Comparison of MAPTIP FLIR Detection Ranges to the EOTDA Prediction Model

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ABSTRACT

The 1993 Marine Aerosol Properties and Thermal Imager Performance (MAPTIP) exercise conducted in the North Sea off the Dutch coast provided data for evaluating the Electro-Optical Tactical Decision Aid Mark III (EOTDA)[1] in a littoral environment. The EOTDA is a strike-warfare planning tool that is installed in the Navy's Tactical Environmental Support System (TESS(3)) and Tactical Aircraft Mission Planning System (TAMPS 6). The objective of this report is to compare predicted detection ranges from the EOTDA with actual reported detection ranges collected during the MAPTIP trials.

During MAPTIP, TNO Physics and Electronics Laboratory the Netherlands employed a Safire infrared FLIR system aboard a P-3 Orion aircraft and used the ship, the Hr. Ms. Tydeman, as a target. Ten sorties were flown and meteorological conditions were continuously recorded aboard the Hr. Ms. Tydeman. Additional weather observations were made at an oceanographic platform and at NAS Valkenburg. The weather information was compiled and converted to Terminal Aerodrome Forecast (TAF) code for input to the EOTDA. The Safire FLIR was installed as a user-defined sensor into the EOTDA using the Minimum Resolvable Temperature (MRT) curves of the manufacturer.

The EOTDA was then run using the standard frigate model included in the EOTDA target menu. When the results are compared with the reported detection ranges, the data was scattered and showed a tendency to over-predict detection ranges. The average error was 51% on first pass. After correcting the FLIR operator observations using the video recordings, the error was reduced to 41%. Clearly, improvements are needed in the EOTDA, such as, a more accurate target model, a ship course tracking capability, and improvements to the background and transmission models.

Keywords: FLIR performance, tactical decision aid, EOTDA, MAPTIP

2. BACKGROUND

2.1 MAPTIP exercise

The MAPTIP exercise was an extensive multinational (NATO AC/243 (Panel 04/RSG.8)) effort conducted in the North Sea off the coast of the Netherlands from 18 October to 3 November 1993. The initial work plan[2] and the final overview report[3] state the objectives and accomplishments, and they list the many assets allocated to MAPTIP from the participating countries.

The purpose of the exercise was to investigate marine aerosol properties and thermal imager performance under Winter coastal influences. The primary measurement site was at an oceanographic platform, Meetpost Noorwijk, located in the North Sea (52° 16' 25.9" North, 4° 17' 8" East) about ten kilometers from the coast. Shore-based imaging systems were located at the Katwijk beach station. The shore based imagers were primarily interested in obtaining long range images of calibrated targets near the horizon. The Hr. Ms. Tydeman, a Netherlands owned oceanographic ship, was used as an additional measurement platform and as an infrared target for the imaging systems. Other targets included lamps on the Meetpost platform, a Lynx helicopter, and the NRaD Piper Navajo aircraft.

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Part of the MAPTIP exercise involved detection range trials using a P-3 Orion aircraft owned by the Netherlands Royal Air Force and employing a FLIR Systems Incorporated, Safire 8-14 micron imaging system. This report uses the detection range data collected aboard the P-3 aircraft using the Hr. Ms. Tydeman as a target to compare with predictions from the EOTDA.

2.2 EOTDA

The EOTDA is a strike warfare mission planning tool. It is a microcomputer code that predicts the performance of a variety of sensors against a variety of user-defined targets and backgrounds. The sensors include long-wave infrared, television, laser, and night-vision goggles (NVGs). The EOTDA was developed through the coordinated effort of several contractors and agencies, with Hughes STX Corporation bringing the final product together under the direction of the Air Force Phillips Laboratory. The Navy has adapted the Air Force developed microcomputer code to a workstation platform for inclusion into the Tactical Environmental Support System version 3.0 (TESS(3)) and the Tactical Aircraft Mission Planning System (TAMPS) version 6.0, under the direction of Naval Research Laboratory, Monterey, California (NRL Monterey). NRL Monterey has added several Navy sensors to the EOTDA, such as A-6E, P-3C IRDS, FA-18, A-7E, and IR Maverick. Additionally, NRL Monterey has purchased a generic ship model from Georgia Technology Research Institute that runs under Thermal Contrast Model 2 (TCM2)[4]. This generic ship model can potentially be used to generate new ship targets for the EOTDA. For now, only two ship targets are available in the EOTDA, a frigate and a gunboat. The frigate is based on a Knox class frigate model. All of the US Navy's Knox Class frigates have been de-commissioned or sold to foreign nations. The gunboat target is based on a model of the oceanographic Research Vessel Point Sur.

