EXPERIMENTAL INVESTIGATION RESULTS OF A HYBRID CERAMIC AND ACTIVELY COOLED BALL BEARING FOR GAS TURBINES

13 October 2016
Brussels, Belgium

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HYBRID CERAMIC AND ACTIVELY COOLED BALL BEARING FOR GAS TURBINES

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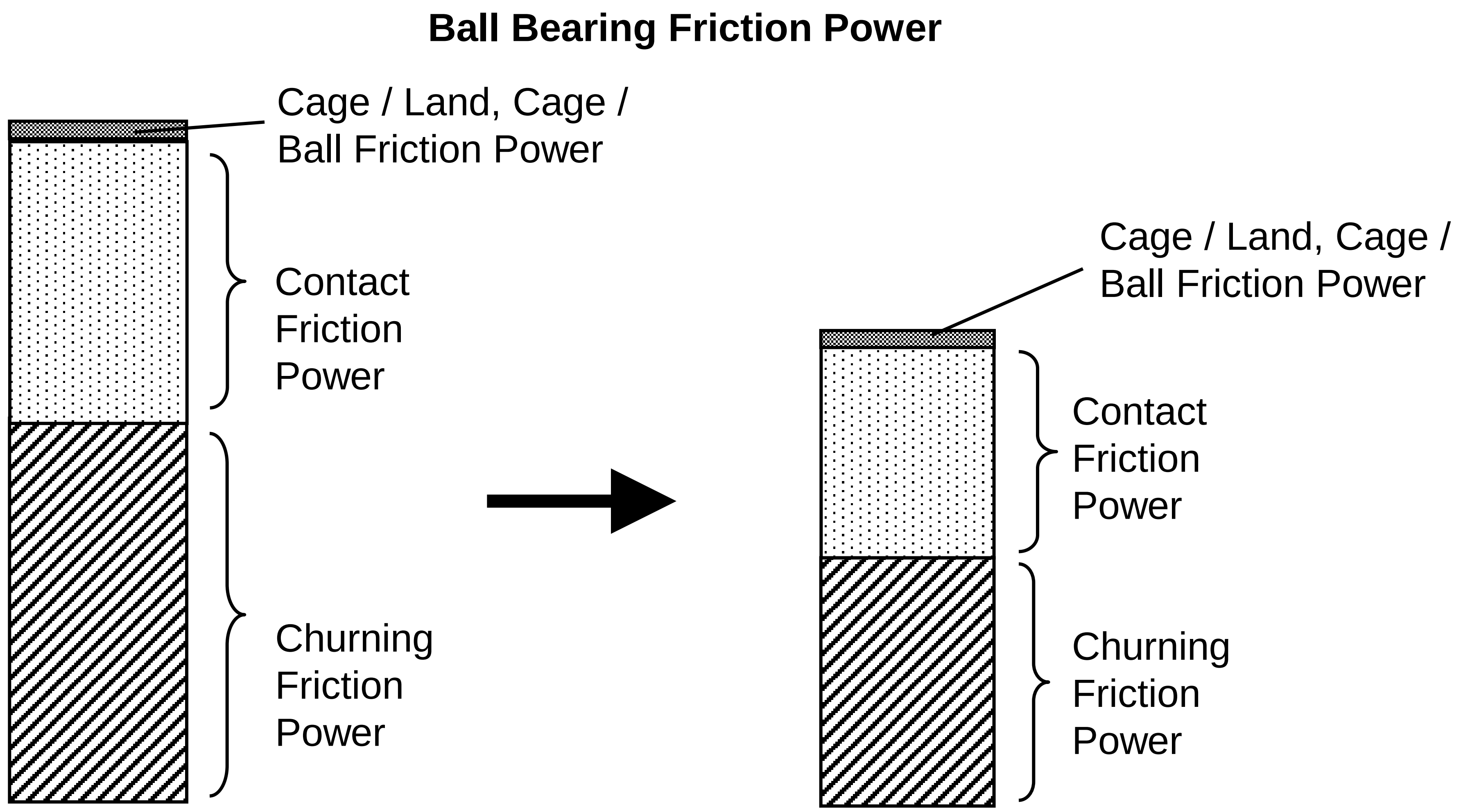
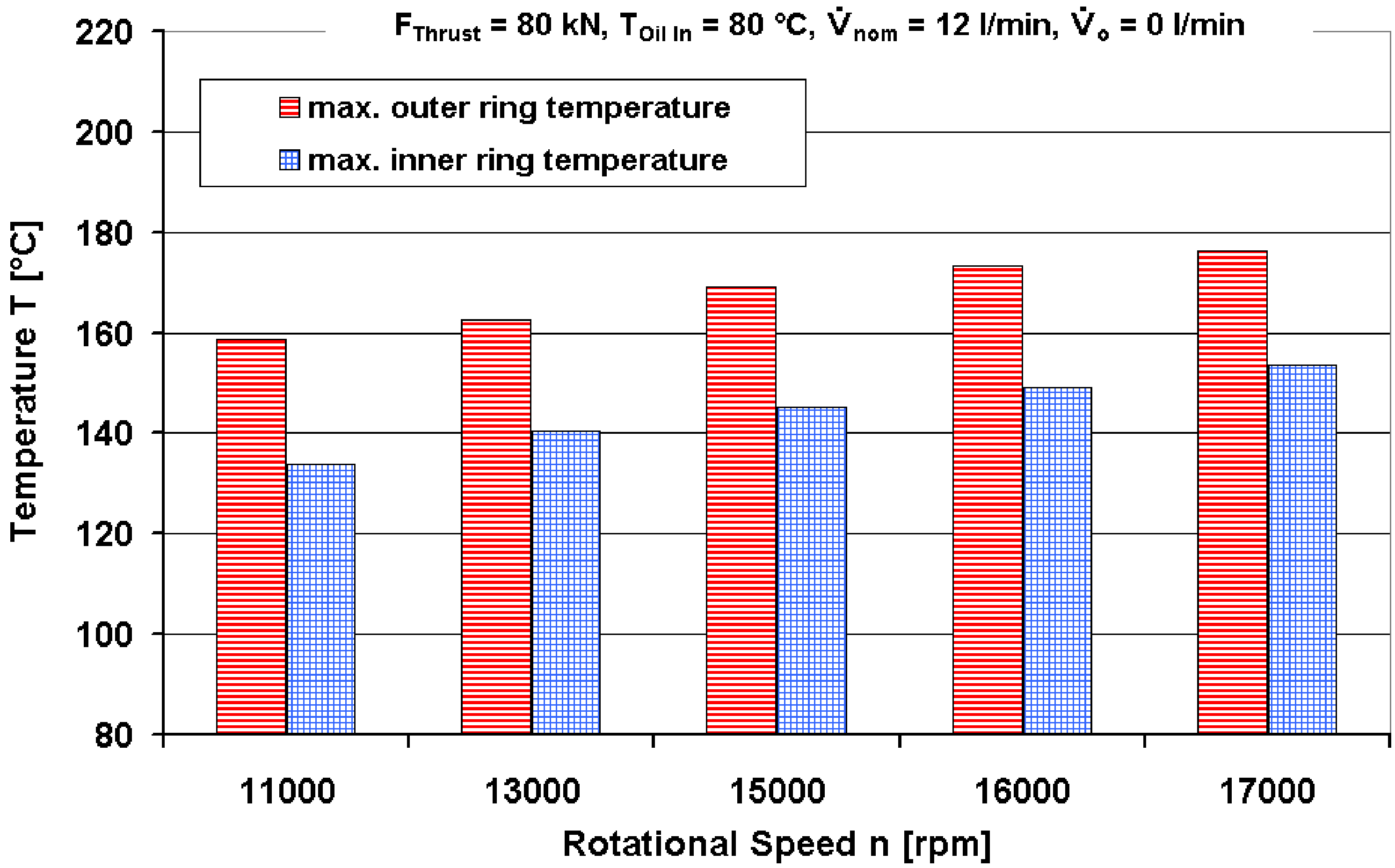
Motivation & Goal

Motivation



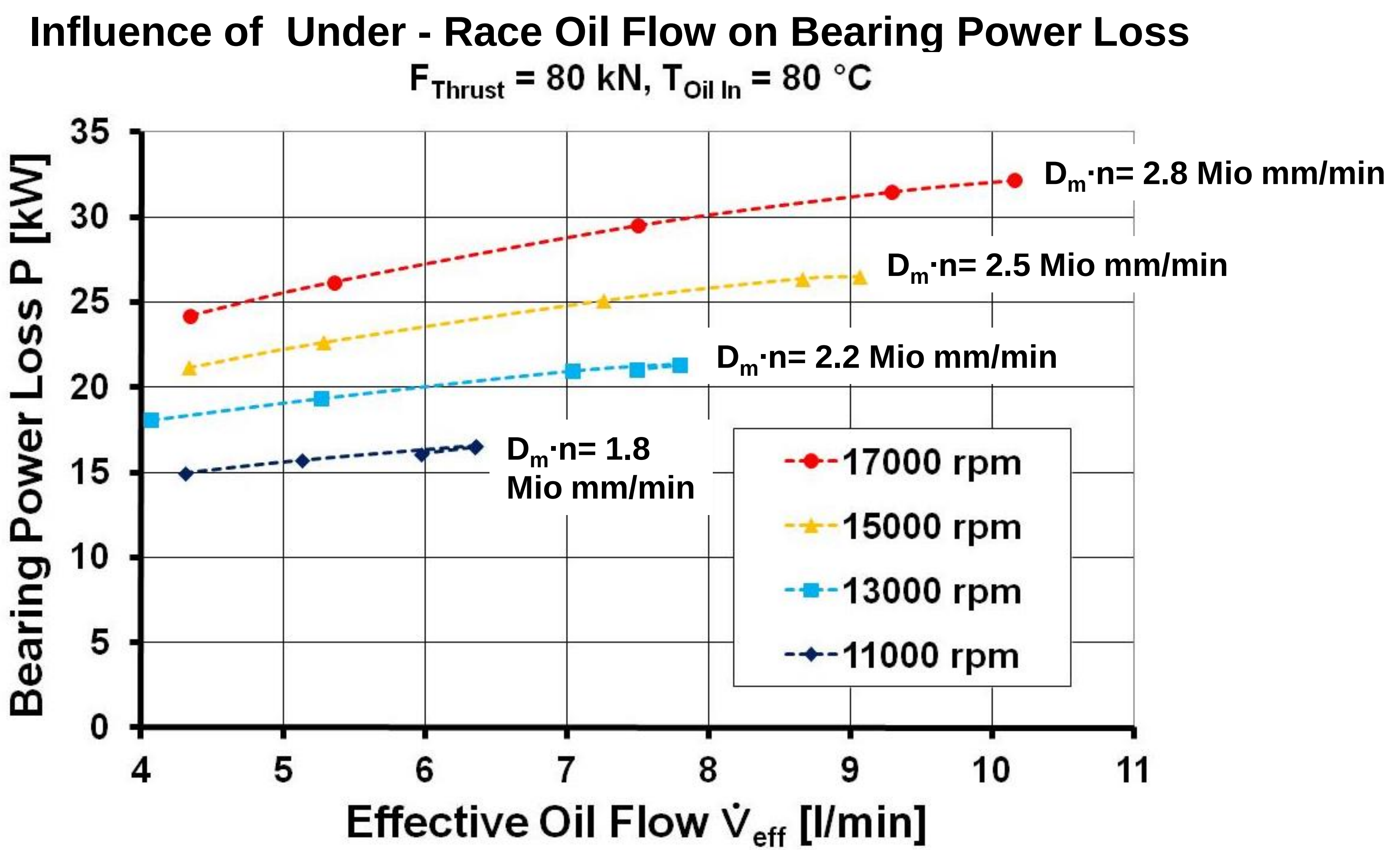
Goal: Reduction of bearing power loss and thermal stressing.

