NORTH ATLANTIC TREATY ORGANISATION

RESEARCH AND TECHNOLOGY ORGANISATION

AC/323(SET-032)TP/29

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RTO TECHNICAL REPORT **TR-SET-032**

Infrared Measurements and Modeling for Ship Self Defence

(La mesure et la modélisation infrarouges pour l'autodéfense des navires)

Final Report of Task Group 16 of the Sensors and Electronics Technology Panel (SET).

Published March 2006

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The Research and Technology Organisation (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote co-operative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective co-ordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also co-ordinates RTO's co-operation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of co-operation.

The total spectrum of R&T activities is covered by the following 7 bodies:

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS Studies, Analysis and Simulation Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These bodies are made up of national representatives as well as generally recognised 'world class' scientists. They also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

RTO builds upon earlier co-operation in defence research and technology as set-up under the Advisory Group for Aerospace Research and Development (AGARD) and the Defence Research Group (DRG). AGARD and the DRG share common roots in that they were both established at the initiative of Dr Theodore von Kármán, a leading aerospace scientist, who early on recognised the importance of scientific support for the Allied Armed Forces. RTO is capitalising on these common roots in order to provide the Alliance and the NATO nations with a strong scientific and technological basis that will guarantee a solid base for the future.

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Infrared Measurements and Modeling for Ship Self Defence

(RTO-TR-SET-032)

Executive Summary

This paper is the final report for NATO AC/323 Sensors and Electronics Technology Panel Task Group Number 16 (TG16) on Infrared (IR) Measurements and Modeling for Ship Self Defence. TG16 was organized in 2000 and continued until the end of 2003. The primary purpose of TG16 was to address the vulnerability of military ships to IR homing missiles. The main research topics related to ship self-defence included:

1) The detection of anti-ship missiles using passive IR search and track sensors;
2) Ship IR signature control via modeling and field testing of candidate techniques; and
3) Passive IR countermeasure techniques.

Member nations at the end of TG16 included Canada, Denmark, France, Germany, Greece, Italy, Netherlands, Norway, Poland, Portugal, Turkey, United Kingdom, and United States, with Australia as an observing nation. The TG provided for the regular exchange of information on national research and development activities related to ship self-defence. TG16 organized two joint field trials during the three-year period including Point Target At Low Level Experiment (POLLEX) for point source detection model validation and Ship Infrared Model Validation Experiment (SIMVEX) for ship IR signature model validation. Many technical reports and conference papers resulted from these trials. The committee also addressed IR modeling tasks associated with ship self-defence, including IR ship signatures, long-range point source detection, and IR propagation phenomena. For IR ship signatures, TG16 focused on an iterative model development/validation process using SHIPIR/NTCS. This code is now the NATO baseline model and used by most military naval shipbuilders. It also continued to validate the IR atmospheric radiation transfer model called Infrared Boundary Layer Effects Model (IRBLEM). TG16 also completed a study of a standard IR environment to use as a baseline for IR ship signature modeling and testing. TG16 published and distributed one IR informational brochure for Navy personnel who are not IR technologists but need to know the variability of IR ship signatures and the effects of the marine environment on IR sensors.

In summary, TG16 has served to forward the understanding of the use of IR technology for ship self defence, to share current information of pertinent national defence programs, and to foster cooperation among NATO countries on IR sensor development and field evaluation programs.

La mesure et la modélisation infrarouges pour l'autodéfense des navires

(RTO-TR-SET-032)

Synthèse

Ce document est le rapport final du groupe de travail 16 de la commission OTAN sur les technologies des capteurs et des dispositifs électroniques (SET) AC/323, sur la mesure et la modélisation infrarouges (IR) pour l'autodéfense des navires. Le groupe TG16 a été crée en 2000 et a poursuivi ses activités jusqu'à la fin de l'année 2003. Le groupe a eu pour objectif principal d'examiner la vulnérabilité de bâtiments militaires aux missiles IR à tête chercheuse. Les principaux sujets de recherche liés à l'autodéfense des navires comprennent :

1) La détection de missiles antinavires à l'aide de capteurs IR passifs de recherche et poursuite ;
2) Le contrôle des signatures IR des navires par la modélisation et les essais en grandeur réelle de techniques proposées ; ainsi que
3) Les techniques de contre-mesures IR passives.

