long as the supplier nations still operated their own wartime DEs, the world's new navies could count on a reliable source of replacement parts. This began to change in the early 1960s.

TABLE 5: TRANSFERS OF USN DEs TO OTHER NAVIES

Nation	Ships	Year of Transfer
Brazil	8	1944-6, 1945-1, 1946-1
Chile	4	1967-4
Colombia	4	1945-1, 1965-1, 1968-1, 1969-1
Equador	1	1967-1
France	14	1944-6, 1950-6, 1952-2
Greece	4	1951-4
Italy	3	1951-3
Japan	2	1955-2
Mexico	4	1964-4
Nationalist China	19	1945-1, 1946-1, 1948-4, 1960-1, 1966-9, 1967-2, 1968-1
Netherlands	6	1950-3, 1951-3
Peru	3	1951-3
Philippines	2	1961-1, 1968-1
Portugal	2	1968-2
South Korea	12	1956-2, 1959-1, 1963-1, 1966-2, 1967-5, 1968-1
South Vietnam	2	1971-2
Thailand	1	1959-1
Uruguay	2	1951-1, 1952-1

Source: Elliott, P., American Destroyer Escorts of WWII, p. 57

3. Corvette/Light Frigate Programs 1945-1965

During the first two decades or so after World War II, the traditional navies had little need for new escort vessels of corvette or light frigate size. DE inventories declined steadily as wartime vessels found new "homes" in the Third World, and the older fleets concentrated their acquisition programs on larger platforms. By 1965, however, a number of countries purchased new warships of light displacement to replace or supplement their existing inventories. These included: Britain, Denmark, France, West Germany, Ghana, Indonesia, Italy, Japan, Nigeria, Norway, Portugal, Spain, Sweden, USSR, and Venezuela. Most of these ships were built by Britain, France, Italy, Spain and the USSR. The latter was by far the largest producer of small escorts during this period, completing 60 Riga class frigates, 12 Kola class, 25 Petya class, and five Mirka class. [Ref. 14] They were lightly armed and optimized for anti-submarine warfare duties. The 1965-66 edition of Jane's Fighting Ships listed only one shipyard as producing "corvettes", and 10 as producing "escort vessels".

4. Corvette/Light Frigate Programs 1965-1980

In 1980, Jane's Fighting Ships listed 22 shipyards as producing "corvettes"; 18 yards were listed as building "escort vessels". Additionally, the number of countries which had acquired new corvette/light frigate hulls since 1965 totalled 30. They were Argentina, Belgium, Bulgaria, Denmark, East Germany, Ecuador, Finland, France, India, Indonesia, Iran, Italy, Japan, North Korea, Libya, Malaysia, Morocco, Nigeria, Norway, Peru, Portugal, Saudi Arabia, Spain, Syria, Thailand, Turkey, USSR, Venezuela, Vietnam, and Yugoslavia. Many of these countries had acquired more than one class of light escorts during the intervening 15 years, and a few had secured ships from both sides of the Iron

Curtain. Most of the new classes were equipped with SSMs, yet retained their ASW capabilities in the form of sonar, torpedoes, and mortars. Also, many more classes of ships in the 600-2,500 ton displacement range were being fitted with helicopter decks, and a few types were armed with short-range surface-to-air missiles (SAMs). Finally, by 1980, 13 of the 30 countries that bought new corvettes/light frigates classes did so while relying entirely or in part on domestic production.

5. Corvette/Light Frigate Programs 1980-Present

The 1993-94 edition of Jane's Fighting Ships lists just 13 shipyards as building "corvettes", down from 22 in 1980. No yards were listed as producing "escort vessels" but, the category of "frigates (light)" was added. This shift in ship designations reaffirms the problem associated with trying to compare vessels, based on formal classification only. This type of vessel has become very popular, and new designs continue to flood the market. Table 6 lists the specifics of some of the most recent designs which are being built or proposed. Since 1980, 26 countries have acquired or have ordered new corvette or light frigate-size warships. SAMs have become more common, as have helicopter decks and, in some cases, helicopter hangers. Most are also equipped with some sort of electronic support measures (ESM) and electronic counter measures (ECM) equipment. Chaff launchers are standard, however, active jammers have yet to become so. This is notably so for Soviet/Russian exports and their indigenously-produced variants. Likewise, vessels manufactured in the United States for export are only equipped with the least capable of the U.S. Navy's electronic warfare (EW) suites. For example, the United States limits EW exports to the SLQ-32 V(1) variant, which excludes an active jamming capability. Chinese exports are evidently an exception; jammers are provided, depending on the customer nation.[2]

TABLE 6: CURRENT CORVETTE/LIGHT FRIGATE DESIGNS

Legend/Class	Omani Corvette	Malaysian	BRECA C20	Sa'ar 5
Displacement	1,400 tons	2,270 tons	2,000 tons	1,200 tons
Length (pp)	76.00 m (wl)	97.5 m (wl)	89.70 m (wl)	76.60 m
Length (oa)	83.70 m	106.00 m	97.00 m	85.64 m
Beam	11.50 m	12.75 m	13.90 m	11.88 m
Depth	7.20 m	.... m	.... m	.... m
Draught	3.50 m	3.08 m	3.90 m	3.17 m
		Sensors		
C2	STACOS	NAUTIS	....	? NTCCS
Fire Control	STING & CASTOR	1802SW	1/3 channels	2 x EL/M 2221
Radars	MW08	DA08	1/2 search	2 search
Sonars	....	SPHERION	TAS or VDS	1 MF + VDS/TAS
ESM	....	MENTOR	....	....
ECM	....		1/2	
		Weapons & Decoys		
Guns	76 mm 2 x 20 mm	57 mm 2 x 30 mm	up to 100 mm 2 + light	1 x 76 mm 2 x 25 mm
CIWS			1/2	2 SEA VULCAN
		Missiles		
SSM	8 x MM40 Exocet	8 x MM40 Exocet	4/8 x SSM	8 x Harpoon 8 x Gabriel
SAM	8 x Crotale	16 x Seawolf	8/16 x SAM	2 x 32 Barak
Torpedo Tubes		2 x 3	2 x 3	2 x 3
Decoys	2 x S.BARRICADE		2 x	
		Machinery		
Arrangement		CODAD	CODAD/CODOG	CODOG
Power	4 x 5,570kW	4 x 8,300bhp	. x ....bhp	2 x 6,000bhp 1 x 30,000shp
Speed	25+ kts	27 kts	30 kts	33 kts
Electric Output	3 x 350kW	3 x ....kW	? x ....kW	2 x 340kW
Bunkers	.... tons	.... tons	.... tons	.... tons
Endurance	....nm @ ...kts	5,000nm @ 14kts	5,000nm @ 12kts	3,500nm @ 17kts
Autonomy			21 days	
Complement	60	146	90	74

Source: "Frigates", *Navy International*, April 1990, pp. 144-146.

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[2] This determination was made after careful review of available open-source literature.

C. MAXIMUM POTENTIAL: ISRAELI SA'AR 5

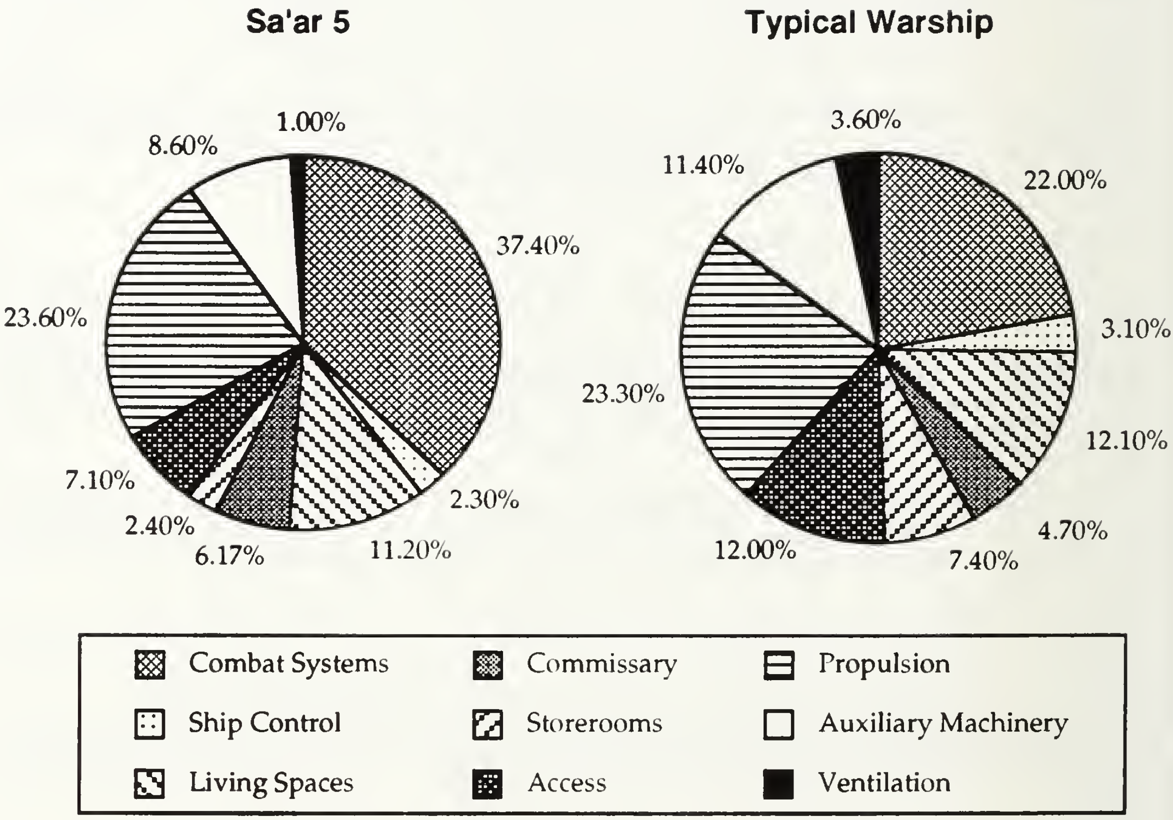
It is difficult to compare two distinctly different classes of warships, since the military potential of an individual class of ships depends on the customer nations unique requirements, and military budget. Additionally, the military infrastructure to support routine ship operations and the competency levels of the crew plays a significant role in the ship's overall level of performance. However, ignoring those factors and comparing the absolute levels of military capability, in terms of numbers of various types of weapons, it is evident that the Israeli Navy's Sa'ar 5 class of corvettes is the most heavily armed.

1. Design Requirements

The Sa'ar 5 is manufactured in the United States in collaboration with the Israeli Navy. Some of the design requirements include: [Ref. 15:p. 212]

- minimum size with a maximum operational capability;
- a high payload to displacement ratio;
- the ability to support helicopter operations, including hanger facilities;
- minimum deck wetness in sea state 4;
- an endurance of 3,000nm at diesel engine cruising speed; and
- provide a maximum speed of 33kts on gas turbine.

Figure 2 illustrates the Sa'ar 5's space allocation compared with that of a typical warship of 3,000 tons displacement. By limiting the ship's operational area and requirements for extensive on-board maintenance facilities, more space has been devoted to warfighting potential. More than one-third of the ship's volume is allocated to combat systems, compared to a norm of 22%. [Ref. 15:p. 212]



Source: Maritime Defence, June 1990, p. 212

Figure 2: Space Allocation Differences Sa'ar 5 vs. Typical Warship

The hull is sub-divided by 11 transverse watertight bulkheads and six fire zones. Stealth features have been incorporated throughout, and include:

- resiliently mounted main and auxiliary machinery;
- thermal/acoustic insulation on the interior of hull in machinery spaces;
- installation of a prairie-masker air system;[3]
- gas turbine and diesel propulsion exhaust eductors;
- diesel-generator exhausts equipped with water-spray injection; and
- radar cross section reduction by form, shielding, and the use of radar absorbant material (RAM). [Ref. 15:pp. 212-213]

2. Weapons Fit

The defensive/offensive weapon-fit of the Sa'ar 5 is particularly powerful for a vessel of its size. It carries 64 Barak point-defense missiles in two 32-cell vertical-launch silos, a 76mm dual-purpose automatic gun forward of the superstructure, and a 5-barrel 25mm Sea Vulcan that is mounted port and starboard on the bridge deck. Anti-ship weaponry includes two quadruple launchers for Harpoon and eight single Gabriel IV launcher cells. Triple Mk32 torpedo tubes are carried port and starboard for close anti-submarine engagements. The ship is capable of embarking a helicopter or unmanned aerial vehicle (UAV) which can be used for reconnaisance and targeting. Additionally, the helicopter can be fitted with air-to-surface missiles or torpedoes.

