SOLUTIONS FOR PROTECTION AND PERFORMANCE ENHANCEMENT OF UNDERWATER SONAR SYSTEMS

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1 INTRODUCTION

This paper details the various methods that are employed to protect sonar sensor systems when operating in the harsh underwater environment. The plethora of different sonar systems for classifying, tracking, identifying, and communicating underwater require protection from the extremes of temperature, salinity, and pressure whilst still providing the optimum performance for the system over its frequency spectrum and viewing angles.

Tods Technology have developed a suite of solutions based on their heritage of supplying domes, windows enclosures, and encapsulation solutions to the world's navies. Due to the classification of these systems only general information is provided on the design and manufacture of these highly tuned acoustic and structural enclosures essential to the continued operation of sonar systems.

The hydrodynamic form of platforms is essential for reducing noise, increasing endurance, and reducing fuel costs. The hydrodynamic shape can cause compromises in the acoustic and structural design. Careful design and tuning of structures within the confines of, whilst ensuring the best sonar performance under acoustic and structural constraints. The hydrodynamic enclosure shape restricts the volume available for the arrays and sensors, so providing size, weight, and performance considerations. Baffling, that reduces noise and reverberation within the array space is essential to obtain the lowest achievable signal to noise ratio thereby enhancing the performance envelope of the sonar is the design intent.

Various advanced acoustic structures are explored including the innovations that Tods Technology are pursuing to further improve these essential sonar systems using acoustically tuned products that can operate effectively across a range of underwater environments and operating conditions.

Details are provided for the Development Test Centre that Tods Technology has established within their Portland production site that provides a suite of in-house underwater testing facilities covering the operational ranges of their products. This suite of testing facilities enables Tods Technology to refine their designs and develop new solutions for their enclosures and baffling systems.

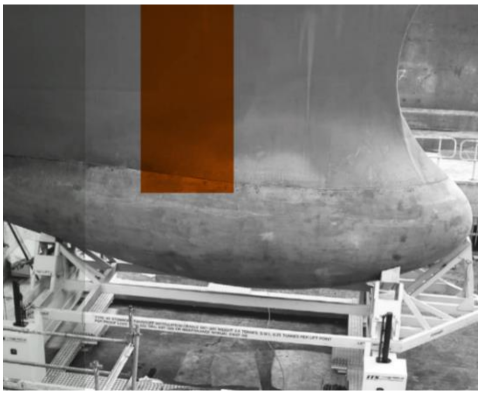

Fig. 1. Platform Installations

2 SENSOR PROTECTION

2.1 Sensor Encapsulation

The underwater environment is harsh and unforgiving, nevertheless, navies around the world keep constant vigilance above and below the surface of the world's oceans. One of the primary directives of a navy is to detect, track, and classify underwater targets and is conducted predominantly using sonar systems including hull-mounted, keel-mounted, conformal, or passive ranging arrays. These systems must operate ceaselessly in an uncompromising environment pertaining temperature, salinity, and pressure across a frequency spectrum and viewing angles. The structures that contain sensors are referred to as windows as they allow for the visualization of underwater objects.

Achieving the balance between structural, acoustic, and dynamic requirements, called for in modern highly complex composite components, is technically demanding. Submergible ship and boat sensors include sonar or radar, each encapsulated within composite structures also known as sonar domes. Encapsulants can be manufactured from different materials to form a layered medium.

Sonar domes are primarily made from either Carbon Fibre Reinforced Polymer (CFRP) or Glass Fibre Reinforced Polymer (GFRP) or a combination of both. Usage of composites allows for lightweight structures whilst maintaining a strong product that can withstand stringent structural requirements.

