

COMSOL CONFERENCE 2016 MUNICH



Implementation of a Thermo- Hydrodynamic Model to Predict “Morton Effect”

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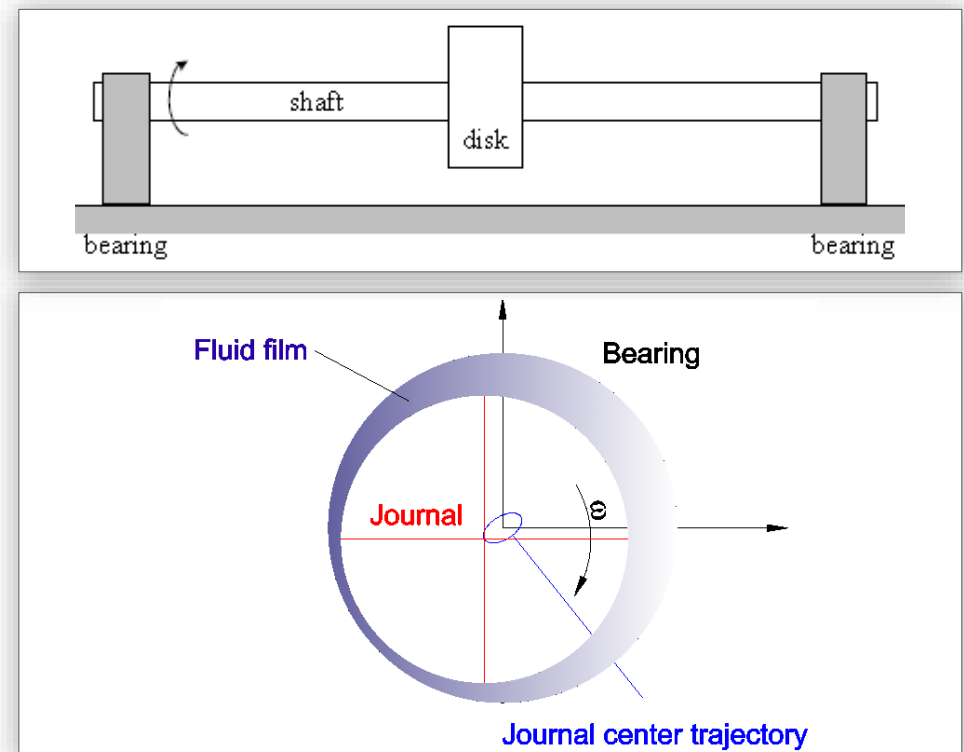


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1.A - Morton effect and its explanations

- Shaft sustained with fluid film bearings
- Every journal has a residual unbalance
- The journal exhibits a synchronous orbit



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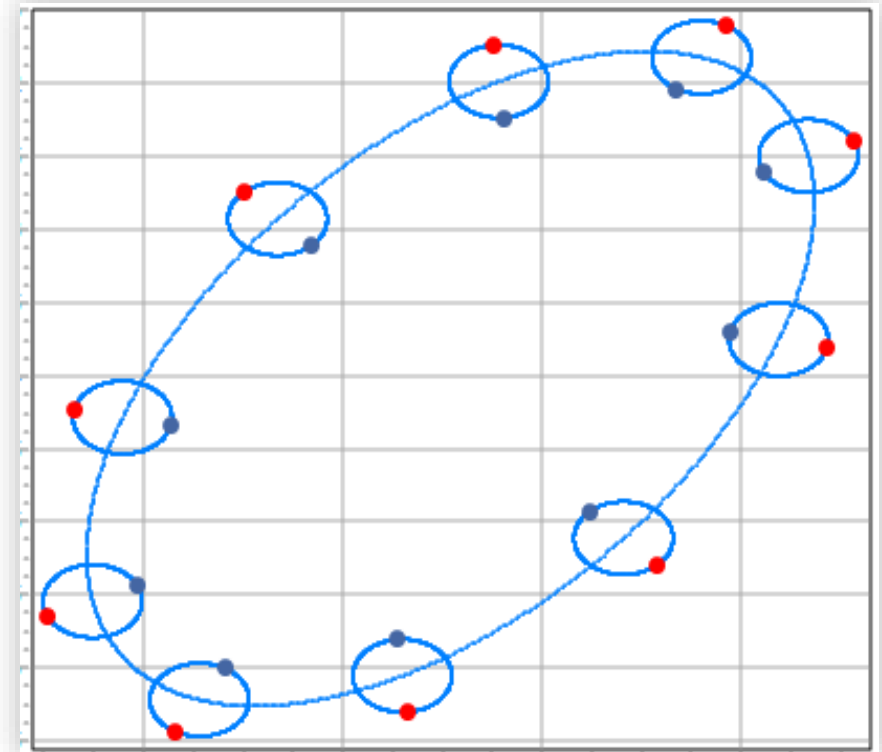


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1.B - Morton effect and its explanations

