TES Modelling of TESSMEX objects M32 and M32T

Elizabeth Chilvers

QinetiQ Winfrith, Brownsea House, Dorset Innovation Park, Dorchester, DT2 8XJ.

Elizabeth Chilvers Tel: +44(0)1305 365436 Email: emchilvers@QinetiQ.com

Abstract: *Target Echo Strength (TES) measurements of TESSMEX object M32 were made over a wide range of frequencies at Loch Goil as part of International collaboration during March 2025, building on related measurements of M32T and M32C made in 2022. To contribute to the understanding of scattering from these objects, a number of modelling studies are being undertaken. The model predictions help identify features of interest in the measurements, aid analysis and provide mutual validation between the modelling and measurements. The models use several techniques to examine scatter features of the objects across the frequency spectrum. Ray Acoustics Modelling is applied at high frequencies to the acoustic scatter (including multiple bounces) from M32 enabling the identification of the causes of significant scatter features. Finite Element techniques tackle modelling M32 and M32T at lower frequencies, modelling not only absorption, transmission and reflection but also coupled vibration.*

Keywords: *Target Echo Strength, TESSMEX*

1. INTRODUCTION

The TESSMEX M32 object [7] is a physical 1:10 scale model of a structure originally defined in the Benchmark Target Strength Simulation (BeTSSi) mathematical modelling workshops [2][3][4], while M32T [7] is a truncated version of M32. To contribute to the understanding of scattering from these objects, a number of modelling studies have been undertaken, implemented within COMSOL Multiphysics® [1]. The results of these models are compared to measurements undertaken by QinetiQ in March 2022 and 2025.

Ray Acoustic modelling of M32 has been undertaken at high frequencies. This technique models sound as a large number of packets of sound energy that travel along rays and interact with surfaces in a probabilistic manner. The complex internal scattering within the objects may be modelled this way, but not diffraction effects nor vibrations associated with coupling into the structure.

Finite Element Modelling was used to model M32 and M32T at lower frequencies. This allows fuller consideration of the behaviour of the surfaces of the objects: modelling not only reflection, transmission and absorption, but also coupled vibration.

2. GEOMETRY

The M32 object is shown on the left of *Fig. 1*. The outer hull consists of a tapered cylinder with faceted hemi-spherical ends. The inner pressure hull consists of a cylinder with a “cat’s-eye” inset sphere (highlighted in blue) at the bow and a “cross-plate” (highlighted in green) at the stern. While they were not part of the theoretical BeTSSi model 32, five support ribs (highlighted in pink) are needed to hold the inner pressure hull in place and a lifting eye (highlighted in orange) is required to suspend the object in the water. Reflections between the cylindrical inner pressure hull and these flat support ribs of M32 are expected to cause additional TES features not predicted for the BeTSSi model 32. The inner pressure hull is air-backed and constructed of 10mm thick steel whereas the water-backed outer-hull is made of 2mm steel.

The M32T object is similar to the stern of M32 as shown on the right of *Fig. 1*. Its outer hull consists of a tapered cylinder with a disk at the bow and a smooth hemi-spherical dome at the stern. The inner pressure hull of M32T is held in pace with two support ribs (highlighted in pink) and consists of a cylinder with a “cross-plate” (highlighted in green) at the stern and a corner inset (highlighted in blue) at the bow.

For the modelling in this paper the source insonifies the object from a fixed distance (22m) from the centre of the object: this was the arrangement of measurements of M32 and M32T undertaken in March 2025 and 2022 respectively at Loch Goil, Scotland. The objects are rotated about their respective centres with an aspect angle of 0° defined as “looking” at bow (the smaller end of M32 and the flat end of M32T). We assume that the object is being perfectly insonified by sound at a pure frequency.

