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COMPARISON OF TRANSMISSION LOSS MODELS AT MID-FREQUENCY AGAINST SHALLOW WATER DATA

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Abstract

To address the vexed issue of validation of transmission loss models for application to the mid-range of acoustic frequencies, a round-robin approach has been adopted in which the outputs from a number of models have been compared. Emphasis has been placed upon the requirements for models for circumstances relevant to continental shelf ocean zones within the Australian region. In particular, the ability to describe transmission in both ducted and downward refracting environments has been considered. To ensure realism in the modelling, all scenarios selected for comparison correspond with ocean tracks for which environmental parameters had been collected, and received sound pressure time series measured. The acoustic signal sources used for these at-sea data collections were small explosives. The subject transmission loss models are from of a variety of types, and these use different techniques to describe the characteristics of the ocean environment. To enable the most valid comparison of results, input parameters have been matched across models to the fullest extent. To attain the closest adherence to the at-sea situation, the seafloor acoustic properties selected for model inputs were those obtained for each track by an *in-situ* technique developed by DSTO. This paper presents the state of progress of this work, including a comparison of models amongst themselves and against measured transmission loss.

1. INTRODUCTION

In this study, the mid-frequency range is taken to encompass the upper band of frequencies used for passive sonar Anti-Submarine Warfare (ASW) and the frequency range associated with active sonar for ASW, about 400 Hz to 10 kHz, in all. This frequency range presents acoustic transmission models with particular challenges, as transmission ranges include, typically, a very large number of acoustic wavelengths. The fact that the ocean is in a state of movement, coupled with the fact that the sound speed gradient and ocean depth may not be known with precision means that the uncertainty in the knowledge of a particular real ocean environment may be significant in wavelength terms. Exact solutions for real ocean scenarios do not exist, plus the authors are not aware of any known solutions for synthetic benchmark cases for the frequency range in question. For this reason, the work program reported below is a comparison between the output of a number of underwater acoustic transmission models with at-sea data.

2. THE SUBJECT SONAR TRANSMISSION MODELS

The work reported in this paper examines the output from three models of underwater acoustic transmission in the shallow water domain: (i) BELLHOP gaussian beam ray model [1]; (ii) RAVE ray model as retained by Thales Australia; (iii) a gaussian beam ray model as retained by DSTO.

BELLHOP is a model retained within the Acoustic Toolbox User interface and Post processor (AcTUP) system which is made available by the Centre for Marine Science and Technology (CMST) at Curtin University [2]. As outlined by Duncan and Maggi [2], the beam technique considers each ray to be the centre of a beam with (in the case of this study) a Gaussian intensity profile as a function of elevation about the ray. The received signal level is obtained by summing the contributions of all beams with significant amplitude. In this way, problems with caustics and shadow zones are reduced. BELLHOP uses reflection coefficient and phase data from a supplied file, which in the present case was obtained by using the BOUNCE reflection model [1, 2].

RAVE is a sonar performance prediction model developed by Thales Pty., but for the present study, the acoustic transmission model within RAVE is the subject. RAVE uses ray tracing to calculate the acoustic signal, and then uses linear interpolation to compute a grid of transmission loss (*TL*) values as a function of range and depth. Reflection from the seafloor is handled using the Hall-Watson model (eg. this model is mentioned by Etter, page 75 [3], the algorithm is given by Viala, et al [4]), for which the input parameters are porosity, grazing angle and frequency. RAVE, as run in this study, uses a seafloor reflection phase of zero, as the received signal is determined as a phase-incoherent value.

The gaussian beam ray model retained by DSTO and used in this study uses reflection coefficient and phase data supplied from a file.

3. SCENARIOS FOR MODELLING

The key activity in this study was the modelling of at-sea scenarios for which environmental parameters had been collected, and received sound pressure time series recorded. The scenarios, for which data is presented below, are relevant to tracks within shallow oceans in the Australian region.