- Inside fluid film bearing a small part of the journal is HOT, while the opposite side is COLD
- Non uniform temperature distribution inside oil
- Thermal bending



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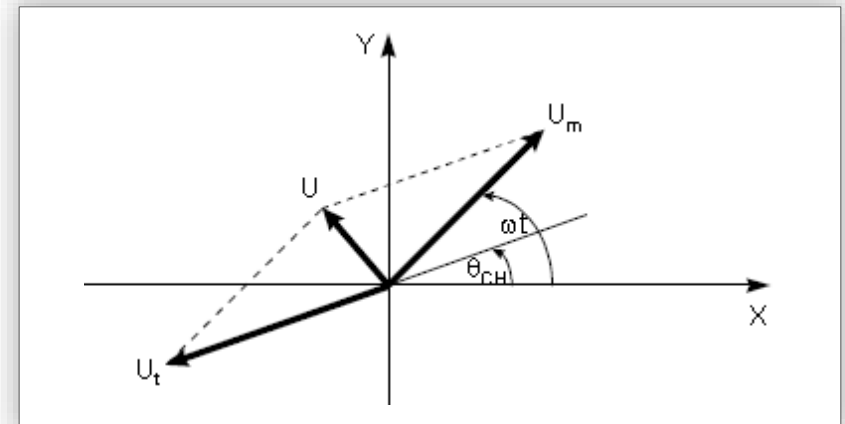
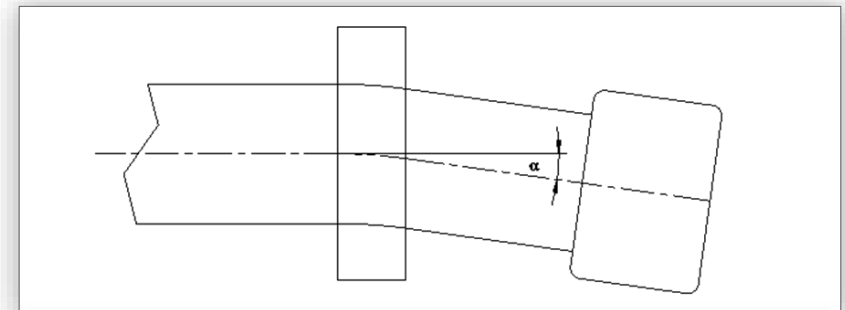
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1.C - Morton effect and its explanations

Now consider an overhung mass...

- Thermal bending causes a certain unbalance
- Thermal unbalance can:
 - ✦ reinforce the effect reducing again minimum film thickness (UNSTABLE)
 - ✦ reduce the effect counter-balancing the mechanical unbalance (STABLE)



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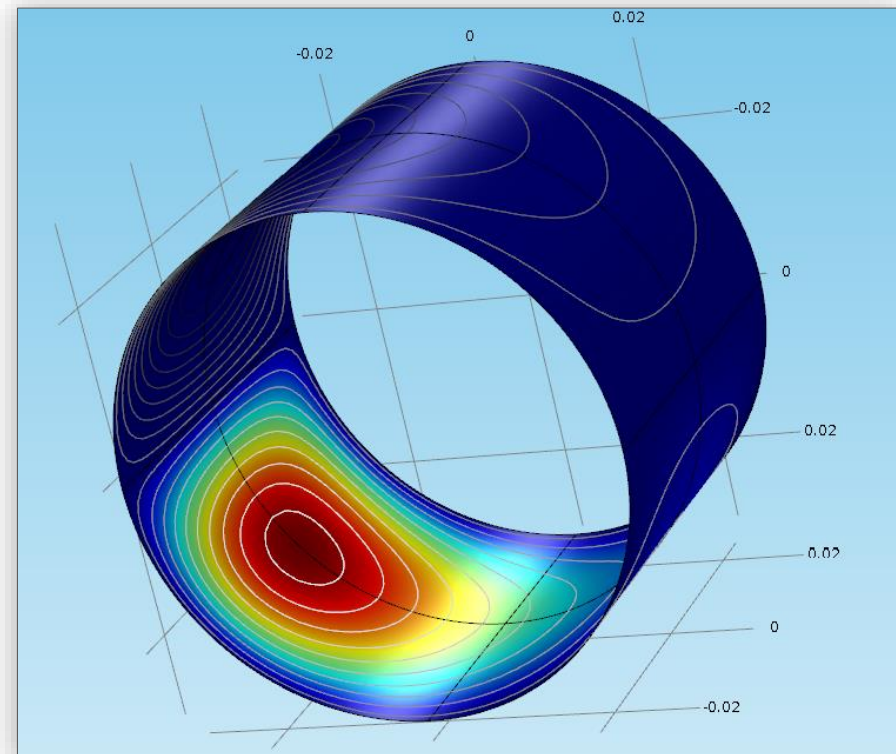
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2.A - Physics behind the effect

