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EFFECT OF PAD AND LINER MATERIAL PROPERTIES ON THE STATIC LOAD PERFORMANCE OF A TILTING PAD THRUST BEARING

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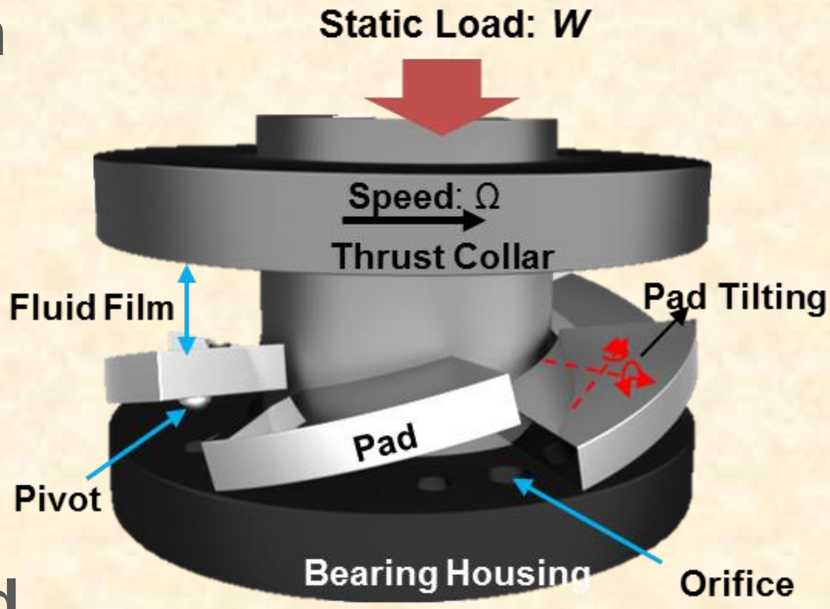
Introduction: Tilting Pad Thrust Bearings (TPTBs)

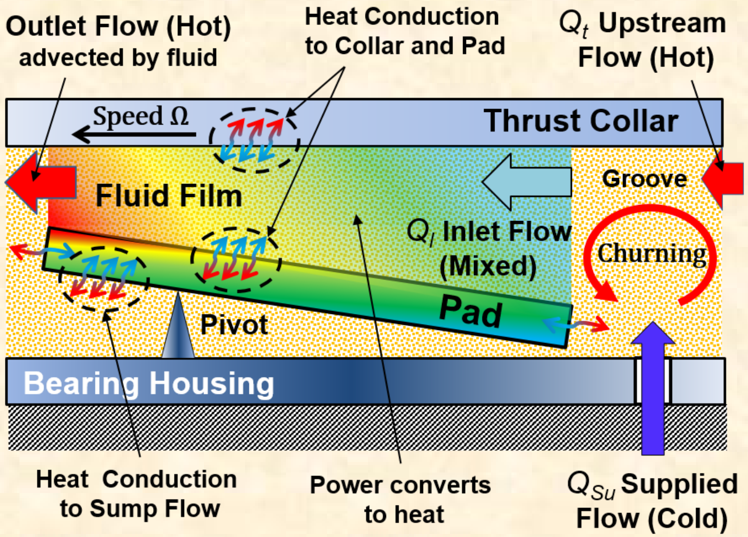
- **Control rotor axial placement in rotating machinery.**
- **Advantages: low power loss, simple installation, and low-cost maintenance.**

- **As lubricant is sheared, fluid film and pad temperatures increase.**
- **Load capacity of bearing depends on lubricant viscosity, a function of temperature.**
- **Pad thermally and mechanically induced deformations shape the operating fluid film thickness and determine the bearing load capacity.**

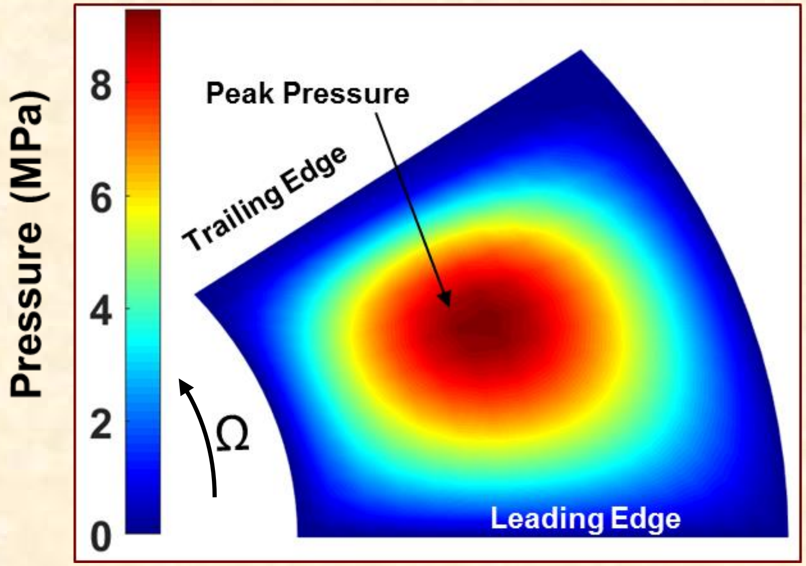


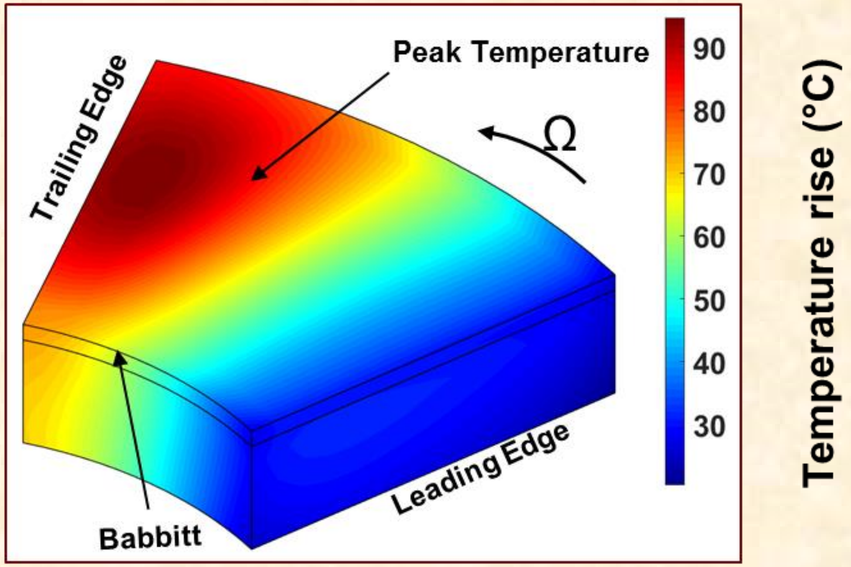
TPTB current computational analysis

- 2D hydrodynamic pressure on pad surface.
  - Cross-film viscosity variation.
  - \+ turbulent flow effects.
- 3D temperature distribution in fluid film.
  - Heat conduction to the pads.
  - \+ turbulent flow effects.
- 3D temperature distribution in pad and liner.
  - Heat transfer on all sides of a pad.



Pressure & temperature gradient in a pad produce elastic deformations.

