INDUSTRIAL ASSESSMENT FOR TORPEDOES

AUGUST 1995

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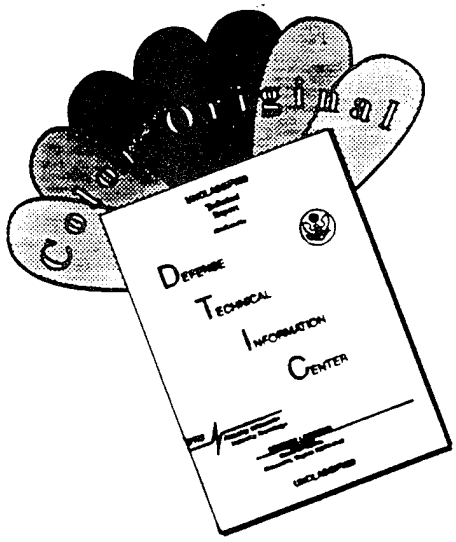

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PREFACE AND ACKNOWLEDGMENTS

Victory in the Cold War era has brought significant changes to the defense industry. Since the peak year in 1985, total defense procurement has declined by 67 percent in real terms. Defense suppliers have responded to these cuts in predictable ways. Factories have been restructured, reduced, or closed. Skilled personnel have been laid-off. Some firms have merged or restructured; others have abandoned defense production entirely. Because these changes could have important consequences for the Department's ability to meet its future mission requirements, we are analyzing the effects of these changes in selected industrial sectors. This report describes the results of one of those studies -- the Department's assessment of the torpedo industry.

This study was prepared under the direction of Mr. John Goodman, Deputy Assistant Secretary of Defense for Industrial Affairs. It was led by Mr. Tim Douglass, Program Executive Officer, Undersea Warfare and Mr. Martin Meth, Director, Industrial Capabilities and Assessments, Office of the Secretary of Defense. Representatives from the Navy, the Defense Logistics Agency, and the Office of the Secretary of Defense actively participated throughout the conduct of the study. The Department especially would like to acknowledge the contributions of Mr. Stephen Hull and Mr. Jim Thompson who served as primary technical advisors with assistance by Mr. Gary Powell who served as the overall study coordinator. The Department would also like to thank Mr. Ed Zdankiewicz, Deputy Assistant Secretary of the Navy (Mine and Undersea Warfare), for his support. Additionally, numerous individuals throughout the Department contributed substantial time and energy. This report would not have been possible without the knowledge, professionalism, and hard work of Dr. John Sirmalis, Dr. Paris Genalis, Captain Scott Atkinson, Captain Gary Nelson, Mr. Pete Duffy, Mr. Gary Letiecq, Mr. Bill Youngstrom, Commander Chip Herzig, Commander Stuart Nelson, Commander Steve Bedard, and Ms. Carol Digirolamo.

We welcome comments on this report. Please address them to Mr. John Goodman, Deputy Assistant Secretary of Defense (Industrial Affairs), 3300 Defense Pentagon, Washington, DC 20301-3300.

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EXECUTIVE SUMMARY

With the end of the Cold War and diminished threat levels, the Department of Defense (DoD) reduced its torpedo inventory requirements. As a result, the current inventory of torpedoes exceeds the Department's requirements and the Navy canceled planned deliveries of new torpedoes ("all-up rounds") after 1996. Based on current threat projections, the Department does not expect to require full production again for approximately 25 years when replacement torpedoes will be needed. Torpedo production capability is waning accordingly, and each of the prime manufacturers currently has excess torpedo production capacity. The Department does, however, have continuing requirements to advance torpedo technologies, upgrade the current torpedoes, and maintain the inventory. The Department expects that planned torpedo technology development, modification, and maintenance programs will sustain required industrial capabilities:

- Technology development programs will retain torpedo design and engineering knowledge and development facilities.
- Planned torpedo upgrade programs will sustain production engineering, systems integration expertise, and limited component production capabilities.
- Maintenance and operational support programs will sustain component engineering and repair skills.

U.S. Navy Torpedo Requirements

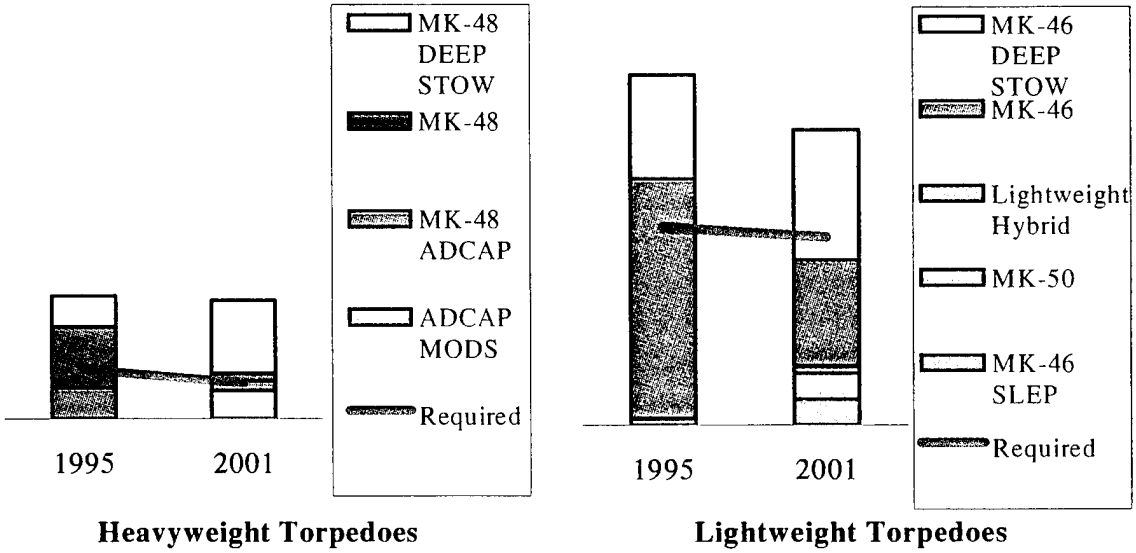
The Department uses acoustic homing torpedoes to locate, pursue, and destroy surface ships and submarines. The U.S. Navy uses two torpedo types, heavyweight and lightweight, for these missions. Heavyweight torpedoes are used solely by submarines and are employed against both surface and submarine targets. Lightweight torpedoes are used by fixed wing aircraft, helicopters, and surface ships for anti-submarine operations.

Torpedoes are complex systems designed to meet exacting performance requirements and operate in a difficult environment. The torpedo mission and undersea environment require a significantly unique design from other commercial or defense products. The result has been the

establishment of a sector with specialized facilities for torpedo development, production, and support. The prime contractor's torpedo systems design and engineering expertise is unique to torpedoes. Many of the components, however, *are* similar to other commercial and defense products and require few novel processes. Future torpedo programs may take more advantage of commercial products and use more common components and designs.

Figure ES-1 summarizes the U.S. torpedo inventory and the Navy's heavyweight and lightweight torpedo requirements.[1] The U.S. Navy has MK-46 and MK-50 lightweight torpedoes, and MK-48 and MK-48 Advanced Capability (ADCAP) heavyweight torpedoes. Currently, the Navy has approximately 4,000 heavyweight torpedoes in inventory, but only requires around 2,000 heavyweight torpedoes to meet projected warfighting needs. Likewise, the Navy has about 14,000 lightweight torpedoes in inventory, but only requires about 8,000. Older, less capable torpedoes are being de-activated and placed in long-term storage ("deep-stow") as the Navy reduces its active inventory.[2]

Figure ES-1. DoD Torpedo Inventory and Requirements



Heavyweight Torpedoes **Lightweight Torpedoes**

Source: Navy Non-Nuclear Ordnance Requirements.

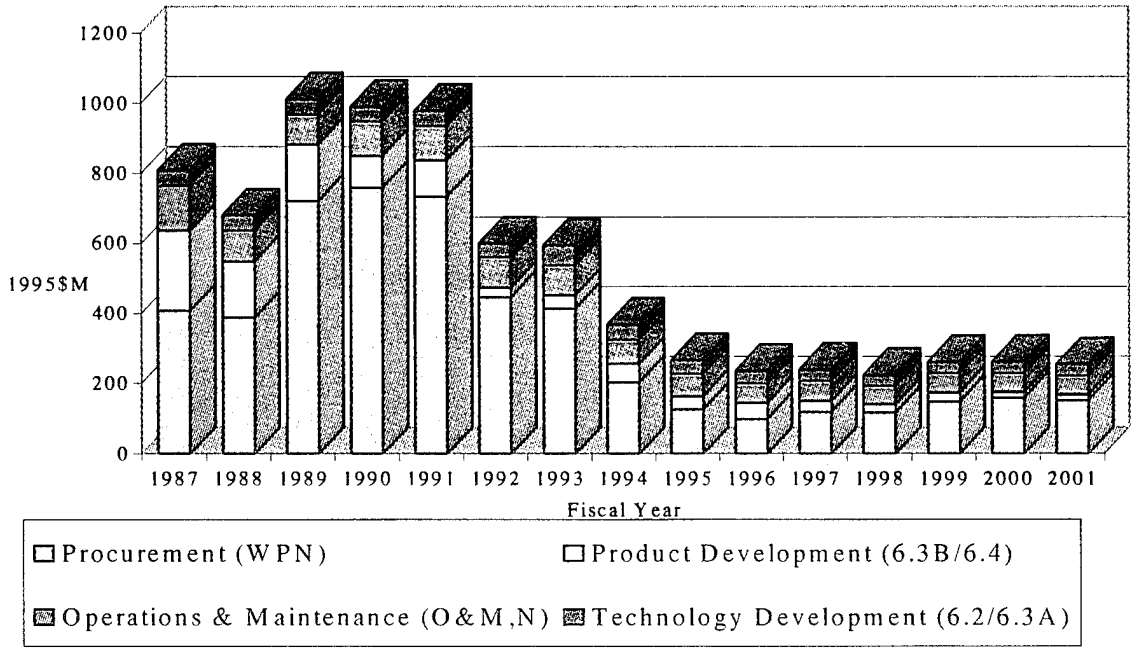
[1] The exact inventory and requirement values for the torpedoes are classified. All inventory and requirement values are therefore expressed in approximate terms.

[2] Although older and less capable, the weapons are still effective and meet operational requirements.

Two torpedoes, the MK-50 and the ADCAP, are being produced for the U.S. Navy. The MK-50 lightweight torpedo production will be completed in July 1996 and is not approved for export. The ADCAP heavyweight torpedo production for the U.S. Navy will be completed in December 1995 and is expected to be produced for export.

Lightweight and heavyweight torpedoes are supported by three activities: technology development, production, and support. The activities are performed by a combination of industry, academia, and Navy facilities and personnel. Figure ES-2 summarizes the torpedo funding supporting the three activities. Torpedo procurement programs use a combination of torpedo development funding (6.3B and 6.4 RDT&E) and production funding (Weapons Procurement, Navy). Currently, Navy-owned and operated activities, with academia and industry support, develop torpedo technologies and maintain the inventory. Three prime contractors, with support from component suppliers, produce torpedoes for the U.S. Navy and for export. Alliant Techsystems and Westinghouse Electric Corporation produce both lightweight and heavyweight torpedoes. Hughes Aircraft Company builds only heavyweight torpedoes.

Figure ES-2. Total U.S. Navy Torpedo Funding by Type



Source: FY1996-FY1997 President's Budget Submission.

Worldwide Torpedo Production

Torpedoes are purchased by almost all navies to support their military needs. In 1994, the value of worldwide torpedo production totaled $655 million, and some analysts expect it to rise almost 70 percent by 2002.[3] The increasing number of countries with diesel electric submarines and littoral[4] warfare surface craft is increasing torpedo demand. Additionally, the need to upgrade older, primarily deep water, torpedoes to improve their performance in shallow water increases demand in this market. The foreign heavyweight torpedo export market may be dominated by Sweden's Bofors (Torpedo 2000) and Germany's System Technik Nord (Seahake).[5] Bofors and System Technik Nord benefit from Sweden's and Germany's practice of packaging heavyweight torpedoes with diesel electric submarine sales. Worldwide lightweight torpedo production may be dominated by GEIE (Eurotorp) if development problems are rectified and the purchasing countries determine the escalating costs are acceptable.

In 1994, total heavyweight torpedo sales by U.S. firms were valued at $200 million, and total lightweight sales were valued at $140 million. That same year, U.S. heavyweight and lightweight torpedo export sales were $15 million each. Foreign sales are expected to represent an increasing percentage of U.S. production. By 1997, for example, Forecast International predicts that total U.S. torpedo exports will reach $115 million or 85 percent of total U.S. production.[6] Export sales include the NT-37 heavyweight torpedo and the MK-46 lightweight torpedo manufactured by Alliant Techsystems. The MK-48 ADCAP heavyweight torpedo (produced by Westinghouse and Hughes) has recently been approved for limited foreign sale. Although not required to meet the Department's requirements, some limited "all-up round" production capabilities will likely be maintained by foreign sales.

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[3] Projections are provided by Forecast International and amended for planned U.S. Navy production. The production expectations are based on a limited number of systems. Changes in customer requirements, national budgets, and system production rates will have significant impact on the projections.

[4] Coastal waters.

[5] GEC Marconi (a UK firm) is expected to sell a significant number of Spearfish heavyweight torpedoes to the UK government, but that torpedo is not expected to be authorized for foreign sale.

