National Aeronautics and Space Administration

Comparison of Models for Rolling Bearing Dynamic Capacity and Life

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STLE
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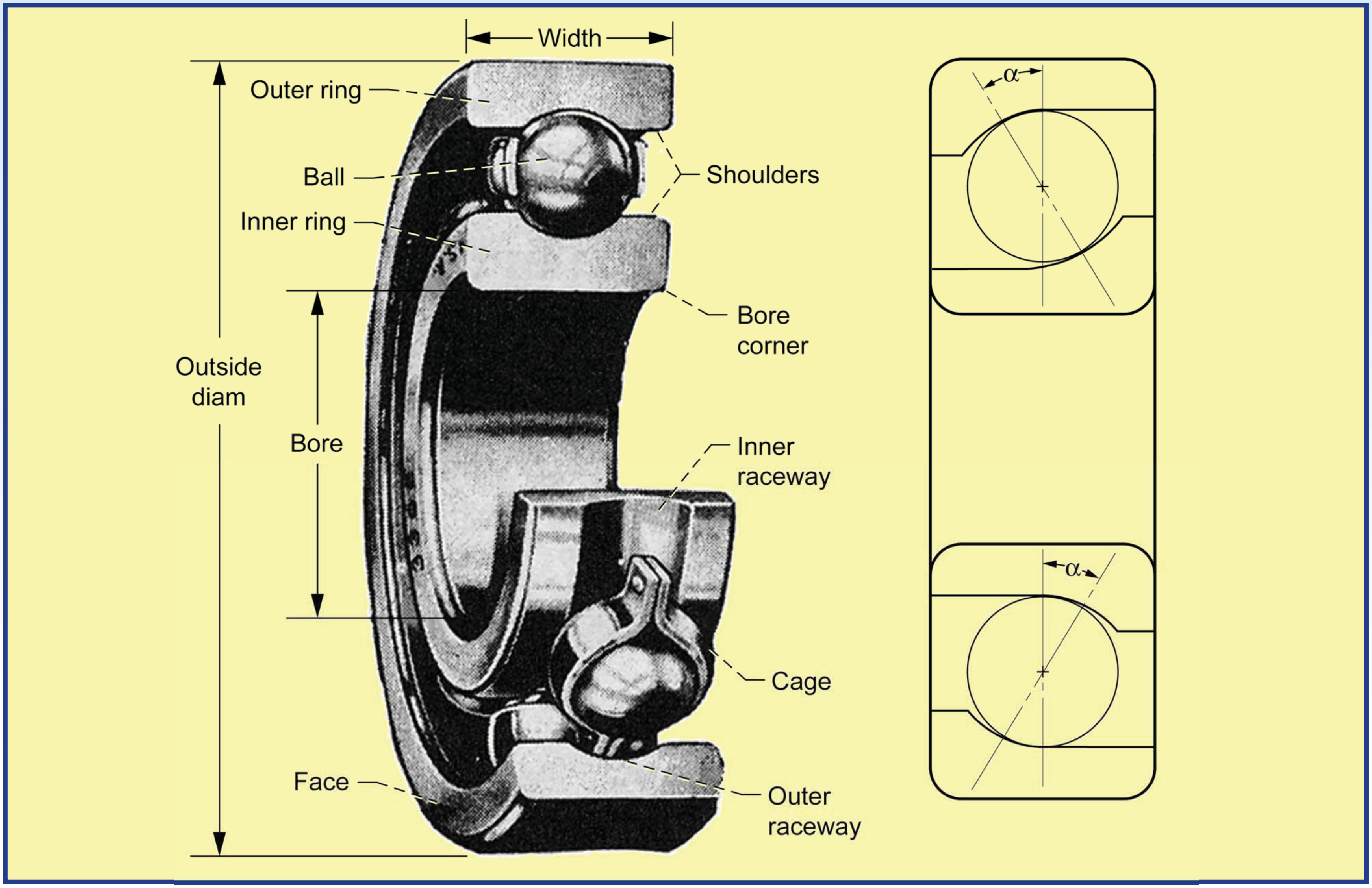
STLE 2013 DETROIT

