Operational Analysis on Torpedo Defence

Since 1998, TNO Defence, Security and Safety has performed operational analysis with the Underwater Warfare Testbed, which provides an environment for the evaluation and validation of systems, concepts and tactics. The Torpedo Defence System TestBed has also been built to simulate torpedoes, torpedo detection systems and torpedo countermeasures.

Surface vessels and submarines must be able to defend themselves against a torpedo attack. Self-defence can be approached as a modular concept. The first module involves 'Detection, Classification and Localisation (DCL)'. DCL triggers the second module: the 'evaluator'. This module starts the last module: 'reactor or effector'. This module launches countermeasures which may consist of soft-kill measures (evasive manoeuvring, decoys and/or jammers) or hard-kill measures (a weapon system designed to take out the threat physically e.g. an anti-torpedo torpedo).

The Netherlands Ministry of Defence (NL-MOD) has recognised the operational need for an effective torpedo defence system (see Figure 1). The Royal Netherlands Navy (RNLN) uses torpedoes in a self-defence role and these torpedoes need to be replaced in the near future. This validates further research regarding the procurement, operational introduction and evaluation of torpedoes and torpedo defence systems.

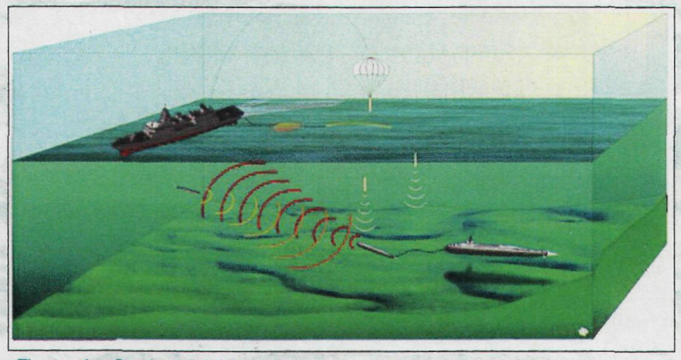


Figure 1: Surface ship torpedo defence systems

Objectives of the TDS 'Torpedoes, DCL and CM' (V503) research programme

At the start of the programme, RNLN ships were not equipped with systems to effectively protect themselves against torpedo attack, especially in complex environments e.g. shallow water. This is an operational shortfall, given the still persistent levels of submarine proliferation. Recent technology advances enable NLMOD procurement and/or development of an effective torpedo defence system.

At present, the RNLN uses two types of torpedoes (MK46 and MK48). In the near future, these torpedoes need to be replaced by new torpedoes that are designed for shallow and deep water operations. The programme aims to develop the knowledge to support the future procurement of new torpedoes and torpedo defence systems. This will enable the RNLN to act as smart buyer, user and, in some cases, smart specifier.

Projects, studies and application

As part of the torpedoes and torpedo defence systems programme, knowledge and systematic descriptions will be developed on:

- Relevant characteristics of platforms, torpedoes and soft-kill countermeasures
- Torpedo and decoy logic of new and existing systems
- Interaction between various torpedo defence system components
- Acoustic detection, classification and localisation (DCL) techniques used by platforms and torpedoes using passive and active sensors
- Relevant characteristics and behaviour of the wake of the platform
- Influence of a vessel's wake on DCL of the torpedo and its own sensor system

The studies that will be performed in the programme are:

- Analysis of the deployment of TDS for area torpedo defence (ATD)
- Analysis of decoy and/or jammer deployment against torpedo attacks
- Analysis of the degradation of the DCL (by ship and torpedo) due to the effects of wake

The resulting data will be used to support the RNLN in the procurement and use of new torpedoes and torpedo defence systems.

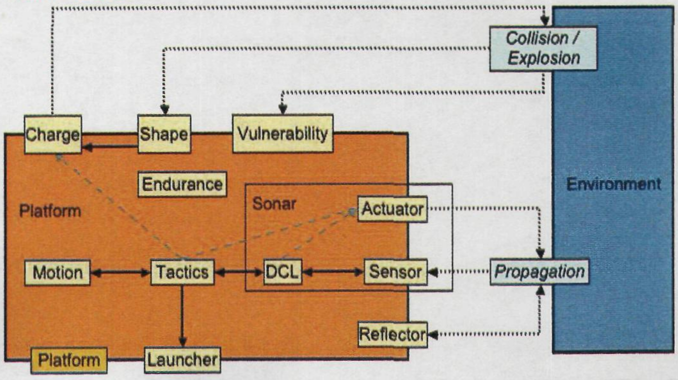
Underwater Warfare Testbed

To provide the RNLN in the future with the required support for acquisition, integration, operational assessment and tactical systems deployment, TNO has designed an Underwater Warfare Testbed (UWT). On top of the UWT, a TDS model has been developed. The testbed, including the TDS model, is dubbed the Torpedo Defence System TestBed (TDSTB). The TDSTB is not only suited for single ship / single torpedo simulations but also has the potential to analyse TDS concepts for multi-ship / multi-torpedo scenarios. Besides these applications, the testbed can also be used to compare the performances of different torpedoes.