[6] Heavyweight torpedo exports are expected to reach about $55 million, and lightweight exports are expected to total $60 million.

Implications of Declining Production Requirements

All three U.S. prime contractors are currently profitable, as are their torpedo businesses. However, since all-up round production is ending and planned procurement programs are relatively small, future profitability is uncertain.

Most torpedo component suppliers have already completed deliveries and are exiting the torpedo business. Vendors supplying consumable and expendable items used for torpedo maintenance will be relatively unaffected by the end of torpedo production. Torpedo component vendors supplying replenishment spares will be affected to a greater degree, but components will continue to be available through vendor re-qualification, life-of-type buys, and reutilization from excess inventories.

Due to rapid torpedo component design and manufacturing process advances, it is unlikely that the same torpedo production processes, products, and skills will be required when full production is again required. Total re-establishment costs are estimated to be between $220 million and $245 million per torpedo type--or, measured in net present value, between $65 million and $75 million.[7] Sustaining torpedo unit production capability for one torpedo type with low-level production until after 2020 would cost between $40 million and $55 million per year.[8] Additionally, between $30 million and $95 million would be required to return to full efficiency. Combined, measured in net present value, these costs for low-level production fall between $605 million and $770 million. Given the substantial margin between the costs of the two approaches and the absence of a requirement for new torpedo production, sustaining limited production was rejected. Additionally, the expenditure would not provide much assistance to the development of a next generation torpedo which would likely rely on new technology and not necessarily require the same production processes.

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[7] Based on Navy developed estimates of contractor recapitalization, test equipment refurbishment, and learning curve efficiency costs.

[8] Estimate based on continued production of 25 MK-50 or ADCAP torpedoes each year.

Planned Programs and Retained Capabilities

The U.S. Navy will continue to support technology development programs to maintain technology leadership for the future. The Navy plans torpedo technology developments in the areas of guidance and control, propulsion, silencing and structures, and warheads and fuzing. Additionally, the Navy is developing process technologies to reduce cycle time and improve affordability. These programs will retain the torpedo systems engineering knowledge base, the component technical knowledge base, and the development and test facilities needed for future torpedo technology developments. Most importantly, these retained capabilities will also provide the technical knowledge base and test facilities needed by industry to transition future design concepts into production and will be available to help industry resolve component production and integration problems.

Several U.S. Navy torpedo upgrade programs are planned to improve shallow or littoral water torpedo operational capabilities to counter the emerging diesel electric submarine threat.

- The MK-46 Service Life Extension Program (SLEP) will resolve the lightweight torpedo's hardware obsolescence problems and incorporate limited shallow water performance improvements. The $8 million total production of approximately 1,000 MK-46 SLEP kits by Alliant Techsystems will begin in 1996 and continue until 1998.
- The Lightweight Hybrid torpedo program will upgrade existing MK-46 torpedoes with modern MK-50 guidance and control components and commercial electronics. The $560 million production of approximately 2,000 kits will be competed. Production will begin in 1999 and will continue until 2010.
- The ADCAP modification program will upgrade the guidance and control system and quiet the propulsion system. Westinghouse won the first of a series of planned contracts in June 1995. Approximately 1,300 kits are planned to be produced by 2003 at a value of $350 million.

The planned torpedo upgrade programs will sustain production engineering, systems integration expertise, and limited component production capabilities.

Torpedoes require maintenance and repair, storage and warshot issue preparation, refurbishment after exercise shots, and engineering services to resolve problems after fleet

introduction. These functions are supported by the Navy's intermediate and depot repair and in-service engineering activities.

In the context of reduced spending on torpedo programs, the Department will examine possibilities to expand industry's role in torpedo technology development, design, and support operations. Such efforts could provide fiscal benefits to the Department and make existing capabilities more robust.

1.0 TORPEDOES

1.1 Overview

The Department of Defense uses acoustic homing torpedoes to locate, pursue, and destroy surface ships and submarines. The U.S. Navy uses two torpedo types, heavyweight and lightweight, for these missions. Heavyweight torpedoes are used solely by submarines and are employed against both surface and submarine targets. Heavyweight torpedoes have a long-range propulsion system and an extended search capability to allow stand-off launch. Heavyweight torpedoes also have a large explosive payload to ensure the destruction of surface ships. Lightweight torpedoes are used by fixed wing aircraft, helicopters, and surface ships for anti-submarine operations. One lightweight torpedo, the MK-46, is also used as a mine payload where it is autonomously launched from a submerged CAPTOR (encapsulated torpedo) mine at an identified target. Torpedoes carried by aircraft and surface ships are much smaller and lighter than torpedoes carried by submarines. Since they are launched from a ship from a torpedo tube or on a missile (Vertical Launch or Anti-Submarine Rocket (VLA or ASROC)) or dropped by an aircraft near the target, lightweight torpedoes do not need the pursuit range and search capabilities required for heavyweight torpedoes.

Three prime contractors, with support from component suppliers, produce torpedoes for the U.S. Navy. Navy torpedo acquisition and technology programs are managed by three Navy organizations. The Program Executive Office for Undersea Warfare manages the acquisition and operational support programs. The Office of Naval Research manages the technology development programs. The Naval Undersea Warfare Center (NUWC), a component of the Naval Sea Systems Command, oversees and executes the technology development projects and provides operations and maintenance support. Various commercial and university organizations provide additional technical support.

1.2 Torpedo Evolution

Torpedo technology has evolved significantly over the past two centuries. The first torpedo, built in the early 1800s, consisted of no more than an explosive charge mounted on the

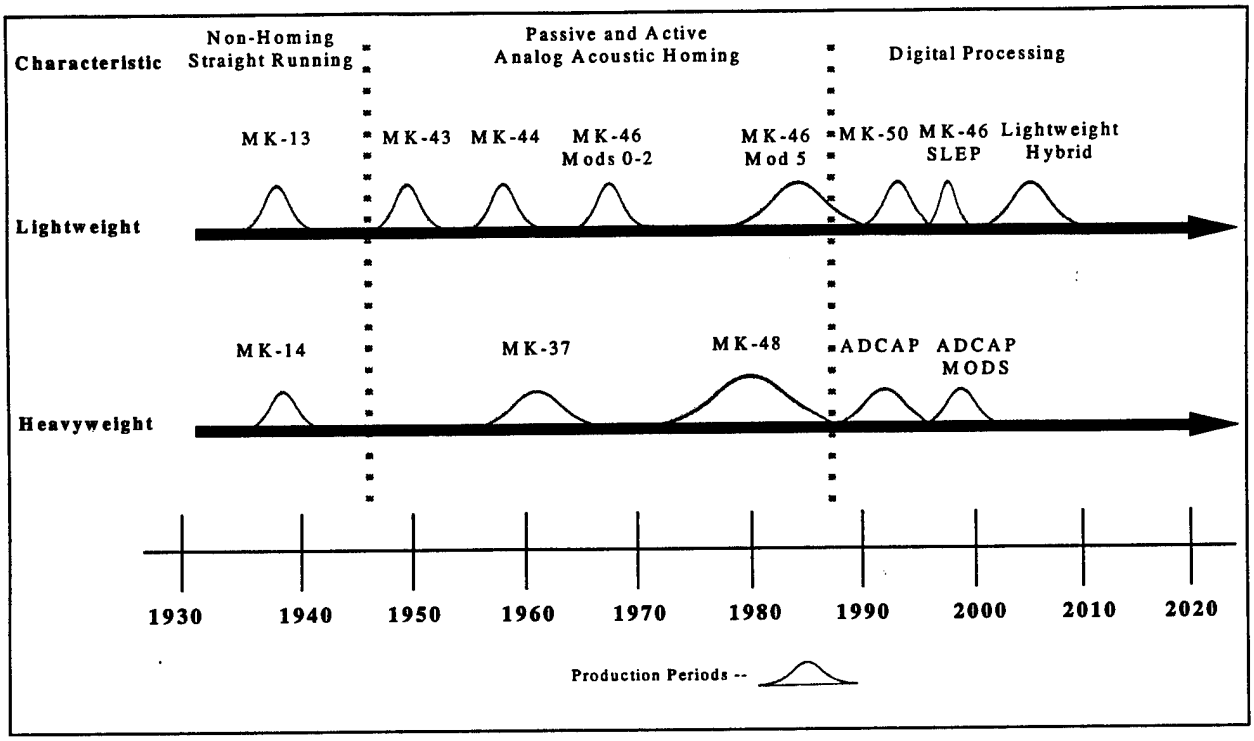
end of a spar that was extended toward an enemy vessel. In the mid 1800s, torpedoes were actually floating explosives, or mines. It was not until the late 1800s that torpedoes became self-propelled weapons.

In 1869, the U.S. Navy established the Naval Torpedo Station in Newport, RI to design, develop, and produce torpedoes. In World War I and World War II, the Naval Torpedo Station designed and built relatively simple non-homing, straight running, steam-powered torpedoes. By 1945, the Navy operated four torpedo stations. During World War II, the Navy torpedo stations and industry manufacturers produced over 25,000 torpedoes. After the war, the Navy transferred production functions to the private sector.

In the post-war period, torpedoes have undergone two major evolutions (see Figure 1-1). The first relied on the development of passive and active acoustic homing. Prior to this time, torpedoes were launched on a straight intercept course with a surface vessel. Sonar offered the ability to track targets by sound reflected off the target (active) or by sound generated by the target itself (passive). In the 1950s, this homing capability provided the first opportunity to employ torpedoes against submarines. The U.S. inventory consisted of two types of torpedoes: the electric MK-37 heavyweight and MK-43 lightweight torpedoes. As the Soviet submarine force developed quieter, faster, and deeper diving capabilities, the U.S. responded with the production of the MK-48 heavyweight torpedo and the MK-46 lightweight torpedo. The MK-48 provided significantly increased speed, endurance, and warhead yield, while the MK-46 provided surface ships and aircraft with improved anti-submarine warfare capability.

The second major evolution occurred in the 1980s with the integration of improved software capabilities and propulsion systems. These systems, used in the MK-48 Advanced Capability (ADCAP) heavyweight torpedo and the MK-50 lightweight torpedo, permitted the detection and prosecution of evolving threat targets and offered increased speed and depth. Historically, there were gaps between production runs of five to ten years.

Figure 1-1. Torpedo Development Cycle



1.3 Existing Products

Currently, the U.S. Navy uses the MK-46 and MK-50 lightweight torpedo, and the MK-48 and ADCAP heavyweight torpedoes (see Table 1-1). Only the MK-50 and ADCAP are still in production, but procurement will be completed in 1996. Torpedo upgrade programs are planned, but no "all-up-round" or full torpedo production is needed for approximately 25 years when replacements for the MK-50 and the ADCAP will be required. It is likely that other upgrade programs will be initiated in the interim to maintain operational effectiveness.

Table 1-1. U.S. Navy Torpedo Description

Torpedo	Type	G&C	Propulsion	Warhead	Platforms	Characteristics
MK-46	Lightweight	Analog	Open cycle OTTO fuel	Bulk Charge	Surface Ships Fixed Wing Rotary Wing	12.75" diameter 8.5' long 500 pounds
MK-50	Lightweight	1980's Digital	SCEPS based	Shaped Charge	Surface Ships Fixed Wing Rotary Wing	12.75" diameter 9.25' long 750 pounds
MK-48	Heavyweight	Analog	Open cycle OTTO fuel	Large Bulk Charge	SSN SSBN	21" diameter 19' long 3000 pounds
MK-48 ADCAP	Heavyweight	1980's Digital	Open cycle OTTO fuel	Large Bulk Charge	SSN SSBN (some)	21" diameter 19' long 3900 pounds

Current Production

MK-50 Torpedo

The fast, deep diving, double hull Soviet threat in the mid-1970s drove the development of the MK-50 lightweight torpedo. The MK-50 was the first digital lightweight torpedo with reprogrammable tactical, autopilot, and sonar signal processing software. It employs a Stored Chemical Energy Propulsion System (SCEPS) which makes it capable of high rates of speeds at deep depths. It also has a shaped charge warhead capable of penetrating titanium double hulls. The break-up of the Soviet Union and its decline as a naval power has significantly reduced the required number of such torpedoes. As a result, the Navy expects to complete procurement of the MK-50 (manufactured by Alliant Techsystems and Westinghouse) in July 1996.

MK-48 Advanced Capability (ADCAP) Torpedo

The ADCAP, is a submarine-launched, wire-guided heavyweight torpedo used against both surface ships and submarines. The ADCAP torpedo was designed to improve the speed, depth, and processing power of the MK-48. It employs digital-based processor technology with reprogrammable software and an improved open cycle OTTO Fuel II based propulsion system.

Hughes will complete ADCAP production by December 1995. Another ADCAP prime contractor, Westinghouse, has already completed production.

1.4 Design Considerations

Threat

The threat influences several key features of the system design. For example, the hull design of the target, such as titanium double hull platforms, affects the required explosive charge and the shape of the warhead. Additionally, required propulsion noise-level is affected by the ability of the target to detect incoming torpedoes and take evasive action or counterfire.