3.1 At-sea Scenarios

The modelled scenarios are Track A and Track R as described by Jones et al [5]. For each track, the data were obtained using a receiver located at 18.3 m depth, while small explosive sound sources were deployed from a ship as it moved away. Each explosive source was set to detonate at 18.3 m depth. Ocean depths were obtained continuously along the tracks using a ship-based high-frequency echo sounder, and were found to be uniform to a reasonable approximation along each track. Bathythermograph recordings were made for each track, from which sound speed variation with depth was determined for modelling transmission. The sound speed profiles used for modelling Tracks A and R are shown in Figure 1. (Note

Thales used a slightly different profile for Track A, based on original bathythermograph data.) From this data, it is clear that Track A represented a strongly downward refracting environment and Track R represented a slightly upward refracting environment, with nearly isothermal conditions in the latter case. The seafloor along each track was assumed to be flat, with depth values 58 m (Track A) and 65.5 m (Track R). The observed sea surface conditions were as follows: Track A – wind speed 1 m/s, swell height 0.0 m; Track R – wind speed 2 m/s, swell height 0.25 m. For simplicity, the sea surface was then modelled as flat.

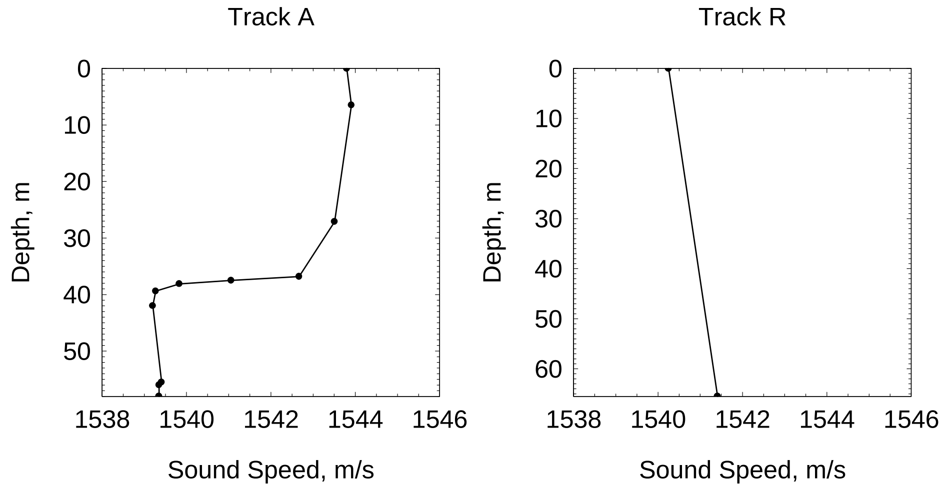

Figure 1. Sound speed versus depth for at-sea scenarios, Tracks A and R

3.2 Seafloor Reflectivity

For consistency, each model was configured to use as close to the same seafloor reflectivity as possible, bearing in mind the different data input types. The seafloor reflectivity, in turn, was obtained for each frequency through the application of an acoustic inversion analysis developed by DSTO [6], and was assumed uniform along each track. (This inversion is independent of the transmission model type.) From this inversion, a value of bottom loss versus grazing angle (eg. Etter [3] equation (5.7)) was chosen for the model used by DSTO, a uniform half-space was chosen for BELLHOP, and a value of porosity was chosen for RAVE. Calculations of *TL* and measured data are presented below for 400 Hz, 1 kHz and 3.15 kHz. The bottom loss data input to the various models are shown in Figures 2, 3 and 4, for the range of grazing angles 0.0 to 30.0 degrees, for both tracks. As each *TL* calculation presented here is based on a phase-incoherent summation of multi-path arrival energy, the bottom reflection phase is not shown.