Motivation



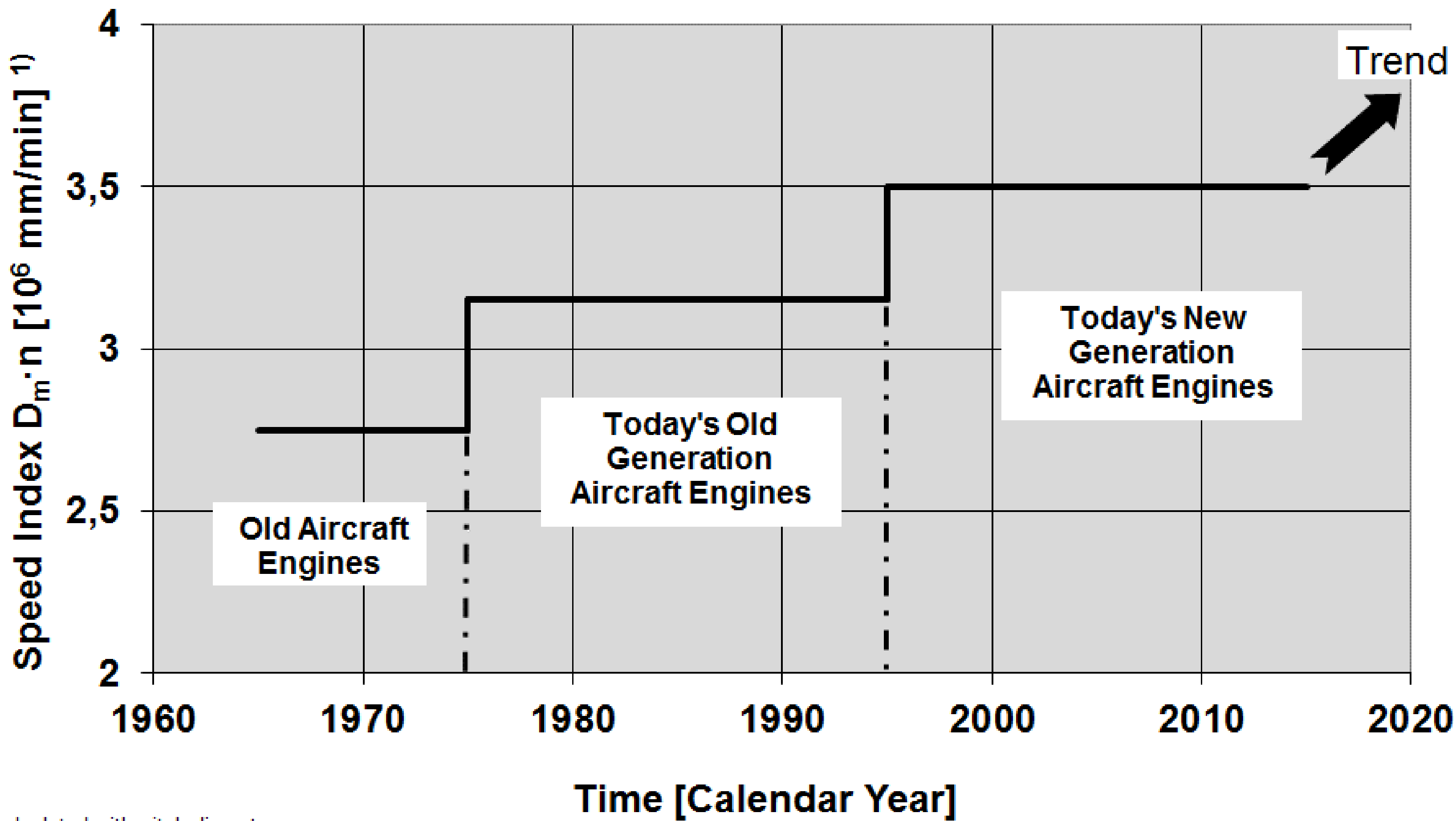
For under-race lubricated bearings the outer ring is the temperature-critical component.

Motivation



A power loss reduction can be achieved by lower oil quantities
…but we also need to control the raceway temperature

Motivation



1) calculated with pitch diameter

Speed Index increases continuously for HP-Bearings

Motivation & Goal

ECO-POLITICS

- The goals described by the European Commision and The Advisory Council for Aeronautics (ACARE) in "Flightpath 2050": reduction of 75% CO_2, 90% NO_x, and 65% noise compared to capabilities of typical new aircraft in the year 2000.

END USER REQUIREMENTS

- End user require more efficient and performance-enhanced engine components. Approximately one third of an airline’s total operating costs are contributed by kerosene costs.

TECHNICAL REQUIREMENTS

- Rolling element bearings determine significantly the mechanical efficiency of an aircraft engine
- Today's state of the art main shaft bearing feature squeeze film damping in order to reduce vibrational loads

Motivation & Goal

Goal:
Increase of Reliability, Performance and Efficiency of Aircraft Engine Ball Bearings

Further additional reduction compared to an all-steel bearing:

- bearing power loss: 10 %
- required total oil flow: 15 %
- damping of rotor vibrations
- temperatures: 10 K
- increase of max. rotor speed by 20%

Measures:

Use of:

- ceramic balls
- integrated squeeze film damper
- direct outer ring cooling concept
- plasma nitrided raceways

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Test Bearing and Rig Test Head Design, Test Conditions

