“Down To Earth”

The Technologies of Space Tribology and Their Transfer from the Space Industry To Terrestrial Applications

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NCT Engineering in Motion

ESTL Keeping Space Moving

Our Mission and Heritage

Special characteristics of Space Tribology

- Tribological failures = mission failures
- Low power, long life (no re-lubrication), high vacuum, thermal extremes, radiation, micro-vibration…

"To increase the efficiency and reliability of spacecraft through the application of good tribology"

To support the space industry of Europe in the development and lubrication of mechanisms for space

European Space Tribology Laboratory (ESTL)
(established in 1972 by ESRO, later to become ESA)

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Diversity of Space Applications

- Hold down and release mechanisms
- Hinges
- Deployment actuators
- Large deployable antennae/solar arrays
- Solar array drive mechanisms
- Reaction wheels
- Deployable booms
- Antenna pointing mechanisms
- Instrument mechanisms (optical scanning, pointing, focus, filter/slit positioning etc.)
- Robotic devices (arms, end-effectors, in-orbit servicing etc)
- De-spin mechanisms
- Separation interfaces….

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All to be developed and tested on ground for specific missions with adequate precision, motorisation margins and life etc.

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Challenges of Space Tribology

Diverse Environments

- Wide thermal range, in vacuum (mostly)
- Volatility and contamination of fluid lubricants, environmental sensitivity of solid

Launch

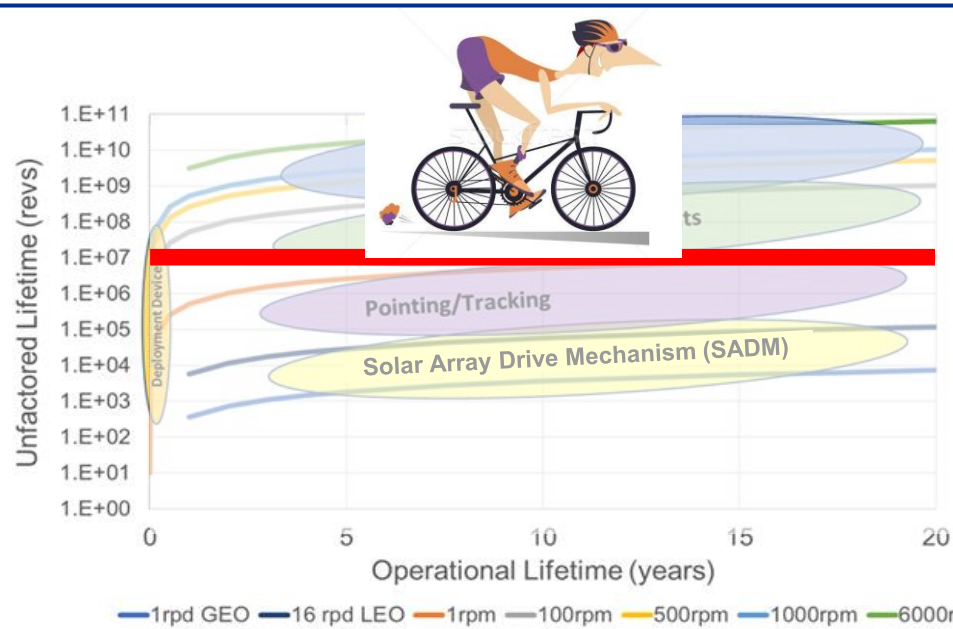
- Bearing stiffness, gapping/truncation

Life and Performance Optimisation

- Optimal preloading
  (life, power, thermal strains)
- Cage stability/micro-vibration minimisation
- Low speed grease effects impact margin

Compressed Development Schedules

- Accelerated life test often needed

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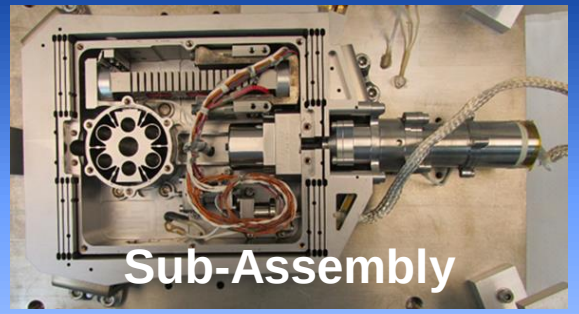
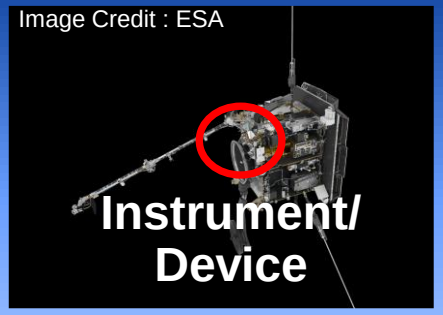
Industry Challenges and Paradigms

“Big”/ Institutional Space Paradigm

(e.g. ESA/NASA Science Mission, Significant Commercial Telecom/EO))

	Tribometer	Unit/ Component	Sub-Assembly	Instrument/ Device	Spacecraft
Programme Months	*2-12 Mo*		*6-36 Mo*	*9-48 Mo*	*36-120 Mo*
Typ. Costs	*€5k-€100k*		*€100k-€1M*	*€500k-€10M*	*€10M-€10Bn*





Programme Months	*1-3 Mo*	*6-12 Mo*	*12-24 Mo*
Typ. Costs	*€5k-€50k*	*€1k-Few €10ks*	*€100k-Few €M*

“New” Space Paradigm

(e.g. Commercial, Smallsat/Microsat/Cubesat)

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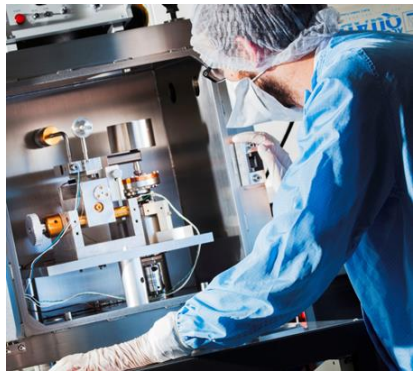
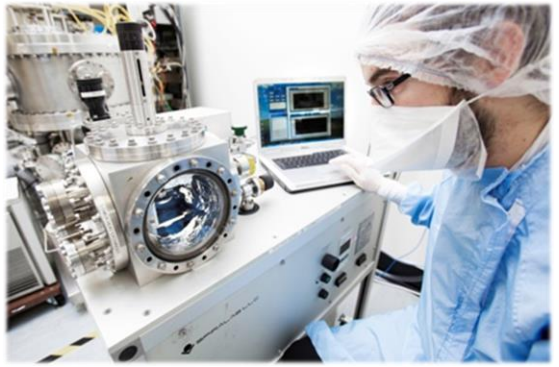
Techniques for Lubricant and Component Assessment