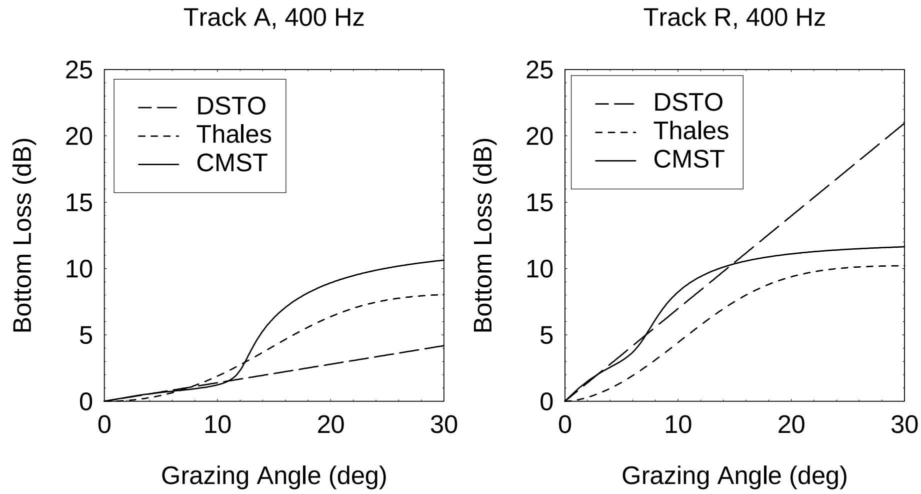

Figure 2. Bottom loss versus grazing angle used by the transmission models, 400 Hz

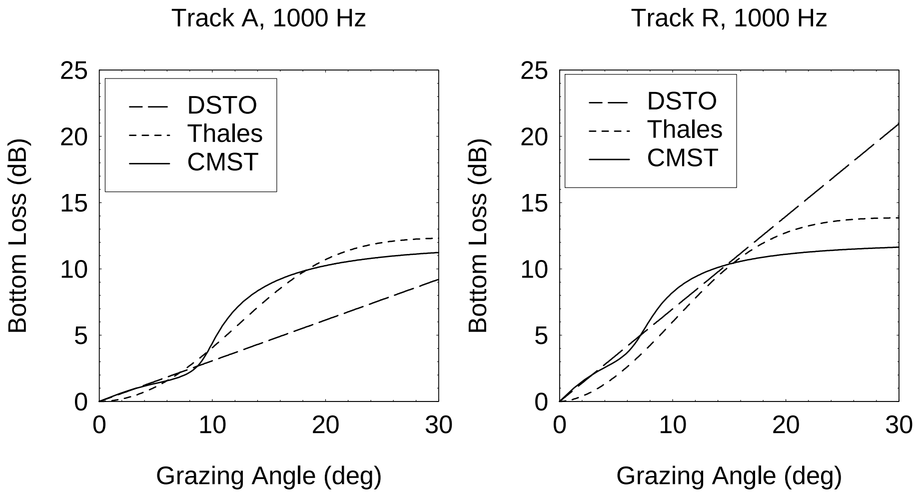

Figure 3. Bottom loss versus grazing angle used by the transmission models, 1 kHz

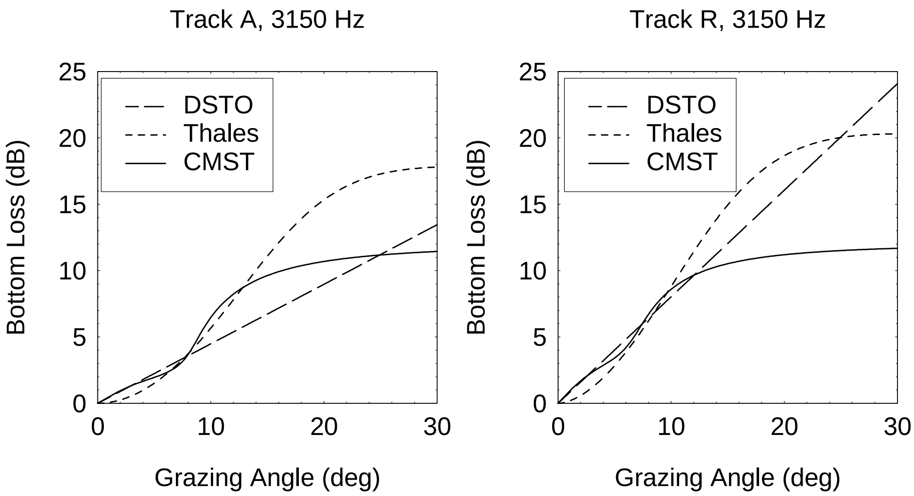

Figure 4. Bottom loss versus grazing angle used by the transmission models, 3.15 kHz

From Figures 2, 3 and 4, at small grazing angles, the bottom loss values inferred by the inputs chosen by CMST for the BELLHOP model are very close to those used by the DSTO model. The inputs chosen by Thales for RAVE also give bottom loss at small grazing angles close to that used by DSTO, with the exception of values for 400 Hz for Track R. Here, the bottom loss for RAVE was capped by the fact that the porosity value cannot exceed feasible limits, here being set at 0.87. It may be noted that in the case of the uniform half-space used by CMST, there is evidence of a rise in bottom loss at grazing angles greater than a critical angle, as is to be expected. The result is that, for a range of angles greater than the critical angle, the bottom loss is greater than for the DSTO assumption. It is interesting to see that, other than for 400 Hz for Track R, the Thales result obtained using the Hall-Watson model exhibits a variation of bottom loss which may be considered to follow the rise in loss beyond the critical angle shown by the half-space data obtained by CMST.

