Modelling Elastohydrodynamic Lubrication

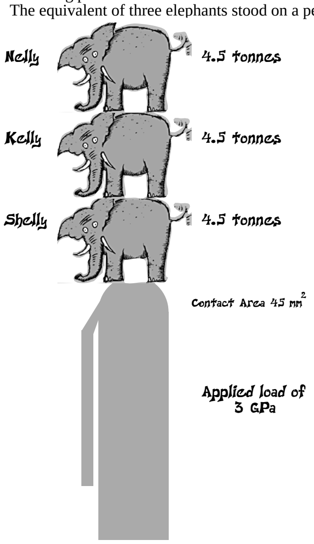
Chris Goodyer, University of Leeds   CASE award with Shell Global Solutions

Lubrication

When surfaces are in contact there is a frictional force. By introducing a flow of a lubricant (oil) into the contact, the surfaces are separated. This reduces the frictional force, meaning less wear and hence minimises the regularity of component replacement.

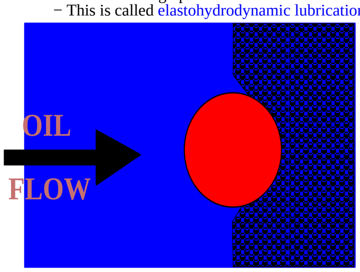
Car Engine Journal Bearings and Gears

- Actual surface areas in contact are very small
- Surfaces are rotating very quickly
- Resulting pressures are of the order of 2 or 3 GPa. The equivalent of three elephants stood on a pen!



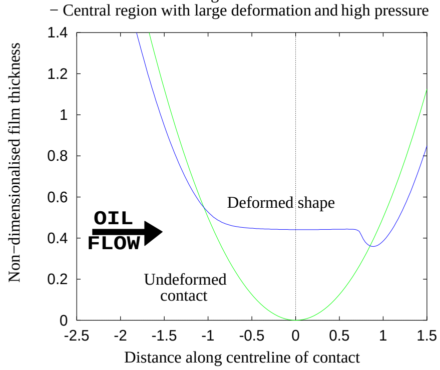
Deformation

- Under such high pressures the surface will deform
- This is called elastohydrodynamic lubrication (EHL)



Journal Bearing Problem Description

- Oil flow from left to right
- Central region with large deformation and high pressure

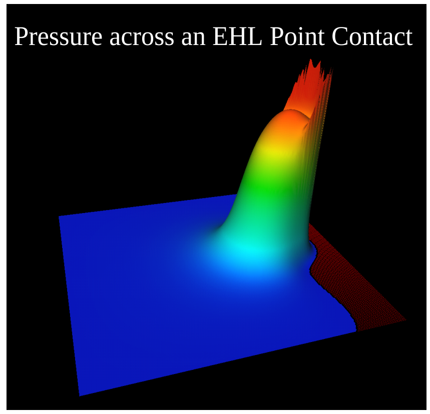


The Problem Today

- Complex lubricants with real−life properties
- Real *rough* surfaces
- All three spatial dimensions represented
- Time dependent problems

Computational Modelling

- Aids industry with the design of parts and lubricants
- Mathematical equations be be solved
- Accurate robust numerical solvers therefore required
- Solutions needed quickly



EHL Equations

The equations form a highly non−linear set of integro−differential equations to be solved for the pressure, ***p***, and film thickness, ***h***.

The Reynolds Equation

$$\frac{\partial}{\partial x}\left(\frac{\rho h^3}{\eta}\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{\rho h^3}{\eta}\frac{\partial p}{\partial y}\right)=6\left\{u_s\frac{\partial(\rho h)}{\partial x}+2\frac{\partial(\rho h)}{\partial t}\right\}$$

- governs the pressure distribution

The Film Thickness Equation

$$h(x,y)=h_{00}+\frac{x^2}{2R_x}+\frac{y^2}{2R_y}+\frac{2}{\pi E'}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\frac{p(x',y')\,dx'\,dy'}{\sqrt{(x-x')^2+(y-y')^2}}$$

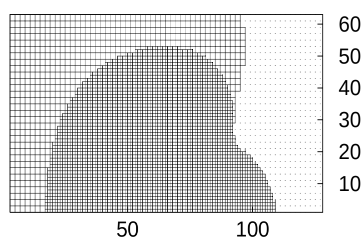
- gives deformation for a given pressure distribution
- double integral is very computationally expensive

