SIMSON – A tool for simulation and analysis of ASW sonar performance in littoral waters

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***Abstract* – Anti-submarine operations and use of sonars in littoral waters is a challenging task. The Norwegian Navy is acquiring new frigates with a sonar suite and an ASW system adapted to the littoral. To assist the navy in optimal usage of the new system in this complex and changing environment, FFI develops a tool for detailed simulation and analysis of sonar performance. Accurate acoustic modelling in strongly range-dependent environment is an important element is this tool. The tool will be used during technical and operational evaluation of the new frigates and as an important part in the education of operators and in development of tactics. This paper presents the main properties of the tool and gives examples of prediction of sonar clutter in coastal waters.**

I. INTRODUCTION

The Norwegian Navy has operated in complex coastal waters for decades and gained valuable experience in performing Anti Submarine Warfare operations in this challenging environment. The experience was the basis for the requirements to the new frigates – The Fridtjof Nansen class – which are entering service in 2007, see Fig. 1. Main challenges in ASW are severe oceanographic conditions, strong reverberation from the seabed, and many false alarms. In addition the submarine will utilize the many underwater hills and canyons to avoid detection. The new ASW system is designed to meet the demanding requirements in various operational scenarios. At the same time the system and the sensors are very flexible allowing for adaptation to specific scenarios.

The optimum usage of such a complex and flexible system requires good understanding of the technical performance, well-trained operators and procedures and tactics adapted to the systems capabilities.

The Norwegian Navy and FFI have experience from the technical and operational evaluation of the Norwegian ULA-class submarines in the 90s. Lesson learned is that complex systems do not perform as expected, and that it is a tedious task to identify the source of the problems and to implement necessary corrections and modifications. A critical element in operational evaluation is a good understanding of the technical performance of the combat system down to a detailed level.

In 2002, project SIMSON[1] was started at FFI to complement other activity concerned with preparation for the technical- and operational evaluation of the new frigates. The short-term goal of the project is to develop a tool for detailed analysis of the ASW combat management system of the Fridjof Nansen class frigates, and thereby understand the processes influencing the overall performance of the system. Special focus is put to the active acoustic ASW sensors. The helicopter dipping sonar is seen as a part of the frigate integrated weapon system. The long term goal is to increase the Navy's ability of simulate and evaluate co-ordinated ASW operations on force level, including multistatic sonar operations.

Fig. 1. The first of the Fridtjof Nansen class frigate will enter service in 2007. The helicopter will be an organic part of the system

In this paper we first look into the challenges with evaluation and effective use of the new ASW system. The SIMSON tool is then described. Some examples of the tools capability of prediction of active sonar clutter will also be given.

II. EVALUATION AND EFFECTIVE USE OF THE NEW ASW SYSTEM

A. A new ASW System for the littoral

The Fridtjof Nansen class frigates will have an ASW system from Kongsberg Defence & Aerospace (KDA). The system is based on the experience gained during the UNISON 2005 project, a research and technology project with participants from the Norwegian Navy, Kongsberg

[1] SIMSON - SIMulation and evaluation of SONar systems and ASW operations.

Simrad, KDA and FFI [1], [2]and [3]. The sonar suite includes a hull mounted sonar with multifunction capabilities and a combined active passive towed array. In addition the organic helicopter will be equipped with dipping sonar and buoys. Main weapon is the lightweight torpedoes delivered from the ship or from the helicopter [4]

False alarm reduction capabilities are built into the system, by specific algorithms and by combining information from own sensors and external sources. Configuration support functions are included to assist the operators in optimising sonar performance in various environmental conditions. For the purpose of evaluation and performance assessment, there are extensive logging and recording possibilities at many levels of the ASW system.

B. Evaluation and effective use

The operational performance of the ASW combat system will depend on the technical performance of the system, the tactics applied, and the skill of the operators and officers using the system. Defining operational performance and describing how to measure the performance is not the issue of this paper. The point here is that a very good understanding of the technical performance of the ASW system in an operation, will be essential in understanding how tactics and operators affects the total performance of the same operation.