Operational Environment

Characteristics of the ocean environment also affect torpedo design requirements. The saltwater environment requires specialized materials and processes, especially for cables, propulsion systems, and electronic components which are exposed to the corrosive effects of salt water. Requirements to use torpedoes in deep or shallow waters also have significant implications. In the deep "blue" ocean environment, a torpedo can find its target from a long distance and, therefore, must have substantial propulsion systems. Additionally, the extreme pressures encountered at depth require specialized torpedo shell construction and propulsion systems. The shallow littoral water environment imposes a different set of design requirements. Surface and bottom reflections, acoustic ray path bending due to varying sound velocity, interference from biological noise, and the physical presence of the ocean floor drive requirements for tactical, autopilot, and sonar signal processors and software.

Launch Platforms

The physical design requirements of the torpedo are driven by load restrictions and launch requirements of the platforms that carry them. Since aircraft can carry only limited payloads, weight is a critical design requirement for lightweight torpedoes.

Training

The need to maintain Fleet proficiency requires that torpedoes be available in two distinct configurations: a combat ready configuration ("warshot") and an exercise configuration for data gathering and training. Exercise requirements demand a capability to record performance parameters, and to command the torpedo to perform specific exercise maneuvers in order to ensure safety to support platforms and to return to the surface for recovery.

Cost

Torpedoes are designed to minimize production, operation and maintenance costs. Lightweight and heavyweight torpedoes typically cost between $500,000 and $1 million each. Operational costs can total up to $41,000 to refurbish a torpedo after an exercise shot, $53,000 for an overhaul, $5,000 to put a torpedo into inactive inventory (deep stow), and $20,000 for demilitarization and disposal.

1.5 Major Torpedo Sections and Subsystems

A combat-ready ("warshot") torpedo consists of three major sections: guidance and control, propulsion, and the warhead. Exercise or training torpedoes contain an exercise section, containing safety monitoring devices and a data recorder, in place of the warhead.

Guidance and Control

The Guidance and Control section houses the torpedo sonar, signal processing, tactical control, and autopilot subsystems. An active sonar transmits sound ("pings") and awaits the return signal reflecting off the target. A passive sonar tracks a target by receiving sound generated by the target itself. The signal processor accepts digital acoustic information from the sonar and processes this information to extract and isolate target characteristics. The signal

processor then delivers this information to the tactical processor which determines the most effective strategic response and provides control input to the autopilot. The autopilot operates the propulsion system and steers the fins to drive the weapon to the target. The heavyweight torpedo guidance and control system includes a tethered guidance wire to transmit mission data and receive control commands from the launch platform.

Propulsion

The torpedo propulsion section includes the fuel storage and delivery subsystem, torpedo engine, propulsor, electrical power generator, and control fins. Torpedo engines are either: (a) electric drives, (b) rocket engines, (c) open-cycle liquid fuel combustion engines, or (d) closed cycle chemical drives. The U.S. Navy's open cycle combustion propulsion system uses a liquid mono-propellant, OTTO Fuel II, in a swash plate combustion engine. The Navy's closed cycle chemical drive is a Stored Chemical Energy Propulsion system (SCEPS) using a lithium and sulfur hexafluoride chemical thermal reaction to generate steam and drive a turbine engine. Some foreign torpedoes use rocket propulsion to reach speeds up to 200 knots.

Warhead

The warhead section contains the explosive material, the exploder (initiator and safing device) and fusing systems. The warhead explosive material may be a bulk charge or shaped charge configuration. The exploder and warhead fusing subsystems may include proximity and contact target sensors. The warhead also includes depth and range or distance separation features to prevent unintended detonation of the warhead.

Exercise

An exercise section replaces the warhead section in an exercise torpedo configuration. The exercise section contains safety monitoring functions and a torpedo data recorder which records torpedo performance for post-run evaluation.

1.6 Torpedo Acquisition Phases

Torpedo acquisition involves three activities: technology development, production, and support of torpedoes. These activities are supported by a combination of industry, academia, and Navy facilities and personnel. Technology development and support primarily are provided by Navy-owned and operated facilities with some academia and industry support. Torpedo production is performed by industry prime manufacturers and subsystem and component vendors.

Development

Historically, new torpedoes have been developed every 15 to 20 years. Since most of the development infrastructure had no commercial equivalent application to sustain it between developments, the Navy established organic facilities and developed the tools and skills required to support major development efforts (e.g. acoustic testing, software development and testing, system simulation, propulsion system development and testing, environmental test facilities, and in-water test ranges). The Naval Undersea Warfare Center (NUWC) Division Newport currently manages and performs most torpedo technology development. In this effort, NUWC is supported by the Applied Research Laboratory of the Pennsylvania State University (ARL/PSU) which provides research, development, and engineering for undersea science and technology. Since its inception in 1945, ARL/PSU has concentrated on research for torpedo guidance and control and thermal propulsion. The Naval Surface Warfare Center (NSWC) conducts warhead explosive technology developments. As the technology matures, torpedo industry prime contractors and vendors take on an increasing role in the technology developments.

Production

Torpedo production involves: the torpedo design, integration, assembly, and test of purchased subsystems; the fabrication of electronic subassemblies similar to those used throughout the aerospace industry; and standard metal component manufacturing. The biggest system engineering challenge for torpedo prime contractors is transitioning torpedo concepts into

production-ready designs and resolving manufacturing problems. Companies entering the torpedo production business have relied on Navy-owned and operated production test facilities and design engineering knowledge. In 1986, one prime contractor transitioned from producing torpedo components to full ADCAP torpedo production within three years with help from NUWC Newport and another prime manufacturer.[9]

Three U.S. prime contractors currently produce lightweight and heavyweight torpedoes: Alliant Techsystems, Westinghouse Electric Corporation, and Hughes Aircraft Company.[10] Alliant Techsystems and Westinghouse produce both lightweight and heavyweight torpedoes; Hughes builds only heavyweight torpedoes. Second tier subcontractors and component vendors support these prime contractors. Approximately 40 percent of torpedo manufacturing is performed below the prime contractor level.

The Naval Surface Warfare Center provides OTTO fuel and warhead explosive production for both lightweight and heavyweight torpedoes.

Operations and Maintenance

Torpedoes require periodic and unscheduled maintenance and repair, storage and issue preparation, and refurbishment after exercise shots. In general, torpedo maintenance is performed in Navy-owned facilities with Navy personnel. Long-term torpedo and warhead storage, and all heavyweight and lightweight depot level repair and maintenance, is performed at NUWC, Keyport, WA. Contractors do, however, provide direct maintenance services under the Navy's Progressive Depot Level Repairable (PDLR) concept where the prime contractor performs limited depot-level repairs at Navy facilities.

1.7 Relationship to other Commercial and Defense Activities

Torpedoes are complex systems driven by the requirements of the difficult environment in which they operate. The torpedo is an underwater, high speed, acoustic homing,

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[9] This is not indicative of the time required to re-establish production capability. All-up round torpedo production was established for an existing design by a torpedo component manufacturer with significant assistance.

[10] Previous manufacturers of torpedoes include Aerojet and Bendix.

autonomously controlled vehicle. Torpedoes must have low radiated noise, high efficiency sonar systems, inertial reference systems, wide range depth sensing systems, embedded signal and tactical data processors, and high energy density non-air-breathing propulsion systems. Consequently, the integration of the technically complex subsystems into a full-up torpedo requires a high degree of specialization. There are no equivalent system design requirements in the commercial sector nor in any other defense product segments. Many of the component technologies and some of the components, however, *are* similar to other commercial and defense products.

Commercial Component Potential

Commercial and other military technologies are migrating into the torpedo industry at the subsystem and component levels. With the possible exception of the MK-50 boiler and the acoustic transducer arrays, mechanical parts typically require few novel processes. The electronic assemblies are similar to those used in missiles, satellites, and avionics. Currently, torpedoes are produced in factories dedicated to military products, driven in part by military accounting and quality acquisition rules. Department efforts to adopt commercial processes and standards may allow production in commercial plants, when regeneration of torpedo production is needed in the future.

Although there is no commercial parallel to torpedoes *per se*, there are several commercial products that use similar technologies. Planned torpedo modification programs will take full advantage of commercial micro-processors. Many individual torpedo components such as advanced metal matrix hull structures, inertial reference systems, commercial electronic components (computer chipsets, analog-to-digital converters), and electronic manufacturing techniques are also used for commercial products. Additionally, advanced battery technologies being developed by the automotive industry may have application to torpedo propulsion systems.

Torpedo/Missile Component Similarity

Both missiles and torpedoes have guidance and control systems, warheads, propulsion systems, and interfaces to launch platforms. Although many of these components are linked to

the unique mission of each weapon and have little in common, some commonality does exist at the subsystem component technology level. First, the guidance and control electronics, signal processors, and autopilot components are largely comparable.[11] Second, while the propulsion system for U.S. torpedoes and missiles differs greatly today, some countries are producing torpedoes with rocket engines based on missile propulsion technologies. Third, torpedo and missile warheads rely on similar design and production capabilities. Fourth, commercial processors are available to perform all required signal and tactical processing functions for both torpedoes and missiles. (The software algorithms embedded in the processors are unique to the operation and performance of the U.S. Navy's underwater weapons.)

Torpedo/Unmanned Underwater Vehicles (UUVs) Component Similarity

Although torpedo and UUV design requirements, functionality, and mission profiles are unique, some component technologies are similar. A number of component technology developments planned for UUVs could benefit torpedoes -- intelligent controllers, depth sensing, high frequency transducer arrays, acoustic signal processing algorithms and architectures, advanced hull structures, silencing, energy sources, hydrodynamics, communications and inertial measurement. Even though some components are similar, UUV production is too low (five each year) to sustain capabilities that could support torpedo production.

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[11] The torpedo sensor systems, by contrast, are not comparable with the radar, infra-red, and electro-optic systems used in missiles.

2.0 THE WORLD TORPEDO MARKET

2.1 Demand

Torpedoes are purchased by almost all navies to support their military needs. The increased number of countries with diesel electric submarines and littoral warfare surface craft is increasing demand for lightweight and heavyweight torpedoes. In addition, the need to upgrade older, primarily deep water, torpedoes to improve shallow water performance further increases demand in this market. Growth will be particularly strong in the export market for lightweight torpedoes. World market information presented here is derived from Forecast International[12] projections, but has been updated to reflect currently planned torpedo production for the U.S. Navy and for export.[13]

2.2 World Production

In 1994, the value of worldwide torpedo production (Figure 2-1) totaled almost $655 million. Production is expected to rise almost 70 percent by 2002 before easing in the next century as replacement demand is met. Current worldwide torpedo producers of both heavyweight and lightweight torpedoes include the United States, the United Kingdom, France, Germany, Italy, Sweden, the former Soviet Union, Japan, and China.[14]

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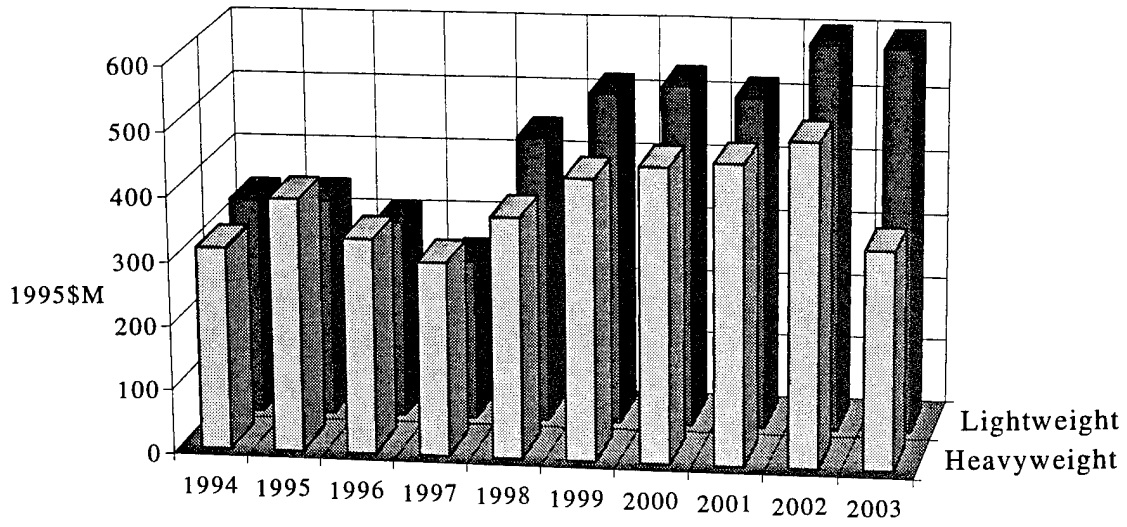
[12] Forecast International is a private research and forecasting firm that concentrates on defense-related markets. Projections are not specifically endorsed by the Department. The production expectations are based on a limited number of systems. Changes in customer requirements, national budgets, and system production rates would have significant impact on the projections.

[13] Torpedo export projections are based on U.S. torpedo manufacturer estimates and predictions of demand for countries currently holding older U.S. manufactured torpedoes.

[14] Little quantitative information is available on production quantities within the former Soviet Union, Japan, or China; however, discussions of torpedo production are included in Section 2.4.