TDSTB

The TDSTB uses the acoustic model ALMOST (Acoustic Loss Model for Operational Studies and Tasks) and contains models for surface ships, torpedoes, decoys and jammers. The set-up is very modular, so new platforms (submarines, helicopters) can easily be added (see Figure 2). The sub-modules (e.g. sonar, launcher, motion etc.) can be exchanged between platforms, so new platforms can be built using

Figure 2: Model structure within TDSTB



Studies are ongoing in a research programme to support the Royal Netherlands Navy in the procurement of new torpedoes and torpedo defence systems.
This article also focuses on the most recent studies into the use of existing sonar systems to detect torpedoes. Detection performance results are used in the Area Torpedo Defence study

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already modelled systems. To start with, the MK48 mod 4 torpedo, the Nixie 25 jammer and the Scutter decoy have been modelled. Tactics and decision rules have also been modelled to allocate behaviour to the platforms and their systems and to define their interactions.

ALMOST

The underwater acoustic aspects are covered by ALMOST, TNO's sophisticated underwater acoustic model for propagation and range prediction. It is able to calculate received signal levels for a wide range of passive, active and intercept sonars. It uses a detailed environment description, including sound speed profiles of a water column and sediment. Echoes and reverberation are modelled for active sonars in both mono-static and bi-static configurations.

Replacement of RNLN torpedoes

Within the research programme, an inventory has been made of differ-ent torpedo types that can be used by possible opponents. Generally, the old torpedo types among the threat torpedoes have less sophisticated electronics and logic.

In addition to these threat torpedoes, an inventory has been made of torpedoes that the RNLN could procure to replace its current torpedoes. These torpedoes will go out of service in the US Navy and will thus become less maintainable. New torpedo types therefore have to be investigated as well as their capability to replace current torpedoes based on the present and future requirements of the RNLN.

Threat torpedoes

The inventory of threat torpedoes is based upon possible opponents that can attack with torpedoes manufactured and delivered all over the world. It involves several torpedo types: straight runner, acoustic homer, wire-guided acoustic homer and wake homer.

The collection of data on threat torpedoes is very difficult because of the classification of this information. These torpedoes are therefore described at a high level. The most relevant parameters and characteristics with respect to detection (of threat torpedoes) and effectiveness of counter-measures are investigated.

An overview has been made of the available information on threat torpedoes. Priorities (essential, necessary and desirable) have been assigned to the collated information. Necessary information can be estimated with the help of generic values.

Physical characteristics are of great importance to detect threat torpedoes; the dimensions and acoustic signature determine detection ranges against incoming torpedoes. In general, data on the dimensions of a torpedo is available. Information on the acoustic signature (radiated noise) is difficult to collect and is classified in most cases.

A torpedo's sonar mode, logic and wire guidance are relevant for applying countermeasures. The acoustic capabilities of a torpedo can determine the effectiveness of a jammer or decoy. For an active torpedo, its logic/intelligence system has great impact on the effectiveness of a decoy. Deploying jammers and decoys to deceive a wake-homing torpedo is not effective. Systems that generate bubbles can deceive these torpedoes more effectively.

For a wire guided torpedo, it is important to launch a torpedo (as a countermeasure) in the direction of the firing submarine as quickly as possible. Usually the submarine carries out an evasive manoeuvre. This reaction to a torpedo attack can break off the wire guidance. As a result, the torpedo becomes less effective as a weapon and the use of counter-measures becomes more effective.