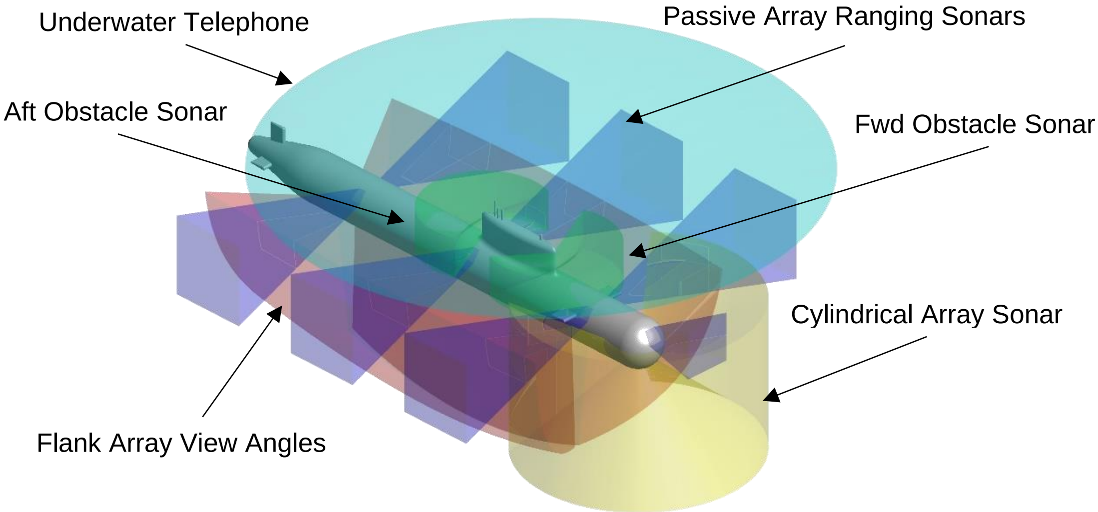

Fig. 2. Sonar Sensors

2.2 Sonar Protection

Sonar domes are large composite acoustic windows that are hydrodynamically shaped and structurally designed to withstand significant shock and slamming loads whilst maintaining its acoustic function. They are installed at the bottom of ships, usually a bow dome but can be a keel dome instead. On submarines, acoustic windows are installed covering a substantial area of the vessel. Sound is the only known energy transmission that can propagate considerable distances underwater.

2.3 Radome Protection

Radomes operate in air at the surface and are required to protect the sensor during submersible operations. Due to being air backed these structures do not equalize the pressure at depth and so are required to withstand the full extremes of pressure to ensure operational availability. Radomes can be constructed from multiple material types constituting a layered medium including A, B, & C Sandwich types.

3 PERFORMANCE

3.1 Sonar Baffling

Acoustic materials, ranging from individual tiles and baffles to proprietary cast coatings are necessary to achieve specific operationally capable acoustic systems. These materials are tailored to each application and are tuned for their performance characteristics to meet exacting customer specifications.

3.2 Acoustics Design

Unique in-house acoustic analysis and test capability provides optimised solutions to control acoustic wave propagation, transmission, and reflection characteristics. Typical acoustic operating conditions require either low transmission loss, impedance matched materials or noise damping where high signal to noise is required.

Table. 1. Stealth Material Applications

Acoustic Function	Purpose
Anechoic	Absorbent
Insertion Loss	Blocking
RhoC	Transparent
Syntactic	Transparent & Buoyant

These four material types each have distinctly different stealth functions within a sonar system.

- Anechoic materials inhibit reflections, false targets and reduce noise within a given system.
- Insertion Loss materials reduce self-noise and prevent leakage of noise between components.
- RhoC materials provide encapsulation and protection of sensors and sensitive equipment with minimal impact on their respective performances.
- Syntactic materials provide an acoustically transparent filler material with buoyant qualities.

There are four main material properties our stealth products must adhere to: acoustic performance, structural performance, manufacturability, and product life cycle. These criteria are fundamental requirements of our stealth materials and are the driving force behind any new development.

3.3 Product Operational Properties

Sonar systems use two basic functions, active and passive. Active sonar is when a generated signal is emitted, and echoes are returned from any surrounding targets. Passive sonar is when the sonar solely receives sound. Active sonar has the disadvantage that it gives away the presence of the emitting platform and so passive sonar is used to maintain covertness which is critical for submarine operations.

Tods domes and windows require a range of sonar signals to pass through virtually unhindered with the intent to optimise detection range and bearing accuracy. Detailed acoustic design is required for the sonar enclosures. Its hydrodynamic form must be maintained whilst protecting the array from the unwanted flow and self-noise generated by the vessel.

The acoustic baffles have two properties, to block sound generated by the host platform from sources such as onboard machinery and propulsion systems and to inhibit reflections by absorbing echoes in the sonar space, preventing false targets, and reducing noise.