To achieve good operational performance, several conditions must be fulfilled: The system of course need to be designed to fulfil the requirements, bugs must be removed from software and hardware, the technical performance in idealistic situation must be understood and hopefully be close to expected or better than expected. Technical performance under operational conditions must be known, and to measure the performance, experiments should be done in realistic scenarios and under realistic environmental conditions. Since only a very few sets of exercises/experiments is realistic to achieve per year, we need a way of extrapolating the result to other conditions. To do so, detailed recordings of system data, reference data (e.g. submarine position and aspect) and environmental information should be made. With the help of analysis and simulations the results will be extrapolated to give the technical performance under various operational conditions. Developments of tactics, operator training and tactical training should then be based on these realistic assumptions of system performance. If necessary, sensor optimising tools and tactical decision aids should be updated to reflect the new understanding of technical performance.

To understand and predict the performance of the ASW system we need to understand the processes influencing it, from the effect of the environment, through sensor processing, picture compilation, operator decisions, and weapon allocation and weapon performance. Project SIMSON aims at establishing a tool to aid this process of “understanding”.

Since the frigates and the ASW system will in the future be used in a variety of situations not foreseen now, the process of predicting and evaluating performance will be a continues task throughout the lifetime of the system. Systematic collection of “real life” experience will also be valuable when writing requirements for updates and new systems.

As stated above, development of tactics, training, planning tools and decision support tools should be based on best possible knowledge of expected performance of the systems in different situations. The ability to predict or simulate sensor performance or system performance is here essential. Accurate and realistic simulations could only be achieved through continuously incorporating the experience from experiments and exercises.

With sonar simulations taking into account the local effects of oceanography and bathymetry, operators and officers can get realistic training for a specific scenario, area and environment. In that way they will be better prepared for the type of situations to occur in that area. Since the high number of false contacts is a challenge in the littoral, realistic simulation of false contacts will be essential.

Planning and decision support tools based on prediction of sensor performance, usually optimise on detection probability. In coastal environment, ASW operations will be disrupted by false contacts. When areas and situations causing false contacts can be predicted, we think this will be an important element in a future support tool. Project SIMSON also aims at establishing a simulation tool for the active sonars, suitable for training purposes and for planning and decision support.