Figure 2-1. Value of Worldwide Torpedo Production by Type (1994 - 2003)

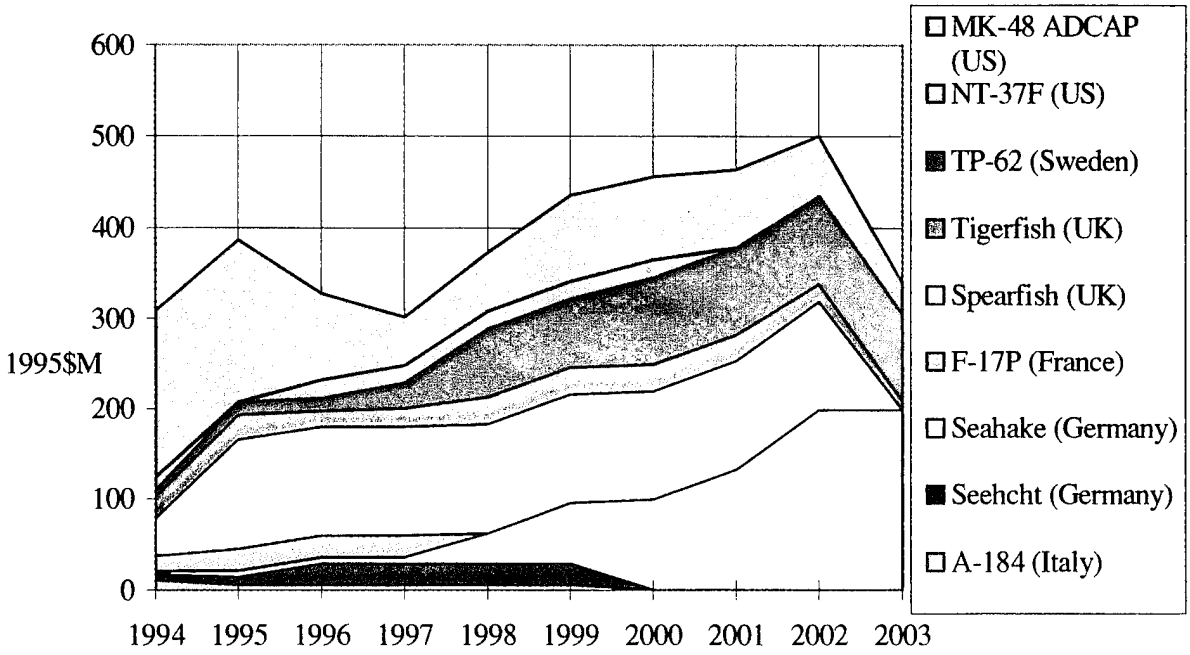


Source: Forecast International/DMS Market Intelligence Report; *Undersea Warfare Forecast*, February 1995.

Worldwide Heavyweight Torpedo Production

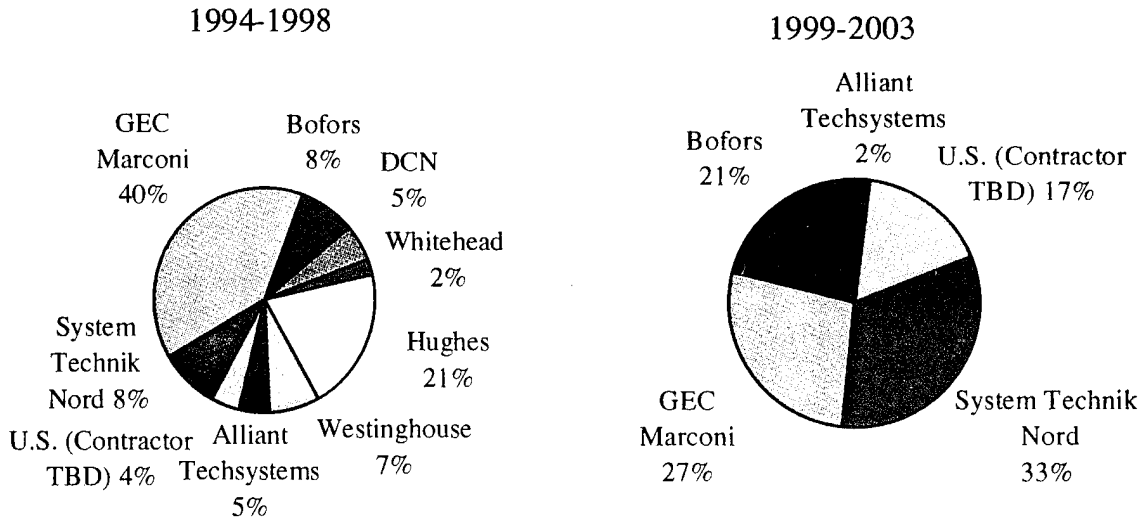
Projected increases in heavyweight torpedo production are linked to new submarine construction. Approximately 4,000 heavyweight torpedoes are expected to be produced in the next decade. In 1994, worldwide production of heavyweight torpedoes amounted to $315 million. That number is expected to rise gradually to $500 million in 2002, and then decline to $340 million in 2003. Figure 2-2 depicts the sales value for each heavyweight torpedo by producing country, and Figure 2-3 summarizes the projected percentage share of global production of the firms which produce those torpedoes. The share of global production held by U.S. firms (Hughes and Westinghouse (ADCAP); and Alliant Techsystems (NT-37)) is expected to decline from around 40 percent in the late 1990s to less than 20 percent in the next century -- due to the ending of "all-up round" heavyweight production for the U.S. Navy and a decline in projected U.S. export sales.

Figure 2-2. Value of Worldwide Heavyweight Torpedo Production (By Torpedo) (1994 - 2003)



Source: Forecast International/DMS Market Intelligence Report; *Undersea Warfare Forecast*, February 1995.

Figure 2-3. Share of World Heavyweight Torpedo Production (by Value of Production)



Source: Forecast International/DMS Market Intelligence Report; *Undersea Warfare Forecast*, February 1995.

Worldwide Lightweight Torpedo Production

In 1994, global production of lightweight torpedoes totaled $340 million. The value of production is projected to decline to $250 million by 1997 due to the end production of the MK-50 torpedo. After 1997, Forecast International predicts that production may to rise to around $600 million per year largely based on initiation of full-rate production of the MU-90 Eurotorp.[15]

Figure 2-4 projects the value of lightweight production, by torpedo. Figure 2.5 depicts the share of global production of lightweight torpedo producers. Eurotorp's share of global production is projected to increase from around 30 percent to almost 80 percent. The share of total production held by U.S. firms is expected to decline from 25 percent in the late 1990s to less than 20 percent -- due in part to the ending of "all-up round" lightweight production for the U.S. Navy.[16]

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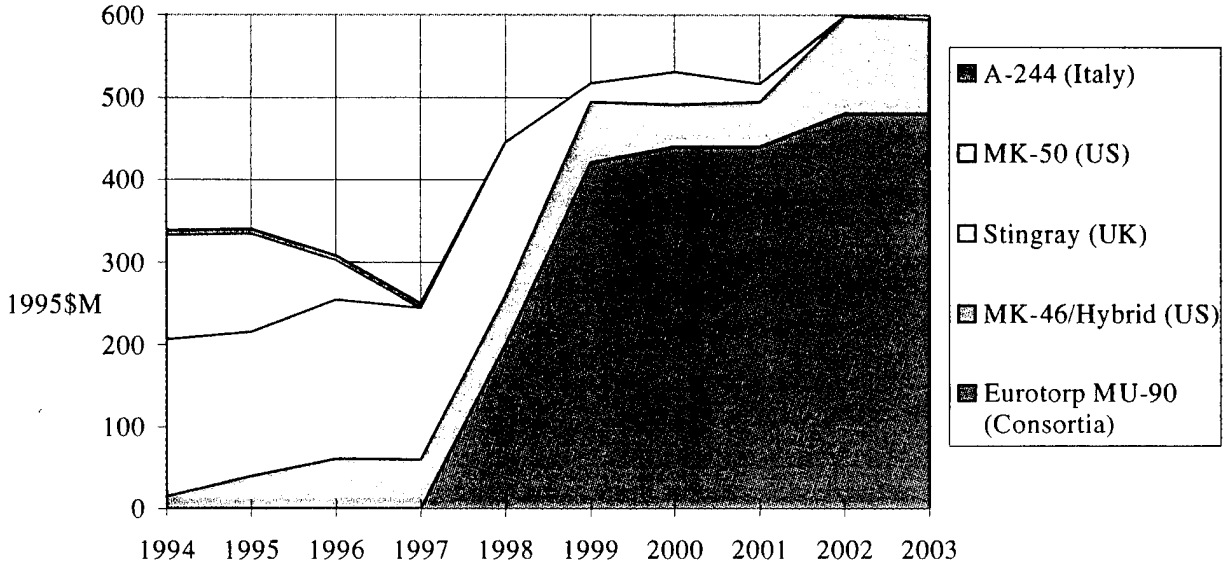
[15] The projection is highly speculative, however, given the Eurotorp's repeated developmental delays and rising unit cost projections. Based on Forecast International's analysis, Figure 2-4 includes a one year slip of Eurotorp's production start-up from their published projections. Forecast International believes that further delays may occur.

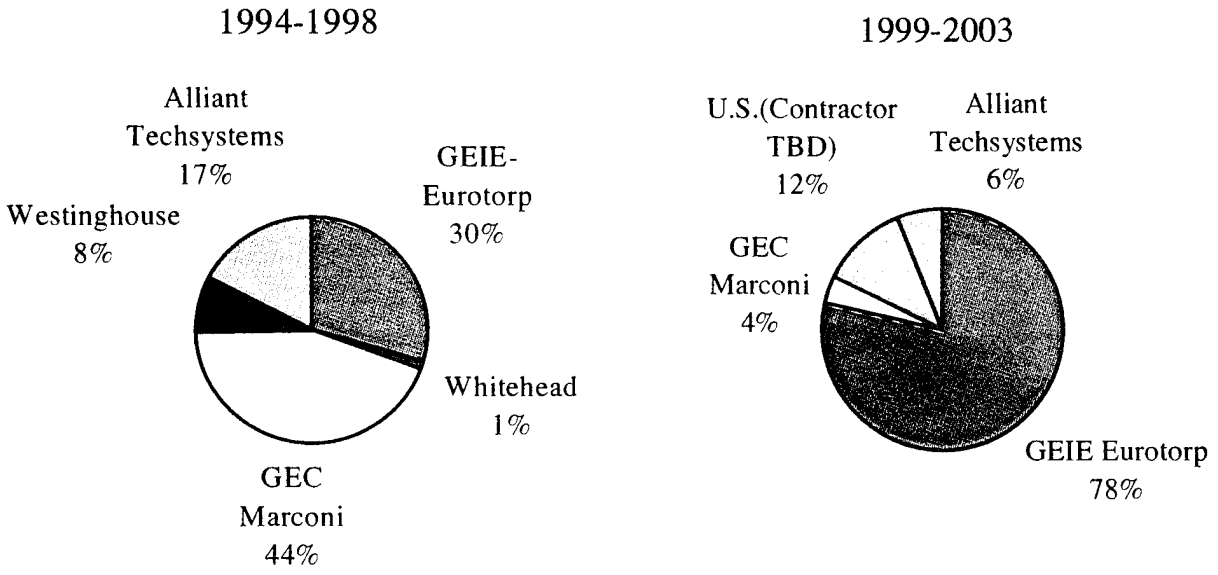
[16] Projections of U.S. torpedo production shares are heavily influenced by Forecast International's projections of Eurotorp sales.

Figure 2-4. Value of Worldwide Torpedo Lightweight Production (By Torpedo) (1994 - 2003)



Source: Forecast International/DMS Market Intelligence Report; *Undersea Warfare Forecast*, February 1995.

Figure 2-5. Share of World Lightweight Torpedo Production (by Value of Production)



Source: Forecast International/DMS Market Intelligence Report; *Undersea Warfare Forecast*, February 1995.

2.3 Domestic Torpedoes

The United States has three prime torpedo manufacturers: Westinghouse Electric Corporation, Alliant Techsystems, and Hughes Aircraft Corporation. In 1994, heavyweight production by the U.S. firms was valued at $200 million, and lightweight production was valued at $140 million.

Foreign sales are expected to represent an important percentage of U.S. heavyweight and lightweight torpedo production. In 1994, U.S. heavyweight and lightweight torpedo export sales were $15 million each. In 1997, foreign sales of heavyweight torpedoes by U.S. producers are expected climb to $55 million or 75 percent of U.S. heavyweight production. A derivative of a 1960s era Navy heavyweight torpedo, the NT-37 is exported by Alliant Techsystems. The MK-48 ADCAP torpedo (manufactured by Hughes and Westinghouse) has recently been approved for limited foreign sale. Foreign sales of MK-46 lightweight torpedoes and upgrade kits are expected to reach $60 million and will represent almost all U.S. lightweight production. The most advanced U.S. Navy lightweight torpedo, the MK-50, is not approved for foreign sale.

Alliant Techsystems has been awarded the MK-46 Service Life Extension Program contract. Westinghouse has been awarded the first of a series of ADCAP torpedo modification kit contracts and may be a competitor for ADCAP foreign military sales contracts. After completing ADCAP production, Hughes will likely compete for follow-on ADCAP modification kit contracts and ADCAP FMS. All three manufacturers are likely competitors for the Lightweight Hybrid program (a modified MK-46).

2.4 Foreign Torpedoes

1. United Kingdom. GEC Marconi Underwater Systems Ltd. is the only British torpedo producer. It currently licenses Tigerfish heavyweight torpedo production to Chilean and Turkish producers. The Stingray lightweight torpedo is produced for both domestic and export sales. The Spearfish heavyweight torpedo is expected to replace Tigerfish torpedoes in the UK inventory, but will not be available for export.

