Changing shapes: How the trachea of the leatherback turtle responds during deep diving

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Two roads diverged in wood, and I-

I took the one less travelled by,

And that has made all the difference. (Robert Frost)

Background

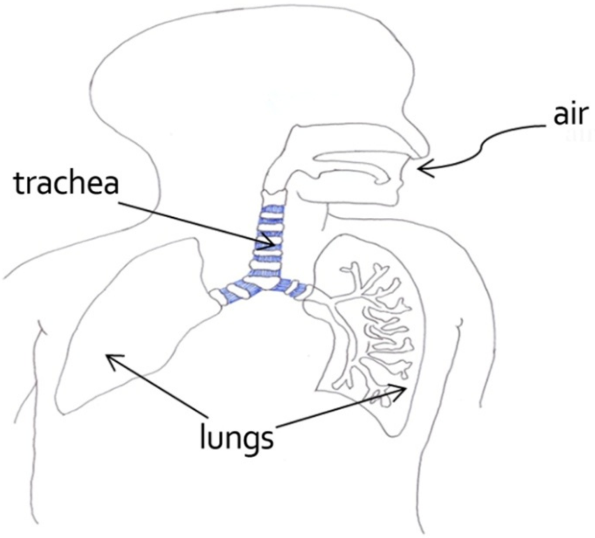

Figure 1: Human breathing system

This research is primarily an engineering project. It focuses on analysing the behaviour of structural materials and identifying the properties of materials that govern the behaviour. The topic arose out of a need to classify how the trachea of the leatherback turtle (scientific classification: Dermochelys coriacea) responds to the extreme water loadings it is subjected to during deep diving (>300 metres). In the following sections a detailed background and overview of the work undertaken to date is presented. The work is an interdisciplinary project and is essentially a zoologically applied model based on engineering principles. For reference, a graphical representation of the trachea and breathing system is

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provided in Figure 1. For a more detailed description of both the trachea and deep diving the reader is referred to the article published by the author in Volume I of the Boolean, the URL link for which is http://publish.ucc.ie/boolean/2010/00/MurphyC/27/en.

Basis for Research

Every material has its own unique properties which govern its behaviour under external loadings. Different materials will react differently under the same external load. Take the three little pigs story for instance. When the wolf huffs and puffs both the straw and timber houses fall down but the brick house does not. The brick house obviously has more resilient material properties than either the straw or timber houses. In order to find out how the leatherback trachea responds to the enormous pressures encountered during deep diving, the material properties of the trachea must be known. At present these material properties remain unknown. This research aims to characterise the material properties of the cartilaginous rings from which the leatherback trachea is composed and, from this, investigate how the entire trachea responds to pressures encountered during deep diving.

Methodology

Normally in engineering problems the material properties are known and the responses of that material are unknown. For example, when designing skyscrapers the properties of the materials employed such as concrete and steel are used to determine the responses of these materials under extreme conditions such as earthquake loadings or wind loadings. In other words known inputs are used to calculate unknown outputs. With the leatherback trachea the opposite is true. The material properties of the cartilaginous rings are unknown. However it is possible to measure output responses such as the load required to produce an applied displacement. This data may be represented in graphical format (Figure 2). The red dotted line in this graph denotes the output response from applying a sequence of displacements to one of the rings. Using a structural model that replicates applying the displacements to the ring it is possible to obtain similar graphs. The shape of these graphs will depend on the material properties used in the model. One set of material properties may produce the green line whilst another set may produce the purple line.

When certain material properties are used in the model though, they will produce data that matches or almost matches (blue line) the data obtained from applying the displacements to the ring. When this occurs, the material properties in the model may be deemed to be reflective of those of the cartilaginous ring. This process of comparing output results in order to find input parameters is more commonly referred to as inverse engineering

