Progress Report

ME 383S – Tribology

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PROBLEM DESCRIPTION

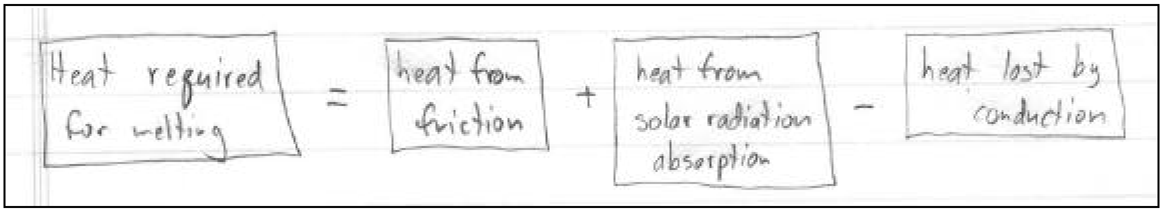
I have been tasked with the problem of finding ways to sustain the thin liquid film of water, designing ideas for channeling the flow, and preventing side leakage. These are important considerations if we are to discover a way to reduce friction for the bobsled and skeleton team.

ANALYSIS

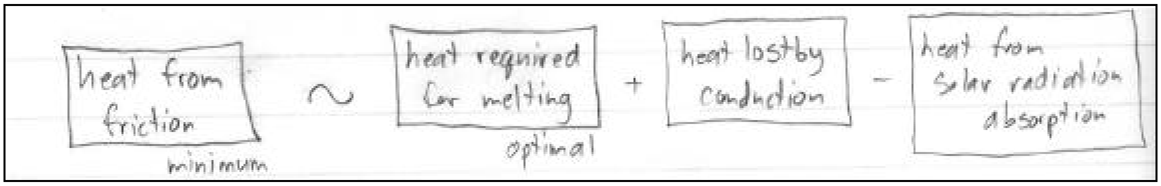
Heat Analysis Ideas

Even though this is not my area of study for this project, I have developed a few ideas, which are now described.

A heat analysis of the skeleton sliding on ice problem can be described as follows. The heat required for melting is dependent on (1) the heat generated from friction between the steel runner and the ice surface, (2) the heat absorbed from solar radiation by the steel runner and the ice surface, (3) minus the heat lost by conduction from the ice to the runner. The simple diagram below illustrates this system.



If we assume an optimal thickness exists for the thin water film that will provide a reduction in friction, then we can begin to understand how to maintain such a film. Maintaining the optimal thickness corresponds to maintaining an optimal melting heat. So, the above diagram can be rewritten as



If a way (or ways) can be found to minimize the heat lost by conduction and to maximize the heat absorbed from solar radiation, then we may be able to maintain a thin film of water that will reduce friction between the sliding steel runner and ice surface.

A few ideas along these lines of thought are:

1. Experiment with the thermal conductivity of the steel runner and supports to see what effect it has on reducing friction and on maintaining a thin film. Results have shown that low conductivity my increase melting, while high conductivity may decrease melting.

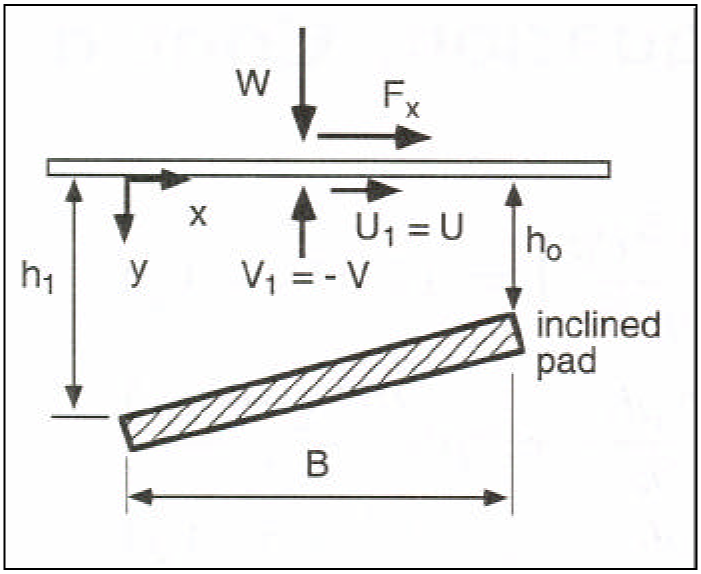
2. Determine the effect of darkening the steel to increase solar radiation absorption. Darker steel may provide more heat for melting and help maintain a thin film, while a shinier steel surface may reduce the thin film thickness.

These are just my ideas of things to try. Most can be accomplished through the correct choice of steel properties for the runners, but surface preparation may also provide results (especially for solar radiation absorption).

If we assume that the thin film of water between the steel runner and ice surface is on the order of 10's of microns, then a control volume analysis of an inclined bearing over a sliding surface is useful.

Inclined Pad Bearing Approach

Assuming that the curvature of the slider is small and that the film is thin (~10 microns), then the inclined pad bearing is an acceptable approximation for the skeleton-sliding problem. The following diagram shows the inclined pad problem.



