A Bobsleigh Ice Friction Model

Edward Lozowski
Department of Earth and Atmospheric Sciences, University of Alberta
Edmonton, Alberta, Canada

Krzysztof Szilder
Aerospace, National Research Council Canada
Ottawa, Ontario, Canada

Louis Poirier
Ocean, Coastal and River Engineering, National Research Council Canada
Ottawa, Ontario, Canada

Ice friction affects us in many ways, from slippery roads to winter sports. In cold regions, ice friction influences ice interaction with itself, which determines the motion of ice floes. It also influences the structural forces resulting from ice interactions with fixed and moored structures and with floating vessels. Ice friction also affects surface transportation over snow and ice. This paper addresses only one aspect of ice friction in winter sports, but it is potentially relevant to other applications, particularly surface transportation over ice. The model of ice friction described here is for a steel bobsleigh runner sliding on ice at high velocity. The model describes ice friction in the fully-lubricated, hydrodynamic regime, where a layer of meltwater completely separates the ice and slider surfaces. The effect of any contact between asperities on both surfaces is neglected. Friction results from a ploughing force, arising from ice deformation, crushing and extrusion, and the shear stress in the lubricating Couette flow. The model takes into account frictional melting, heat conduction into the ice, and the lateral squeeze flow of the lubricating liquid. The effect of pressure on the melting temperature is also accounted for. Sensitivity testing of the numerical model has been conducted to examine the influence of such factors as runner dimensions, sliding speed, ice temperature, and g-forces. A comparison with recent measurements of bobsled ice friction made by one of the authors is encouraging, suggesting that the model has identified and adequately represented the most essential physical processes.

INTRODUCTION

The scientific literature on ice friction has a long history, going back to Joly (1886) and beyond. It involves many areas of science and engineering, including physics, chemistry, tribology, fluid dynamics, thermodynamics, ice mechanics, mechanical engineering, and sports engineering. Oksanen (1983), Colbeck (1993), Bromley (1999), Rosenberg (2005), Penny et al. (2007), Kietzig et al. (2010), and Poirier (2011) have reviewed the literature on ice friction. Much of the ice friction literature is empirical, and there is a paucity of theory to link the various experimental investigations. Only recently have numerical models been formulated to predict ice friction in sliding sports such as speedskating (Lozowski and Szilder, 2013; Lozowski et al., 2012). The ability of these recent models to predict ice friction coefficients within 10% of measured values suggests that they capture the essence of the important physical processes that control ice friction in competitive skating.

The processes that determine ice friction can be summarized as follows. The low ice friction coefficient in competitive sliding sports is the result of a liquid water lubricating layer separating the blade and ice. It arises as frictional heating melts the ice surface. The thickness of the meltwater layer varies with ice temperature and sliding speed, but it is of the order of 1 micrometre. Friction arises from shear stress in this layer and the ploughing force required to deform permanently the ice and leave a groove or track behind the slider. The melting takes place at the pressure melting point, but the effect of pressure melting on the friction coefficient is minimal. It is certainly not the cause of low ice friction during skating (Colbeck, 1995). Conduction of heat into the ice and slider and lateral squeeze flow of the lubricating liquid from under the slider tend to reduce the thickness of the lubricating layer and hence increase the friction coefficient. Premelting prevents completely dry friction at the onset of slider/ice contact, but the quasi-liquid layer is typically too thin to permit the very low friction coefficients that are observed. Hence, premelting is also not the fundamental cause of low ice friction in competitive sliding sports.

In this paper, we apply these concepts to formulate a numerical model of ice friction for a bobsleigh runner. We use the model to explore the sensitivity of the ice friction coefficient to the various model parameters, such as runner geometry, sled speed, and ice temperature. We also compare the model predictions to some recent experimental measurements (Poirier, 2011; Poirier et al., 2013).

MODEL DERIVATION

Because the underlying physical principles are the same, the derivation of the model follows a similar path to that for a vertical, gliding, speedskate blade (Lozowski and Szilder, 2013). However, because the geometry and other parameters of the problem differ, we present a full derivation of the bobsleigh model. For simplicity, we consider a single, smooth, bobsleigh runner, gliding on pristine ice that is both smooth and flat. We do not consider runners tracking in a pre-cut groove (as at the start) or in a groove left behind by a