
ESTL
Keeping Space Moving

50 Years of Space Tribology in Europe

What have we learned about "Keeping Space Moving"…and what next?

Simon Lewis

European Space Tribology Laboratory (ESTL)

ESMATS 20th September 2021

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1966
Birth of Tribology

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Credit Associated Press

1966
Birth of Tribology

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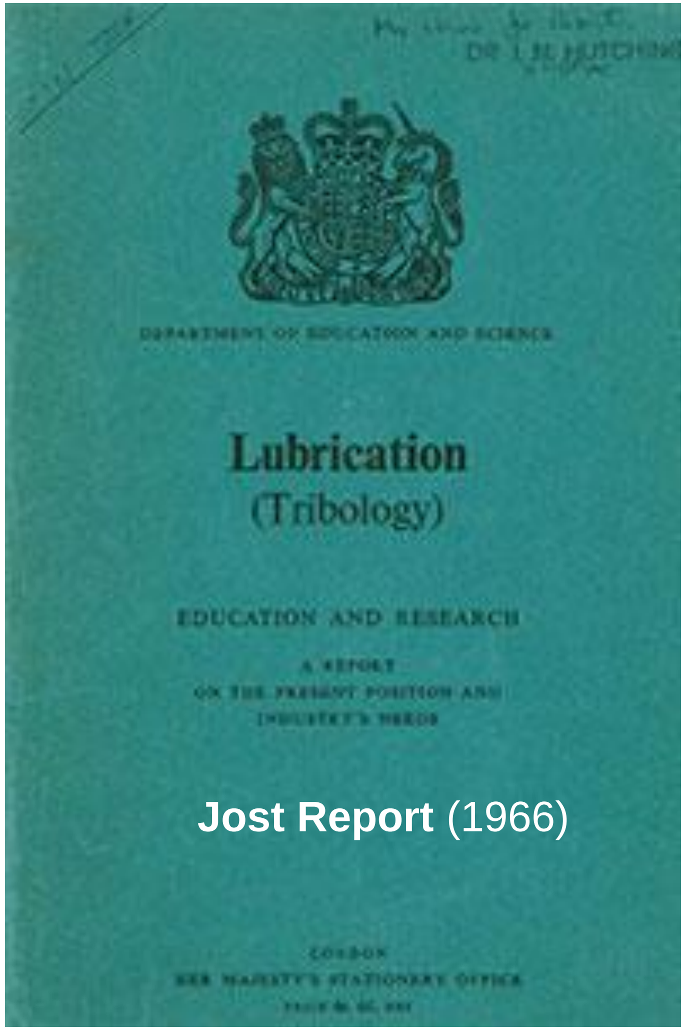
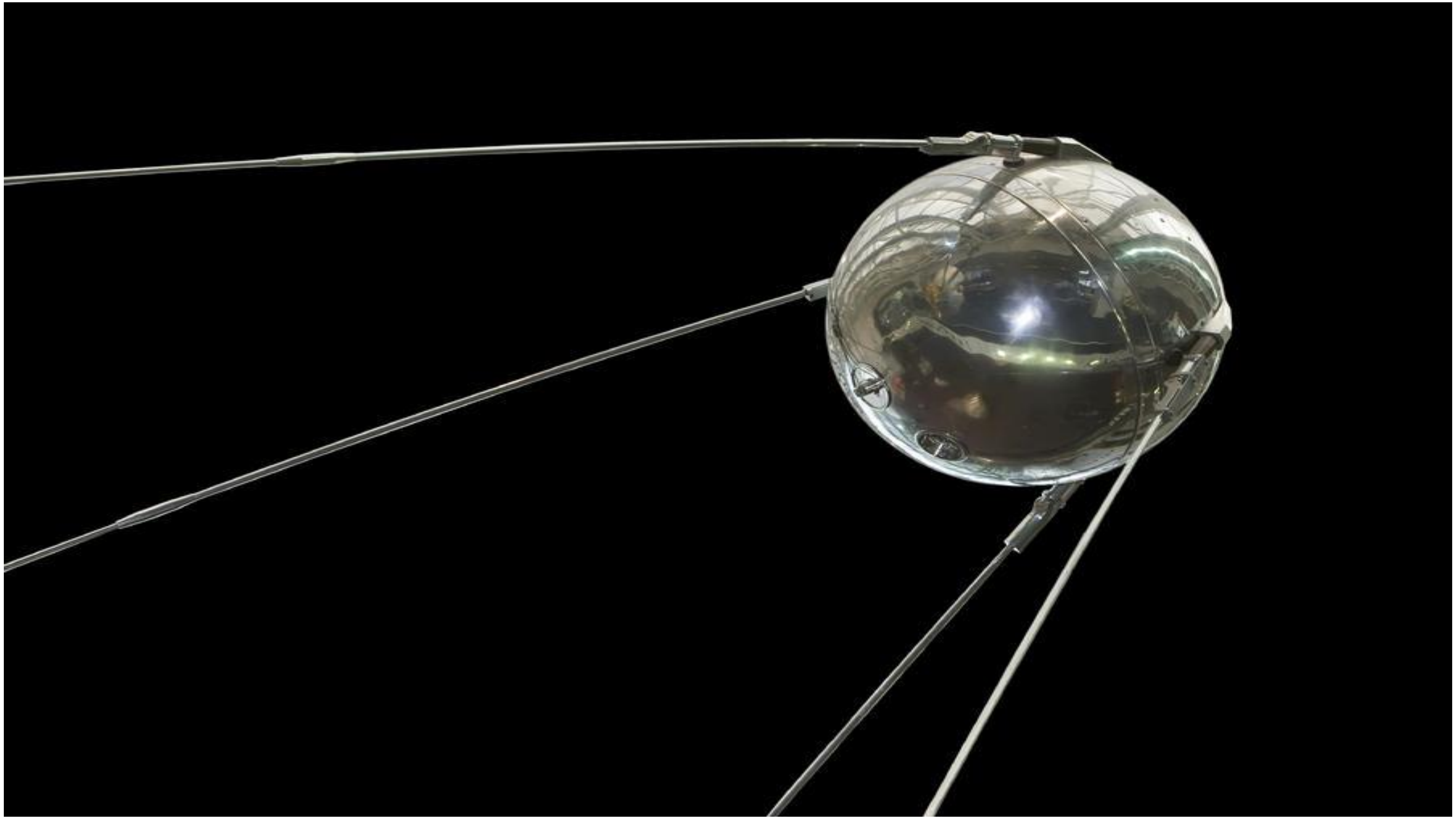


