Reply to the ‘Comment on “The Relationship Between Friction and Film Thickness in EHD Point Contacts in the Presence of Longitudinal Roughness” by Guegan, Kadiric, Gabelli, & Spikes’ by Scott Bair

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We must confess to being surprised and dismayed that our paper on the impact of bearing roughness on friction has aroused such passion as to warrant a Comment from Professor Bair.

Bair’s Comment is ostensibly an expression of concern that we applied a mean shear stress analysis to match our smooth surface data with the Eyring shear thinning model of lubricant viscosity rather than integrating over the varying pressure of the EHD contact. He is indeed correct that for this quite low pressure steel/glass contact we should have integrated and this would have resulted in a higher calculated Eyring shear stress and a different α . He makes much of the importance of using a non-Barus viscosity pressure equation and highlights the Yasutomi model. In fact, at these low pressures and the test temperature there is little difference between the viscosities calculated using the Yasutomi and Barus models.

As we understand it, Bair’s argument is mainly based on the idea that by varying only the Eyring stress it is not possible to fit our measured friction data for a smooth contact with an integrated model if we use the quoted α value of 19.2 GPa^{-1} . Here there might be a slight misunderstanding; both this value of α and the Eyring stress were found by fitting the non-integrated argsinh model. When we use these parameters and integrate over the contact area assuming a Hertz distribution of pressure, we find indeed that these predict a lower friction that does not

match the friction measurements. However, as shown in Fig. 1, it is perfectly possible to find quite reasonable values of α and the Eyring stress that enable us to match the integrated model with our data.

Bair’s Comment then segues into a general criticism of the Eyring shear thinning model to which he has long taken exception. This issue has been fully discussed in [1–3] and need not be revisited here except to note that at the end of his Discussion, Bair suggests that the linear shear versus log strain rate behaviour characteristic of Eyring shear thinning results from viscous heating and that this has been mistaken for a non-Newtonian response. This misconception originates from early work using high-pressure capillary viscometers which are very susceptible to viscous heating at high shear stress. Only in the 1970s did it become evident that because of thermal effects capillary viscometers are not suited to measure viscosities at high shear stresses [4]. However, as described in [1], in EHD contacts the linear shear–log strain rate response only becomes evident at high shear stresses *after* a correction is applied to negate the effect of viscous heating and is thus most certainly not a product of the latter.

We shall ignore Bair’s intemperate Conclusion.

In his Appendix (which appears to have little relevance to his overall Comment) Professor Bair takes exception to the attribution to Barus of the well-known exponential dependence of viscosity on pressure, pointing out that Barus fitted a linear equation to his viscosity data on marine glue. In his paper Barus fitted both a linear and an exponential model [5]. It is not clear when and why his name became associated with the exponential dependence of viscosity on pressure rather than the linear one. We presume that it occurred as evidence emerged in the first three decades of the twentieth century that the viscosity of many liquids fitted this model much more closely than the

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Fig. 1 Comparison between the original non-integrated argsinh law $\tau_E = 4.7$ MPa, $\alpha = 19.2$ GPa $^{-1}$ (in blue), an integrated model using $\tau_E = 8$ MPa, $\alpha = 16$ GPa $^{-1}$ (in red) and the friction data (Color figure online)

linear expression at high pressures: Hersey may be the culprit [6]. It has, of course, been known for many years that the Barus equation is not generally valid at very high pressures (e.g. [7]), but in our work we used relatively low pressures.

Finally, we should point out that our paper is not, except peripherally, about lubricant rheology, but is focussed on the impact of longitudinal roughness, as present in many rolling bearings, on friction. It shows the significant practical effect that this roughness results in a marked increase in friction in low entrainment speed conditions even when a separating lubricant film appears to be present over the

whole contact, a finding of both academic and practical importance.

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