Lubricant Assessment (oils, greases and solids)

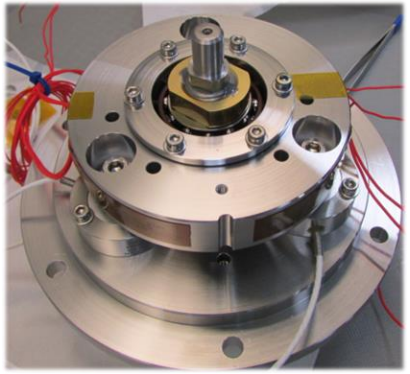
- Pin-on-Disc (PoD)
- Spiral Orbit Tribometer (SOT),
- Vacuum Mini Traction Machine (VMTM)





Component Thermal Vacuum Test Facilities

- Bearings/gears/actuators



Mechanism and Sub-Assembly Thermal Vacuum Facilities

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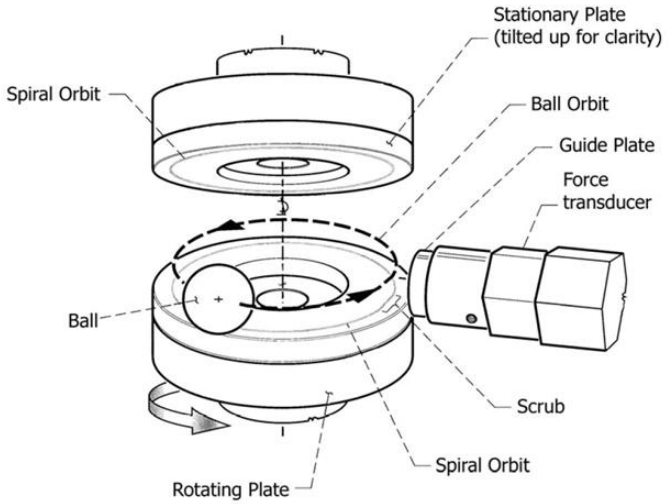
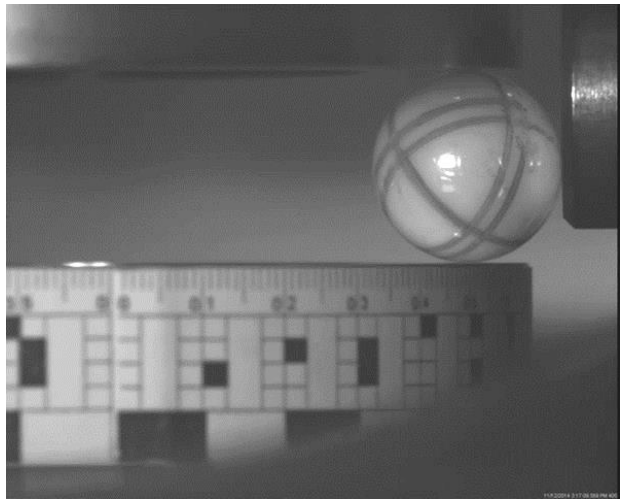
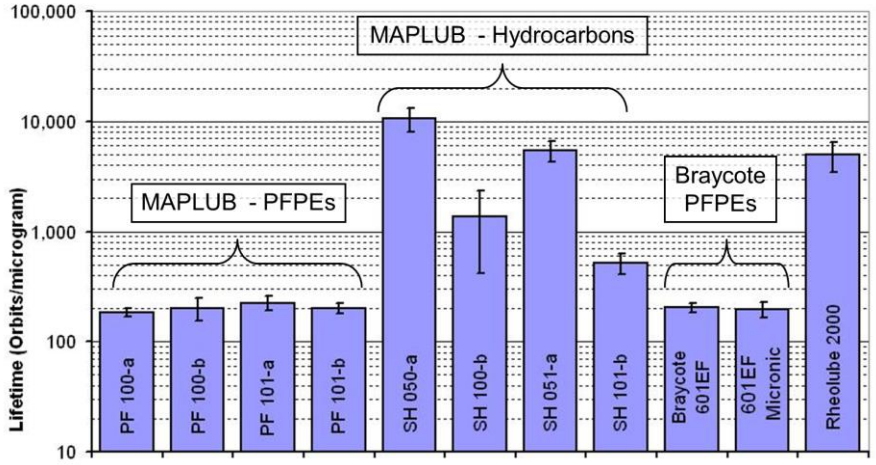
Spiral Orbit Tribometer (SOT)





- Unique rolling tribometer for assessment of oils, greases and solid lubricants
- Ball spirals outwards, collision force with static plate correlates to friction
- Representative kinematics of an angular contact bearing (rolling, sliding, pivoting)
- Full thermal vacuum control (typically -40°C to +120°C, 1 x 10^{-7} mbar, cover gasses etc.)
- **Short test durations, high repeatability**



Example Uses:

- Ranking oil, grease and solid lubricant performance v stress, temperature, environment etc.
- Evaluation of new fluid lubricant chemistries (e.g. ionic liquids)
- Assessment and optimisation of solid lubricants
- Understanding transfer-film formation and hybrid lubrication

