Final Results for Representative MHK Turbine Acoustic Predictions under Operating Conditions

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Introduction

This report presents the final acoustic predictions for a representative MHK turbine. The goal of this work was two-fold and aimed to, 1) provide an acoustic signature for a representative MHK turbine and 2) present a framework under which MHK developers and researchers could predict turbine acoustics, prior to building and testing, to enable cost-effective quieter designs mandated by regulators. Before this year there had been no publicly available data on the acoustic signature of an MHK turbine and while devices are currently being deployed, the lack in number of measurements is still a limiting factor in understanding the impact noise from these devices will have on the environment. By designing a representative turbine and predicting its acoustic signature, a baseline noise level can inform both design and environmental considerations. Additionally, this work presents the steps required to perform an acoustic analysis, demonstrates where the analysis falls within the whole design framework, identifies the necessary tools, and the minimum required information.

Representative MHK Turbine

A MHK turbine was designed to represent typical devices currently being designed, tested, and deployed. It will also provide baseline power and acoustic performance, to support the growth of the MHK industry and allow for further improvements. The turbine utilized a straight transfer of wind turbine technology (i.e. sharp trailing-edge foils, circular root, hollow blades, etc.) with details specified in Table 1 and the final turbine shown in Figure 1. The chord and twist distributions were optimized with Blade Element Momentum (BEM) theory.

Table 1: Design specifications for the representative MHK turbine

Design Parameter		Value
Turbine diameter		5 m
Inflow velocity		2 m/s
Tip Speed Ratio		5.5
Foils		
	Inboard	FFA-W3-301
	Midspan	FFA-W3-241
	Tip	FFA-W3-211
Material: Isotropic Fiber Glass		
	Young's Modulus	35 GPa
	Ultimate Stress	580 MPa

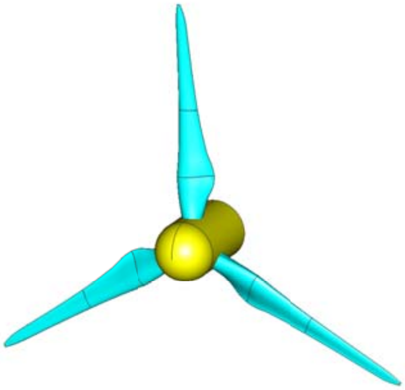

Figure 1: The representative MHK turbine.

Design Framework for Acoustic Analysis

There are key tools and steps used in the design and analysis of a turbine. Performance and survival design specifications dictate the blade design, which then needs to be validated through structural and fluid simulations. These will report the likelihood of blade failure and its performance. Depending on the results, a few design iterations may take place before a final blade is presented and then built and tested. As seen in Figure 2, the structural and fluid results can also be used as input to a full acoustic analysis without introducing supplementary modeling and analysis effort. Modal analysis will determine the structural frequency response of the blade while integrated quantities from a RANS (Reynolds Averaged Navier-Stokes) simulation are sufficient to give the response of the flow to the rotor and its rotation. The integrated quantities include the displacement boundary-layer thickness, separation point, and friction velocity. As with structural and CFD analyses, the results from an acoustic analysis can dictate changes to the blade design. It should be noted that acoustic packages are starting to be included in commercial CFD codes, but do not incorporate any of the structural information.

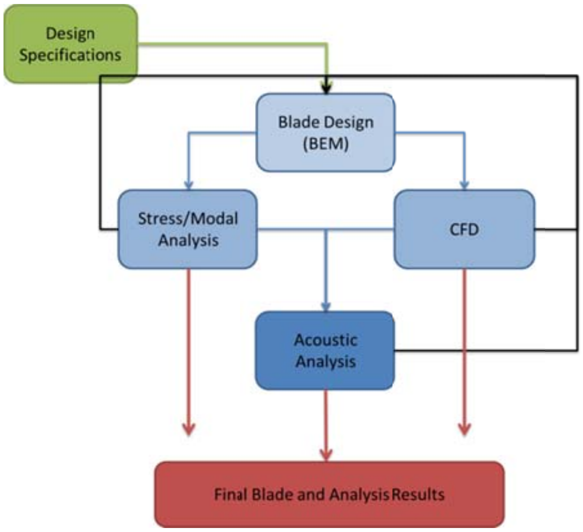

Figure 2: Design framework, including acoustic analysis.