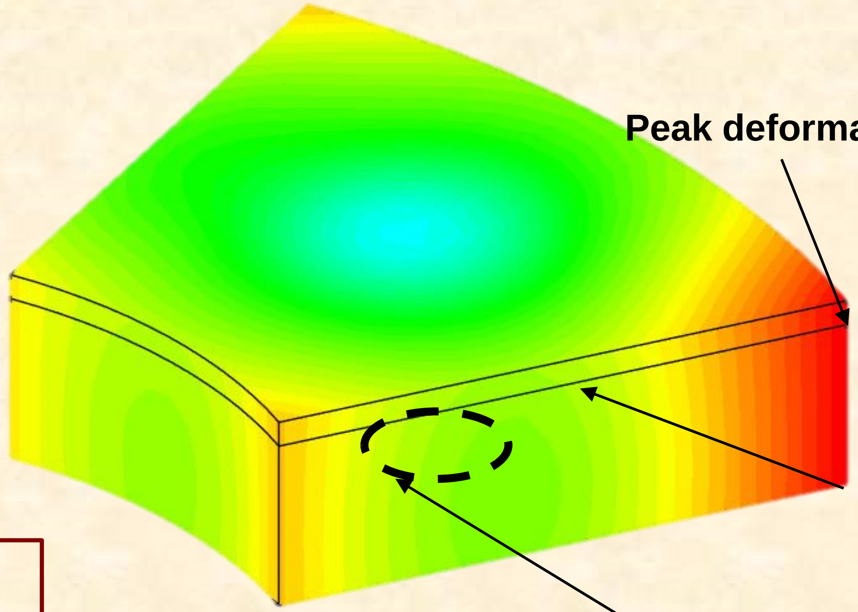




Elastic deformations in a pad & liner

Fluid film model couples to an in-house Finite Element model with pad elasticity and pivot stiffness.

Pressure and temperature → 3D deformation field in a pad as well as pad rigid body motion about pivot.



Both pad deformations change the film thickness → bearing performance

Paper GT2019-90231 **includes validation of predictive model for**

1) **Pad deformations vs ANSYS® analysis results.**
2) **Pad temperature vs measurements in [1] for a mid-size TPTB.**
   Includes operation spanning laminar to turbulent flow conditions.

[1] Mikula. 1986, J. Trib., 29.

Objective

To quantify the influence of both pad and liner material properties on the performance of an example thrust bearing.

⇨

Steel base material with Babbitt layer or a Polyether ether ketone (PEEK®) liner.

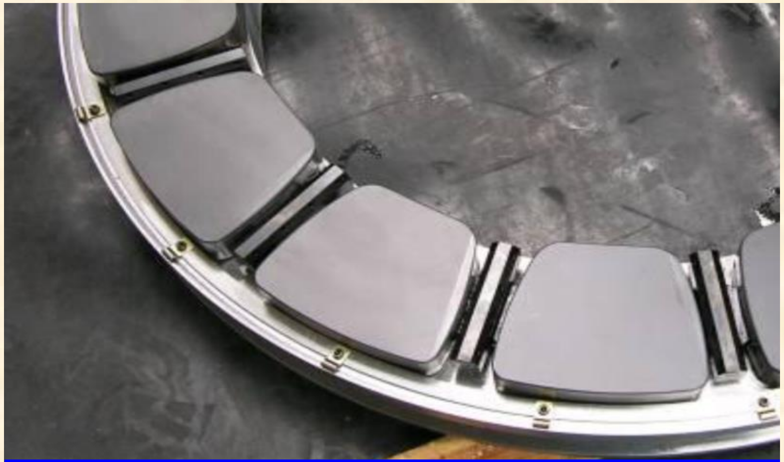
Justification

High power density, low viscosity fluids, and extreme operating conditions enable polymer based materials as alternatives to white metal alloys (Babbitt).

- **Compared to Babbitt, PEEK® and PTFE®) (Poly-tetra-fluoro-ethylene)**
  - **low wear rate,**
  - **corrosion proof and chemical resistance**
  - **tolerance against particle contaminants**
- **Solid PEEK® pads eliminate need for polymer/steel bonding.**

PEEK® → hard-polymer

PTFE® → soft-polymer



Steel-Polymer TPTB

Whole Polymer TPTB

Physical Properties: Babbit vs Hard Polymer

	Units	Steel	Babbitt (White Metal)	Hard-Polymer (PEEK®)
Thermal Conductivity	W/(m.k)	51	55	0.87
Thermal Expansion	10^{-6} /^{0}C	12	23	47
Young Modulus	GPa	210	52	12.5
Poisson Ratio	[-]	0.3	0.3	0.35
Max. Temperature Limit	^{0}C	[-]	120	160
Refs.		[1]	[1,2]	[2,3,4]

❑ **Low thermal conductivity:**

Pros: reduces pad temperature rise → minimizes pad thermal deformation.

Cons: isolates film from t pad → increases film temperature rise.

❑ **Low elastic modulus:**

Cons: increases pad mechanical deformation → large demand for supply flow.

May cause oil cavitation at a pad trailing edge.

[1] Glavatskih, S., and Fillon, M., 2006

[2] Yuki et al., GT2014-26798, 2014

[3] Markin et al., Tribol. Int., 2003

[4] Zhou et al. J. Lubricants, 2015

Prior Work on Liner Materials for TPTBs

2004, ASME/STLE Joint Conf. : **Glavatskih and Fillon → account for effects of pad face liner.** **OD= 0.28 m, Ω= 3 krpm, 2.0 MPa/pad**

As the thickness of soft-polymer liner increases:

- **Pad temperature lessens,**
- **Film temperature raises at the pad trailing edge,**
- **Film thickness decreases at the pad leading edge.**

2014, ASMEGT2014-26798: **Sumi et al. compare measured pad temperatures of a hard-polymer liner TPTB against those in a Babbitted TPTB.** **OD= 0.73 m, Ω= 3.6 krpm.**

- **The Babbitted pads bearing fail to carry specific loads larger than 6 MPa as the white-metal reached its melting temperature.**
- **The hard-polymer liner bearing, however, carried up to 12 Mpa.**

Compared to Babbitted pad bearings, literature on polymer lined pad bearings is limited.

Predictions for the Effect of Pad Liner Material on Thrust Bearing Performance

Eight-pad TPTB

Based on Mikula. 1986, J. Trib., 29.

Max surface speed = 13.5 - 278 m/s

Reynolds No. $Re = \frac{\rho R_m \Omega h_{min}}{\mu}$

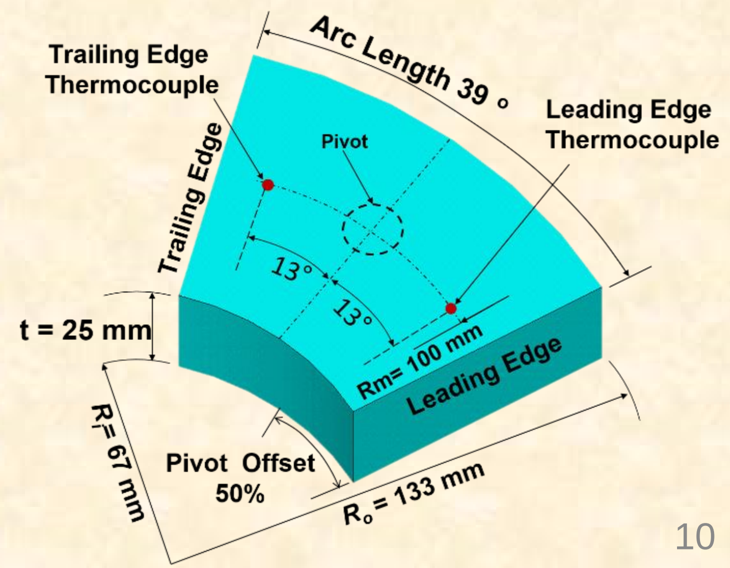
Lower critical Re_L = 580
Upper critical Re_U = 800 for turbulence flow

[1] Abramovitz, S., J. Franklin Ins.,1955
[2] Gregory, R., J. Lub. Tech., 1974.