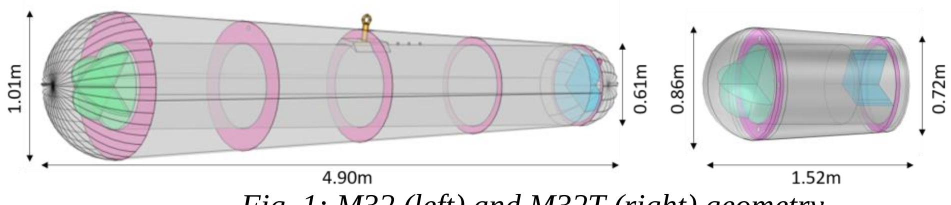

Fig. 1: M32 (left) and M32T (right) geometry.

3. RAY ACOUSTIC MODELLING

This technique models sound as a large number of packets of sound energy that travel along rays and interact with surfaces in a probabilistic manner. As described in [1] "Ray acoustics is valid in the high-frequency limit where the acoustic wavelength is much smaller than the characteristic geometric features." M32 is rotated about the central lifting eye and for each aspect angle considered, rays are released from the centre of a square receiver in a cone towards the object. When each individual ray interacts with the surface the probabilities that the rays are reflected, transmitted or absorbed is determined from the angle of incidence when the rays hit the surface, the properties of the material and its thickness, as well as the medium behind it. The rays that are scattered back towards the source will hit the receiver, where the strength of the acoustic impact of these rays is counted up and the times at which they occur recorded. Individual rays can also be tracked and their interaction with the object examined.

Range vs aspect "waterfall" plots can be created by considering the time at which the sound particles (rays) are captured by the receiver plate and the aspect of rotation of M32, about a vertical axis through its central lifting eye. Choosing finer aspect resolution, or releasing additional rays, produces more detailed waterfalls, but the run time of the models increases linearly. The limit on how a fine resolution can be produced is associated with computational time, not the methodology: investigations of specific areas of interest could be undertaken at a finer resolution.

Fig. 2 shows the Ray Acoustic predicted waterfall plot at 30kHz using one million rays. Many, but not all, of the dark (high value) lines running through the plots can be identified as reflections from the inner pressure hull and support ribs. Other notable features are from the inset sphere and cross-plate of the inner pressure hull.

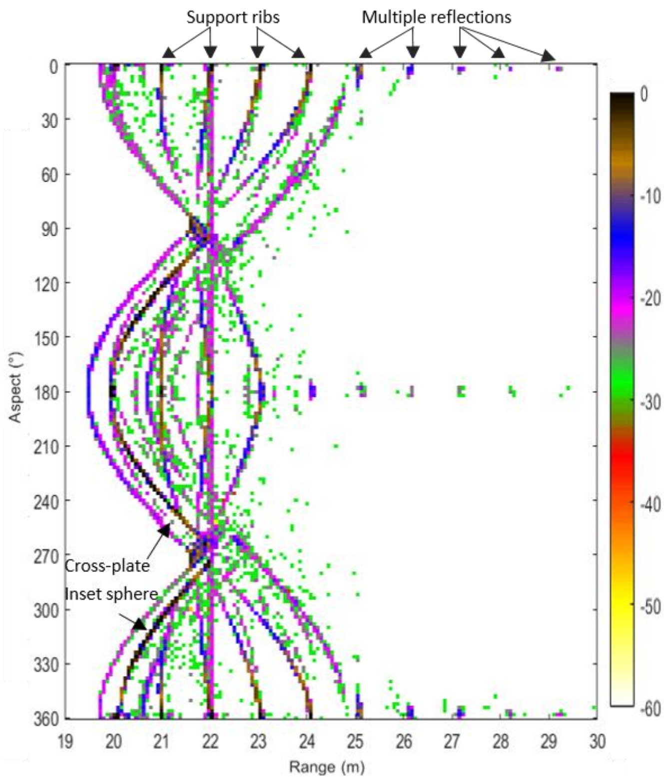

Fig. 2: Range vs aspect waterfall plots of M32 at 30kHz. Ray Acoustics Prediction.