A greater signal to noise ratio increases detection range and improves bearing accuracy, essential to maintaining a tactical advantage. Advances in signal processing can help to offset lower signal to noise ratios, but fundamentally the proper design and installation of acoustic treatments will further enhance the signal to noise.

Tods materials are required to withstand demanding operational conditions in the underwater environment. Materials are validated through robust structural, acoustic, and environmental testing regimes to underpin design analysis and provide vital qualification evidence.

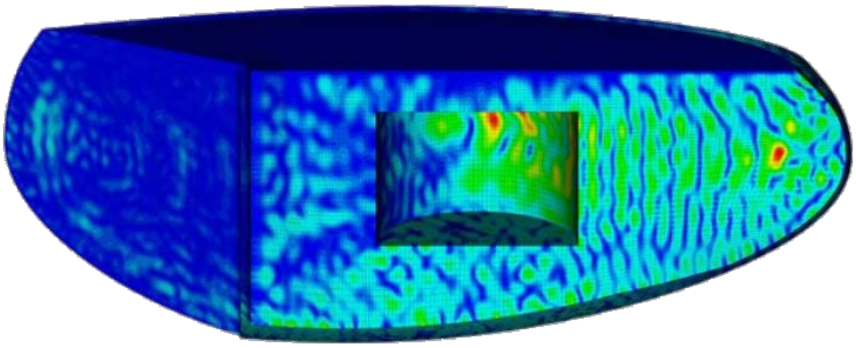

Fig. 3. Sonar Performance Analysis

3.4 Fundamental Physical Interactions

The physics governing the transmission and reflection of sound at boundaries between materials can be used to quantify and predict the behaviour of the sonar signal interacting with the domes, windows, and baffles, [1,2,3].

The acoustic impedance (Z_0) is the product of the sound speed (c) and density (ρ) of the material the signal is propagating in. The sound speed is a function of the elasticity of the material and the density.

$$Z_0 = \rho c$$

The reflection (R) and transmission (T) coefficients can be determined from the signal amplitude (A_i) and acoustic impedance (Z_n), which in turn is derived from the material properties of density and sound speed in the medium.

$$A_i + A_r = A_t$$

$$R = \frac{A_r}{A_i} = \frac{Z_2 - Z_1}{Z_1 + Z_2} = \frac{\rho_2 c_2 - \rho_1 c_1}{\rho_1 c_1 + \rho_2 c_2}$$

$$T = \frac{A_t}{A_i} = \frac{2Z_2}{Z_1 + Z_2} = \frac{2\rho_2 c_2}{\rho_1 c_1 + \rho_2 c_2}$$