Au moment de sa dissolution, le TG16 était composé de représentants du Canada, du Danemark, de la France, de l'Allemagne, de la Grèce, de l'Italie, des Pays-Bas, de la Norvège, de la Pologne, de la Turquie, du Royaume-Uni et des Etats-Unis, avec l'Australie comme observateur. Il a permis des échanges d'information réguliers sur les activités nationales de recherche et développement dans le domaine de l'autodéfense des navires. Le TG16 a organisé deux essais conjoints sur le terrain au cours de cette période de trois ans, y compris l'expérience « Cible ponctuelle à bas niveau » (POLLEX) pour la validation de modèles de détection de sources ponctuelles et « Expérience de validation de modèles infrarouges de navires » (SIMVEX) pour la validation des modèles de signature infrarouge de navires. Les résultats de ces essais ont donné lieu à un grand nombre de rapports et de textes de conférence. Le comité a également examiné des tâches de modélisation IR associées à l'autodéfense des navires, y compris les signatures IR des navires, la détection à grande distance des sources ponctuelles et les phénomènes de propagation IR. En ce qui concerne les signatures IR, le groupe TG16 a axé ses efforts sur le développement de modèles itératifs et le processus de validation, à l'aide de SHIPIR/NTCS. Ce code est désormais le modèle de référence de l'OTAN utilisé par la plupart des constructeurs de navires militaires. Il a également poursuivi la validation du modèle de transfert du rayonnement atmosphérique, appelé « modèle infrarouge des effets de la couche limite » (IRBLEM). Le TG16 a, en outre, réalisé l'étude d'un environnement IR standard qui servira de référence pour la modélisation et les essais des signatures de navires. Le comité a édité et diffusé une brochure informative destinée aux personnels de la marine qui ne sont pas des experts en IR, mais qui ont besoin de connaître les effets de la variabilité des signatures IR des navires sur les capteurs IR.

En résumé, le TG16 a permis d'élargir nos connaissances dans le domaine de l'exploitation des technologies IR pour l'autodéfense des navires, de mettre en commun des informations courantes concernant les programmes de défense pertinents et d'encourager la coopération entre les pays membres de l'OTAN dans le domaine des programmes de développement et d'évaluation en conditions opérationnelles.

Task Group Number 16 (TG16) on
"Infrared Measurements and Modeling for Ship Self Defence"

Final Report

BACKGROUND

Research Study Group Number 5 (RSG.5) started in June 1968 and was initially called RSG.5 on Anti-Ship Infrared (IR) Missile Characteristics, Backgrounds and Countermeasures. It was modified in October 1984 to become RSG.5 on Maritime Infrared Targets and Background Signatures: Measurements and Characterization. The RSG.5 effort focused on improvement of the methodology of target and background measurements. After completing a number of common trials, the group decided to emphasize work on ship and model comparison and validation studies.

Upon the dissolution of RSG.9 in October 1994, RSG.5 agreed to assume responsibility for some of the tasks of that group on Signal Processing Techniques for the Detection of Point Targets in IR surveillance. RSG.5's tasks expanded to include projects on the IR surveillance of air targets for ship self-defence, including the assessment of the detection range of IR search sets against point targets.

When RSG.8 on Atmospheric Propagation Effects on Electro-Optical (E-O) Systems was closed in 1996, RSG.5 assumed the responsibility for some of its tasks. These included field experiments to understand the effects of atmospheric phenomena such as scintillation and refraction on the ability of IR sensors to detect targets, and the validation of models that simulate the effects of the atmosphere on E-O sensors.