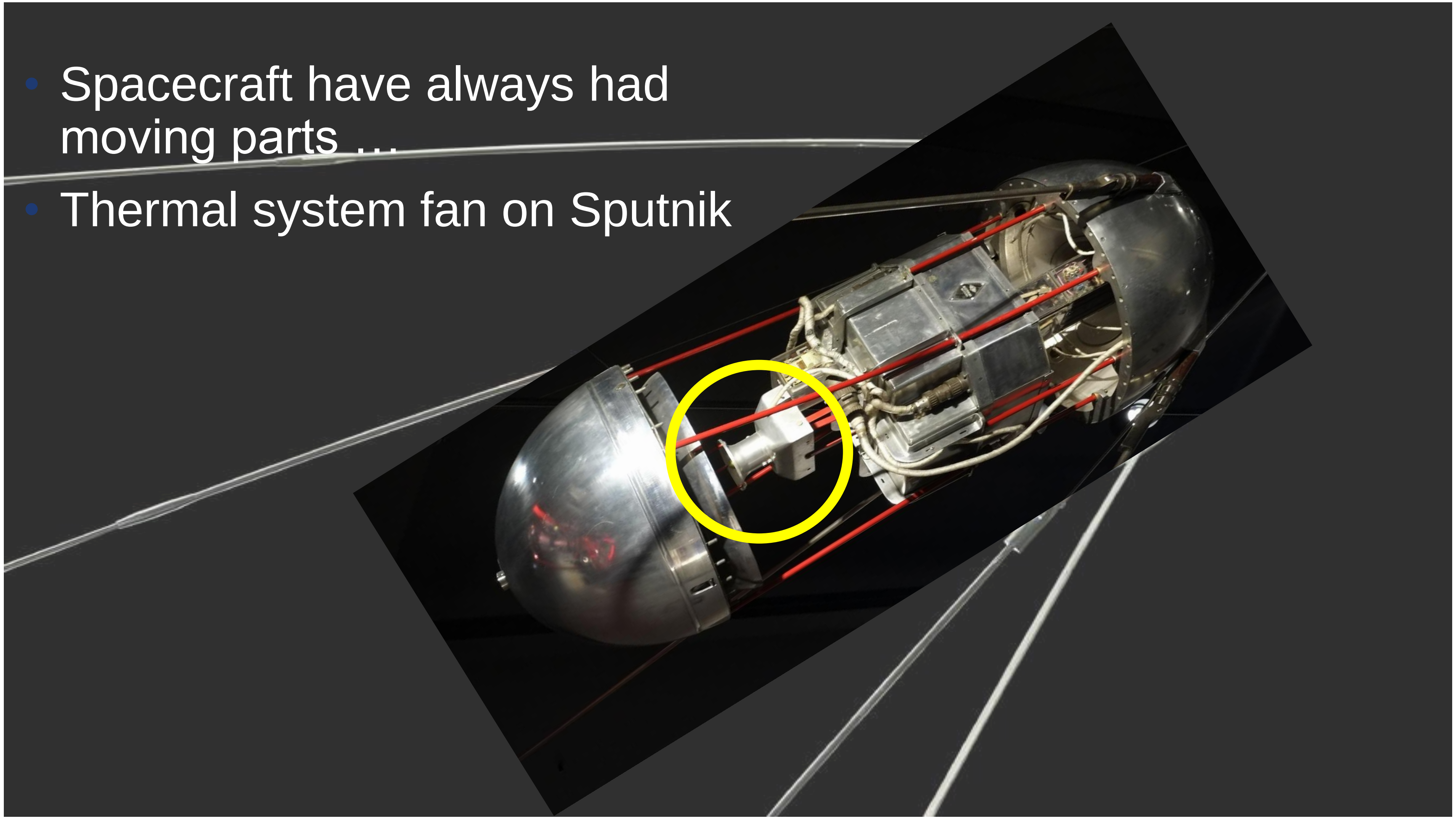
Jost Report (1966)

Sputnik (Launched Oct 1957) – Birth of Space Tribology



Sputnik (Launched Oct 1957) – Birth of Space Tribology

- Spacecraft have always had moving parts …
- Thermal system fan on Sputnik



Space Tribology In Europe

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

Space Tribology In Europe

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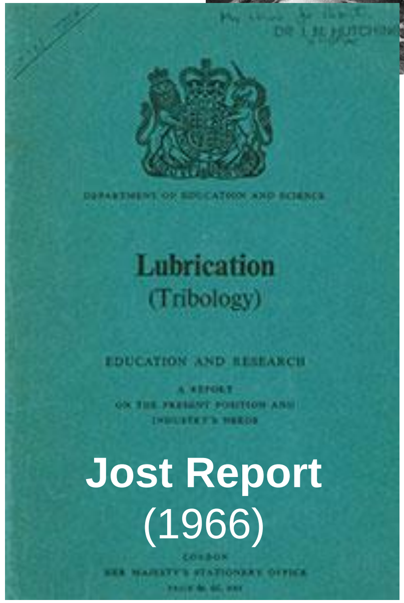
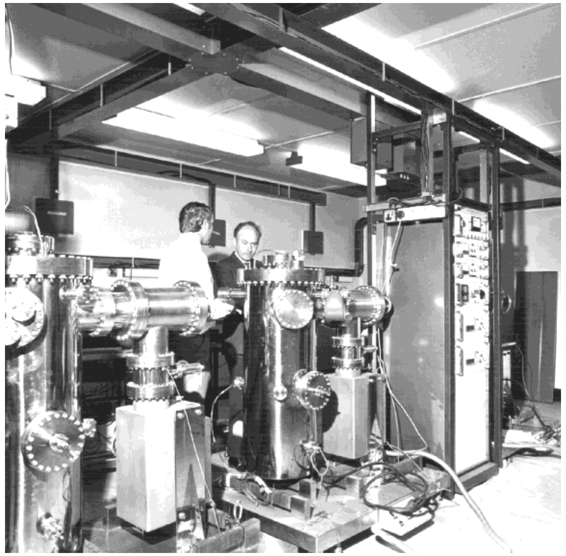
European Space Technology Centre (ESTEC)
Opened in 1968