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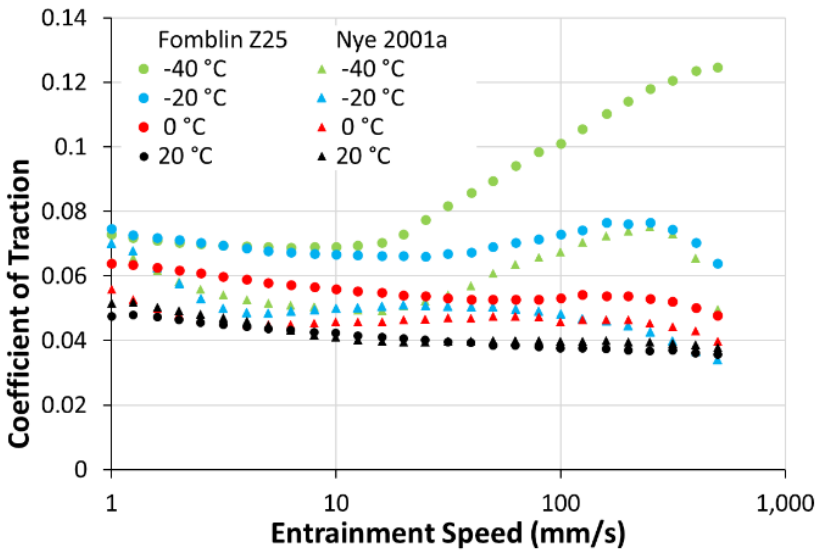
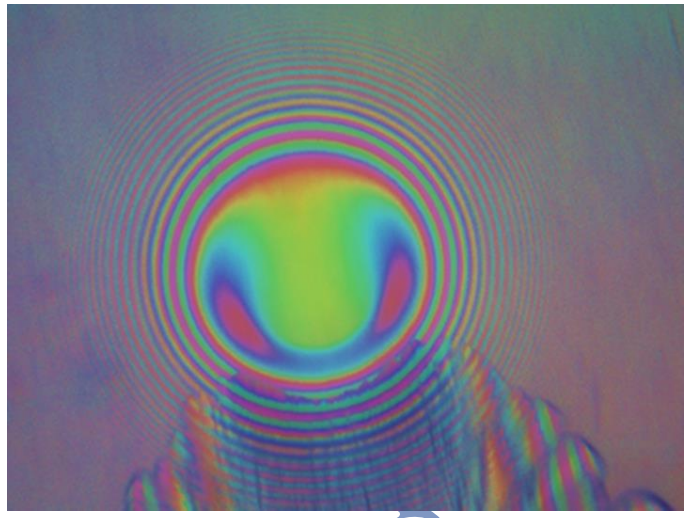
Vacuum Mini Traction Machine (VMTM)

- Unique traction machine design within vacuum chamber
- In-situ traction measurements and in-situ optical interferometry (film and meniscus formation)
- Thermal vacuum control (-100°C to +120°C, 5 x 10^{-6} mbar, cover gasses etc.)
- Slide-roll ratio 0 - >200, Entrainment speed <10^{-2} to ~ 4m/s

Example Uses:

- Lubricant traction coefficient assessment as function of temperature & speed
- Impact of dwell and wake effects on lubricant performance.
- Hybrid lubrication studies





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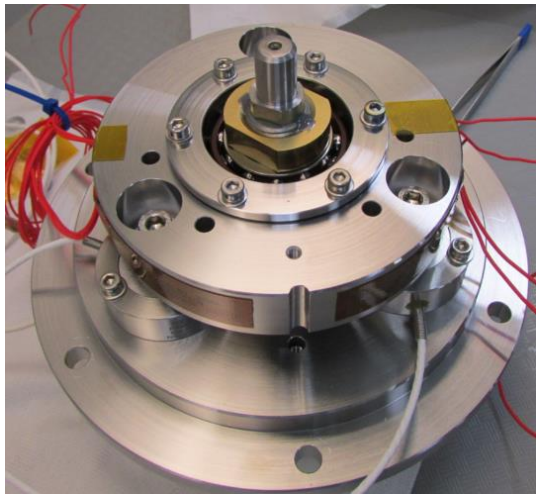
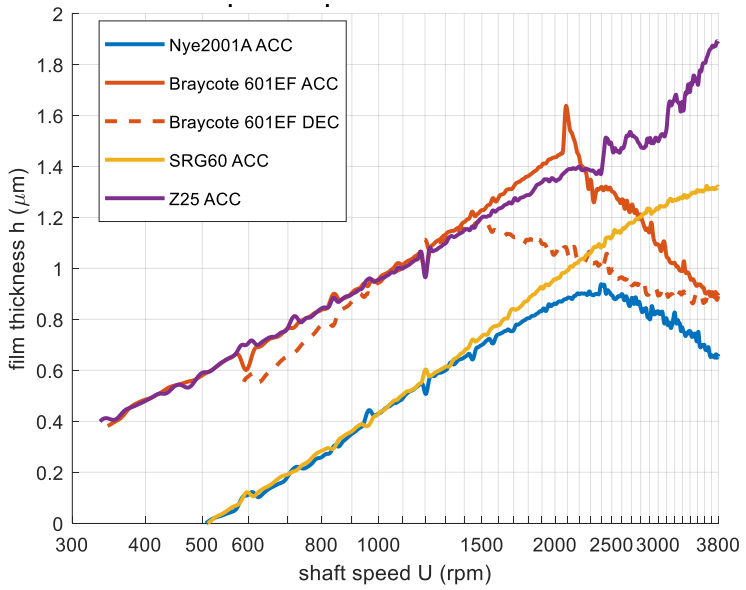
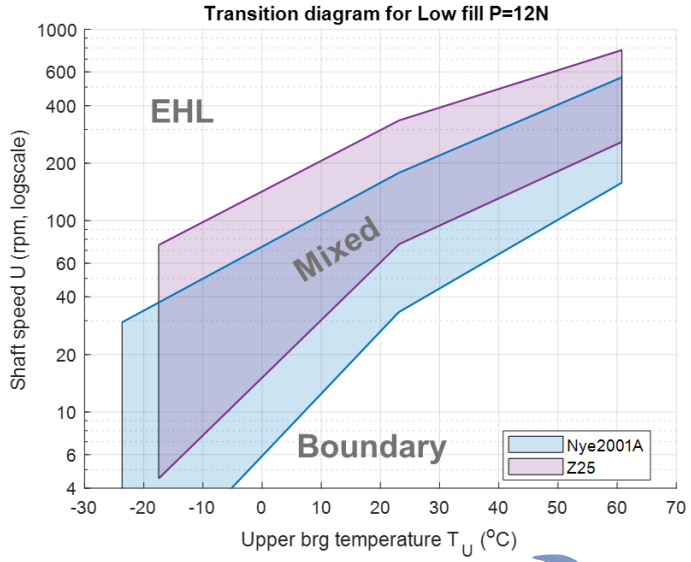
Advanced Bearing Test Rig (ABTR)





