to service is impressive. The early nature of these failures causes concern with the way the data are used to compare to theory. The Weibull plot (the authors' Fig. 5) shows a slope of ~.7. In Weibull analysis, a slope of this magnitude supports an infantile failure mode with the failure rate improving with operating time. It is dangerous to predict a 10 percent life, projecting from these "early" failures. An alternate approach would be to assume a more classical slope for aircraft engine bearings (1.3–1.5) and not allow the few failure points to establish the slope. It is doubtful that sufficient time exists on the bearing population to project a 10 percent life of 204,000 hours. For example, what is the average time on the population?

Part 2

In reviewing Part 2 of the paper, this discusser was distressed to see the authors take data from a component test at Po = 4.825 GPa and apply this to full scale bearings at values of Po = 1.61 and 1.37 GPa. A contact stress of Po = 4.825 GPa probably causes subsurface stresses to be in a range where cyclic plasticity comes into play. In most component test on AISI 52100 operating at this stress level, the material would receive a different heat treat (higher hardness) that would be used on aircraft engine bearings requiring stabilization for higher operating temperatures. Would the authors comment on the heat treating of the parts from the quoted test results, as well as review other implied data that indicate AISI 52100 exceeds the life of M50 by two to one?

The conclusion reached, and expected, is that the new method gives far greater differentiation between bearings, of moderate loading, operating at low lambda ratios and high lambda ratios. This wide variation in performance has been recognized by the experienced bearing design engineers, although previous calculation techniques do not account for the extremes. Both of the bearings of Part 2 operate at lambda ratios near 1.0, and have surface finishes of .16 mirometers. Comparing the results from Part 1 and Part 2, it appears that a race surface finish change to 0.08 mirometers would result in an extremely long projected life for the LCA or the HCA. Would the authors comment on the benefits of such a surface finish change?

In summary, the new life prediction method being proposed may add significantly to bearing life technology. Controlled testing will be required to establish the constants and to determine the stress limits of various different bearing materials.

W. E. Poole[3]

Rolling contact bearing research during the last decade has shown that with modern steel manufacturing processes, bearings have an endurance limit, below which subsurface fatigue failure doesn't occur, [D1, D2]. In [D2] the authors defined the theoretical basis for these laboratory observations and how it relates to traditional life predictions. In this paper, the authors apply their theoretical technique to actual applications to help explain obvious deviations from accepted life prediction techniques.

This is most welcome. Bearing application engineers have long recognized that many applications deviated substantially from Lundberg-Palmgren type life predictions with performance routinely exceeding predictions. Bearing life prediction capability hasn't kept up with advances in bearing performance, now perhaps our prediction capability will come of age.

This improved understanding of bearing performance provides a basis for improved reliability. As designers become aware of the importance of surface effects on bearing performance [D3] they will alter the emphasis of bearing design from a calculated fatigue life to improved contact dynamics. Bearing life improvements will result from better lubricant cleanliness, better surface finish and geometry at the contact interface and reduced contact shear stresses from reduced friction and contact traction.

In Part 2 of this paper, the authors present data showing improved performance of 52100 steel compared with M50 when operated with thin EHD films. No explanation is offered, however insight into marginal EHD film lubrication is available in the literature. Surface peeling and microspalling occur as a result of operating with marginal EHD film thickness and has been related to large carbides in high alloy steel, [D4]. It follows that material with a fine microstructure free of large carbides, such as 52100, should perform better than M50, a high alloy tool steel, in marginal EHD film applications. This is further evidence that bearing life is sensitive to conditions at the contact interface.

It is hoped the authors will extend their work to include local surface effects, including contact slip and traction. Much work has already been accomplished to show the stress concentrations due to surface roughness and the mitigating effects of soft metal coatings on these contact stresses, [D5]. We need a theoretical basis for the observed life improvements with thin surface films, [D6] and an organized method for accounting for this benefit during design.

Broad acceptance will be required to maximize the benefit from this refined approach for bearing life prediction. We routinely accept that other structural members may have infinite life under some stress conditions, its reasonable to believe the same physics applies to rolling contact fatigue. Aircraft gas turbine overhaul shops report that very few bearing rejects are due to fatigue, [D7]. With the understanding we are getting from work such as this, designers will be freed from needless worry about fatigue and can address the actual causes of bearing malfunction. The industry will be the beneficiary.

Additional References

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Authors' Closure

The authors wish to thank all the discussers for their interest in the paper and the comments. With respect to the specific points raised in their respective discussions, we offer the following replies:

Dr. J. C. Clark

Part 1

We agree that asperity contact induced stresses are progressively important as the lubrication regime moves from full

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