2. France. The principal French torpedo producer is DCN International. It produces F-17 heavyweight torpedoes for domestic and export sales. DCN in cooperation with Italian and

German contractors is developing the new MU-90 Eurotorp. The Eurotorp program is managed by GEIE with DCN as prime contractor. Two other French companies, Thomson-Sintra and SAFT, will produce the MU-90's homing head and batteries. In 1999, France is expected to procure 120 MU-90 Eurotorp torpedoes per year at a cost of $1 million (or greater) each.

3. Italy. Whitehead Motofides is the only Italian torpedo producer. It produces the A-184 heavyweight and the A-244 lightweight torpedoes at modest levels. In 1999, the Italian Navy plans to procure MU-90 Eurotorp torpedoes -- at a rate of approximately 180 per year. Italian suppliers to the Eurotorp include Whitehead Motofides (warheads and body shells), Alenia Elsag Consorzio Systemi Navali (software), and SEPA (control systems).

4. Germany. System Technik Nord is the only torpedo producer in Germany. It produces the Seehecht heavyweight torpedo for the Norwegian Ula class and German type 206A, 209, and 212 diesel submarines. System Technik Nord's Seahake (a joint development with France and Italy) will replace the Seehect and will be exported to several European countries. System Technik Nord will produce the Eurotorp's propulsion system. Germany may procure 100 lightweight MU-90 Eurotorps per year.

5. Sweden. Bofors AB is the principal Swedish torpedo producer. Bofors' latest heavyweight torpedo, the TP-62 (Export "Torpedo 2000"), is undergoing operational evaluation. This heavyweight torpedo is unusual in that it can be forward-launched from surface ships and can be launched from bottomed submarines. Production will begin in 1997 and reach an annual rate of 96 torpedoes per year. Between 1997 and 2003, Bofors will produce 600 TP-62s for the Swedish Navy and an additional 300 for Denmark and Norway.

6. Former Soviet Union. The former Soviet Union has three research and production institutes that provide the majority of the weapons for sale on the open market. Specific unit production and sale values are not known.

The Region Institute in Moscow produces air-drop and underwater rocket powered torpedoes. The APR-2 is a rocket powered lightweight torpedo offered for airdrop or encapsulated as an underwater mine; a third-generation APR now in development, will double its predecessor's acoustic range. The Schval is a 200 knot, rocket powered heavyweight torpedo offered for high-end submarines such as Akula and Sierra. A second-generation Schval is also in development and will offer a dual speed function to search acoustically at 60 knots and dash with

rocket propulsion at speeds up to 300 knots. Region Institute also manufactures two torpedo type weapons that have guidance and control systems to steer to the target as they drop through the water, but have no propulsion system.

The Gidropribor Design Institute in St. Petersburg produces the TEST 71 and 96 heavyweight torpedoes. These torpedoes are configured for anti-submarine and anti-surface warfare and are sold on the world market with the Kilo (636 and 877) submarines. Gidropribor also sells a 65 centimeter diameter super-heavyweight wake-homing torpedo, the SAET-65, on the world market, offered as a shore-launched coastal defense torpedo.

The Mashzavod Institute in Tartarstan produces the 53-65KE wake-homing heavyweight torpedo, sold as an option package with the Kilo. It is also being marketed as a shore-launched coastal defense torpedo.

7. Japan. Mitsubishi Heavy Industries, Ltd. produces the MK-46 lightweight torpedo under a Memorandum of Agreement with the United States and is developing the GRX-4 lightweight torpedo with digital processing guidance and control and SCEPS propulsion similar to the MK-50. It also produces the Type 89 heavyweight torpedo. These torpedoes are sold only to the Japanese Defense Forces.

8. China. Specific projections of China's torpedo production are not known. China has produced the YU-1, a non-homing strait running torpedo, and the YU-2, an electrically powered homing torpedo, but generally purchases other countries' older inventories or combines torpedo and submarine purchases.

2.5 Competition in the Export Market

Significant competition exists in the current export market, however, competition will decline as a select few torpedoes begin to dominate the export market.

Heavyweight torpedo exports may be dominated by Bofors (Torpedo 2000) and System Technik Nord (Seahake). Bofors and System Technik Nord benefit from Sweden's and Germany's packaged sales of their diesel electric submarines (the Swedish A-19/T-96 and the German 209 and 212 boats), with their heavyweight torpedoes. The NT-37 and the ADCAP are

also expected to be exported, however, they often require extensive launch and fire control system changes and do not have the benefit of packaged submarine sales.

If projections are correct, lightweight torpedo exports may be dominated by the GEIE Eurotorp which could represent around 80 percent of worldwide production. GEC Marconi will remain a strong exporter with the lightweight Stingray. Alliant Techsystems, which has sold over 5,000 MK-46s to over 23 foreign nations, will continue to export MK-46 torpedoes and upgrade kits. Another possible lightweight export is a modified MK-46 torpedo known as the Lightweight Hybrid torpedo which may be available after 2003.

3.0 DoD REQUIREMENTS

The current inventory of heavyweight and lightweight torpedoes exceed the Department's requirements. The Department does not have a requirement for production of more heavyweight or lightweight torpedoes beyond the current contracts -- until replacements are needed for the ADCAP and MK-50 in approximately 25 years. The Department does, however, have requirements for advancing torpedo technologies, upgrading the current inventory, maintaining the inventory, and supporting torpedo operations.

3.1 Requirements and Inventory

With the end of the Cold War, the DoD will not require torpedo production after the final torpedo deliveries are made in 1996. The Department will have sufficient MK-50 lightweight and ADCAP heavyweight torpedoes in inventory to meet its requirements and will have excess MK-46 lightweight and MK-48 heavyweight torpedoes. The inventory of heavyweight torpedoes will be sufficient to provide more than 70 weapons per submarine, or more than four complete loadouts for each submarine. The total inventory of all lightweight torpedoes exceeds the utilization capacity of all lightweight launch platforms.[17] A portion of the older, less capable, MK-46 and MK-48 torpedo inventory is placed in long-term storage in an inactive status called "deep stow" for contingency reserve. The deep stow weapons are still effective and meet operational requirements. In the event of a conflict, the active torpedo inventory will be resupplied by activating and upgrading "deep-stow" torpedoes.

Figure 3-1 provides a proportional representation of the U.S. torpedo inventory and the Navy's heavyweight and lightweight torpedo requirements.[18] Currently, the Navy has approximately 4,000 heavyweight torpedoes in inventory, but only requires around 2,000 heavyweight torpedoes to meet projected warfighting needs. Likewise, the Navy has about

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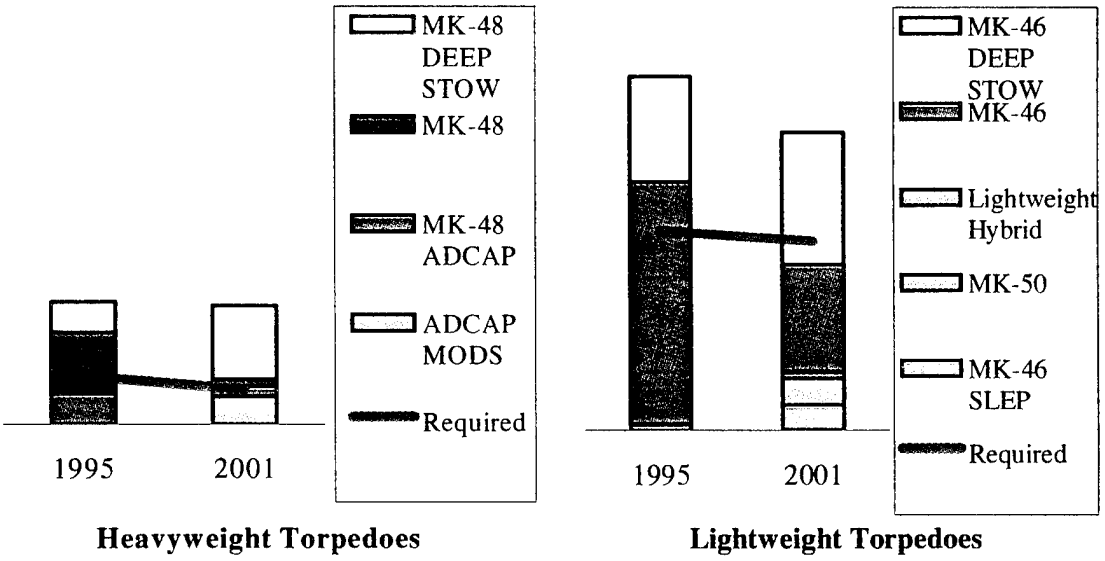
[17] Navy Industrial Base Study, TASC, December 1994.

[18] The exact inventory and requirement values for the torpedoes are classified. All inventory and requirement values are therefore expressed in approximate terms.

14,000 lightweight torpedoes in inventory, but only requires about 8,000 to meet the warfighting needs.[19] Torpedoes in excess of these requirements are being de-activated and placed in deep-stow or cannibalized for parts.

While the current heavyweight and lightweight torpedo inventories *quantitatively* exceed the Navy's requirement, the Department needs to continue to make *qualitative* improvements to the torpedo inventory to meet new operational requirements -- most notably to provide better shallow water capabilities.

Figure 3-1. DoD Torpedo Inventory and Requirements



Source: Navy Non-Nuclear Ordnance Requirements.

Heavyweight Torpedoes

In 1992, the end of the Cold War and the transition from a large Soviet "blue water" threat to a largely littoral water warfare threat drastically changed the U.S. Navy Order of Battle. Retirement of older SSNs and SSBNs was accelerated, and new submarine construction was reduced. As a result, the Navy also lowered its MK-48 and ADCAP inventory requirements.

Approximately 4,000 heavyweight torpedoes are currently in inventory. Around 3,000 are in active inventory (nominally 1,000 ADCAP and 2,000 MK-48) and approximately 1,000

[19] These figures include the MK-46 lightweight torpedoes used for CAPTOR mine payload.

(MK-48) have been deactivated and placed in deep stowage. Westinghouse will begin delivery of ADCAP modification kits in October 1996 to upgrade almost all of the ADCAP inventory by 2001.

Lightweight Torpedoes

The same threat reduction and shallow water requirement changes have likewise significantly affected the lightweight torpedo requirement. In 1994, the Navy reduced its lightweight torpedo requirement to approximately 8,000 torpedoes; around 14,000 remain in the current inventory. The active lightweight torpedo inventory is comprised of approximately 9,500 MK-46 torpedoes and around 300 MK-50s. An estimated 4,000 additional MK-46 torpedoes are in the process of being cannibalized or are in deep stowage. By 2001, approximately 1,000 MK-50 torpedoes will be delivered, 1,000 of the MK-46 torpedoes will have had service life extensions, and 50 Lightweight Hybrid torpedo upgrades will be delivered. Of the projected 5,200 MK-46 torpedoes shown as deep stow in 2001, approximately 2,000 will be inactive, but not converted for long-term storage.

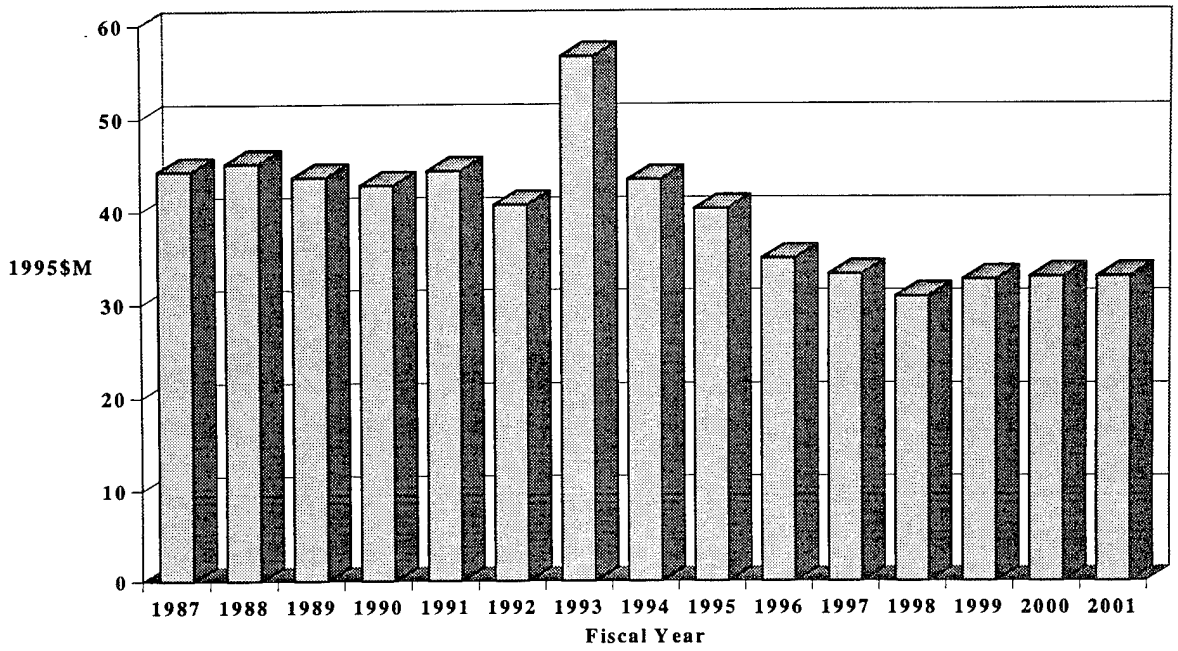
3.2 Technology Development

Although there will be no new torpedo production after 1996, continued technology development programs are required to maintain technology leadership for the future. Continued technology developments will ensure new torpedo component and system design concepts are available for new modification programs and future production programs. The Navy plans to continue product technology developments in the areas of guidance and control, propulsion, silencing and structures, and warheads and fuzing. Additionally, the Navy is developing process technologies to reduce cycle time and improve affordability.