Acoustic Results

Two acoustic analyses were performed on the representative MHK turbine to predict the noise produced, under normal operating conditions, of a hollow (water filled) and solid blade. Barring any publicly available measurements, these results provide a baseline acoustic signature that can be used to inform insonification studies of fish and other marine life [1] and compared against measurements of anthropogenic sources [2]. It was noticed during the hollow blade analysis, as seen in Figure 3, that significant portions of the structural modes functioned as monopoles at low frequencies. This means that the blade was "breathing" and radiating noise equally well in every direction, thus an analysis of a solid blade was necessary to determine the overall impact this had. Additionally, as seen in Figures 4 and 5, the low frequencies of the acoustic spectra are dominated by the leading edge (LE) noise, which is caused by the inflow turbulence interacting with the physical structure of the blade. The trailing edge (TE) noise is primarily a result of the hydrofoil shape and performance, which dictates how the flow separates from the trailing edge and if any vortex shedding further excites the sharp TE, and contributes to the higher frequencies as a result of its smaller length scales. The Applied Research Laboratory at Pennsylvania State University performed the acoustic analyses using their in-house boundary element model, CHAMP (Combined HydroAcoustic Modeling Program).

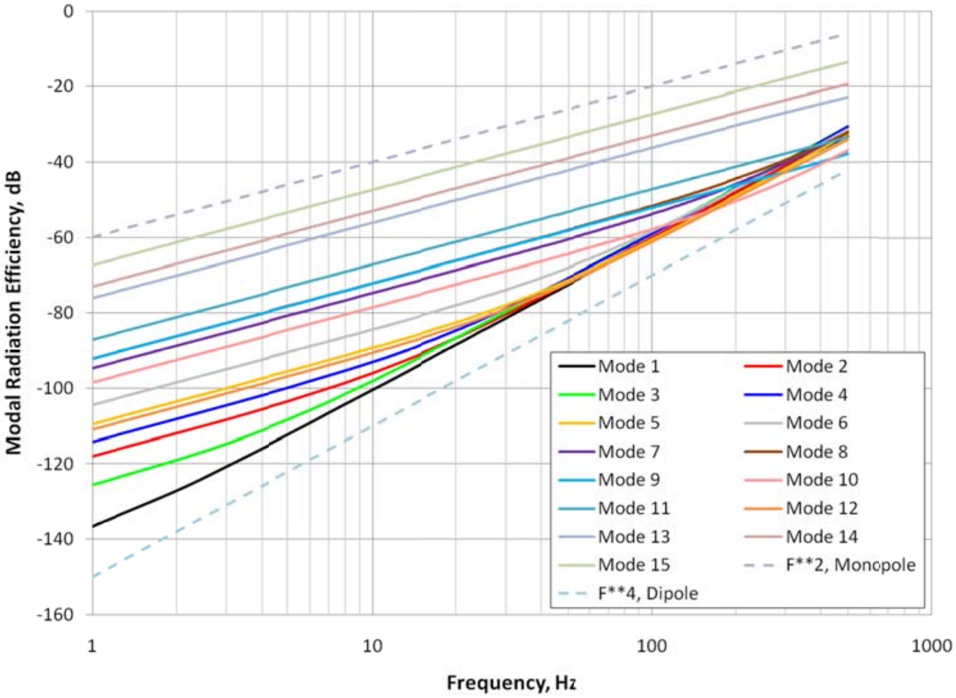

Figure 3: Modal radiation efficiencies of the hollow blade.

Solving for an integrated power, the total sound power of the hollow and solid blades are, 128 dB and 123 dB respectively, referenced to 1 µPa at 1 m. While there is some uncertainty within the prediction, 3 dB is usually used as the threshold for humans noticing an audible change in volume. It should also be noted that decibels are a logarithmic ratio relative to a reference value, where water typically uses 1 µPa