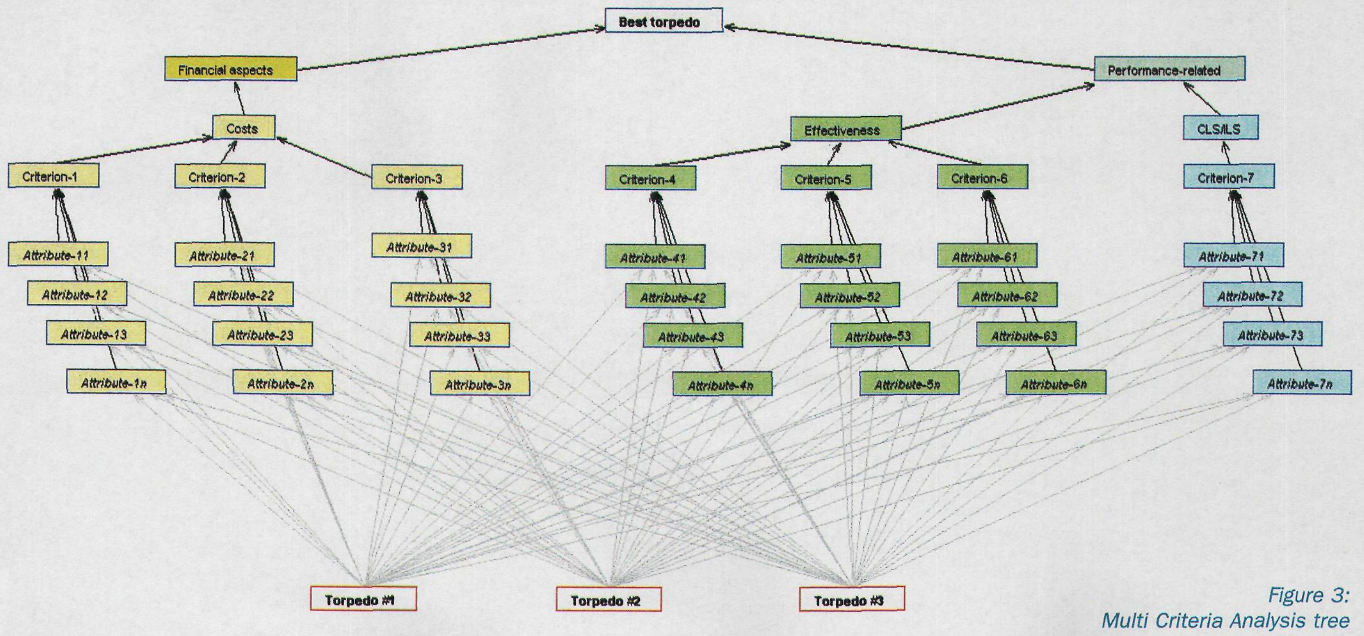

Figure 3: Multi Criteria Analysis tree

Operational Analysis on Torpedo Defence (continued)

In the near future, MK46 and MK48 torpedoes must be replaced by new torpedoes which meet new operational and technical requirements. Extra information on candidates for replacement of these torpedoes has been requested from the manufacturers using a Request For Information (RFI). The RFI concentrates on a range of information in different areas.

With the help of the RFI and exercise launches, much insight can be gained on the operation of new torpedoes. This will enable comparison of different torpedoes.