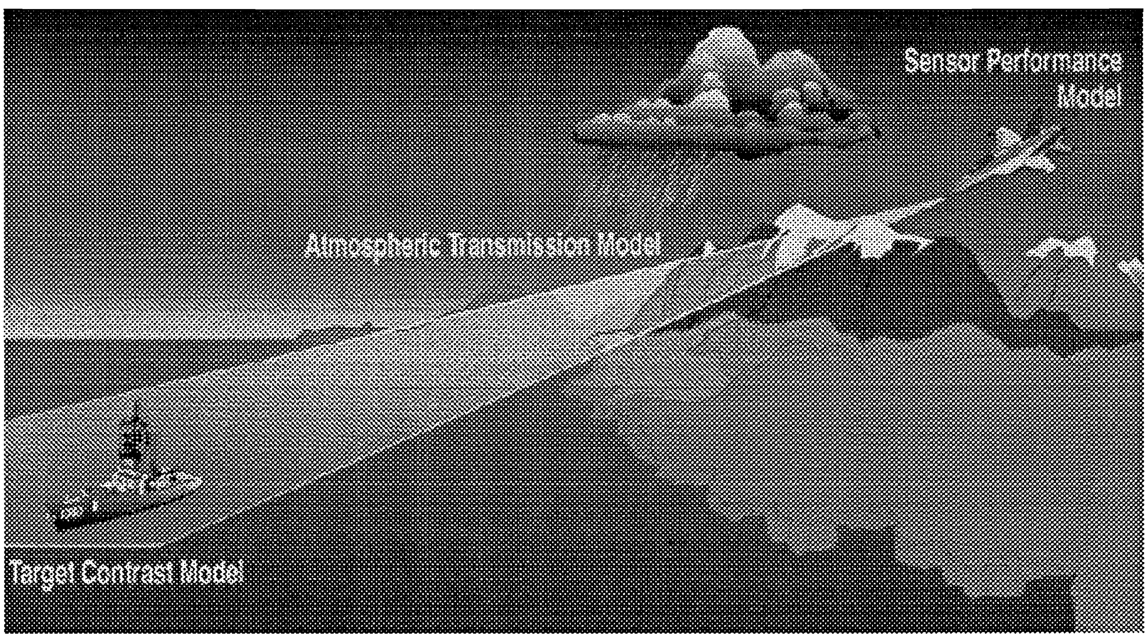

Figure 1. EOTDA scene composition: the sensor performance, atmospheric transmission, and target contrast models.

As depicted in Figure 1, the EOTDA consists of three primary modules, the sensor performance model, the atmospheric transmission model, and the target contrast model. Ideally, the largest uncertainty from the EOTDA predictions should come from the sensor performance model. This is because there are natural human perception and performance differences among operators, and the Johnson criteria[5] is inherently limited in being able to express the radiance of a given target area as an equivalent bar chart. If we assume input data are sufficiently accurate and the scene complexity fits within the modeling constraints, then attributing a maximum of 20 percent error to the transmission and target contrast models, and 25 percent to the sensor performance model[6] yields an expected rms error expectancy for the overall EOTDA of 38 percent. A 38 percent margin of error typically holds for the land background predictions from the EOTDA, and operators have been able to fine-tune the EOTDA for repeated scenarios to achieve prediction accuracies approaching 90 percent[7]. However, predictions using ocean targets have shown errors exceeding 50 percent[8,9]. Evaluations of marine targets and backgrounds do not exhibit results as good as the land backgrounds for a variety of reasons. But, the main source of errors is most likely the water background model rather than the transmission, sensor performance, or target models[10]. The water background includes a significant reflected sky component. Thus accounting for wind ruffling of the surface and accurately modeling the sky and cloud radiance is much more critical to water than soil backgrounds. Current effort is directed to improving these components of the model.