3. Countermeasures

The Sa'ar 5's installed countermeasures systems include a comprehensive ESM/ECM outfit, equipped with passive listening and threat

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[3]The Prairie-Masker air system works to reduce the ships radiated acoustic signature by forcing air bubbles out through tiny holes in bands around the engineering spaces (below the water line) and out through holes in the ships screw(s).

evaluation capabilities, and multiple active jammers. So-called "soft kill" systems include four 72-tube chaff and infrared (IR) flare launchers, two 24-tube smoke rocket launchers, and a Nixie torpedo decoy system.

4. Electronics

One of the most impressive aspects of the Sa'ar 5 is the amount of indigenously-built electronic equipment. The ship will include a fully integrated command and control system, developed in Israel, featuring 17 color tactical displays with most functions, such as electronic warfare or surface-picture compilation, available at most consoles, plus facilities for a task-force commander. [Ref. 16:p. 299] Two main computers (one of which is redundant), linked by a local area network (LAN), will connect the system.

Israel's IAI (Israel Aircraft Industries) Elta division has developed an improved, 3-D version of the Automatic Missile Detection Radar for the Sa'ar 5. This S-band radar is designed to automatically detect incoming sea-skimming missiles, carry out automatic threat evaluation, and designate them to the ship's Barak anti-missile fire-control channel. [Ref. 16:p. 300] The Sa'ar 5 will be equipped with two EL/M-2221-GM STGR (search, track, and guidance radar) fire-control radars for the Barak missiles. [Ref. 16:p. 300]

It will feature an additional fire-control/surveillance channel in the form of two multi-sensor stabilized integrated systems (MSIS) from Electro-Optics Industries, another Israeli company. These systems carry three sensors: a forward-looking IR (FLIR) operating in the 8-12m band, laser, and a daylight television camera. [Ref. 7:p. 250] Finally, the communications intelligence/direction finding (COMINT/DF) system, electronic warfare suite, and decoy launching systems are all produced in Israel. [Ref. 16:p. 301] The hull-mounted sonar and Nixie torpedo-decoy systems are manufactured in the United States. The Sa'ar 5 will be fitted for both a variable depth and a towed array sonar systems, however, neither system will be installed initially.

D. CONCLUSION

Small warships were produced in large numbers by the mature navies during World War II to fulfill a limited role: escorting merchant ships. Their primary armament included depth charges for use against submarines, and medium and small-caliber guns for use against surface and air threats. During and after the war, they proved to be much more versatile, in fact, and though space and weight were limited, they proved readily adaptable to a wide range of weapons capabilities and missions. As a result, they became the platform-of-choice for most of the post-war ex-colonial fleets.

New designs and technological improvements in weapon and sensor capabilities with reduced weight requirements have allowed small warships to assume additional roles. By the mid-1960s, rather than continuing to purchase "second-hand" warships from the mature navies, some developing navies began to acquire new ships which are tailor-made to their particular circumstances and needs. In addition to purchasing new warships, some countries have developed the capability to produce some or all of these ships indigenously. The reasons for this include: a desire for reduced reliance on other countries; local employment; an expanded shipbuilding capability; and an export base. Corvette and light frigate-size vessels have the potential of being heavily armed and technologically sophisticated and may well serve as the "capital ship" of smaller navies.

The next chapter will look at some of the ways in which small warships are able to increase their military capabilities. These will include modular designs which allow the same ship to perform different missions, "stealth" features which reduce the detectability, and the sophisticated weapons which are being utilized on these platforms.

IV HULLS, WEAPONS, AND SIGNATURE MANAGEMENT

Technological improvements have allowed warship designers to build more military potential into smaller ships. Ships of corvette/light frigate-size can now be classified as multi-purpose platforms. The mature navies have traditionally been the leaders of technological innovations, and the rest of the world has relied upon them for advanced systems. However, more nations are developing the economic and industrial capabilities necessary to produce advanced ships and weapon systems. This chapter explores technological advances in terms of ship hull designs, weapon systems, and signature management techniques, and how they are or could be incorporated in corvette/light frigate-size hulls.

A. SHIP HULLS

1. Increases in Size

For the past 30 years, the FAC and FPB have been the preferred choice of small navies. With anti-ship missiles on a small displacement hull, these vessels were promoted as the "naval equalizer", cheap and yet under certain circumstances capable of sinking larger warships. They are the descendents of the American PT-boats, British MTBs, and German *Schnellboote* of World War II. But, like their predecessors they have not influenced the naval balance of power as greatly as their supporters envisioned.

A growing understanding of their limitations has caused the popularity of these small vessels to wane. Larger displacement craft have proven necessary in order to mount the electronic and defensive systems required for a vessel to survive against a determined adversary equipped with advanced weapons and aircraft. The corvette/light frigate is the natural "next step-up" for many navies. The trend in acquisition of FACs and Corvette/Light frigate vessels is shown in Figure 3. It can be seen that the acquisition of new FACs peaked during the early 1980s and dropped off sharply after 1984. This trend suggests a realization of the FAC's limitations and thus a need for larger, more capable ships. A counter argument might be that the market for FAC-size vessels was simply saturated at that point. The final answer probably will not be revealed until those FACs which are currently in the inventories of the world's navies have served their useful lives and are in need of replacement.

The establishment of EEZs and the requirement to patrol these ocean areas provides additional reasons for a maritime nation to acquire larger vessels. Larger displacement craft, besides having greater endurance, provide additional internal volume, and offer a more stable platform from which to operate helicopters. Smaller nations unable to afford separate Navy and Coast Guard units might be best served by purchasing multi-purpose vessels. These ships could be designed and configured for an extensive weapons suite, however, it need not be fitted from the outset. The concept of designing and constructing a ship for eventual upgrade has a number of advantages, including: lower initial cost; and guaranteed space and weight requirements being satisfied. Malaysia, for example, is currently looking to build 18 to 24 Offshore Patrol Vessels over a

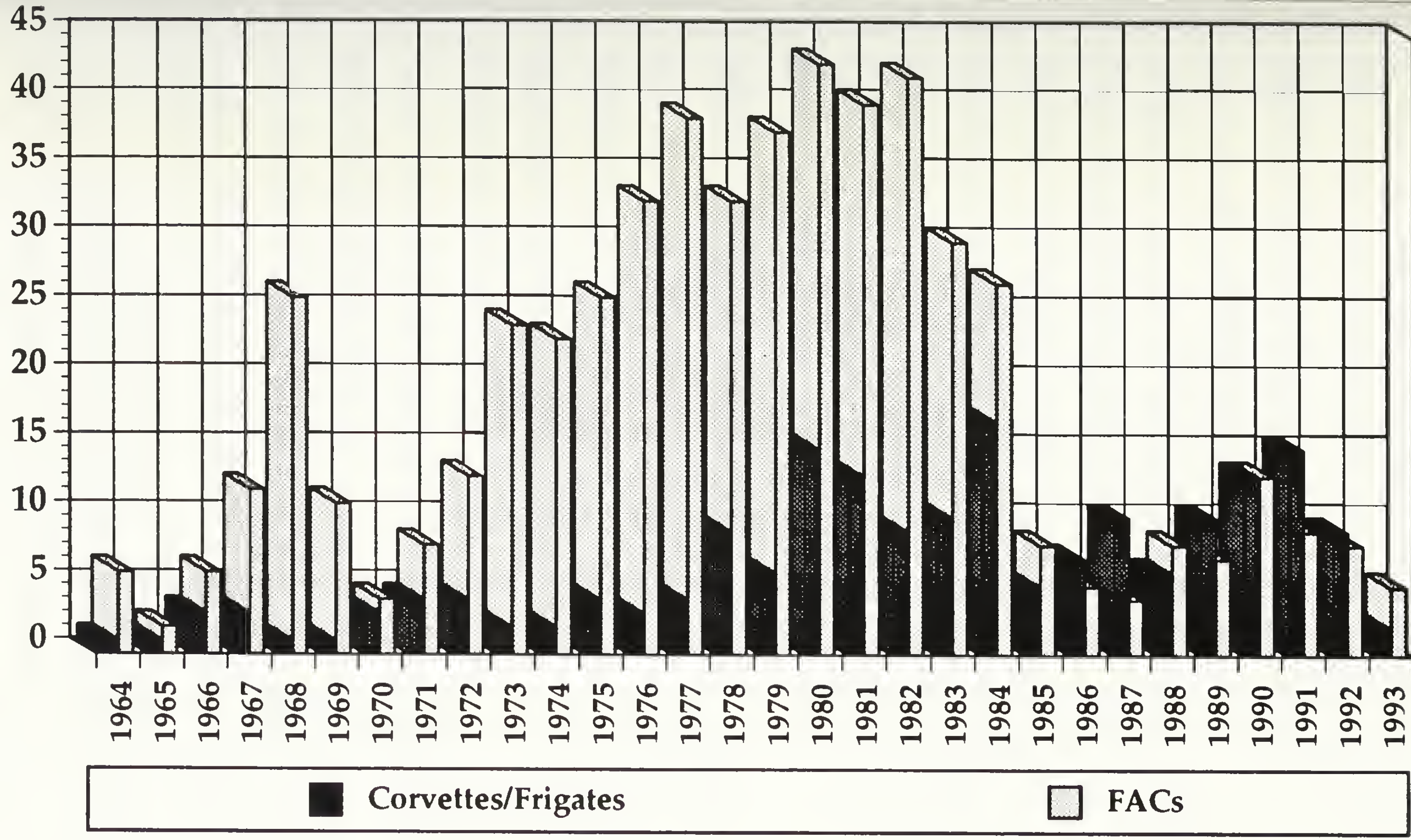

Figure 3: Corvette vs. FAC Acquisition Patterns

Sources and Methodology: Acquisition of FACs (missile armed) was derived from commissioning dates based on data in Small Craft Navies. [Ref. 6] Corvette/Frigate data was derived from commissioning dates based on successive issues of Jane's Fighting Ships. (Data does not include FACs manufactured in China, since Ref. 6 did not contain accurate numbers or dates of completion)

20-year period with which to patrol her extensive EEZ. [Ref. 17:p. 45] Other countries, particularly those in the Far East are expected to have similar needs.

2. Modular Equipment Concepts

The concept of warship "modularity" is still fairly new, but has been tried, to different degrees, by a number of companies. Basically, modularity involves the ability to change a ship's "mission profile" by rapidly adding or exchanging major components. For example, by replacing a gun system with a missile launcher, a vessel tasked for coastal patrol duties one day can theoretically be made fit to perform a sea denial mission the next. This capability has been made possible by the creation of standard-size containers and consoles that are linked to a common computer databus using common computer language.

Modularity is utilized by the U.S. Navy in the form of its Mk 41 vertical launch system (VLS). These VLS "cells" can be loaded with a variety of different weapons, including Tomahawk cruise-missiles, vertical launch ASROC (VLA), and Standard SAMs. As said, the concept is still fairly new in foreign navies, so the full extent of its merits and drawbacks are unknown. In addition, it is not known how many countries will be able to afford to purchase "extra" equipment and allow it to sit idle in a warehouse. There is also the question of crew proficiency. When a ship undergoes a dramatic shift in roles or capabilities, will it be necessary to change crews, or can one complement be trained to cope with a "balanced" spectrum of warfare capabilities and missions?

