# Simulation Apps Advance Tribology Research

Researchers at the Gear Research Centre (FZG), Technical University of Munich (TUM), Germany, packaged their multiphysics model into an app for the simulation of thermal elastohydrodynamically lubricated (TEHL) gear contacts. Their story is a lesson in tackling complex, coupled multiphysics problems that combine structural mechanics and heat transfer with computational fluid dynamics.

by **VALERIO MARRA**

A good example of how complex 21st century engineering simulation problems are is elastohydrodynamic lubrication (EHL). EHL describes the coupling between the deformations of two mating surfaces, such as in bearings and gears, and the hydrodynamics leading to the separation of both surfaces. If thermal effects are considered, the problem is referred to as thermal EHL (TEHL). The lubricant film thickness is usually in the order of microns or below, but sufficient to provide low friction and wear. Detailed understanding of the mechanisms of TEHL helps to improve the power density, efficiency, and noise-vibration-harshness (NVH) behavior of drive systems.

The key is the design of the lubricated contacts of machine elements to treat the lubricant itself as a machine element. TEHL simulation contributes to a thorough understanding of the lubricated contacts and reduces the number of prototypes. Multiphysics modeling and computer simulation of TEHL contacts is the best way to get to the heart of such a problem (Figure 1).

## ⇨ TOO SMALL TO MEASURE

With lubricant films and deformations of the solid bodies measuring in microns, any attempt to learn more about TEHL by placing a sensor in the contact region is extremely difficult. "The lubricant film thickness between two gear flanks is in the range of a micron, which equals approximately one-tenth of the diameter of a human hair. Typical contact pressures of up to 2 GPa correlate to about 30 passenger cars on the size of a thumbnail," explained Thomas Lohner, department leader of EHL-Tribological-Contact and Efficiency at the Gear Research Centre (FZG), Technical University of Munich (TUM), Germany.

Using numerical simulation, engineers can design TEHL contacts in order to derive appropriate combinations of gear surfaces and lubricant. The difficulty is that TEHL simulation is a

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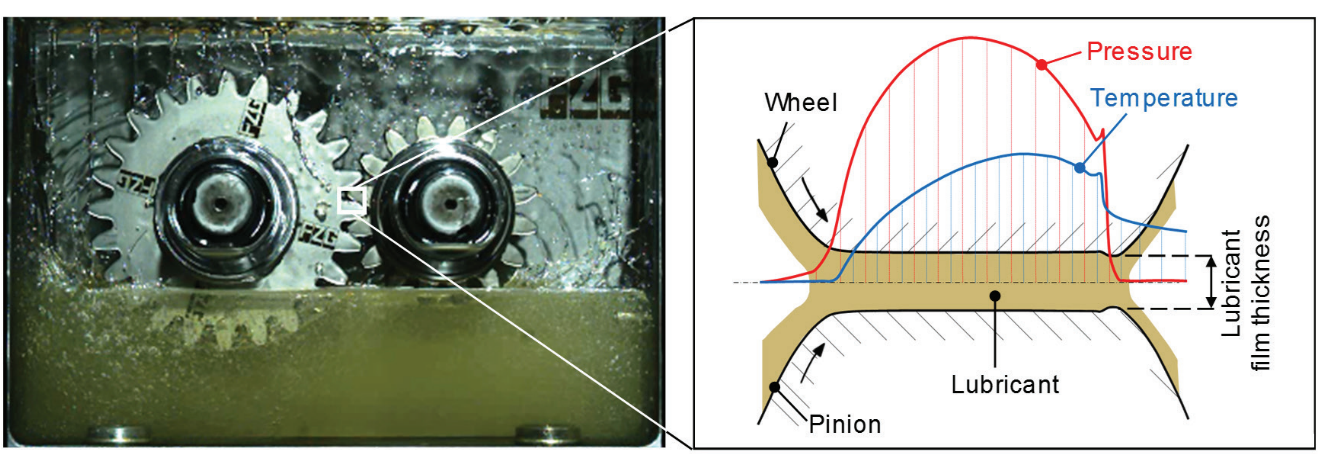



**FIGURE 1.** High-speed camera image of a dip-lubricated gear pair under operation (left) and schematic illustration of the EHL contact (right).