- In-situ measurement of torque, preload, lubricating film thickness in angular contact bearings (transition mapping)
- High range of speeds (0.0006 – 3500 RPM)
- Thermal vacuum control (-60°C to +70°C)
- Monitors lubricant film thickness, solid lubricant wear and transfer film formation



Example Uses:

- Validation of accelerated test methodologies for solid lubricated bearings
- Understanding transfer film formation
- Oil and grease lubricant starvation and regime studies
- Understanding of low-speed grease performance anomalies
- Lubrication numerical model validation

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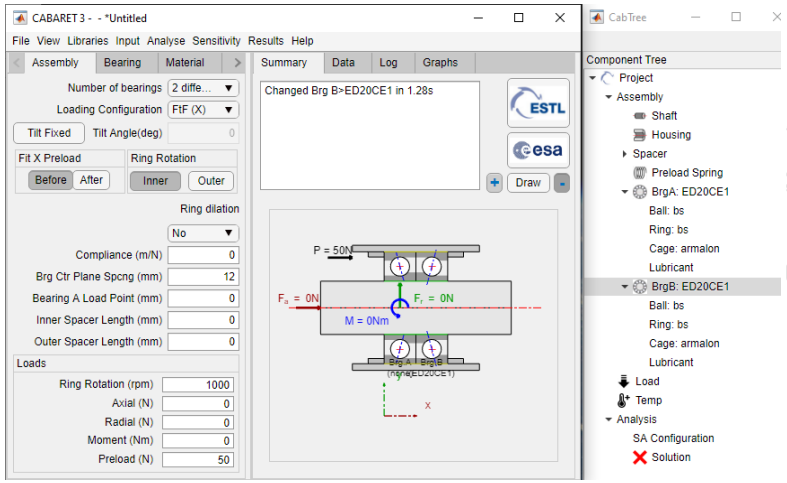
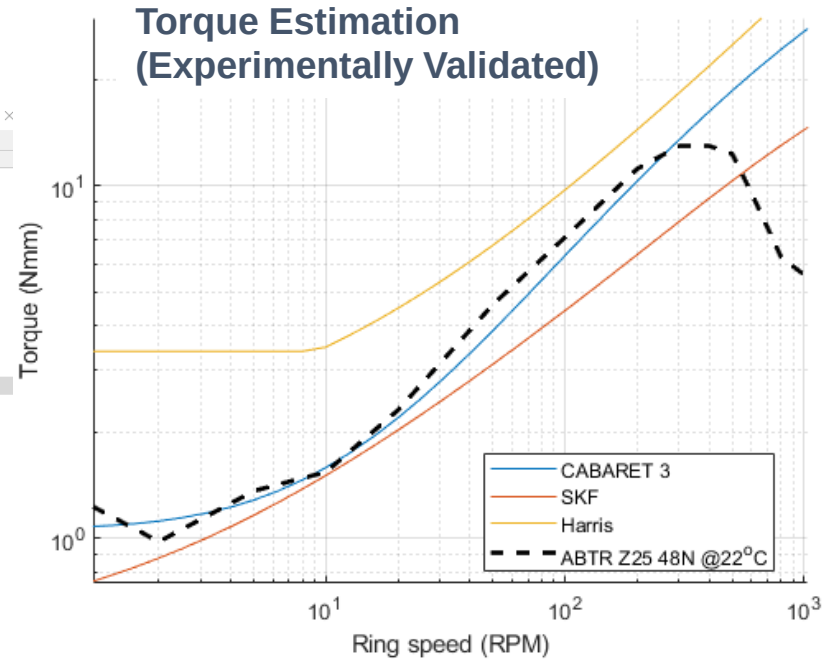
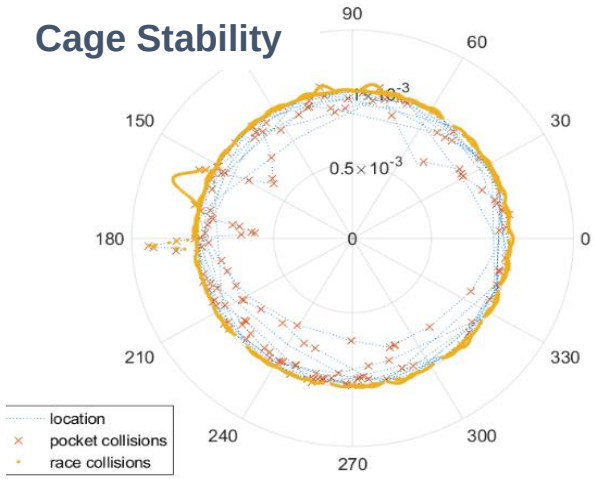
Bearing Modelling Tools

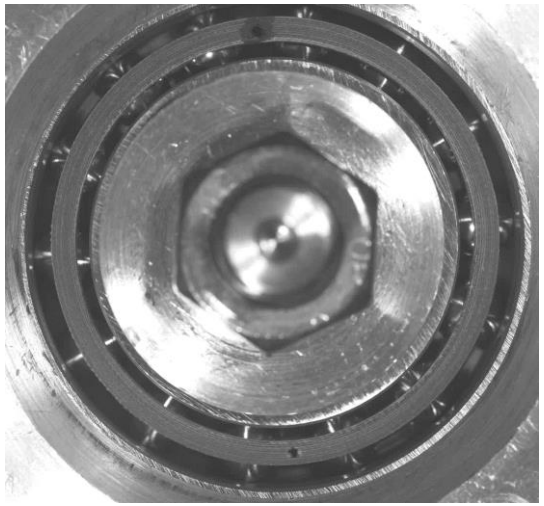
Space Industry Codes

- CABARET (ESTL)
- RBSDYN (CNES)
- Specific – DOC (APO-GEE)









Example Uses:

- Accurate torque (for fluids and solid lubrication), optimisation of preload & bearing system stiffness, impact of launch vibration (gapping/truncation, load capacity), thermal strains/differentials and conductance, cage stability