3. APPROACH

3.1 Evaluating EOTDA performance

The basic approach for verifying the accuracy of the EOTDA in a littoral environment is to compare the EOTDA predictions to the actual reported detection ranges measured during the MAPTIP trials. The weather data measured aboard the target ship, the Hr. Ms. Tydeman are entered into the EOTDA, and then the EOTDA is run using the target model that most closely represents the characteristics of the actual target, the Hr. Ms. Tydeman. The results are then compared to the actual detection ranges reported by the operator of the P-3 FLIR system during the exercise, and further verified by observing the post-flight video recording.

Ideally, all the parameters that influence the amount of scene radiance responded to by the FLIR sensor should be accurately measured and compared with the model predictions. However, for this data set the FLIR range performance was measured, but scene radiometric measurements and path transmission measurements were not made.

The total scene radiance focused on the detector element and responded to by the FLIR system, N_{FLIR}, is represented by Equation 1 .

$$N_{FLIR} = \int_{\nu_1}^{\nu_2} \left[\varepsilon(\nu)\tau(\nu,R)\left(\frac{1}{\pi}\right)W\left(T_{Tgt},\nu\right) + \rho(\nu)\tau(\nu,R)N_{Bkg}(\nu) + N_{Path}(\nu,R) \right] F(\nu)d\nu \qquad (1)$$

where $\varepsilon(\nu)$ is the emissivity at wavelength ν

$\rho(\nu)$ is the bi-directional reflectance distribution function (BRDF) at wavelength ν

$\tau(\nu, R)$ is the atmospheric transmittance at wavelength ν through slant-path range R

$W(T_{Tgt}, \nu)$ is the radiant emittance for a zero-range scene temperature T_S, and wavelength ν

N_{Path} (ν, R) is the path radiance at wavelength ν through slant-path range R

N_{Bkg} (ν) is the background radiance incident on the target and reflected toward the FLIR

$F(\nu)$ is the relative spectral response of the FLIR detector at wavelength ν

The path radiance, N_{Path} in Equation 1, is ignored by the EOTDA. Since detection range depends on the temperature contrast between two or more pixel areas, the path radiance is subtracted out when taking the difference between the areas. The transmittance, τ, is accounted for in the EOTDA by using a simplified version of the LOWTRAN7[11] code. The transmittance is calculated for a four kilometer slant path, and then Beer's Law is used to extrapolate to all other ranges along the path. Since the path transmission was not measured during the MAPTIP exercise between the P-3 and the target ship, the accuracy of the transmission model within the EOTDA cannot be determined with these data.

In the EOTDA the emisivity, ε, and BRDF, ρ, are treated differently for the background than for the target. The water background uses a semi-empirical wave slope probability algorithm[12] to determine the proportions of sky radiance reflected toward the sensor and the amount of emission from the water itself in accordance with the relationships of the standard Fresnel equation for water. The target emissivity and reflectance are treated more simply than for the background. The target emissivity, ε, and corresponding reflectance, ρ, are represented as constants in the EOTDA with values of 0.9 and 0.1 respectively. Since the EOTDA contains only long-wave sensors, this approximation can be used with reasonable accuracy. Figure 2 shows a graph of a typical alkyd-based enamel used as a final coat on many ships. In the 8-14 micron band the reflectance is small and reasonably constant with view angle lending itself to a more simplified treatment than the 3-5 micron band, which would need a more complex BRDF algorithm to properly model. The zero-range radiant emittance, W, for the ship is determined from a target facet model based on the intermediate grade thermal contrast model, TCM2, developed by Georgia Technological Research Institute[4].