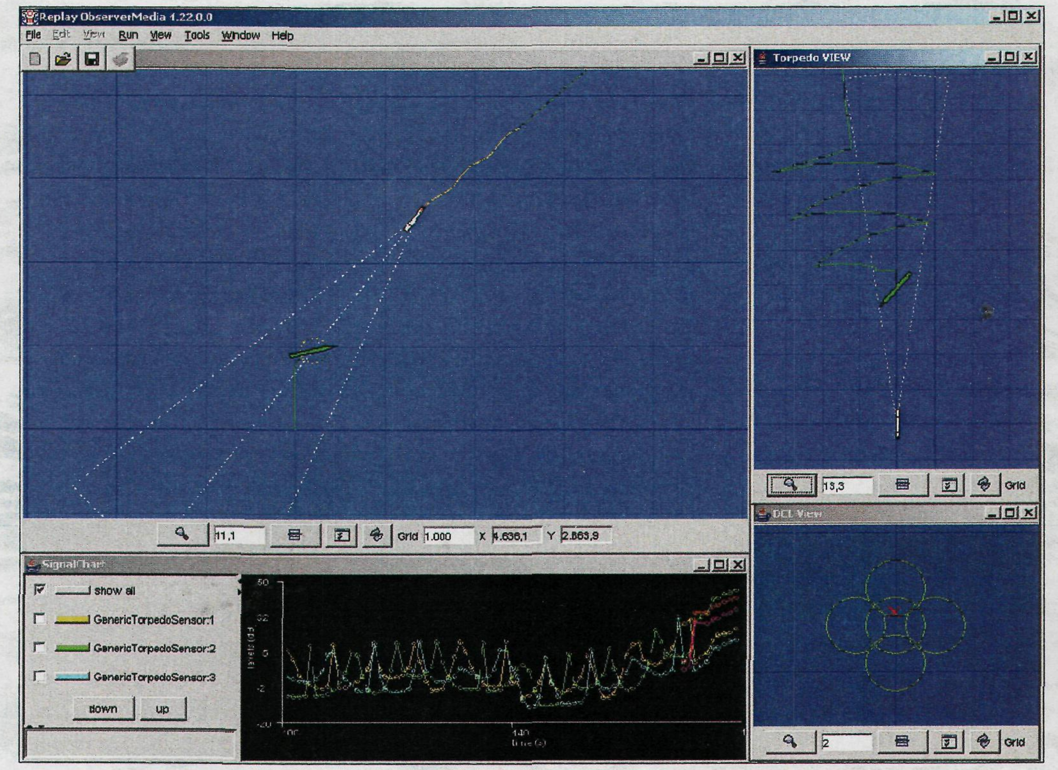

Figure 4: Graphical overview of a run of a generic torpedo in the TDSTB

Comparison of candidates

Three different methods (multi criteria analysis, live firings and modelling) are used to compare the different torpedoes.

Possible candidates for replacement of the present torpedoes are compared with the help of Multi Criteria Analysis. Financial aspects and performances of the different candidates are compared at the highest level (see Figure 3). Cost and performance-related issues are sub-divided in different parent/child trees representing criteria and attributes.

The effectiveness of different torpedoes is determined for each of the attributes on a pre-defined score scale. Weights have been assigned to the different criteria on different levels. In this way, the total score of a torpedo type can be determined.

Live firings are used to demonstrate that new torpedoes meet technical specifications. In a specific scenario, exercise torpedoes are launched on different targets in varying environmental conditions. Decoys and jammers can also be deployed. Test data are recorded by the torpedo itself and other registration systems on board the ships involved.

General information on essential technical and operational aspects is necessary for global torpedo modelling. The torpedo signature is relevant for the procurement and the use of the torpedo. MK48 and generic torpedoes have been modelled in the TDSTB (see Figure 4). The torpedo sonar performance is compared by modelling in ALMOST.

Torpedo detection systems

Within the programme, torpedo detection and torpedo defence systems (applicable to RNLN surface ships) are also investigated. An inventory has been made of possible detection systems including attributed preferences.

Torpedo detection is a crucial aspect in defending a ship against a torpedo attack. If an incoming torpedo has been detected, decoy and jammer deployment can be effective.

Only sonar detection systems have been considered in this inventory. To detect torpedoes, three categories of sonar systems can be identified:

1. Hull-mounted sonar
2. Towed sonar
3. Sensors at distance e.g. sonar buoys and dipping sonar

Systems on board RNLN surface ships and helicopters are mainly used to detect submarines. With these systems, and without the aid of specific torpedo detection software, it is very difficult to detect incoming torpedoes. Using ALMOST, the detection ranges of the available RNLN sonar systems have been determined for an indication of the detection performance.

Comparison of sonar detection performance

Active and passive detection ranges have been determined against wire guided acoustic homers, wake homers, acoustic homers and straight runners. Detection ranges against torpedoes depend, amongst others, upon area; month/season; wind speed; torpedo speed and depth; radiated noise; target strength and target aspect.

The detection results strongly depend upon the season (i.e. the sound speed profile). Maximum active and passive detection ranges differ significantly per sonar type (towed versus hull-mounted)

Torpedo detection system requirements

The moment a torpedo has been detected, it is necessary to know the torpedo attack direction. Hull- mounted sonar systems can determine the attack direction in a simple way. This is not simple for towed systems. The left/right discrimination can only be obtained with the help of twin, triple or quad arrays (with left/right beam forming).

In addition to the use of a single detection sonar, several sonar systems can also be used simultaneously. Position and speed can be determined more accurately using cross bearings.

The following list shows examples of torpedo signals that can be detected by passive sonar:

- Launch-impulse transient (signals dependent on the launch type)
- Active sonar transmissions of a torpedo
- Broadband radiated noise (generated by propulsion). This noise can easily be detected with an energy detector. The modulation generated by the rotation of screws can be filtered out of this broadband noise e.g. with the help of DEMON-analysis
- Narrow band noise (also generated by propulsion). From this NB, noise spectral lines can be filtered, which are a fingerprint for the classification process

Some of the signals can be detected at great distance which enables the timely deployment of countermeasures.