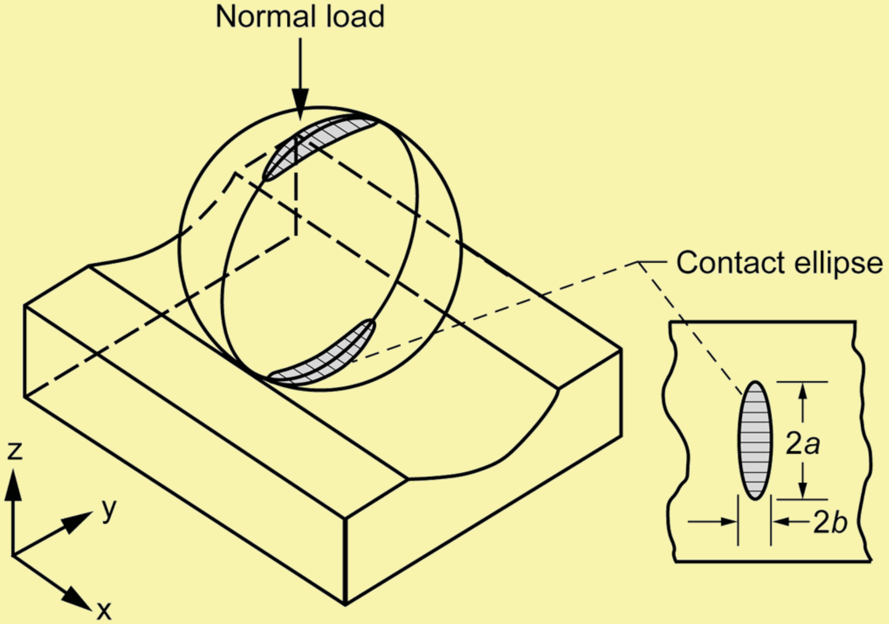
Objectives

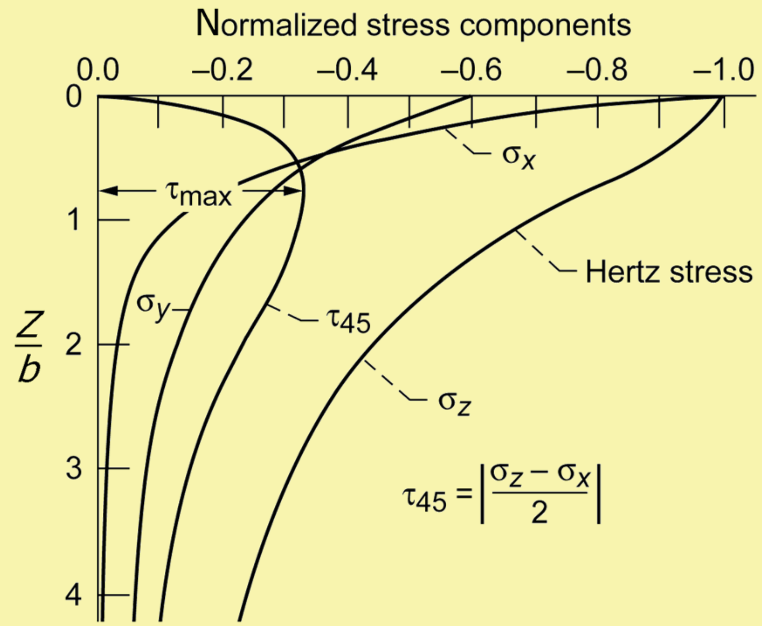
- Update Lundberg-Palmgren (LP) life model
- Incorporate Updated LP and Zaretsky (Z) models into ADORE bearing code
- Benchmark updated LP and Z life models to contemporary bearing life data
- Compare Lundberg-Palmgren with Zaretsky life models

Deep Groove and Angular Contact Ball Bearing



Ball Bearing Stresses Below Contact Patch





Stressed Volume: ***V = a * Z * [track length]***

Ball Bearing Life

1947 Lundberg-Palmgren Life Model

$$L_{LP} = K_{LP}\left(\frac{1}{\tau_o}\right)^{c/e}\left(\frac{1}{V_o}\right)^{1/e}\left(Z_o\right)^{h/e} = K_{LP}\left(\frac{1}{\tau_o}\right)^{9.3}\left(\frac{1}{V_o}\right)^{0.9}\left(Z_o\right)^{2.1}$$

where

L_{LP} = Lundberg-Palmgren L_{10} life

K_{LP} = Material & geometry constant

τ_0 = Maximum orthogonal shear stress

V_0 = Stressed volume

Z_0 = Depth to maximum orthogonal shear stress

c, h, e … exponents chosen to fit experimental data

L-P Model Stress-Life & Load-Life Exponents

for Lundberg-Palmgren model, point contact

$$L_{LP} \sim \left(\frac{1}{\tau_o}\right)^{c/e} \left(\frac{1}{V_o}\right)^{1/e} \left(Z_o\right)^{h/e} \sim \left(\frac{1}{S_{\max}}\right)^{9.3} \left(\frac{1}{S_{\max}^2}\right)^{0.9} \left(S_{\max}\right)^{2.1} \sim \left(\frac{1}{S_{\max}}\right)^{n}$$

where

c, h, e, n, p … **exponents**

Q **= Applied load**

S_{max} **= Max. Hertz stress**

$$n = \frac{c+2-h}{e} = 9.3 + 2(0.9) - 2.1 = 9 \;\Rightarrow L \sim \left(\frac{1}{S_{\max}}\right)^{9}$$

$$S_{\max} \sim Q^{1/3} \quad \Rightarrow L \sim \left(\frac{1}{Q}\right)^{3}$$

Ball Bearing Life

1987 Zaretsky Life Model

$$L_Z = K_Z \left(\frac{1}{\tau_m}\right)^c \left(\frac{1}{V_m}\right)^{1/e} = K_Z \left(\frac{1}{\tau_m}\right)^{10.3} \left(\frac{1}{V_m}\right)^{0.9}$$

where

L_Z **= Zaretsky L_{10} life**

K_Z **= Material & geometry constant, where $K_Z \neq K_{LP}$**

τ_m **= Maximum shear stress**

V_m **= Stressed volume**

c, e **… exponents**

(exponent 'h' in LP equation → 0)

Zaretsky Model Stress-Life & Load-Life Exponents

for Zaretsky model with point contact

$$L_Z \sim \left(\frac{1}{\tau_m}\right)^c \left(\frac{1}{V_m}\right)^{1/e} \sim \left(\frac{1}{S_{\max}}\right)^{10.3} \left(\frac{1}{S_{\max}^2}\right)^{0.9} \sim \left(\frac{1}{S_{\max}}\right)^n$$

