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A NOVEL MULTISCALE THERMAL METHODOLOGY FOR APPLICATION IN AEROSPACE TRANSMISSION SYSTEMS

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1. ABSTRACT

Environmental targets for reducing emissions in the aerospace industry require the development of more efficient engines which impose a greater thermal load on the transmission system. Accurately accounting for heat sources in the system, such as hydrodynamic lubrication regimes, are essential for the design of effective thermal management. This paper develops a framework which integrates the Reynolds methodology for hydrodynamic lubrication with CFD, describing the coupling methodology and verified on two-dimensional journal bearing case at various operating parameters.

2. INTRODUCTION

Emissions targets are set for the European Aircraft Industry in Flightpath 2050 [1]. Greater energy density in the engine core is necessary for enhancing efficiency, however, must not significantly increase the size and weight of the system. Theses parameters inevitably increase the power density through transmission components: gears, rolling element bearings and journal bearings. A thermal management system is required as part of the transmission system to relieve the heat generated by the interaction of components and prevent thermal related failure. Many of the contacting regions of these components operate in a thermal elasto-hydrodynamic lubrication (TEHL) regime where a film of lubricating oil separates the contacting bodies, reducing wear and friction between them and generating heat in the oil due shearing and compression of the fluid. Furthermore, cavitation of the fluid in these regions is commonly present and oil is dispersed from the region due to the high pressure that develops in the fluid.

Approximate methods are generally applied in transmission system simulations to account for heat generation in TEHL regions, such as between gear teeth, however, do not fully account for the physical properties of the flow. CFD methods are found to be challenging to implement practically in these regimes due to the scale of the region, generally in the order of 10μm in journal bearings, and require highly refined meshes to resolve the gradients in the region. A methodology within Tribology based on the work of Reynolds [2], which applies the thin film assumptions to derive a simplified system of equations for TEHL regimes, is well validated against experimental measurements and is computationally inexpensive compared with CFD methods. To incorporate more physically

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representative hydrodynamic lubrication behaviour in high power lubricated transmission system simulations at a practical computational cost could be achieved with an integrated CFD-TEHL model. The aim of this paper is to develop a framework which integrates CFD and TEHL, investigating the coupling approach between the methodologies and verifying the performance across a range of operating parameters.

3. METHODOLOGY

The TEHL model is based on Reynolds lubrication theory which derives the equation for pressure in a hydrodynamic lubrication regime:

$$\frac{\delta}{\delta x}\left(\frac{\rho h^3}{12\mu}\frac{\delta p}{\delta x}\right)+\frac{\delta}{\delta z}\left(\frac{\rho h^3}{12\mu}\frac{\delta p}{\delta z}\right)=\frac{\delta}{\delta x}(\rho U h) \tag{1}$$

The TEHL methodology also includes a temperature equation for the film:

$$\nabla\cdot\left(\rho c_p U T\right)-\nabla\cdot(k\nabla T)=\mu\left(\frac{U}{h}\right)^2 \tag{2}$$

Furthermore, the methodology incorporates cavitation of the fluid due the diverging geometry in the region, elastic deformation of the surfaces and variation of fluid properties. A full description of the TEHL model implementation in OpenFOAM is given in [3].

The CFD model applies the Navier-Stokes equations including the energy equation:

$$\frac{\delta\rho}{\delta t}+\nabla\cdot(\rho U)=0 \tag{3}$$

$$\frac{\delta}{\delta t}(\rho U)+\nabla\cdot(\rho U U)-\nabla\cdot(\mu\nabla U)=-\nabla p+F_b \tag{4}$$

$$\frac{\delta}{\delta t}\left(\rho c_p T\right)+\nabla\cdot\left(\rho c_p U T\right)-\nabla\cdot(k\nabla T)=0 \tag{5}$$

A two-dimensional journal bearing model is used to verify the interfacing between the regions. Figure 1a shows the geometry of the case with the film (TEHL), groove (CFD) and bush (SOLID) regions identified. Figure 1b presents an overview of the field coupling between the regions at the inlet to the film region, with the arrows representing the direction of information transfer between the regions.