CFD physics: Reynolds equation

$$\left\{ \begin{array}{l} \nabla_T \cdot \left(\frac{-\rho h^3}{12\mu} \nabla_T p + \frac{\rho h}{2} (v_a + v_b) \right) = \frac{\partial(\rho h)}{\partial t} \\ p(x, y) = 0 \end{array} \right. \quad \begin{array}{l} (x, y) \in \Omega_1 \\ (x, y) \in \Omega_2 \end{array}$$



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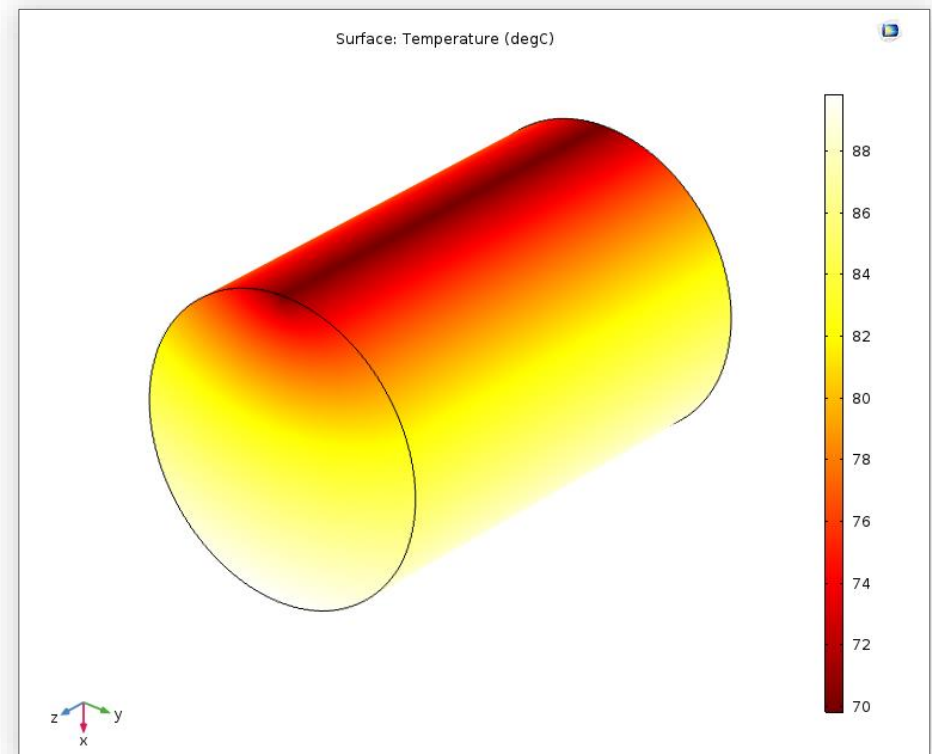
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2.B - Physics behind the effect

Thermal physics

Energy generation rate + Influx energy rate
= energy accumulation rate

$$\dot{q} + \nabla \cdot (k\nabla u) = u_t$$



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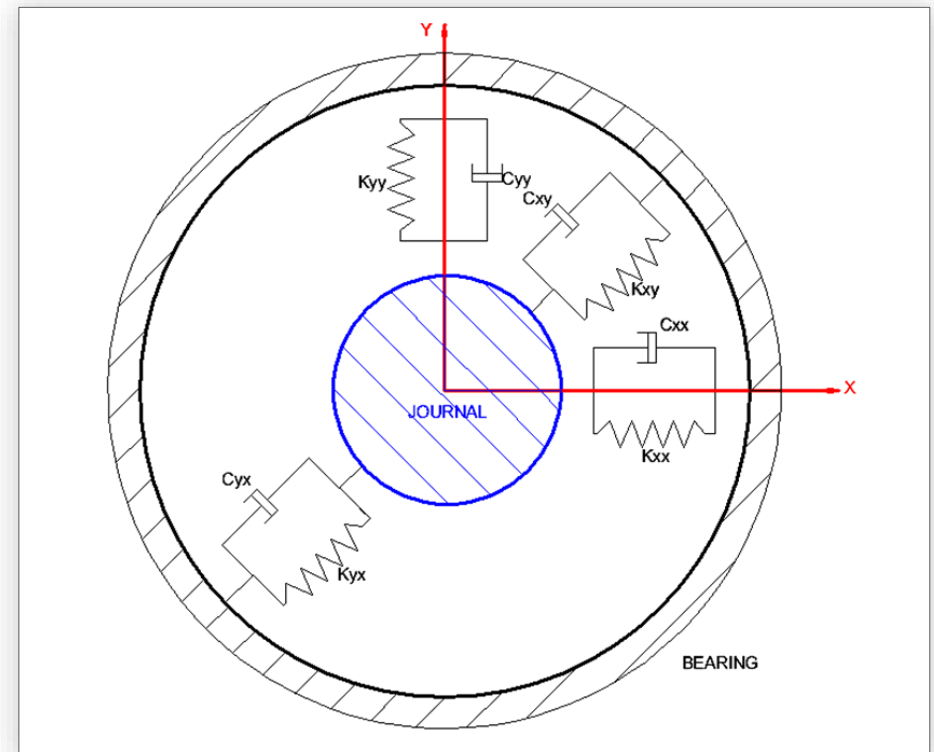
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2.C - Physics behind the effect