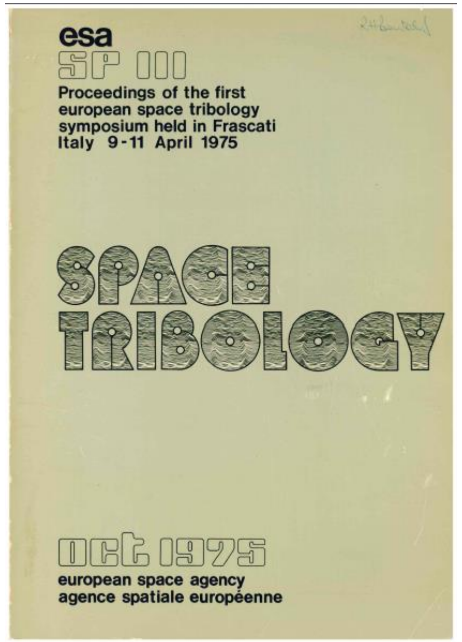


Jost Report
(1966)

One small step…
16th July 1969



European Space Tribology Laboratory (ESTL)
established in 1972
(by ESRO which merged with ELDO in 1975 to become ESA)



First European Space Tribology Symposium (1975)

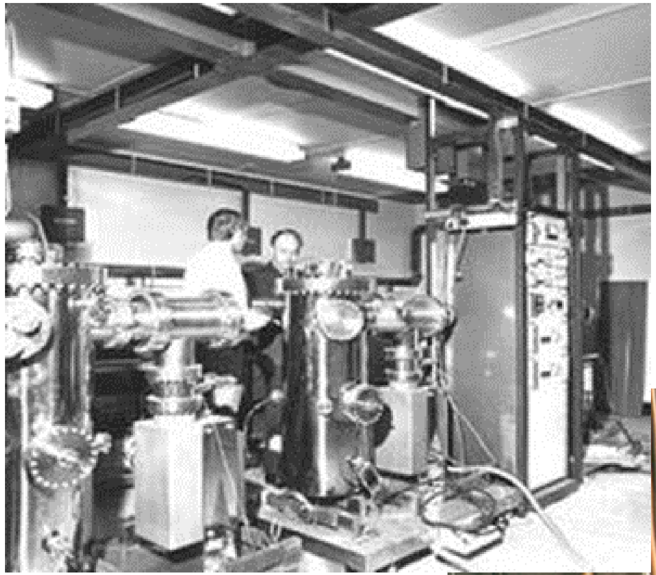
<u>Fundamental objective of ESTL :</u>
"*To increase the efficiency and reliability of spacecraft through the application of good tribology*"

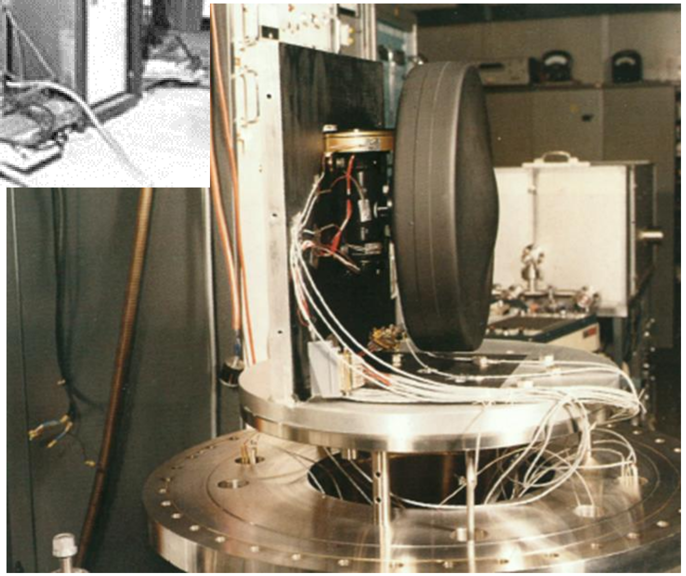
ESTL's Initial Research Areas

- Mechanism Tests (1972-77)
  - Long term test of 6 "solar paddle" drives – SADMS (1 rpd)
  - Accelerated Life test of a SADM
  - Life and performance test of a gimballed momentum wheel
  - De-spin mechanism lifetest
  - Antenna Pointing Mechanism lifetest
  - BAPTA – Bearing and power transfer assemblies life and acceptance tests

- R&D Programme
  - Dry lubricated slip rings
  - Life of lead lubricated bearings and development and optimisation of the process
  - Performance of anti-creep barriers
  - Friction and wear of self-lubricating rod end bearings