Active sonar systems have a totally different challenge to detect a torpedo: the target strength is low because of the relative small reflection surface of the torpedo.

Because of its high speed, the signature of the torpedo can simply be determined from bottom and surface reverberation. A short Doppler-sensitive pulse can obtain a good target solution expressed in speed and position. The pulse repetition time is another disadvantage of active sonar systems; you have to wait for a number of transmissions to collect good target data.

Because of its high speed, a torpedo approaches very rapidly which restricts the reaction time to deploy countermeasures. The speed of a ship can further reduce the reaction time.

Operational requirements are also important. In most cases, the surface ship deployed for torpedo detection has an Anti Submarine Warfare task. During a torpedo attack, the surface ship uses its sonar systems to detect submarines. Therefore, a combined system is preferred e.g. one single towed array for the detection of submarines and torpedoes. For this purpose, low frequency arrays have to be extended with a higher frequency component for better detection of an incoming torpedo.

It is not simple to detect an incoming torpedo. Hull-mounted and towed sonar systems both have advantages and disadvantages. A combination of the two detection systems (hull-mounted and towed sonar) per ASW ship will result in a better detection performance because of the all-round coverage of these systems. If the detection systems are passive and positioned far enough from each other, the torpedo position can be determined with the help of a cross fix. It is necessary to use sensor systems that can discriminate between left and right to determine the attack direction.

Because an ASW ship also has to detect torpedoes, torpedo detection systems should be integrated into sonar systems for submarine detection. Combining these systems will minimize extra limitations during an ASW operation.

Countermeasures

After the detection and classification of an incoming torpedo, countermeasures can be deployed to deceive or eliminate the torpedo. Countermeasures involve carrying out an evasive manoeuvre and/or deploying decoys and jammers. Hard-kill systems are also available to physically eliminate a torpedo.

Torpedo jammers are used to send a lot of sound/noise into the water to stop the torpedo from finding the target. Sufficient broadband noise in the right frequency band can also be transmitted into the water so that the torpedo considers this noise to be radiated by a possible target.

A torpedo decoy is a system that reacts to an incoming torpedo. The decoy receives the transmitted signals and transmits a reaction signal simulating the signature of the platform to be protected. Besides transmitting a reaction signal, the decoy also transmits noise simulating the propulsion noise of the surface ship.

These countermeasure systems can be towed and launched. The launched systems are stationary (they hover at a certain depth in the water), only move in depth or are mobile (moving mainly in a horizontal direction).

As well as investigating the deployment of soft-kill systems (decoys/jammers), a few hard-kill systems for physically eliminating an attacking torpedo were also investigated.

Defence concepts

If systems are deployed as countermeasures, in most cases it is wise to deploy jammers in combination with decoys. If the threat only consists of passive torpedoes, deploying jammers is sufficient.

The jammer will cause the torpedo to temporarily lose contact with the target, thus giving the target (ship) time to carry out an evasive manoeuvre. As soon as the torpedo passes the jammer, the torpedo will search for the target again. If the torpedo starts an active new attack and decoys are active at that moment, the torpedo will probably select one of these decoys as the target. With mobile decoys, the torpedo will be distracted from the target ship.

Hard-kill systems are torpedo-like systems with high speed and manoeuvrability. Hard-kill systems must be fired with high accuracy in the direction of the target. Therefore, it is very important to have a good estimate of the position and speed of the incoming torpedo. Currently, just knowing that position accurately enough is still an enormous challenge.

Latest developments show the use of a (stationary) decoy equipped with an explosive device. If the torpedo approaches this decoy closely enough, the decoy explodes, thus eliminating the torpedo.

Jammer and decoy requirements

A jammer must be able to transmit high power in a broad frequency spectrum. The signals must consist of broadband noise with the possible addition of screw noise (to attract the torpedo). Most jammers are stationary, because they only have to create a temporary soundscreen. Jammer mobility is therefore less important. The depth pre-set may, however, be important.

A decoy has to imitate a target. At the right moments, it re-transmits the required signals to the incoming torpedo. The decoy must therefore be able to quickly analyze the incoming signals of the torpedo and transmit an appropriate reaction. Moreover, attention has to be paid to the required Doppler-shift and modelling of highlights of the target. The reaction time of the decoy depends upon the position of the decoy with respect to the positions of the torpedo and the surface ship to be simulated. If the decoy has been launched in the direction of an incoming torpedo, the minimum reaction time is directly proport-ional with the launch distance.