Mechanical physics and
multibody dynamics

$$M\ddot{X} + C\dot{X} + KX = Mu\omega^2 \begin{pmatrix} \sin \omega t \\ \cos \omega t \end{pmatrix}$$



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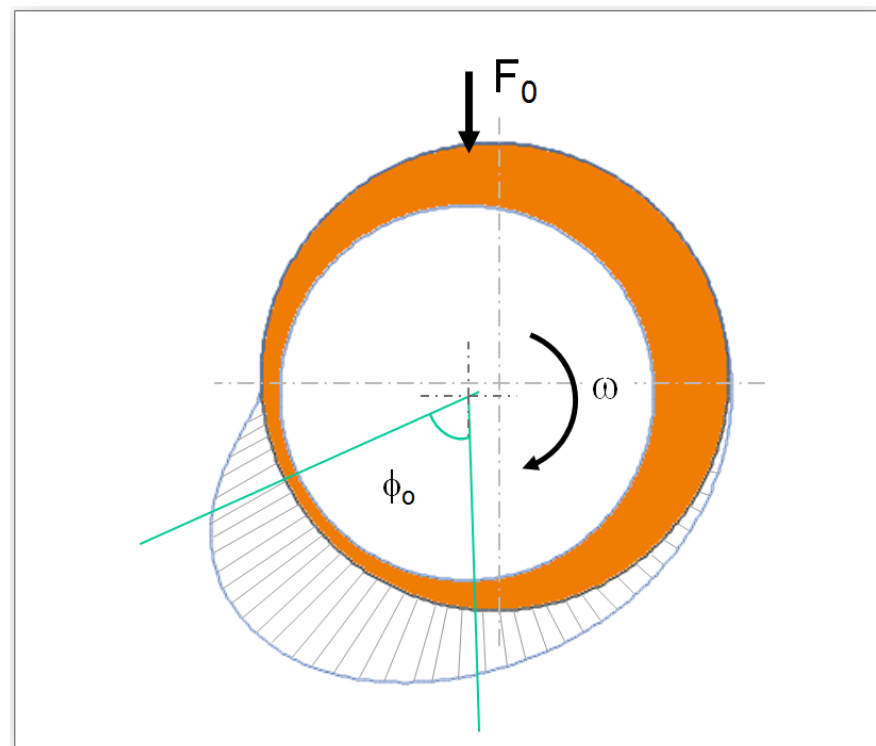
3.A - Approximation and methodology

*Static equilibrium position
(short bearing approximation)*

$$F_0 = \mu\omega RL \left(\frac{L}{C}\right)^2 \frac{\varepsilon \sqrt{16\varepsilon^2 + \pi^2(1 - \varepsilon^2)}}{(1 - \varepsilon^2)^2}$$

$$\tan(\phi_0) = \frac{\pi\sqrt{1 - \varepsilon^2}}{4\varepsilon}$$

A. C. Balbahadur, R. G. Kirk, Part I—Theoretical Model for a Synchronous Thermal Instability Operating in Overhung Rotors, *International Journal of Rotating Machinery*, 10(6): 469–475, 2004



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3.B - Approximation and methodology

Orbit and motion (short bearing approximation)

$$k_{xx} = K_{xx} \frac{C}{F_0} = \frac{f_{r0}}{\varepsilon(1 - \varepsilon^2)} (f_{r0}^2 + 1 + 2\varepsilon^2)$$

$$k_{yy} = K_{yy} \frac{C}{F_0} = \frac{f_{r0}}{\varepsilon(1 - \varepsilon^2)} (f_{t0}^2 + 1 - \varepsilon^2)$$

$$k_{yx} = K_{yx} \frac{C}{F_0} = \frac{f_{t0}}{\varepsilon(1 - \varepsilon^2)} (f_{r0}^2 - 1 + \varepsilon^2)$$

$$k_{xy} = K_{xy} \frac{C}{F_0} = \frac{f_{t0}}{\varepsilon(1 - \varepsilon^2)} (f_{r0}^2 + 1 + 2\varepsilon^2)$$

$$c_{xx} = C_{xx} \frac{C\omega}{F_0} \frac{2f_{t0}}{\varepsilon(1 - \varepsilon^2)} \left((2 + \varepsilon^2)f_{r0}^2 + 1 - \varepsilon^2 \right)$$

$$c_{yy} = C_{yy} \frac{C\omega}{F_0} = \frac{2f_{t0}}{\varepsilon(1 - \varepsilon^2)} \left((2 + \varepsilon^2)f_{t0}^2 - 1 + \varepsilon^2 \right)$$

$$c_{xy} = c_{yx} = C_{xy} \frac{C\omega}{F_0} =$$

$$= \frac{2f_{r0}}{\varepsilon(1 - \varepsilon^2)} \left((2 + \varepsilon^2)f_{t0}^2 - 1 + \varepsilon^2 \right)$$