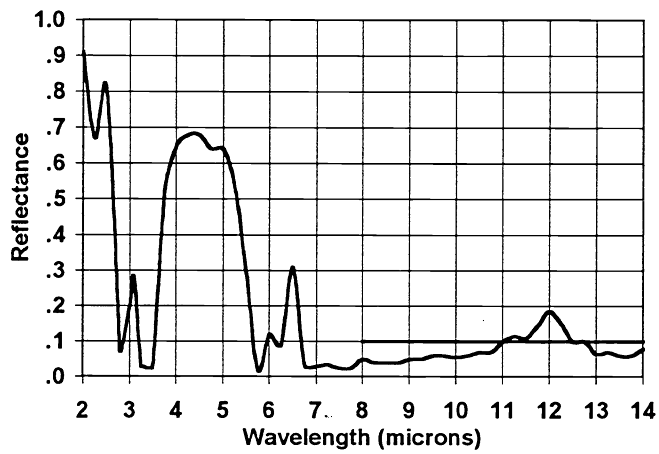

Figure 2. Reflectance of alkyd base enamel used as a final coat on many ships.

3.2 Matching an EOTDA target model to the Hr. Ms. Tydeman

A representative facet model must be available within the EOTDA for each target of interest in order to accurately calculate the target and background radiance contrast. In practice, this would be impossible, so the compromise is to generalize the target into various types. Only two ship targets, a frigate and a gunboat, are available from the menu choices of the EOTDA version 3.1. Since the Hr. Ms. Tydeman is not one of the menu choices, the frigate model was selected as the best approximation to match the actual target, the Hr. Ms. Tydeman. As suggested by Table 1, the tonnage and longitudinal surface area are similar between the Tydeman and the frigate, and it is obviously a better match than the gunboat. A more accurate representation of the target could possibly be constructed from the generic ship model, which will be available for the EOTDA in late 1996.

Ship Target	Length (m)	Beam (m)	NLD (m)	Disp. (tons)
Hr. Ms. Tydeman	90	14.4	4.75	2900
Knox class frigate	134	14.3	4.6	3011
Gunboat (R/V Pt. Sur)	41.1	9.75	2.74	539

Table 1. Dimensions of the Hr. Ms. Tydeman and the EOTDA target choices.

3.3. Determining the Safire FLIR sensor performance

The factor $F(\nu)$, Equation 1, indicates that the sensor performance must be modeled to determine the system response to the given scenario in terms that can be translated to detection range. Table 2 shows the significant technical specifications of the Safire sensor employed aboard the P-3 Orion aircraft. Because the Safire sensor is not available in the current sensor menu of the EOTDA, it was entered as a user-defined sensor. This involved entering the instantaneous field of view (IFOV) and a table of Minimum Resolvable Temperature (MRT) difference values into data fields of the EOTDA. Figures 3 and 4 show graphically the values entered into the EOTDA to drive the sensor performance model.

WFOV lens	28° x 16.8°
NFOV lens	5° x 3°
Scanner type	Serial-Parallel
Spectral band	8-14 micron
Detector type	MCT (4x4 array)
WFOV IFOV	≤ 0.93 mRad (Horiz.)
NFOV IFOV	≤ 0.167 mRad (Horiz.)
NETD	≤ 0.1 °C
Cooling	Split-Stirling

Table 2. Safire FLIR Specifications

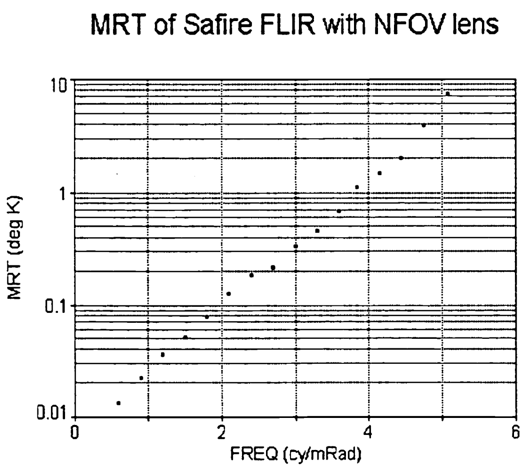

Figure 3. Minimum Resolvable Temperatures for the Safire FLIR narrow field of view lens.