where

c, h, e, n, p **… exponents, and** $h = 0$

S_{max} **= Max. Hertz stress**

Q **= Applied load**

$$n = c + \frac{2}{e} = 10.3 + 2(0.9) = 12$$

$$S_{\max} \sim Q^{1/3} \quad \Rightarrow L \sim \left(\frac{1}{Q}\right)^4$$

Load-Life Relationship for Point Contact

$$L = \left(\frac{Q_c}{Q} \right)^p$$

where

L = L_{10} life

Q_c = Dynamic load capacity for L_{10} = 10^6 revolutions

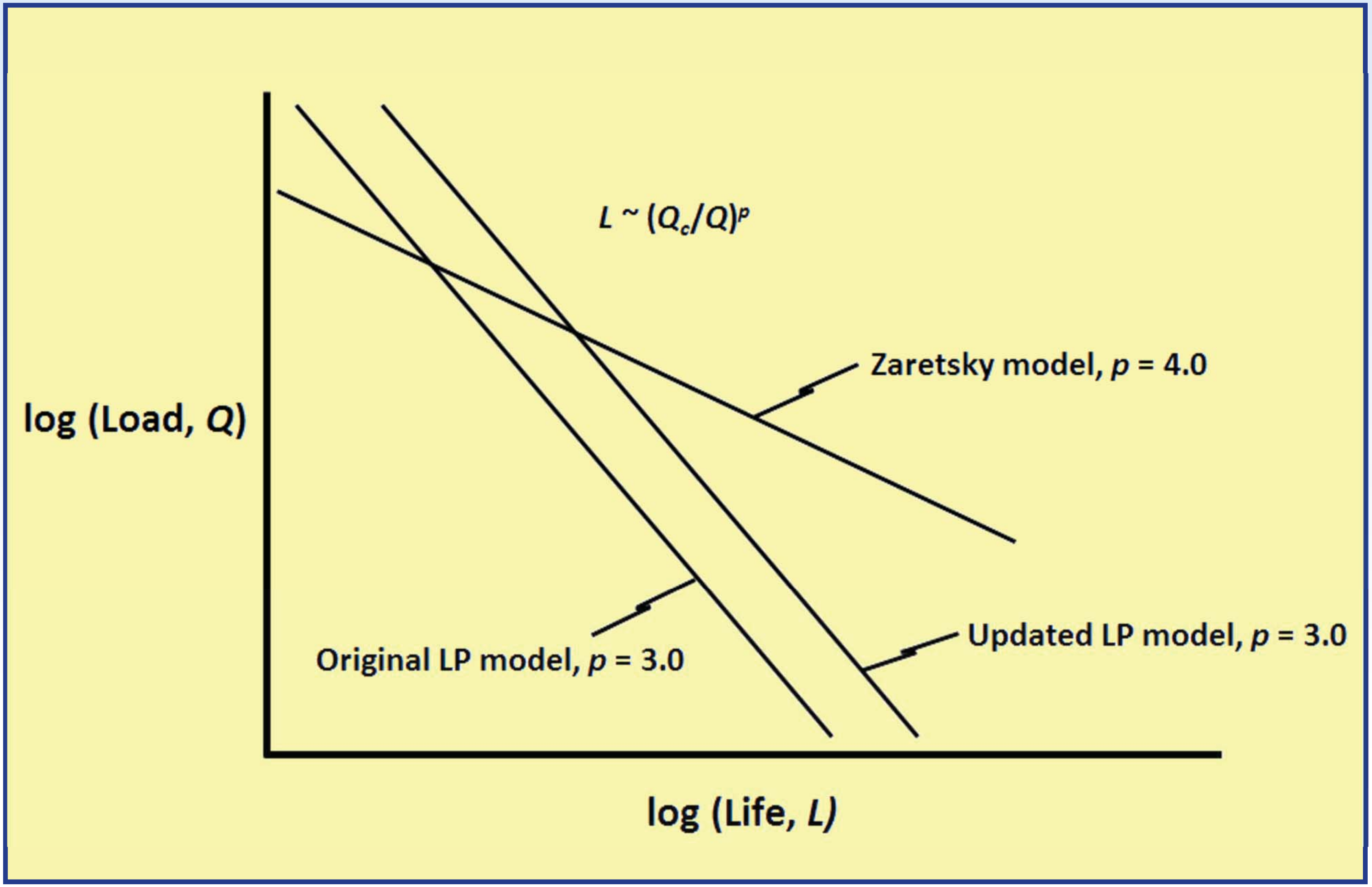
Q = Applied load

p = Load-life exponent, → $p = n/3$

Lundberg-Palmgren model: $p = 9/3 = 3$

Zaretsky model: $p = 12/3 \approx 4$

Comparison of Load-Life Relationships



Procedure

Update Lundberg-Palmgren life model

- Separate material & geometry constants from model
- Incorporate into bearing code ADORE
- Derive a new geometry constant
- Benchmark life model to published life data
- Compute new bearing dynamic capacity

Apply similar process to Zaretsky model

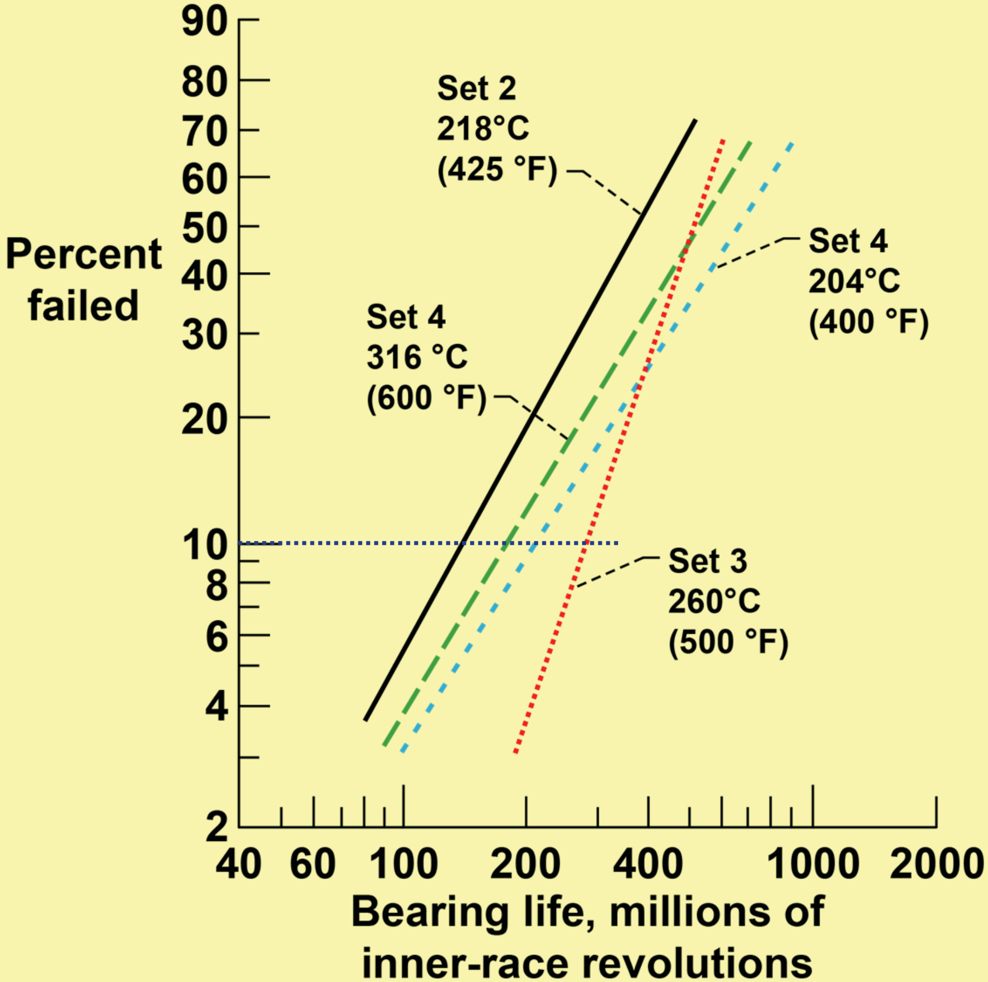
Compare lives: Orig. LP, Updated LP, Zaretsky Models