The data for Track A show a clear increase in bottom loss with frequency, with data for Track R showing a small increase. This is simply in accord with the result obtained by the DSTO inversion technique [6] and any explanation in terms of seafloor composition is beyond the scope of this paper.

4. MODELLING RESULTS AND DISCUSSION

4.1 Track A

The calculations of *TL* produced by the various models for Track A are shown in Figures 5 and 6 together with at-sea measurements of *TL*. Source and receiver depths for both measurements and calculations are for 18.3 m in all cases. Each model was run in phase-incoherent mode.

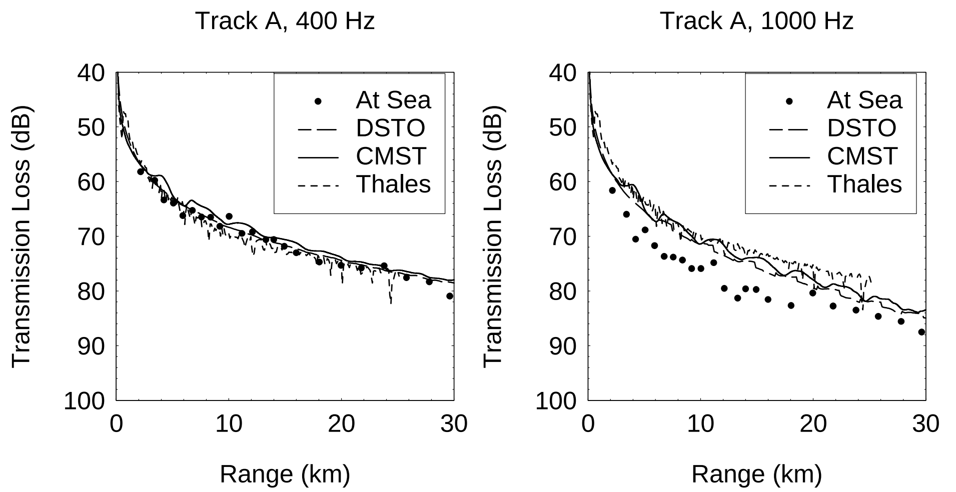

Figure 5. Phase-incoherent *TL* versus range for Track A, 400 Hz, 1 kHz

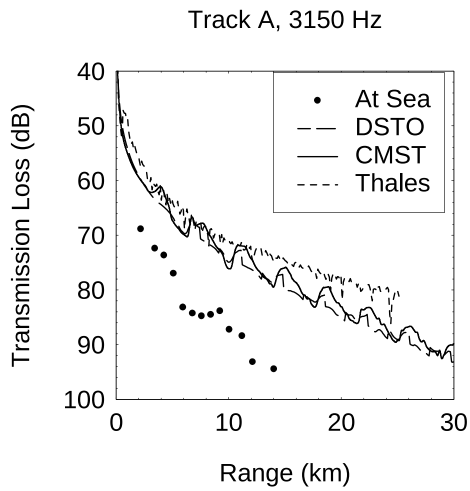

Figure 6. Phase-incoherent *TL* versus range for Track A, 3.15 kHz

The measured data in Figures 5 and 6 are obtained by phase-coherent averaging over a one-third octave band centred at the stated frequency. These values are obtained at discrete points, corresponding with the ranges at which small explosives were dropped. It is worthy to note that the use of a fixed receiver and a moving source produces the equivalent result as a fixed source and moving receiver if the situation is reciprocal, which has been assumed.