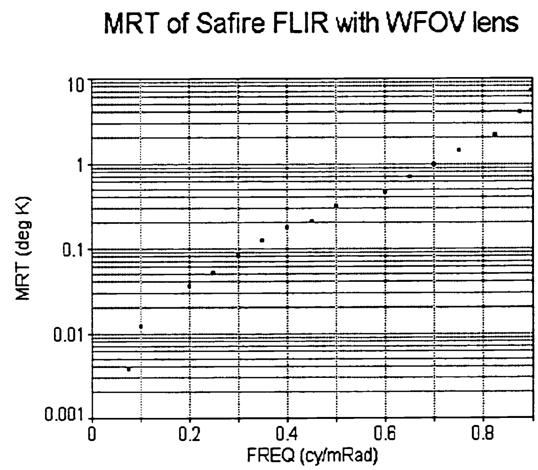

Figure 4. Minimum Resolvable Temperatures for the Safire FLIR wide field of view lens.

3.4 EOTDA meteorological input parameters.

The EOTDA makes FLIR performance predictions on the basis of meteorological data entered by the user in TAF code format. The data for this report were primarily from the data recorded *in situ* aboard the Hr. Ms. Tydeman. The measured parameters included: air temperature, dew point temperature, relative humidity, wind speed, wind direction, sea surface temperature, salinity, and the course, speed, and GPS position of the ship.

The EOTDA allows menu selection of an aerosol model. The marine aerosol model was used for these data because it produced the best results. Using the navy aerosol model (NAM) produced greater errors and a greater tendency to over-predict detection ranges. The marine aerosol model was developed for coastal land conditions, and NAM model for open ocean, so neither model was ideally suited to handle the over-water coastal aerosols. The results in this report are biased to produce the best performance from the EOTDA whenever choices could be made concerning inputs to the EOTDA (i.e., scene complexity, visibility, and aerosol model) without compromising the actual measured data from MAPTIP.

4. RESULTS

4.1 Detection range predictions

Sample P-3 data and a table of reported detection ranges are available in separate report[12]. The report also contains infrared imagery from the other platforms employed during the MAPTIP trials. The results presented here are a comparison of the these reported data to the EOTDA predictions.

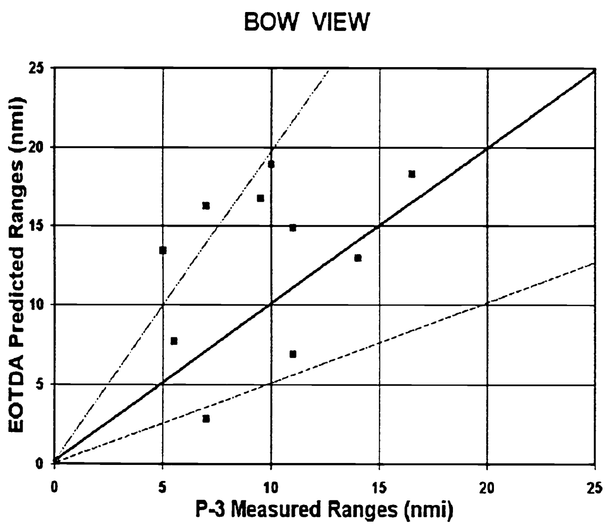

Figure 5. Bow view of predicted v. measured ranges.