- Commercial Consultancies
  - Reaction wheel consultancies



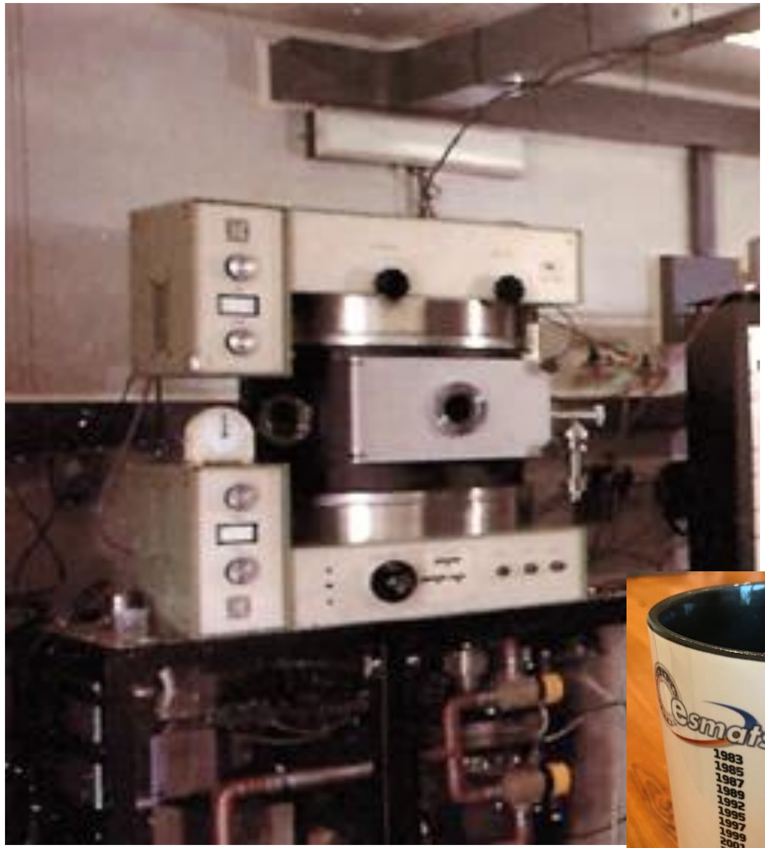


OTS 2
Hardware Test Beginnings

- SADM TV test lifetest and acceptance test
  - Acceptance test of 2x FM units carried out in 1976
  - Accelerated Lifetest on QM completed April 1977 (7 years simulated over approximately 6 months)

Commercialisation of Lead Lubrication in Europe

- Ion-plating process qualified
  (ESTL-TP -015, March 1983)
- Wide adoption, becoming mainstay of solid lubrication for ~15 years
- Coating volume small
  (limiting component and batch sizes)
- Subsequent development showed
  - Corrosion prevention
  - PFPE degradation inhibition
- Sputtered “Plasmag” or “PVD” lead and silver developed (1999)
  - Larger facility
  - Economic batch size and larger components
- Extensive use of lead in telecom applications, silver in turbopumps



Some Missions

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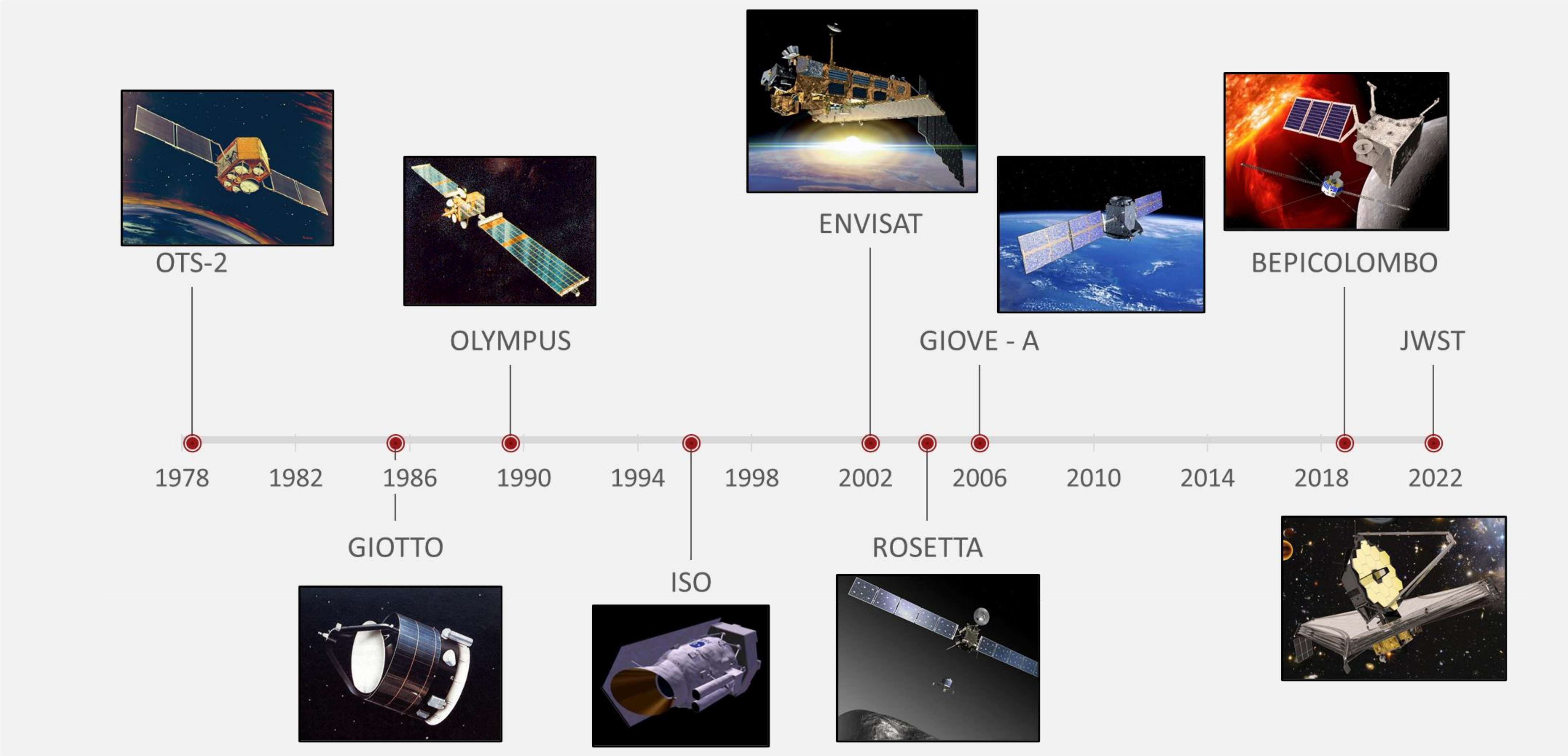
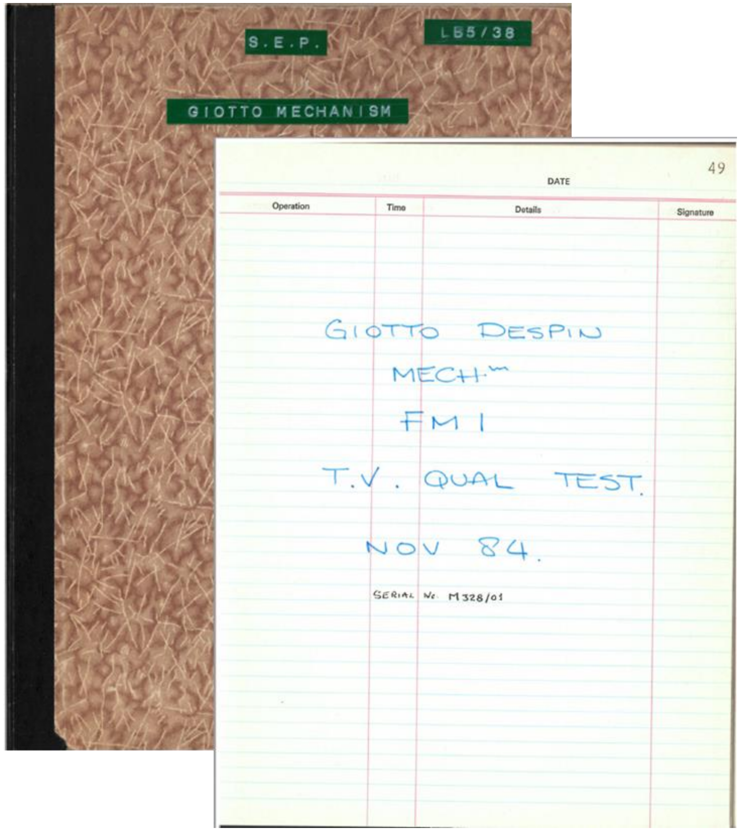