Shaft rotational speed	**4-13 krpm**
Max surface speed ΩR_o	**13.5-278 m/s**
Specific load per pad *W/(Ap Np)*	**0.69-3.44 MPa**
Number of pads, Np	8
Outer/Inner diameters	267/133 mm
Pad arc length [°]	39°
Pivot offset [%]	50%
Lubricant	ISO VG32

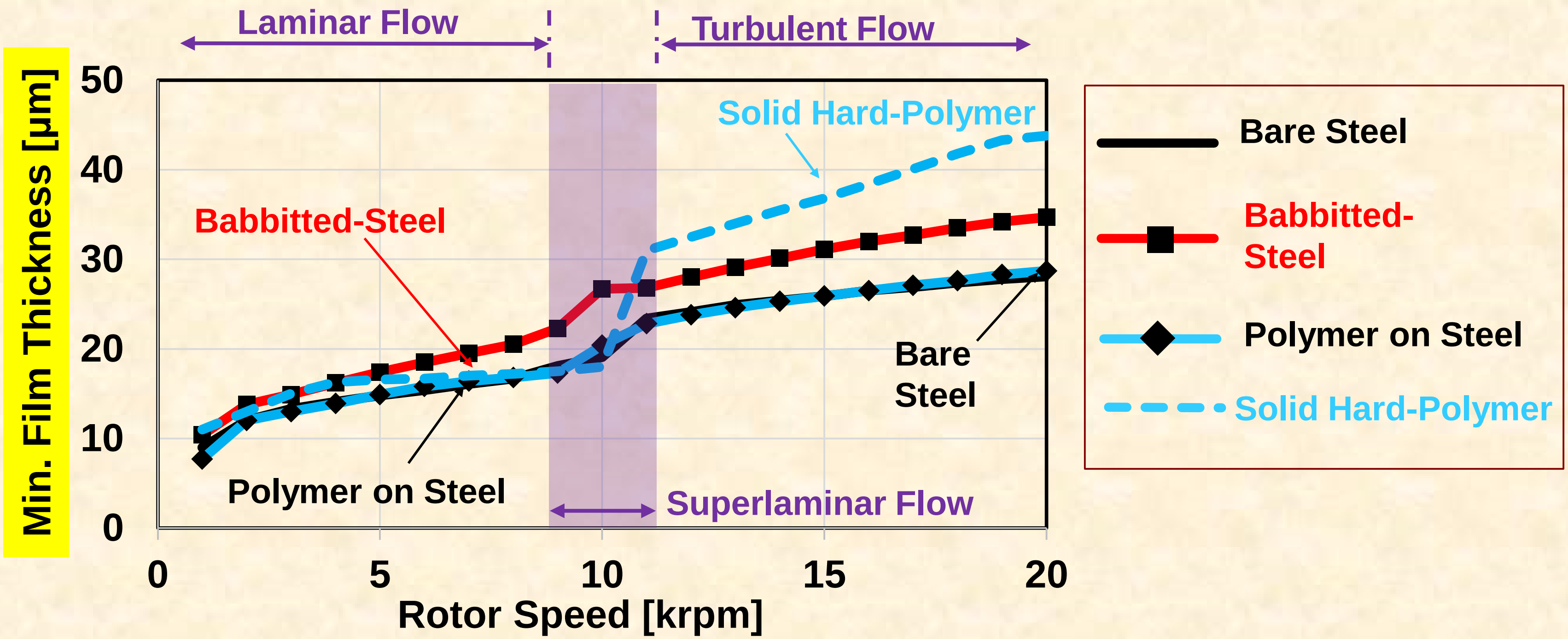
Four pads with same thickness (25 mm)

- **Bare steel pad (with no liner or Babbitt):**
- **Solid hard-polymer pad**
- **Babbitted-steel pad:**
  - **23 mm thick steel + 2 mm thick Babbitt**
- **Steel pad with hard-polymer liner**
  - **23 mm thick steel + 2 mm thick liner**



Film Thickness vs. Speed

Oil Temp = 46 ^{0}C
Load = 3 MPa

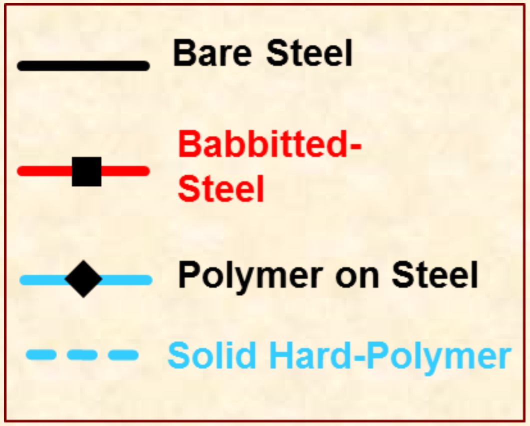


- **Flow transits to <u>turbulent flow</u> for shaft speed > 9 krpm.**
  - **Solid hard-polymer pad shows a large 13 µm jump in minimum film thickness due to a significant drop in film temperature (onset of turbulence)**

- **Minimum film thickness at highest speed (20 krpm)**:
  - **Hard-polymer pad = 43 µm.**
  - **Bare steel pad =28 µm.**

Film Temperature Rise vs. Speed

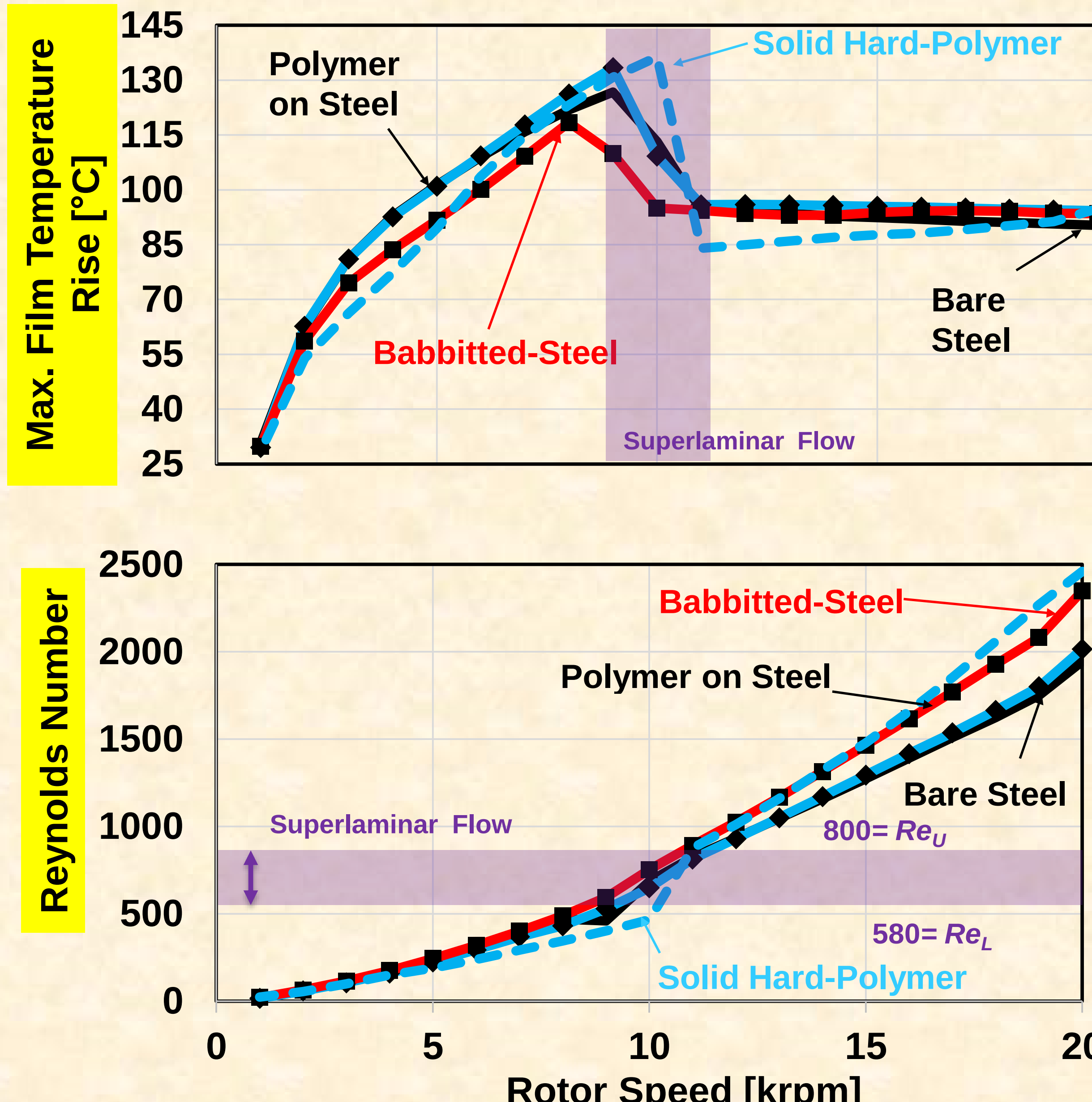
Oil Temp = 46 ^{0}C
Load = 3 MPa



The Babbitted-steel pad has the lowest film maximum temperature rise:

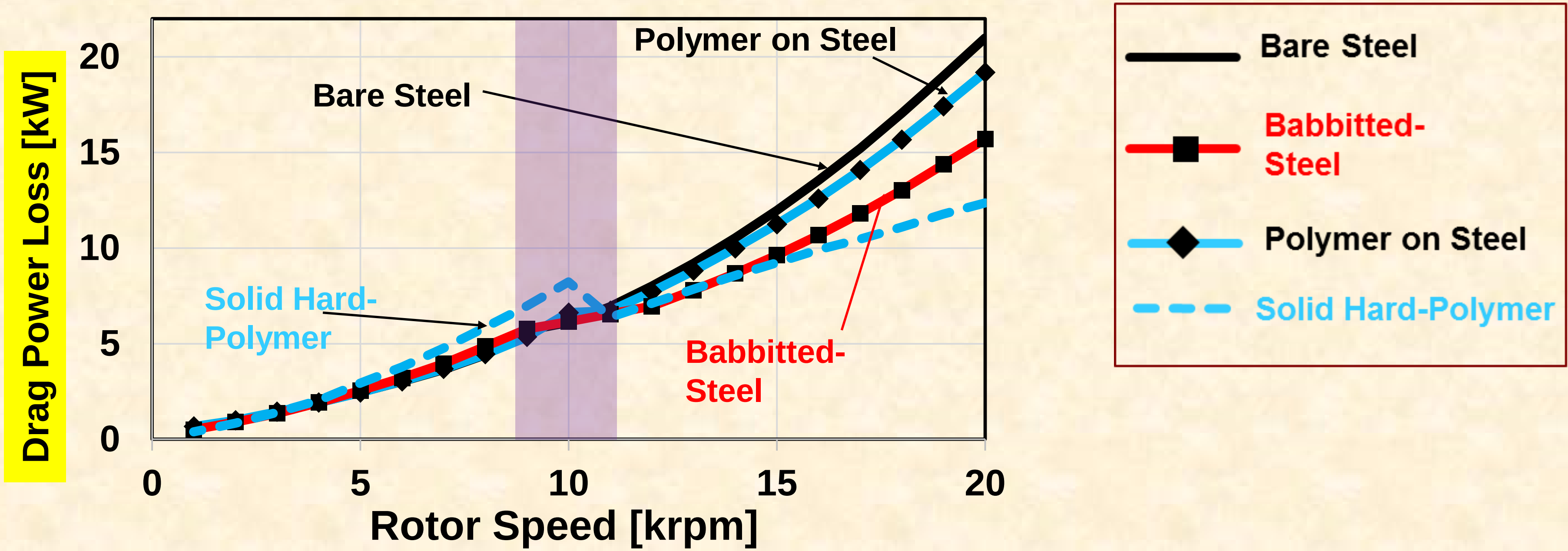
- **20°C lesser than that in the hard-polymer pad due to an early transition to superlaminar flow.**

The solid hard-polymer pad produces largest film temperature = 136C+46C= 182°C, near oil flash point at 196°C for ISO VG32 oil.



Drag Power Loss vs Speed

Oil Temp = 46 ^{0}C
Load = 3 MPa



❑ <u>**Under laminar flow (shaft speed < 10 krpm)**</u>

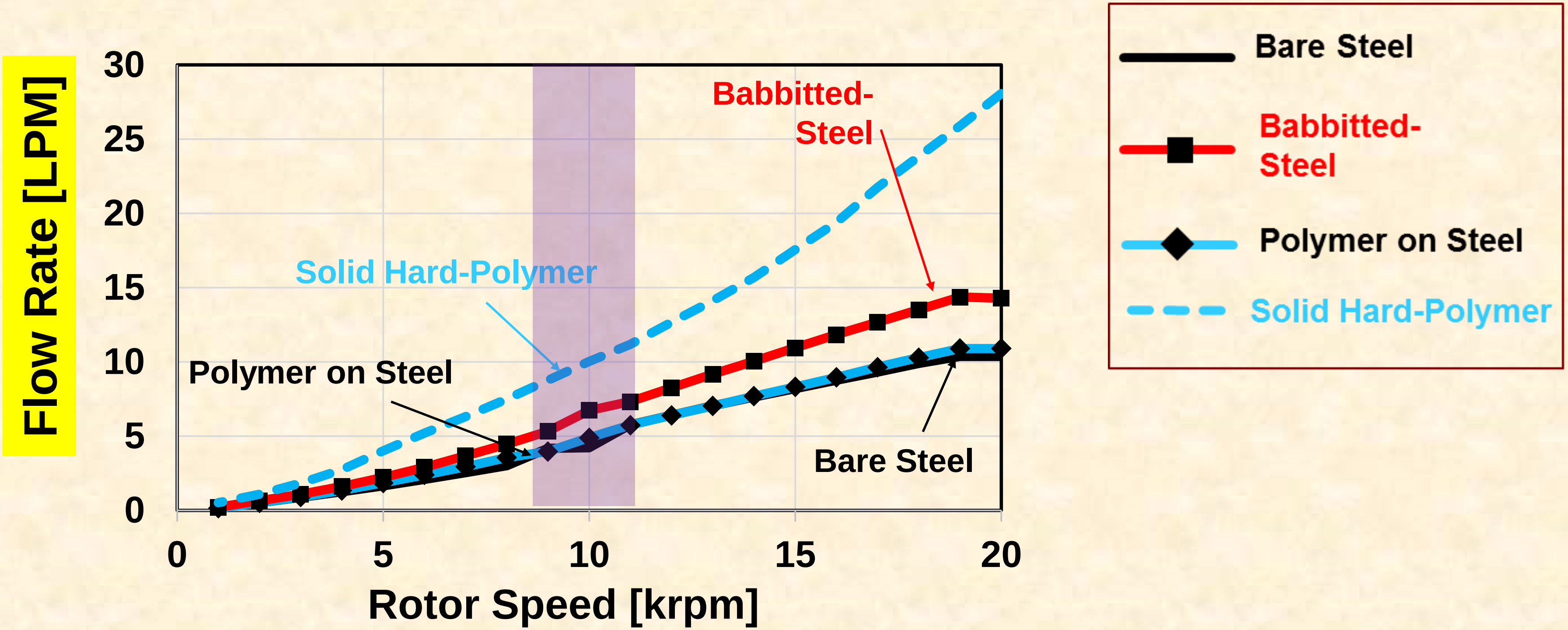
Solid hard-polymer pad produces the largest drag power loss, 25% more than those for other pad types.

❑ <u>**Under turbulent flow (shaft speed > 12 krpm)**</u>

Due to its higher film thickness, solid hard-polymer pad produces the smallest drag power loss: 22% and 35% lesser than those for a Babbitted-steel pad and the polymer liner-steel pad, respectively.