The length of the slider is L (into the paper). It can be shown that the pressure of the fluid film as a function of position x is [1]:

$$p(x)=\frac{6hnUx\left(1-\frac{x}{B}\right)}{h^2\left(2h_0+n\right)}+\frac{12BhVx\left(1-\frac{x}{B}\right)}{h^2\left(2h_0+n\right)}+p_a$$

The first term is the hydrodynamic pressure, the second term is the squeeze-film, and the third term is the ambient pressure. h is the viscosity and $n = h_1 - h_0$. When the pressure is integrated over x, the average pressure is given by [2]

$$p_{avg} = \frac{6hUB}{h_0^2}\left[\frac{1}{a^2}\log\left(1+a\right) - \frac{2}{a\left(2+a\right)}\right]k_Y$$

where the bracketed term is now denoted as q_s and $a = h_1/h_0 - 1$.

The load capacity can be expressed in terms of the average pressure as [2]

$$W = p_{avg}BL$$

The pad bearing problem presented so far is based on an infinitely long pad ($L \to \infty$). However, for the skeleton/ice slider problem, we need a pad of finite length with a small length to width ratio (L/B). The following figure illustrates the difference in pressure distribution when side leakage is taken into account [2].

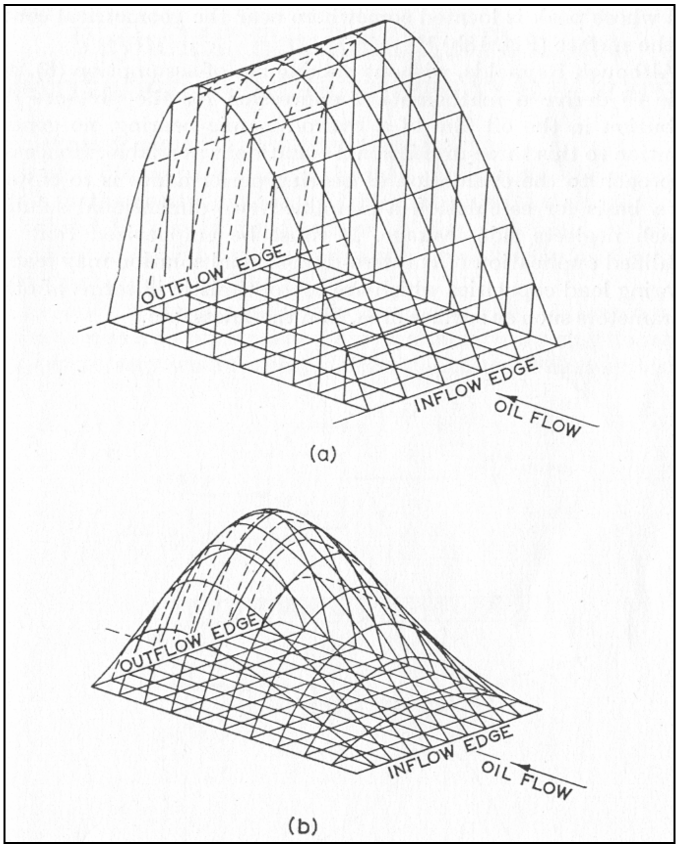
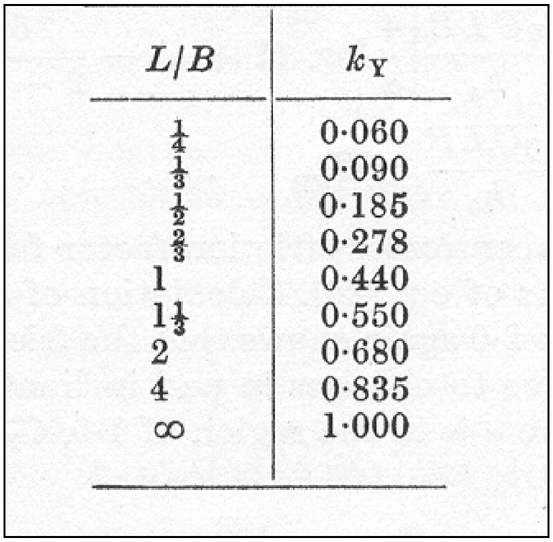


Figure (a) is the infinite length pad bearing approximation and figure (b) is the finite length pad bearing approximation.

To account for side leakage, we can introduce a correction factor, k_Y, into the infinite pad bearing approximation [2].

$$p_{avg} = \frac{6hUB}{h_0^2}\left[\frac{1}{a^2}\log\left(1+a\right) - \frac{2}{a\left(2+a\right)}\right]k_Y$$