Fig. 3 shows the waterfall plot produced from the measurement of M32 undertaken in March 2025 also at 30kHz for a short pulse. It should be noted that the measurements were not undertaken at exactly horizontal elevation and that in reality the domed ends of M32 are faceted, they are not the perfect hemi-spheres modelled. Ray Acoustics modelling requires significant run time to predict low TES levels therefore, for ease of comparison with the model output, the measurement on the right of *Fig. 3* has a lower threshold of approximately -30dB applied and contamination removed.

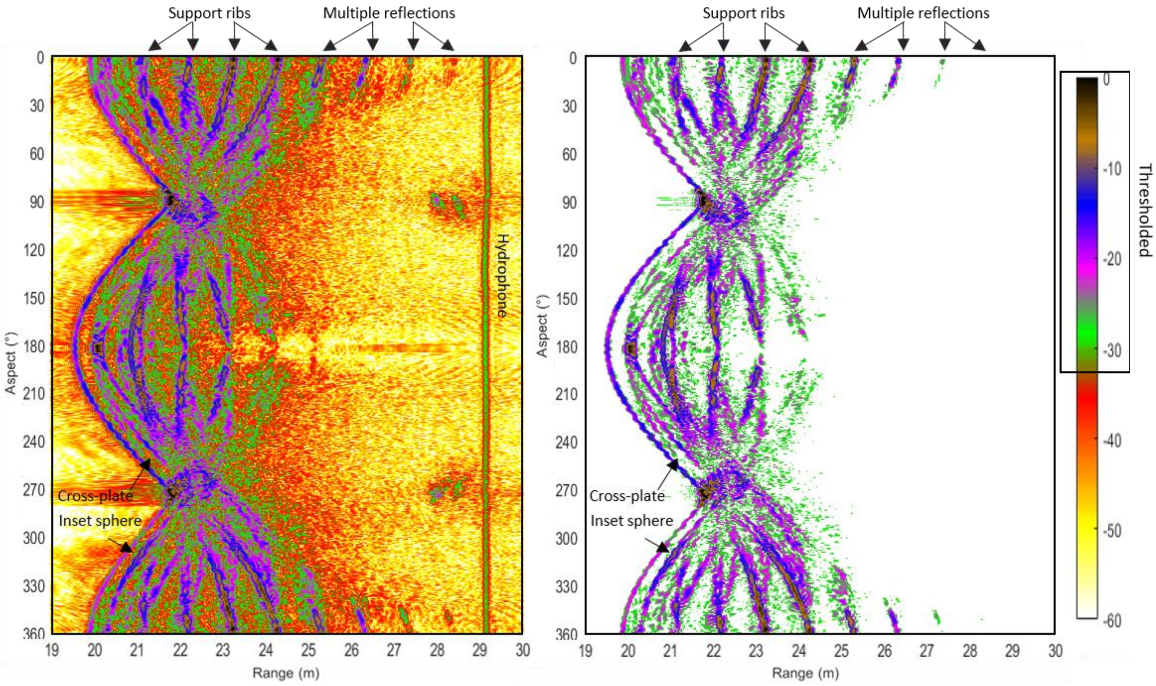

Fig. 3: Range vs aspect waterfall plots of M32 at 30kHz. Full Measurement (left) and with a threshold applied (right).

Most of the features are in the same place and a good comparison can be seen, but there are some notable differences. Features can be seen in the predicted waterfall around 0°/360° and 180° extending beyond the rest of the waterfall. These are caused by multiple reflections between the support ribs and show returns with an apparent range beyond the actual target. These multiple reflections are also seen in the measurement at 0°/360° but those at 180° are only seen at higher frequencies. The response of the inset sphere and cross-plate is also slightly higher in the model. These could be due to damping effects not yet modelled.