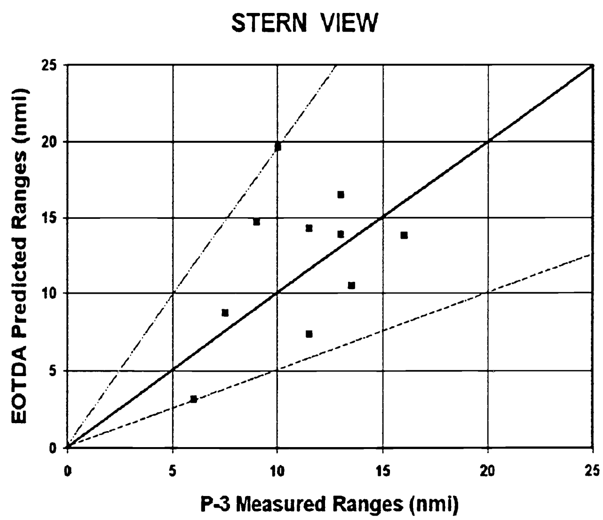

Figure 6. Stern view of predicted v. measured ranges.

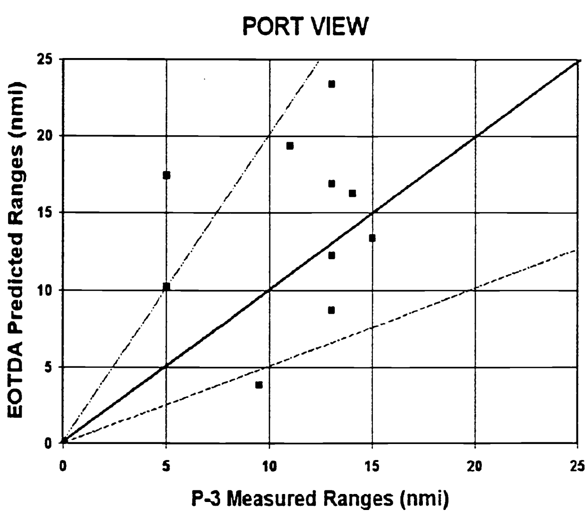

Figure 7. Port view of predicted v. measured ranges.

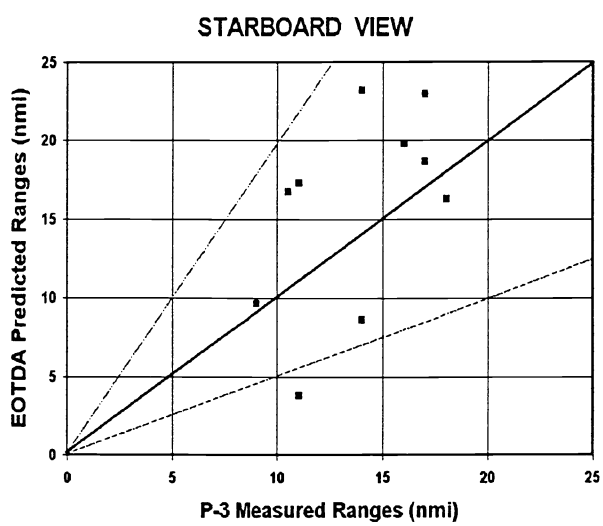

Figure 8. Starboard view of predicted v. measured ranges.

Figures 5-8 are scatter plots of the measured detection ranges for each measured aspect angle of the target. Deviation below the diagonal line shows under-prediction and above the line over-prediction of detection ranges. Also shown are error bars at 50 percent above and 50 percent below the ideal. Most of the data fall within these 50 percent error bars. On first pass through the data the average error was 51 percent. It was later found from reviewing the video recordings that some of the reported detection ranges should have been detected sooner by the FLIR operator. When the measured detection ranges were corrected, the overall average error dropped from 51 percent to 41 percent. The data presented in Figures 5-8 are from the initial operator reported detection range values and Figure 9 shows the combined data from all approaches and has been corrected by reviewing the video tapes.