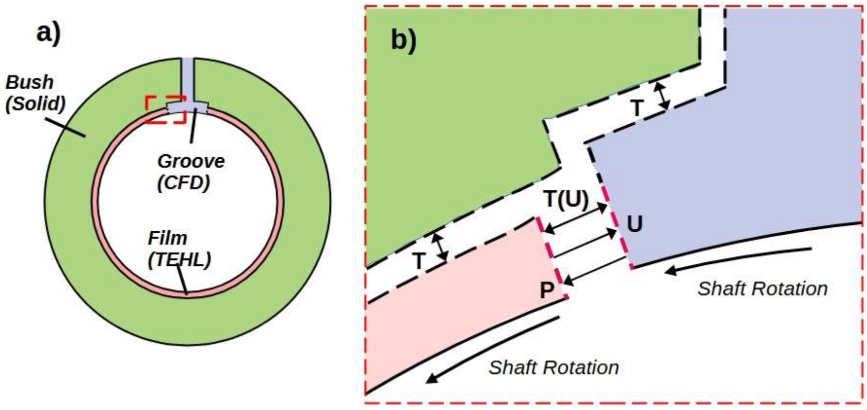
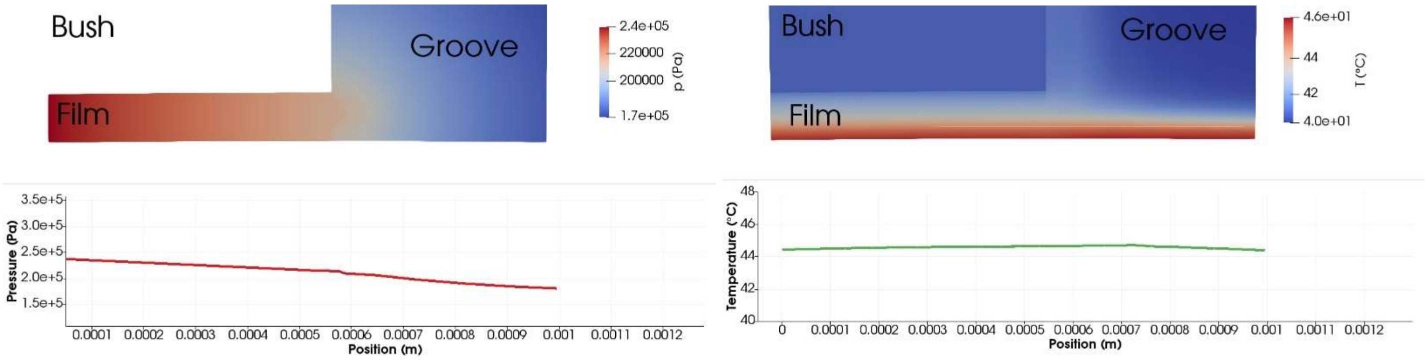


Fig. 1 2D Journal bearing case (a) and an overview of the coupling setup between the film and groove regions (b)

4. RESULTS

Figure 2 shows preliminary results at the interfaces between the film (TEHL) and groove (CFD) regions in the two-dimensional journal bearing case. The pressure field in Figure 2a shows the continuity across the boundary between the solutions of each region. Similarly, good continuity is seen the temperature field in Figure 2b.



a b

Fig. 2 Solutions across the film inlet interface of Pressure (a) and Temperature (b).

5. CONCLUSIONS

The CFD-TEHL implementation in OpenFOAM is shown to perform on a two-dimensional journal bearing case across a parameter range of eccentricity 0.4-0.8, rotational speed 2000-4000rpm and supply pressure of 1-2 bar. Good continuity is shown across the interfaces, verifying the coupling methodology between each model.

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