DISCUSSION

I. Etsion

The paper treats an important problem which, as was pointed out correctly, has been a matter of much controversy ever since the formulation of the lubrication theory. The submerged bearing is in many aspects similar to a face seal. Indeed the concept of the “0” cavitation configuration is known in the seal literature since the work by Findlay [17] in 1968. Findlay used the same approach as in the present work to show a cavitation region extending into the converging film of a face seal. The rationale behind these analyses is the required net zero end flow in the case of submerged operation. The “0” cavitation concept preserves this requirement and maintains flow continuity on the cavitation boundaries as well. It results, however, in a pressure discontinuity across the fluid film at \( \eta = \eta_c \). Another, possible solution which preserves both the net zero end flow and the pressure continuity can be obtained from equation (8) by setting \( \Pi = \Pi_0 \) at \( \xi = \xi_0 \). This solution, however, does not comply with the flow continuity on the cavitation boundaries. An inevitable question is which of the above two deficiencies is more severe?

The results presented in Figs. 15 and 16 show good correlation between the “0” cavity concept and the results of Jakobson and Floberg for a “universal cavitation parameter” of \(-0.1\). Unfortunately, these results are compared with “half film solution” which is based on a cavitation parameter that equals zero. A more realistic comparison would require the same value of the cavitation parameter for all the solutions compared. If this is done, the solution of the cavitation region based on equation (8) becomes

\[
\xi_0 = \left(1 + \frac{2 \Pi_{min}}{Q}\right)^{1/2}
\]  

D-1

where

\[
\Pi_{min} = \frac{p_{min} C^2}{6 \mu \Delta R (L/D)^2}
\]

Hence, for a cavitation parameter \(-0.1\) and \(L/D\) ratios 0.25 and 0.5 \(\Pi_{min}\) becomes \(-1.8\) and \(-0.4\), respectively. It is clear that a cavitation region thus obtained from (D-1) depends on \(L/D\). Therefore, the eccentricity locus and load capacity are also \(L/D\) dependent similar to the results shown in Figs. 15 and 16 for the “0” cavitation.

Adisonal Reference


N. Tipei

The author is to be commended for this paper which introduces new concepts for a better understanding of cavitation phenomena in bearings. The initial limitations, regarding the short bearing approximation and the submerged arrangement of the journal bearing, only partially affect the validity of the analysis which should be extended to other conditions.

The previous work of Geoffrey Taylor, Pearson and Pitts and Greiller has provided up to a certain point, valuable information on the generation and on the number of streamers in subcavitated regions. However, the present analysis yields specific and detailed calculations, to be applied in lubrication problems.

This discusser would like the author’s comments on the following points:

1. How much of an effect does the surface tension have on the boundary conditions at the liquid-gas interface?
2. The usual nonslip boundary conditions let a thin film of lubricant to be carried by the journal, even in subcavitated regions. Can the assumption of dry surfaces be critical in some cases?
3. For “I” cavitation the diagrams, Fig. 14, do not show values for \(\epsilon > 0.8\). In opposition to short bearing theory, should the circumferential pressure gradient also be considered at higher \(\epsilon\) values?

In conclusion, the present work is a significant contribution in a still not well understood chapter of lubrication. The extension of this analysis to other types of bearings should be welcome.

Author’s Closure

The author is grateful to Dr. Etsion’s addition of a reference to the earlier work of Findlay, who was concerned with the lift and leakage of a face seal as affected by waviness induced cavitation. It may be mentioned that the tracking dynamics of face and shaft seals would be dependent on the cavitation process.

The alternate solution suggested by Dr. Etsion is in essence an adaptation of the Gumbel approximation [2], which is at best a convenient short cut. The author can see no merit in offering it as a likely improvement. The crucial concepts to be emphasized here are that:

1. The Swift-Stieber condition [4, 5] is reconcilable with the short bearing approximation and thus should be asserted; and
2. Unless...
the gap is filled with lubricant, no pressure can be developed. As to the issue of pressure discontinuity at the film re-establishment point, it need only be said that it is inevitable to allow such a solution if one accepts the physical reality of a short partial arc journal bearing. Clearly, one must again rely on matched asymptotic expansion [16] to remove the pressure discontinuity at both entrance and exit edges.

One can examine the possible merits of equation (D-1) as a partial improvement over the conventional short bearing approximation. This idea had already been tried in a study of squeeze-film dampers [13]. While there was a definite improvement over the conventional short bearing approximation, there remained significant inexplicable discrepancies from experimental facts. One inherent fault in the Gumbel-Etsion proposition is that the cavitation domain would be always contained within the divergent portion of the gap. Figure 10 clearly shows that the reestablishment point may be in the convergent point of the gap, depending on the precise value of $\epsilon$ (which fixes $\pi_{\text{min}}$). For instance, if the numerical value of $\pi_{\text{min}}$ should be quite small, the Gumbel-Etsion approach should yield results very close to the half-film approximation, which are contradicted by the author’s results for $\Pi_{\text{min}} = -0.01$. Thus, one may safely conclude that, with whatever partial improvement may be offered by the use of equation (D-1), some uncertainty associated with the precise location of the film re-establishment point will result. The argument can only be resolved by a subjective cost-benefit judgment.

The author is flattered to receive the kind remarks from Dr. Tipei, whose contributions to the field of lubrication theory have been the source of inspiration of the author's own efforts. Specific questions raised by Dr. Tipei are answered as follows.

1. Assuming that perfect wetting takes place between the lubricant and the bearing wall, then the miniscus may have a radius of curvature which is lower-bounded by one-fourth of the gap where cavitation breakup takes place. One immediate consequence is that the film pressure at the meniscus can be lower than the cavity pressure by the amount of $4\sigma/h$, where $\sigma$ is the surface tension of the lubricant-void interface. Typically, $\sigma$ has a value of about 30 dynes/cm. Thus, if the gap is 2.5 $\mu$m (1/10 mil), then the associated pressure jump at the meniscus may approach $0.12 \times 10^6$ dynes/cm$^2$ (1.74 psi). However, pressure jump is only one facet of the total phenomenon. At the breakup meniscus, using the local gap as the geometric scale, the lubrication theory provides the upstream, far-field asymptotic limit. On the downstream side, the flow (assuming absence of streamers) ultimately becomes a thin film free surface flow over a moving wall. Transition between these two vastly different flow fields takes place in the vicinity of the meniscus [10]; inertia effects, in addition to surface tension, may be important because shear stress effects are minimal on the downstream side. Instability of the meniscus flow field with respect to a transverse wave is probably the cause of the streamer structure. Consequently, the precise plan form of the meniscus boundary cannot be resolved to a scale of the bearing gap and may further be altered by the streamer structure, which should have a wavelength somewhere between the bearing gap and the bearing length. There is also reason to believe that the Swift-Stieber condition should be corrected for surface tension effects.

2. The non-slip boundary conditions can be reconciled with the “dry cavity” model (associated with the “I” configuration) by accepting wetness to be satisfied by a film of molecular dimensions. Inertia effects, however, can be responsible for residual films in the “dry cavity.”

3. Circumferential pressure gradient is proportional to $H^{-3}$. Therefore, given a small but finite $L/D$, the short bearing approximation would eventually become inadequate if $\epsilon$ is allowed to approach unity. The author would recommend caution against using short bearing results at very large values of $\epsilon$. A value of 0.8 is a reasonable upper bound for trusting short bearing results.