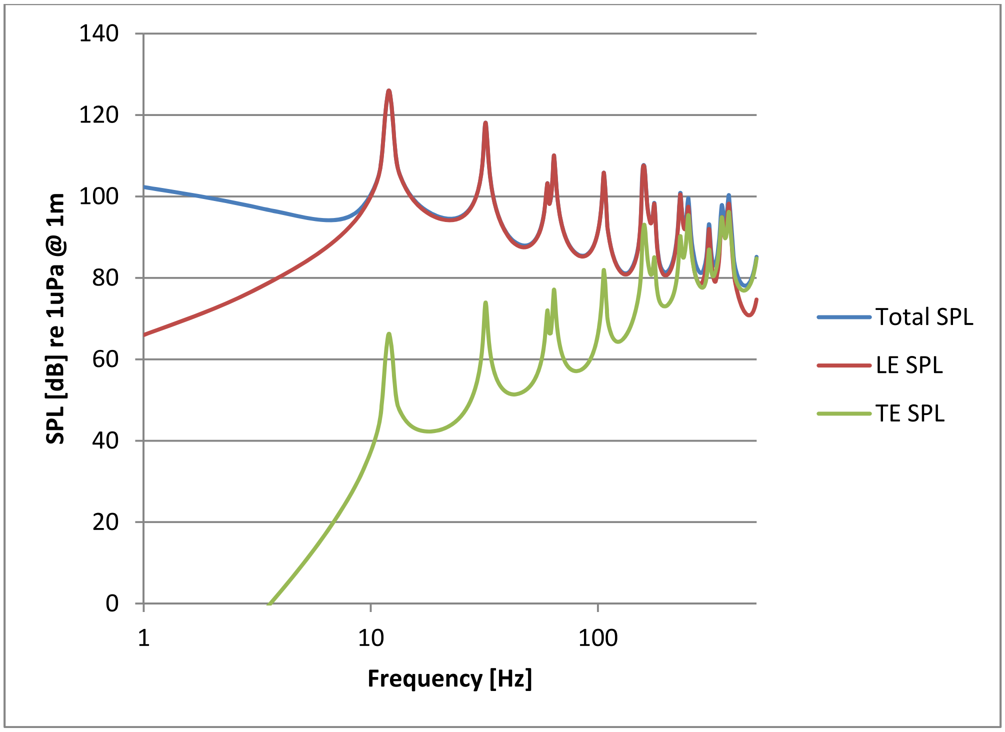

Figure 4: Sound pressure levels of the hollow blade with LE and TE components.

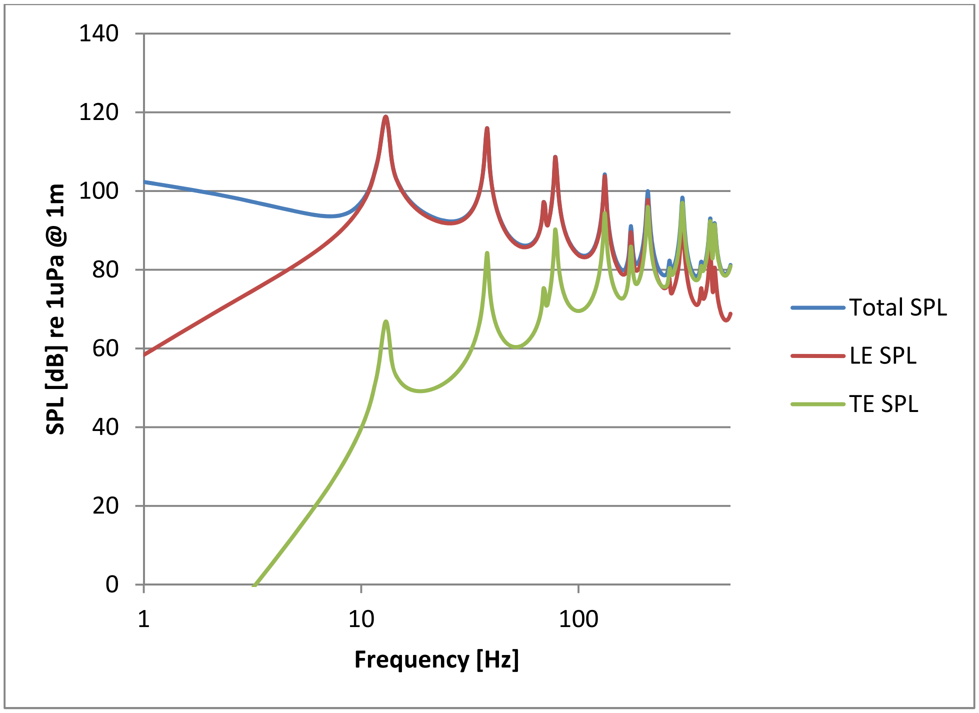

Figure 5: Sound pressure levels of solid blade with LE and TE components.

and air is 20 μPa, and as such a direct comparison to a standard *loudness* chart is not possible without first transforming the values. Not only does the total sound power level drop when using a solid blade, but the frequency response changes as well; though the asymptotic sound pressure levels remain relatively unchanged. This is due to a change in the structural modes and indicates that thinning the skin (composite laminate) of a hollow blade will increase the total sound power. A shear web may help mitigate, but not eliminate this trend.