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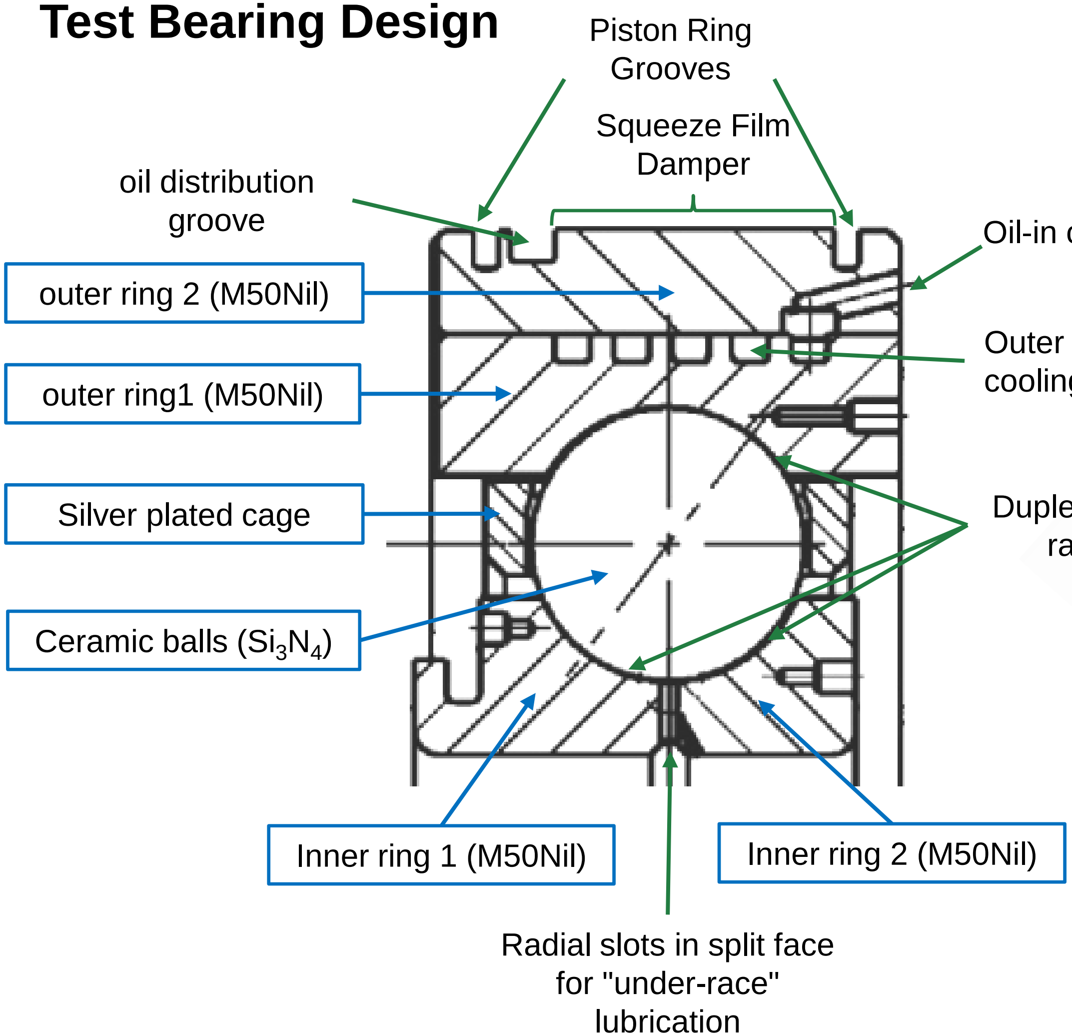
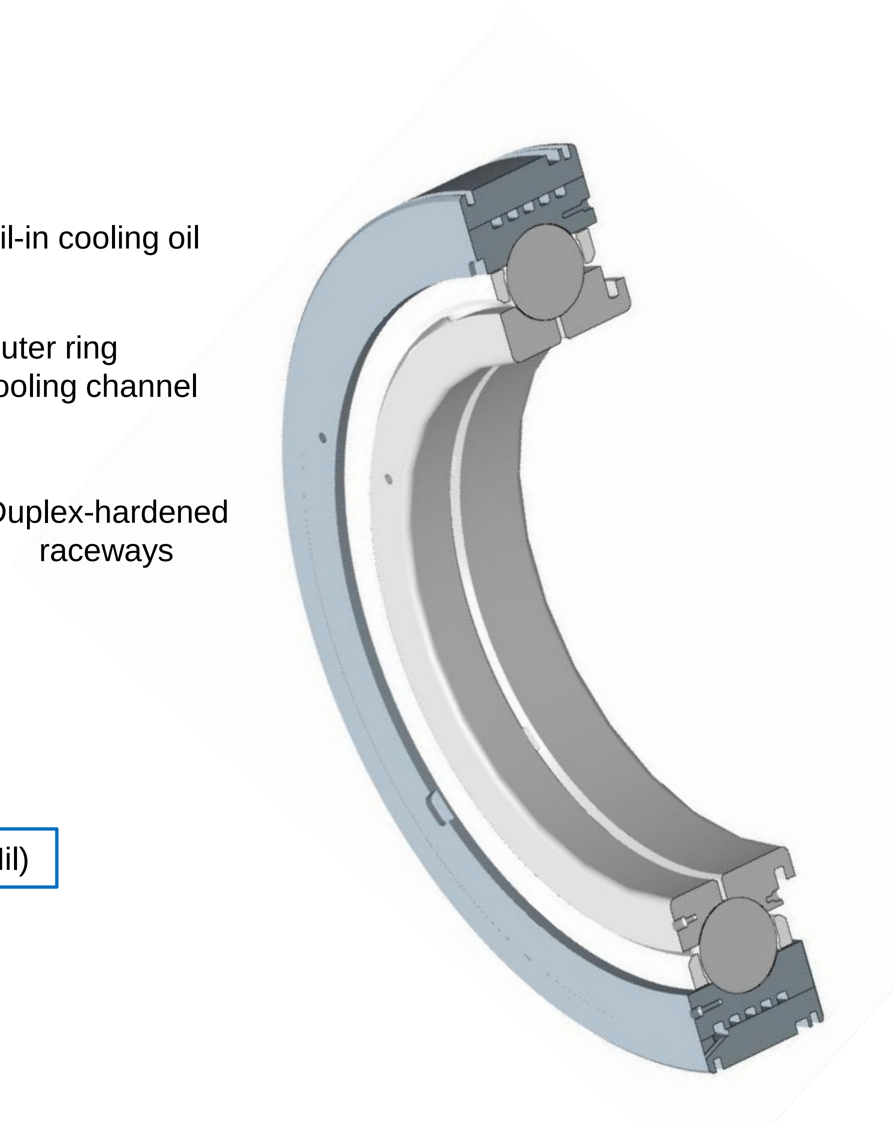
Test Bearing and Rig Test Head Design, Test Conditions

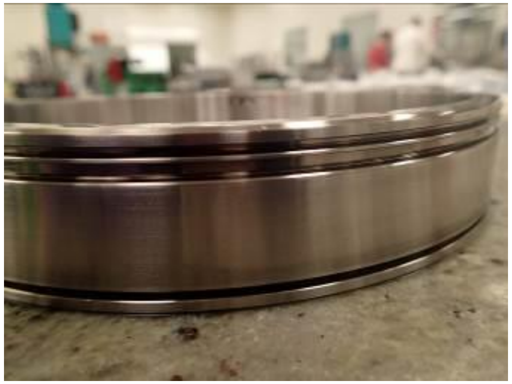
Test Bearing Design



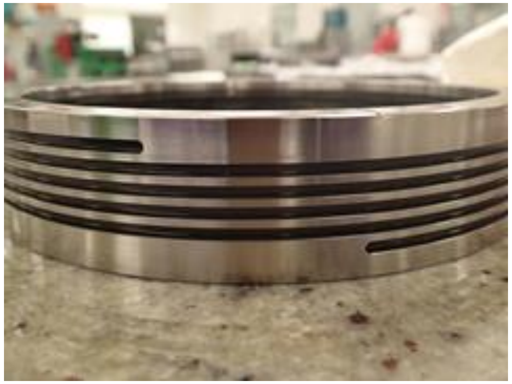


Test Bearing and Rig Test Head Design, Test Conditions

Bearing Components prior to Rig Test



outward outer ring featuring piston ring grooves for squeeze film damping



inward outer ring featuring helical cooling channel

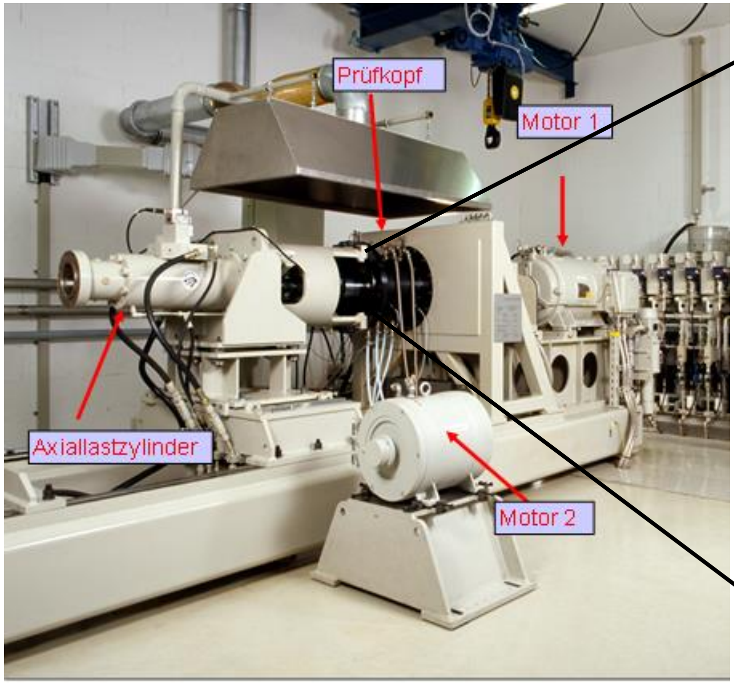
loaded inner ring with radial oil slots in the split face

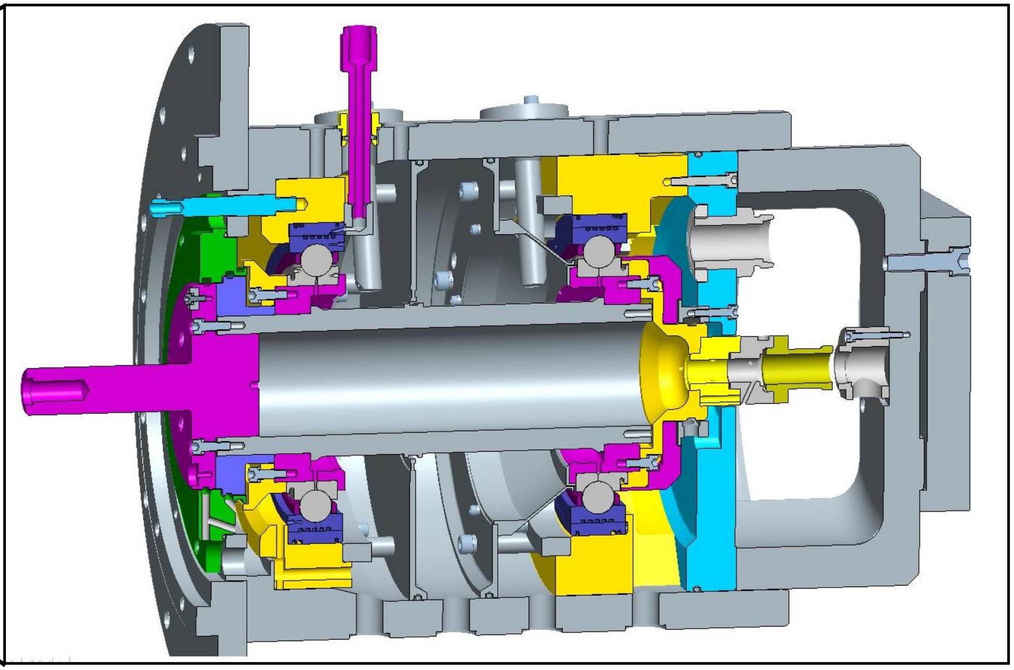
cage/ball assembly

Test Bearing and Rig Test Head Design, Test Conditions

Test Rig: AN62

- Location: Schweinfurt, Germany
- Speed Capability: depending on gearbox installed; w/ current gearbox up to 26000 rpm
- Motor Power: 120 kW (161 hp)
- Axial and radial loads up to 200 kN (45,000 lbf), misalignment testing
- capability for tests with co- and counter-rotating bearings (intershaft bearings)
- three independent oil systems
- sensor technology: static, telemetry, vibrations, piezo, strain gages, chip detectors, cage speed, etc.