Supply Flow Rate vs Speed

Oil Temp = 46 ^{0}C
Load = 3 MPa

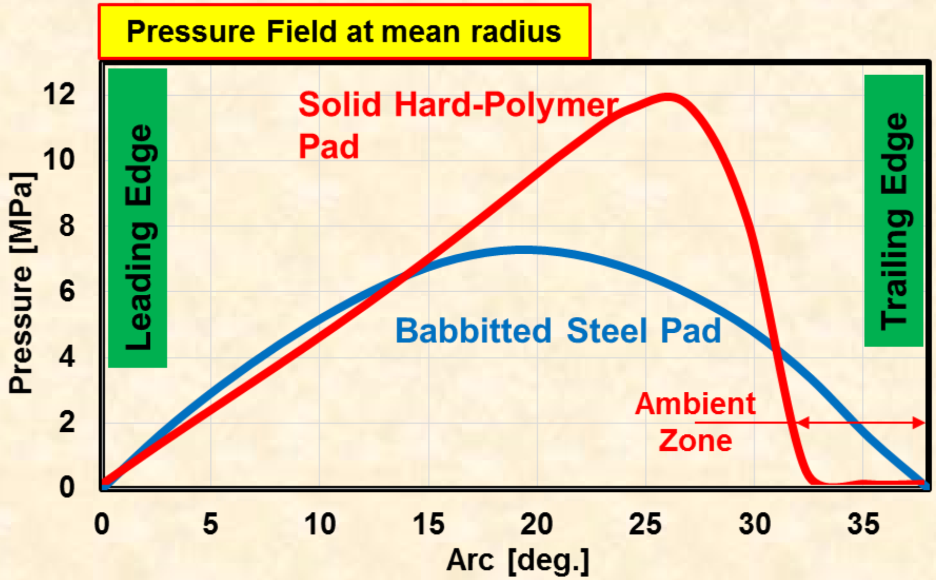


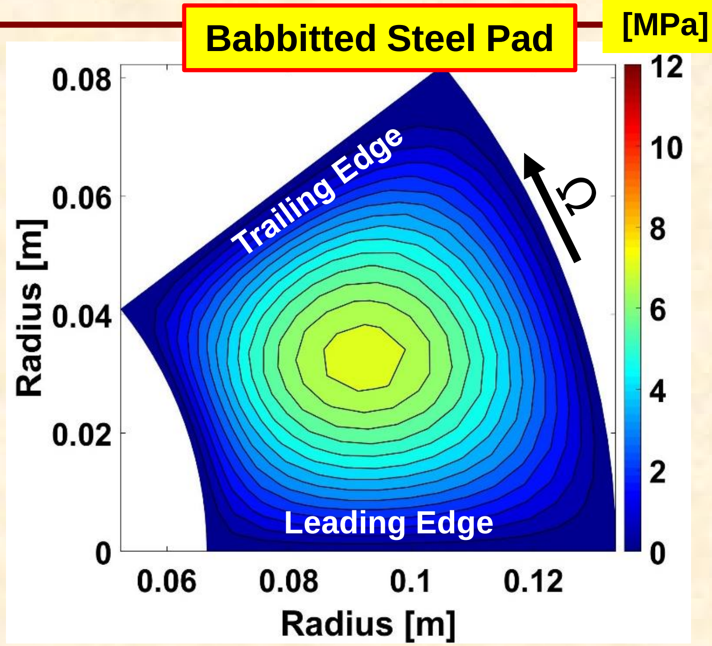
Due to large mechanical deformation at the pad leading edge → Flow for the hard-polymer pad is significantly higher than those for the other pad types.

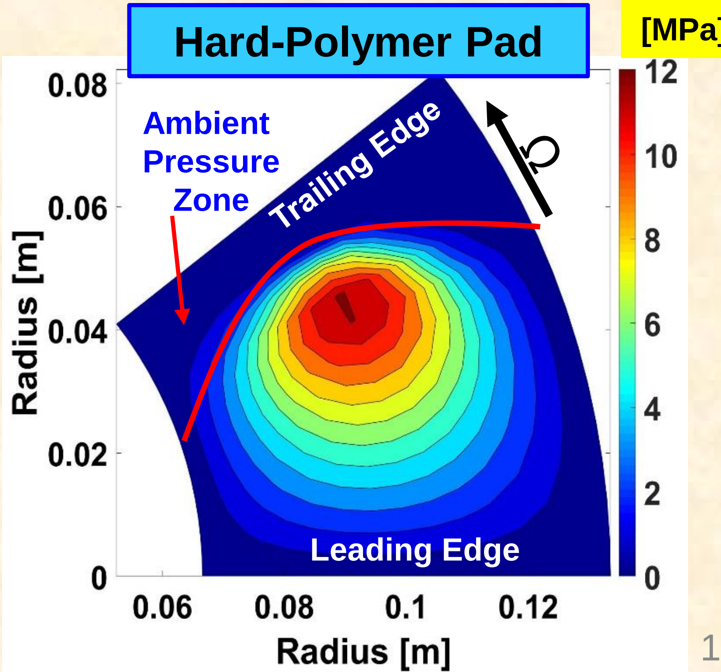
Due to a larger thermal rise, the polymer liner-steel pad requires a low flow rate, ~ 2/3 of the one for the Babbitted-steel pad.

Hard-Polymer vs Babbitted Pad: Pressure Field

Speed = 10 krpm, Load/Pad = 3.0 MPa, Oil Temp = 46 ^{0}C,







Babbited-Steel pad:

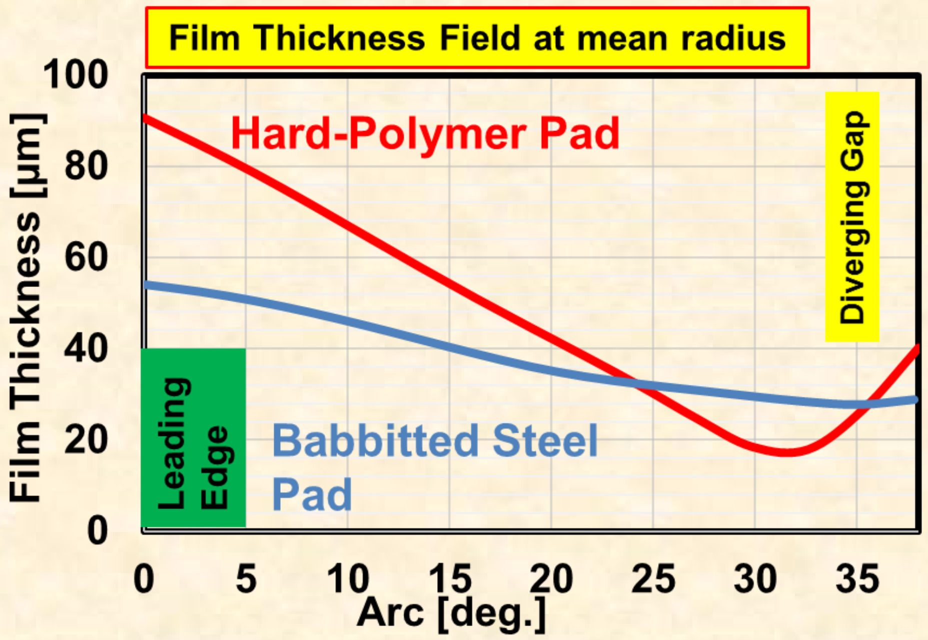
- Pressure extends over whole pad.
- Low peak pressure ≈ 50% of one in hard-polymer pad.