The bottleneck of decoy deployment is transmitting the right signal by the decoy on time. Since modern torpedoes can change the signal type per transmission, it is very difficult for a decoy to compose and transmit the right signal in time. This is relatively simple when deploying a decoy against older torpedo types, because such torpedoes transmit the same signal continuously.

A mobile decoy can distract the torpedo in another direction because the decoy moves away from the ship. A disadvantage of mobile decoys is the selection of the movement direction of the decoy before the decoy has been launched. Afterwards, the ship has to monitor this movement to be able to carry out an evasive manoeuvre at the right time and in the right direction.

Torpedo defence systems

Currently, two torpedo defence systems are being studied:

1. SLAT (Système de Lutte Anti-Torpille – Whitehead Alenia Sistemi Subacquei or WASS) deployment of jammers followed by (mobile) decoys (see Figure 5)
2. ATDS (Advanced Torpedo Defence System – Rafael, Israel) deployment of a towed decoy (for torpedo attraction and localization) and an expendable decoy (for torpedo diversion)

A torpedo defence system is an integrated system that executes detection, classification and localisation of the torpedo and advises on the counter-measures to be deployed.

The system can be sub-divided in three parts (see Figure 1):

1. Sensors for the DCL (detection, classification and localization of a torpedo)
2. Evaluators based on logics and tactics
3. Reactors for the deployment of countermeasures (e.g. decoys, jammers and evasive manoeuvres)

Integrated systems with one or more sonar systems for detection, classification and localisation (DCL) are developed for torpedo defence. After DCL, a decision system advises on deploying which types of countermeasures at which moments. The bearing of the torpedo can generally be estimated with high accuracy. Dependent upon the type and direction of the threat, counter-measures can be deployed. This depends upon the available decoys/jammers and possible evasive manoeuvres. Counter-measures can be integrated into commercially available torpedo defence systems.
An inventory has been made of torpedo defence systems, including their characteristics, manufactured by different countries. Many countries are developing integrated torpedo defence systems – most just use towed arrays to detect a torpedo. A few countries are developing combined systems that also use hull-mounted sonar.

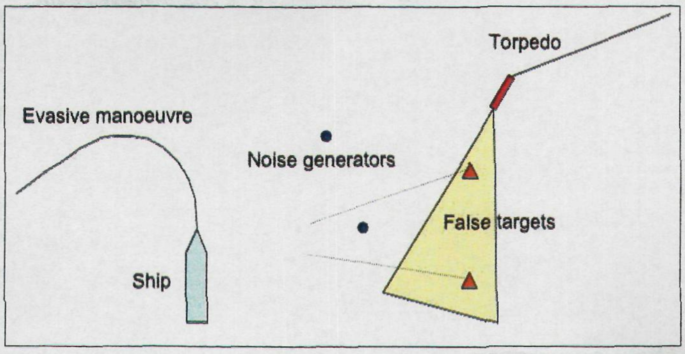

Figure 5: Torpedo defence concept of WASS: deployment of jammers followed by decoys

In an integrated torpedo defence system, it is important to combine existing sonar systems (possibly extended with higher frequency detections) to improve the monitoring of torpedo detection. For many navies, the torpedo defence system needs to be a semi-automatic system that operates at a 'background level' and gives a warning the moment that a torpedo is detected. During an ASW operation, it is more important to detect a submarine before it can come close enough to fire a torpedo. This is the reason that operators generally search for submarines during these operations and a torpedo defence system only has to give a warning at the moment a torpedo has been detected.

Development of tactics

A torpedo defence system advises on the countermeasures to be deployed. Since manufacturers do not know which procedures are used per country, these procedures can be implemented by the navies themselves. A number of tactical studies have to be carried out to determine the right decision rules that will be used to implement tactical procedures. Tactical studies can be carried out with the help of a torpedo simulation environment like the TDSTB.

Studies are being carried out with the help of the TDSTB to evaluate future Torpedo Defence Systems for the Royal Netherlands Navy. Emphasis lies on Torpedo Defence concepts that are a combination of:

- Jammers: masking own ship
- Decoys: emulating own ship to distract the torpedo
- Evasive manoeuvre: moving own ship away from the torpedo
- Hard-kill: eliminate the torpedo physically e.g. with help of a decoy with explosives

Area Torpedo Defence

Defence does not always take place at an individual level but can also be carried out collectively. In a formation of ships at sea (dynamic) or in an amphibious operation area (static), defence in depth and mutual interference are important aspects with great influence on self and mutual defence capabilities. This collective defence (Area Torpedo Defence, ATD) can substantially contribute to defence. However, the extent of the contribution of STDS (Ship Torpedo Defence System) and ATD to the protection of ships is not sufficiently clear.