Bearing Life Database Parameters

- 120-mm bore, 20º angular contact ball bearing
- 15 balls, 20.6 mm (13/16”) dia.
- AISI M-50 steel, consumable electrode vacuum melted (CEVM)
- Synthetic paraffinic oil (PAO)
- Speed 12,000 rpm (1.44 Million DN)
- Thrust load 25,800 N (5800 lb)

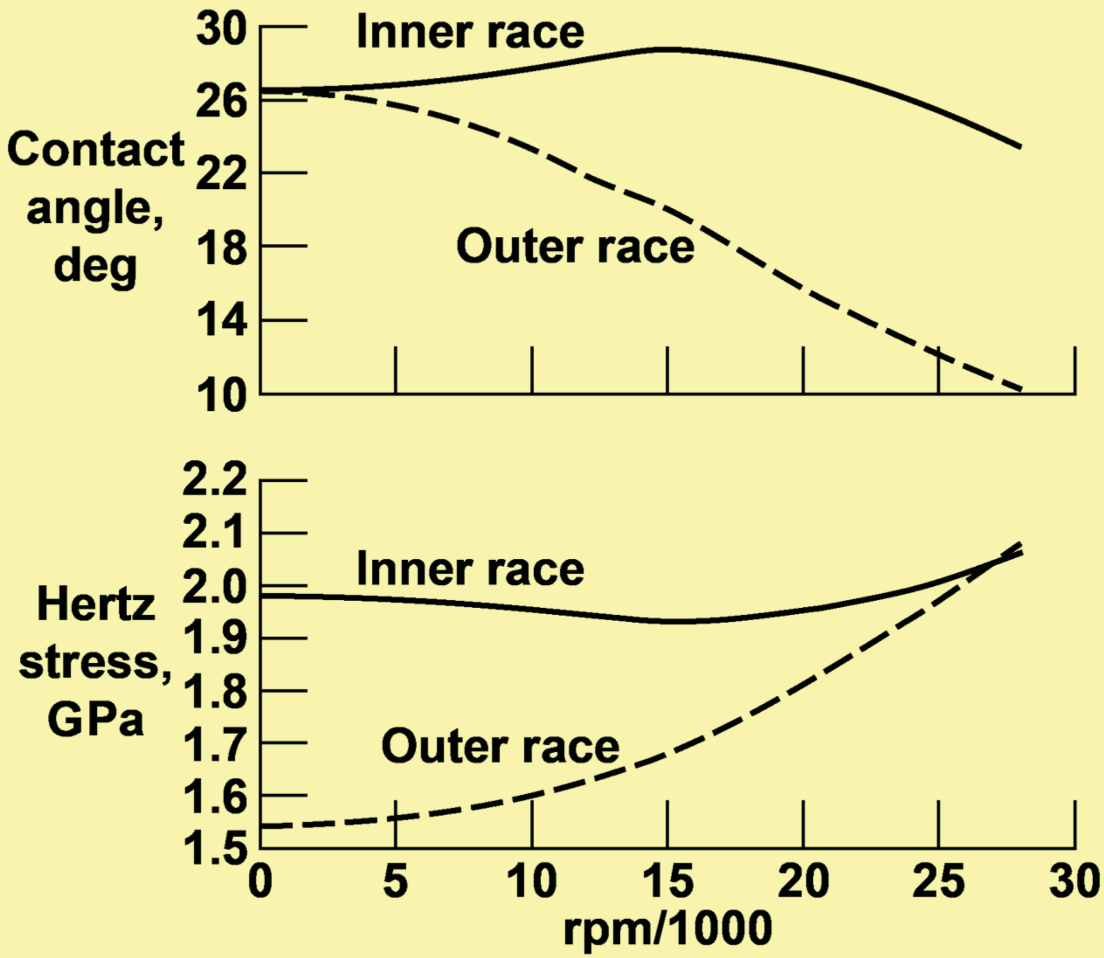
Bearing Life Database

120-mm bore, 20º contact angle, CEVM, AISI M-50 Steel, PAO oil @ 12,000 rpm, 25,800 N (5,800 lb) thrust load



Speed Effect on Hertz Stress and Contact Angle

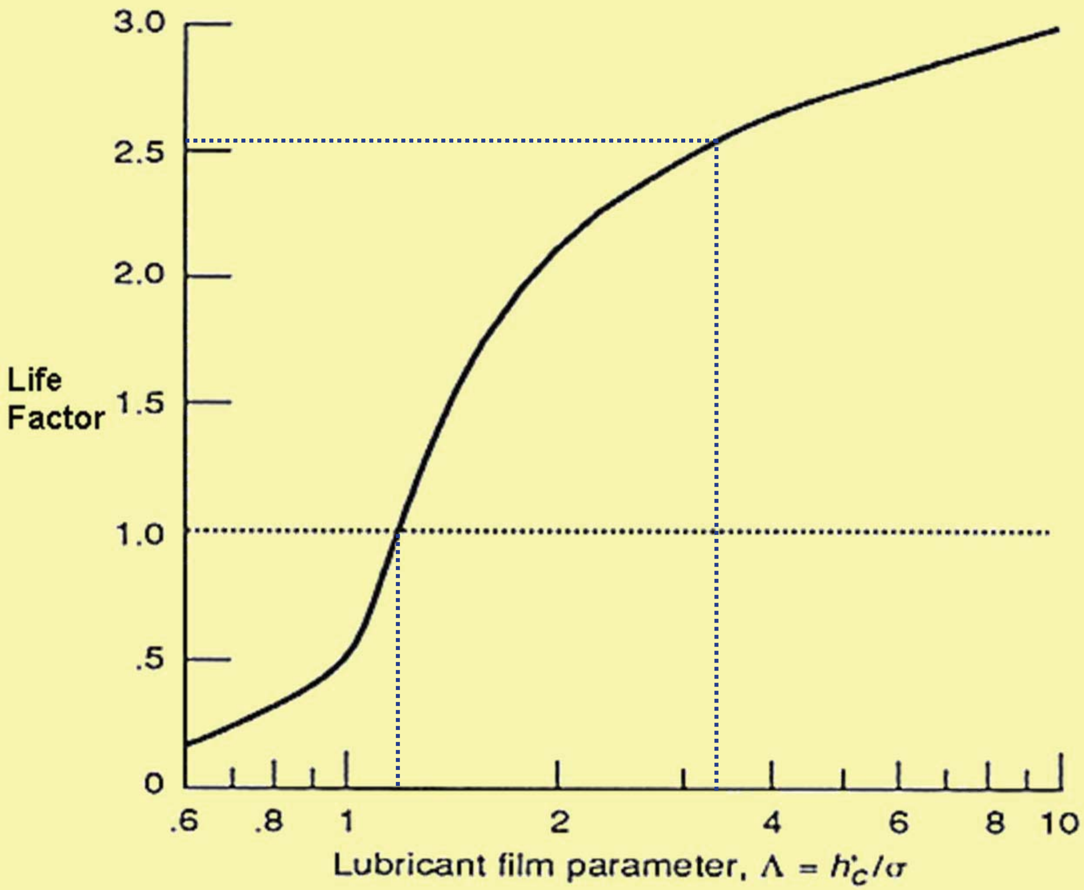
120-mm bore, 24º contact angle, VIM-VAR, AISI M-50 Steel,
@ 25,800 N (5,800 lb) load, MIL-L-23699 oil @ 218 ºC (425ºF)