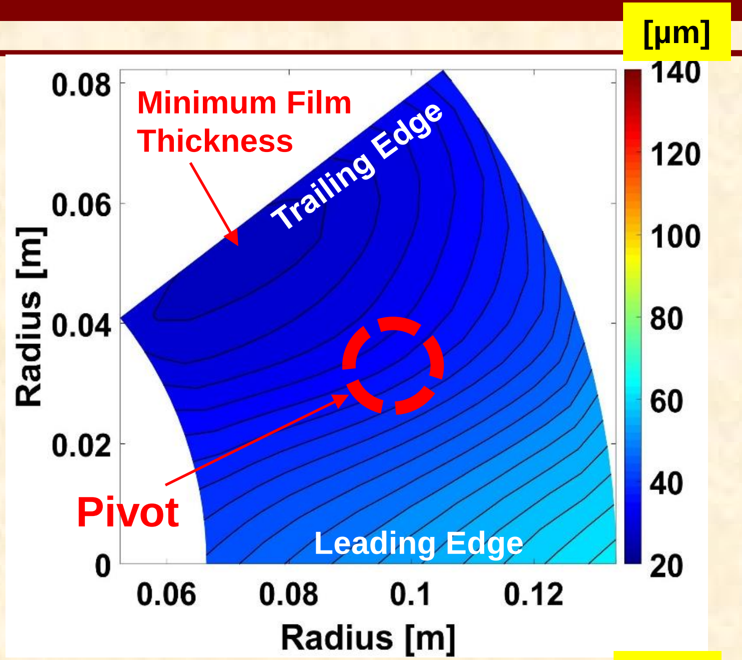
Solid hard-polymer pad:

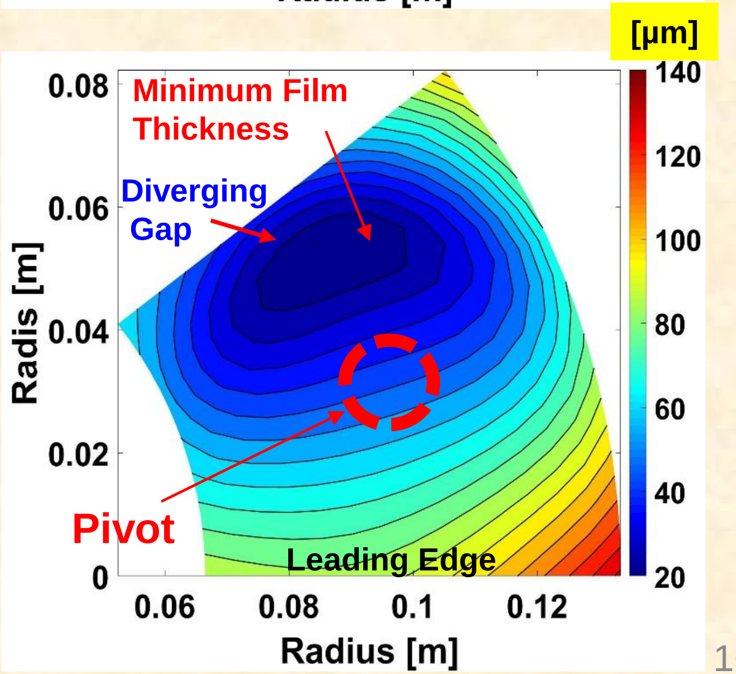
- Areas denuded of oil near trailing edge.
- Large peak pressure ≈ 4 x specific pressure.

Hard-Polymer Vs Babbitted Pad: Film Thickness

Speed = 10 krpm, Load/Pad = 3.0 MPa, Oil Temp = 46 ^{0}C,



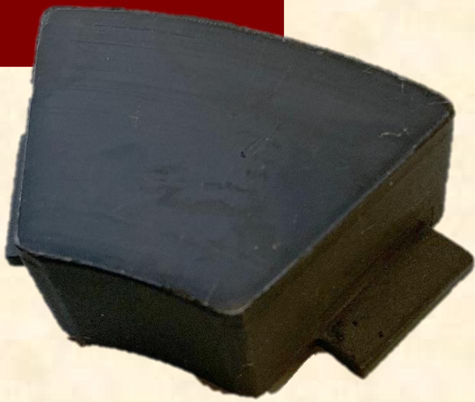




Solid hard polymer pad vs common-use Babbitted-steel pad produces:

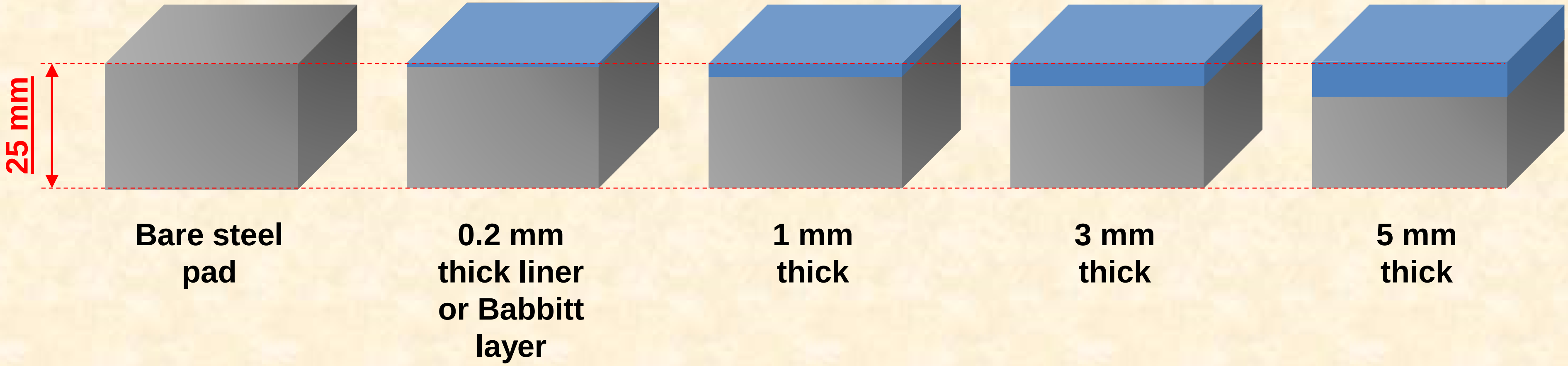
- **Smaller minimum film thickness.**
- **Diverging gap near pad trailing edge**
- **Larger maximum film thickness.**

Effect of liner thickness on TPB performance



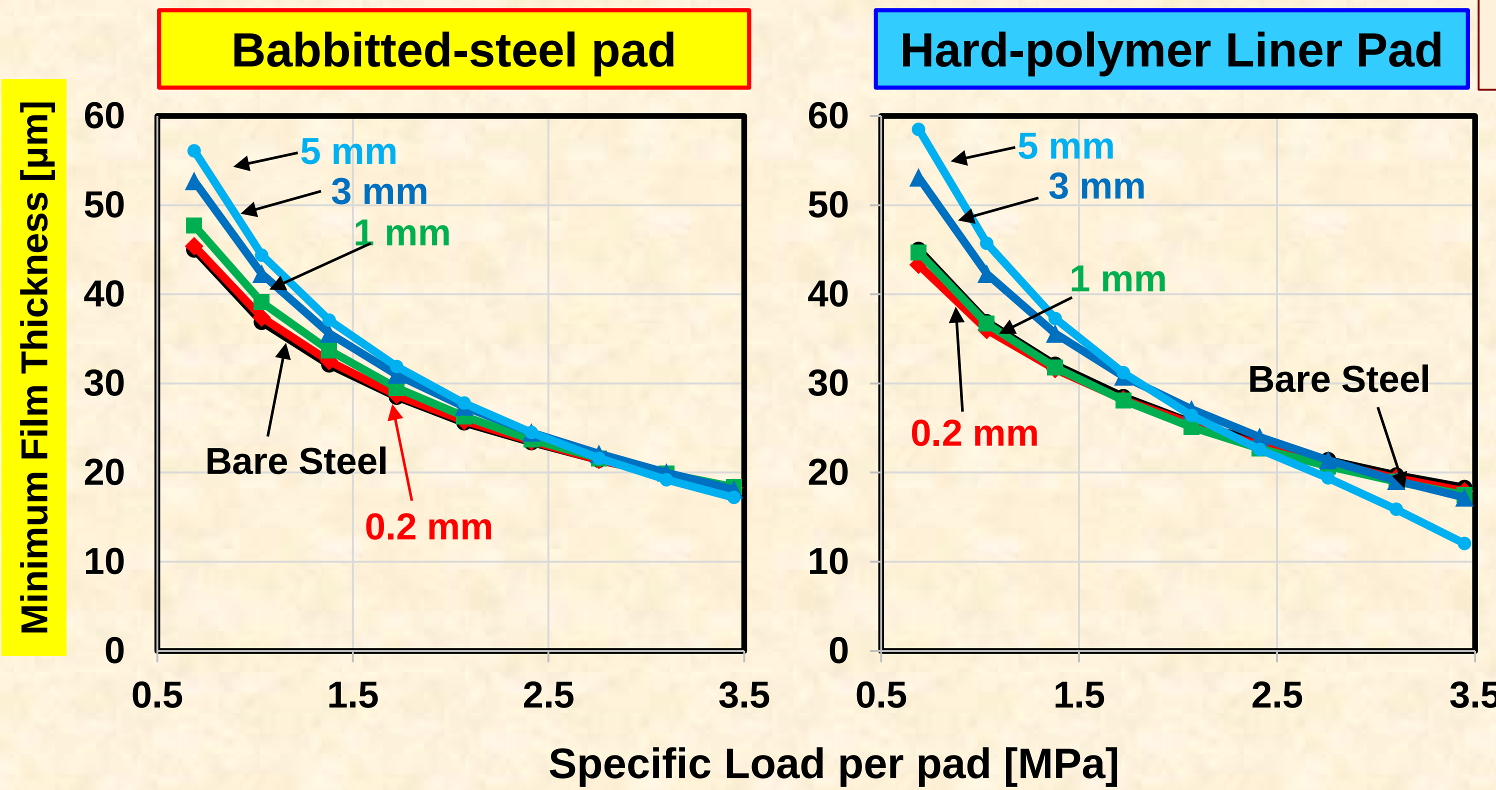
For a drop-in pad change in bearing: keep pad thickness = 25 mm.