$$1 + R = T$$

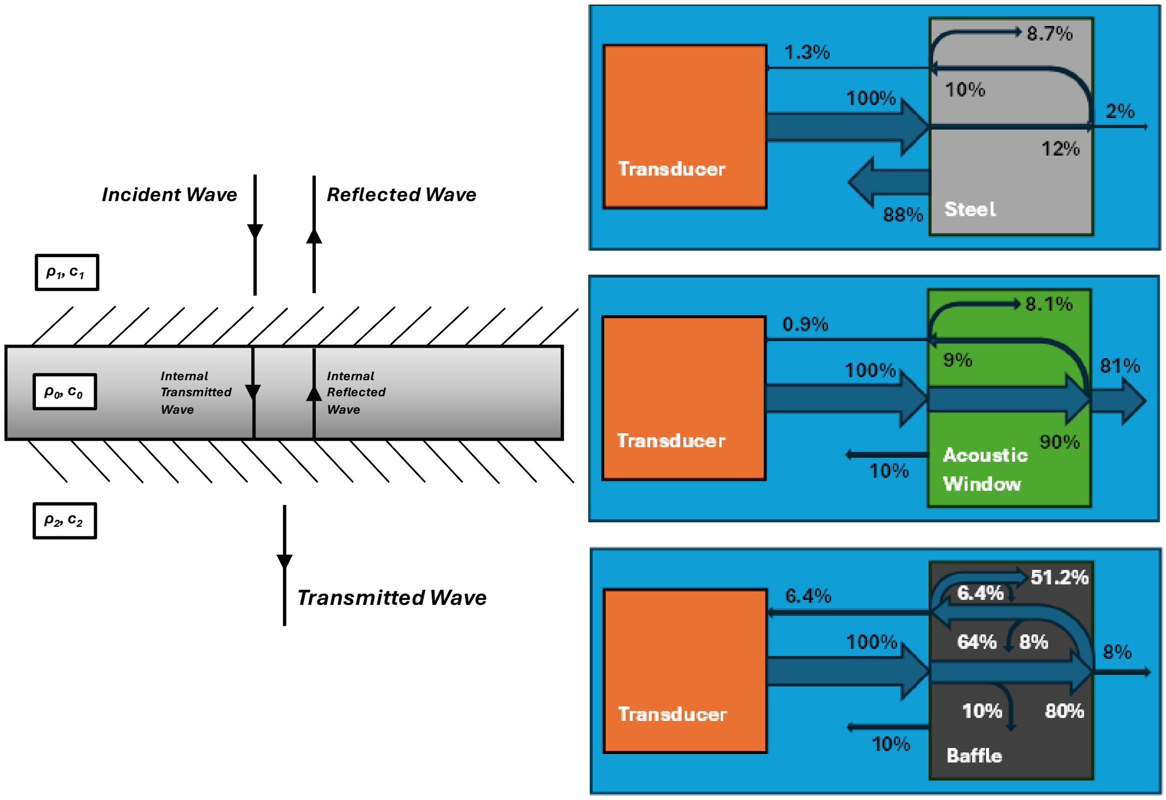

Fig. 4. Sound Transmission and Reflection through Materials.

If the acoustic impedance of the material changes from low to high such as passing from water to steel, then most of the signal is reflected in phase with the incoming signal. This would result in a high Target Strength which is undesirable for stealth (Fig. 4 top right).

The transmission at a boundary, for example from a transducer in water transmitting through a dome or window will be attenuated by the material it passes through as well as some of the signal being reflected. The amount of signal passing through the window compared to that reflected depends upon the acoustic impedance difference between the two boundaries. If the acoustic impedance closely matches, then the signal is predominantly transmitted, and a small amount is reflected (Fig.4 right middle).

For baffles the material are layered with a close match to the acoustic impedance of water but with high absorption characteristics. Careful design allows for multiple reflections and phase changes within the baffle which provides enhanced performance when compared to a single layered material.

The propagation signal (P) can be calculated at any distance and time from emission from the sonar. The governing equation is the wave equation which can be simplified for an outgoing sonar signal in its complex form, k is the wavenumber and ω is the angular frequency.

$$P = Ae^{-i(kx+\omega t)}$$

These fundamental physical interactions can be exploited by careful design of the materials' structure and chemistry to further improve transmission where required and reduce reflections, improving the signal to noise ratio at the sonar.

4 DEVELOPMENT

4.1 Background

Tods Technology investment in onsite testing facilities includes: Dynamic Mechanical Thermal Analyser (DMTA), Pulse Tube, Insertion Loss (IL) Tank, Wave Speed Tank, Viscometer and Particle Size Distribution Analyser. These facilities increase our knowledge and understanding of stealth material properties and allow us to tune and tailor them. The following primary parameters define the stealth material performance characteristics.

Table. 2. Stealth Material Applications

Test Method	Parameter
DMTA	E’, E’’ & tan(δ)
Pulse Tube	IL & ER dB
Insertion Loss	IL dB
Wave Speed	V_l , V_s ms^{-1}
Viscometer	μ
Particle Size Distribution	μm

4.2 Pulse Tube

A world leading Pulse Tube, providing a wide range of capability and fidelity. This bespoke piece of equipment is 7.6 m long and precisely machined to provide a smooth surface throughout, thus minimising any interference to the acoustic signal. Optimal performance for its normal plane testing is ensured by the inclusion of the smallest practicable sensor ports. A representative range of pressure and temperature conditions can be established in order to test candidate materials in a simulated operational environment.

4.3 Insertion Loss Tank

For any structure requiring high sonar performance, materials need to be acoustically transparent at the operational frequencies of the sonars they protect. This requires a low insertion loss, validated through measurements at a variety of frequencies and angles of incidence. Sample panels can be mounted in the Insertion Loss Tank to allow measurement of these properties as part of the testing and validation of real product, and this forms part of a comprehensive set of tests at our Development Test Centre.