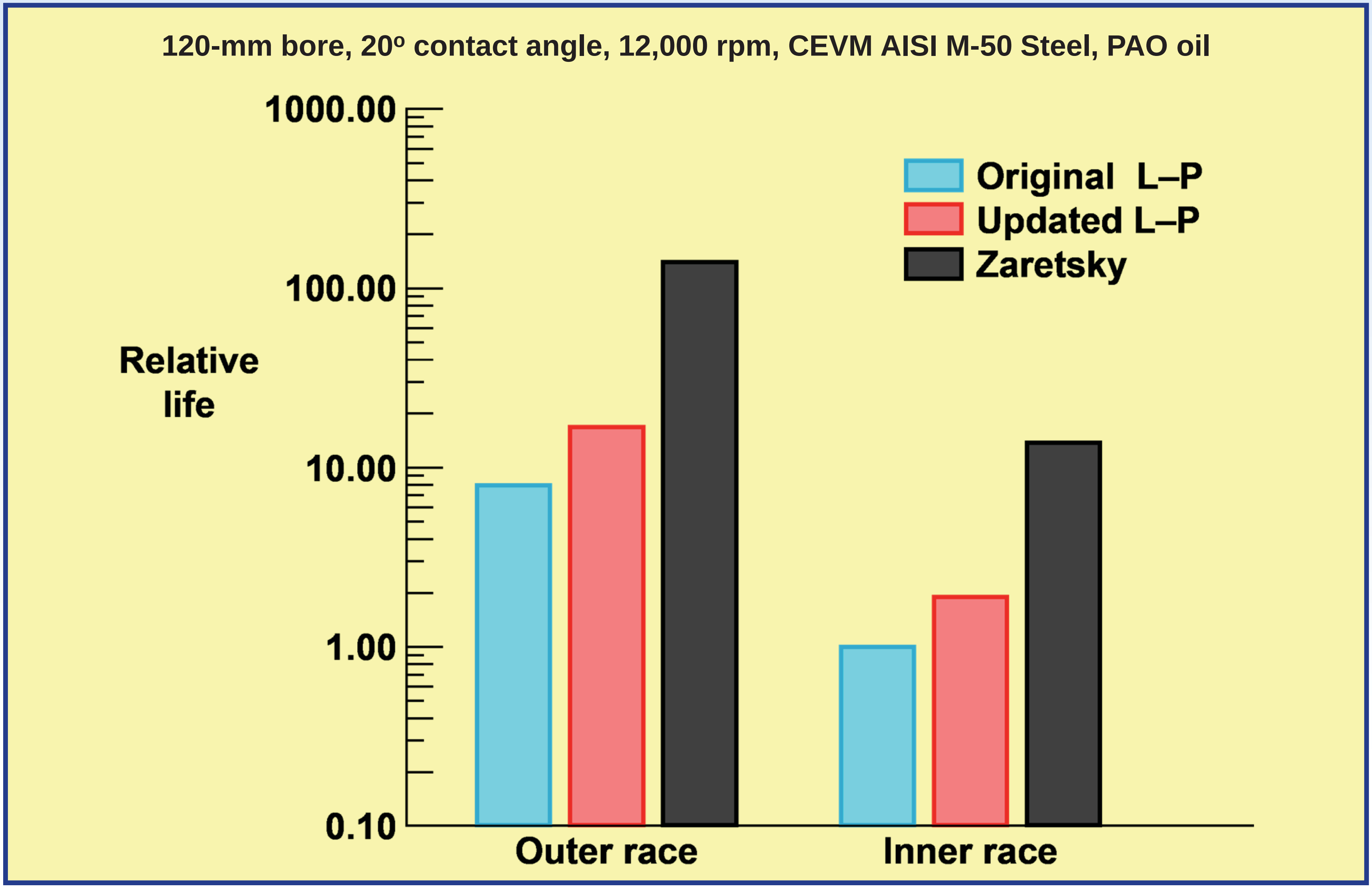
STLE Life Factors Applied

120-mm bore, 24º contact angle, VIM-VAR, AISI M-50 Steel, @ 12,000 rpm, MIL-L-23699 oil @ 218 ºC (425ºF), Film parameter Λ = 3.38