Two innovators in the concept of modularity are the German company of Blohm+Voss and the Danish Navy. Blohm+Voss has developed and successfully exported their MEKO classes of corvettes and frigates to seven nations so far. The Danish Navy has incorporated modularity into its new Standard Flex 300 (STANFLEX 300) class of multi-mission ships. The STANFLEX 300 ships are smaller than corvettes, however, the concepts which they demonstrate are readily adaptible to larger vessels.

a. Blohm-Voss MEKO Designs

(1) Design Concept. The German shipbuilders Blohm + Voss, in an effort to control rising warship costs, began to explore the potential of utilizing containerized weapon and electronic systems, and main and auxiliary machinery. Initial design studies proved promising and the company decided to move forward with the concept in 1969. The idea is based on using standard-sized and interchangeable so-called Functional Units (FES) with standard interfaces. Where containers are inappropriate -- as in the consoles within a combat information center, for example -- standard pallets are used.

(2) Advantages. The MEKO/FES concept not only enables a standard hull to be used with a wide variety of weapon fits, but also has advantages during building, maintenance, refit and modernization. These advantages include:

- time and cost savings as a result of parallel construction and outfitting of hull and Functional Units;
- non-disturbance of units after factory completion and testing;
- time and cost savings by eliminating duplication of factory setting-up aboard ship;
- clear division of responsibility between equipment manufacturer and shipbuilder;

- rapid removal and replacement of Functional Units without disturbing other onboard systems;
- refit and repair of Functional Units in clean conditions ashore; and
- replacement of obsolete weapon and electronic systems without the need for major structural alterations.

(3) Initial Platforms. The concept has so far proved itself in terms of flexibility and ease of manufacture. The first ship ordered under this new concept, a MEKO 360 (3,600 tons) for Nigeria took a total of 38 months from start to completion. This is exceptionally fast for a ship of that size and complexity. About a year later Argentina ordered four MEKO 360.H2s, capable of operating two helicopters. The first of these took only 30 months from laying down to commissioning; the last was completed in 14 months.

(4) Improvements. Improvements to the basic design have been incorporated as a result of the Falklands experience as well as advances in computer technology. Damage control improvements include independent control and monitoring systems (data bus), independent ventilation systems, independent seawater firefighting systems, and independent power distribution systems for each of the ships seperate sections. [Ref. 18:p. 22] By this arrangement the ship is sub-divided into nine (MEKO 200) or 14 (MEKO 360) self-contained independent seawater fire fighting systems. Improvements in computer architecture have made it easier to change Functional Units, and interface them with a Data Information Link (DAIL) system. MEKO's latest Mod 3 version incorporates extensive stealth design features that reduce the ship's radar and IR signatures, and hence its detectability and targetability.

Blohm & Voss has utilized the MEKO concept thus far to manufacture MEKO 140 corvettes and MEKO 200 and 360 frigates. They have been purchased, or manufactured under license, by Argentina, Australia, Greece, New Zealand, Nigeria, Portugal, and Turkey.

(5) The Future. Blohm+Voss has developed the MEKO Mod. 4 as the next step in the highly successful MEKO line. It consists of the MEKO 100, a 1,000 ton class multi-role vessel. The basic platform can be configured with any one of five different propulsion arrangements without the need of changing the ship's main structure. Based on the speed requirements of the customer, the propulsion variant is selected, which will determine the ship's overall length in turn. The ship's internal layout and weapon and sensor suites are based upon one of five mission areas: Search and Rescue, Offshore Patrol Vessel, Surveillance Patrol Vessel, Anti-Air Warfare, or Anti-Submarine Warfare. The customer can choose any one of these layouts, or customize the vessel for his navy's unique needs.

b. STANDARD FLEX 300 Designs

(1) Background. During the 1980s, the Danish Navy faced block obsolescence of three different classes of ships. A total of 22 ships, including six fast patrol boats, eight *Daphne* class patrol craft and eight ex-USN minesweepers required replacement. The solution was to design a common hull which could utilize interchangeable modules for each mission. The result was the STANFLEX-300 concept, a 300 ton glass-reinforced plastic (GRP) sandwich hull designed for rapid exchange of four modules. In 1985, the first seven Standard Flex ships were ordered. As of early 1992, 13 had been contracted and another three are expected. [Ref. 19:pp. E50-52]

(2) Mission Profiles. The various Standard Flex roles include surveillance, minelaying, combat, MCM, and future ASW. It is reported that less than 12 hours are needed to change roles completely, including exchanging four containers, and amending the software. [Ref. 19:p. E51] The container boxes are positioned one forward and three in line along the after deck. They may be of three types: closed with equipment on top, such as missile launchers, closed for storage, or open-sided with a gun on top. Two minerails bedded in the after deck can take a 60-ton mineload.

Although the basic idea behind the STANFLEX-300 is that weapons and non-permanent equipment are installed in four containers per ship, some items are not containerized. The ASW torpedo tubes are, for example, mounted on pallets ready to be mounted in prepared positions that are provided with the necessary power and databus connections. Harpoon missiles and Sea Gnat decoy launchers will be installed in the same way. [Ref. 20:pp. 40-41]

3. Alternative Hull Concepts

There is currently a number of navies and private companies experimenting with ships which utilize non-monohull displacement concepts. Most of these designs operate with a reduced wetted area and include: SWATH (small waterplane area twin hull), SES (surface effect ship), ACV (air cushion vehicle), and hydrofoils. Some of the countries experimenting with these designs include the United States, Russia, Germany, Spain, Italy, and Sweden. Most of these designs have thus far proven to be expensive both in terms of development and actual operation. The potential future for these designs is uncertain.

4. Producer Nations

Many of the navies currently purchasing light warships insist that some or all of the production be undertaken within their own country. This requirement has a number of purposes: it allows the country to develop or expand its naval shipbuilding capability, it helps to promote employment, it makes the purchasing country less dependent on others, and it creates an export base. A study carried out by the Sales Organization of the British Ministry of Defence, concluded, in early 1982, that there existed a world market for 114 frigates over the next decade, but that only 14 of these would likely be built outside the procuring country. [Ref. 21:p. 297] Countries such as Argentina, South Korea, Greece, Turkey, Australia, and India have undertaken co-production agreements as part of the terms for procurement of new warships.

B. SURFACE-TO-SURFACE ANTI-SHIP CRUISE MISSILES

1. Overview

The SSM has become the primary offensive weapon for most navies. No one type of SSM is the same, although many of the enabling technologies are similar. The only common feature is their mission, which is to harm their victim with a direct hit. All other aspects -- such as their size, weight, launching procedures, guidance principle and flight profiles -- are very dissimilar over the wide range of missiles currently available or in development.

The results of an SSM hit on a surface vessel -- dramatically displayed during the 1982 Falklands War and during the Iran-Iraq conflict of the 1980s -- are a potent reminder of the efficacy of such weapons. One missile hit can neutralize a warship even if it is not sunk outright; secondary fire and explosions can disable a ship for the duration of a conflict.

2. Diffusion of Suppliers

While guided bombs were used against shipping as long ago as World War II, it was only in 1958 and 1962 respectively that the Soviet Union introduced Styx -- SS-N-2A (active radar homing) and 2B (IR homing) -- generally into their naval weapon inventory. The proliferation of cruise missiles is of concern but so is the proliferation of the technology and capability for manufacture of indigenous designs. According to the *Jane's Weapons Systems* series there were just five countries in 1970 (USSR, France, Israel, Italy, and Sweden) producing seven different ship-launched SSMs.[1] By 1980, the number had risen to eight countries (above five, plus United States, China, and Norway), producing over one dozen different variants. The number of different types of SSMs has continued to grow, as has the number of producer nations. Japan, South Africa, Taiwan, and the United Kingdom have added themselves to the list of producer nations, and Brazil is known to have a program in development. [Ref. 22:pp. 157-159] Table 7 lists the SSMs currently being exported and the countries which reportedly deploy them.

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[1]Analysis is limited to designs which lend themselves easily to being deployed on warships of the size under consideration (600-2,500 tons).

TABLE 7: EXPORTED SSMs AND THE COUNTRIES REPORTEDLY DEPLOYING THEM

Missile Designation Country of Origin	Countries Reportedly Deploying SSMs
Exocet MM-38/40 AM-39, SM-39 **France**	Argentina, Bahrain, Belgium, Brazil, Brunei, Darussalem, Cameron, Chile, Colombia, Equador, Germany, Greece, Indonesia, Iraq, South Korea, Kuwait, Libya, Malaysia, Morocco, Nigeria, Oman, Peru, Qatar, Saudi Arabia, Thailand, Tunisia, U.A.E., U.K.
Gabriel Israel	Chile, Equador, Israel, Kenya, Singapore, South Africa, Taiwan, Thailand
Hai Ying 1,2,4 **PRC**	Bangladesh, Egypt, Iran, North Korea, Pakistan
Harpoon USA	Australia, Canada, Denmark, Egypt, Germany, Greece, Indonesia, Israel, Japan, South Korea, Netherlands, Pakistan, Portugal, Saudi Arabia, Singapore, Spain, Thailand, Turkey, U.K., Venezuela
Otomat Italy	Egypt, Iraq, Italy, Kenya, Libya, Nigeria, Peru, Saudi Arabia, Venezuela
Penguin Norway	Greece, Norway, Sweden, Turkey, U.S.
RBS-15 Sweden	Finland, Sweden, ordered by Yugoslavia
Sea Killer Italy	Iran
Styx a/b/c (SS-N-2) **USSR**	Algeria, Angola, Bulgaria, Cuba, Egypt, Ethiopia, Finland, Germany, India, Iraq, North Korea, Libya, Poland, Romania, Somalia, Syria, Vietnam, South Yemen, Yugoslavia

Sources: Journal of Electronic Defense, January 1992, p. 58., International Countermeasures Handbook, 1991, pp. 26-27.

This diffusion of producer nations has complicated the task of determining weapons capabilities and countermeasures. Some of the many questions which must be answered for each potential threat include: What are the weapons operating parameters? How many have been produced? Who has purchased them? Are there any effective defensive techniques? Does the seeker have a home-on-jam (HOJ) capability? Will installed ESM system be able to identify the emitter as a threat? Does the country operating the weapon have the capability to alter the operating parameters?

3. Current Capabilities and Distribution

a. Exocet

Perhaps the best-known Western manufactured SSM, the Aerospatiale Exocet, sank the British destroyer *Sheffield* and the container ship *Atlantic Conveyor* in the Falklands. It has also been used by Iraq in the Iran-Iraq War, severely damaging the U.S. frigate *Stark*, and hitting numerous tankers. It is widely distributed with more than 2,800 missiles of different variants delivered and in service in 29 countries. [Ref. 22:p. 157] It exists in ship-launched (MM38 and MM40), air-launched (AM39), and submarine-launched (SM39) versions, all of them fueled by a solid rocket, and all sea skimmers with active-radar homing. The MM38 and MM40 versions are also deployed from coastal defense batteries. The original MM38 version, which has been in production since 1972, has been ordered by 18 navies to arm 185 ships. [Ref. 23:p. 960] The MM40 is a longer-range version in a more compact canister as compared to the original MM38. Total weight is 1,150 rather than the 1,750 kg of MM38, and typically 2 MM40s can be carried for every one MM38. Over 800 AM39 and 500 MM40 missiles were ordered as of late 1992. [Ref. 23:p. 960]

The Exocet's rocket propulsion translates into a shorter range than is possible for a turbojet, however, it also allows for lower boost altitudes and therefore complicates the defender's early detection. The surface-launched version is fired from a fixed launcher (elevated to 12 deg), and the two-second boost brings the missile to a maximum altitude of 30-70 m [98-229 ft]. The missile's cruise altitude depends upon distance from the target and sea state, and can be as low as 2.5 m [8.2 ft]. [Ref. 7:p. 173] Table 8 lists the characteristics of the different versions of Exocet. Currently, Aerospatiale is producing the MM40 Block 2 for French service, which offers improved seeker performance and allows ripple firing for saturation attack. [Ref. 23:p. 960] The MM40 was recently chosen by Malaysia, Oman, and Qatar to equip their corvette fleets with two quad-four Exocet launchers per vessel. [Ref. 23:p. 960]

