Impact Loads Experienced by the Cervical Spine During High-Speed Water Entry

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Accident databases and medical literature have documented injuries to the cervical spine of individuals participating in water sports. These water sports often give rise to the upper torso entering the water free surface at high speeds. In the interest of reducing the injury frequency, the question of requiring the participants to wear some type of helmet has been raised.

An experimental testing program has been implemented whose focus was to quantify the loading implications on the cervical spine of a head form with and without a helmet entering the water surface. The test procedure included head entry at both zero and non-zero yaw angles. Using an instrumented Hybrid III ATD and 50% head form, time histories were collected for the three moment and force components experienced at lower and upper neck locations as functions of forward speed, yaw angle, and immersion depth. This procedure was performed for a bare head, a head fitted with an open face helmet, and a head fitted with a full-face helmet at yaw angles of zero, thirty, sixty, and ninety degrees. The forward speed varied from ten to thirty miles per hour.

Data collected during the testing described above can be then used for estimation of the hydrodynamic loads applied to an analytical representation of a human biofidelic model (MADYMO) during water entry simulation. The analytical simulation allows for determination of the attainable immersion depth of a full body as a function of forward speed and helmet type. Relative comparisons of load levels, as a function of forward speed, can be generated for the various helmet types tested.

Classical hydrodynamics indicates that forces acting on a given body are functions of size, shape, and speed. This fact is clearly represented in experimental data collected in this effort. Hence, larger less streamlined shapes will experience larger loading than smaller more streamlined counterparts given equivalent speed and submersion levels.

Test data provided in Figure 1 are for a constant immersion depth of 12.4 and 6 inches, respectively. The orientation of the head to the flow direction is inverted and face forward, against the flow. This experimental data indicates that drag and extension moments increase for open helmet and are greatest for full helmets when compared to bare head data.

Results from this on-going effort are, at below a critical speed the attainable immersion depth is independent of the size and shape of the head and helmet form. Thus, comparison of the experimental data at equivalent immersion depths and speeds and then subsequently with injury criteria is justified. In this sub-critical area, all forces and moments experienced with a helmet are larger than the bare-head case.

Above the critical speed, hydrodynamic forces may be sufficient to limit submersion depth depending on the geometry of the helmet. Current results indicate that the loading experienced with helmets may be comparable in magnitude to the bare head case for immersion depths below 3 inches. However, this is not true for the case when a helmet edge encounters a larger cross-flow component causing a large ventilated or separated cavity to form. The drag associated with this type of cavity flow can be severe, resulting in larger loads than experienced by a bare-head.

The primary limitation of this study is the modeling of hydrodynamic loading. Traditional, zero forward speed, impact theory hydrodynamics is in the process of being empirically modified to account for non-zero forward speed influences. The basis for the empirical correction is the data collected from head-form only drop tests. The full body mass - hydrodynamic coupling has been neglected in this effort thus far.

No one in either the marine or biomechanics area has attempted to predict the cervical spine loads resulting from solution of the coupled body mass - impact hydrodynamics problem. Research with human biofidelic model (MADYMO) is being performed to couple the head-form test data with full body mass dynamics resulting in prediction of cervical spine loading during high-speed water entry. Figure 2 shows interaction modeling and human body dynamics during impact and subsequent post-impact immersion into the water surface. Further research is being performed to refine the body and water interaction forces within the analytical simulation.

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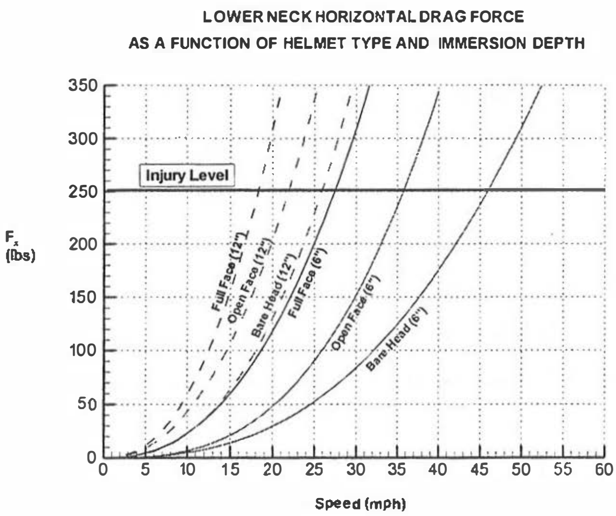
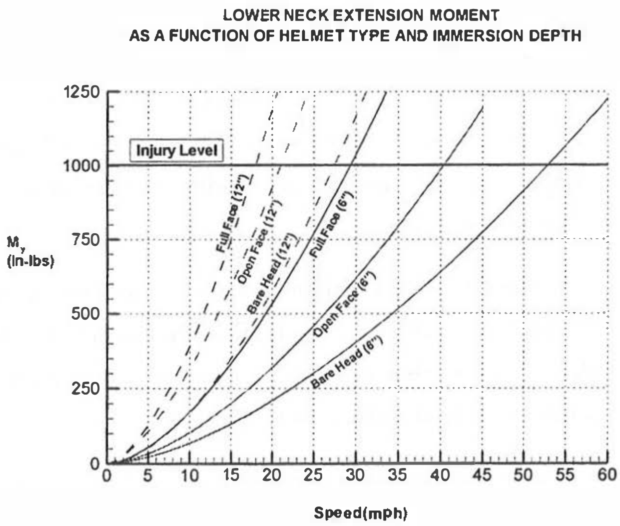
Figure 1: Lower neck shear force and extension moment.