Giotto



- ESTL Role
  - Lubricant selection, trade-off and resolution of uncertainties by early test
  - Qualification TV accelerated lifetest… we still have the log-book

From BAPTISM to CABARET Bearing Modelling

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Cabaret ˈkabəreɪ,ˌkabəˈreɪ/ (noun)

An entertainment while seated…

usually in a night club.

Code for Analysis of BeArings in Rocket Engine Turbopumps

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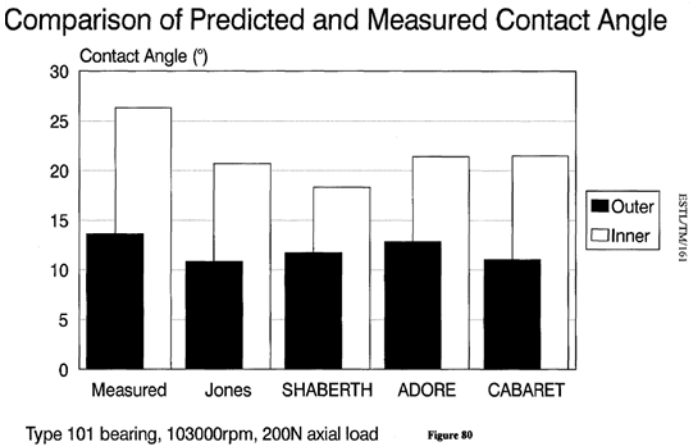