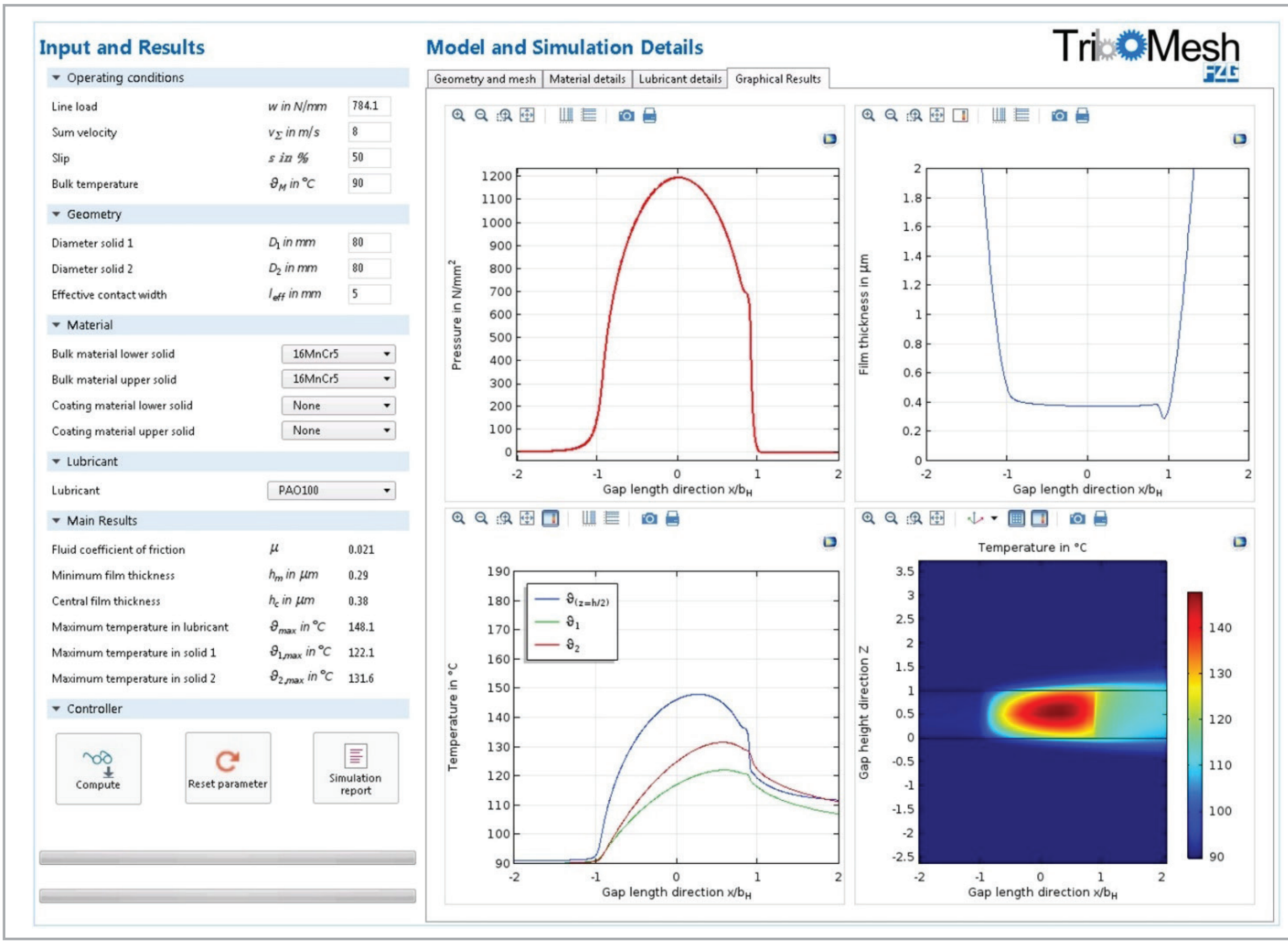



FIGURE 2. This custom simulation app packages a complex, coupled physics solution to TEHL into an easily accessible tool for everybody in the research center to use.