This study concentrates on the torpedo defence capability of formations of ships. This means that the phase in which the submarine is detected and subsequently killed by the accompanying sub-surface and surface platforms is not studied. The attacking submarine(s) has (have) launched a single torpedo or multiple torpedoes to eliminate high value target(s), (HVU) and other target type(s) which sail in different formations. First, the formation of ships has to detect the attacking torpedo. As a reaction, the formation can deploy countermeasures e.g. jammers, decoys, evasive manoeuvres and hard-kill.

Study objective

The study objective was to conceptually analyse the deployment of a TDS for dense formations of ships. The defence assets have to be deployed in such a way that the probability of detecting hostile torpedoes is maximized for the total formation.

'Escaping probability' is the probability that a torpedo never enters the safety zone of the ship. The safety zone is an area around the ship, defined by the safety distance (safety distance is a minimum approach distance between a torpedo and the closest point of the ship). A similar safety zone around the formation of ships is defined as the Torpedo Defence Area.

Knowledge of torpedo defence of dense formations of ships (Area Torpedo Defence) has been built up and described systematically to be able to conceptually analyse the deployment of Torpedo Defence Systems for ATD.

This study concentrated on the torpedo defence capability of formations of ships. Emphasis lay in determining the formation that maximizes the probability of detecting hostile torpedoes.

Study plan and 'Measure of Effectiveness'

In this limited budget project, only exemplary formations of RNLN ships have been studied and none of possible NATO task groups. The RNLN task group (amphibious formation) was studied in two variations:

1. Task group in transit
2. Non-stationary kernel of HVUs in an amphibious formation

The RNLN task group in transit (see Figure 6) can be compared with the small "Task force for SLOC protection" (Sea Lines Of Communication) that protects economic shipping while transiting a choke point within a war zone. In the task force (composed of RNLN ships), three categories of ships are considered:

- Two AAW frigates (ADCFs) provide an all-round defence
- Two ASW frigates (M-frigates) provide ASW defence and limited AAW defence
- Three HVUs (merchants or navy ships- LPD of JLSS) are without any self defence

One Measure of Effectiveness has been used in this study to get a rough indication of the performance of different formations in the analyses: the detection range (Pdet = 0.5) of a sonar system against each torpedo type (dependent upon the threat direction).

In the following sections, two examples of formations for Area Torpedo Defence for a task group in transit, and for a task group with a non-stationary kernel in a sea base, are presented. Detection ranges of the sonar systems, used in examples of formations for transit and in a sea base, are represented graphically. The area covered by formations in transit is visualized using graphical representations. Since the ships sail in a fixed formation, a static representation is sufficient.

For quick visualisation of the sea base area covered by the sonar systems of moving units, a sonar coverage simulation tool has been made. Any number of units can be entered in this tool, with their HMS sonar range and, if applicable, their towed array sonar range. A sea base area to be protected can be visualized as a square.

RNLN task group in transit

Figure 6 gives an overview of the maximum detection ranges against torpedoes calculated for the sonar systems of a RNLN formation in transit. One M-frigate sails in front of the kernel and one M-frigate sails behind the kernel. The ADCFs sail on the flanks of the kernel.

Since the HVUs sail close together, the detection range against torpedoes reckoned from the centre of the kernel of HVUs is rather long. This applies to each torpedo threat direction. Further, a second layer with the help of the Hull-mounted sonars of the frigates is available.

The conclusion is that this formation gives good protection against each torpedo threat.

