8 Model Limitations

8.1 No Hydrodynamic Friction

The model was unable to be confirmed with experimental data due to COVID-19 closing various recourses. It is anticipated that friction will cause energy losses throughout the system that are proportional to part velocity squared. This will cause performance degradation that cannot be predicted by the model without experimentation.

8.2 Hydrodynamic Cavitation

Hydrodynamic cavitation may occur in liquids that undergo rapid changes in pressure whereby small vapour-filled cavities form and then rapidly implode causing shockwaves. Some speargun parts are likely to move so quickly that cavitation occurs, however cavitation is difficult to observe and quantify. It is likely that cavitation, if it occurs, will present as fluctuations in friction.

8.3 Rubber Data

The rubber data was derived by letting the samples dissipate for 30 minutes prior to recording the energy released, during which time approximately 30% of the input energy was dissipated. The simulator will not mirror actual performance if the gun isn’t loaded for exactly 30 minutes before firing.

If the gun is fired after 30 minutes, the shaft performance will be lower as more energy will have dissipated from the rubber.

If the shaft is fired before 30 minutes has elapsed, the system energy will be higher. It may even be higher than the frictional losses, in which case reality would outperform the simulator.

The literature review also indicated that the rubber is at least partially sensitive to strain rate; the rubber may display uncharacteristically low tension force if it is to contact significantly faster than the sample. If this was a significant factor, it would disproportionately affect faster shooting spearguns, as well as conventional and roller guns more than inverted guns.

8.4 Free Recoil

The dynamic equations assume a *free system* and do not account for the holding of the speargun, hence the recoil energy predicted is the *free recoil energy*, not the actual recoil energy. Regardless of the way the diver holds and fires the speargun, a portion of their mass will be added to the stock mass; this increases shaft performance and reduces recoil.

Divers will hold the speargun in different ways. A bent elbow, lax grip and no effort to resist recoil will result in the least kinetic energy imparted to the spear shaft. A rigid two-handed grip with locked elbows and bracing for recoil will impart the greatest kinetic energy to the spear

When pool testing occurs, the spearguns will be shot with a lax grip and a bent elbow; this will give the poorest possible performance. It is better to underestimate performance and exceed expectations than set unattainable objectives. The efficiencies gained from the semi-sprung mass that is the divers arm will contribute to discrepancies between the model and reality.

8.5 Unknown Drag Coefficient

$$Drag\ Force = 0.5\ \times Cd\ \times area \times density\ \times velocity^2$$

The shaft drag coefficient cannot be determined without experimentation and measuring the shaft velocity at various points during its trajectory. Performance at various ranges with an estimated drag coefficient is an educated guess (0.82 – from wikipedia). The actual drag coefficient must experimentally derived for each shaft diameter.

8.6 Unknown Cavity Strength

A formula that predicts penetration depth of low-speed non-deforming projectiles is:

$$Penetration\ (m) = \frac{mass\ \times\ velocity^2}{2\ \times area\ \times cavity\ strength}$$

The cavity strength has units $\frac{N \times s^2}{m}$ are represents the fish body's resistance to penetration. The simulator uses a preliminary cavity strength of 20 Mpa, slightly less than the strength of human skin, to represent fish tissue.

The cavity strength would be best represented by ballistic gelatine and should be experimentally derived for the specific context of underwater speargun shafts.

8.7 Required Testing

Each of the three speargun power systems requires testing with different energies, band diameters and shaft diameters to determine approximate frictional losses.

The shaft velocity at the muzzle and at various ranges must be recorded for each shaft diameter to determine spear drag coefficient. The muzzle velocity must be measured one shaft length from the muzzle to ensure that the bands are not still acting to accelerate the shaft.

Shafts of varying kinetic energy and diameter should be shot into ballistics gelatine with the impact velocity and penetration depth recorded to determine cavity strength.

8.8 Limitations Summary

Drag and cavitation will degrade the actual performance when compared to the model. Efficiency will by increased by incorporating a portion of the diver's arm as a semi-sprung mass added to the stock, giving actual recoil instead of free recoil. Model accuracy will be affected by how long the diver waits between loading the speargun and firing the speargun; this could either enhance or detract from predicted performance.

Regardless of limitations and testing still required, the model serves as a good comparison between different speargun configurations and rigging options.