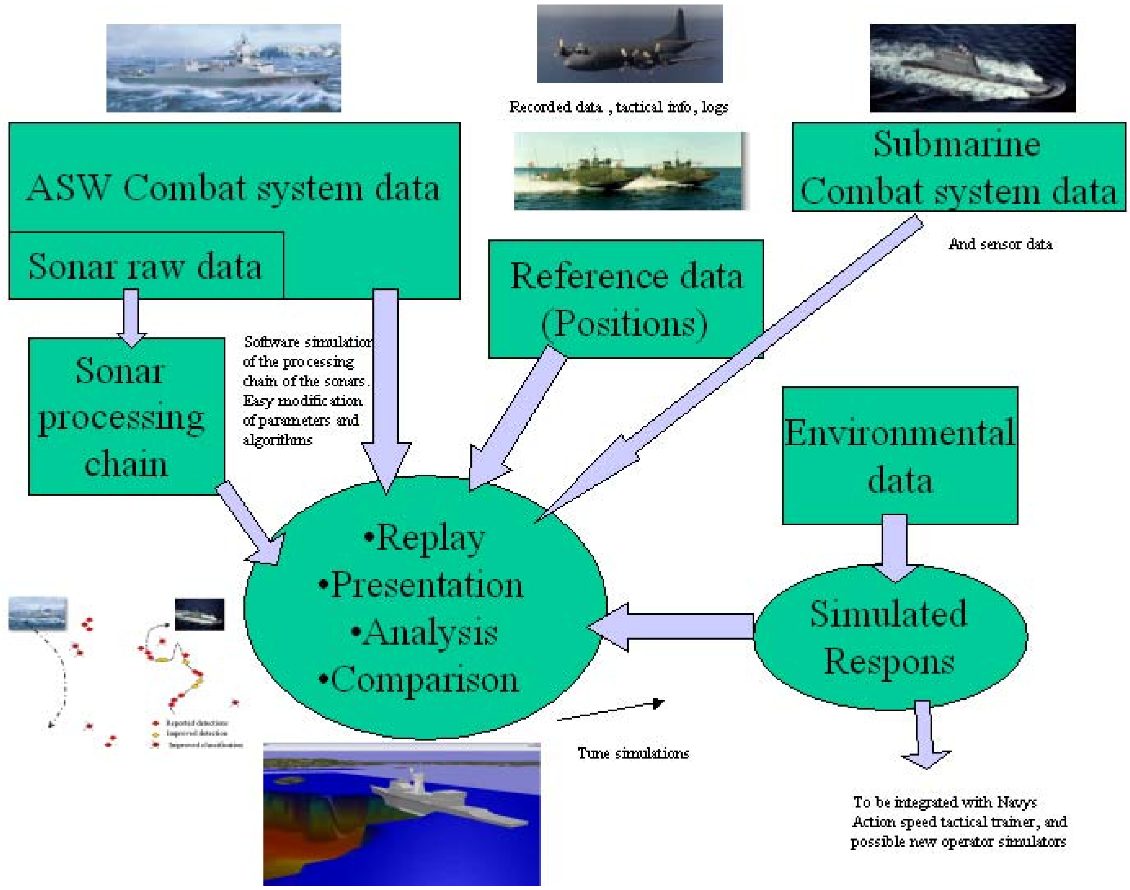

Fig. 2. Layout of the SIMSON tool

III. THE SIMSON TOOL

Project SIMSON at FFI started in April 2002 and lasts for 3 years. The objectives of the project are to develop software to support post exercise analysis of ASW combat management functions both for frigates and submarines and to develop an analysis and simulation tool for the ASW-sensors of the Fridtjof Nansen class frigates. Focus is on realistic acoustic modelling of active sonars in littoral areas. The processing chain from sensor to decision maker will be implemented to support the analysis.

A schematic of the tool is given in Fig. 2. Basis for the analysis is recorded sonar data, combat system data and reference data from units involved in an exercise or experiment. The sonar data are recorded at different processing levels. To get an overview, recorded data are visualized and presented together with reference data and environmental data. The performance is measured by comparison with reference data. In order to explain any variation in performance, recorded sonar data are compared with simulated sonar data. The simulations will be based on our best knowledge of the environment (based on direct measurements during the trial, forecasts or database information). We are also interested in investigating the performance in situations where recorded data are not available (e.g. another pulse type, tilt, sonar depth, or even for a different season or in a different area). To do so, we need to simulate/generate the scenario and the sonar settings and to simulate sonar response. To be able to assess the performance of the different processing algorithms, a full sonar processing chain for the most common active sonar processing modes will be implemented in the analysis tool. Different processing algorithms and parameter settings can then be tested, see illustration in Fig. 3. If available, software from the vendor will be implemented.

By including analysis of combat management functions including operator interaction, we have the ability to see how the combat system utilize the technical sensor performance and how overall performance is influenced by the operator, the combat management system and the procedures and tactics.

The tool will be used for: 1) Technical and operational evaluation of the ASW system of the new frigates 2) Analysis of ASW performance in small and larger exercises, 3) Co-ordinated analysis of several units (including submarines), 4) Test-bed for new algorithms, methods and concepts, 5) Basis for input to models on operational level, 6) Simulation of detailed sonar output in different scenarios.

Input data to the tool is recorded on different levels and from different sources. This is primarily information available from the combat system, such as: hydrophone data, echo positions, classification information, track, operator interaction, orders from ASW officers, weapon allocation, and information from tactical network.

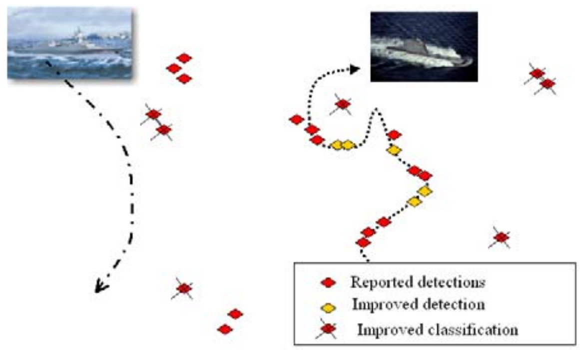

Fig. 3. Schematic output of tool, indicating comparison of on-board system processing and offline improved processing.

Also information from outside sources is critical for the analysis, e.g. position data from involved units, the submarines target solution of the frigate, environmental data e.g. bathymetry, meteorological data, oceanography, pipelines and other underwater installations.

Main components of the tool will be:

- An acoustic model
- The sonar processing chain
- Analysis functions
- Presentation
- Data storage for easy access of historical data from trials, tests.