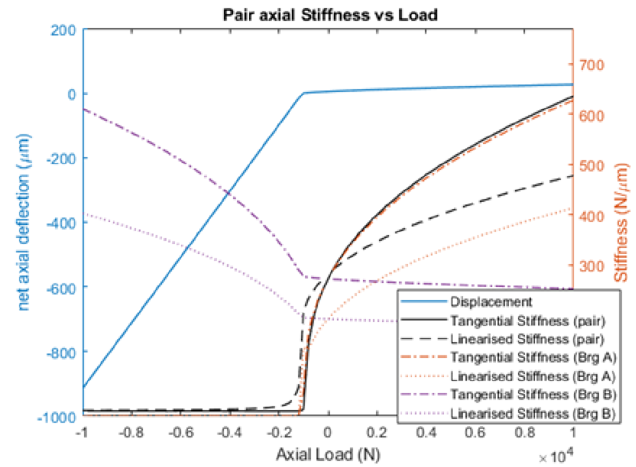

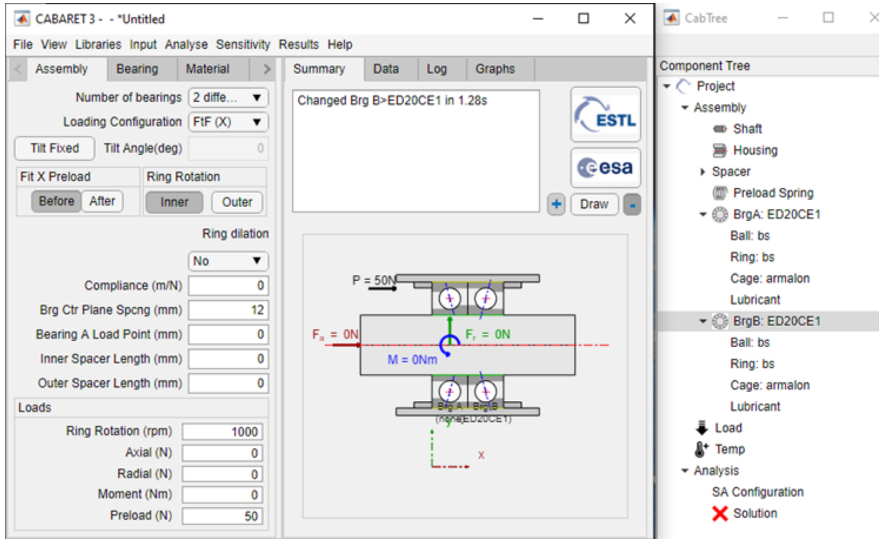

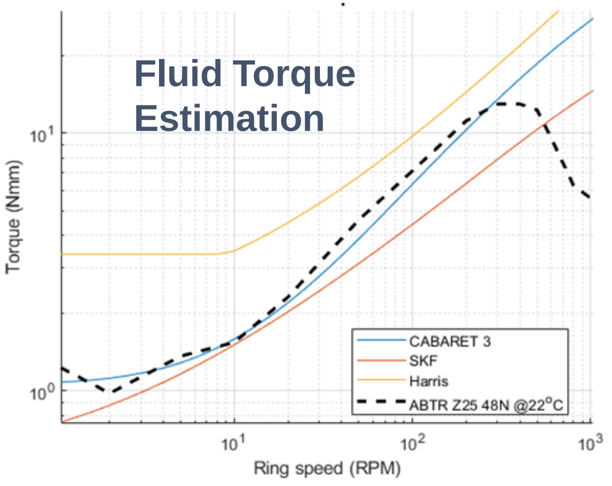

Olympus

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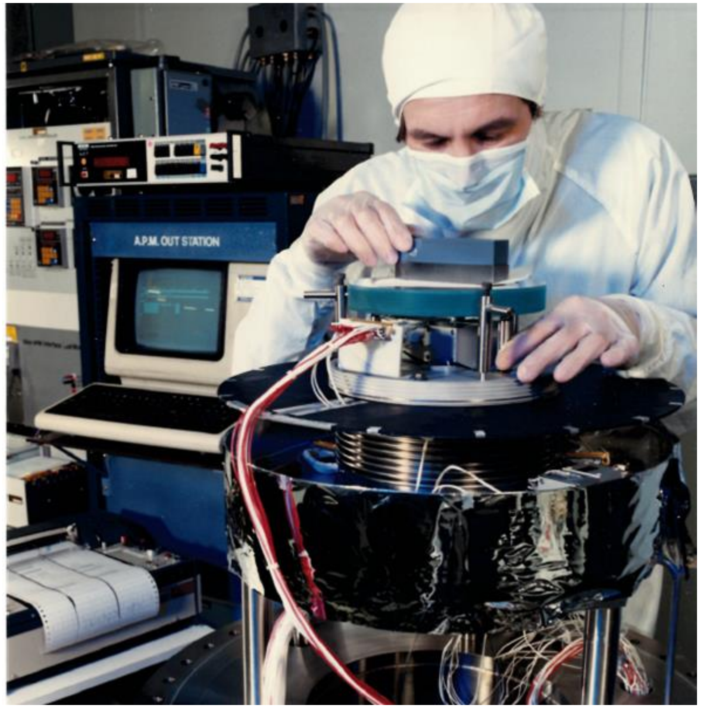
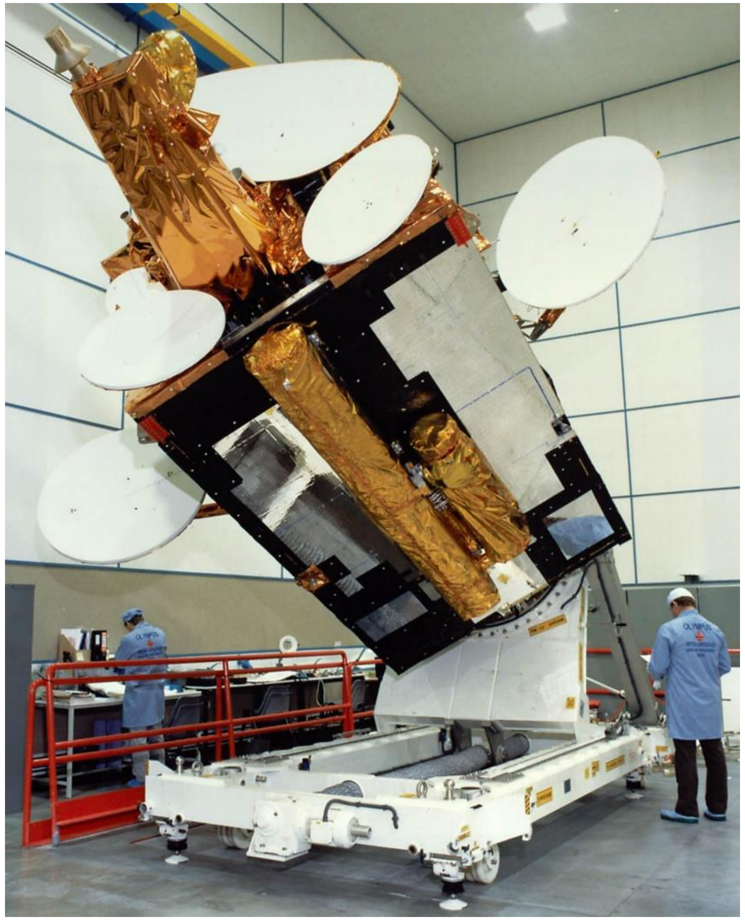
- SADM lubrication using ion plated lead

- Wheel Development
  - KG80 with antioxidant and TCP (boundary lubricant)
  - Optimised cage for stability
  - Tested re-lubrication reservoir

- Swashplate APM Development (5 flown)
  - Thin section, gothic arch bearings
  - Lubricant selection – Braycote 601
  - Specialised test rig for APM angular measurement accuracy via customised high accuracy inclinometers