Technology Development Funding

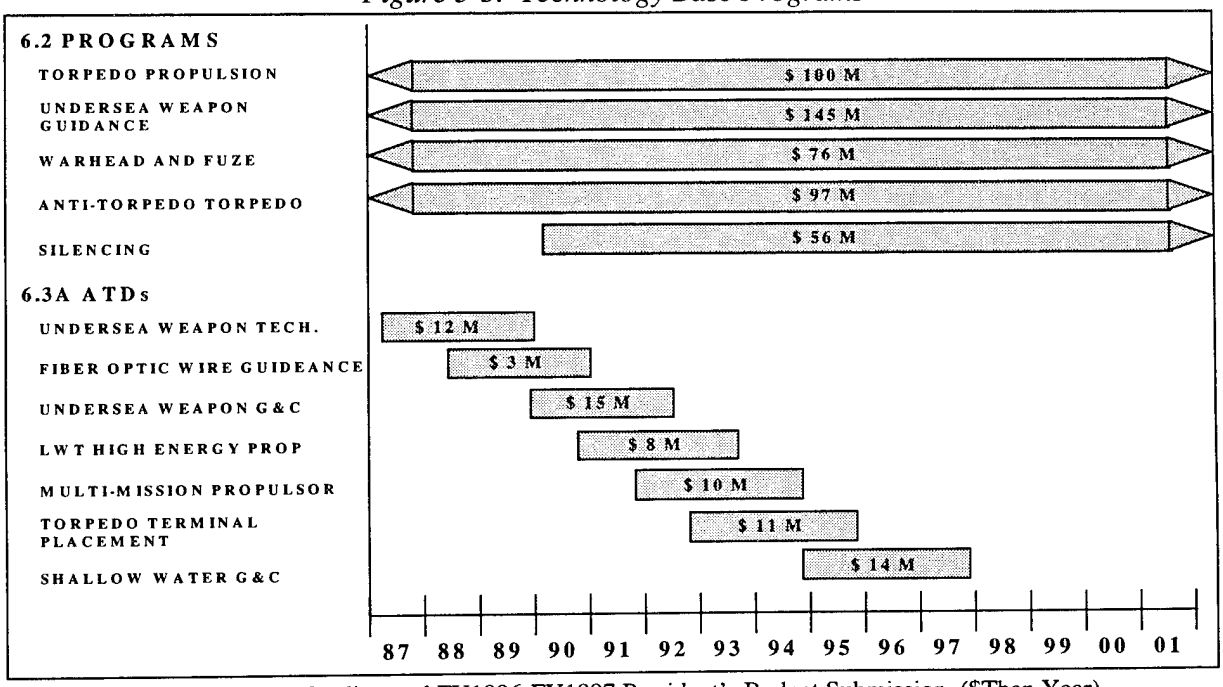
Figure 3-2 illustrates the historical and projected torpedo technology base funding profile. Between 1995 and 2001, technology base funding will level out to approximately $30 million.

Figure 3-2. RDT&E (6.2/6.3A) Funding



Source: FY1996-FY1997 President's Budget Submission.

Figure 3-3. Technology Base Programs



Source: Historical program funding and FY1996-FY1997 President's Budget Submission, ($Then Year)

Technology Development Programs

Figure 3-3 illustrates the currently planned torpedo technology base projects including Exploratory Development (6.2) and Advanced Technology Demonstration (6.3 ATD) projects.

Guidance and Control. Today's torpedo guidance and control systems were designed to operate against deep diving, high speed threat targets in the open ocean. Shallow water poses a more difficult operational environment because of the presence of boundaries (bottom and surface), high levels of background noise, rapidly changing thermocline structure,[20] and frequently high levels of turbidity. Additionally, future guidance and control production costs need to be reduced if necessary upgrades are to remain affordable. Funding includes 6.2 projects averaging $17 million per year, and Advanced Technology Demonstrations each averaging $3-5 million per year. The Applied Research Laboratory of Pennsylvania State University (ARL/PSU) manages the guidance and control projects with support from NUWC. Specific projects include: (1) the Multitone Correlator to develop advanced algorithms for the shallow water environment; (2) the Sea Snake Towed Array to reduce attenuation losses and increase signal level; (3) the High Resolution Array and the Wide Band Array to allow greater target discrimination in a "cluttered" or shallow water environment; (4) a common torpedo signal processor to reduce costs by using commercial products; and (5) the anti-torpedo torpedo guidance and control.

Propulsion. As with the guidance and control system, today's propulsion systems are optimized for deep diving high speed targets. In the shallow water environment, stealth and affordability are top priorities. The 6.2 torpedo propulsion project is funded an average $7 million per year and is executed primarily by NUWC Division Newport, with participation by ARL/PSU. Specific projects include: (1) the High Energy Density Rechargeable Battery project to reduce torpedo exercise costs; (2) the lightweight high power density electric drive project to provide littoral water stealth; (3) the hydrogen-oxygen power plant project to reduce the propulsion system size; and (4) the aluminum fueled advanced vortex combustor project to achieve very high speeds.

Silencing and Structures. Stealthy operations require other silencing technologies in addition to propulsion quieting. Specific projects include acoustically damped hulls, flexible

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[20] Temperature gradients in the water.

shaft couplers, advanced motor mounts, coatings, active cancellation systems, and analytical models. The 6.2 propulsion silencing program averages $5 million per year and is worked in coordination with the Unmanned Underwater Vehicle program.

Warheads and Fuzes. The Navy will develop torpedo warhead and fuze technologies to meet the reduced shallow water explosive requirements. The 6.2 warhead technology exploratory development project is funded at an annual average of $5 million and is being executed by NSWC White Oak. Specific projects include more efficient (smaller) warheads, variable yield warheads, advanced modeling for optimizing warheads, and using micro electro-mechanical systems to improve torpedo safety.

Cycle Time and Affordability. System development and production engineering "cycle times" directly affect torpedo affordability. Additionally, separate lightweight and heavyweight torpedo support infrastructures increase torpedo "ownership" costs. Computational processing and synthetic modeling techniques will be used to facilitate simulation testing of new torpedo design concepts and improve computer integrated manufacturing. This project will be coordinated between government and industry to allow collaborative development and production design. Additionally, common torpedo system design approaches will be evaluated to improve lightweight and heavyweight support infrastructure integration.

3.3 Procurement

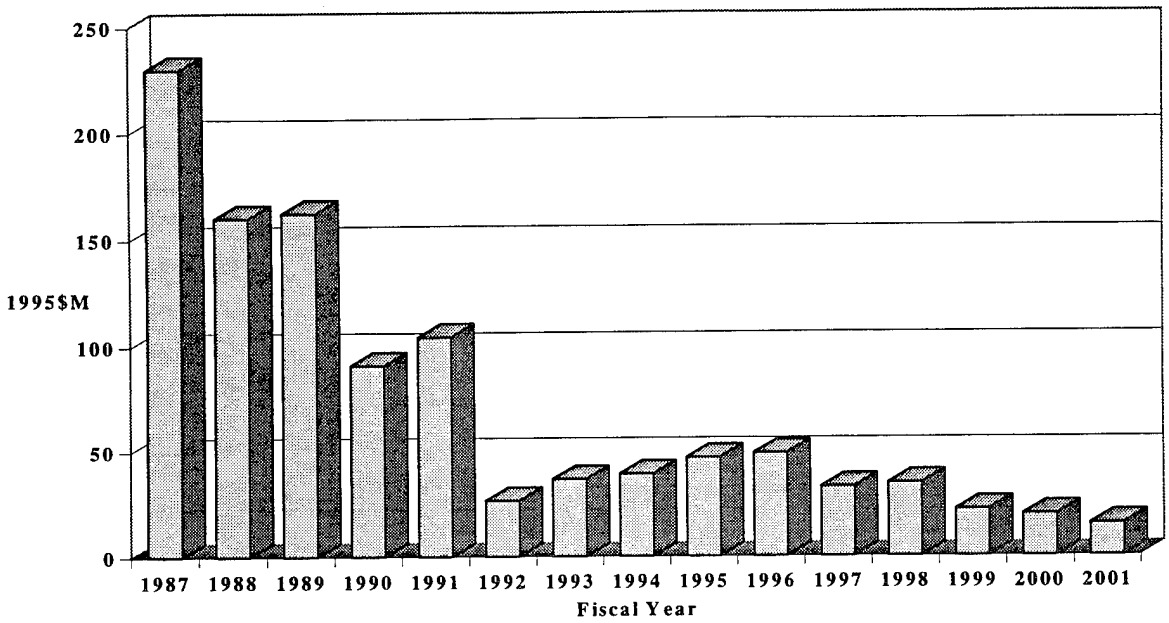
Procurement Funding

Since procurement of "all-up rounds", or whole torpedoes, is not required beyond the completion of the MK-50 and ADCAP production contracts the Navy plans only to procure SLEP kits for the MK-46 and upgrade kits for the ADCAP and the MK-46.

Torpedo production and modification programs use a combination of torpedo development funding (Figure 3-4) and actual production funding (Figure 3-5). The torpedo product development funding (6.3B and 6.4 RDT&E) is different from the technology development funding (6.2 and 6.3A) in that it supports the engineering and manufacturing developments and the prototype testing needed to ready a torpedo design for production. The

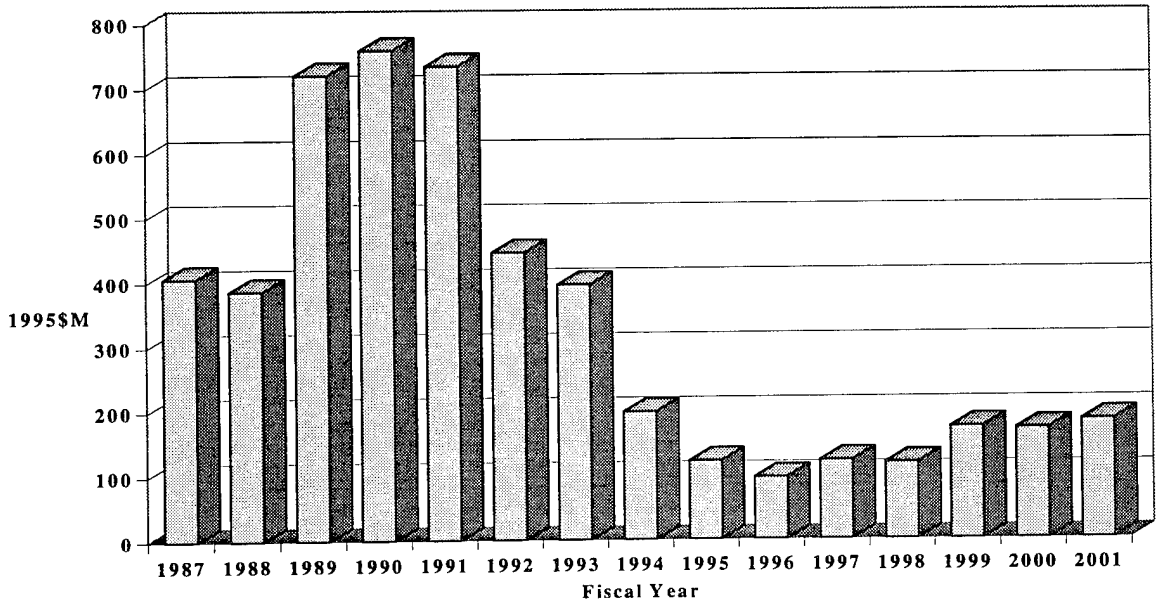
actual production and in-production engineering are performed with procurement (Weapons Procurement, Navy (WPN)) funding.

Figure 3-4. Product Development (6.3B/6.4) Funding



Source: FY1996-FY1997 President's Budget Submission.

Figure 3-5. Production (WPN) Funding



Source: FY1996-FY1997 President's Budget Submission.

Procurement Programs

Beyond completing production of the MK-50 and ADCAP torpedoes, three procurement programs are planned: the MK-46 SLEP, the Lightweight Hybrid, and the ADCAP Modification.

MK-46 Service Life Extension Program. The MK-46 SLEP will modernize torpedo hardware and resolve two major performance shortfalls. The MK-46 SLEP incorporates shallow water performance improvements -- a stop-gap measure until the Lightweight Hybrid torpedo is produced to fully address the modern diesel submarine threat in littoral waters -- and a new propulsion system seal. The $8 million total production of approximately 1,000 MK-46 SLEP kits by Alliant Techsystems will begin in 1996 and continue until 1999.