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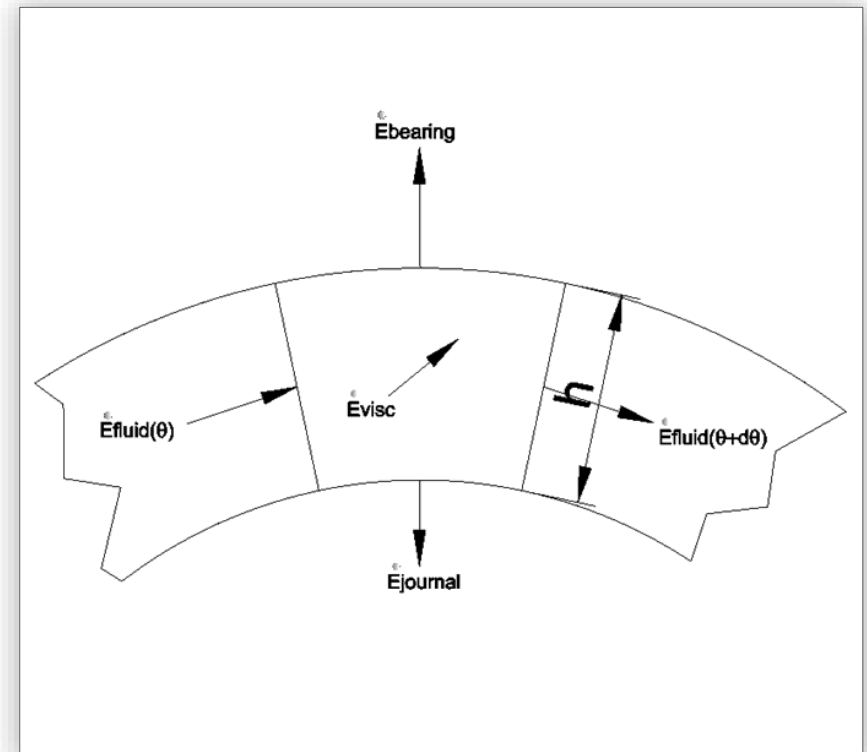
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3.C - Approximation and methodology

*Temperature distribution
(short bearing approximation)*

$$\dot{E}_{visc} = \dot{E}_{fluid}(\vartheta + d\vartheta) - \dot{E}_{fluid}(\vartheta) + \dot{E}_{journal} + \dot{E}_{bearing}$$

$$\frac{dT}{d\xi} + \frac{2H}{\rho c \omega h} - \left(\frac{2HT_{amb}}{\rho c \omega h} + \frac{2\mu\omega R_j^2}{\rho c h^2} \right) = 0$$



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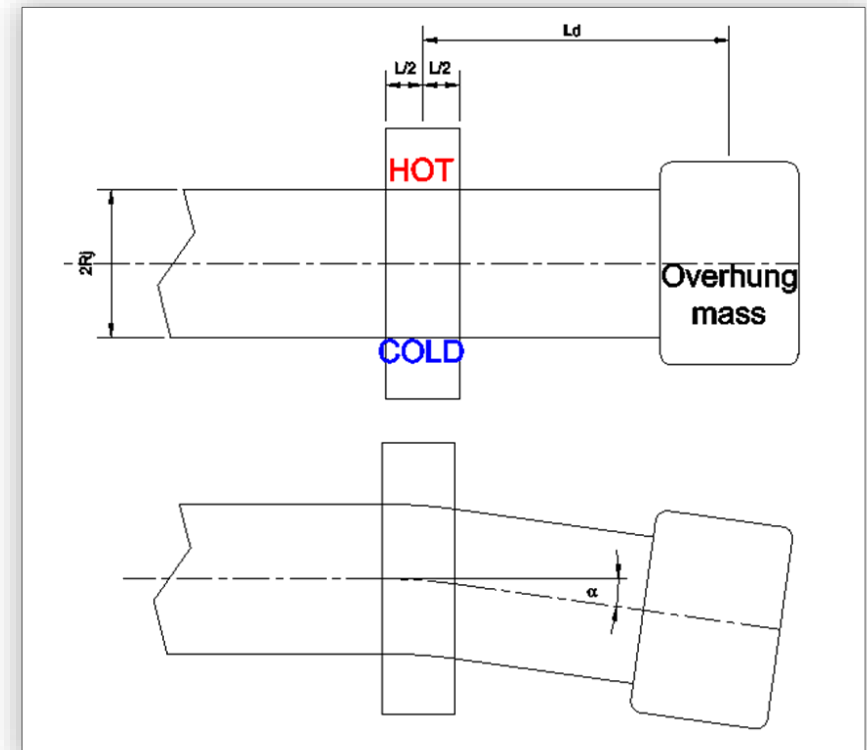
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3.D - Approximation and methodology