- Early attempts at bearing condition monitoring using PAXS accelerometer data

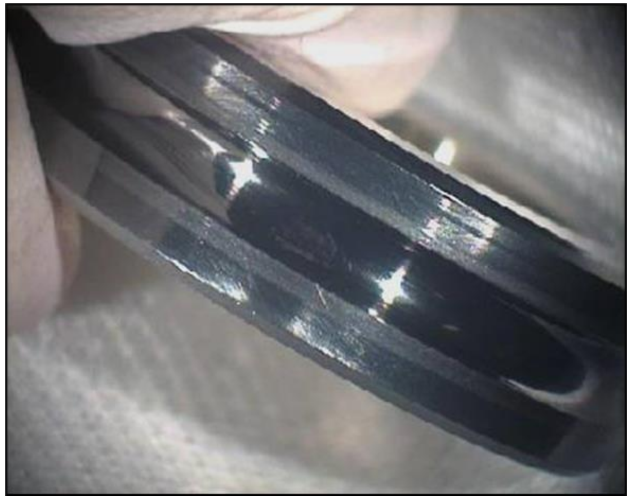


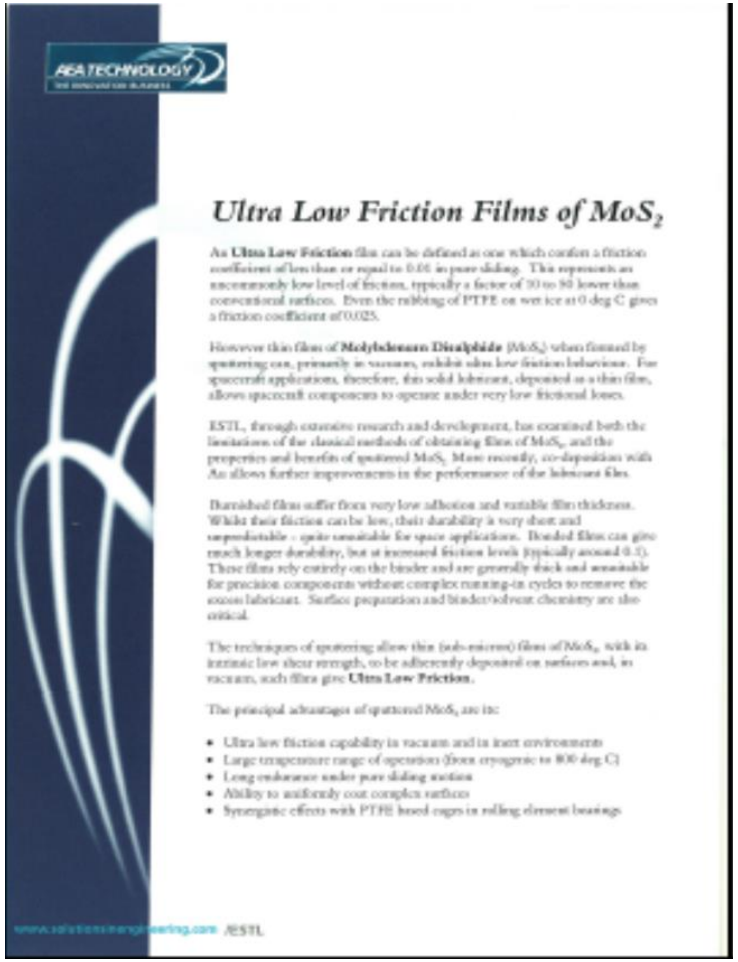


Parallel Development of Sputtered MoS_2

- Development and commercialisation of sputtered MoS_2 with "ultra-low friction" $\mu<0.01$

  (μ~0.025 for wet ice at 0ºC)





Ultra Low Friction Films of MoS_2

An **Ultra Low Friction** film can be defined as one which confers a friction coefficient of less than or equal to 0.01 in pure sliding. This represents an uncommonly low level of friction, typically a factor of 10 to 50 lower than conventional surfaces. Even the rubbing of PTFE on wet ice at 0 deg C gives a friction coefficient of 0.025.

However thin films of **Molybdenum Disulphide** (MoS_2) when formed by sputtering can, primarily in vacuum, exhibit ultra low friction behaviour. For spacecraft applications, therefore, this solid lubricant, deposited as a thin film, allows spacecraft components to operate under very low frictional losses.

ESTL, through extensive research and development, has examined both the limitations of the classical methods of obtaining films of MoS_2, and the properties and benefits of sputtered MoS_2. More recently, co-deposition with Au allows further improvements in the performance of the lubricant film.

Burnished films suffer from very low adhesion and variable film thickness. Whilst their friction can be low, their durability is very short and unpredictable – quite unsuitable for space applications. Bonded films can give much longer durability, but at increased friction levels (typically around 0.1). These films rely entirely on the binder and are generally thick and unsuitable for precision components without complex running-in cycles to remove the excess lubricant. Surface preparation and binder/solvent chemistry are also critical.

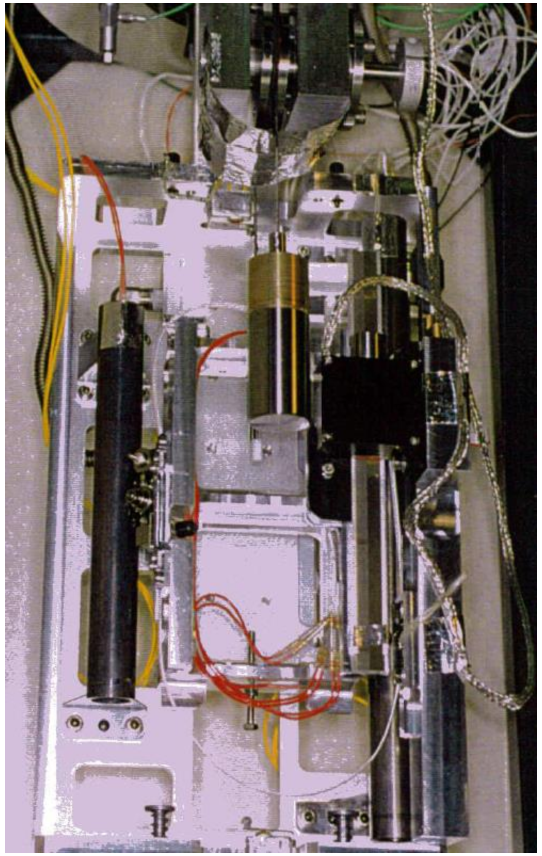
The techniques of sputtering allow thin (sub-micron) films of MoS_2, with its intrinsic low shear strength, to be adherently deposited on surfaces and, in vacuum, such films give **Ultra Low Friction**.

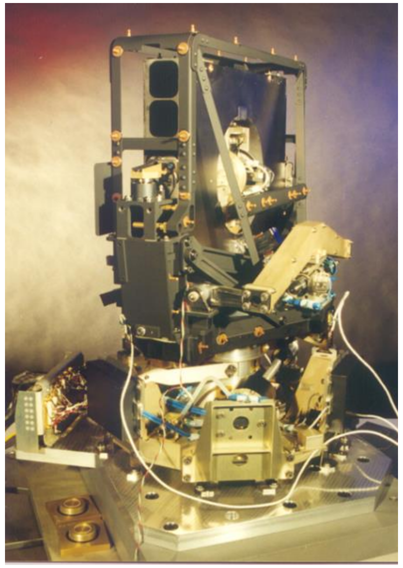
The principal advantages of sputtered MoS_2 are its:

- Ultra low friction capability in vacuum and in inert environments
- Large temperature range of operation (from cryogenic to 800 deg C)
- Long endurance under pure sliding motion
- Ability to uniformly coat complex surfaces
- Synergistic effects with PTFE based cages in rolling element bearings