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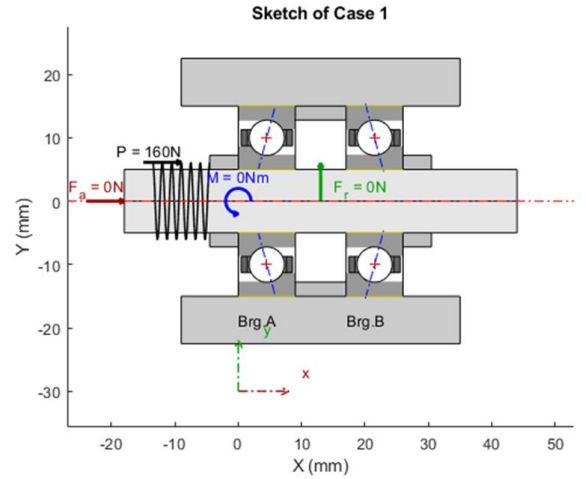
Bearing System Design and Analysis

- Originally: Turbopump and reaction wheel bearing analysis - now general use..
- Design for large thermal differentials, stiffness, truncation avoidance, and/or minimal bearing contact stresses
- Bearing systems for active and passive preload variation



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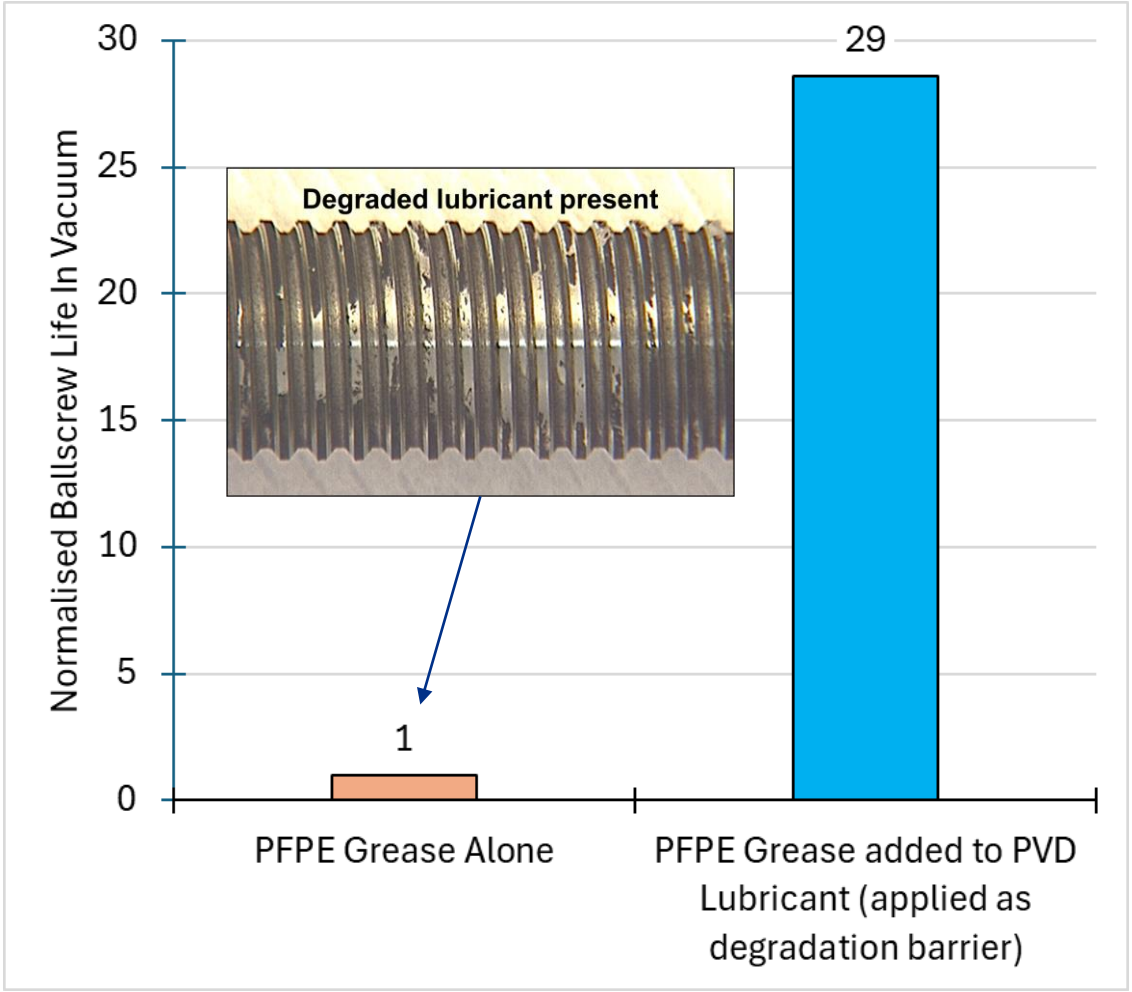
Lubricant Synergies