TABLE 8: EXOCET CHARACTERISTICS

	Versions			
	MM38	AM39	SM39	MM40
Diameter	34.8 cm [13.7 in.] all versions			
Length	520 cm. [205 in.]	469 cm [185 in.]	580 cm [228 in.]	580 cm [228 in.]
Span	100 cm [39.4 in.]	110 cm [43.3 in.]	113.5 cm [44.7 in.]	113.5 cm [44.7 in.]
Weight	750 kg [1653 lb]	655 kg [1444 lb]	666 kg [1468 lb]	855 kg [1884 lb]
Warhead	165 kg [364 lb] all versions			
Speed	Mach 0.93 all versions			
Range	42 km [46 kyd]	50-70 km [55-77 kyd]	50 km [55 kyd]	65 km [71 kyd]

Source: Friedman, N., Naval Institute Guide to World Naval Weapon Systems, 1991/92, 1991, p. 173.

b. *Harpoon*

The only Western missile to rival the Exocet in terms of numbers produced and operational flexibility is the American Harpoon, produced by McDonnell Douglas. Harpoon was conceived in 1965 by the Naval Air Systems Command as a longer range (25 nm) follow-on to the Bullpup missile, and the program began formally in 1968, following the 1967 *Eilat* sinking. [Ref. 7:p. 187] Harpoon was envisioned as a AGM-84 air-launched weapon with a range of almost 60 miles, but a ship-launched RGM-84 version was added in 1970, while an encapsulated UGM-84 version for submarine launch began production in 1972. [Ref. 6:p. 45] General production started in 1976, and Harpoon has been a great technical and commercial success in the American and export markets since. More than 6,000 have been produced and deployed by the United States and 20 international customers, including nine NATO navies. It is an all-weather missile that employs an active radar seeker. [Ref. 23:p. 960] The Harpoon's basic range-and-bearing mode of operation is identical to that of the Exocet, with cruise course and height controlled by an inertial navigation system and radar altimeter, respectively, and the radar seeker activated only at the last moment to provide accurate homing without giving the target much opportunity to take counter-measures. Improvements have been developed which incorporate increased range, way-point flight profiles, and selectable terminal maneuvers. The use of way-points helps to prevent the target ship from knowing the direction of the attacker, and allows multiple missiles fired from the same platform to attack the same target from different directions.

c. Other Anti-ship Missiles

Although Styx, Exocet, and Harpoon are the most widely distributed anti-ship missiles, they are by no means the only ones. Otomat, Gabriel, and Penguin also enjoy wide distribution, as do China's Hai Ying series of missiles. The Norwegian Penguin, which differs from its contemparies in that it uses of a passive IR seeker for terminal homing and is therefore not detectable by ESM, is in service with the navies of Greece, Norway, Sweden, Turkey, and the United States. [Ref. 24:p. 27]

4. Supersonic SSMs

Supersonic SSMs have been long favored in the Soviet Union and China, but have only received limited interest in the West so far. Advantages of a supersonic SSM include: reduced flight time, thus avoiding the need for target position updates, and reduced target reaction time. The principle disadvantage of current supersonic SSMs is their need to fly at higher altitude than Western "sea-skimmers", which increases the defenders chance of detection.

a. The ANS

The West's only supersonic next-generation SSM is the Franco-German ANS (Anti-Navire Supersonique). In 1987 it had all but completed its development stage but has since been frozen. Germany's Ministry of Defense (MoD) has expressed its intention to pull out of the program because of budget constraints, [Ref. 23:p. 960] but has appropriated funding to finish development. [Ref. 22:p. 156] It has been reported that France is also delaying the program, due to severe financial constraints and the more pressing needs of other programs. [Ref. 23:p. 960]

If ANS performs as its makers claim, it will be powered by a rocket/ramjet combination with Mach 2 to 2.3 speed, a range of 100km in a lo-lo-lo flight profile, and 200-250km in a lo-hi-lo or a hi-hi-lo attack, and will be capable of 15G maneuvers. [Ref. 23:p. 960] This high speed, coupled with the ability to perform such high terminal maneuvers (weaving), will cause problems for many of the currently fielded shipboard defensive systems.

b. Chinese Programs

China reportedly has two different supersonic SSMs under development, the C-101 and HY-3 (C-301) missiles. Neither system is expected to enter service before 1995. Both weapons have been offered for export, but there have been no public reports of foreign orders. [Ref. 25:pp. 512-513] Table 9 provides pertinent estimated data.

TABLE 9: CHINESE SUPERSONIC SSMs UNDER DEVELOPMENT

	C-101	HY-3 (C-301)
Diameter	54 cm	76 cm
Length	650 cm (ship launched) 750 cm (air launched)	946 cm (missile only) 985 cm (overall length)
Weight	1850 kg (ship launched) 1500 kg (air launched)	3400 kg
Warhead	300 kg	513 kg
Speed	Mach 2.0 (680 m/sec)	Mach 2.0 (680 m/sec)
Range	45 km	130 km

Source: *Jane's Intelligence Review*, November 1992, pp. 512-13.

5. Missile Associated Radars

In any examination of a potential threat scenario, it is customary to consider "threats" as including not only the weapons themselves but also the fire-control radars whose emissions can provide advanced warning of an attack. However, in considering the potential threat from systems of Western origin it is necessary to take into account the fact that many Western SSMs are designed to work with a variety of different types of radar and are in many cases largely autonomous in operation, needing only an initial input of target position before going off on their own. This input can be generated by something as simple as a commercial marine radar that ESM may find indistinguishable from other radars aboard merchant ships in the vicinity. This is especially true when operating within a countries littoral region where commercial shipping traffic can be expected to be dense.

C. SURFACE-TO-AIR MISSILE SYSTEMS

Air-flight weapons, whether launched from aircraft (air-to-surface missiles or anti-ship missiles), from other warships or shore batteries (SSMs) or from submarines (SLMs) are a great threat to surface craft. A credible air defense can be provided by shore-based aircraft if a warship limits its operations to coastal waters, but for operations at any distance from the coast, warships must be provided with means of self-defense. More than 800 surface ships world wide are currently armed with SSMs, and hundreds more are deployed on submarines and fixed and rotary aircraft. The Falklands and Gulf Wars demonstrated the practical difficulty of defending against such weapons. Future SSMs are expected to fly at Mach 2+, maneuver laterally at 15Gs, and carry heavily armored warheads. Theoretical studies show that installing a 35mm thick armor plate in front of the warhead in an Exocet-size missile increases the weapons weight by only 30kg, yet is sufficient to defeat 20mm ammunition fired by a close-in weapons system. [Ref. 26:p. 1301]

At the heart of any anti-missile system must be an ability to locate the target at maximum range. The system must then calculate a fire control solution to put sufficient explosive force close enough to the incoming missile to destroy it completely, or damage it sufficiently to prevent it from damaging its target -- a so called "mission kill". SAMs are generally categorized according to their range and thus their capability to defend a given area. Area defense missiles provide an ability to protect not only the firing unit but ships in company as well. The U.S. Navy's SM-2 series of SAMs is the best known of the West's area defense missiles. Point defense missiles because of their limited size and range are typically used for defending the firing unit only, although they might be able to provide limited coverage for another unit in close proximity.

1. Area Defense Missile Systems

The size of the warships under consideration (600-2,500 tons) limits their ability to carry the heavier, long-range air defense SAMs. Current generations of long range SAMs are usually reserved for warships of 4,000 tons or larger.

2. Point Defense Missile Systems

One of the primary shortcomings of FAC-size vessels (and many current corvette/light frigate sized vessels) is their inability to adequately defend themselves against anti-ship missiles and aircraft equipped with stand-off weapons. This was demonstrated in 1986 when U.S. Navy A-6E Intruder aircraft hit and crippled a Libyan "Combattante II" FAC with Rockeye laser guided bombs and a Harpoon AGM-84A missile, from a range of seven miles. [Ref. 27:p. 60] In two more engagements the cruiser *Yorktown* (CG-48) hit another FAC with two Harpoon RGM-84A missiles, and a group of A-6Es crippled a Soviet-built Nanuchka type missile corvette with a Harpoon AGM-84A. [Ref. 27:p. 60]

Point-defense SAM systems allow engagement of air threats at ranges considerable greater than do most gun systems. This provides an added degree of depth to a ship's defenses. The addition of SAMs to a warship does not automatically guarantee success against SSMs however, as was proven by the USS *Stark*, equipped with Standard SAMs, and the Libyan Nanuchka, equipped with SA-N-4 SAMs. Table 10 lists the specifics of the various SAM missiles currently in production and utilized by corvette/light frigate sized vessels.

The number of countries manufacturing these weapons continues to grow as does their level of sophistication. Many of the systems currently under production are improvements of systems originally developed in the United States. For example, the Italian Aspide missile is an improved version of the American Sea Sparrow missile. It is widely deployed and can be configured in a lightweight quadruple launcher on warships as small as 300 tons. [Ref. 7:p. 388]

TABLE 10: PRINCIPAL POINT DEFENSE MISSILES

	Dimensions	Weight	Warhead	Speed	Range
Brazil SSA-N-1	15 cm x 2.72 m (5.9 x 107 in.)	85 kg. (187 lb.)	12 kg. (26.4 lb.)	M 2.0+	max 6 km. (6,600 yds)
China (PRC) RF-61/SD-1	28.6 cm x 3.99 m span 1.166 m	320 kg. (705 lb.)	cont. rod warhead	M 3	10 km -low 8 km - alt
France Crotale Naval	15 cm x 2.89 m span 54 cm	80 kg. (176 lb.)	15 kg. (33 lb.)	M 2.3	8.5-13 km 6.5 km against sea skimmer
France Mistral	90 cm x 1.81 m	17 kg. (37.5 lb.)	3 kg. (6.6 lb.)	M 2.6	6 km aircraft 4 km helos
France * SAAM/ASTER	18 cm x 2.6 m	100 kg. (220 lb.)	10-15 kg. focused		5-15 km
NATO Sea Sparrow	8.03 x 141.5 in.	500 lb.	86 lb.	M 4 + (AAM)	8-14 nm.
Israel Barak	17 cm x 2.175 m	98 kg. (216 lb.)	22 kg. (48.5 lb.)	580 m/sec	0.5-10 km
Italy Aspide	20.3 cm x 3.7 m	200 kg. (485 lb.)	35 kg. (77.2 lb.)	M 4.0 (AAM)	15 + km
Sweden RBS 70	10.6 cm x 1.32 m	15 kg. (33 lb.)	1 kg (2.2 lb.)	M 1 +	5,000 m
Russia SA-N-4	21 cm x 3.2 m	168 kg. (370 lb.)	18 kg. (40 lb.)	M 2 +	1.6-13 km
Britain Sea Cat	7.5 x 58.3 in.	138 lb.	45 lb.	M 0.6	1,500-5,000 yards
Britain Sea Wolf	18 cm x 2 m	82 kg. (180 lb.)	14 kg. (31 lb.)	M 2	approx 5 km
United States RAM	5 x 111 in.	162 lb	5 lb.	M 2 +	5 nm.

Note: * indicates that the system is still in development
Source: Friedman, N., The Naval Institute Guide to World Naval Weapons Systems 1991/92, 1991, pp. 378-411.

D. NAVAL GUNS

Despite the advent of sophisticated missiles for use against surface and air targets, the naval gun has remained a standard air defense weapon. Guns can be used against air and surface targets, as well as targets ashore. Additionally, the need to counter SSMs that "leak-through" a missile defense screen has prompted the development of weapons such as Phalanx and Goalkeeper, and has helped to advance the designs of ordnance and fire control systems. Advances in design have made possible weapons with much higher rates of fire, and ammunition with increased lethality over what was available during World War II.

