Simulation of Puck Flight to Improve Safety in Ice Hockey Arenas

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Abstract. Ice hockey boards are equipped with protective glass to prevent the spectators from being hit by the puck. Although the height of the board with protective glass is 2.05 m, this is not high enough to prevent the spectators from puck collisions - severe accidents have occurred in the past. This study investigates, which increase of height of the safety glass is necessary to significantly reduce the risk of severe puck injuries for the spectators.

For this reason the flight of the puck is simulated using a rigid body puck model. Flight curves from 29 different initial positions on the ice rink were calculated, using 12 different initial take off angles and the maximum initial speed and spin that has been determined experimentally with three top level players.

The simulations show that an increase of the security glass by 0.8 m will lower the relative frequency by 37% of those shots with a potential to hit a spectator. The maximum velocity of such dangerous shots was decreased from 22.6 to 15.9 m/s. However, this reduced velocity and number of dangerous shots do not protect the spectators completely from injuries. The simulation model suggests that a barrier of 6.37 m protective glass leads to a 100% reduction of all dangerous shots.

1 Introduction

Ice hockey is a dangerous game – you can read that on the instruction manuals for hockey equipment. This warning is not only valid for the players, but for the spectators of ice hockey games, too. Some serious face injuries happened to viewers of this game. For this reason ice hockey boards are equipped with safety glass but the existing height of 2.05 m seems not high enough to prevent the spectators from being hit by the puck. The purpose of this study is therefore, to investigate which increase of the height of the protective glass is necessary to significantly reduce the risk of severe puck injuries for the spectators.

2 Method

Puck flight is described by Newton-Euler differential equation for a three dimensional rigid body (Haug 1989). The differential equations of motions are integrated using MatLab (The Mathworks, Inc. Natic, USA). The external aerodynamic forces on the puck are the sum of the drag, lift and sideward forces \( F_D \), \( F_L \), and \( F_S \) respec-
tively. The external aerodynamic moment consists of two parts, the pitch moment ($T_M$) and the spin down moment ($T_N$). The pitch moment is dependent on the factor $q$ “equation 5”, which is the dynamic pressure, multiplied by the planform area of the disc, as were lift and drag. The spin down moment is estimated from the decay of the spin rate measured at real puck shots described subsequently.

![Figure 1](image)

**Fig. 1:** The puck local body fixed coordinate system (X, Y, Z) has its origin in the puck’s center of mass. The Z axis of the local coordinate system is the main spinning axis, it is pointing upward at the beginning of each shot. V is the direction of flight, N is in the plane of Z and V, perpendicular to V. S is pointing sideward and is perpendicular to N and V.

Due to spin of the puck the air speed in the direction of the spin is greater than at the side where the spin is opposite to the air stream. Consequently by Bernoulli’s theorem the pressure at the one side is lower than at the other. This effect causes the puck to move transversely to the left or the right depending on the direction of the spin. Assuming there is no wind and the puck is spinning around its local Z axis the side force ($F_S$) is caused by the Magnus force “equation 4”, which is proportional to the spin and the stream velocity $v$, relative to the spinning rim (de Mestre 1990). This dependency is accounted for in a cos dependency of the sideward force on the angle of attack.

\[ q = 0.5 A \rho v^2 \]  
\[ F_D = q C_D (\alpha) \vec{e}_v \]  
\[ F_L = q C_L (\alpha) \vec{e}_n \]  
\[ F_S = 0.2 \rho v^2 \pi r^2 \omega_z \cos(\alpha) \vec{e}_n \times \vec{e}_v \]  
\[ T_M = q C_M (\alpha) \vec{e}_S \]