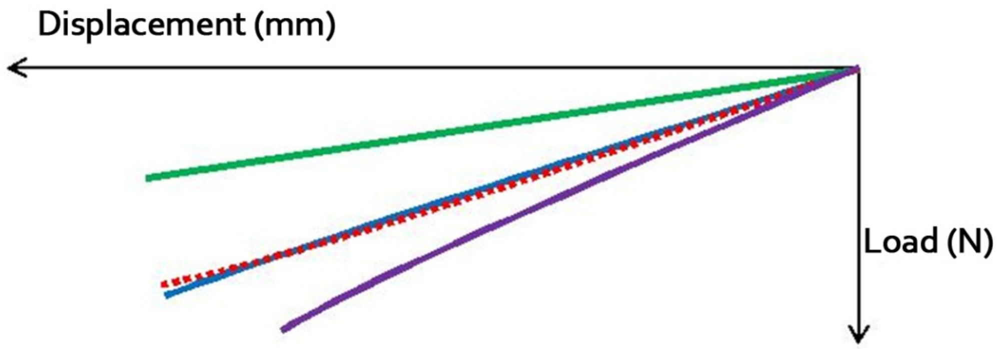

Figure 2: Load-displacement data

and comprises a major portion of my research. An optimisation technique that minimises the error between the laboratory and model data with respect to the material properties in the model is applied to obtain the 'best-fit' model. The material properties in the model are based on theory. Most of the time spent on the research to date has been devoted to finding the material model which produces the most accurate results. It has involved numerous laboratory material testings, theoretical material research and computer programming. During this time the models have become more sophisticated and reliable. There is a noticeable difference between earlier and more recent models, both visually (Figure 3) and in the results produced.

Results

The results presented confirm the feasibility of applying an inverse methodology to ascertain the material properties of the tracheal cartilage of the leatherback turtle. The changes in shape of the ring observed during the testing correlate well with those in the model results (Figure 4), suggesting that an appropriate material model was used in the structural analysis. Several material models have been considered so far. The results of more recent and more developed models are showing improvements in accuracy, as evidenced by

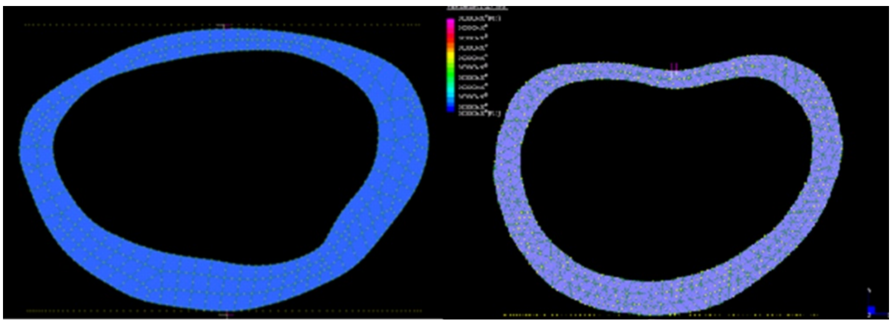

Figure 3: Comparison of preliminary model (left) with more recent model (right)

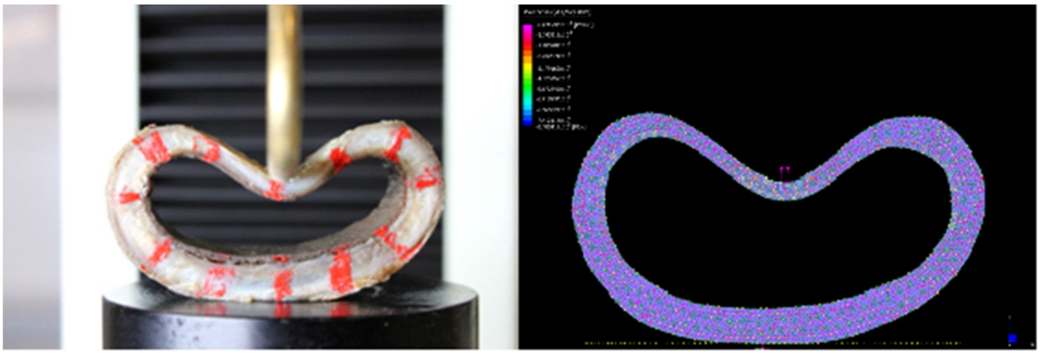

Figure 4: Displaced shapes of ring in laboratory testing (left) and structural model (right)

the comparison between the results data for preliminary models, which have a noticeable discrepancy, and more recent models (Figure 5), which have less.

