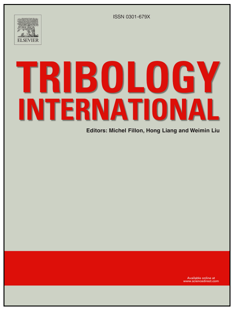
Accepted Manuscript



A stable numerical strategy for Reynolds-Rayleigh-Plesset coupling

Alfredo Jaramillo, Gustavo C. Buscaglia

PII: S0301-679X(18)30418-3

DOI: 10.1016/j.triboint.2018.08.022

Reference: JTRI 5366

To appear in: *Tribology International*

Received Date: 20 June 2018

Revised Date: 10 August 2018

Accepted Date: 20 August 2018

Please cite this article as: Jaramillo A, Buscaglia GC, A stable numerical strategy for Reynolds-Rayleigh-Plesset coupling, *Tribology International* (2018), doi: 10.1016/j.triboint.2018.08.022.

A stable numerical strategy for Reynolds-Rayleigh-Plesset coupling

Alfredo Jaramillo[a], Gustavo C. Buscaglia[a]

(a) Instituto de Ciências Matemáticas e de Computação, Universidade de São Paulo, 13560-970 São Carlos, Brazil

August 21, 2018

Abstract

The coupling of Reynolds and Rayleigh-Plesset equations has been used in several works to simulate lubricated devices considering cavitation. The numerical strategies proposed so far are variants of a staggered strategy where Reynolds equation is solved considering the bubble dynamics frozen, and then the Rayleigh-Plesset equation is solved to update the bubble radius with the pressure frozen. We show that this strategy has severe stability issues and a stable methodology is proposed. The proposed methodology performance is assessed on two physical settings. The first one concerns the propagation of a decompression wave along a fracture considering the presence of cavitation nuclei. The second one is a typical journal bearing, in which the coupled model is compared with the Elrod-Adams model.

Keywords: Reynolds equation, Rayleigh-Plesset equation, cavitation, numerical simulation.

1 Introduction

Cavitation modeling is a challenging issue when studying the hydrodynamics of lubricated devices [1, 2]. It is experimentally known that gases (small or large bubbles of air or vapor) appear in the liquid lubricant in regions where the pressure would otherwise be negative. The volume occupied by these gas bubbles affects the pressure field, to the point of preventing it from developing negative regions. It is customary to think of the whole fluid (lubricant + gas) as a mixture for which it is possible to define effective fields of pressure (p), density (ρ) and viscosity (μ). These three fields are linked by the well-known Reynolds equation, which expresses the conservation of mass and must thus hold for the cavitated mixture as well as for the pure lubricant.

Notice, however, that while in problems in which the lubricant is free of gases the density and viscosity are given material data, in problems with significant gas content ρ and μ are two additional unknown fields (totalling three with p). The overall behavior of the mixture exhibits low-density regions (i.e., regions where the fraction of gas is high), in such a way that the overall pressure field does not exhibit negative (or very negative) values.

These low-density regions are usually called *cavitated* regions, though the gas may have appeared there by different mechanisms: cavitation itself (the growth of bubbles of vapor), growth of bubbles of dissolved gases, ingestion of air from the atmosphere surrounding the lubricated device, etc.

Many mathematical models have been developed over the years to predict the behavior of lubricated devices that exhibit cavitation, and most of them have been implemented numerically (see, e.g., [2]). The most widely used models assume that the data (geometry, fluid properties) and the resulting flow are smooth in time, with time scales governed by the macroscopic dynamics of the device. In particular, the fast transients inherent to the dynamics of microscopic bubbles, though being the physical origin of cavitation, are averaged out of the model. To accomplish this, these models propose phenomenological laws relating ρ, p and μ. These laws vary from very simple to highly sophisticated and nonlocal, and may involve one or more additional (e.g., auxiliary) variables.

A representative example of the aforementioned models is Vijayaraghavan and Keith's bulk compressibility modulus model [3, 4]. Without going into the details, it essentially postulates that

$$p = \begin{cases} p_{\mathrm{cav}} + \beta \ln\left(\frac{\rho}{\rho_\ell}\right) & \text{if } \rho \geq \rho_\ell \\ p_{\mathrm{cav}} & \text{otherwise} \end{cases} , \tag{1}$$