PVD coatings to extend life by inhibition of fluid lubricant tribo-degradation

- PVD films of MoS_2 or Pb to inhibit PFPE degradation



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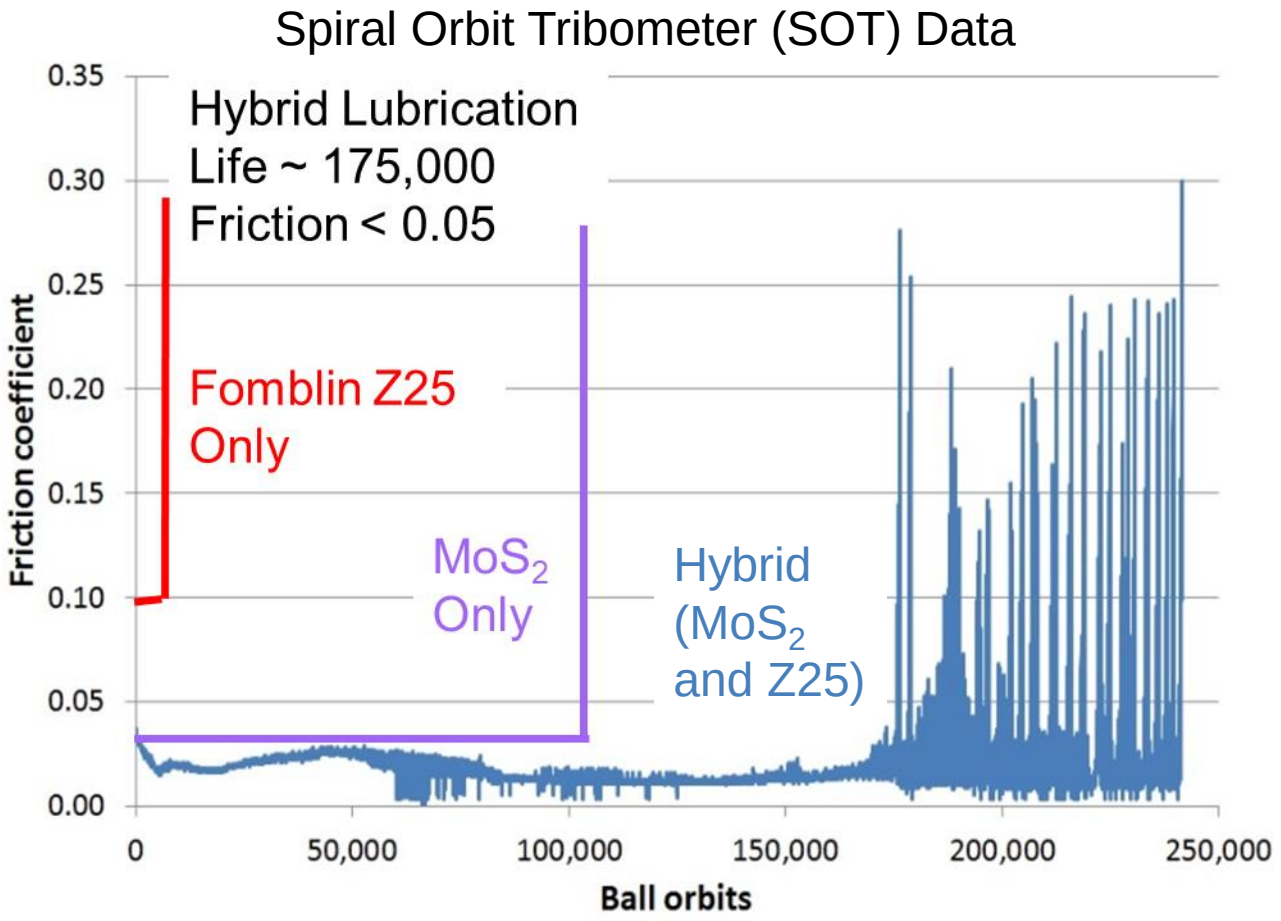
True Hybrid Lubrication behaviour

- Apparent synergistic lubricant life extension
  - Hybrid Friction ≈ **MoS_2**
    (less than oil)
  - Hybrid Life **> MoS_2 Life + Oil Life**
    (by factor ~2)



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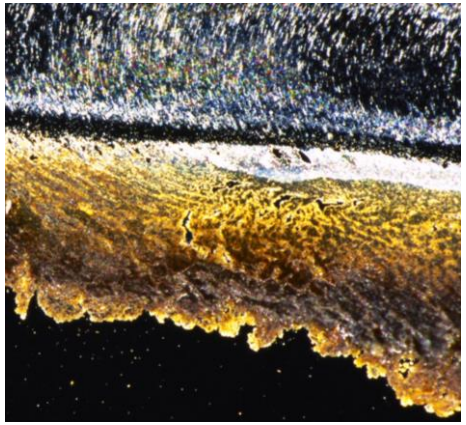
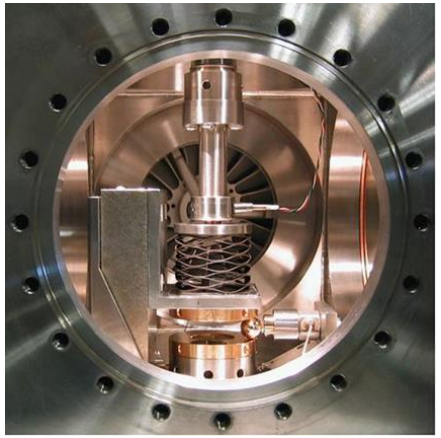
Mapping Lubricant Degradation By Mass Spectrometry Techniques

Conventional Vacuum Residual Gas Analysis (RGA)

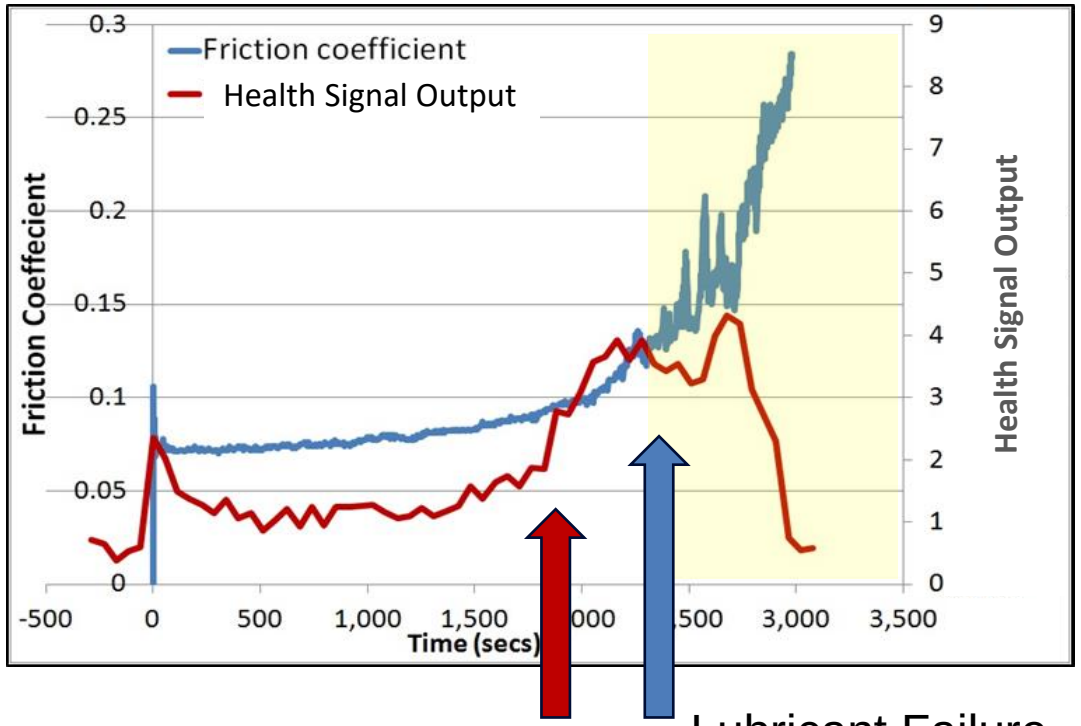
- Limited to modest m/z range and positive ions
- Early detection of Phase 2 (final stage) degradation species and so incipient lubricant failure
- Basis of a health sensor capable of indicating lubricant distress BEFORE it is tribologically detectable.