Note that the graphs in Figure 5 are for separate loading conditions. Similar results would have been obtained though had the same loading conditions been applied to both sets of data.

Benefits and Future Research

Future work shall continue to improve on the accuracy of the models. Once the material properties have been ascertained they shall be used to model the response of the entire trachea to the pressures encountered during deep diving, as opposed to a single ring. To model the hydrostatic pressures a uniform pressure distribution that increases with depth shall be applied on the trachea's external side. The benefits of undertaking this research are wide-ranging. From an engineering point of view it provides a unique forum in which to apply the concept of inverse engineering for material classification, allowing for advantages and limitations to be assessed. The results may also assist zoologists researching the study of deep diving not only in the leatherback turtle but indeed many other mammals and reptiles, possibly including Man. Knowledge of the material properties of the tracheal cartilage of the leatherback turtle shall facilitate the modelling of the entire trachea during deep dives, thereby producing realistic and accurate measures of the physical response of the trachea to increasing hydrostatic pressures. Lastly, the results may even inform studies in clinical research and surgical procedures, particularly in the area of tracheomalacia, a condition that causes premature tracheal collapse during increased airflow. Using the inverse methodology described medics could obtain indicative measures of the material properties of the tracheal cartilage, which could help with the treatment of the condition.

Colm Murphy is a third year PhD student in the Department of Civil and Environmental Engineering and is working under the supervision of Dr. Denis Kelliher. The research is being carried out in conjunction with Emeritus Professor John Davenport of the School of Biolog-

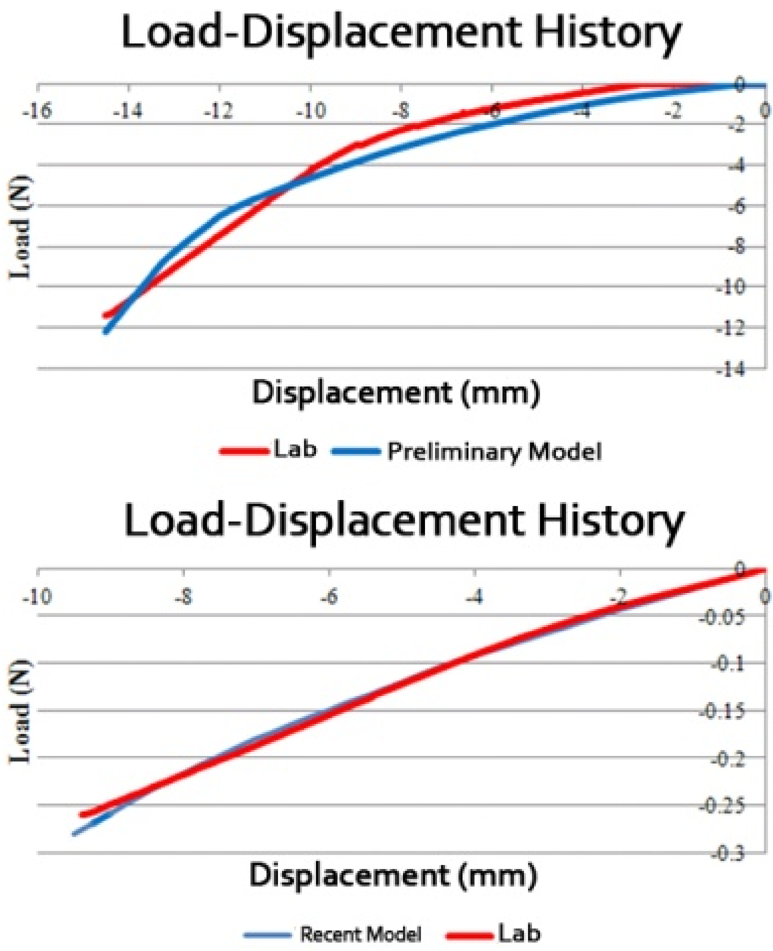

Figure 5: Comparison of data for preliminary model (top) and recent model (bottom)

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