Lubricant model

- equations governing the pressure, ρ, and viscosity, η
- model being used may be viscoelastic
- temperature dependence also included here
- these are all also non−linear in ***p***

Numerical Representation

- Pressure and film thickness calculated at sample points in a mesh
- Reynolds Equation solved using finite differences
- Each equation solved to update variables in turn
- Repeated iteratively to converge on the true solution



Adaptive Meshing

- Some regions of solution have larger errors than others
- The ability to mesh finely in these regions can concentrate computational work where most needed
- Error estimation needed to identify where to refine
- High pressure region with large deformation shown above finely meshed

Multilevel Techniques

- Numerical convergence is slow on fine grids
- Errors removed more easily on coarse grids
- ***Multigrid*** used to transfer solutions between grids to get accurate results quickly
- Deformation calculation very time consuming
- ***Multilevel Multi−Integration*** used to estimate many calculations using coarser grids
- Evaluation time vastly reduced for very fine meshes
- Combining these techniques generates results hundreds of times faster than could be achieved a decade ago

High Performance Computing

Use of parallel computers enables further reduction in the time required to obtain accurate solutions.

Time Dependent Problems

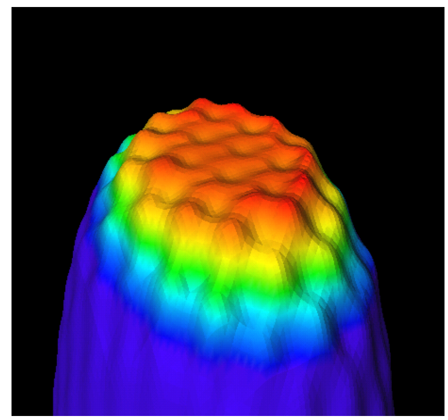
- All EHL problems represent motion of parts, with oil flow between them
- Inside machinery physical conditions vary, *e.g.* when gear teeth engage, hence loads and speeds may be changing continuously
- To obtain transient solutions many hundred individual EHL problems need to be solved. This means that fast solution techniques are very important for the calculations to be of use to industry.

The choice of timestep size is important because
- if it is too large then errors will enter the solution
- if it is too small then unnecessary computational work may be done

The use of Variable Timestepping can therefore be used to balance errors in space and time automatically. In addition to providing accurate solutions this will also often lead to a significant reduction in the required work.

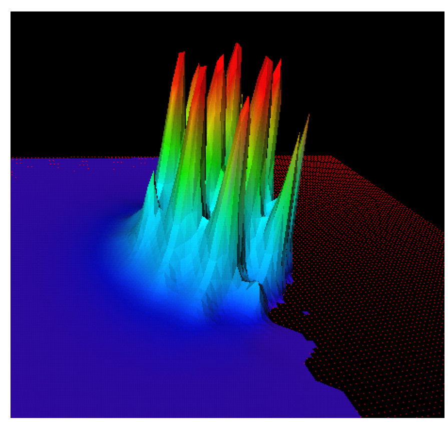
Surface Features

- Real contacts are not perfectly smooth
- Dents and ridges occur once in use
- Small deviations in the surface geometry produce large variations in the pressure and film thickness
- Surface roughness is the combination of many small amplitude deviations from the ideal profile



Example : True Surface Roughness

Represented above is the contact geometry of an EHL point contact with a pattern of bumps and dimples applied across the undeformed bearing. This models the very rapidly varying shape of a real surface. The resulting pressure distribution is shown below.



Conclusions

- Efficient modelling tools have been developed for practical industrial problems.
- New robust computational methods have been used to obtain solutions far more quickly than before.
- Multidisciplinary work has enabled computer modelling, visualisation and parallel computing to aid the development of research leading to new and better oils.

This work was done as part of a PhD with Prof. Martin Berzins at the University of Leeds, funded by an EPSRC CASE Award with Shell Global Solutions
Industrial supervisor Dr Laurence Scales

Chris Goodyer
Computational PDEs Unit
School of Computing
University of Leeds
Leeds, LS2 9JT

ceg@comp.leeds.ac.uk