coupled or multiphysics problem. The lubricant is a fluid, so the model requires computational fluid dynamics (CFD), for which the modified Reynolds equation, a reduced form of the Navier-Stokes equations, is frequently used. Lubricant properties such as viscosity depend strongly on pressure and temperature variations. Furthermore, the flow behavior of the lubricant becomes nonlinear for high shear rates. Contact heat is created by shear and compression within the thin lubricant film and distributed by convection and conduction. Temperature changes affect lubricant properties, which influence the hydrodynamics and as a result the elastic deformation, which in turn affects heat generation. Each quantity affects the other, which results in a highly nonlinear iterative loop, including the elastic deformation of the gear surfaces informed by a coupled structural mechanics analysis.

## ⇨ FROM PAPER TO MODEL TO APP

Lohner and his team built an application based on a solution method published by a colleague, Prof. Wassim Habchi from the Lebanese American University, Byblos, Lebanon [1]. However, a publication is not a working code that can predict answers. “We implemented the solution using the COMSOL Multiphysics software, which we found convenient to use,” explained Lohner. “It allowed us to modify the Reynolds equation as needed and couple it with other physics to create our TEHL mathematical model,” he said. “Coupling different physics and equations is what COMSOL is all about and served us well.”

The main advantage of using the software is the ability to choose the physics, add customized equations, and then couple everything together to create a working solution [2] without the need to know the details of the numerical solution techniques available, concentrating instead on the modeling aspects. “We are a research center focusing on the design and optimization of machine elements, particularly gears” he explained. “The interface and multiphysics approach behind COMSOL allowed us to focus on the engineering problems rather than the numerical algorithms behind the solution. Furthermore, we benefit from the continuous developments and updates of the software.” For the pressure and film thickness calculation, the researchers used the Weak Form Boundary PDE interface to input the generalized

Reynolds equations [1]. For temperature calculation, the researchers used mainly predefined interfaces available in the software [2].

Lohner and his team created a simulation app called “TriboMesh” (Figure 2) that made their work even simpler to use and distribute it within the research center. To this aim, they used the Application Builder tool available in the software. Apps allows their colleagues to use simulation in practical ways to search for new solutions.

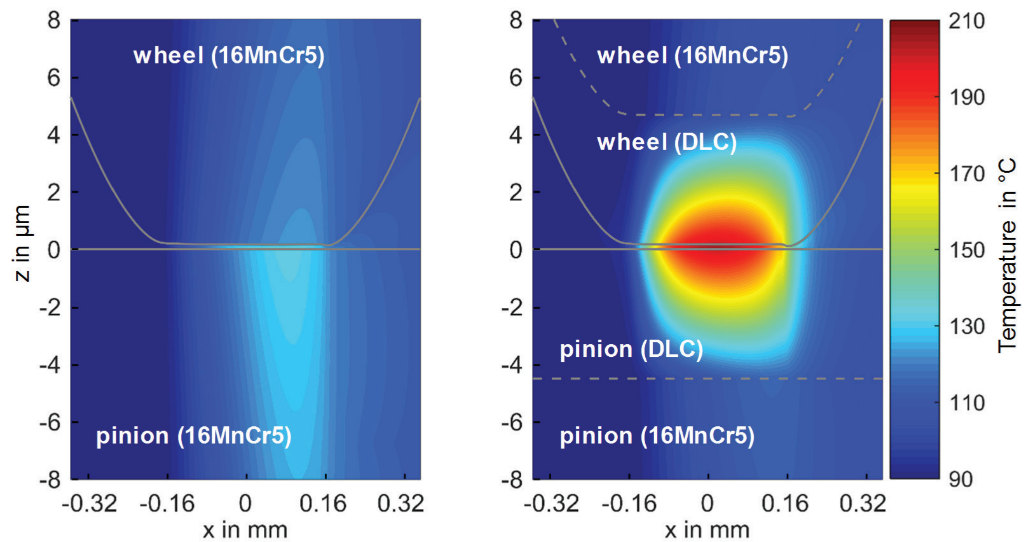



FIGURE 3. TEHL simulation results: temperature distribution of an uncoated (left) and DLC-coated gear pair (right).