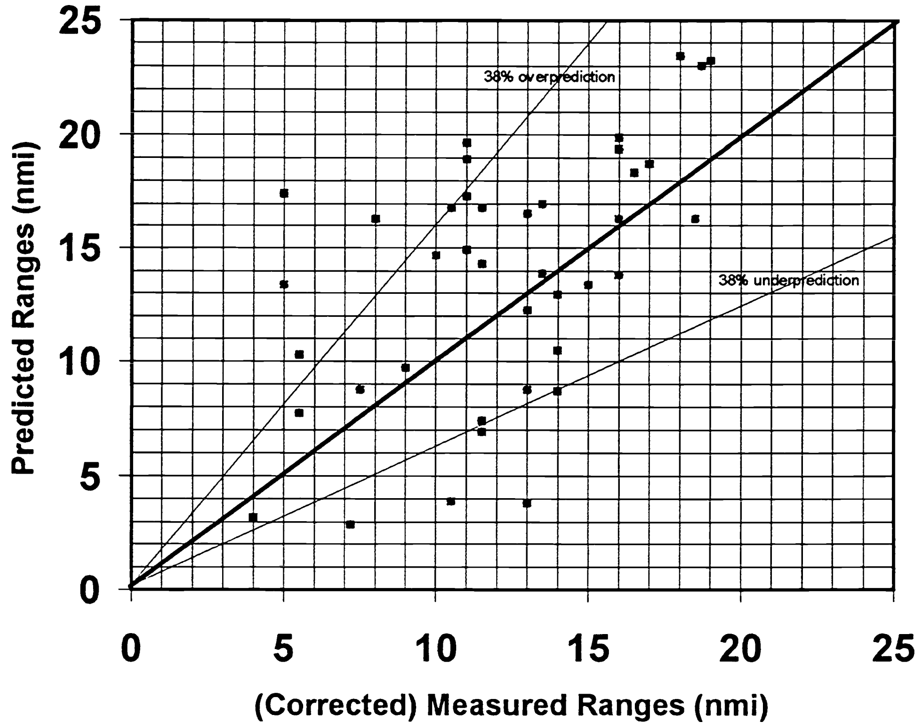

Figure 9. Predicted v. measured detection ranges for all approaches.

The spread of the scatter did not correlate with type of weather or air-sea temperature differences. In other words, the scatter remained large whether the weather was clear or cloudy, humid or dry. The scatter did not vary with view angle relative to the ship either as can be seen in Figures 5 through 8. This was unexpected. It is typical for the model to have greater error with the bow and stern approaches. This is because of the relatively small and more complex target area and a greater sensitivity to geometric errors in view angle. Perhaps the large number of heading changes required by the MAPTIP trials caused the error to be distributed among the view angles. There was a slight tendency to over-predict detection ranges, which is consistent with other trials that exercised the EOTDA in a marine environment[9].

The average error of 41% shown in Figure 9 was obtained after correcting the detection ranges based on the video replay and selecting input options that produce the best results. Theoretically, the scatter should fall within 38% without manipulating the results which is typically obtainable for the soil backgrounds of the EOTDA. And when operators can establish correction factors to fine-tune the EOTDA for an area of operation based on pilot feedback from similar operations, the accuracy can be increased to within 10% error 80% of the time[7]. To be useful as a mission planning tool, the EOTDA must predict detection ranges better than operator estimates based on heuristics related to humidity, visibility, or cloud forecasts. It is therefore important that the scattered results from marine scenarios be improved.

5. CONCLUSIONS

As outlined in the work plan[2], the MAPTIP trial had several objectives related to modeling coastal aerosols and thermal imaging systems performance. Upon completion of the tests it was noticed that the FLIR performance data were available and that the Safire FLIR could be installed into the EOTDA as a user-defined sensor, so evaluation of the EOTDA was added to the objectives. However, one of the shortcomings of using the Tydeman as a target was that the MAPTIP requirements specified a great deal of maneuvering. Unfortunately, the EOTDA was designed primarily for stationary targets. The EOTDA does not allow tracking heading changes of the target. Figure 10 is a plot of course changes throughout the day of October 27. This is typical of the maneuvers required throughout the MAPTIP trials. Figure 11 is a long-wave infrared image of the port and starboard views of a frigate. It illustrates how much the two sides of the ship can differ in apparent temperature when the ship is on a constant heading. In this example, the thermal contrast is significantly greater for the starboard view, making the ship much more vulnerable to an attack toward the starboard. Area analysis of the ship and background yields ship temperatures of 20.4 °C port and 29.0 °C starboard, while the background temperatures were nearly the same at 13.5 and 13.2 °C port and starboard. This means the temperature contrast was more than twice the amount (15.8 °C v. 6.9 °C) for the starboard approach than for the port view. In the case of the Tydeman, the solar loading and wind cooling were probably more evenly distributed among the port and starboard sides due to the large number of course changes. But the EOTDA assumes a constant heading and would not take into account the distributed loading, which may account for some of the scatter. It would be interesting to check the results after a ship course tracking capability is added to the EOTDA.