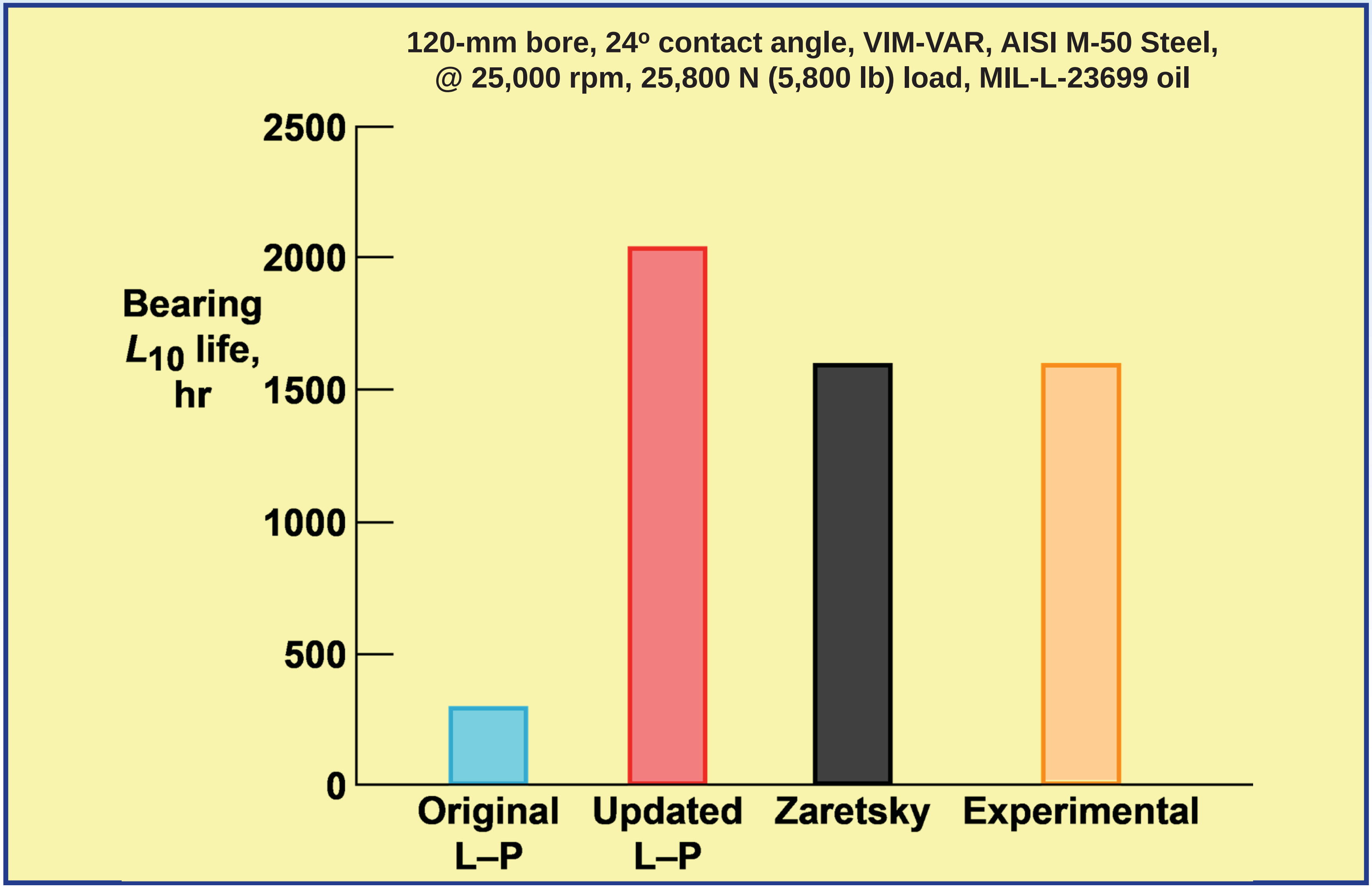
Material (AISI M-50)	2.00
Steel Processing (VIM-VAR)	6.00
Hardness (R_C=62)	1.05
Lubrication	2.52
Life Factor Product	31.75