Lightweight Hybrid Torpedo Program. The Lightweight Hybrid torpedo will provide the U.S. Navy with a cost-effective lightweight digital torpedo against the diesel electric submarine threat. The Lightweight Hybrid program will upgrade the MK-46 torpedo with the MK-50 torpedo sonar array and transmitter, navigational sensors, a Commercial Off The Shelf (COTS) based, digital-based, sonar receiver, and an open system architecture COTS-based guidance and control subsystem and propulsion system sections. Modifications to the MK-46 propulsion system include a variable speed capability, dual winding alternator (DWA), and the MK-50 thermal battery and lanyard start assembly. The Lightweight Hybrid will retain the baseline MK-46 torpedo warhead. The development contract will be awarded in 1996 with deliveries of Low-Rate Initial Production (LRIP) torpedoes beginning in 1999. Production of around 2,000 kits is planned between 1999 and 2010 and will total $560 million.

MK-48 ADCAP Modifications Torpedo Program. The ADCAP modification program includes an upgrade to the guidance and control system and quieting of the propulsion system. The guidance and control upgrade increases onboard computer memory capacity to accommodate software improvements necessary to detect and classify targets in littoral waters. It also replaces over 1,800 obsolete integrated circuits to improve reliability and maintainability. The propulsion upgrade decreases the radiated noise signature of the ADCAP open cycle propulsion system to reduce the target's ability to detect and evade the torpedo. Westinghouse won the initial contract

for the ADCAP modification kits in June 1995. A total of approximately 1,300 kits will be produced by 2003 at a value of $350 million.

3.4 Operations and Maintenance

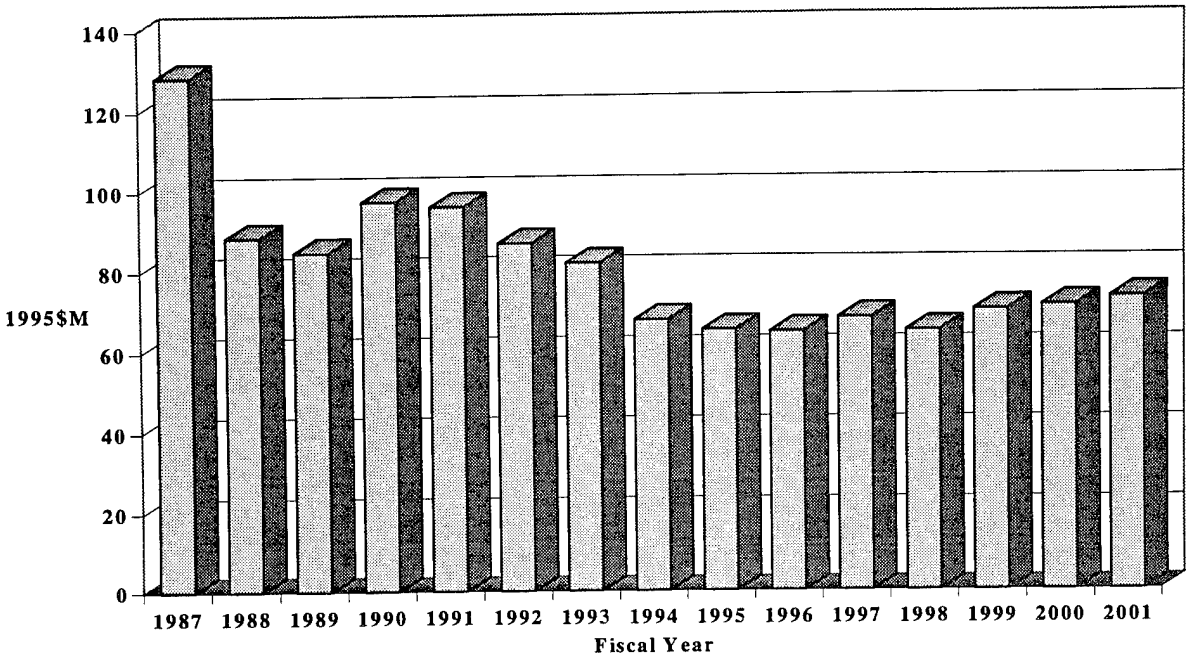
Torpedoes require maintenance and repair, storage and warshot issue preparation, refurbishment after exercise shots, and engineering services to resolve problems after fleet introduction. These functions are supported by the Navy's intermediate and depot repair and in-service engineering activities.[21]

Operation and Maintenance Funding

Figure 3-6 depicts the historical and projected torpedo Operations and Maintenance funding (O&M). O&M funding has declined since 1987 due to reductions in the exercise operating tempo, savings from support facility consolidation, and the use of a less expensive lightweight exercise torpedo.

[21] Integrated Logistics Support includes a full range of product support including maintenance planning; manpower, personnel, and training; supply support; support equipment; packaging , handling, storage, and transportation; configuration management; computer resources; and facilities. This assessment's focus is on industrial and related Department capabilities and thus does not address all aspects of torpedo support. It does not, for example, address organizational maintenance which is limited primarily to visual inspection, exterior cleaning, and the installation and removal of selected components (i.e., arming wires and suspension bands).

Figure 3-6. Operations and Maintenance (O&M) Funding



Source: FY1996-FY1997 President's Budget Submission.

Operations and Maintenance Programs

The torpedo maintenance and supply requirements are determined by the number of torpedoes in inventory, component age, the training tempo, and the required availability level. Hazardous materials used during operations and maintenance require proper handling and disposal.

Torpedo Maintenance. Maintenance on torpedoes and sub-components is required both to keep the active inventory up to readiness standards and to return an exercised torpedo back to Ready-for-Issue (RFI) stockpile. These are primarily performed by intermediate and depot maintenance activities.

Intermediate level maintenance includes post-exercise maintenance and routine preventive and corrective maintenance and is performed by the Navy's three heavyweight and six lightweight torpedo Intermediate Maintenance Activities. Post-exercise torpedo refurbishment costs range from $8,000 for a MK-46 to $41,000 for a MK-50. The MK-50's Stored Chemical Energy Propulsion System (SCEPS) refurbishment is the primary cost difference.

Depot level maintenance actions include more in-depth torpedo and component repair and periodic overhauls and are performed by NUWC Division Keyport. Torpedo overhaul costs range from $12,000 for a MK-46 to $53,000 for a MK-50. Torpedo modifications are generally performed by the Navy during depot repair. The Depot also provides deep-stow, general storage, and demilitarization operations.

Supply Support. Support for torpedo maintenance and operations requires spare and repair parts, expendables and consumables, shells, and containers. The Navy maintains inventories of spares in its own parts warehouses. Early in the life cycle of a new torpedo development, the prime contractor supplies almost all spare parts. As the system matures, spares are purchased directly from the second tier or other qualified suppliers.

Hazardous Materials. Hazardous materials are used and handled in torpedo operations and maintenance -- notably the OTTO Fuel II used for MK-48, ADCAP, and MK-46 torpedo propulsion and the lithium used in MK-50 SCEPS engine. The Navy has begun to reclaim OTTO fuel from torpedoes after exercises and has implemented other initiatives to reduce hazardous waste generation. Explosives and fuzes require special packaging, handling, storage, and transportation requirements. Ozone depleting substances have been used for electronic component cleaning in the production and maintenance processes. The torpedo prime contractors have developed alternative cleaning processes to reduce the use of ozone depleting substances.

4.0 CAPABILITIES TO MEET DoD REQUIREMENTS

The Navy, industry, and academia have developed significant and essential technical capabilities to support the design and production process and to support the torpedo inventory:

- The Navy and the Pennsylvania State University have established the torpedo systems knowledge base and specialized test facilities needed to support concept developments for the future.
- Industry has developed the torpedo systems integration, component design, and manufacturing process knowledge base needed for torpedo production.
- The Navy has also developed the skill base and facilities needed to support torpedo maintenance and resolve in-service problems.

The planned programs will support the torpedo design and engineering knowledge, development facilities, production engineering and systems integration expertise, and limited component production capabilities. These capabilities will support the re-establishment of torpedo production when needed. Sufficient capabilities will be retained within industry, the Navy, and in academia to meet the Department's requirements.

In the context of reduced spending on torpedo programs, the Department will examine possibilities to expand industry's role in torpedo technology development, design, and support operations. Such efforts could provide fiscal benefits to the Department and make existing capabilities more robust.

4.1 Technology Development Capability

The planned development funding will maintain the capability to meet torpedo technology development requirements. The $30 million annual development program funding will retain the torpedo systems engineering knowledge base, the component technical knowledge base, and the development and test facilities needed to ensure continued technology development capability for the future. These capabilities are currently provided by the Naval Undersea Warfare Center, the Naval Surface Warfare Center, and the Applied Research Laboratory at

Pennsylvania State University. The specialized test facilities for torpedo propulsion, guidance and control, and the full torpedo system will be available for new concept exploration technology developments.[22] These facilities also support the torpedo system engineering and testing required to transition concepts to production units. In addition to the land-based test facilities, in-water testing ranges will be retained to provide production system design developmental testing and production proofing. Planned technology programs will retain the torpedo component and system engineering expertise to support torpedo technology developments and provide system design and integration expertise for the eventual re-establishment of torpedo production.

4.2 Production Capability

Three U.S. prime contractors currently produce torpedoes. They are Alliant Techsystems, manufacturer of the MK-46 and MK-50 lightweight torpedoes and the NT-37 heavyweight torpedo; Westinghouse, producer of both MK-48 ADCAP and MK-50 torpedoes, and Hughes Aircraft Mississippi Inc., producer of the MK-48 ADCAP heavyweight torpedo. Although full-up production will be completed by the end of 1996, some production capabilities will be maintained through ADCAP FMS and modifications, direct commercial sales of the NT-37, MK-46 SLEP upgrades and FMS sales, and Lightweight Hybrid upgrades.

Alliant Techsystems, Inc.

Alliant Techsystems (ATK), headquartered in Hopkins, MN, is a diverse armament manufacturer and a market leader in solid rocket propulsion, munitions, anti-submarine warfare, mine warfare, and sensor technology. Torpedo activities are part of its Marine Systems

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[22] These facilities include a system-level propulsion test facility for open cycle thermal and electric propulsion systems; an environmentally contained high energy propulsion test facility; a 500,000-gallon torpedo propulsion noise test system capable of testing full-scale torpedo hardware; the largest reverberant acoustic test tank in the U.S., a launcher facility complex; and the largest, quietest anechoic test chamber in the world capable of testing full-scale torpedo hardware. Of note is the weapons analysis facility providing complete synthetic environment simulation of torpedo acoustics with real time, sonar element-level, hardware-in-the-loop simulation of torpedo guidance and control.

Division.[23] ATK is the sole source supplier for the MK-46 lightweight torpedo and one of two producers of the MK-50 lightweight torpedo. Alliant Techsystems is capable of producing 50 torpedoes per month. ATK will continue lightweight torpedo production of foreign and domestic MK-46 SLEP upgrade kits, MK-46 FMS production, and spare parts production. In addition to the lightweight torpedo production, Alliant Techsystems produces and exports the NT-37 heavyweight torpedo, a derivative of the MK-37 torpedo used by the U.S. Navy in the 1960s. ATK will thus retain both lightweight and heavyweight production capabilities and will be a competitor for the Lightweight Hybrid.

Alliant Techsystems' financial performance is highlighted in Table 4-1. In 1993, the company reduced its workforce and facility space by 30 percent, resulting in extraordinary changes and a loss for the year.

Table 4-1. Alliant Techsystems Corporate Financial Performance

($M)	1992	1993	1994
Net Sales	1,187	1,005	775
Operating Profit	88	-60	40
Operating Margin	7.4%	-6.0%	5.2%
Net Earnings	39	-114	32
Return on Sales	3.3%	-11.3%	4.1%
Return on Assets	7.5%	-24.9%	7.3%
Return on Equity	21.9%	-172.7%	34.8%

Source: Alliant Techsystems' 1994 Annual Report.

The Marine Systems Group includes Global Naval Systems (torpedoes, combat and mine countermeasures, and surveillance systems) and Engineering Services business areas. Sales from the MK-50 torpedo accounts for 37 percent of the Marine Systems sales and 13 percent of Alliant

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[23] Alliant Techsystems' torpedo component production is performed in a government-owned, contractor-operated (GOCO) facility in New Brighton, MN. Final integration and test takes place in ATK's Mukilteo, WA facility. Alliant Techsystems also maintains an office at the proofing and testing facility at NUWC Division Keyport and an engineering team at NUWC Division Newport.

Techsystems' corporate net sales.[24] Fiscal performance data is not available at the division or unit level, but company officials indicate that the Torpedo Systems unit is more profitable than the company's five percent operating margin.

Westinghouse Electronic Corporation

Westinghouse's Naval Systems Division, located in Cleveland, OH was established after Westinghouse purchased Gould's Oceanic Division in March 1988.[25] The Cleveland facility has been involved in the production of torpedoes for more than 50 years and has produced both lightweight and heavyweight torpedoes. This facility produces 18 MK-50 torpedoes per month with a capability of 24 MK-50 torpedoes and 24 ADCAP torpedoes per month. Westinghouse completed ADCAP heavyweight production in 1994, but won the ADCAP Modification kit four year production contract in June 1995. The ADCAP modification kit production will partially sustain Westinghouse's systems integration, electronic and mechanical systems production, and test capabilities in the areas of guidance and control, warhead and propulsion. NUWC Keyport will perform the kit installation. Westinghouse is a likely competitor for the Lightweight Hybrid.

Westinghouse corporate and Electronic Systems Division financial performance is summarized in Table 4-2. In 1992 and 1993, the company experienced net earnings losses due to changes resulting from discontinued financial business operations. In 1994, with this restructuring accomplished, the company returned to profitability.