All three calculated curves of *TL* are very close to the measured data at 400 Hz, however all three underestimate *TL* at 1 kHz. At 1 kHz the DSTO *TL* is greatest, with the Thales result from RAVE being least – at 25 km range there is a mean difference of very approximately 1 dB between the DSTO and CMST results and 3 dB between the DSTO and Thales results (averaging by eye).

All three models greatly underestimate *TL* at 3.15 kHz. In addition, the DSTO and CMST results are similar, but the Thales result from the RAVE model is about 7 dB less at

25 km range. The reason for which all models underestimate that measurement is not known, however sample calculations show that the measured *TL* may not be realised by modelling unless the bottom loss is modelled as much greater than the inversion result. Figure 7 shows *TL* calculated for the model retained by DSTO with higher levels of modelled bottom loss. The measured *TL* is approached by this modelling only if the seafloor bottom loss versus grazing angle value is about 100 dB/radian, i.e. 4 times the value obtained by the DSTO inversion technique, and not necessarily achievable with feasible bottom parameters of porosity, or sound speed and density. Figure 7 is interesting in that it shows the effect of bottom loss on the *TL* for a downward refracting shallow water environment. This has lead the authors to consider that the underestimation of *TL* by the RAVE model at 3.15 kHz, relative to the DSTO and CMST results, may be due to the fact that the Hall-Watson curve (labelled “Thales”) in Figure 4 does, in fact, show a lower bottom loss than assumed for the other models for very shallow angles. This is under present investigation.

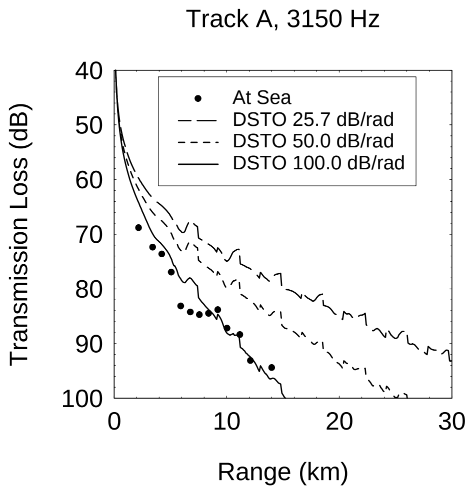

Figure 7. Phase-incoherent *TL* versus range for Track A, 3.15 kHz, alternate bottom loss

At-sea measurements for Track A were limited to a single bathythermograph recording at the start of the track, and another at the end. It is possible that the sound speed versus depth profile may have varied along the track, for example, due to internal wave phenomena, thus causing the high frequency *TL* to diverge from modelling based on a uniform sound speed profile. This has not been investigated further.

In Figure 6, in particular, calculations of *TL* from the BELLHOP model run by CMST show a cyclic variation about the mean *TL* versus range. This is evident to a lesser degree for the DSTO-run model. In fact, a ray diagram, shown in Figure 8 shows downward refraction with bottom-reflection skips at an interval of very close to 4 km. This accounts for the spacing of “ripples” or features in the *TL* versus range curves. From Figure 8 it does appear that the peak in received level at about 3½km (and corresponding peaks at 7½, 11½ km, etc) is associated with the ray transmitted horizontally from the source, with this ray becoming horizontal again at said range, and at receiver depth. The null in transmission at about 5 km (and corresponding nulls at 9, 13 km range, etc.), appears to be associated with the horizontally-transmitted energy striking the seafloor and being well away from a receiver at 18.3 m.

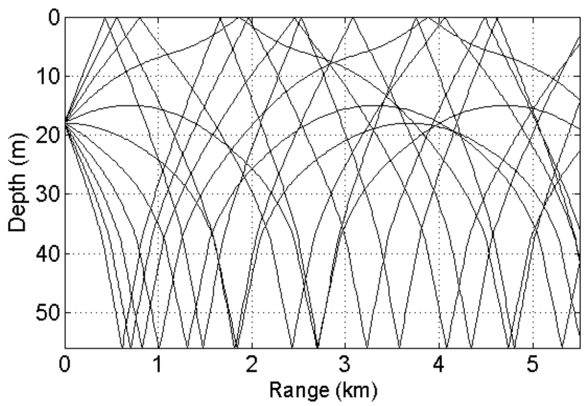

Figure 8. Acoustic ray diagram for Track A, 11 rays over ± 2½ degrees

4.2 Track R

The calculations of *TL* produced by the various models for Track R are shown in Figures 9 and 10 together with at-sea measurements of *TL*. Source and receiver depths for both measurements and calculations are for 18.3 m in all cases. Each model was run in phase-incoherent mode.