It is worth noting that in the preceding discussion TES has been treated as monostatic; with the source and receiver as points in the same location. However, the modelled results, like the measurements, will include small bistatic elements. For the Ray Acoustic model, rather than the prediction at a single point, rays that impact a square receiver are captured. The size of this receivers is important. A larger receiver is more sensitive as it captures more rays, however it is less monostatic. Yet by simply reducing the receiver size many of the low-level green and purple details are lost (there is effectively a low-level cut-off). Thus a larger number of initial rays must be modelled for the smaller receiver. For the measurements the source and receiver are different transducer arrays, so they also record TES with a small bistatic angle

4. FINITE ELEMENT MODELLING

This technique allows fuller consideration of the behaviour of the surfaces of the object: modelling not only reflection, transmission and absorption but also coupled vibration. The object is set inside of a sphere of water. The outer layer of this sphere simulates an infinite domain using a Perfectly Matched Layer. For this finite element model to be accurate the mesh of the object, as well as that of the surrounding water, must have elements no larger than one fifth of a wavelength. Thus, as the frequency increases, the computational demand increases dramatically.

The Sound Pressure Level (SPL) can be calculated and visualised as a colour over a horizontal slice through the modelled volume. *Fig. 4* shows this in the water viewed from above at 3kHz where M32 and M32T are insonified at an angle of 240° aspect as an example. In the dark blue "shadow zone" incident sound has been partially blocked by the body. Interference between the incident sound and that reflected from the object cause the alternating bands of SPL. The interference bands are also present within the water filled regions between the outer-hull and inner pressure hull of the object.

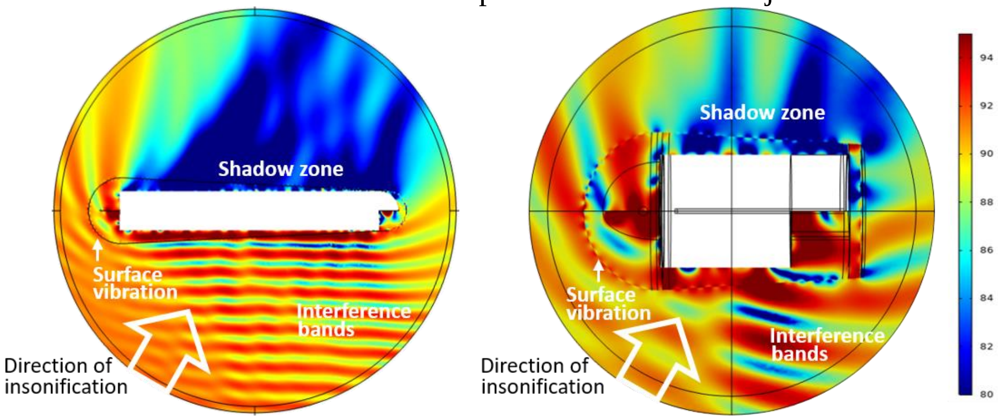

Fig. 4: FEM predicted sound pressure level in water at 3kHz. M32 (left), M32T (right). Note: M32 is set inside a larger sphere of water than the smaller M32T.

Finite Element Modelling (FEM) also predicts the coupled vibration of the steel inner and outer hulls of the objects. Oscillations in colour, linked to the surface vibration excited, can be seen in *Fig. 4* around the outer-hull of the objects. The sound vibrations in the inner flooded regions will also impact on the walls of the pressure hull, causing them to vibrate and set up sound vibration in the air filled volume, having its own SPL although this is markedly less than in the surrounding water.

The frequency domain Integrated Target Strength (ITS) predicted by FEM may be extrapolated from this near field prediction. The predicted ITS at 22m can be compared with that calculated from the measured response to insonification by a Linear Frequency Modulation (LFM) chirp and to a continuous wave (CW) pulse at the same distance.

Fig. 5 shows the FEM predicted ITS of M32T at 22m in black compared with the ITS from the measurements undertaken in 2022 at 3kHz and 5kHz. However it should be noted that the FEM predictions have assumed that the object is orientated perfectly; that it is not tilted, whereas the 2022 measurements contained an alignment offset of about 1.5°. For both frequencies a short 5-cycle pulse and a longer 13ms pulse (39-cycle for 3kHz and 65-cycle for 5kHz) have been extracted from the LFM chirp. At 5kHz there were also measurements of the response to a short 5-cycle CW pulse and a longer 13ms CW pulse. The longer pulses exhibit a sharper variability – this is more like the model predictions which relate to an infinitely long pulse. Good agreement can be seen, particularly at 5kHz.