Relative Life for Three Models

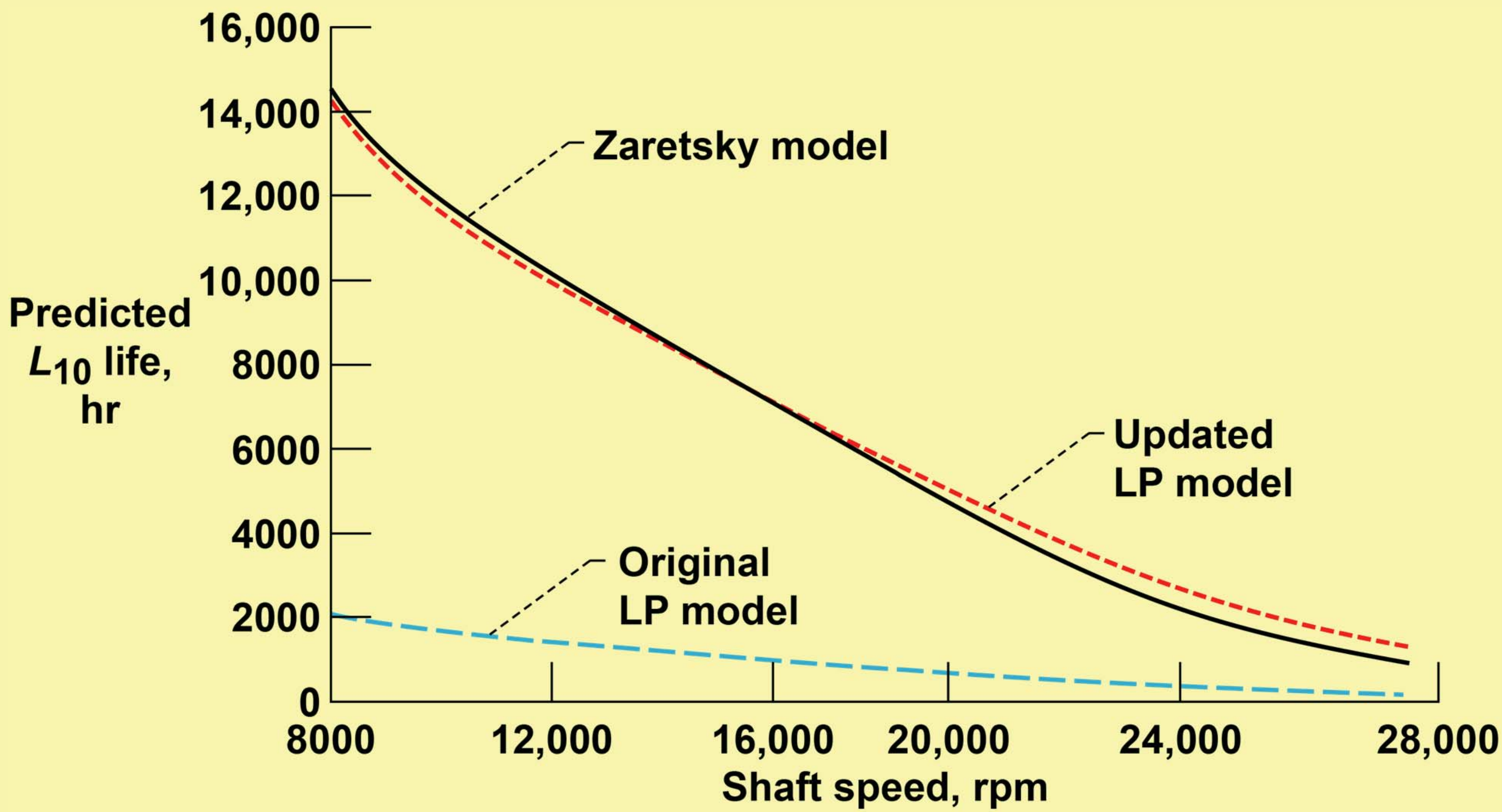


Analysis applied to 3 Million DN Bearing

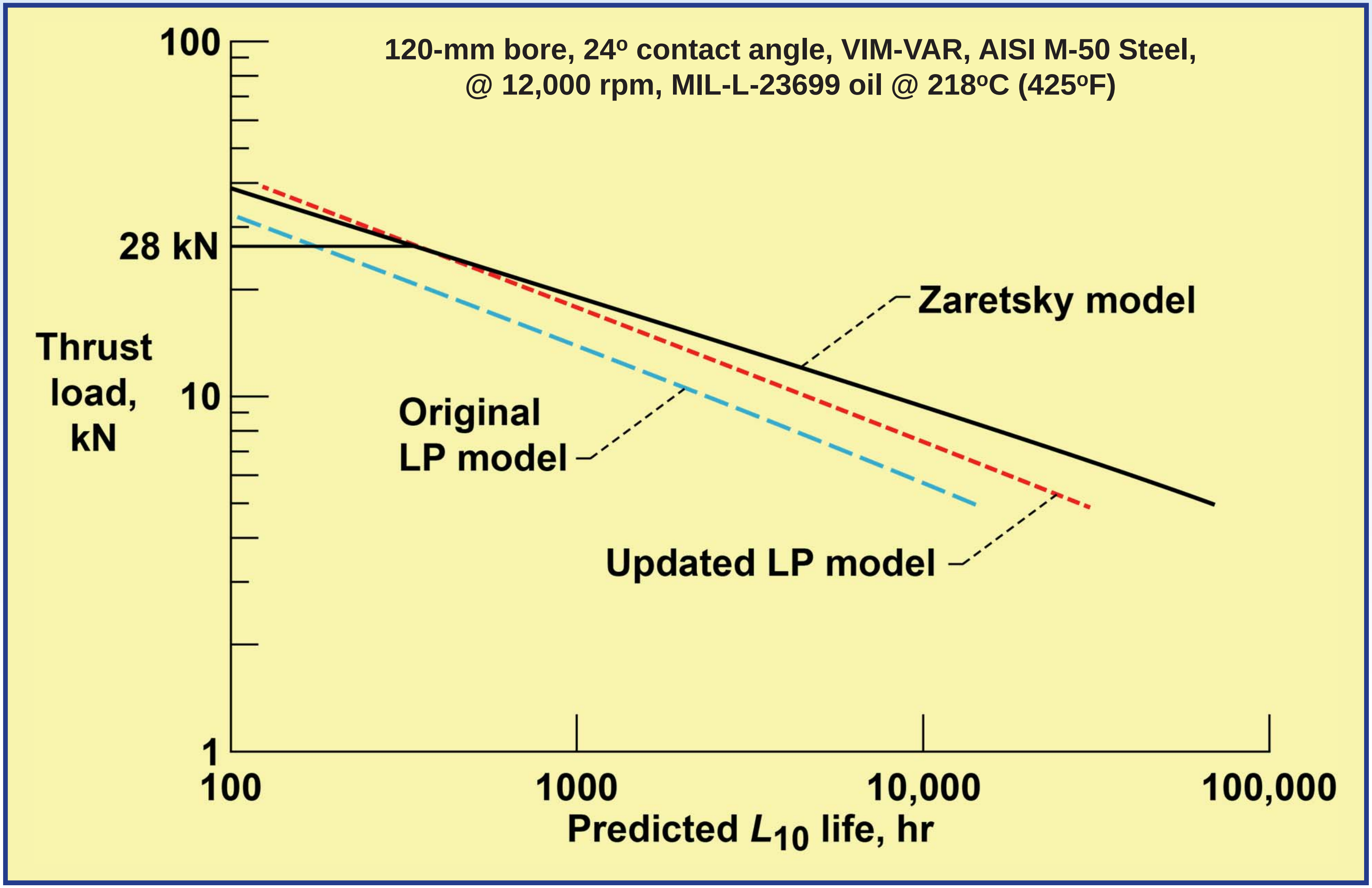


Effect of Speed on L_{10} Life

120-mm bore, 24º contact angle, VIM-VAR, AISI M-50 Steel,
@ 25,800 N (5,800 lb) load, MIL-L-23699 oil @ 218 ºC (ºF)