Terrestrial Applications

- Vacuum system/pump condition monitoring/maintenance optimization.



Lubricant Failure

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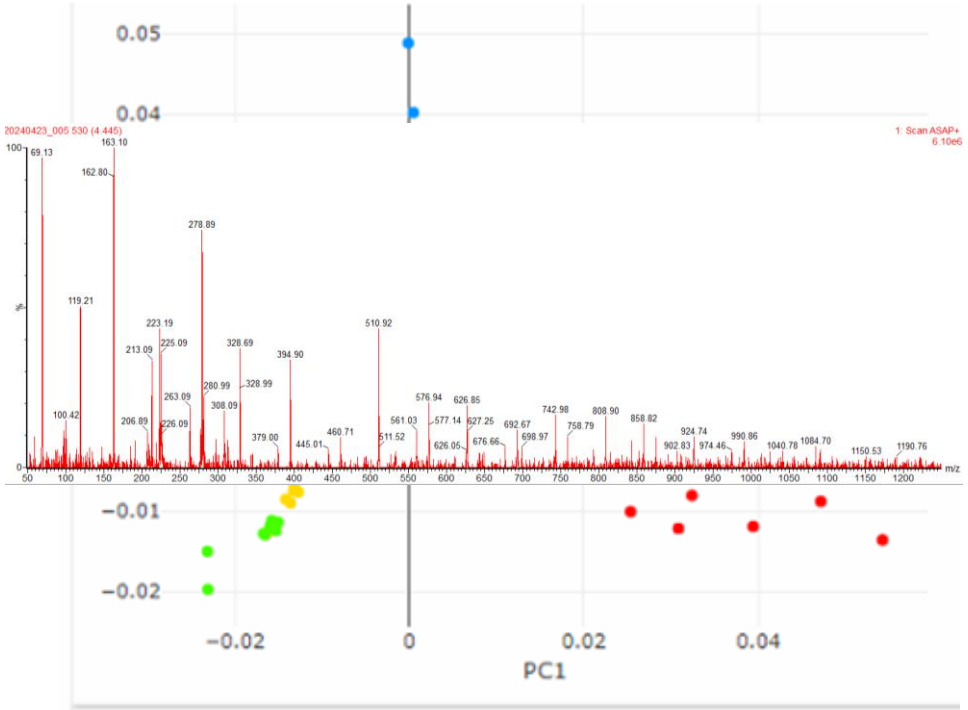
Mapping Lubricant Degradation By Mass Spectrometry Techniques

- Wide Range Mass Spectrometer
  - Single quadrupole mass spectrometer, 50-1250m/z, positive and negative ions
  - Very small (sub-µg) lubricant samples
  - Comparative statistical analysis of spectra (e.g. Principal Component (PC) analysis)
  - Detection of Phase 1 degradation species – **and basis of a lubricant condition monitoring technique**.

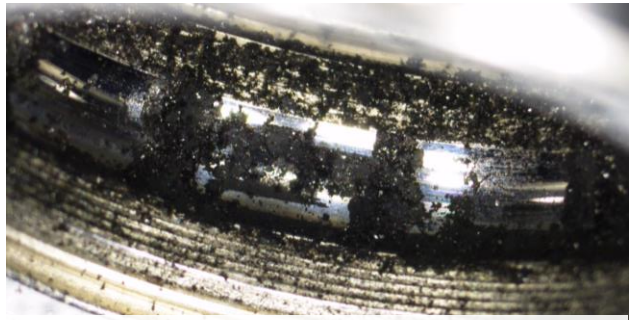
Gearbox

Negative Ions Only



Fresh grease; Gearbox; Front Bearing; Rear Bearing

Motor Front Bearing



Motor Rear Bearing

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Condition Assessment of Oils and Greases

Space Applications

- Health assessment during R&D Test
- Post-operation quantification of fluid lubricant health by statistical analysis
- Confirmation of batch-batch similarity
- Understanding additive function
- Contaminant detection
- Confirmation of substrate/solvent cleanliness
- Impact of long-term storage, thermal, atomic oxygen and radiation-induced degradation…

“Spin Out” to Terrestrial Applications

- As for space plus…
- In-service health assessment of oils and greases supplementing/replacing conventional (less sensitive?) lubricant analysis.
- Detection of counterfeit lubricants/confirmation of correct product use.
- Forensic engineering (post-failure assessments)
- Optimisation of maintenance frequency, techniques and strategies

Other Technology Spin-Out Examples

New lubricant formulations and chemistries
- Ionic fluids, PFAS free, blends, new surface pre-treatments and additives

Industrial vacuum pumps and systems
- bearing analysis
- lubricant performance evaluation
- lubricant health monitoring/supply
- impact of process gases on lubricants