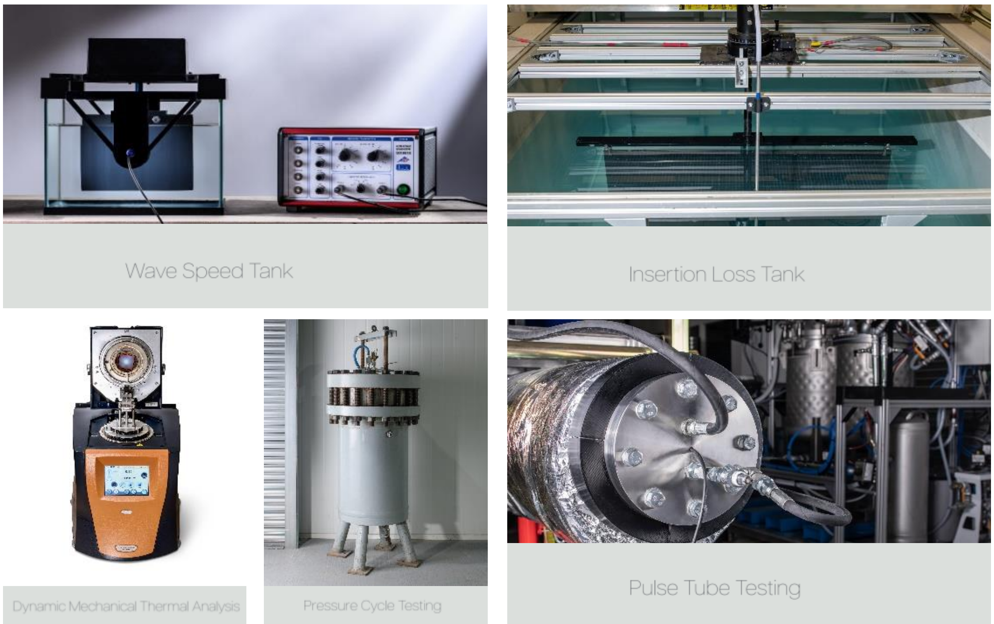

Fig. 5. Material Test Facilities

4.4 Wave Speed Test Tank

The fundamental characteristics of any candidate acoustic material are required for the prediction of impedance performance and the Wave Speed Test Tank provides the ability to measure this. Ultrasonic measurements can be used to determine the sound speed for different wave propagation types against angle for many different material types and compositions. Other acoustically relevant material properties such as elastic moduli can also be derived. An adapter rig also allows determination of the sample density.

4.5 Dynamic Mechanical Thermal Analysis

DMTA equipment provides dynamic elastic moduli measurement against temperature and frequency. This data provides direct input parameters for the calculation of viscoelastic properties of the samples. It can also be used to derive detailed data on the rheological behaviour of the material. Prediction models can then use this data to optimise the performance of the system across the environmental parameters and frequency range.

5 CONCLUSION

Tods can provide a wide range of composite solutions for sonar systems that encapsulate and enhance their acoustic and structural requirements. From structural and acoustic design through to testing and qualification, Tods has the expertise to provide solutions for the world’s navies sonar problems.

6 BIOGRAPHIES

Ray Browne has over 25 years of experience in underwater acoustic design and research experience. He has a background in Electronic and Computer Engineering and a PhD in underwater acoustics. His career commenced with signature management of helicopters. Ray spearheads our Acoustic Department and our Development Test Centre facility.

Toby Browne graduated with a Computer Science degree from Coventry University and during his time there, conducted a Summer Placement at Tods. After University, he returned to start his career as a Development & Test Engineer and recently transitioned into the role of Acoustic & Development Engineer at Tods Technology.

Simon Clark has over 35 years of composite design and research experience. He gained a PhD in marine composite structures at Southampton University and worked as a composite ship surveyor in Lloyds Register of Shipping then at Tods as a Chief Engineer for both marine and aerospace sectors.

7 REFERENCES

1. A. Pierce, Acoustics, An Introduction to its physical principles and applications (McGraw-Hill, 1989)
2. R.J. Urick, Principles of underwater sound (McGraw-Hill 1975)
3. L.L. Beranek, I.L. Ver, Noise and vibration control engineering, Principles and applications John Wiley & Sons Inc 1992)