Test Bearing and Rig Test Head Design, Test Conditions

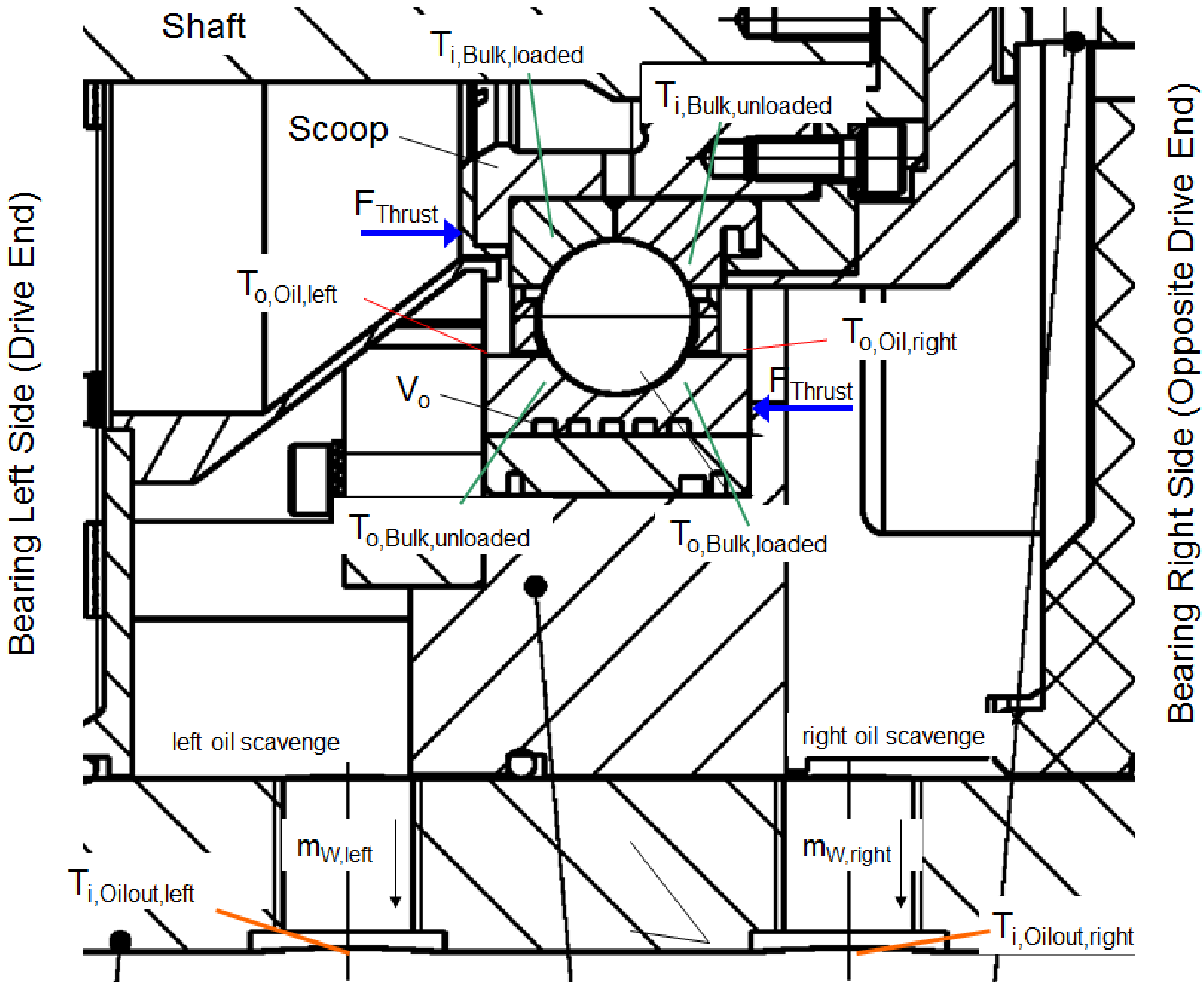
Test Conditions:

- Rotational Speed: 14000 - 24000 rpm ($D_m \cdot n$ = 2,35 to 4 Mio mm/min)
- Axial Load: 26,7 - 80 kN (p_0 = 1540 to 2440 MPa, [224 to 354 ksi])
- Oil In Temperature: 80°C and 110°C (176 and 230 °F)
- Under-race Oil Flow: 5, 6, 8, 10, 12 (14, 15) l/min (1.3 to 4 gallons/min)
- Outer Ring Channel Oil Flow: 0, 1, 2, 3, 4, 6, 8, 10 l/min (up to 0.8 gallons/min)
- Engine Oil per MIL-PRF 23699

Measured Variables:

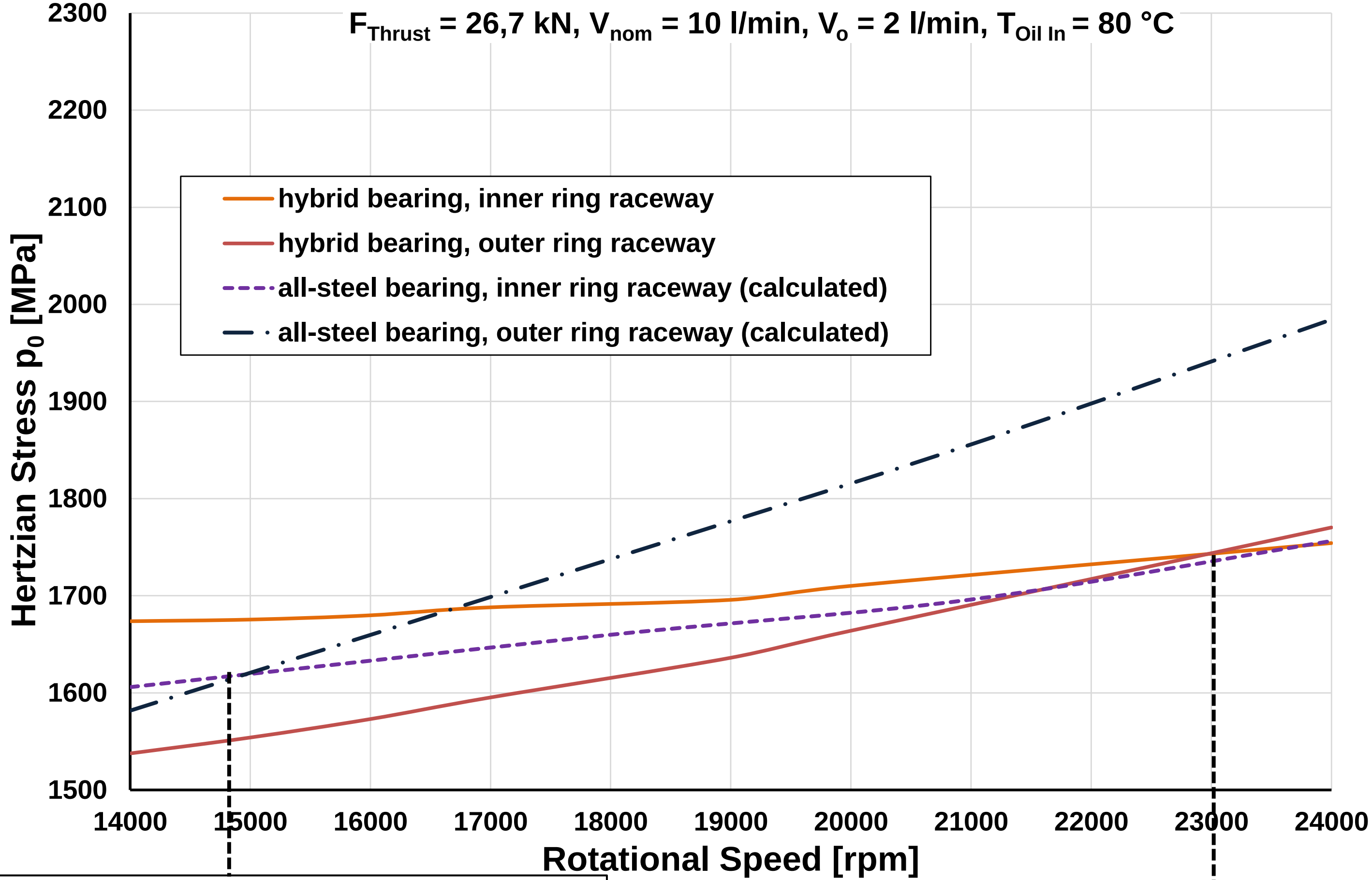
- Outer and Inner Ring Temperatures
- Bearing Power Loss
- Oil Flow Qty, Oil Pressure, Oil Temperatures
- Vibrational Accelartion
- Axial Load, Shaft Rotational Speed

Test Bearing and Rig Test Head Design, Test Conditions



Test Bearing and Rig Test Head Design, Test Conditions

Hertzian Stress



identical Hertzian stresses for outer and inner race of steel brg

identical Hertzian stresses for outer and inner race of hybrid brg

Experimental Investigation Results: Oil Flow

Experimental Investigation Results

Pictures of rig tested hybrid bearing

loaded inner ring half

bearing with one inner ring half removed, showing the ceramic balls and the cage

cage/ball assembly

outer ring

bearing side view

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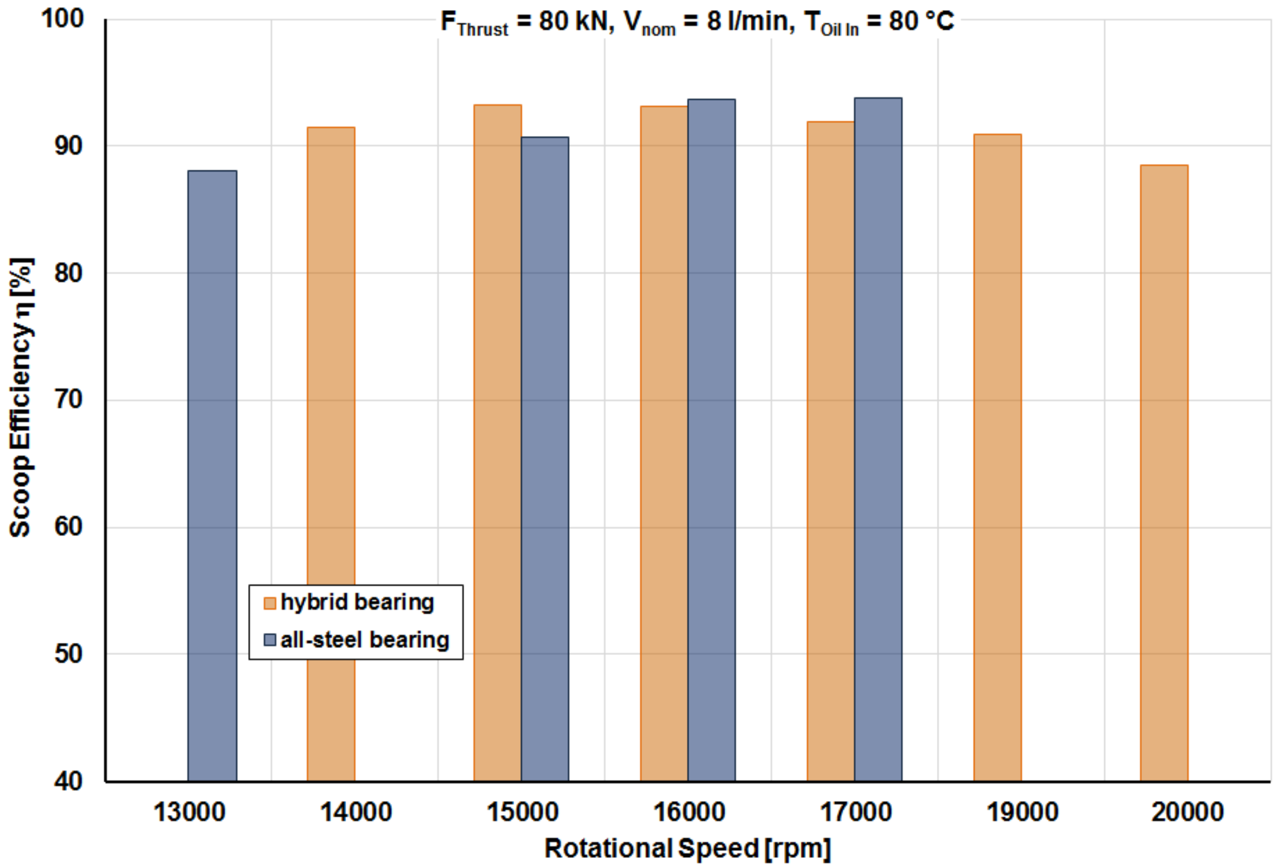
Experimental Investigation Results: Oil Flow