With the merging of the NATO Defence Research Groups and the Advisory Group for Aerospace Research and Development into the Research and Technology Agency (RTA) effective 1 January 1998, RSG.5 was closed. Under the RTA Sensors and Electronics Technology (SET) Panel, RSG.5 was re-established as Task Group Number 06 (TG06) with the same title and Terms of Reference (TOR) as RSG.5 had. TG06 closed at the end of 1999. TG16, which generally followed the objectives of RSG.5/TG06, began in 2000 under a new TOR and continued through 2003.

With the closing of the TG16 organization, this final report is hereby submitted to NATO to summarize the history of TG16 during 2000-2003.

PURPOSE OF TG16

As IR homing missiles represent a serious threat to naval units, the need continues for the investigation of the vulnerability of ships to such threats. Current technology includes low-cost imaging seekers with powerful image processing algorithms. The purpose of TG16 was to address research topics related to ship self-defence including:

(1) the detection of anti-ship missiles using passive IR search and track (IRST) sensors;

(2) ship IR signature control via modeling and controlled field tests of candidate techniques; and

(3) passive IR countermeasure techniques.

TG16 MEMBERSHIP

The following countries were members of TG16: Canada, Denmark, France, Germany, Greece, Italy, The Netherlands, Norway, Poland, Portugal, Turkey, United Kingdom and United States, with Australia as an observing nation. TG16 has been a closed committee and was chaired by the United States. The committee met twice a year, with the location of the meetings rotating among the member nations.

WORK OF THE GROUP

One of the main interests of TG16 was the regular exchange of information on national research and development activities related to ship self defence and topics of common interest. The remainder of this paper describes the areas of activity by TG16 during the period of 2000 through its end in 2003. This paper illustrates the scope and depth of the activities of TG16 during this period and the impact that it has on the Navy-related E-O research and development programs of each of the member nations.

DATA EXCHANGE

One of the emphases of TG16 has been the exchange of information at each meeting on the status of Navy-related E-O projects. At each meeting, each country presented a national report and submitted an informal report for attachment to the minutes for distribution. In addition, the host country provided presentations and demonstrations of relevant topics in more detail than was done via its national report. This exchange of information proved to be very valuable in keeping panel members abreast of other countries' current research and development activities and fostered many joint data exchange agreements, studies and testing activities.

TG16 regularly monitored the development of national and multinational E-O systems for shipboard self defence, in particular, ship signature reduction programs, IRST systems and ship IR countermeasure programs. Of particular interest were the capabilities of IR decoys and water washdown techniques used by NATO countries, the development and deployment status of IRST sets, techniques to lower the IR signature of military ships and other techniques such as the shipboard Tactical Decision Aid.

JOINT FIELD TRIALS

TG16 organized and conducted two joint field trials during 2000-2003. The following is a summary of these two trials.

Ship Infrared Model Validation Experiment (SIMVEX)

The SIMVEX field trial was conducted at the Cape Scott test facility at Osbourne Head (near Halifax), Canada, during 6-21 September 2001. The main purpose of the test was to conduct very controlled measurements on an unclassified ship, the CFAV Quest, as quality measurement data to validate the SHIPIR ship signature code. The data from this test was used to determine the accuracy of SHIPIR in different situations. Areas for SHIPIR improvements were identified from the trials. One important result from the trial was the development of a common radiometric analytical technique for comparing the measurement results from different radiometric IR imagers. Several national and TG16 reports and conference papers resulted from this trial.

Point Target at Low Level Experiment (POLLEX)

The POLLEX field trial was conducted at Mariteleradar in Livorno, Italy, during 2-18 May 2001. The purpose of the field trial was to collect a new data set of point source data in a marine environment to validate IR sensor range performance models against low elevation point source targets. Several important physical effects were measured including optical distortion, blur, sub- and super-refraction, scintillation and background radiance and clutter in both the mid- and long-wave IR bands. The data was used to validate propagation codes such as IRBLEM. Several national and TG16 reports and conference papers resulted from this trial.

SWG4 Trials

TG16 members participated in the 2001 and 2003 SWG4 trials to collect IR signatures of participating ships and released IR decoys. During 2003, SWG4 agreed to make IR a major focus for its 2004 trials and will seek guidance from TG26 in planning this effort.