1. Medium Caliber Guns

There are relatively few producers of naval guns in the medium-caliber (35-mm and up) range. They include: France's 100-mm mounts; Italy's OTO-Melara 127-mm and 76-mm mounts; Sweden's Bofors mounts in 120-mm, 76-mm, 57-mm, and 40-mm; Russia's 130-mm, 100-mm, 76.2-mm, and 57-mm mounts, Britain's 4.5-in. mounts, and the United State's 5-in. mountings. Surface warships of 2,500 tons displacement and below are realistically limited to guns of five-inch (127 mm.) and below because of the stresses that are imparted to the ship during firing. The vast majority of light frigate and corvette-size vessels carries the three inch (76 mm.) dual purpose gun, as their principal gun armament. Guns of 57-mm and 40-mm are also very popular on smaller craft as either a main or secondary battery.

a. Five Inch Guns

The Italian Lupo class frigates (2,500 tons full load displacement) of the Italian, Peruvian, and Venezuelian navies are the only recent examples of vessels of light frigate-size or smaller with five-inch guns. All carry the OTO

Melara 5 in (127 mm)/54 gun which is capable of firing 45 rounds a minute out to 16 kilometers (8.7 nm), against surface targets. [Ref. 28:pp. 316, 456, 811] These guns are lighter and have a higher rate of fire than their U.S. counterparts.

b. Three Inch Guns

Three inch (76 mm.) naval guns are widely distributed and are capable of being used against surface vessels, aircraft, and anti-ship missiles. The Russian Navy produces a number of variations of a 76.2 mm/60 gun design. This weapon can be found on most smaller Russian frigates, corvettes, and missile hydrofoils, has a rate of fire of 120 rounds/minute, and a maximum range of 14,000 meters against surface targets. [Ref. 7:p. 447] The Italian OTO-Malera 76 mm/62 is one of the most successful recent medium-caliber weapons, and is widely exported. It is licensed for manufacture in Japan, Spain, and the United States (as the Mk 75). The 'Compact' version of the 76 mm/62 fires at a rate of 85 rounds/minute, which can be increased to 100 rounds/minute with the addition of a retrofit kit. [Ref. 7:pp. 430-431] The latest version, "Super Rapid" was designed specifically for SSM defense. It has a selectable rate of fire of one, 10, or 120 rounds/minute. [Ref. 7:p. 431] In addition to the new mounting, OTO-Melara has developed a new prefragmented round filled with tungsten cubes. This shifts more of the mass toward the outer body as it spins, making for a greater moment of inertia about the projectile's axis and thus for better stability in flight. [Ref. 7:p. 431] The Italian Navy believes that a single "Super Rapid" mount controlled by a Dardo fire control system should be able to engage four subsonic sea-skimming SSMs, approaching on courses 90 degrees apart, before any approaches within 1,000 meters of the target ship. [Ref. 7:p. 431]

c. *Other Sizes*

Naval guns in sizes other than three and five inches are available and continue to be manufactured and upgraded. These weapons may serve as either the main or as a secondary battery on smaller ships. France, Italy, Sweden, Switzerland, and Russia are the primary producers.

2. Point Defense Gun Systems

Point defense gun systems are designed specifically to deal with SSMs, and are commonly termed close-in weapons systems (CIWS). They rely on either a very high rate of fire of inert projectiles to destroy or fuze an incoming SSM (e.g., U.S. Phalanx), or on larger caliber rounds which utilize proximity or time-delay fused ordnance to destroy the incoming threat. Typical calibers of CIWS systems range from 20-mm to 76-mm.

a. *20-mm to 30-mm Systems*

Systems within the 20-mm to 30-mm CIWS range include the U.S. Phalanx, French SAMOS, Italian Myriad, Netherlands Goalkeeper, Spanish Meroka, Swiss Sea Zenith, and Russian 30-mm and twin 30-mm mounts. With the exception of Spain's Meroka and Switzerland's Sea Zenith systems all the CIWS systems within this group utilize either a single or dual "gatling" guns. The French SAMOS system is the only one of the group which does not have an associated fire-control radar system. Instead, it relies entirely on electro-optical tracking by a Volcan fire-control system. [Ref. 7:p. 428] Details of specific capabilites are provided in Table 11.

TABLE 11: CLOSE-IN-WEAPON SYSTEMS (20-MM TO 30-MM)

System Country	Caliber	Rate of Fire	Muzzle Velocity	# of Barrels	Effective Range	Ammunition Capacity
SAMOS France	30-mm			1 x 7 gatling		
Myriad Italy	25-mm	10,000 rnds/min.	1270 m/s	2 x 7 gatling	1,000m+	2,000 rnds
Goalkeeper Netherlands	30-mm	4,200 rnds/min.	3,300 ft/sec	1 x 7 gatling	2,000m	1,200 rnds
Meroka Spain	20-mm	9,000 rnds/min.	1,300 m/s	1 x 12 single	1,500m	720 rnds
Sea Zenith Switzerland	25-mm	850 rnds/min.	1,335 m/s	1 x 4 single		415 rnds/gun (1,660 rnds)
AK-630 Russia	30-mm	3,000 rnds/min.	1,000 m/s	1 x 6 gatling	2,500m	
CADS-1 Russia	30-mm			2 x 6 gatling		
Phalanx U.S.	20-mm	1,000-4,500 rnds/min.	3,650 ft/sec.	1 x 6 gatling	1,625 yards	989 rnds

Source: Friedman, N., Naval Institute Guide to World Naval Weapon Systems 1991/92, 1991, pp. 426-474.

b. *Heavier than 30-mm Systems*

Close-in weapon systems with calibers greater than 30-mm consist of either a single or dual barrel mountings. These weapons very often are designed to engage surface and air targets as well as SSMs, and may also be utilized for shore bombardment. The Italian firms of Breda and OTO-Melara and the Swedish firm Bofors produce the majority of the guns in this category.

The primary benefit of using weapons of this size against anti-ship missiles is their greater range. However, the range benefit can be negated by missiles performing large oscillations in either the horizontal or vertical plane, since the weapons aim point is based on a predicted position. A number of companies are currently working on course-corrected ammunition which would help to defeat maneuvering targets.

3. Overall

The majority of naval gun systems capable of operating from light frigate-size vessels and smaller is produced in a limited number of countries. Italy and Sweden control a large percentage of the market with their OTO-Melara, Breda, and Bofors weapons, while France, Switzerland, Netherlands, Russia, and the United States also contribute. Advances continue to be made in the areas of weapon rates-of-fire, dispersion, and ammunition lethality. Improvements in lethality due to technological innovations such as the proposed AHEAD (advanced hit efficiency and destruction) ammunition, under development by Oerlikon-Contraves, and course-corrected ammunition, should it prove feasible, would provide an alternative to point-defense missile systems for engaging maneuvering targets (SSMs).

E. SIGNATURE MANAGEMENT

Increasing attention is being given to reducing a ship's characteristic signatures. These include electronic emissions, radiated noise levels, IR emissions, and radar reflectivity. These signatures can be used by an enemy to detect, track, and initiate an attack against a ship. The open press has variously referred to attempts to manage detectable signatures as CCD (camouflage, concealment & deception), 'observable countermeasures', 'signature management', and 'stealth'. So-called 'stealth' technology has been used throughout history. The Trojan horse was a form of 'stealth' and so are smokescreens, camouflage paint and many other physical and electronic methods of avoiding detection or confusing enemy intelligence by denying him information on the size, intentions and capability of friendly forces.

Reducing the ship's various emission signatures that are exploited by SSMs will reduce the ship's detectability, therefore increasing the effectiveness of ECM and making the ship more survivable in combat. Stealth applications in terms of acoustic quieting reduce the radiated noise level that the ship transmits into the water, which makes them better ASW platforms.

The navies of the major industrial powers have incorporated various degrees of stealth into warship designs over the years. Efforts have ranged from simple applications of broad-band radar absorbing materials (RAM) all the way to exotic multi-million dollar floating stealth-technology testbeds. The U.S. Navy recently revealed photographs and specifications for *Sea Shadow,* a "black program" which had been conducted, starting in the mid-1980s, to test various stealth methods as applied to warships. The Arleigh Burke destroyers have benefited from this research and utilize hull shaping, acoustic quieting, IR suppression, and RAM coatings as methods of signature management. The British Navy applied inexpensive broadband netting to its surface fleet during the Falkland's War. [Ref. 29:p. 986] The French Navy's newest La Fayette class frigate is advertised to incorporate a number of stealth measures, including hull shaping and the application of RAM to reduce radar cross-section. The Danish

Navy has incorporated a number of stealth characteristics into both the STANFLEX-300 and larger Thetis class patrol vessels. The Swedish Navy is conducting experiments with *Smydge*, a SES prototype which incorporates extensive stealth technology.

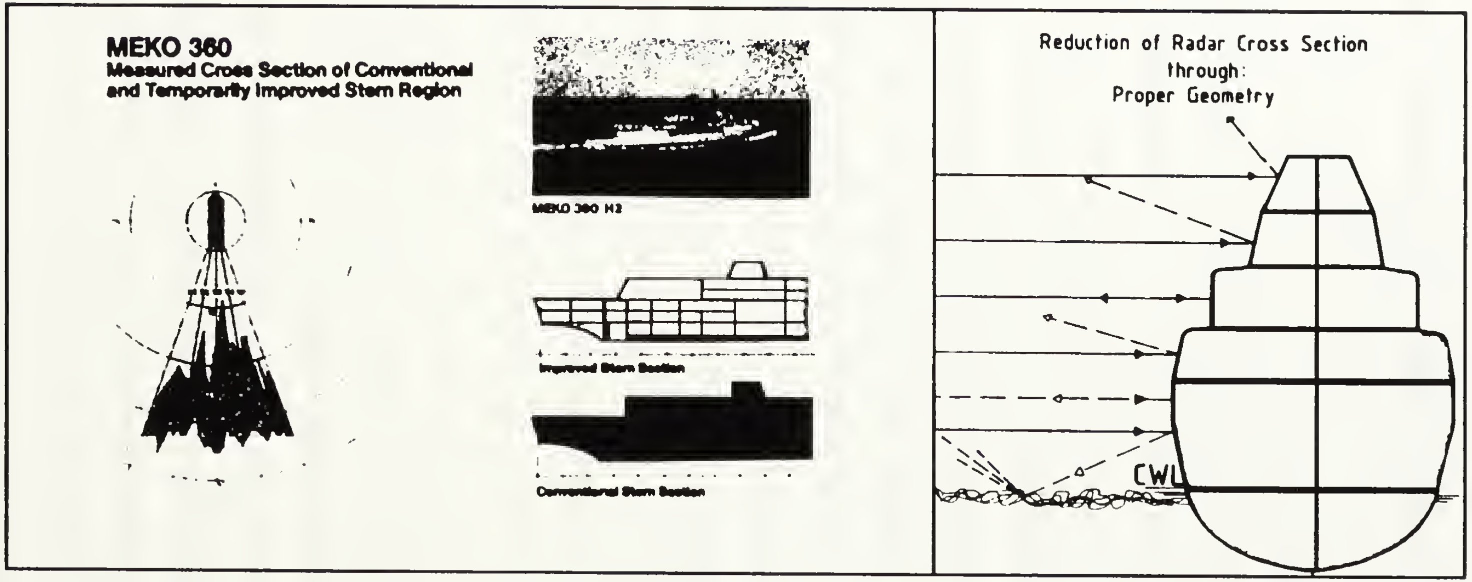
1. Radar Reflectivity Management

In the same way that materials can be made transparent, opaque or reflective to light, so they can be to radar. In order for a naval target to reflect radar, the target or features of the target must be the same size or larger than the illuminating wavelength of the radar waves.

The amount of radar energy reflected by a target is influenced by the size of the target, but also by its angular orientation, the absorption coefficient of the materials from which it is constructed and by the frequency of the illuminating radar. Radar cross section (RCS) is also influenced by the pulse width of pulsed radars. This effort to reduce the ship's RCS is aimed primarily at improving survivability against radar homing, anti-ship cruise missiles. The primary methods of reducing a vessels RCS is through hull shaping and/or the application of RAM.

a. Hull Shaping

Probably the easiest and most widely employed method to reduce a ships RCS is through hull shaping. Shaping is a simple concept in which designers orient reflective surfaces in such a way that instead of reflecting incident radar energy back they reflect it away from the illuminating source. Figure 4 shows the reductions in RCS which are possible by altering the shape of a ships hull. Corner reflectors and rectangular cavities return incident energy along the incoming path over a wide range of incident angles, whereas flat and



Source: MEKO-Technology, Blohm+Voss AG, P.O. Box 10 07 20 D-2000 Hamburg 1

Figure 4: Methods of Hull Shaping to Reduce Radar Cross Section (RCS)

curved surfaces return very little energy to the source except at normal incidence. The presence of corners and cavities on a naval vessel are the most significant features in producing a radar signature which can be detected from a wide range of surveillance locations. Large flat surfaces are only significant when observed from points which are at 90° to those surfaces. The main technique employed is to shape the superstructure to concentrate the echoes away from the enemy in one of a number of predetermined directions. This has lead to a superstructure that remains "box-like" but with sloping sides. Additionally, strong corner reflectors (orthogonal structures or di-hedrals and tri-hedrals) can be opened up by a few degrees and "detuned".

b. RAM Materials

In a radar absorbing material, radar waves enter the material with little reflection at the surface. The materials within the RAM are "electrically lossy" and absorb microwaves; minimal reflection takes place. Essentially, RAM converts micro-wave energy into heat via loss mechanisms which include resistance, di-electric and magnetic losses. Radar absorbers are usually either narrow band (resonant) and absorb at specific frequencies, or broadband and absorb over a wide frequency range. RAM coatings generally are produced in rigid sheet form or as coatings or spray-on materials.