$$\eta = \frac{m_{W,left} + m_{W,right}}{m_{nom}}$$



Scoop Efficiency very similar between all-steel and hybrid bearing
→ enables direct comparison of steel and hybrid bearing

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Experimental Investigation Results: Temperatures

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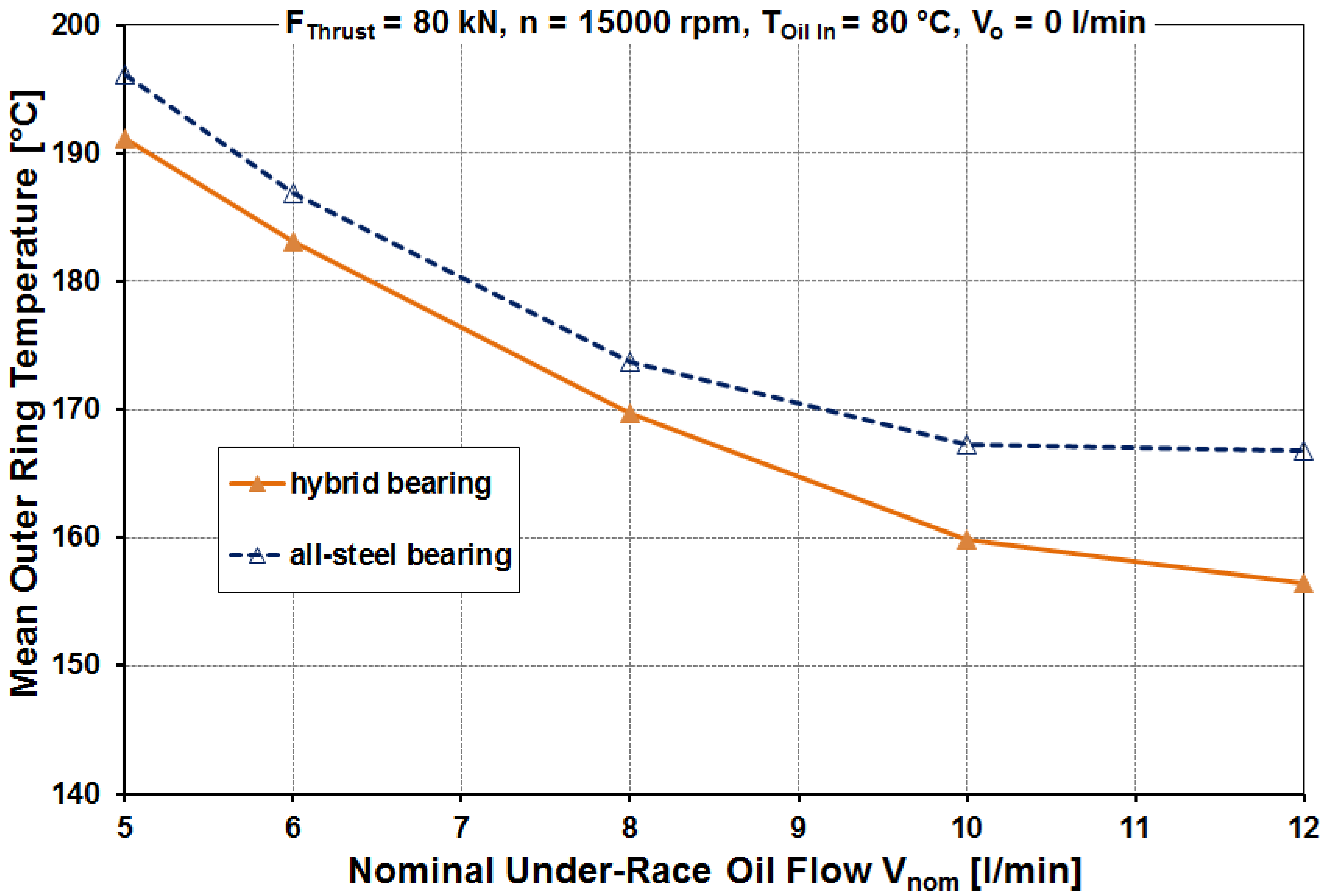

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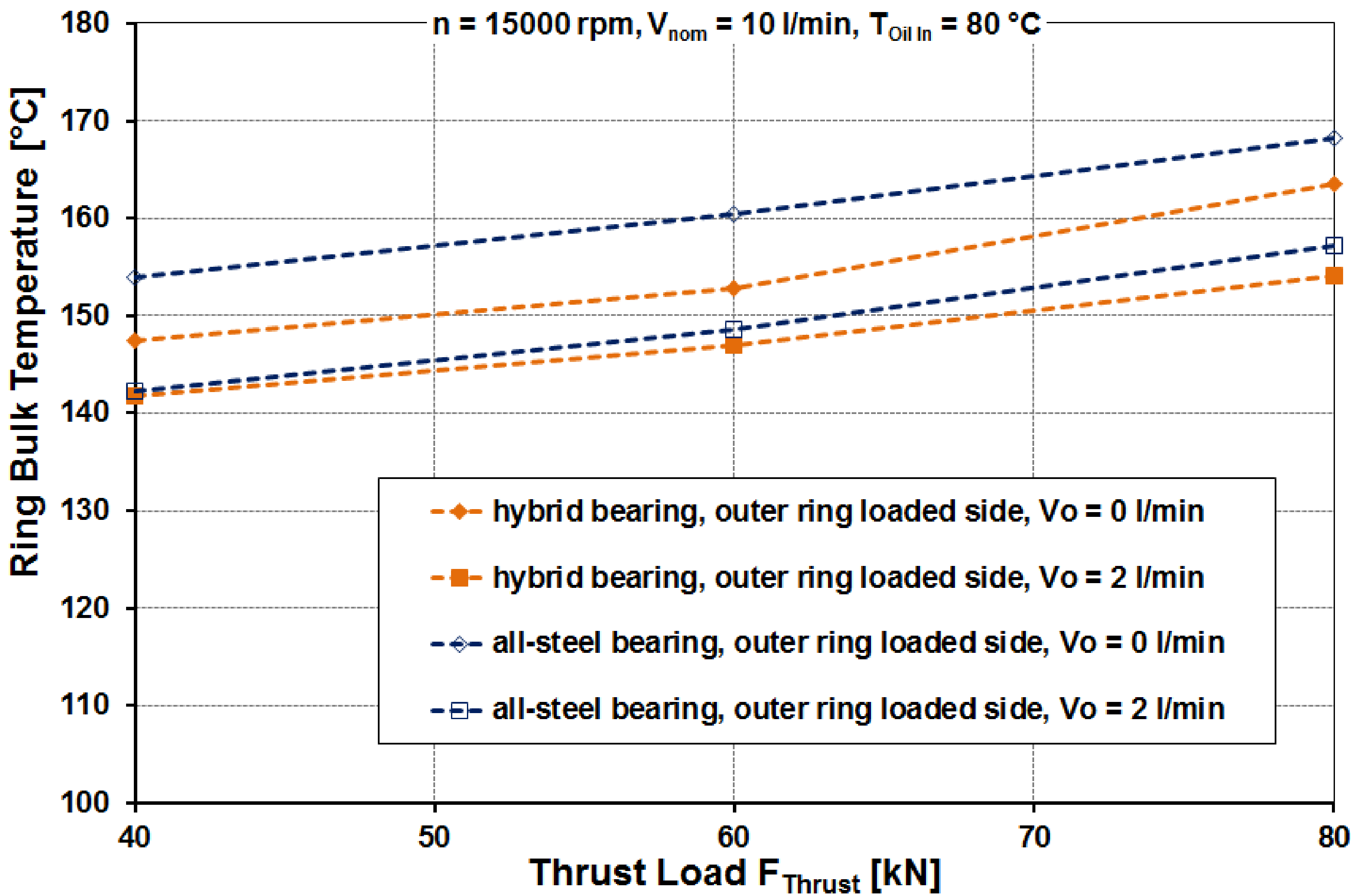