Unbalance (mechanical, total, limit)

$$U_t = m_o y_o = m_o \frac{\alpha \Delta T}{R_j} L L_o$$

$$U_{thr} = \frac{0.15 W}{\omega^2}$$



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4 – Comsol implementation

The screenshot shows the COMSOL Multiphysics interface with the 'Global Equations' settings panel open. The 'Global Equations' section is active, displaying the equation $f(u, u_t, u_{tt}, t) = 0$ and the initial conditions $u(t_0) = u_0$, $u_t(t_0) = u_{t0}$. A table below lists the variables and their initial values:

Name	f(u, u_t, u_{tt}, t) (1)	Initial value	Initial value
T	$-A \cdot T / l1 + B / l1^2 \dots$	T0	0
		0	0

The screenshot shows the COMSOL Multiphysics interface with the 'Parameters' table open. The table lists the following parameters:

Name	Expression	Value	De
A	0.016164	0.016164	
B	1.32297	1.323	
epsi	0.0288	0.0288	
Omega	1	1	
tf	pi	3.1416	
T0	65	65	
dt	0.1	0.1	

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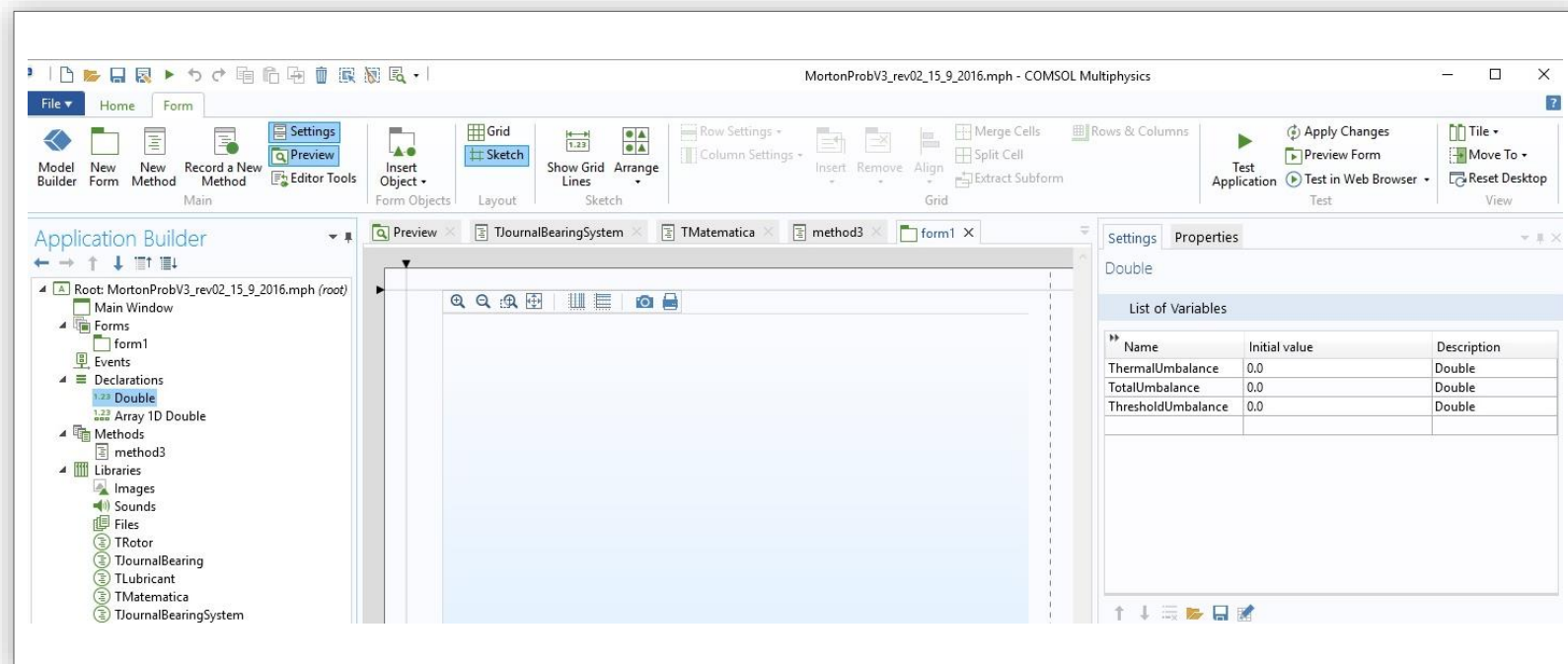
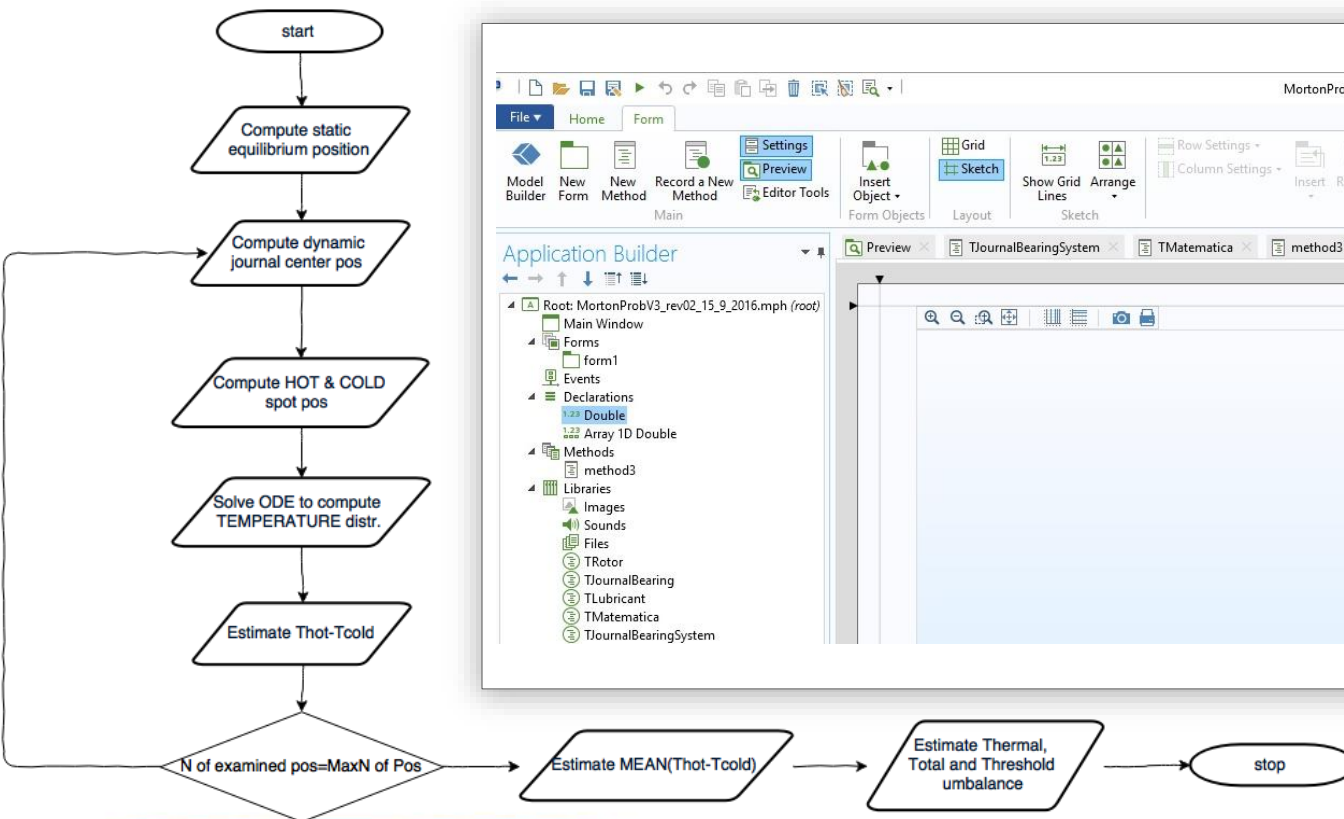
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4 – Comsol implementation