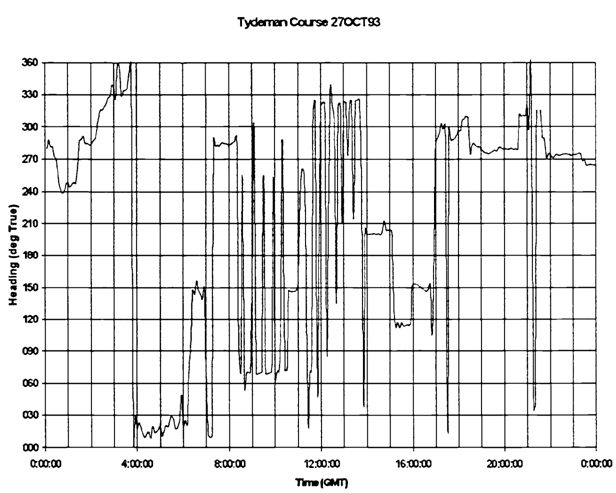

Figure 10. Hr. Ms Tydeman course changes for 27 Oct.

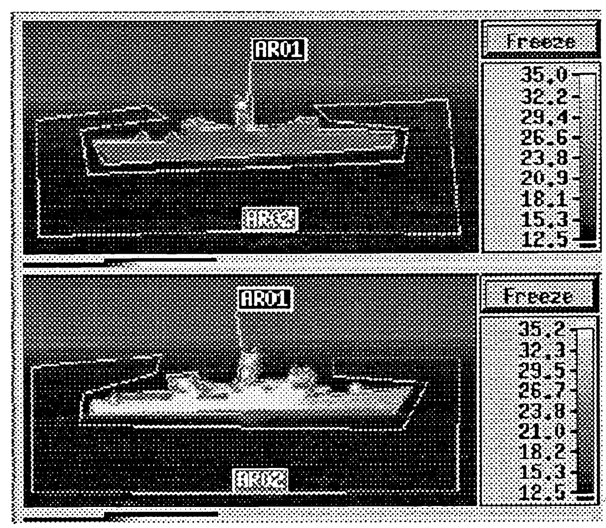

Figure 11. Target/background analysis. The port view (top) and starboard view (bottom) are both 8-12 micron images of same ship at same time.

Another shortcoming of the EOTDA is that is does not allow the user to input the sea surface temperature. Instead the EOTDA determines sea surface temperature from a formula based on ambient temperature and latitudinal position. Using this method, the EOTDA under-predicted the physical sea temperature by an average error of 29 percent. Since the P-3 FLIR was flown at 500 and 1000 foot altitudes, the depression angles toward the target are small. Thus depending on wind conditions, the reflected sky would be the dominant contributor to the background radiance. Since radiometric radiance measurements were not made directly from the P-3, it is not possible to put a figure on how much the error from EOTDA in calculating sea surface temperature contributed to the overall scatter distribution. It would be a relatively easy modification to the EOTDA to allow the operator to enter the sea surface temperature from the keyboard, and this is planned in future versions of the EOTDA.

A problem of even more concern than the course tracking capability and allowing the user to enter sea temperatures is the water background model itself. The water background model uses a semi-empirical method[13] for determining the wave-slope probability distribution. Modifications are in process to improve the sky radiance calculation and add the SeaRad[14] water background model to the EOTDA. It will be interesting to find out if the results improve when the new water background model is completed.

6. ACKNOWLEDGMENTS

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