COMPARISON OF THREE-DIMENSIONAL DYNAMIC MODELS FOR GOLF CLUBHEAD-BALL IMPACTS

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Impulse-momentum (IM) principles are often used to model the impact between a clubhead and golf ball [1]. In 2020, Danaei et al. proposed an adjusted IM model that improved accuracy with regards to ball spin [2]. IM models are discrete; therefore, the time-varying contact forces are unknown. Researchers have used finite element (FE) models of impact, but these are computationally expensive. A three-dimensional (3D) continuous dynamic contact model addresses these disadvantages of IM and FE models. The purpose of this research is to compare different contact models for the purpose of modelling a golf drive.

Maw et al. proposed an analytical model (MAW) for the oblique impact of an elastic sphere [3]. This model predicts the reversal of tangential forces observed in several experiments [4,5]. The model was originally developed for a perfectly elastic 2D oblique impact. For a 3D golf impact model, the tangential force is calculated in the same manner and applied in the opposite direction of relative velocity at the contact point. The original MAW model uses Hertzian contact theory for the contact area and normal force. We used a Hunt-Crossley model in the normal direction to make the collision inelastic [6]. With this model, the coefficient of restitution (COR) will decrease with increasing clubhead speed.

Arakawa proposed an analytical model for the angular velocity of a golf ball during an oblique impact in which the dynamic friction is related to the time derivative of the contact area [5]. As the contact area decreases, beyond the point of maximum compression, the tangential force reverses. Similar to MAW, for the 3D application in this paper, the tangential force is applied in the opposite direction of relative velocity. Again, Hunt-Crossley damping is used in the normal direction to model the inelastic collision [6].

The third impact model considered is the volumetric contact model with a two-layer ball proposed by McNally et al. [7]. The two layers of the ball can rotate relative to each other and are connected by a 3D torsional spring and damper [7]. This allows the ball to vibrate and is intended to capture the characteristics observed in experimental studies [7]. Similar to the first two models, the normal force contains a damping term to make the collision inelastic.

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To simulate ball impact, a continuous multibody dynamic model is developed using the software MapleSim (Maplesoft, Waterloo, Canada). The clubhead and ball each have 6 degrees of freedom. Initial conditions for both bodies are from experimental data collected by a golf equipment manufacturer [7]. The data includes 555 drives from 56 elite golfers. To tune the parameters of each model, the genetic algorithm in MATLAB was used for its reliability to find the global minimum. The objective function was to minimize the normalized mean absolute error for all launch conditions. Table 1 shows the experimental mean, and the mean absolute error (MAE) and standard deviation (STD) for each impact model.

Table 1: Mean value, mean absolute error, and standard deviation of launch conditions.

Launch Conditions	Exp. Mean	MAW		Arakawa		McNally		Danaei	
		MAE	STD	MAE	STD	MAE	STD	MAE	STD
Speed (mph)	158.9	2.27	3.07	2.29	3.12	2.12	2.91	1.51	1.27
Launch (deg)	14.5	0.52	0.59	0.76	0.86	0.54	0.58	0.68	0.50
Azimuth (deg)	2.19	1.13	0.52	1.16	0.54	1.07	0.52	0.78	0.49
Backspin (rpm)	2980	385	356	634	592	228	239	213	257
Sidespin (rpm)	490	298	334	316	348	227	252	150	188

Predicted ball speed, launch angle and azimuth are very similar for all contact models. However, ball speed is marginally improved with the IM model from Danaei et al., which is also the most accurate for backspin and sidespin. The volumetric contact model with the two-layer ball, proposed by McNally et al., is the second most accurate. The MAW and Arakawa contact models have significant backspin and sidespin errors. These models were developed for oblique impacts but, impacts with a driver are much closer to a perpendicular impact. As a result, for predicting the launch conditions of a golf drive, the Danaei adjusted impulse-momentum model provides the most accurate results at very low computational expense.

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