Change in polymer thickness or babbitt thickness → change in steel backing portion thickness.



Babbitt vs Hard-Polymer Liner: Min. Film Thickness

Speed = 4 krpm,
Oil Temp = 46 ^{0}C,

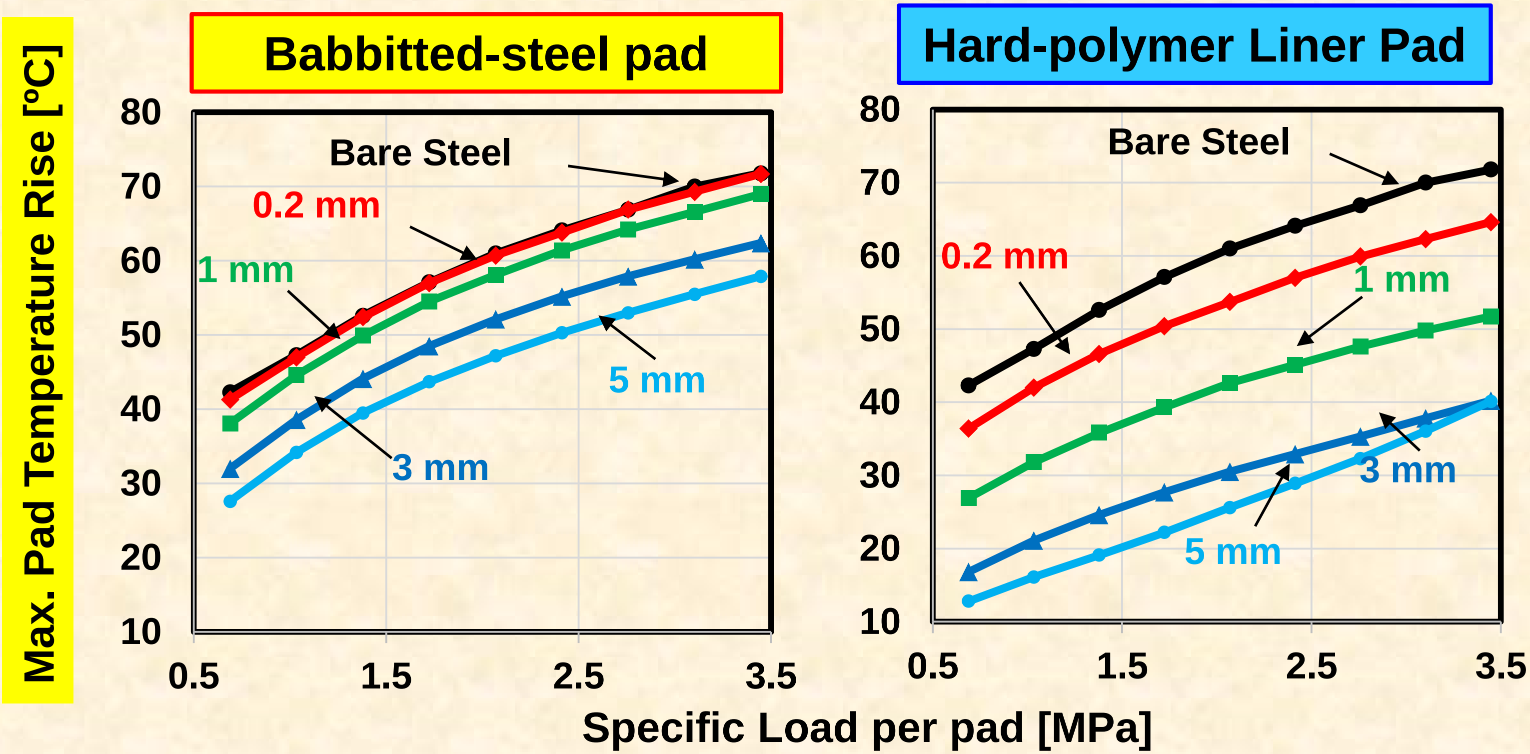


Under a light load < 1 MPa → minimum film thickness increases as babbitt or hard-polymer liner thickness increases

Under a heavy load > 2 MPa → **opposite effect.**

Babbitt vs Hard-Polymer Liner: Max Pad Temperature

Speed = 4 krpm, Oil Temp = 46 ^{0}C,



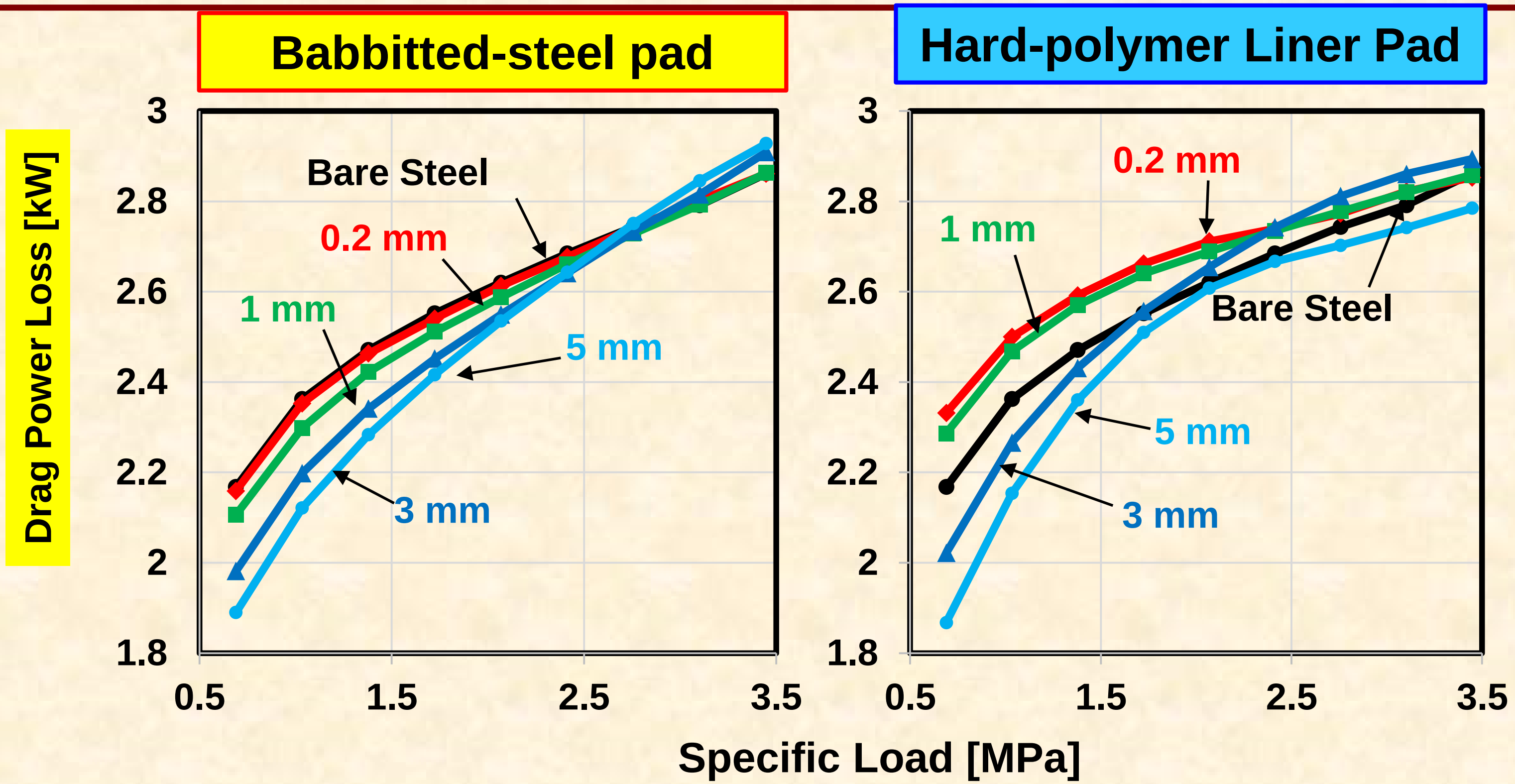
A Babbitt layer should be sufficiently thick (>1 mm) to effectively lower the pad peak temperature rise.