The screenshot shows the Comsol Multiphysics software interface. The top menu bar includes File, Home, and Method. The toolbar contains various icons for building models, editing, and debugging. The left pane shows the Application Builder tree with a project named 'MortonProbV3_rev02_15_9_2016.mph'. The main window displays a Java code editor with the following code:

```
119 //dynamic cold spot position
120 xc = xj+FJournalBearing.JournalRadius*Math.cos(FRotor.Speed*t+g0+Math.PI);
121 yc = yj+FJournalBearing.JournalRadius*Math.sin(FRotor.Speed*t+g0+Math.PI);
122 thc = Math.atan2(yc, xc);
123 xic = TMatematica.mpippi(Math.PI-(FRotor.Speed*t+g0+Math.PI-thj));
124
125 //solve differential equation for temperature distribution around journal circumference
126
127 FEps2 = Math.sqrt(TMatematica.sqr(xj)+TMatematica.sqr(yj))/FJournalBearing.RadialClarence;
128
129 model.param().set("epsi1", FEps2);
130 model.study("std1").run();
131 useGraphics(model.result("pg3"), "graphics1");
132
133 if (i2 == 1) {
134     model.result().table("tbl1").clearTableData();
135     with(model.result().numerical("gev1"));
136         set("table", "tbl1");
137     endwhile();
138     model.result().numerical("gev1").setResult();
139 }
140 else {
141     with(model.result().numerical("gev1"));
142         set("table", "tbl1");
143     endwhile();
144     model.result().numerical("gev1").appendResult();
145 }
146
147 // model.result().numerical("gev1").setResult();
148 double sol[][];
149 sol = model.result().numerical("gev1").getReal();
150
```