Early, first-generation RAMs were mostly narrowband, resonant, quarterwave, threat-specific materials. These were tailored to counter the threat of Exocet missiles. [Ref. 29:p. 988] Subsequently, in second and third generation RAMs maximum attenuation has been traded for improved broad-band performance.

2. Acoustic Quieting

The chief sources of noise and vibration on a large naval vessel are usually associated with the operation of engines and auxiliary machinery and with the noise generated by rotating propellers. Machinery of different types will radiate sound at distinct frequencies (or tonals). Thus, there are specific tonals associated with gearing caused by the meshing of gear teeth; there are tonals associated with the blades of turbines; and there are a wide variety of tonals caused by the design of an electric motor.

Many of the methods to reduce the amount of transmitted noise from a surface ship have been learned from the operation and experiences of submarines. These include: single and double rafts on which equipment is mounted in order to isolate it from the hull; flexible joints on piping runs; acoustic enclosures; application of sound deadening insulation on the inside surface of the hull; and the application of anechoic tiles to the exterior of the ship. Active measures can include air-fed systems such as 'Prairie Masker', which operates by bubbling a thin film of air on the exterior of a ships hull, and around the propellers, in order to reduce acoustic detection ranges.

3. IR Management

As is the case with radar cross-section, prediction of IR signatures relative to background IR levels is of great importance. The radiation incident upon an object, its absorbability and reflectivity, and its thermal conductivity and heat capacity will all influence the surface temperature of an object. So too will ambient conditions, such as rain and other precipitation, and the effect of conduction by sea wash and air flow when the ship is underway.

The principal objective of IR signature control is to address the middle IR (MIR) between 3mm and 6mm; and the far IR (FIR) between 6mm and 15mm regions. Two well-known "windows" occur where transmission of IR energy is greatest. These are centered on 4mm and 10mm. [Ref. 29:p. 992] The MIR region is significant because these are the frequencies used by missiles equipped with IR seekers, while the FIR region is utilized by IR surveillance devices.

The main producer of IR radiation is the engine exhaust and the area in the immediate vicinity of the engine uptakes. One obvious way of eliminating an above-water engine exhaust signature is to have the diesels and auxiliaries vent underwater. Diesel engines can withstand the high backpressure involved, but it is still necessary to have them vent above water on starting. In the case of gas turbine powered ships, the metal surfaces of the exhaust can be cooled and the hot exhaust exhaust plume can be cooled by diluting it with cool air drawn into the upper part of the engine uptakes.

4. Swedish *Smyge*

The Swedish Navy is conducting tests on a grp-foam (glass reinforced plastic) sandwich twin-hull SES technology demonstrator named *Smyge*. Smyge's main purposes are:

- to provide experience of stealth technology in order to give future combat vessels a high life expectancy due to them being difficult to see visually, with radar, IR, magnetic or hydro-acoustic sensors at affordable cost;
- to serve as a test platform for new weapons systems, sensors, communications and navigation equipment, individually and with other systems in field conditions; and

- to provide experience of SES technology and the suitability of the configuration for seakeeping and as a weapons platform, and operational characteristics in heavy weather and ice conditions. [Ref. 30:p. 243]

The 30 meter, 140 ton demonstrator is capable of speeds of 50 knots, and carries a crew of 14 (6 officers, 8 ratings). [Ref. 30:p. 243] All normally exposed weapons and equipments have been made retractable where possible and covered with flush hatches, and merged into the form as far as possible when they cannot be concealed. Waterjet propulsion has been selected because of its lower noise levels at higher speeds. The weapon-fit comprises a Bofors 40-mm dual-purpose Trinity gun, contained in a low radar cross section (RCS) cupola, two RBS.15 anti-ship missiles on retractable launch ramps, and 400-mm wire-guided/homing A/S torpedoes launched through a hatched port in the stern. [Ref. 30:p. 243] A dipping sonar or light towed array sonar can be raised and lowered from the "moonpool", located at the center of gravity of the vessel for easy handling.

F. CONCLUSION

Modularity of design and the concept of building ships with the space and weight for later additions of weapons provides great benefits, particularly for navies who expect to operate relatively close to home. Ships configured to perform EEZ patrols primarily, can, during periods of regional tension, re-configure to perform naval missions. This provides poorer maritime nations with a flexible naval platform.

The technologically developed countries of the world, primarily Western Europe and the United States, continue to be the major suppliers of advanced weapons systems. These countries have the research and development (R&D) capability and the technological base necessary to produce the most advanced weapons. The widespread distribution of these weapons and the technology which makes them work, principally anti-ship missiles, has resulted in a number of indigenous programs.

Reductions in characteristic signatures of ships are expected to continue as more shipbuilders take advantage of lessons learned from the industrialized world. This is especially true in the area of hull shaping, which is basically a no cost benefit to ship design. Future ships can be expected to be more difficult to detect, and the armament which they carry will be less certain.

The next chapter will examine the various electronic and computer-based command and control systems which are available for installation into smaller ships. As technology progresses and computational capability becomes more compact, the military capabilities of smaller ships improves. Ship hulls are expected to remain functional for approximately 30 years, however, electronic systems are considered obsolete with ten years or less.

V. ELECTRONIC AND COMMAND DECISION SYSTEMS

A. ELECTRONICS

While it may be possible to compromise on displacement and length, machinery and armament, there is one area where there is no room for compromise in a warship's design -- and that is the area of electronics. The heart of any modern warship is its electronic equipment, for virtually every aspect of a warship's design demands some connection with electronics. Any major advances in warship capabilities in all likelihood will be centered around electronics. This could include new or improved methods to integrate and display data, faster computer processing capability, better detection or counter-detection capabilities, or better target discrimination.

The main area for concern relates to the surveillance and detection of all friendly, hostile and neutral targets, the integration of all relevant data gathered concerning those targets, and the control and direction of weapons used to defend the ship or attack hostile forces. The electronics systems integrated with the weapons make up the ship's combat system.

B. ELECTRONIC WARFARE SYSTEMS

1. Defining Electronic Warfare

Electronic warfare (EW) and the equipment which supports it is highly specialized. "The exploitation of the enemy's use of electronics, and the taking of measures to counter his use of such techniques, is known as Electronic Warfare, or EW." [Ref. 31:p. 34] In doing so, EW can frequently be of greater tactical value than radar which, generally, only pinpoints the location of a contact (target) without having the ability to identify it. On the other hand a complete EW suite, which includes ECM and ESM, has the ability to intercept, characterize, and execute deception procedures against hostile radars and missile seekers.

2. Producers and Consumers

Many countries are acquiring modern weapons and electronics that are easy to transport, operationally simple and effective against expensive, sophisticated U.S. weapons and platforms. As a result, U.S. aircraft and ships are vulnerable in many parts of the world where they long have been immune to advanced weapons and EW threats. Table 12 lists the countries which are primary producers of EW equipment and those third-world countries which are recipients. This table lists all EW equipment transfers not just naval systems. In addition to these primary suppliers, a number of countries have recently begun producing EW equipment for export. These include Australia, Chile, Denmark, Norway, South Africa, and Spain. Further down the road looms the spectre of nations such as Brazil, Czechoslovakia, Hungary, India, Japan, Singapore and Taiwan getting into the game. All already have or are capable of developing an indigenous EW base and all have the potential of becoming exporters. [Ref. 32:pp. 42-47]

TABLE 12: THIRD WORLD COUNTRIES WITH EW CAPABILITY

	Country Manufacturing Equipment					
	U.S.	Russia	France	Italy	Israel	U.K.
Algeria		x				
Argentina			x	x	x	
Bahrain	x					
Brazil			x	x		x
Brunei						x
Chile					x	
Colombia					x	
Equador				x	x	
Egypt	x		x	x		
India		x	x			x
Indonesia			x		x	
Iran	x					
Iraq		x	x			
Israel	x				x	
Jordan	x		x			
Kuwait	x		x			
Libya	unknown sources					
Malaysia	x		x			
Morocco			x			
Nigeria				x		
N. Korea		x				
Oman						x
Pakistan	x					
Peru			x	x		
Qatar			x			
Saudi Arabia	x		x			x
Singapore	x				x	
S. Africa					x	
S. Korea	x					
Syria		x				
Taiwan	x				x	
Thailand	x				x	
Tunisia			x			x
U.A.E.	x		x	x		x
Venezuela	x			x		

Source: *Journal of Electronic Defense*, November 1992, pp. 42-47

3. Chaff and Decoy Launchers.

Chaff and decoy launchers are the portion of an EW system which launch various off-board countermeasures, flares, and decoys. Decoy launchers are considered essential as an extremely cost-effective means of self protection. For a start, since they operate from locations away from the ship itself, their use offers a minimum-risk solution to the anti-ship missile problem. The greatest protection is provided by integrated EW systems which automatically deploy expendables (chaff and flares) and calculate and recommend ship courses to steer. Israel utilized a combination of chaff and tactics during the 1973 Arab-Israeli conflict to neutralize Arab *Styx* missiles. Over 50 *Styx* missiles were fired, with not one hit. [Ref. 33:p. 325]

Ships typically deploy chaff (and IR decoys) by launching them from fixed or trainable launchers, using rockets or mortars. Rockets provide longer range (for the dilution role) and do not impose any load on the surrounding deck. This is important since deck flex, in the case of an aluminum superstructure, can result in the round either not reaching its full range or not firing. Rockets however, are relatively large, and a designer must protect against backblast. Both types exist in considerable variety and are widely available. Major manufacturers of launchers and expendables include France, Germany, Israel, Italy, Sweden, Taiwan, Russia, Britain, and the U.S. [Ref. 7:pp. 475-546]

a. Chaff Techniques

Chaff launched from a ship can have one or more of three distinct functions. Firing at long range, the chaff can provide a targeting radar or an incoming missile with multiple spurious targets. If all targets must be engaged, the attack is diluted, and close-in weapons have a better chance of dealing with those weapons which do lock onto the ship itself. The second, intermediate-range function is to seduce the missile seeker away from the ship target onto a decoy cloud. Finally, there is a last-ditch tactic, centroid seduction. The missile's seeker generally homes on the centroid of the target's return, seeing the ship target as a complex array of point and corner reflectors. If a large chaff cloud is added, it moves the centroid up and away from the ship target, and the missile may pass overhead or to the side. Sophisticated SSMs however, will incorporate one or more counter-countermeasures to help it distinguish the target ship from the chaff cloud.

b. Other Decoys

In addition to being able to fire radar reflecting chaff, decoy launchers also fire flares designed to decoy SSMs equipped with IR seekers. These flares may be fired separately from or as part of a chaff cloud. The latest addition to the off board countermeasure arsenal is the addition of sophisticated active decoys. These decoys would either be fired from a chaff launcher of deployed from the ship to float on the water of hover in the vicinity. The advantage of these types of active devices is their ability to transmit electronic signals in hopes of decoying even the most sophisticated missile seekers.

4. Electronic Counter-Measure Devices

ECM devices fall into two broad categories, intercept receivers (often termed ESM, electronic support measures) and active counter-measures (jammers and more sophisticated deception devices). ESM includes not only attack warning but also passive detection of air and surface forces beyond the sensor's horizon. The success of defensive EW activities depends very much on the defender's ability to detect and recognize the presence of a threat in a timely fashion, and on his ability to counter the threat with whatever means he has available, whether by jammers, chaff or other forms of off-board decoy.

