DISCUSSION

R. F. Gans[1]

The authors are to be congratulated for pushing forward on the difficult topic of very narrow gap gas lubrication. As they remark, physical justification for the slip flow condition is not possible in the usual small Knudsen number sense. My paper [8] tried to provide a rationale to show that the slip flow equation was a valid approximation. I used a rough approximation to the correct physics, and I was able to show that the slip flow condition was a correct approximation to the first approximation for rarified gas lubrication in the limit of small Mach number. Unfortunately that double approximation turns out not to be very good, and it is desireable to improve it. Such improvement must come from the Boltzmann equation; increasing the order of slip approximation cannot be justified physically when the gap is less than a mean free path. In that case one would expect the "correction terms" to be larger than the initial errors.

The authors make shrewd use of prior work, realizing that lubrication flow is simply a combination of Poiseuille and Couette flow and applying existing solutions of these two problems to their own problem. The resulting work is an improved approximation based on the linearized Boltzmann equation, exactly what is needed in this area. In addition they consider the possibility of nonisothermal conditions across the layer, and, more importantly, along the layer. I have often wondered about the nearly universal assumption of isothermal conditions. Partial contact must lead to nonisothermal conditions, and the authors have provided the community with the first tools to attack that problem.

[1]Department of Mechanical Engineering, University of Rochester, Rochester, NY 14627

I will close this with a warning to those who are new to the use of kinetic theory to solve lubrication problems. The linearized Boltzmann equation is inappropriate unless the speed of relative motion across the gap is small compared to the local sound speed. Tangential temperature differences must also be small compared to the mean absolute temperature of the gas layer. I have not looked at the order of the approximation, but it may be first order, an error proportional to the Mach number (or thermal Mach number).

Authors' Closure

The authors would like to thank the discusser for his valuable comments. As he pointed out, one of the general assumptions in considering rarefied flows based on the linearized BGK model equation is that macroscopic velocities, pressure gradients, and tangential temperature differences are "locally" small in the gas layer. (By contrast, this paper's final result, equation (43), was derived from a practical but limited assumption that tangential temperature differences are small in "overall" slider length compared to the running wall temperature, whereas the original assumption holds for velocities and pressure gradients.) Another important fact in deriving the generalized lubrication equation is that the lubrication flow is a linear combination of such basic flows as Poiseuille flow and Couette flow, not only for continuum flows but also for rarefied flows, provided the thin-film assumption holds.

From a practical standpoint the generalized lubrication equation can be applied to obtain static and "dynamic" characteristics of small and light-load flying head sliders with ultra-small clearances, which will be a future standard type of sliders.