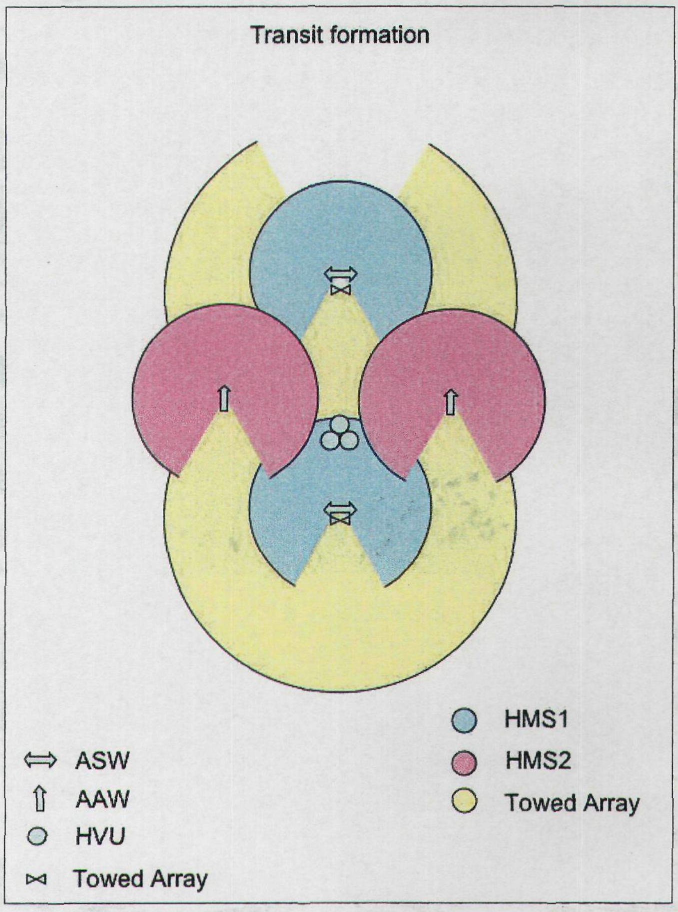

Figure 6: Overview of the maximum detection ranges against torpedoes calculated for the sonar systems of a RNLN formation in transit

RNLN task group in a sea base

The objective is to defend the sea base area against torpedo attacks. Torpedoes have to be detected before they enter the sea base area. The sea base is represented as a square. The HVUs operate within the borders of the sea base.

Figure 7 gives an overview of a RNLN task group in a sea base in which all protecting units sail in circles through or around the sea base. The blind sectors in Figure 7 change as a consequence of the dynamic behaviour of the protecting frigates.

The escorts sail around the sea base area, which enables maximum achievable detection ranges and sufficient reaction time before the torpedo enters the sea base. Extra units can be deployed in the gaps for a larger covered area.

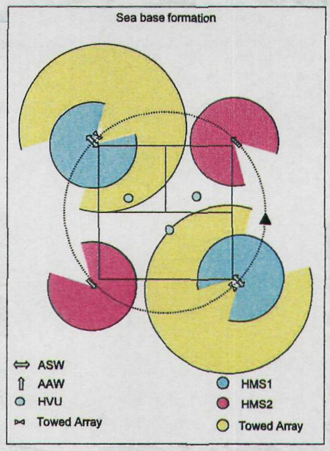

Figure 7: Overview of the maximum detection ranges against torpedoes calculated for the sonar systems of a RNLN task group in a sea base in which all protecting units sail in circles through or around the sea base

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Operational Analysis on Torpedo Defence (continued)

Summary of results

The main results of the formations for detection of hostile torpedoes are:

- In a formation in transit, escorts can sail at fixed relative positions
- If HVUs in a task group in transit sail close together, long detection ranges and a layered defence are possible
- For short detection ranges, escorts should operate in an uncoordinated way (random patterns) in their own boxes to defend the sea base. If escorts operate outside their own box, gaps in the covered area will occur
- For long detection ranges, escorts should sail in a highly coordinated way (fixed patterns) through or around the sea base for defence against hostile torpedoes. In this way, the covered area can be enlarged.

Future work

The next phase of the TDS research programme concentrates on the following aspects:

- Systematic descriptions will be made of a selection of different systems (torpedoes, sonar systems, decoys, jammers and Torpedo Defence Systems)
- Elaboration of countermeasure concepts
- Determination of operational requirements on a TDS with the help of simulation
- Further research into candidates for replacement of current torpedoes of RNLN
- Further research into applicable TDS for surface ships

In 2004, the first version of the TDSTB was released to the RNLN. The RNLN is using the testbed in operational studies and can compare the performance of TDS systems. However, the development continues and focuses on adding new systems (e.g. other torpedoes and jammer/decoys and detailed modelling of the frigate sensor suite) and updating the operational tactics of the frigates. The TDSTB is a torpedo defence simulation model that can be used easily and extended to the needs of its users.

TNO is willing to discuss the use and possible release of the unclassified version of the testbed to other countries. To facilitate future international collaboration on TDS modelling and simulation, the simulation kernel of the testbed is designed with a generic interface, with a clear separation between kernel and domain models. In the near future, other models simulating Mine Warfare, Anti Submarine Warfare and Network Enabled Capabilities will be linked to the UWT to use the same model architecture.

Editor's note

A full list of references can be found with the original paper.