The simulation app has already been deployed to selected colleagues on local workstations. In the future, the app will also be available to colleagues and project partners through the COMSOL Server™ product, which allows users to run apps via a web browser.

One use of the app is for understanding how a diamond-like carbon (DLC) coating improves the efficiency performance of gears. “We conducted test rig experiments that showed that the coefficient of friction is much lower for DLC-coated gears compared to uncoated gears,” Lohner explained. But why? The coating was on the surface, so how could it affect the lubricant? Exercising their app with all of the physics inputs from a test rig showed that the DLC coating trapped heat in the TEHL contact, lowering the viscosity of the lubricant and decreasing friction (Figure 3) [3]. “The DLC coating provides thermal insulation, and we could not have proved our hypotheses well without the simulation. We gained a detailed understanding of heat flows in the system and the resulting lubricant behavior,” Lohner said.

## ⇨ ADVICE FOR OTHERS: START SMALL AND BUILD

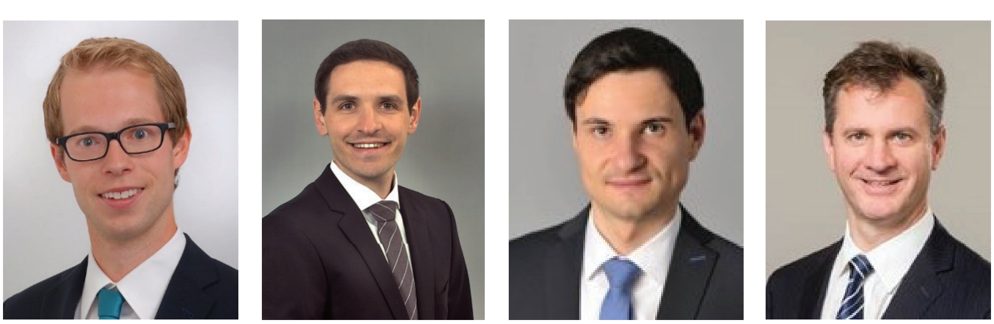
For those using multiphysics simulation and apps, Lohner and his team offer sage advice based on their experience. “It is almost impossible for someone who begins to work on very complex systems to begin by doing the whole problem,” he said. “You have to modify your problem to make it as easy as possible in the first step.” In his example, their first cut at the problem modified the Reynolds equation to couple it with simple elasticity equations, ignoring thermal effects. “We then moved on to adding in more complex effects, step by step,” he said. “You have access to all of the complexity you need in COMSOL, so it is easy to program it into your solution as needed.” He cautioned not to be lulled into thinking accessibility is the same as solving the entire problem well. “You really need to go step by step in a methodical way because the problem is very complex. You must make sure that every step is verified before moving onto the next step,” he said. ❖

## REFERENCES


*1. W. Habchi, A full-system finite element approach to elastohydrodynamic lubrication problems: application to ultra-low-viscosity fluids [Dissertation], Institut National des Sciences Appliquées de Lyon, Lyon, France, 2008.*

*2. Thomas Lohner, Andreas Ziegltrum, Johann-Paul Stemplinger, and Karsten Stahl, Engineering software solution for thermal elastohydrodynamic lubrication using multiphysics software, Advances in Tribology, Volume 2016 (2016), Article ID 6507203.*

*3. Andreas Ziegltrum, Thomas Lohner, Karsten Stahl, TEHL simulation on the influence of lubricants on the frictional losses of DLC coated gears, lubricants, Volume 6 (2018), doi:10.3390/lubricants6010017.*

Members of the research group EHL-Tribological-Contact and Efficiency from the Gear Research Center (FZG) at the Technical University of Munich (TUM), Germany: (left to right) Andreas Ziegltrum, research associate; Enzo Maier, research associate; Thomas Lohner, department leader; and Karsten Stahl, full professor and director of FZG.