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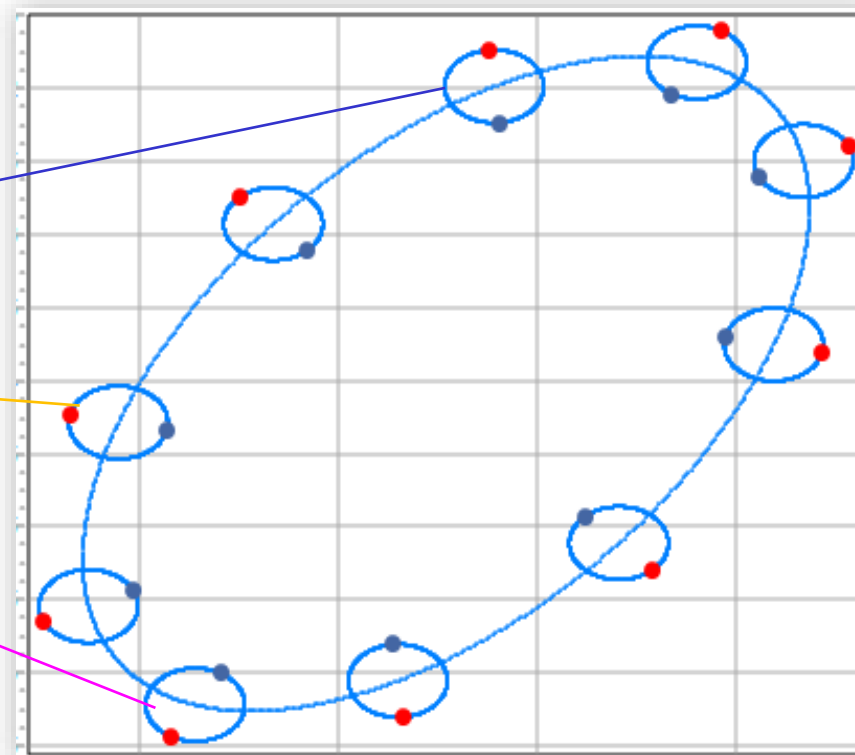
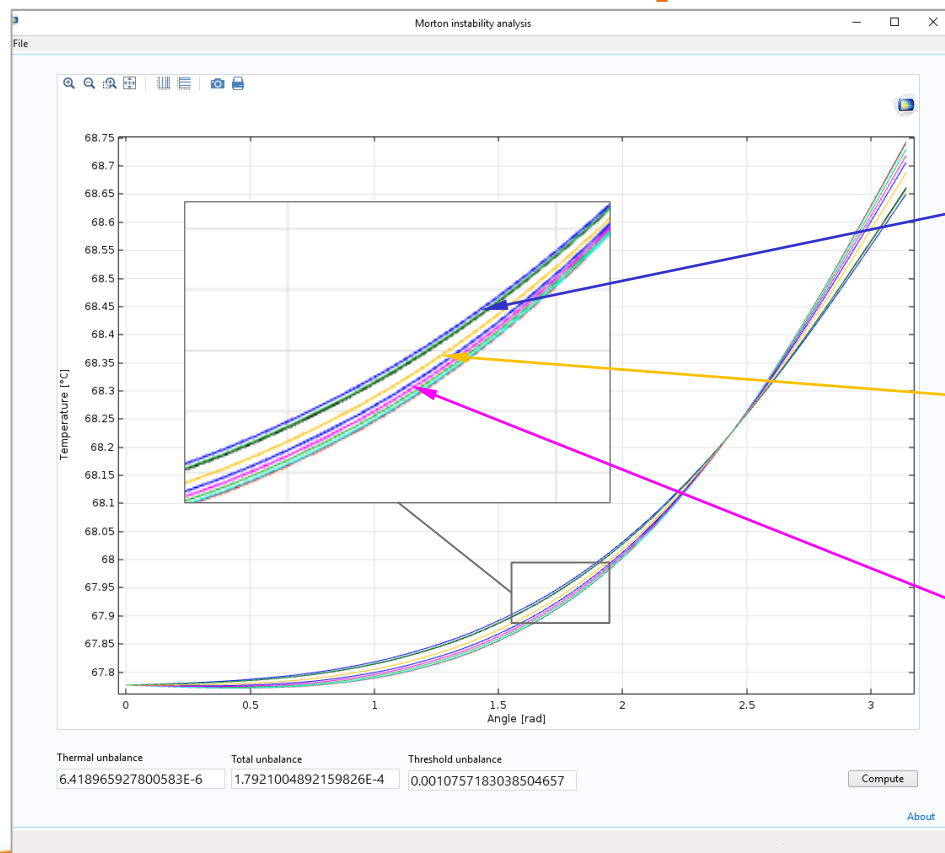
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4 – Comsol implementation



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Conclusion & future works

Implementation of a model to predict Morton effect (suggested by the literature)

- Hard numerical computation made by COMSOL
- A dedicated algorithm uses result computed with COMSOL

FUTURE WORKS

Eliminate approximation introduced to compute

- temperature distribution
- static equilibrium position

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**Thank you for
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