MODELING AND SIMULATION STUDIES

IR Ship Signature Studies

This topic had so much interest that one-day workshops on IR ship signature activities were included in each of the six TG16 meetings, and SHIPIR training sessions were held at two TG16 meetings. Each year, one workshop was limited to TG16 member activities and the other was open to non-TG16 members, including the shipbuilder community, to exchange lessons-learned using the SHIPIR code. Each workshop reviewed the historical improvements and validations associated with SHIPIR, recent upgrades to SHIPIR were presented, and each participating activity presented its current IR ship signature activities. The current state of SHIPIR is that its predictive capability is approaching experimental error and is now used by all NATO navy organizations and most major shipbuilders. The IR ship signature studies included activities related to national signature codes and the effects of such techniques as water-spray signature reduction techniques.

Atmospheric Modeling

During this period, the development of the Infrared Boundary Layer Effects Model (IRBLEM), which accounts for refraction, turbulence and aerosol extinction in the marine boundary layer up to 50 m above water, was completed. The final version was distributed to all TG16 members. Additional model validations were performed using POLLEX field trial data. Due to extensive interest in the IRBLEM model, a training class was held at the Fall 2002 TG16 meeting.

Background Modeling

IRTool: This model was developed for ONR in support of IRST research and development activities and was distributed to all member nations to determine its utility to NATO-related Navy projects.

Standard Infrared Environment

This topic, which was originally started by RSG.5 in 1995 to investigate the establishment of a set of standard IR environments for use as baselines for ship signature modeling and IR ship signature testing, was completed

by TG16. France submitted the final technical report, which includes a data set that can be used as a reference for specifying the IR signature of new ships and for ship susceptibility studies against IR missile seekers.

Infrared Sensor Evaluation Model (IRSEM)

This topic, to develop a surface IRST performance model, was not completed.

OTHER TOPICS

Comparison of Radiant Intensity Calculation Techniques

This long-term topic of interest to RSG.5/TG06 members was continued by TG16. With the widespread use of thermal imagers to collect radiometric signatures of ship targets, a radiometric technique was investigated to compare the radiometric intensity measurements from different thermal imagers with different spectral responses. The results of the TG16 studies in this area are presented in a technical report authored by Norway titled *Methodology for Radiant Intensity and Equivalent Blackbody Temperature Calculations From Infrared Images*. This paper describes the IR contrast calculations of equivalent temperatures of maritime targets and discusses a virtual band method to facilitate comparison between IR cameras with different optical bandwidths. This paper is the result of the TG16 SIMVEX trial and was prepared for general use in the IR measurement community. One other product from this work was a software package titled *WinISAS (Windows Infrared Signature Analysis Software)*, which was developed by Canada for IR image calibration and analysis. Copies of the software and the user manual were distributed to interested members.

IR Ship Signature Specification and Evaluation

TG16 agreed to address this important topic to establish a methodology for specifying the IR signature for new ship design. Several technical papers were presented during TG16 meetings. Items to be specified include the signature properties, the distribution of the signature, the environmental conditions and the ship conditions and a general methodology to verify the ship signature specifications.

Informational Brochures, Technical Reports and Conference Proceedings

TG16 members have either individually or jointly prepared formal documents on activities related to measurements and modeling for ship self defence. These have included informational brochures, technical reports, and conference proceedings. The following is a list of documents associated with TG16 during the period 2000-2003.

Informational Brochures

TG16 developed one informational brochure, titled *Electro-Optical (E-O/IR Sensors for Naval Applications*. This brochure is the third informational brochure prepared by RSG.5/TG06 and TG16 for interested Navy personnel who are not IR technologists. The other two were titled *The Variability of Infrared Ship Signatures*, RSG.5, 1993 and *Atmospheric and Background Effects on EO/IR Sensors*, RSG.5, October 1997. All three have been widely distributed among NATO navies.

Technical Reports and Conference Proceedings

TG16 members have published and distributed a large number of technical reports associated with its activities and have presented results at international technical conferences. For the sake of brevity, only a brief list of publications from technical conferences is presented to illustrate the topics addressed by TG16.