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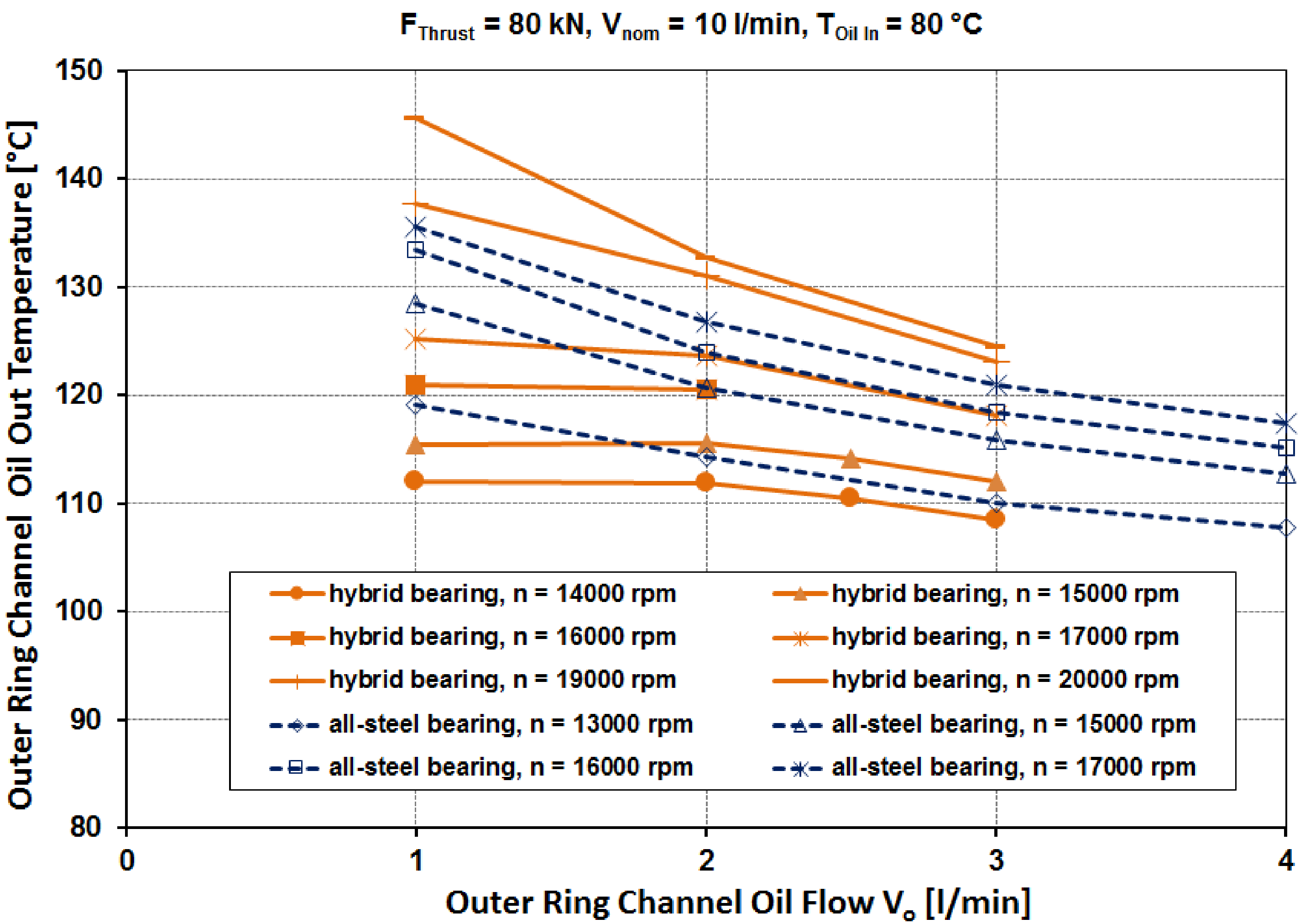

Experimental Investigation Results: Bearing Power Loss & Heat to Oil (HTO)

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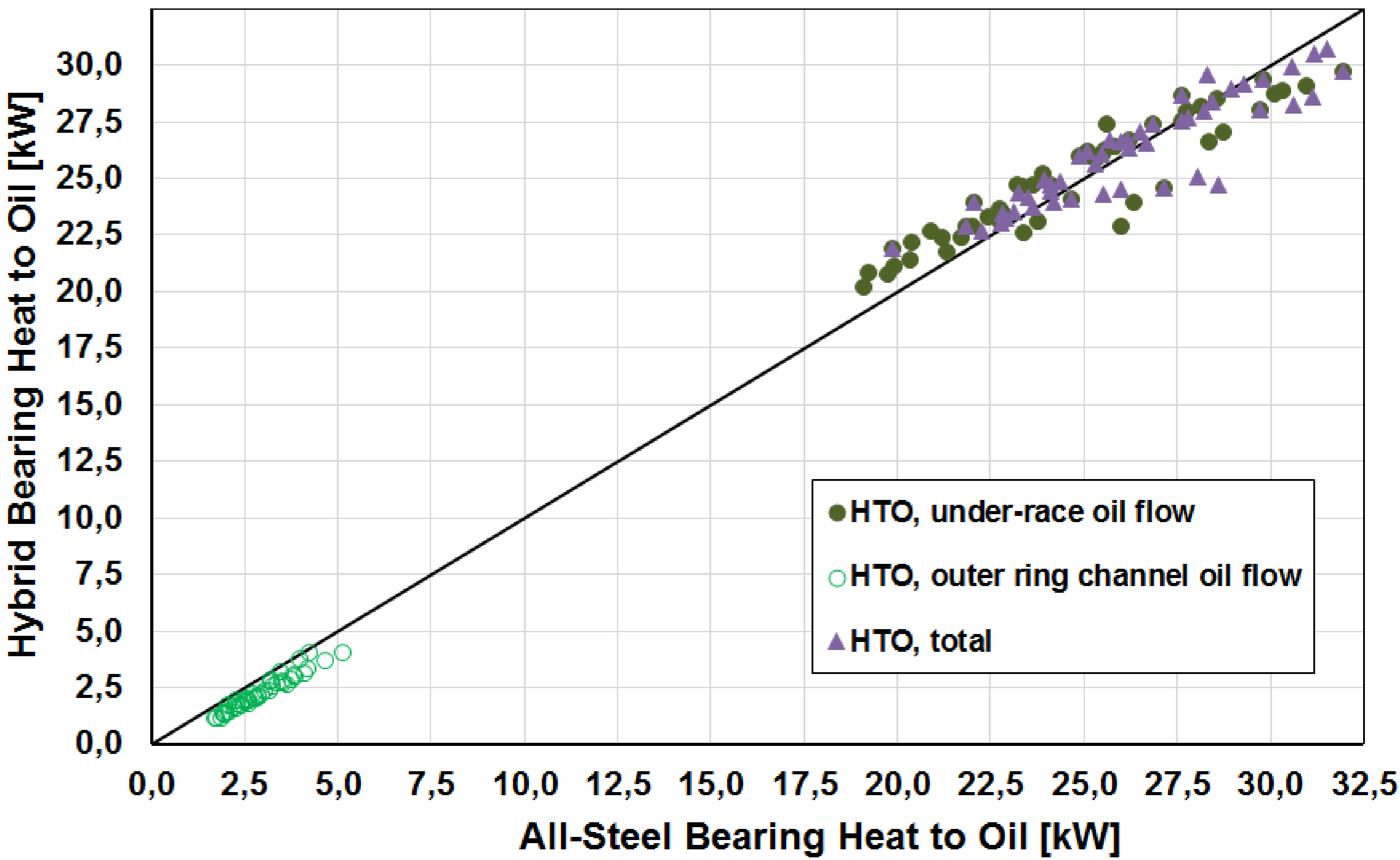
$$HTO = m_w \cdot c_p \cdot (T_{OilOut} - T_{OilIn})$$



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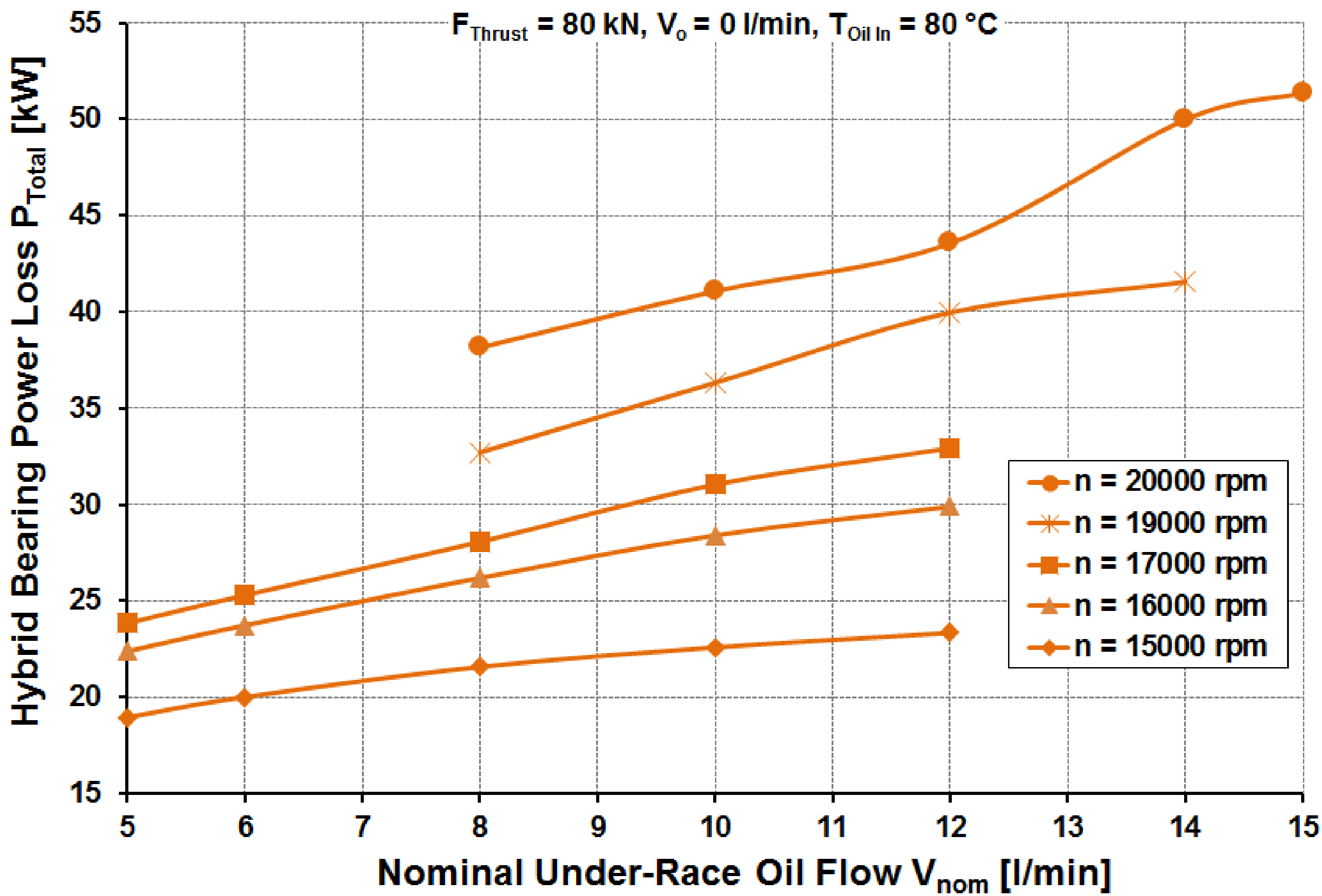