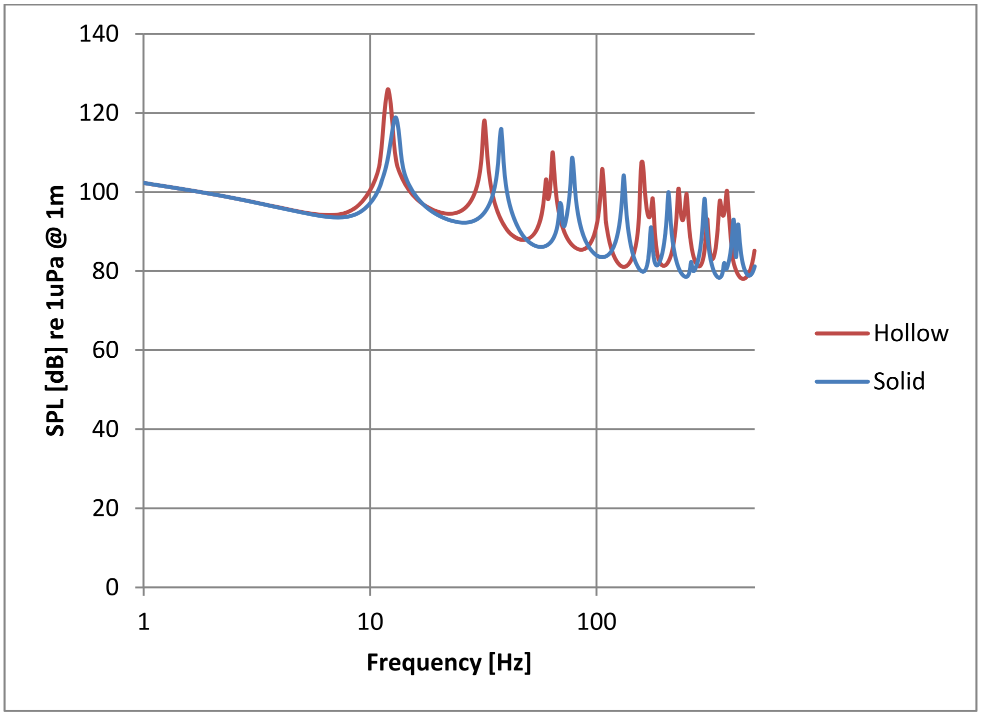

Figure 6: Comparison of the total sound pressure levels for the hollow and solid blades.

Preliminary results from PNNL demonstrate a low risk of injury to juvenile Chinook salmon from tidal turbine noise [1]. They also showed a decrease in injury as treatments continued over multiple days. Treatment sound levels were determined from measurements of a 6 m OpenHydro Tidal Turbine and ranged from 133 to 163 dB, with an exposure time of 24 hrs. Moreover, because of their migratory nature, it is unlikely for Chinook salmon to congregate around a turbine. There are many possible reasons the measured OpenHydro spectra is louder than that predicted by this work, not the least of which are an absence of mechanical noise (e.g. gearbox, generator, etc.) in our analysis and the dissimilarity of design between the two turbines. Washington University has taken acoustic measurements within Puget Sound and found the ambient sound level to be approximately 105 dB and the local ferry producing 179 dB re 1 µPa at 1 m [2].

The acoustic predictions made within this study provide a baseline signature for a representative blade that appears reasonable given the lack of publicly available measured data around similar devices. This methodology and these results can be used to influence turbine blade designs in order to mitigate the sound produced. They can also be used to inform future, and compare against previous, insonification studies meant to predict the environmental effects of acoustics on aquatic species.

Future Work

These results and the analysis framework will be presented at an upcoming conference and published within its proceedings. Also, it is SNL intent to publish this work within a prestigious journal and to create internal SNL SAND report. A continuation of this analysis is planned under AOP subtask 1.4.1.7, where an innovative MHK turbine will be designed, manufactured, and tested within the Pennsylvania State University 48" water tunnel. The new turbine will be based on Task 1.3.2.4, with improvements made to capture lessons learned. Acoustic measurements made within the water tunnel will be compared against acoustic predictions of the new turbine to validate the computational framework, and against the predictions made within this work to further develop an understanding of how turbine design influences the noise produced.

While the CHAMP process is proprietary to Penn State ARL, it may be possible for developers to contract them to perform an acoustic analysis. Though only preliminarily discussed with Penn State, it may also be possible to produce a non-proprietary version of CHAMP that would be accessible to all. SNL staff is actively looking at non-proprietary tools to determine if a sufficient alternative exists, as the foundational physics used within CHAMP are publicly available. This would ensure a smooth transfer of this capability to industry and regulators to support best-design practices in limiting acoustic environmental effects.

References

[1] M.B. Halvorsen, T.J. Carlson, and A.E. Copping, "Effects of Tidal Turbine Noise on Fish", PNNL-20787, Sep. 2011.

[2] C. Bassett, J. Thomson, and B. Polagye, "Characteristics of underwater ambient noise at a proposed tidal energy site in Puget Sound", *OCEANS 2012*, pp. 1-8, 20-23 Sep. 2010.