What is the Re in a Whale's Aorta?

Fluid flow through a pipe is often used as an example in a fluid mechanics course to introduce the concept of Reynolds number (Re) and laminar and turbulent flow regimes to chemical engineering students. However, biological examples can also be used which may elicit additional engagement and interest by exploring a different aspect of chemical engineering. One such example that works extremely well for introducing Re is the animal circulatory system. Made up of a series of blood vessels that can be approximated as having circular cross-sections, the circulatory system contains blood that can be easily used in the calculation of Re. For example, the Re of the human aorta (the largest artery in the body that branches directly off the heart's left ventricle) has been measured to be in the laminar range between ~800 and 1500 along its length during rest in an adult human. However, Re can increase above this range and transition to the turbulent regime due to exercise or anatomical changes.[1] When resting human anatomical and physiological properties are used to calculate Re, a Re value of 1070 is obtained (Table 1) that is directly in line with measured values of Re at rest.[1]

In addition to examining Re in the human aorta, the diversity of life allows for additional (and more extreme) insights into fluid flow. Consider presenting the aforementioned Re data for the human aorta to your students, and then asking them to predict what the Re would be in the aorta of a whale! Fortunately, anatomical and physiological data for whales are available in the literature and can be used to make this calculation. In a 1959 publication, Race et al.[2] described the anatomy of the heart from an adult male sperm whale (mass 21,708 kg, length 13.4 m) that was found dead off the coast of Peru. The heart had a mass of 116 kg, and the aorta had a diameter of 20 cm. Additionally, based on measurements of the left ventricle, the sperm whale was predicted to have a resting cardiac output (i.e. volumetric flow rate) of 453 L/min.[2] Using these values and other reported values for whale blood viscosity, and making an assumption about whale blood density, the Re of the sperm whale aorta can be calculated to be ~7400, which is in the turbulent flow regime and is ~7x higher than that in the human aorta at rest (see Table 1). This type of analysis can be applied to other animals as well to illustrate even more diverse calculations of Re (e.g. mice, hummingbirds, elephants, etc.). Additionally, these calculations can be repeated under different human anatomical and physiological conditions (exercise, changes in blood vessel compliance, coronary artery disease, etc.) so that students can see how fluid mechanics can be applied to human health and disease.

TABLE 1
Anatomical and physiological properties used to calculate Re for a human and a sperm whale. Sperm whale blood density was assumed to be similar to that of humans. Blood velocity was calculated as cardiac output divided by aorta cross sectional area. Re was calculated as (density × velocity × diameter) / viscosity.

Property	Human	Sperm Whale
Cardiac output (L/min)	5	453[2]
Aorta diameter (cm)	3[3]	20[2]
Blood velocity (cm/s)	11.8	24.0
Blood density (kg/m^3)	1060[4]	1060
Blood viscosity (cP)	3.5[5]	6.9[6]
Re	1071	7384

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