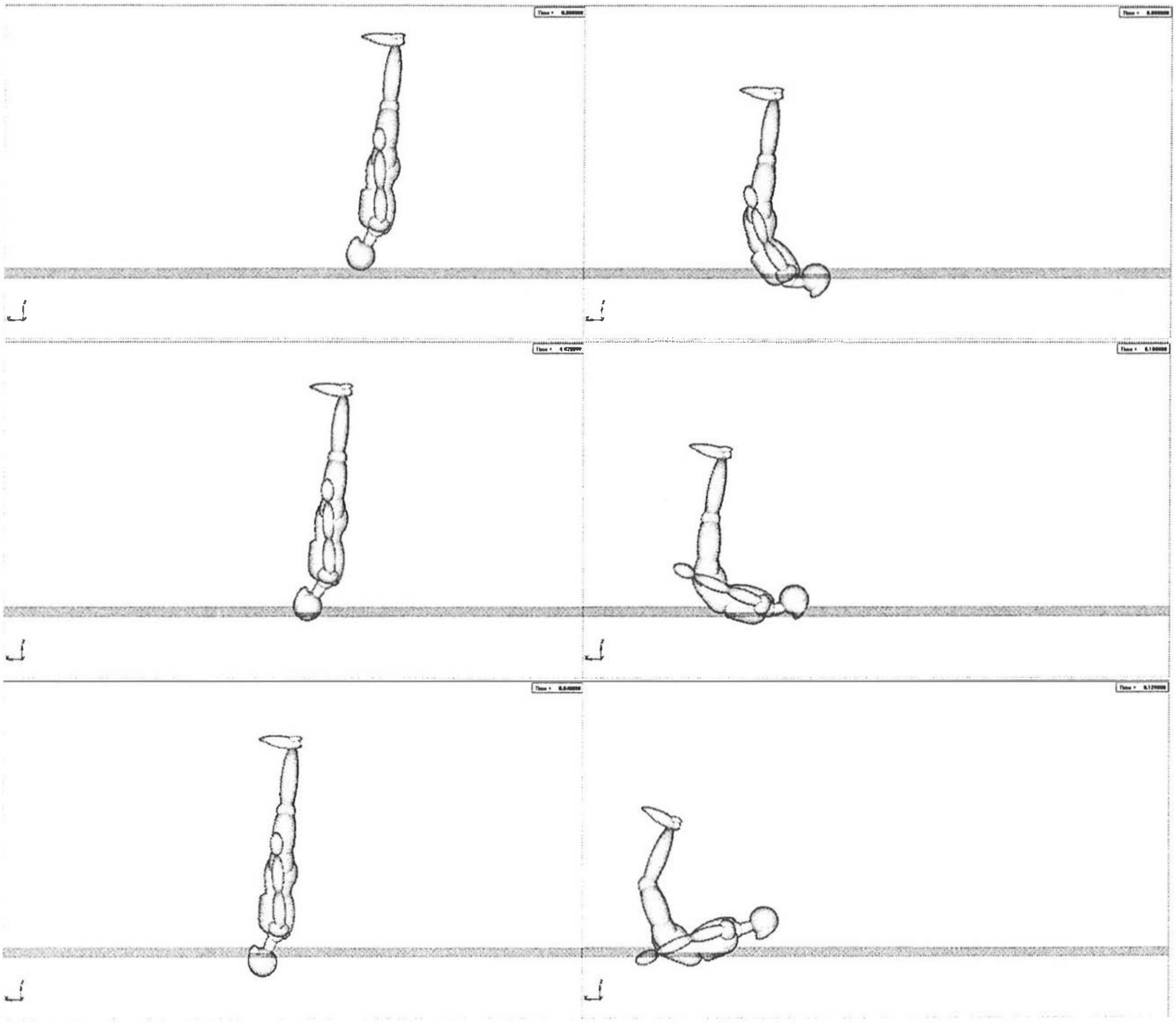


Figure 2: Water entry at a forward speed of 40 mph.