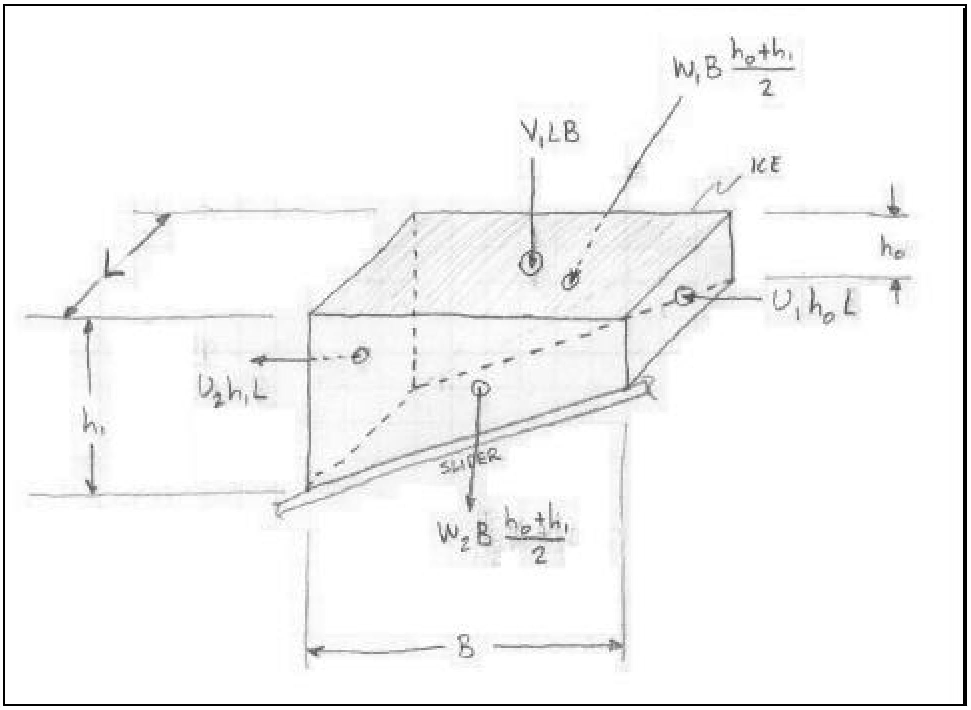
The following table presents these correction factors based on the ratio of L/B [2].



L/B	k_Y
$\frac{1}{4}$	0·060
$\frac{1}{3}$	0·090
$\frac{1}{2}$	0·185
$\frac{2}{3}$	0·278
1	0·440
$1\frac{1}{3}$	0·550
2	0·680
4	0·835
∞	1·000

Volumetric Flow Rate Analysis

A control volume analysis is shown in the figure below.



If we assume that side leakage is uniform on both sides, then

$$W_2 = W_1$$

and

$$|W_2| = |W_1| = W$$

The flow analysis can be written as

$$V_1 L B + U_1 h_0 L = 2WB\frac{h_0 + h_1}{2} + U_2 h_1 L$$

If we use the side leakage correction factors, then the flow analysis becomes

$$V_1 L B + U_1 h_0 L = U_2 h_1 L$$

with the correction factors applied such that h_0 and h_1 are corrected.

RESULTS

The results of the analysis are presented as equations and tables.

Film Thickness as a function of x

$$h(x) = h_0 + n\left(1 - \frac{x}{B}\right)$$

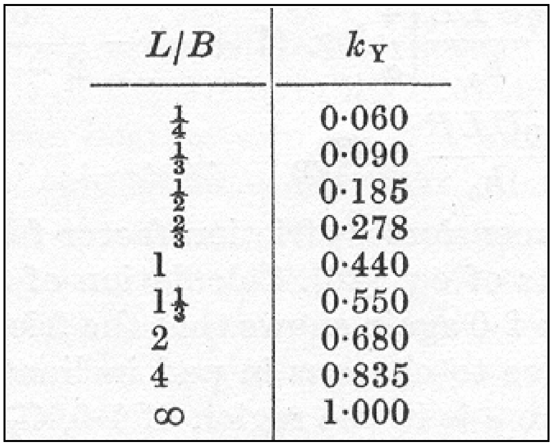
Pressure as a function of x

$$p(x) = \frac{6hnUx\left(1 - \frac{x}{B}\right)}{h^2\left(2h_0 + n\right)} + \frac{12BhVx\left(1 - \frac{x}{B}\right)}{h^2\left(2h_0 + n\right)} + p_a$$

Average Pressure with side-leakage correction factor

$$p_{avg} = \frac{6hUB}{h_0^2}\left[\frac{1}{a^2}\log\left(1 + a\right) - \frac{2}{a\left(2 + a\right)}\right]k_Y$$

Side-Leakage correction factors [2]



L/B	k_Y
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Reynolds Equation accounting for side leakage

$$\frac{1}{h}\frac{d}{dx}\left(h^3\frac{dp}{dx}\right)+\frac{1}{h}\frac{d}{dz}\left(h^3\frac{dp}{dz}\right)=12V+6U\frac{dh}{dx}$$

Volumetric Flow Rate of Control Volume with side leakage

$$V_1LB+U_1h_0L=2WB\frac{h_0+h_1}{2}+U_2h_1L$$

CONCLUSIONS

Combination of my results with those of the rest of the class may provide a set of simultaneous equations of the form n equations in n unknowns. My results have helped to show the relationship between film thickness, hydrodynamic pressure, and volumetric flow rates. Further analysis will be required before any useful data can be forwarded to the U.S. Olympic skeleton and bobsled teams.

REFERENCES

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