Torpedo sales accounted for two percent of total consolidated corporate sales and seven percent of the Electronic Systems Division sales. Profitability data is not publicly available for this level of operation, but company officials indicate that torpedo manufacturing has been profitable despite the decline of torpedo production and the highly competitive fixed price contracts.

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[24] Alliant Techsystems' FY1995 Annual Report.

[25] Westinghouse also owns and operates a circuit card and electronic subassembly manufacturing facility in Puerto Rico to support torpedo production; in addition, it maintains an office at the proofing and testing facility at NUWC Division Keyport and an engineering team at NUWC Division Newport.

Table 4-2. Westinghouse Corporate Financial Performance

Westinghouse Electronic Corporation

($M)	1992	1993	1994
Net Sales	9,251	8,875	8,848
Operating Profit	793	146	619
Operating Margin	8.6%	1.7%	7.0%
Net Earnings	-1,394	-326	77
Return on Sales	-15.1%	-3.7%	0.9%
Return on Assets	-14.2%	-3.1%	0.7%
Return on Equity	-62.7%	-31.2%	4.3%

Electronic Systems Division

($M)	1992	1993	1994
Sales	2,855	2,597	2,467
Operating Profit	225	83	165
Operating Margin	8.0%	3.2%	6.8%

Source: Westinghouse's 1994 Annual Report.

Hughes Aircraft Mississippi Inc.

Hughes Aircraft Mississippi Inc. (HAMI), located in Forest, MS, has been the lead producer of the ADCAP heavyweight torpedo since 1984.[26] The company operates a 223,000-square foot facility dedicated to the production and integration of the ADCAP torpedo. In 1992, Hughes became the sole source supplier for the ADCAP torpedo after winning the final $183 million contract for 324 units. Hughes is producing 22 ADCAP torpedoes per month and has a facility production capability of 25 per month. Hughes did not win the ADCAP modification contract and, at the completion of current ADCAP production contract, Hughes is expected to restructure their product orientation and facilities. Hughes will likely continue to provide

[26] The majority of engineering and program management personnel dedicated to the ADCAP program are located at Hughes' Fullerton, CA headquarters. Hughes also maintains a field office at the NUWC Division Keyport proofing and testing facility and an engineering team at NUWC Division Newport.

torpedo system engineering and software engineering support services and be actively involved in torpedo technology developments until the opportunity to compete for the ADCAP FMS production and the Lightweight Hybrid program.

Hughes corporate (GM-Hughes) and Hughes Defense Electronics segment financial is summarized in Table 4-3. The Defense Electronics segment, which includes the torpedo operations, is Hughes' largest by sales volume, its profit margins are lower than the consolidated corporate numbers. The largest business unit in Defense Electronics is Weapon Systems which accounts for 47 percent of the segment's revenue. The Weapon Systems unit includes missile, armament, and naval and maritime systems (including torpedoes). Profitability data is not available for these operations, but company officials indicate that torpedo manufacturing has been profitable despite the competitiveness of recent fixed price contracts.

Table 4-3. Hughes Corporate Financial Performance

GM-Hughes Electronics

($M)	1992	1993	1994
Net Sales	12,297	13,518	14,099
Operating Profit	-251	1370	1529
Operating Margin	-2.0%	10.1%	10.8%
Net Earnings	-922	922	1,049
Return on Sales	-7.5%	6.8%	7.4%
Return on Assets	-6.5%	6.5%	7.1%
Return on Equity	-13.5%	12.6%	13.2%

Hughes Defense Electronics Segment

($M)	1992	1993	1994
Net Sales	5,547	6,112	5,591
Operating Profit	-596.6	538	538.6
Operating Margin	-10.8%	8.8%	10.4%

Source: Hughes' 1994 Annual Report.

Specialty Production

Naval Surface Warfare Center (NSWC) Indian Head produces the OTTO Fuel II used in the propulsion systems of the MK-46, MK-48, and ADCAP torpedoes. Although no new torpedoes will be produced after next year, torpedo operations and training requirements will sustain OTTO Fuel II production.

NSWC White Oak produces torpedo warheads and fuzes. While production of warheads and fuzes for torpedoes is no longer required, other Defense warhead and fuze production and Navy torpedo technology programs will sustain the unique production facilities.

Vendor/Supplier Capabilities

The subtier suppliers for the torpedoes are not as specialized in their production as the prime manufacturers. A study on the ADCAP vendor base found that only 17 percent of the total value of vendor sales was defense related, suggesting that subtier suppliers have a broad customer base and are less defense and torpedo dependent manufacturers.[27]

Reestablishing Production Capability

Reestablishing Torpedo Manufacture. In 1993, the U.S. Navy assessed the time and cost to re-establish production from a cold base.[28] The Navy determined it would take between four to six years to re-establish full-rate production under peacetime conditions. The worst case estimate included two years to present the first torpedo after a decision to resume production, two more years to begin low rate delivery, and two more years to reach full-rate production.[29] The delay prior to low-rate production includes one year for long-lead items and one year to resolve fabrication issues. Both of these could be ameliorated by advance purchases of long-lead items

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[27] National Security Assessment of the Domestic and Foreign Subcontractor Base: A Study of Three U.S. Navy Weapon Systems, Department of Commerce, January 1992

[28] Torpedo Industrial Base Study, Undersea Warfare PEO, September 1993. This assessment did not examine the effect of design departure from existing torpedoes nor project the impact of improved manufacturing technology processes.

[29] The estimate assumed no production knowledge base or retained facilities.

and the application of modern computer integrated manufacturing process techniques. Total re-establishment costs were estimated to be between $220 million and $245 million per torpedo type--or, measured in net present value, between $65 million and $75 million.[30] The cost estimate included contractor recapitalization, test equipment refurbishment, and "learning curve" efficiency costs.[31] The largest cost component is the "learning curve" to reestablish process proficiency to produce at full-rate to desired quality levels. The study also identified that sustaining torpedo unit production capability for one torpedo type with low-level production until after 2020 would cost between $40 million and $55 million per year.[32] Additionally, some efficiency costs would be incurred to reestablish full-rate production from low-level production.[33] Combined, measured in net present value, these costs fall between $605 million and $770 million. Given the substantial margin between the costs of the two approaches and the absence of a requirement for new torpedo production, sustaining limited production was rejected. Additionally, the expenditure would not provide much assistance to the development of a next generation torpedo which would likely rely on new technology and not necessarily require the same production processes.

Reestablishing Component Manufacture In the last several years, many vendors that supplied various items such as cables, circuit cards, castings, components, piece parts, etc., have left the torpedo business. In these situations, the prime contractor assumed production or qualified a new vendor to build the item. More complex torpedo subassemblies required more time and money to qualify replacement vendors. Three subassemblies were considered particularly complex: (1) the heavyweight acoustic nose array, (2) the heavyweight depth sensor assembly, and (3) the lightweight acoustic nose array. Other torpedo components required less

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[30] The present value calculations are based on a 4.9 percent discount rate. (as specified by the Office of Management and Budget and draft DoD Comptroller Economic Analysis Instruction - DoDI 7041.3. ($1995)

[31] Westinghouse developed the MK-50 production capability with over $65 million in five years and the MK-48 ADCAP with approximately $100 million in four years. ($1995) This is not representative of the cost required to reconstitute production. Although these were new designs, Westinghouse had torpedo production capabilities retained from MK-48 production and relied on Navy and other primes' corporate knowledge to resolve production process issues. Costs to initiate production at Hughes are not available and would also not be representative.

[32] Estimate based on $42 million per year for the MK-50 and $52 million for the ADCAP for 25 units of each torpedo type ($1995).

[33] $31 million for the MK-50 and $94 million for the ADCAP.

specialized processes, were similar to commercial products, or will be replaced by new designs in planned torpedo upgrades.

Heavyweight Acoustic Nose Array. The nose array for the ADCAP torpedo is a unique item due to the process-related knowledge a vendor must possess to ensure a consistent production yield. The vendor's production process must be re-qualified if production stops for more than a year. The ADCAP modification program does not require acoustic nose array production. ADCAP export sales may sustain production capabilities. Future U.S. Navy nose array designs will be of a sufficiently different design and will not require the same manufacturing techniques.

Heavyweight Depth Sensor Assembly. The ADCAP's depth sensor assembly provides accurate depth measurement that is crucial to guidance and control. One component of the depth sensor, the transducer, requires unique manufacturing processes. The ADCAP modification program does not require depth sensor assembly production. ADCAP export sales will sustain production capabilities. Transducer designs will be improved and will not require the same manufacturing techniques.

Lightweight Acoustic Nose Array Like the heavyweight acoustic nose array, the lightweight nose array requires specialized manufacturing processes. Alliant Techsystems and Westinghouse have finished production of the acoustic nose arrays for the MK-50. The Lightweight Hybrid torpedo will require nose array production. At least one potential bidder for the hybrid program has preserved the production capability in anticipation of contract award. The Navy is also evaluating an array purchase to meet MK-50 spares requirements and provide a stock buffer while production processes are re-established.

Although these three components require unique and difficult manufacturing processes, the near-term requirements will be met for the lightweight acoustic nose array and the two heavyweight components will most likely not require the same manufacturing techniques in the future.

4.3 Operations and Maintenance Capability

The planned program funding is sufficient to support the necessary skills and facilities needed for torpedo operations and maintenance. The depot and the intermediate maintenance operations (maintenance and repair, preparation for storage and warshot issue, exercise shot refurbishment, system testing, and engineering services) will retain the torpedo industrial capabilities needed for torpedo maintenance and support.

Supply Support - Although the individual suppliers may change over time, the vendor base has sufficient torpedo production orders to retain replenishment spare and consumable production capability needed to support continued operations and maintenance. The demand for consumable and expendable items will not change appreciably with the termination of torpedo production. Routine torpedo exercise activity and funding are sufficient to sustain adequate supply support for consumables and expendables and the supply availability will be maintained. Component production vendors, however, are supported by torpedo production to a greater extent. Some component vendors such as Lockheed Martin, Allied Signal, and Propulsion Technologies have already left the business due to production termination. Sufficient capability exists in the vendor base to enable requalification of new replenishment part sources as part of the normal vendor management process. Additionally, life-of-type procurements, cannibalization and reutilization from excess inventories, upgrades with emphasis on commercial, non-development items, and reverse engineering are options available to obtain needed replenishment components.

Maintenance - The number of maintenance activities has decreased significantly in the last five years. Current maintenance activities though, provide adequate capabilities for expected requirements. NUWC Division Keyport currently manages and provides all torpedo maintenance and support capabilities except for some industry PDLR support. The current Operations and Maintenance funding is sufficient to support Keyport's facilities and knowledge base. NUWC Division Keyport will retain torpedo exercise turnaround, intermediate maintenance, and all depot maintenance capabilities. As part of the Department's privatization initiative, these functions will be examined to identify the appropriate role of industry in maintenance operations. Increased industry participation may retain additional capabilities beyond those presently required.

The handling, storage equipment, and facilities needed for explosive components and hazardous materials will continue to be available. These include the special storage, reclamation, and disposal facilities and equipment needed to store and reclaim OTTO Fuel II and lithium. Torpedo explosive warhead storage, assembly, disassembly, and repair facilities will also be retained at NUWC Keyport's Torpedo Explosive Operating Complex.

5.0 CONCLUSIONS

- The Department expects that planned torpedo technology development, modification, and maintenance programs will sustain required industrial capabilities.
- The two types of torpedoes, heavyweight and lightweight, are designed to meet different physical and operational requirements. The Navy plans to increase torpedo component commonality.
- Torpedo design requirements, unique from other commercial or Defense products, have resulted in the establishment of a sector with specialized skills and facilities for torpedo development, production, and support. Some torpedo components are similar to commercial and other defense products.
- Three prime contractors, with support from component suppliers, produce torpedoes for the U.S. Navy. All three prime contractors are currently profitable.
- The DoD will not require torpedo production after the final MK-50 and MK-48 ADCAP torpedoes are delivered in 1996 until replacements are needed in approximately 25 years.
- Reduced DoD requirements for torpedoes, and strong foreign competition, has led to significant U.S. prime and subsystem contractor production overcapacity.
- Many vendors have completed deliveries and are exiting the torpedo business. Vendors supplying consumable and expendable items will be relatively unaffected by the end of torpedo production. Torpedo component vendors supplying replenishment spares will be affected to a greater degree, but supplies will continue to be available.
- Foreign sales (ADCAP, NT-37, and MK-46) will represent an increasing percentage of U.S. production. Although not specifically required to meet the Department's requirements, these export sales will retain some limited "all-up round" production capabilities in the U.S.
- The Department does have requirements for advancing torpedo technologies, upgrading the current inventory, maintaining the inventory, and supporting torpedo operations.

    * Technology development programs will retain torpedo design and engineering knowledge and development facilities. These capabilities will assist the re-establishment of torpedo production when needed.
    * Adequate capabilities exist to support the Navy's planned upgrade programs. These programs will sustain production capabilities at the prime contractors.
    * The planned operations and maintenance program funding will retain the skills and facilities needed for torpedo support.

- In the context of reduced spending on torpedo programs, the Department is evaluating the extent to which more torpedo technology development, design, and support operations can be performed by industry.
- The lead time and recapitalization costs associated with the re-establishment of a full production capability are preferable to the more expensive option of preserving production capabilities for increasingly obsolete designs.