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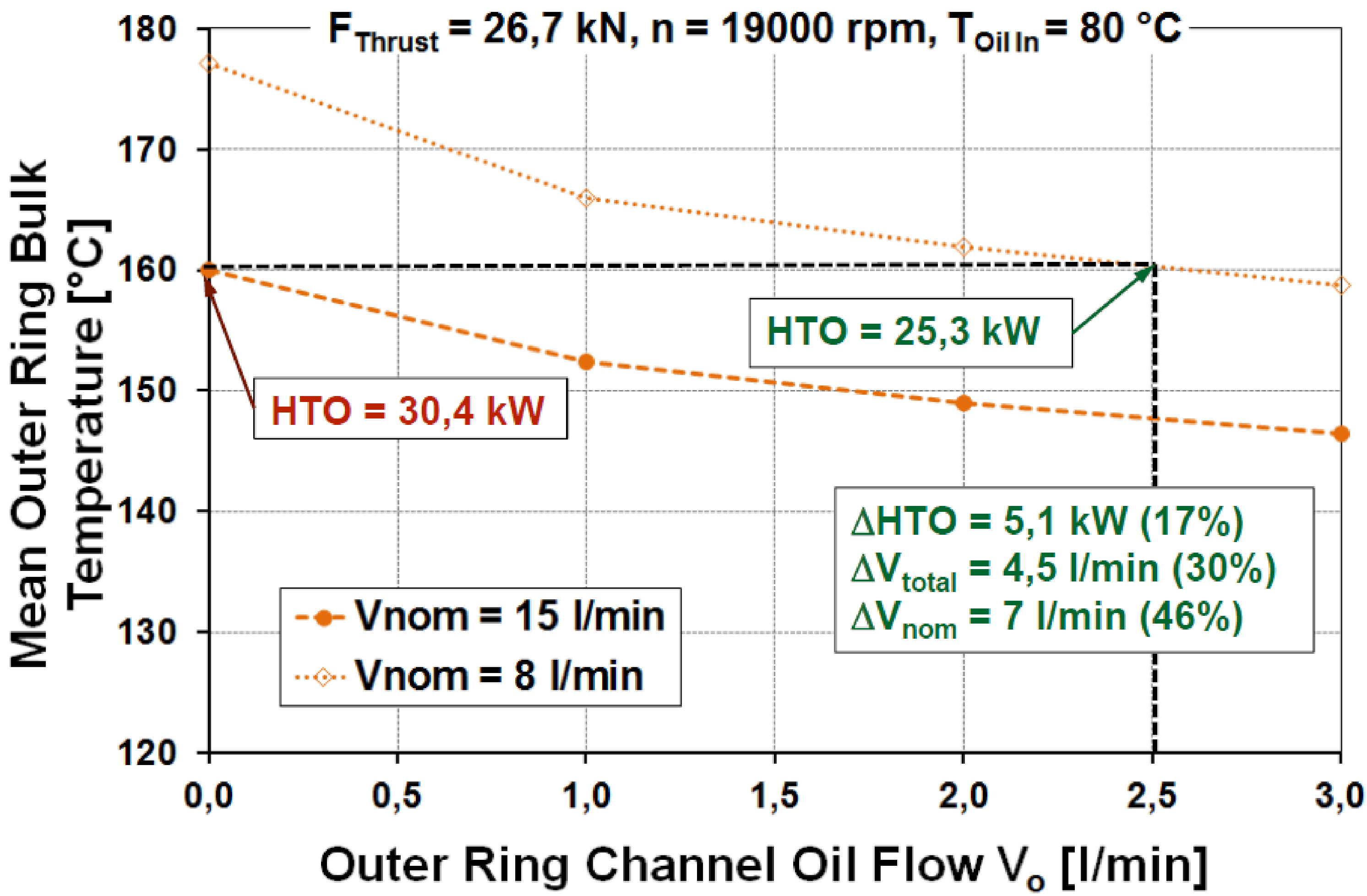

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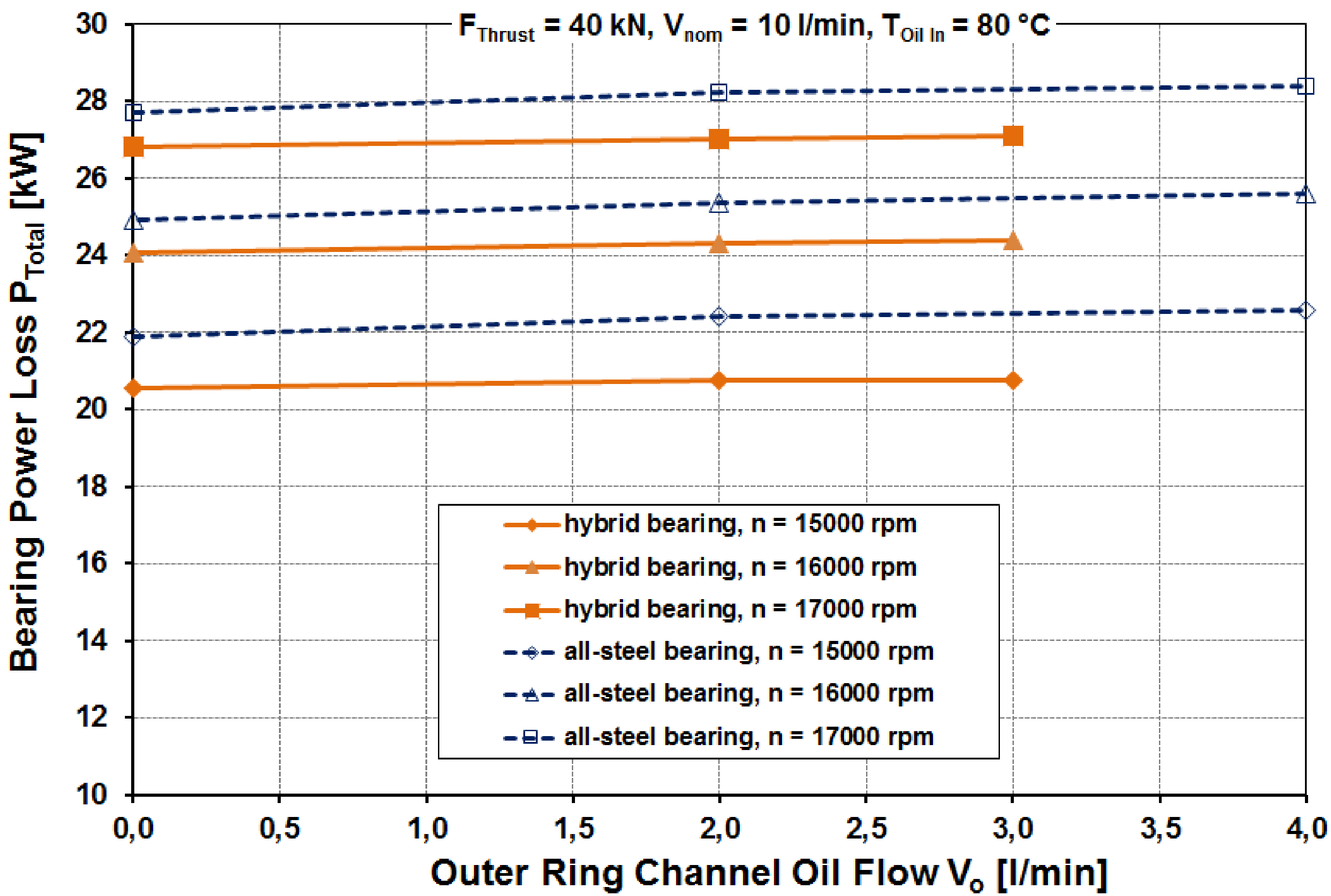