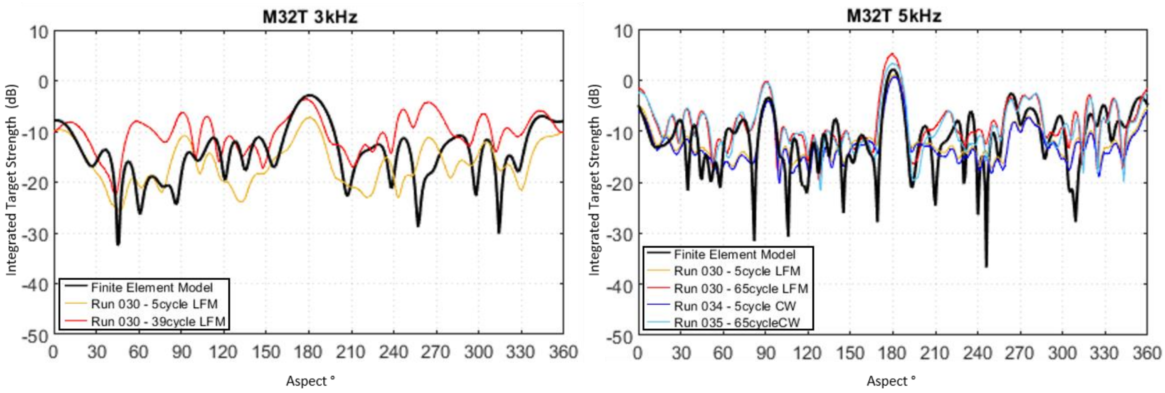

Fig. 5: FEM predicted Integrated Target Strength of M32T (in black) compared with measurements (colour) *at 3kHz (left) and at 5kHz (right).*

5. CONCLUSIONS AND FUTURE WORK

A number of modelling studies have been undertaken to contribute to the understanding of acoustic scattering from the TESSMEX objects M32 and M32T. Ray Acoustic and Finite Element Modelling have been used to examine scatter features from the objects at various frequencies. These models compare well with measurements undertaken so provide mutual validation between the modelling and measurements.

The modelling conducted thus far can be extended and built upon. This may include additional frequencies, to examine areas of interest more closely and sensitivity studies of the predicted TES to a number of factors such as material properties and alignment offset. The modelling could also be extended to other objects, such as TESSMEX M32C.

It should be noted that the modelling undertaken assumes that the object is insonified at pure frequencies. Short pulses might also be investigated using Fourier techniques. However, this would increase by orders of magnitude an already computationally demanding process.

REFERENCES

[1] **Comsol MultiPhysics,** *COMSOL Acoustics Module User's Guide*, v6.2, 2023.

[2] **Gilroy, C. De Jong, B. Nolte, and Schäfer,** *BeTSSi II - Benchmark Target Strength Simulation*, WTD 71/FWG, 2013.

[3] **B. Nolte, I. Schäfer, C. de Jong and L. Gilro**y, BeTSSi II Benchmark on Target Strength Simulation, *In Forum Acusticum proceedings*, Krakow Poland, 2014.

[4] **Ehrlich, Fillinger, Gilroy, Nijhof, Schäfer,** *BeTSSi IIB Workshop Task Specification V1.pdf* 2016.

[5] **F. Ihlenburg**, *Finite Element Analysis of Acoustic Scattering*, Springer-Verlag, 1998.

[6] **Atalla, Sgard**, *Finite Element and Boundary Element Methods in Structural Acoustics and Vibration,* CRC Press, 2015.

[7] **Bundeswehr Technical Center For Ships and Naval Weapons, Maritime Technology and Research**, *Engineering drawings of M32,* WTD 71 110-001181-1483/00-00-000, 01-00-000, 02-00-000, 02-01-000, 02-02-000, May 2017.

[8] **TNO,** *M32T_surfaces_AsBuild_rev1_20211028.pdf,* October 2021.