Fusion power (in vessel)
- anti-adhesion and low friction coating assessments

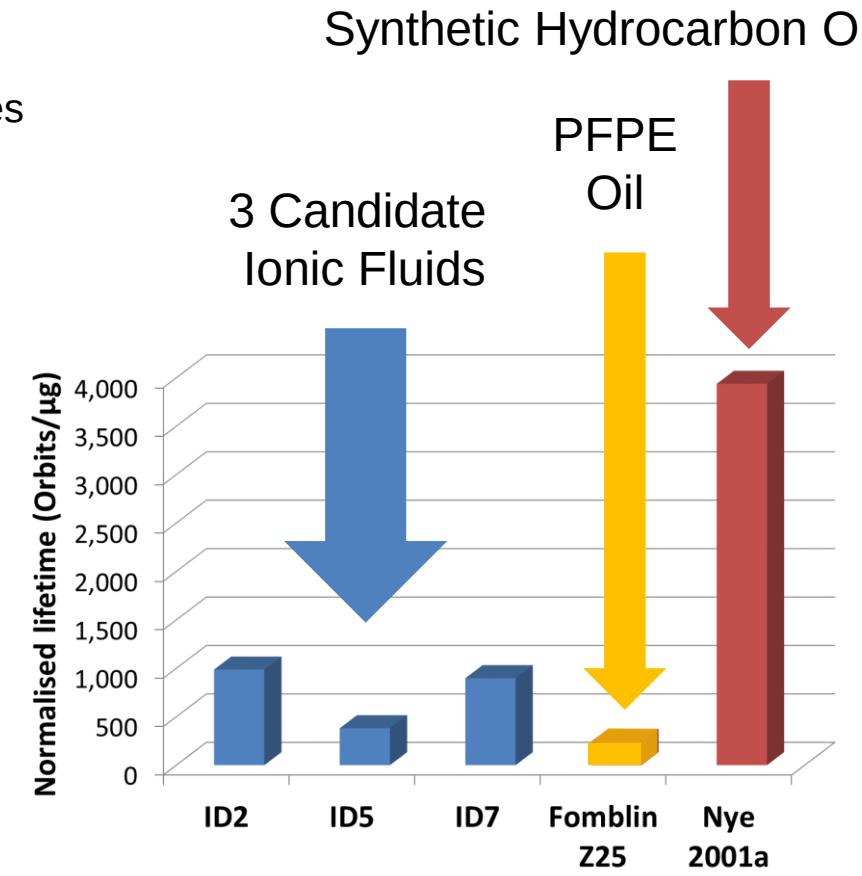
Optics and semi-conductors
- lubricant performance evaluation & selection

Medical X-Ray Systems
- lubricant development/supply

Motorsport
- selection and optimisation of additives to prolong life/add resilience.

“High-end” mechanical watches
- balance wheel lubrication study

Consultancy tools for many sectors…



SOT lubricant life data in vacuum

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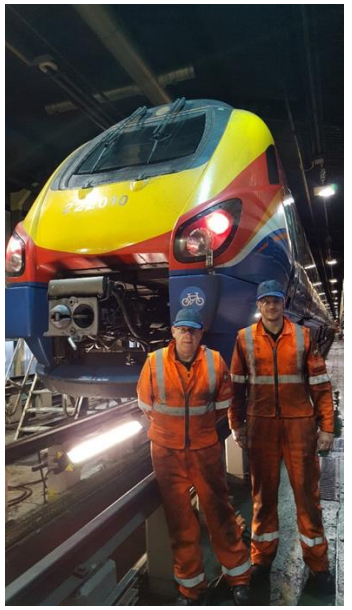
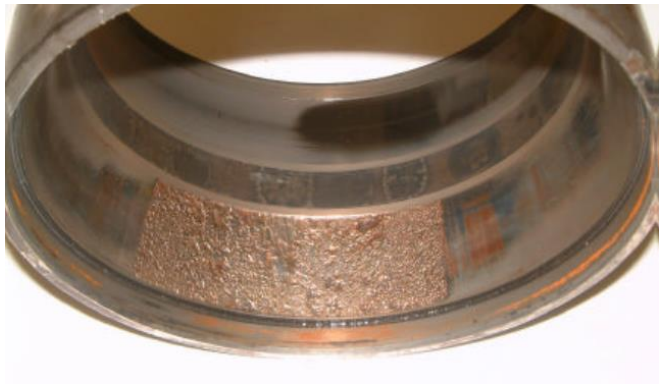
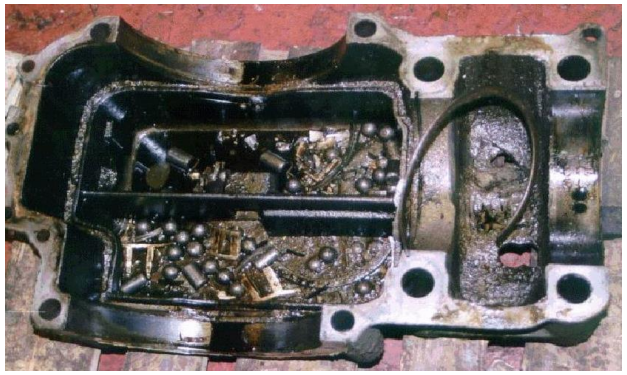
Industrial Tribology and Forensic Engineering

- Forensic Engineering & Materials Assessment
- Industrial Tribology R&D
- Independent Engineering and Bearing Assessment
- Expert Witness







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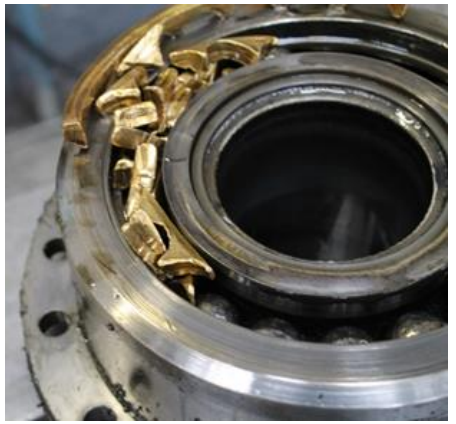
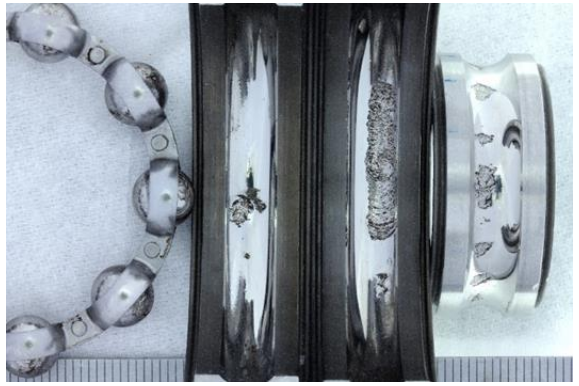
Rail Industry Consulting - Spin-Out Example

- “CAB4RAIL” Bearing Code
  - Advanced bearing analysis, extended to railway bearing types
  - Analysis supplements condition/life extension assessments and failure investigations



- Lubricant Condition Assessment with Wide Range Mass Spectrometer
  - Identification of contaminants, wear debris assessment
  - Lubricant health quantification
  - Post-failure assessment



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Concluding Thought

Tribological techniques and expertise originating in the space industry can be beneficial in addressing the challenges of “terrestrial” industries.

- Bearing system design and function
- Lubricant performance and trade-off (both solid and fluid)
- Lubricated system performance monitoring
- Maintenance/life extension planning
- Forensic engineering and failure examinations

Thank You

- >+300°C

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