Analysis of Shear Forces between Satellite Telemetry Tag and Whale Blubber in a Drag Force Simulation

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Statement of Purpose: Satellite telemetry tags are a common form of surveillance and analysis for the health of large cetaceans. Current tag designs, however, anchor in the fascia of the whale, resulting in damage to tissue and shorter retention times (Robbins J. Nat. Fish Wildlife Found. 2016; iii-100). Current research is focused on the design of a blubber-only implantable satellite telemetry tag that has a smaller footprint and surface modifications to increase retention while minimizing stress concentrations and tissue trauma. Retention, qualified by mechanical stability, is confirmed through mechanical tests that simulate forces tags will be exposed to in the field. To better examine these forces, Finite Element Analysis (FEA) is being developed in this work to assess the effects of feature architecture and spatial configuration; as well as stiffness of features and underlying tag body on the distribution of shear stress at the surface of the tag during service condition simulations.

Methods: Material properties of humpback whale blubber was obtained through rheometric testing. Small amplitude oscillatory shear frequency sweeps on biopsy punches of humpback whale blubber were used to determine storage and loss moduli of samples at four tissue depths (skin, upper blubber, lower blubber and connective tissue). A Prony Shear Relaxation model – an incompressible material model used to interpret non-Newtonian rheological data representing relaxation and stiffness as parameters – was used in the simulation. The storage (G') and loss (G") moduli and calculated discrete parameters were compared to validate use in the simulation (Figure 1).

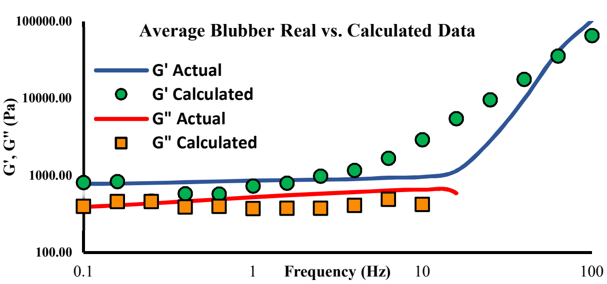

Figure 1. Storage-loss moduli of humpback whale blubber and parameters. Storage (G') and loss (G") moduli of blubber, at four levels (total depth of 10") were averaged. A custom MatLab application (ResPect) fit a curve to the parameters G' and G" resulting in discrete data that was applied to a Prony Shear Relaxation viscoelastic model in the FEA model.

A transient structural model in ANSYS Workbench 18.1 was used for a drag force simulation. Tags tested in this model were composed of 316L stainless steel (8.82" long with an outer diameter of 1.49"). Three different geometries for each tag design with 25%, 50%, and 75% exposure levels were examined. Variable drag forces, determined by height-diameter ratios, were exposed to the tags in a fixed cube of blubber. The simulation aimed to examine how deformation and strain of blubber responded to different exposure levels and tag designs.

Results: The blubber deformed significantly in relation to the tag. Higher exposure levels resulted in higher deformation and increased maximum strain. These maximum strains were found to correlate directly with the surface geometries (Figure 2). Additionally, after further examination, it was found that points of tag indentation result in immediate stress concentration at the surface.

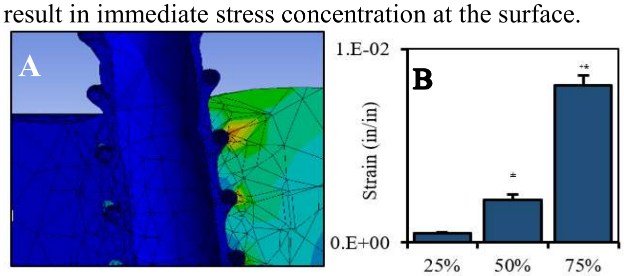

Figure 2. Maximum principal strain at exposure levels. (A) Maximum strain of 25% exposed surface modified design. The highest concentrations of strain (orange-yellow areas) were observed as expected at leading edges of surface features on tag. (B) Average maximum strain of 25, 50 and 75 percent exposure levels for drag simulation. Exposure levels compared using ANOVA with a standard t-test ($p<0.0001$). *, ±, + indicate significance between all exposure levels.

Conclusion: This investigation found increased strain in blubber as exposure level to drag forces increase, concentration of strains and stresses at various surface features, and changes in strain and stress distribution as exposure levels change. Tags with sharp indentations have significantly thinner walls at these locations, and higher stress concentrations may indicate that modification of sharper indentations may be necessary. Future work will focus on a pull-out simulation utilizing cohesive zone modeling to examine the effect of an adhesive hydrogel surface coating on stress concentrations as well as the characterization of species specific blubber differences including blue whales.

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