Even a thin 0.2 mm hard-polymer liner isolates pad from film to lower the pad temperature rise.

A thick 5 mm hard-polymer liner reduces a pad temperature rise up to 30°C, ~ ¼ of that for bare steel pad.

Babbitt vs Hard-Polymer Liner: Drag Power Loss

Speed = 4 krpm, Oil Temp = 46 °C,



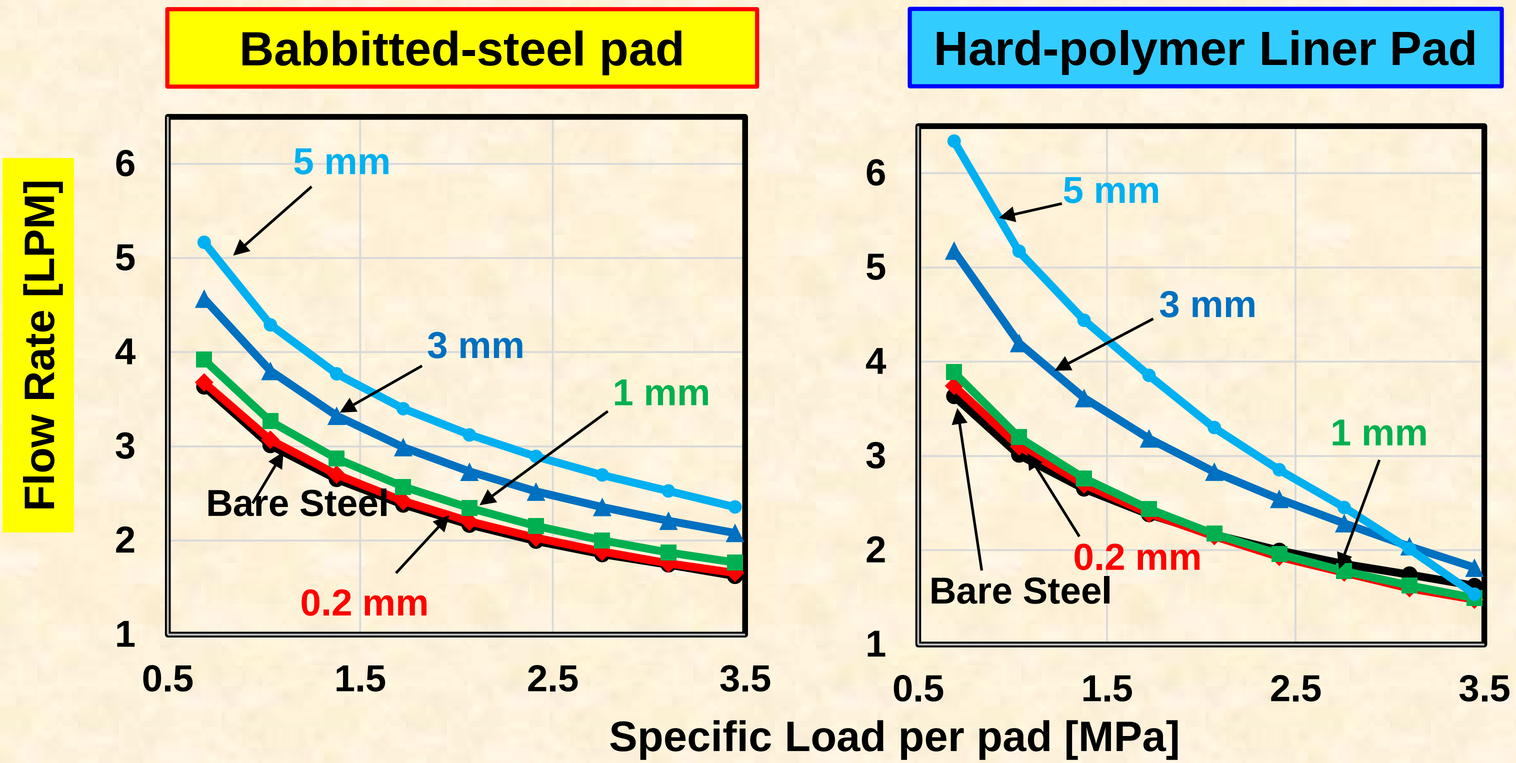
Both Babitt thickness and a hard-polymer liner thickness influence the drag power loss.

<u>Under a light specific load >2.0 MPa</u>, due to a larger film thickness, a thicker liner produces a lesser power loss,

<u>Under a heavy specific load >2.0 MPa</u>, all pads show ~ the same drag power loss, as their film thicknesses are similar.

Babbitt vs Hard-Polymer Liner: Flow Rate

Speed = 4 krpm, Oil Temp = 46 ^{0}C,



For both hard-polymer liner-steel pad and Babbitted steel pad, the layer thickness does change the flow rate, <u>due to changes in fluid film thickness.</u>

A thick 5 mm babbitted-steel pad requires a flow rate almost twice that of the baseline steel pad.

A thin line of hard-polymer does not affect flow rate, however, a thick layer does.

Conclusion

Effect of Pad and Liner Material Properties on the Static Load Performance of a Tilting Pad Thrust Bearing

Conclusion

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- A solid hard polymer pad can improve bearing performance for operation at a high rotor speed as it offers a low drag power loss and a large fluid film thickness.
- Both a solid hard-polymer pad and a hard-polymer liner on a steel pad isolate the fluid film to increase the oil temperature near its flash point.
- Due to a large mechanical deformation of the hard-polymer pad, the analysis predicts lubricant cavitation at the pad trailing edge when operating under a heavy load.
- Compared to a Babbitted-steel pad, a thin liner of hard-polymer on a steel pad lower the pad thermal deformations → reduces the fluid film thickness → a lesser flow rate but more drag power losses.

Planned Work

A hard-polymer pad improves bearing load performance; however, it demands a significantly larger supply flow rate.

- **Work will focus on modeling the effects of flow starvation on the static load performance of polymer lined TPTBs to minimize the supply flow and the drag power loss.**

Thanks to the Turbomachinery Research Consortium for a multiple year support and continued interest.

Questions (?)

Learn more at http://rotorlab.tamu.edu