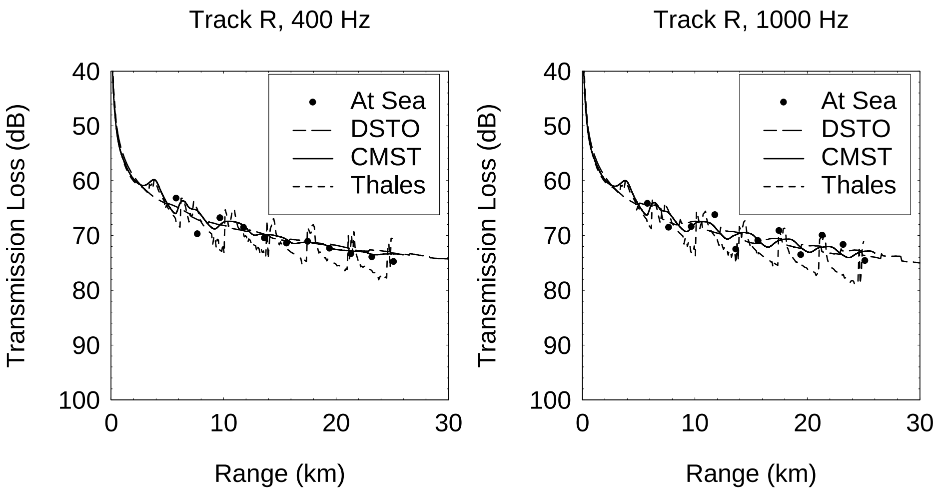

Figure 9. Phase-incoherent *TL* versus range for Track R, 400 Hz, 1 kHz

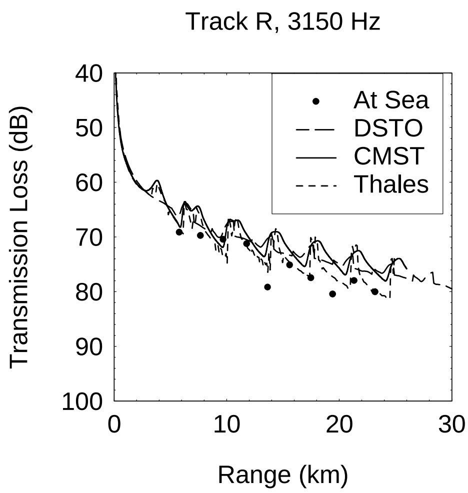

Figure 10. Phase-incoherent *TL* versus range for Track R, 3.15 kHz

All three calculated curves of *TL* are very close to each other and to the measured data at 400 Hz and 1 kHz, however all three slightly underestimate *TL* at 3.15 kHz. At-sea measurements for Track R included a number of bathythermograph recordings along the track, and these are each consistent with the sound speed profile shown in Figure 1, which was used for modelling purposes. Apart from the agreement between models, the only noteworthy feature of the calculations is that all show a cyclic variation about the mean *TL* versus range, at an interval of about 4 km. This is most evident with RAVE, least evident with the DSTO model, and exists for all models at 3.15 kHz. This is expected to be due to the cyclic nature of refracted-surface reflected rays, and similar to the variations shown for Track A, however this was not investigated further.

6. CONCLUSIONS

Three acoustic transmission models, intended for operation at mid-frequencies, have been compared for long-range shallow water scenarios for which at-sea transmission loss data is available. The models agree very well with each other and with at-sea measurement for the frequencies 400 Hz and 1 kHz, but differences have been observed at the frequency 3.15 kHz. In this work, care was taken to ensure that the effects of differences between the models' sub-components, in particular, the description of the seafloor boundary, were minimal. Regardless, it does appear that differences between the outputs of the models may be due to the precise nature in which the seafloor reflection is modelled at small grazing angles. This highlights the difficulty of using any model for an absolute prediction of received signal level for a real shallow ocean scenario, and reinforces the need for an accurate description of the ocean environment, including variation with range, to be available to provide input data for the model.

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