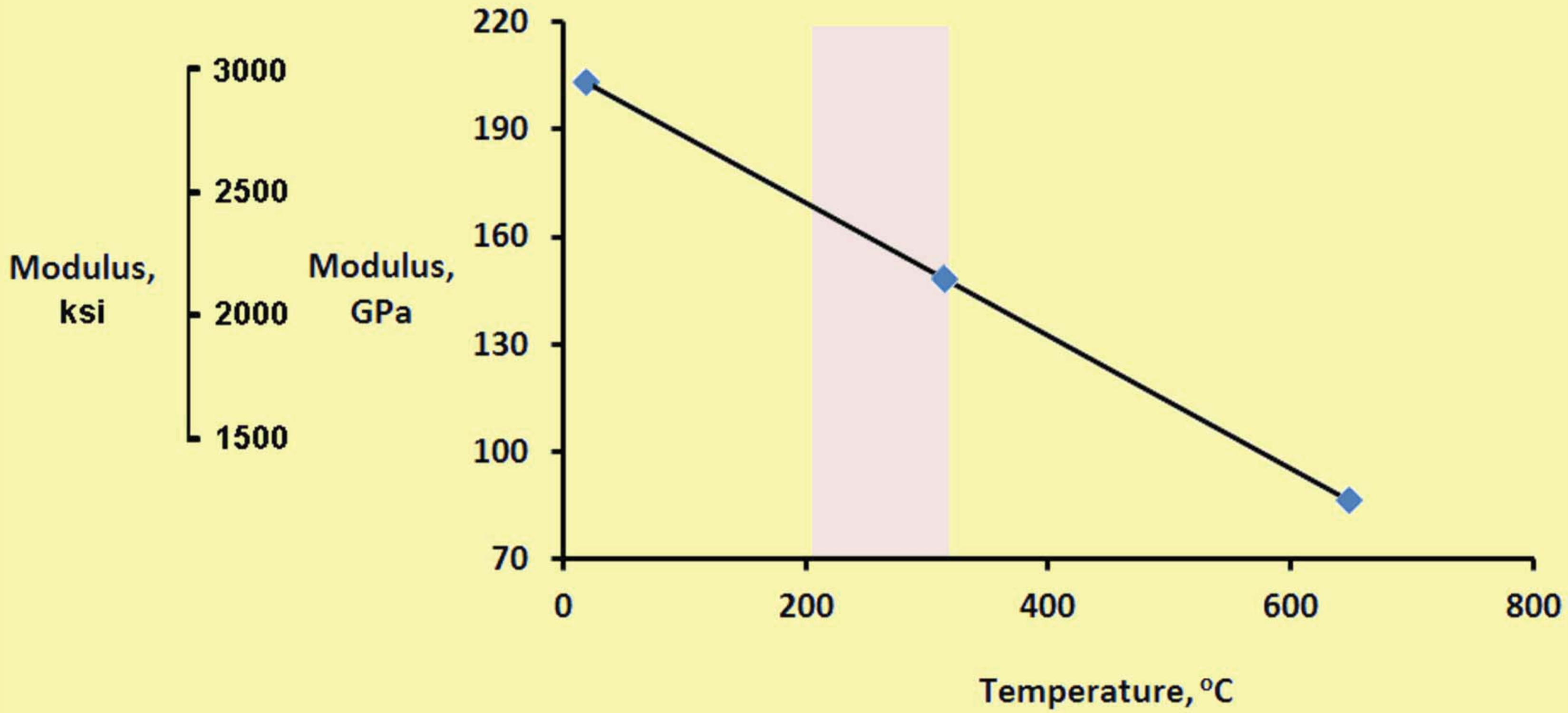


Effect of Thrust Load on L_{10} Life



Variation of Elastic Properties with Temperature

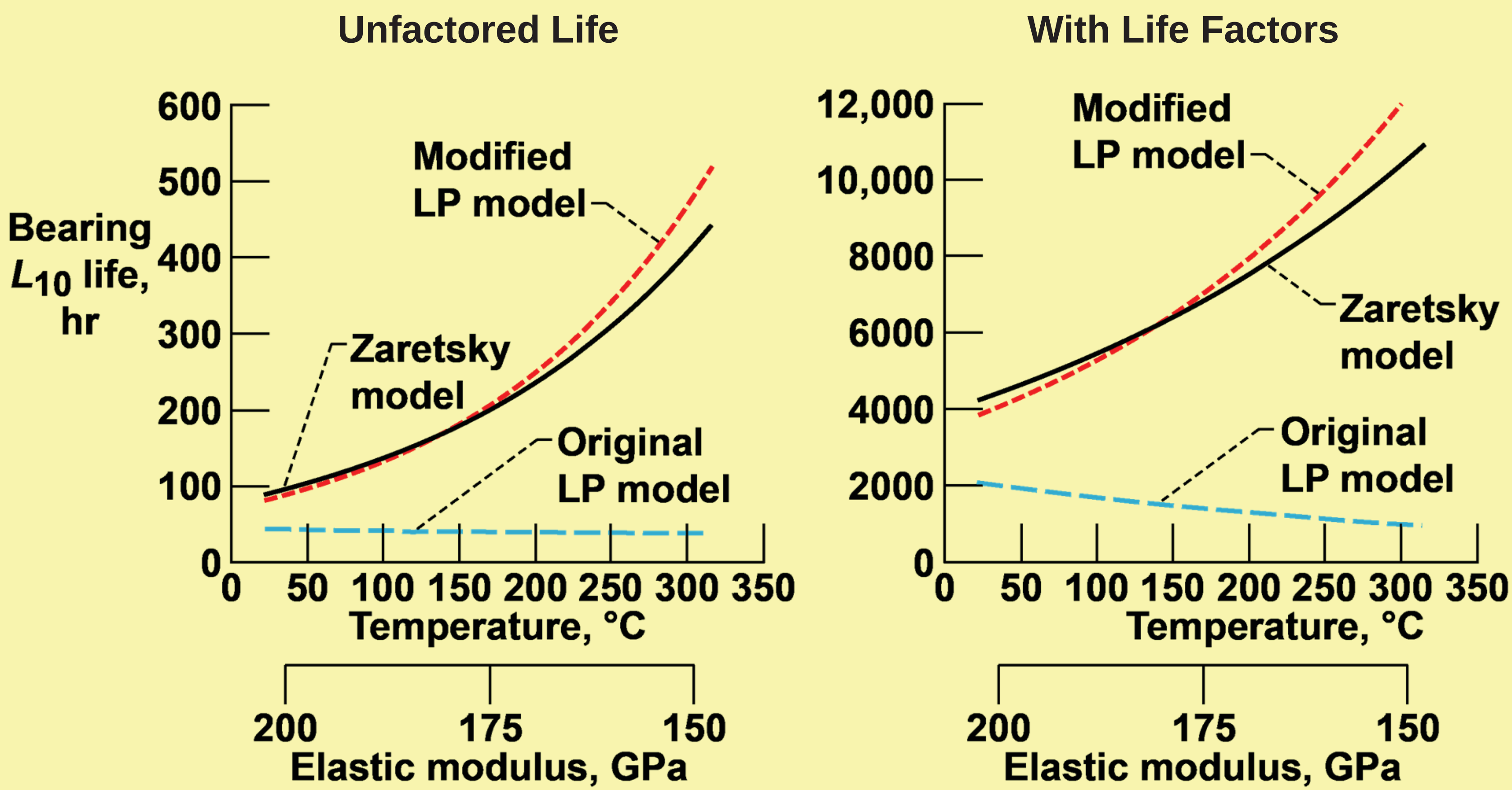
Lower modulus means lower stress, longer life



Source: MatWeb, Online Materials Information Resource
http://www.matweb.com/

Effect of Variation of Elastic Properties on Life

120-mm bore, 24º contact angle, VIM-VAR, AISI M-50 Steel,
@ 12,000 rpm, 25,800 N (5,800 lb) load, MIL-L-23699 oil



Summary of Results

- **Variation of elastic modulus with temperature has significant effect on life. Higher temperatures → longer life**
- **Updated Lundberg-Palmgren model → 7 times life, primarily due to modulus change @ elevated temperature.**
- **Updated Lundberg-Palmgren & Zaretsky models give similar results. Zaretsky model shows shorter life at high speed.**
- **Zaretsky model predicts longer life at light loads and greater life reduction as loads increase.**