The system will consist of three logical layers: data, business and presentation. The presentation layer will offer a graphical interface for the user. First step will be to import the data and organise the data in an internal data structure. Next step will be to present an overview of available data. Third to set up analysis and produce results. The system will utilise the latest Microsoft .NET technology and the programming language C#. For geographical based presentations the Map service (MARIA) will be used. This is the same presentation used in the Norwegian Command Control and Information system (NORCCIS II) [5]. Analysis could then be performed in a familiar environment for the officers and operators. In addition much of the functionality needed is already present in MARIA. The same will be true for most of the geo based information (bathymetry, meteorology, oceanography, pipelines, wrecks, installations…). Presentation in 3D is available to improve the intuitive understanding of a situation, see Fig. 4.

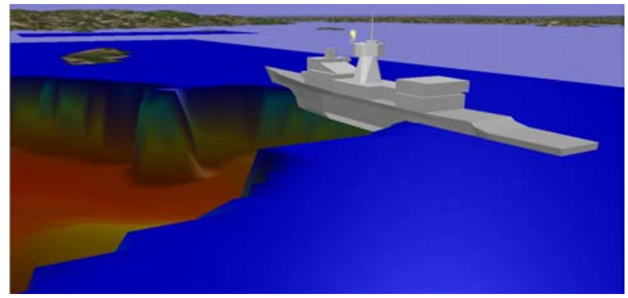

Fig. 4. The Simson tool will use Map Service of MARIA for geo-referenced presentations. Example of 3D presentation is given here.

There will be several potential users of the tool:

- The officers wanting to get an overview of the exercise with important events.
- The ASW officers and operators that need to learn how the system performed and why, and what could be improved?
- The analyst team performing detailed technical studies during technical and operational evaluation.
- The scientist and system developer that want to try out alternative algorithms and concepts on real data.

A further development of this tool will aim at including the torpedo, and the passive sensors. For improved tactics in the littoral it is very important for the submariner to have a feeling for the frigates picture and for the frigate to know the submariners picture. Coordinated analysis between the two is therefore important. Further on integration of torpedo counter measure simulation will take place, and also the ability to analyse multistatic operations, where synchronisation in time/position and processing is important. Use of future advanced sonar targets based on autonomous underwater vehicles will also be included.

IV. ASW SONARS IN THE LITTORAL AND ACTIVE SONAR CLUTTER PREDICTION

The main challenge when operating ASW sonars in coastal waters, see Fig. 5, is the oceanographic conditions and reverberation. Even when submarine echo levels are well above the threshold, detection is problematic. This is due to the large number of contact candidates or false contacts presented to the operator. The operator has to spend much time investigating many possible submarine contacts and may therefore miss short living real contacts. Several ways of reducing this problem is implemented in existing sonars (see chap II). In earlier research, FFI has identified good correlation between position of sonar echoes and bathymetric structures [6]. Wegge [7] also showed that by using an accurate acoustic model, oceanographic information and detailed bathymetry, echo intensive areas can be predicted. We have identified that many bathymetric features give rise to track with non-zero speed. The research is based on real sonar data from a medium frequency hull-mounted sonar.

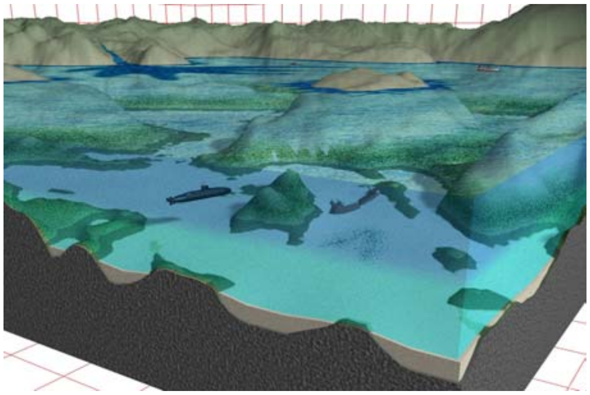

Fig. 5. Artist impression of coastal waters.

Some initial results are shown of the analysis of sonar data from a strong range dependent coastal area in Norway (from [7]). This to give an indication of the challenge and of our capability of simulating some of the effects observed.