Compared to their Soviet counterparts, many Western naval radars can be significantly more difficult to detect and identify on ESM because they operate in crowded frequency bands and radiate at low peak power levels. In some cases their emissions may be indisquingishable from commercial radar signals. Because of the widespread use of monopulse tracking techniques, Western fire-control radars and missile seekers are also more difficult targets for ECM than their more conservative Soviet equivalents.[1]

All corvette/light frigate vessels currently being purchased are equipped with some sort of ESM equipment, however, not all are equipped with active jammers. The vessels supplied from the former Soviet Union, and now Russia, are by far the most obviously lacking in active jamming capabilities. The Chinese supply some of their customers with jamming equipment and not others. This may be due to the customer not wishing or being able to afford the equipment, as much as it could be a policy on the part of the Chinese government.[2]

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[1]For a more detailed description of Soviet and Western design practices, including operational frequency bands see, Ian Hall, "Western Weapons Systems, Countering the Home Grown Threat", *The International Countermeasures Handbook*, 16th Edition, 1991.

[2]This determination was made after careful review of current open-source literature.

C. RADAR SYSTEMS

A comprehensive examination of radar fundamentals is beyond the scope of this paper, however, a brief overview of basic principles, current systems, and advanced technologies is included.

1. Radar Basics

Radar systems, although varied, are all designed to perform a similar function: to transmit and receive electro-magnetic energy in order to detect the presence of objects. Radar's primary uses on ship are for surveillance of the sea and air zones around the ship and acquisition and tracking of targets of interest. Surveillance covers a wide variety of functions, from detecting high-speed SSMs, to detecting the ships those missiles are intended to hit. After detecting the presence of a contact it is necessary to obtain periodic updates in order to calculate the contact's bearing, range, course, speed, and altitude (airborne contacts). These periodic updates, fused with information from other sensors or platforms, permits a ship to develop a "track" on a contact.

Surveillance radars are generally categorized as being either two dimensional (2-D) or three dimensional (3-D). Two dimensional radars provide only a range and bearing to a contact, while 3-D radars also provide an angular component (from horizontal) which is converted to altitude. Most current radars utilize a rotating antenna and are therefore able to obtain updates only as often as the antenna scans past the contact. Typical long-range air-search radars scan at six to 12 rotations per minute, surface-search radars at 12 to 24 rotations per minute, and fire-control radars at 40 to 60 rotations per minute. Phased array radars on the other hand, such as the U.S. Navy's AEGIS (SPY-1) radar, are able to electronically steer their radar energy, which enables contact updates several times per second, if necessary. [Ref. 7:p. 337]

The number of companies manufacturing naval radar systems is limited. Companies such as Marconi, Thompson-CSF, Philips, Elta, Gem Elettronica, BEAB (formally PEAB), Ercisson, Contraves, Plessey, and Raytheon produce most of the current naval radars.

2. LPI Technology

Low Probability of Intercept (LPI) systems are most commonly discussed in connection with proposed "stealthy" aircraft and ships. Their attraction is that they achieve constant radar coverage without giving away the presence of the platform whence they radiate. LPI performance can be achieved in two complementary ways. One is to spread the radar signal over so broad a spectrum of frequencies that it is mistaken for random noise; the signal could be detected (e.g., by the receiver) only if the random combination were decoded. The other is to break up the characteristic radar scan into a pseudo-random hopping from one beam position to another. This entails electronic scanning, and any fixed phased-array radar, like SPY-1, should be programmable for such scanning.

a. Uses for "Quiet" Radars

LPI, or "quiet", radars are advertised as being useful for the following:

- wherever navigation or detection of surface vessels is desired without emitting high peak power pulses;
- coastal monitoring;
- ideally suited to prevent the detection of a submarine by ESM; and

• allows vessel movements to be monitored, without being detected by radar receivers, to aid policing actions.

b. Operational Systems

The application of LPI radar technology is still new, however a number of companies have fielded operational systems. The two systems which currently show the most promise are PILOT and SCOUT. Both operate on the same principle of frequency-modulated continuous-wave (FMCW) transmission, and each utilizes 1 watt (1W) or less average power.

(1) PILOT Covert Naval Radar. PILOT is a naval LPI radar that uses FMCW technology. PILOT is a joint venture of Signaal, Philips Electronics of Sweden, and the Philips Research Laboratories in the United Kingdom. The feasibility of FMCW technology was demonstrated in the spring of 1986, and PILOT was announced in April 1988. The system has undergone extensive testing, both at sea and in the laboratory. In one case a PILOT-equipped ship was able to turn on her radar during a radar-silence exercise without being detected by ships operating in company with her. [Ref. 7:p. 279] The FMCW transmissions of the PILOT radar have an average power of 1 Watt, compared to the 10kW peak and 10W average power levels for a conventional pulsed radar. [Ref. 34:p. 1177] PILOT has an ESM counter-detection range of approximately 1.3 nautical miles since ESM receivers are triggered by the presence of a powerful peak signal. [Ref. 34:p. 1177] PILOTs capability to detect small, non-metallic surface vessels has also been tested.[3]

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[3]For complete details of test conditions and results see, Magnavox Signaal Systems Company, PILOT Trial-Report, "Searching for the Limit", June 1989.

(2) SCOUT. SCOUT is the Signaal equivalent of the Swedish PILOT. It is a solid state FMCW radar, operating in I band, with a selectable output power of 1 milliwatt to 1 Watt. [Ref. 35:p. 6] It has demonstrated the ability to detect fast patrol boats (FPB) at a range of 15 nm, larger ships to the radar horizon, and small wooden boats at 8 nm. [Ref. 35:p. 6]

D. ELECTRO-OPTIC SYSTEMS

Electro-optic (EO) systems utilize sensors to search various portions of the frequency spectrum. IR sensors utilize the IR windows centered at 4μm and 10μm and electro-optic systems utilize the visible portion of the electromagnetic spectrum much the same way as the human eye. They can be utilized to search for, and track targets, and in the controlling of weapons directed against those targets. EO systems are now being recognized as providing a vital alternative to radar fire control when electronic silence has to be maintained. They may be configured for "stand alone" operation or as an integral part of a fire control radar. The majority of currently available systems employ IR and television sensors, and utilize a laser to determine range to the target. The laser could also be utilized in illuminating targets for laser guided munitions. EO systems are manufactured by Canada, France, Germany, Israel, Italy, Netherlands, Sweden, Russia, Britain, and the United States.

E. COMMAND AND CONTROL SYSTEMS

1. Definition

A 'command system' is often used to refer to a tactical computer system which serves the command and control process. Because of the ambiguous nature of the term 'command system', the term Combat Direction System or CDS was introduced. A CDS is a computer or collection of computers, organized into a system, which provide all the facilities for directing the fighting capabilities of a warship. [Ref. 31:p. 96] This includes the ability for command and control, but also covers the semi-autonomous computer sub-systems which control each sensor and weapon.

2. Purpose

Tactical data-handling systems, or CDS, perform two related functions. First, they integrate available sensor data into a meaningful tactical picture, generally in the form of a 2-D plot of the sea and surrounding air area. Such a plot includes some attempt to identify the occupants of that surrounding area, at least in terms of friendly, enemy, or neutral.

Secondly, they often partially or completely automate the results of decisions taken by means of the plot. For example, using an electronic plot, an officer may designate a target for attack with one or more of the ships available weapons. This designation at a console in the combat information center (CIC) will result automatically in the proper orders being given to, say, the gun control console. In some systems automation extends further. The combat system identifies particularly urgent threats, based on sensed information and previously incorporated instructions, and initiates reactions (such as launching chaff or firing missiles) against them. In such cases the display allows the monitoring officer to abort the reaction while it is being made.

The need to integrate and automate command functions is a result of the number and speed of available weapons and platforms. It may be that the driver toward automation on smaller ships is primarily the need to limit manpower while still taking advantage of external sources of data, such as data links to shore and airborne radars.

The essence of any tactical situation is that it is dynamic, and therefore, a system designed to aide the tactical decision maker must be able to display not only instantaneous sensor data but also enough of the history of the movement of any target to permit projection ahead. Integration of ESM and active-sensor data may also be valuable as a means of identifying given tracks.

3. Fire Control Systems

Fire Control Systems (FCS) consist of the sensors (radar, sonar, electro-optical) used to detect, acquire, track, and direct ordnance, and the associated computers used to calculate proper aim points and correction of weapons. FCS may be incorporated as part of a Tactical Data System, or operate completly independently. The boundary between a highly automated FCS (which can be fed by a command/control tactical data system) and a full command/control system incorporating fire-control calculations is not very clear.

4. Centralized vs. Distributed

The terms centralized and distributed refer to the computer architectural arrangement of the combat-direction system.

a. Centralized Systems

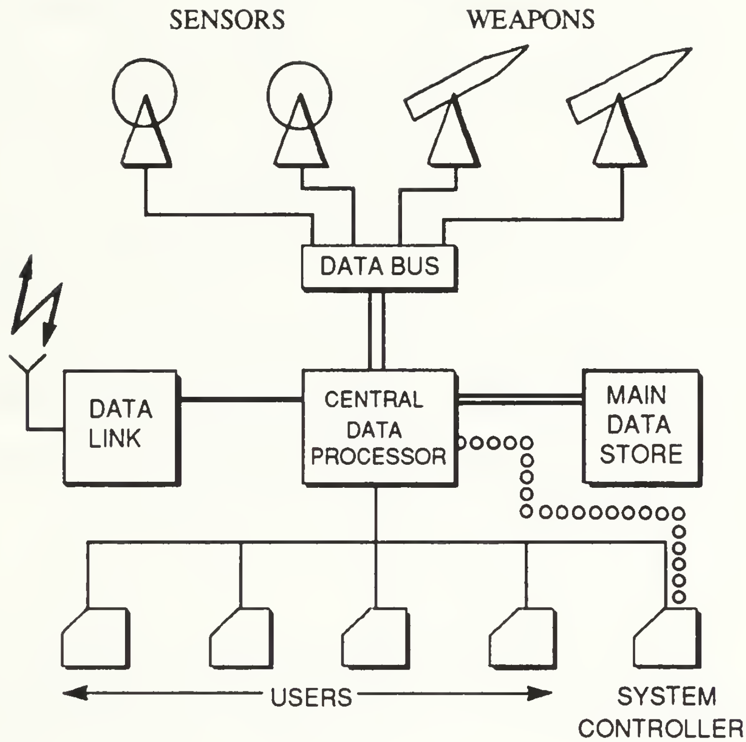
A fully centralized system is configured so that all data handling and mathematical computations for fire control solutions are handled within a central computer. The major advantage is that since both the tactical picture and at least some of the system functions are bundled together in one machine, it can (at least in theory) execute those functions very quickly to respond to a rapidly developing tactical situation. This type of architecture has several major disadvantages, however, including:

- the input/output channel of the picture-keeping computer is a choke point whose capacity may be easy to exceed, given modern automatic-detection radar systems;
- the more centralized the computer, the more seperate functions it must perform on a time-shared basis. Ultimately there is only one processor to carry out all the different functions;
- the computer itself is a point of vulnerability. If it dies, so does the system; and
- highly centralized systems are not quickly modified.