POLLEX Trial

- A. de Jong et al, *TG16 Point Target Detection Experiment POLLEX, Livorno 2001*, Proc. SPIE Vol. 4820, Infrared Technology and Applications XXVIII, Seattle, July 2002.
- Guy Potvin et al, C_n^2 *Estimations at POLLEX*, Proceedings SPIE Vol. 5237, Optics in Atmospheric Propagation and Adaptive Systems VI, Barcelona, September 2003.

SIMVEX Trial

- E. Stark et al, *SIMVEX 2001 Trial – Radiant Intensity Contrast*, FFI Report 2002/02568, June 2002.
- D. Fraedrich et al, *SHIPIR Model Validation Using Spectral Measurements Results from the NATO SIMVEX Trial,* SPIE Conference, April 2003.

Infrared Modeling

- D. Fraedrich and A. Goldberg, *A Methodological Framework for the Validation of Predictive Simulations*, *Eur. J. of Operational Research*, V124, 2000.
- D. Fraedrich and R. Gover, *Statistical Uncertainty Analysis as a Tool for Model Validation*, Proceedings of the Third International Symposium on Sensitivity Analysis of Model Output, 2001.

Small Target Detection

- A. de Jong et al, *Enhanced IR Point Target Detection by Atmospheric Effects*, Proc. SPIE Vol. 4820, Infrared Technology and Applications XXVIII, Seattle, July 2002.
- A. de Jong, *Intensity Variations of Small Airborne Incoming Targets, Popping-up Above the Horizon*, SPIE Vol. 5237, Optics in Atmospheric Propagation and Adaptive Systems VI, Barcelona, September 2003.
- A. de Jong, *Encountering Bird Alarms in Full-Stare IRST's,* July 2000 SPIE, San Diego.
- A. de Jong, *Refraction Effects of Atmospheric Inhomogeneities Along the Path*, SPIE Volume 5237, Optics in Atmospheric Propagation and Adaptive Systems VI, Barcelona, September 2003.
- A. de Jong et al, *IR Detection of Very Small Invading Surface and Sub-Surface Targets in Littoral Waters*, Proceedings 5th International MSS Symposium, Gaithersburg, December 2002.

Atmospheric Modeling

- K. Stein, *IR Propagation through the Marine Boundary Layer – Comparison of Model and Experimental Data*, 9th International Symposium on Remote Sensing.

Other

- T. Taczak et al, *Naval Threat Countermeasure Simulator and the IRCRUISE Missiles Models for the Generation of Infrared (IR) Videos of Maritime Targets and Backgrounds for Input into Advanced Imaging IR Seekers*, SPIE Conference, 2001.
- E. Guven, *Electro-Optical and Infrared Applications in Defense*, Armed Forces Communications and Electronics Association Turkey Chapter, 2002.

LIAISON WITH OTHER NATO ACTIVITIES

During the 2000-2003 time period, liaison was maintained by TG16 with the following NATO organizations:

- NATO Special Working Group 4 (SWG.4) on Electronic Warfare, for participation in sea trials.
- TG07 on Missile Signature Modeling, for the validation of the NIRATRAM missile signature model.
- TG12 on Characterization and Optimization of Advanced Thermal Imagers, for joint trial participation.
- TG15 on Maritime Target and Background Signatures and propagation in cm and mm Wavelengths, for joint field trial participation.
- TG32 on Integration of Radar and Infrared for Ship Self Defence, for joint field trial participation.

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Signature reduction
Target signatures
Vulnerability

14. Abstract

This paper is the final report for NATO AC/323 Sensors and Electronics Technology Panel Task Group Number 16 (TG16) on Infrared (IR) Measurements and Modeling for Ship Self Defence. TG16 was organised in 2000 and continued until the end of 2003. The primary purpose of TG16 was to address the vulnerability of military ships to IR homing missiles. The main research topics related to ship self-defence included:

1) The detection of anti-ship missiles using passive IR search and track sensors;
2) Ship IR signature control via modeling and field testing of candidate techniques; and
3) Passive IR countermeasure techniques.

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