Several runs with a Norwegian frigate using hull-mounted sonar were performed in a Norwegian fjord. Frequency modulated pulses were used, and the signals were processed by the sonar and recorded at echo level, i.e. positions of detected signal. Tracking were then applied offline.

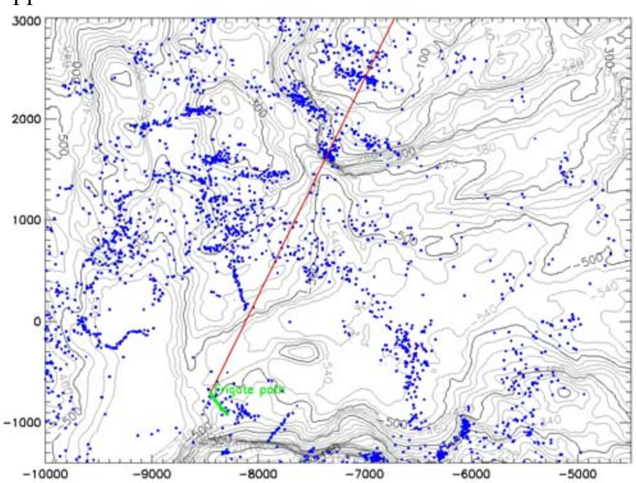

Fig. 6. Track candidates based on 40 sonar transmissions from frigate sonar are shown. The green line indicates position of frigate. For every transmission the estimated position for every track candidate is plotted as blue dots. All track-candidates lasting 3 transmissions or more are plotted. The red line indicates the cross section used for acoustic simulation in Fig. 7.

In Fig. 6 the track candidates during 7-minute period is shown. The tracks are based on 40 transmissions from the sonar. For every transmission the estimated position for every track candidate is plotted as blue dots. All track-candidates lasting 3 transmissions or more are plotted. The green line in the lower part of the figure indicates position of frigate during the period.

We observe that most track candidates can be associated with geographic structures (steep gradients), but there are also steep gradients with no tracks associated. This can be explained by the oceanographic conditions and the properties of the sonar. In other words: only the structures insonified by the sonar will scatter energy back to the sonar and give rise to echoes and tracks. This is illustrated by the transmission loss plot in Fig. 7, where we see how the energy in the surface channel “hits” the bottom at the range of 3500m. This coincides with the track candidates near the end of the red line in Fig. 6. The steep gradient at 3000m is not insonified and no track candidates are observed at that range.

The acoustic model used, is the sonar prediction model LYBIN, from Norwegian Defence Logistic Organisation [8]. In 2001 this model was evaluated at the SACLANTCEN with very good recommendations [9]. Essential input to the simulations is high-resolution bathymetry data. Example output is shown in Fig. 7

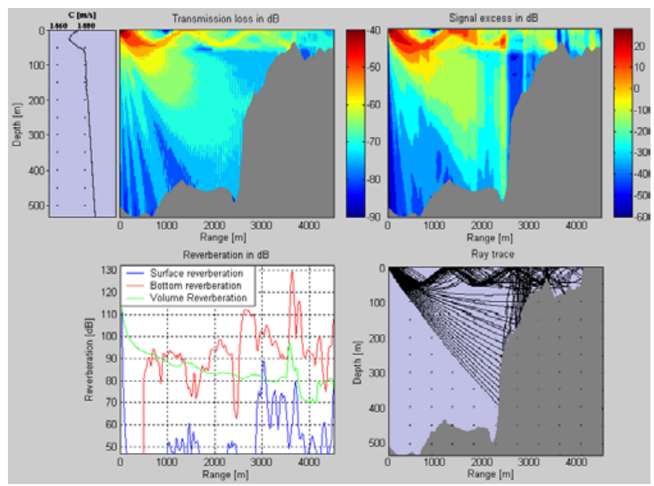

Fig. 7. Results from acoustic model for the cross section defined by the red line in Fig. 6. Top left plot show the predicted transmission loss, while top right plot give the signal excess. Lower right plot gives a fan of rays representative for the sonar beam width and the sound velocity profile. Curves for bottom-, volume,- and surface reverberation is given in the lower left plot. Notice the local maxima of the bottom reverberation (red curve).