High Speed Capability

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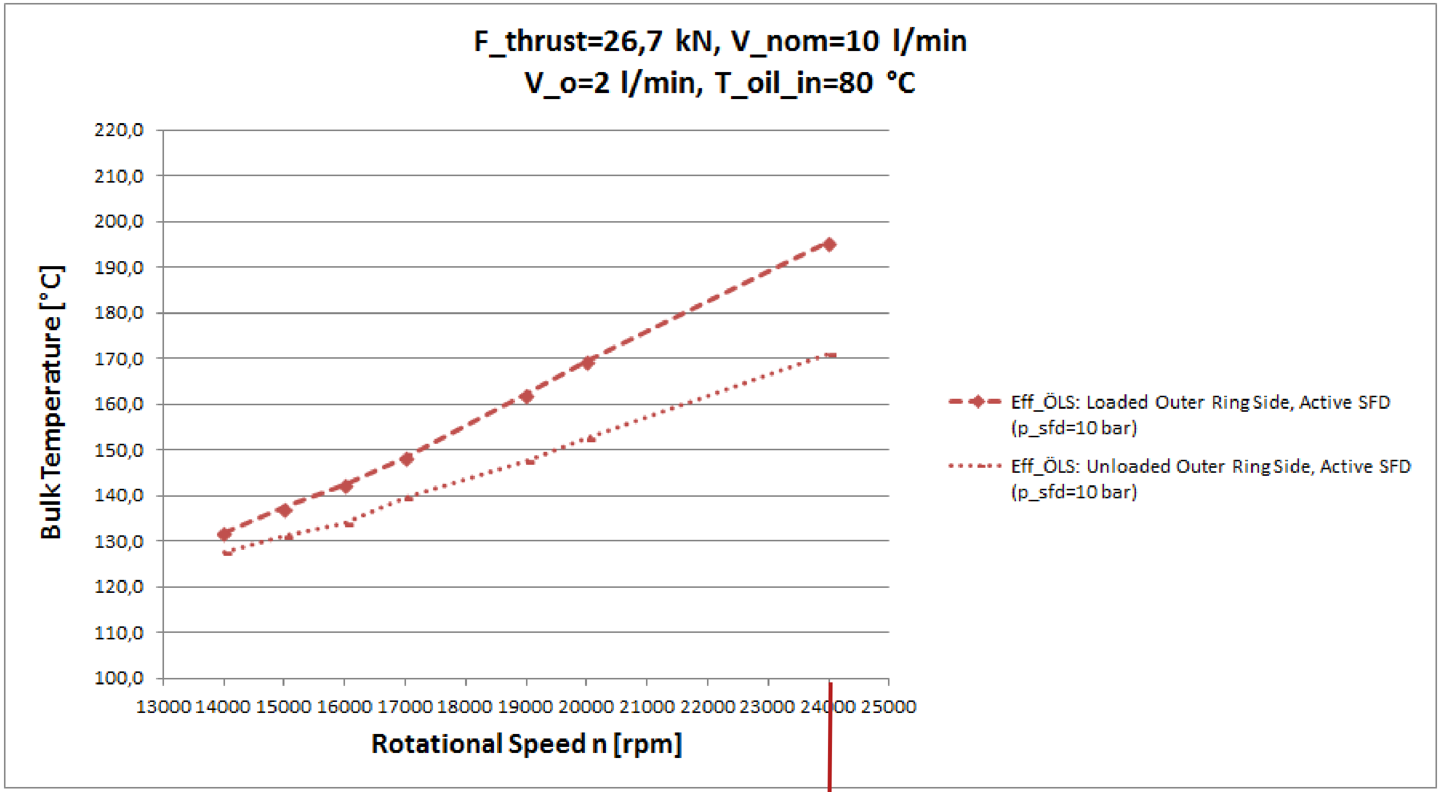

$D_m \cdot n$ = 4,02 Mio mm/min

Speed Index > 4 Mio mm/min at T_{OR} < 200°C achieved by selective adjustment of under-race and outer ring channel oil flow quantity

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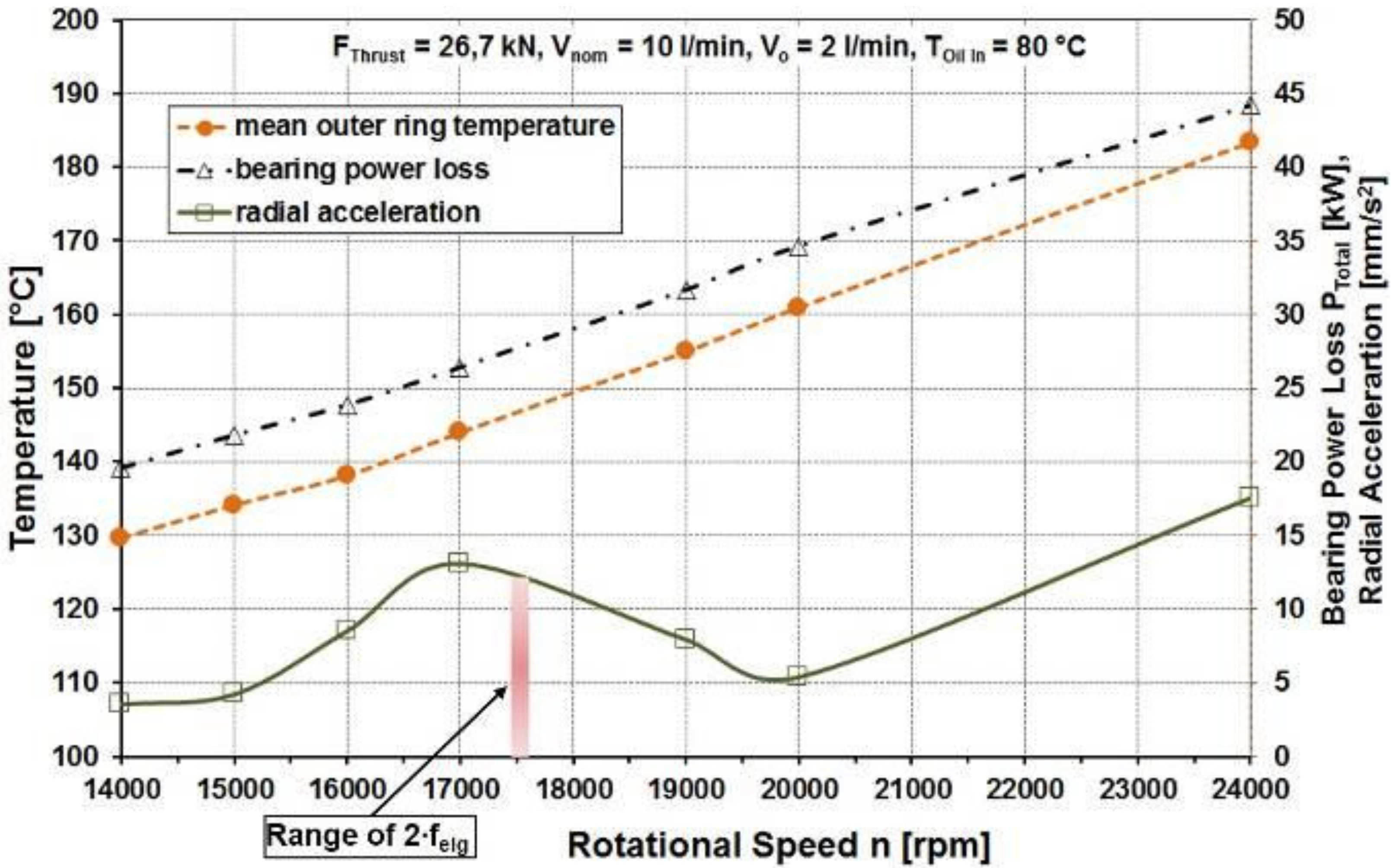
High Speed Capability



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Conclusion & Outlook

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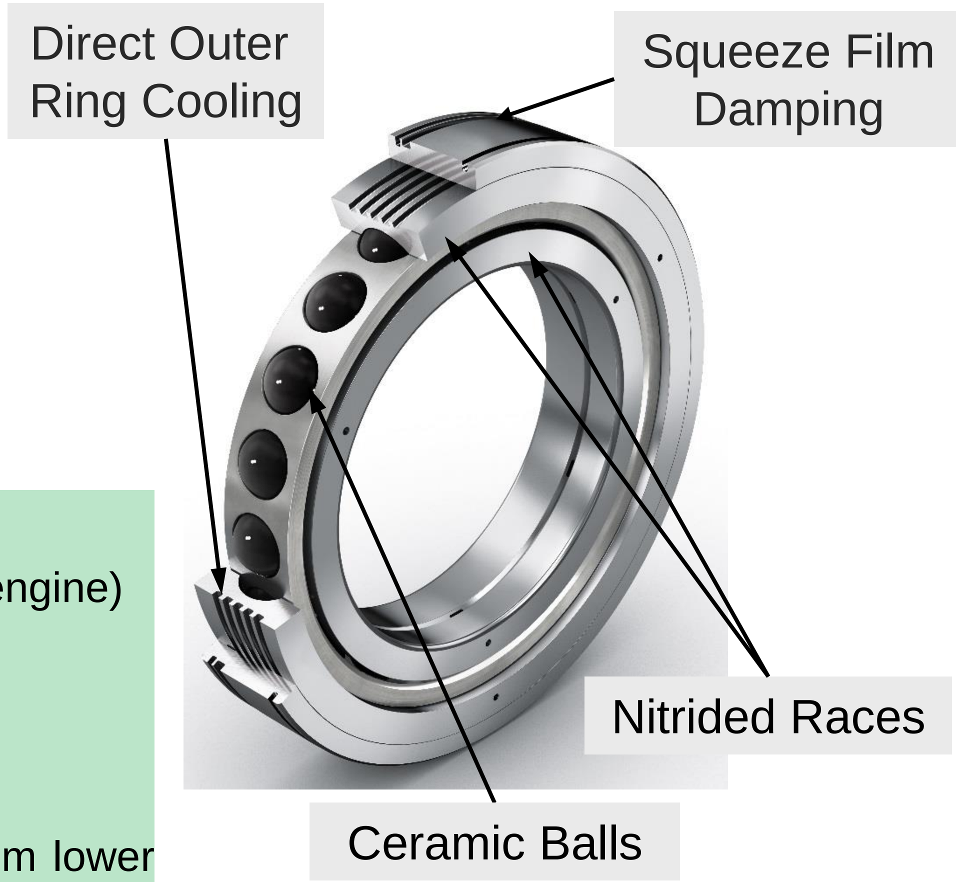
Specific Benefits:

- Oil Flow Savings up to 50 %
- Power Loss Reduction up 25 %
- up to 25 K lower temperatures
- High speed capability above $4 \cdot 10^6$ mm/min



Overall Benefits

- Increase in mechanical efficiency (bearing & engine)
- Reduction of weight (smaller oil pump etc.)
- Reduction of engine fuel consumption
- Reduction of engine emissions
- Improvement in material fatigue strength (from lower brg temperature)
- Increase of reliability
- Reduction of total cost

Conclusion & Outlook

Fuel Consumption Benefit by using Direct Outer Ring Cooled Hybrid Ball Bearing

Calculation Example:

- Bearing Power Loss Reduction: 4 kW per bearing
- #3 ball bearing (HP shaft) with DORC
- 4 kW saving per gas turbine
- Heat Value (Jet A1): 42500 kJ/kg
- Overall Engine Efficiency: 38 %
- Gas Turbine fleet: approx. 5000 engines in service

Source: GE Aviation

→ Kerosene savings per engine: 7800 kg/a (CO_2 savings: 25 t/a)

→ Kerosene savings for fleet: 39000 t/a (CO_2 savings: 123000 t/a)

→ USD savings* for **fleet**: **16 Mio USD/a** (45000 USD/d)

→ USD savings** for **fleet**: **31 Mio USD/a** (84000 USD/d)

** US$/bbl = 53; ** US$/bbl = 100;*

Thank you for your attention!