Figure 5 is a simplified diagram of a centralised CDS. The British ADAWS (Action Data Automation Weapons System) is an example of a centralished CDS in which the central computer performs fire control calculations as well as maintaining the tactical picture.

b. Federated Systems

A federated system is one in which the central computer is utilized to maintain the tactical picture, and separate computers linked to the



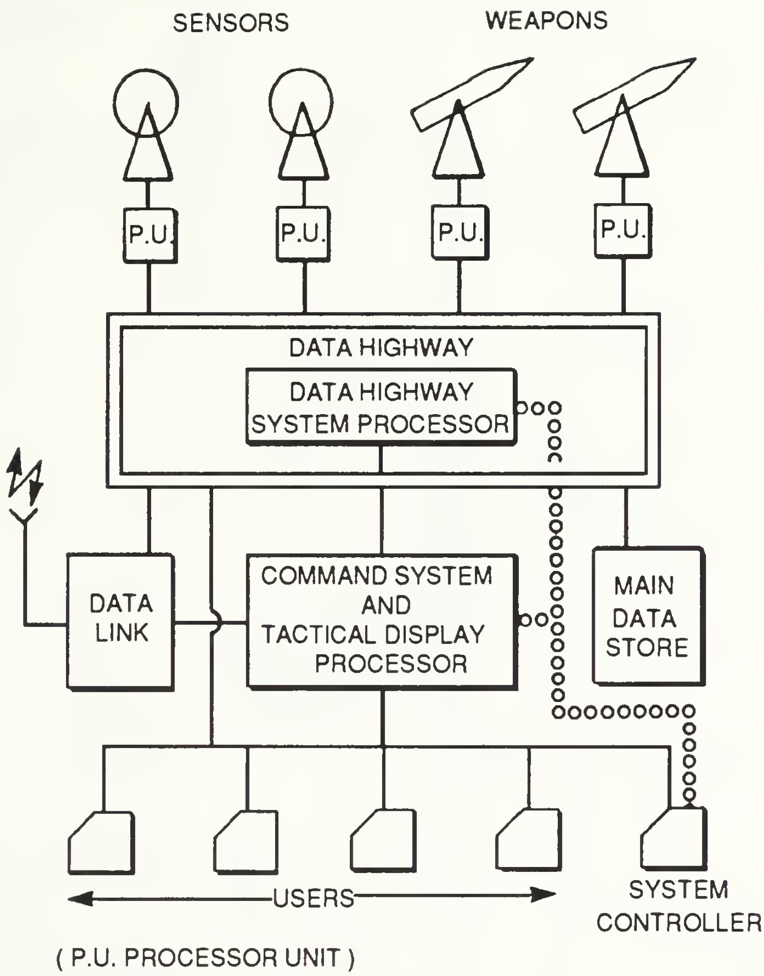
Source: Pakenham, W.T.T., Capt, RN, Naval Command and Control, Brassey's Defense Publishers, 1989, p. 97.

Figure 5 : Centralised Combat Direction System

central computer handle much of the processing. Compared to a fully centralized one, a federated system has a very important advantage. Each console can be programmed independently, so new systems and new functions are relatively easy to fit into the system. There are two distinct federated architectures. One is star-like: the picture-keeper connects to a series of secondary machines, each of which connects to particular sensors and/or weapons. The other is a linear or ring-like combination of computers, each assigned a particular role, and all wired tightly and directly together. The latter architecture is a step toward a fully distributed system, but it is very different because of the tight relationship between the computers in the network. In the latter case the key feature is that messages are sent directly from computer to computer, without any intervening data bus. Some messeages may have to pass through several computers (which may not operate on them) before reaching the appropriate address. The effect of a data bus, if it is combined with the appropriate software, is to seperate messages and message handling from the main computers.

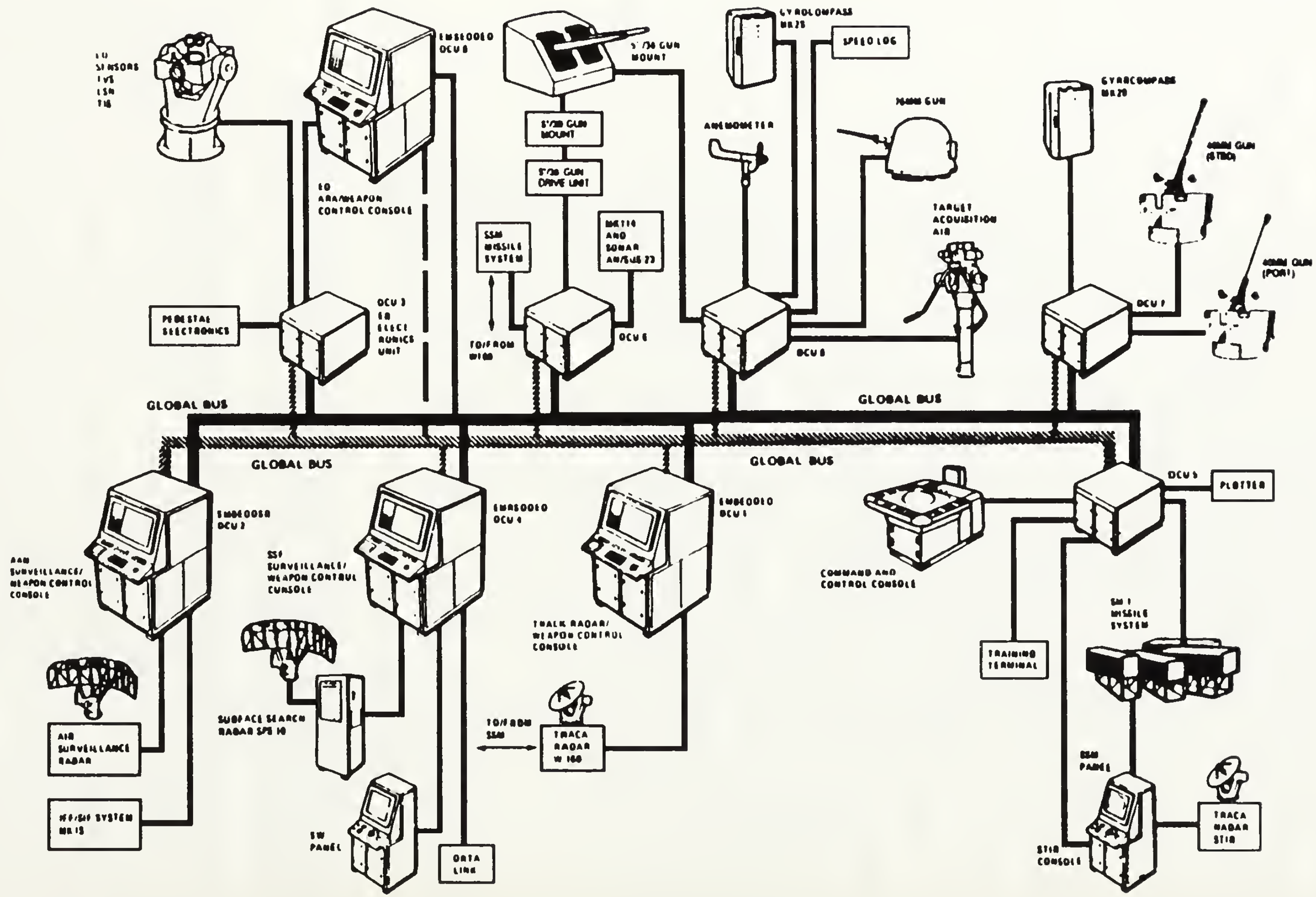
c. *Distributed Systems*

As minicomputers become more powerful, a greater degree of distribution becomes attractive. There are two quite different distributed architectures currently. In the first, weapons, sensors, and processors all ride a common ship bus. Examples are the Hughes H930 and the Plessey NAUTIS systems. Such a system has no bottlenecks at all. Each processor can execute any function (e.g., track keeping or gun fire control), since all share the same stream of data and messages. Figure 6 is a generic example of a distributed Combat Direction System, and figure 7 is an example of a Hughes H930 Mod 4 distributed CDS. Hughes claims that their H930 system is the only truly



Source: Pakenham, W.T.T., Capt, RN, Naval Command and Control, Brassey's Defense Publishers, 1989, p. 102.

Figure 6: Distributed Combat Direction System



Source: Friedman, N., The Naval Institute Guide to World Naval Weapon Systems 1991/92, p. 89

Figure 7: Hughes H930 Mod 4 Modular Distributed Combat Direction System

distributed system in current service, that systems described as distributed are really no more than multiprocessor types in which the seperate processors are so tightly connected that the failure of any one will disable the system as a whole. [Ref. 7:p. 87]

The alternative is to arrange the processors in a local-area-network (LAN), a special-purpose data bus. This bus in turn connects to the weapon/sensor bus or busses. The LAN acts as a central computer complex; but unlike a single-computer system, it degrades gracefully. Each machine in the LAN carries its own version of the tactical picture, updated by actions taken by the other processors (and transmitted within the LAN). Such a system has the advantage that intra-LAN message traffic need not compete with the traffic along the weapon and sensor busses, so picture updates can be quicker and more complete. The major drawback to such a configuration is that the nodes at which the LAN connects to the weapon/sensor bus(es) form points of vulnerability. The LAN type of architecture is typified by the Dowty-SEMA SSCS (British) and by the Contraves Cosys 200 (Swiss).

5. Current Systems

The vast majority of the current CDSs exported for corvette/light frigate sized platforms is made within European countries. Italy and the Netherlands produce the majority of the CDS systems exported, although France and Britain also contribute. Systems such as Signaal's Sewaco series, Selenia's IPN 10 and IPN 20 systems, Thompson-CSF's TAVITAC (Vega IIIC), BEAB's (formerly PEAB) 9LV series, and Ferranti's CAAIS series of CDS systems are widely exported. Newer systems appear to be taking advantage of improvements in computer computational power as more distributed and federated architectures are appearing.

F. CONCLUSION

The number of producers of electronic equipment for naval vessels is concentrated primarily within the Western European nations. These countries produce the majority of the radar, fire control, and CDS systems currently available for export. Countries such as Isreal, however, produce many of their own electronic systems including radars, EW equipment, optronics, and CDS. The availability of equipment seems to be unlimited between producers and consumers, as long as hard currency is available. An example of this is the acquision of the Signaal STACOS CDS for the new Saudi Arabian corvettes. Producers are taking advantage of advances in technology and are utilizing more federated and fully distributed types of architecture in newer command data systems. This distributed architecture, coupled with redundant data paths greatly reduces the chance that a single hit will disrupt all combat functions. The new Sa'ar 5 corvette for Israel is expected to be fitted with redundant command data system communications paths and three locations onboard where all or some command functions can be performed. [Ref. 16:p. 299]

Developments in LPI sensors, to include radars and EO search and track systems is progressing and appears to have great utility. The development of these systems is, like most others, concentrated within a reasonably small number of countries. These systems by the nature of their operations will make it more difficult to exploit the electro-magnetic spectrum against an adversary.

VI. CONCLUSIONS

The future challenges facing U.S. naval forces, and the direction from which those challenges might come are more uncertain now than anytime in the last 40 years. Littoral disputes between countries over rights to natural resources, humanitarian assistance, piracy on the high seas, and naval quarantines to prevent the oceanic transport of dangerous materials are only some of the challenges facing naval forces. The Navy of the United States, designed during the Cold War, has been optimized to fight open ocean warfare against the former Soviet Union. The future, however, is expected to be contained not on the high seas, but in the littoral regions of other nations.

The number of producers of warships is expanding as a number of countries in the Pacific Rim develop a shipbuilding capability, with the help of the Western European countries. The number of producers of high technology systems to equip those warships is not increasing as rapidly, however. A limited number of countries, predominantly within the European continent, continue to produce the majority of the high technology weapons and electronics which are exported to other countries. The unlimited distribution of high technology weapon systems and electronics will likely mean that future naval confrontations will occur between participants who are similarly equipped.

A. CONCLUSIONS

Based upon an evaluation of the material the following conclusions are presented.

The level of sophistication of small warships is increasing, mostly due to the availability of equipment and technology from the Western European countries. These countries have come to rely on exports in order to reduce unit costs for equipment and ensure employment.

Without an identifiable threat which generates significant public condemnation, manufacturers of high technology weapons and equipment will continue to provide the best for those with hard currency.

The number of small fast attack craft in the inventories of smaller navies is expected to remain high, however, many navies will acquire larger corvettes and light frigate-size ships.

The concept of modular equipment modules and ships built with a "fitted-for-but-not-with" approach will become more prevalent. This will make ships more flexible in their capabilities, and make it more difficult to "know" how a ship is equipped at any given time.

Ship characteristic signatures are expected to become more "stealthy", due to improvements in hull design, LPI communications and radars, passive sensors, and acoustic quieting techniques.

Anti-ship missiles will continue to be the "weapon-of-choice" for surface warships. New designs will likely be supersonic, will take advantage of advanced technologies including low observable shapes and materials and passive or LPI seekers. Additionally, they will likely incorporate high-G terminal maneuvers to avoid defensive systems.

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