Based on the hypothesis that bottom reverberation is the effect that causes the majority of false alarm tracks, we wish to compare track positions with local maxima in the predicted reverberation (red curve in Fig. 7). This comparison is done in Fig. 8. For three different frigate positions we have shown tracks generated in a fixed area of 2.5x2km. For each of the frigate positions the bottom reverberation is modelled with a 1-degree resolution in bearing. For each bearing, the extent of local reverberation maxima is indicated by line segments.

We find that position of track data and modelled reverberation show good correlation. The detailed terrain information enables a good visual correlation between bathymetric structures and sonar data, and also enables us to predict false alarm areas fairly well.

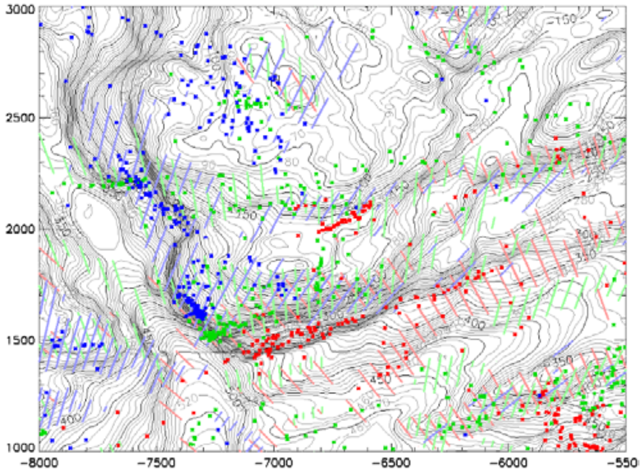

Fig. 8. Comparison of track positions and predicted reverberation areas. Track candidates (dots) and extent of local maxima of predicted bottom reverberation (lines) are shown. Each colour represents data for a given frigate position.

Our work is in an initial phase and more work is needed. We will further adapt the acoustic model to the range dependent environment in coastal areas and the computational speed must be increased. Analysis of more sonar data from different scenarios and new areas will be done to validate the model. The next step is to look into clutter generated using low frequency sonar, where also sub-bottom features play an important role. We already have experimental data available.

V. SUMMARY

Norway is now focused on operations in the littoral. A large effort is made to assure optimum use of existing and new underwater warfare systems. From 2006 the technical- and operational evaluation of our new frigates will be a very important task. A good measure of operational performance is difficult to achieve due to very few exercises and real situations. Detailed knowledge of the performance at every stage of the process is therefore necessary to extrapolate the results for the few exercises. Simulation capability is crucial in order to evaluate performance for “all possible” options available, and to develop optimised settings and tactics.

The tool described in this paper will aid the Navy in the evaluation process of the ASW systems, and will also be the basis for future development of evaluation tool for coordinated ASW operations including multistatic operations.

ACKNOWLEDGMENT

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REFERENCES

[1] O A Eriksen, KDA (2001): Integrated ASW system design, UDT Europe 2001 Conference Proceedings

[2] John-Mikal Størdal, FFI, Wictor Nicolaysen, FFI, Ole Refsahl, KDA (1999): UNISON 2005 - Technology for the Next Generation of Combat Systems for Undersea Warfare, UDT Europe 99, Nice, 1 July 1999

[3] Wictor Nicolaysen, FFI, Jon Wegge, FFI, John-Mikal Størdal, FFI, Ole Refsahl, KDA (1999): UNISON 2005 - Understanding the underwater battlefield, DSEi 99, Chertsey 15 September 1999

[4] www.mil.no/fregatter

[5] www.teleplan.no

[6] Jon Wegge (2002): “Correlation between sonar echoes and sea floor topography” in “Impact of Littoral Environmental Variability on Acoustic Predictions and Sonar Performance” edited by Nicholas G. Pace and Finn B. Jensen, SACLANT Undersea Research Centre, La Spezia, Italy, Kluwer Academic Publishers

[7] Wegge, Dombestein, Gjersøe, Hjelmervik, Tveit (2003), Active Sonar Clutter Prediction, UDT Europe 2003

[8] Mjølsnes, Svein (2000): LYBIN SGP-180(C) - Model Description, The Royal Norwegian Navy Materiel Command, Bergen.

[9] Carlo M. Ferla, Cinzia Isoppo, Giovanna Martinelli and Finn B. Jensen (2001): Performance assessment of the LYBIN - 2.0 propagation-loss model, SACLANTCEN MEMORANDUM, SM-384.