Envisat

Test setup for TV test of MIPAS linear rails





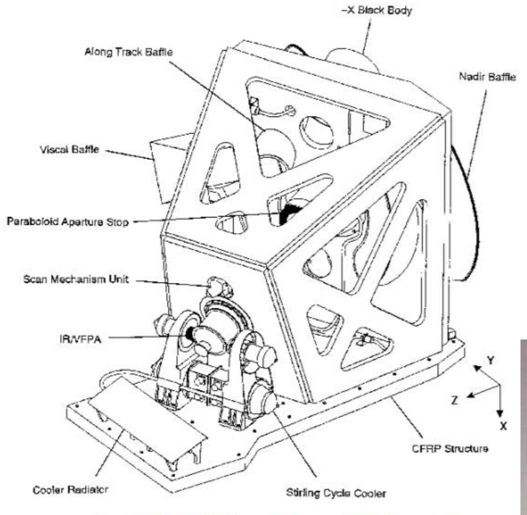
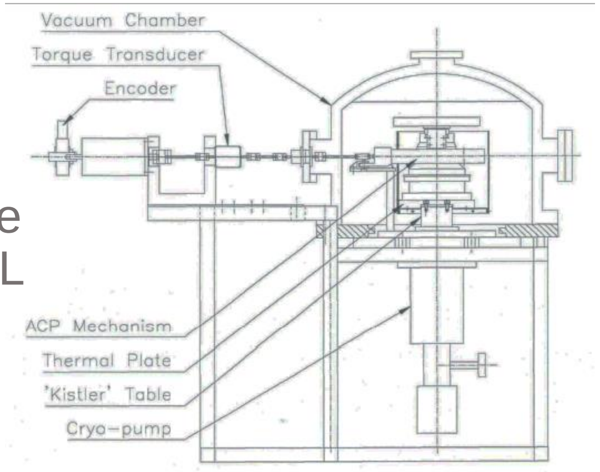


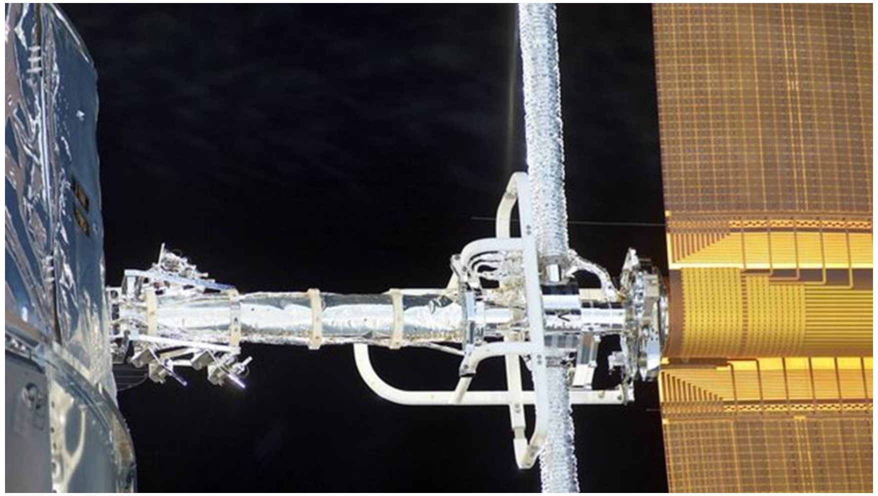
Figure 1.2 Main Features of the AATSR Instrument

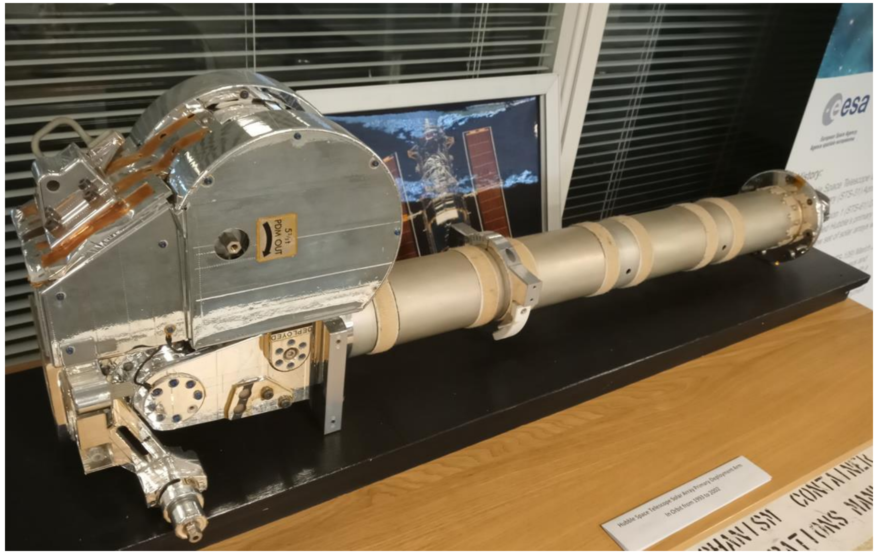
GOMOS, its ACPM was life tested at ESTL



AATSR – its scan bearings were tested for 10^9 revs

Hubble Space Telescope





Rosetta

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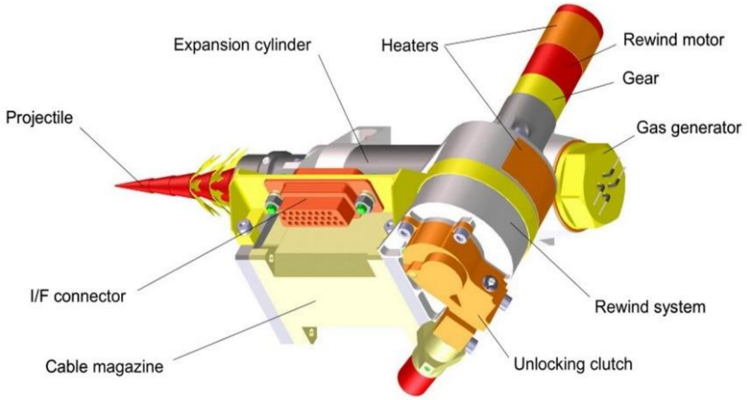
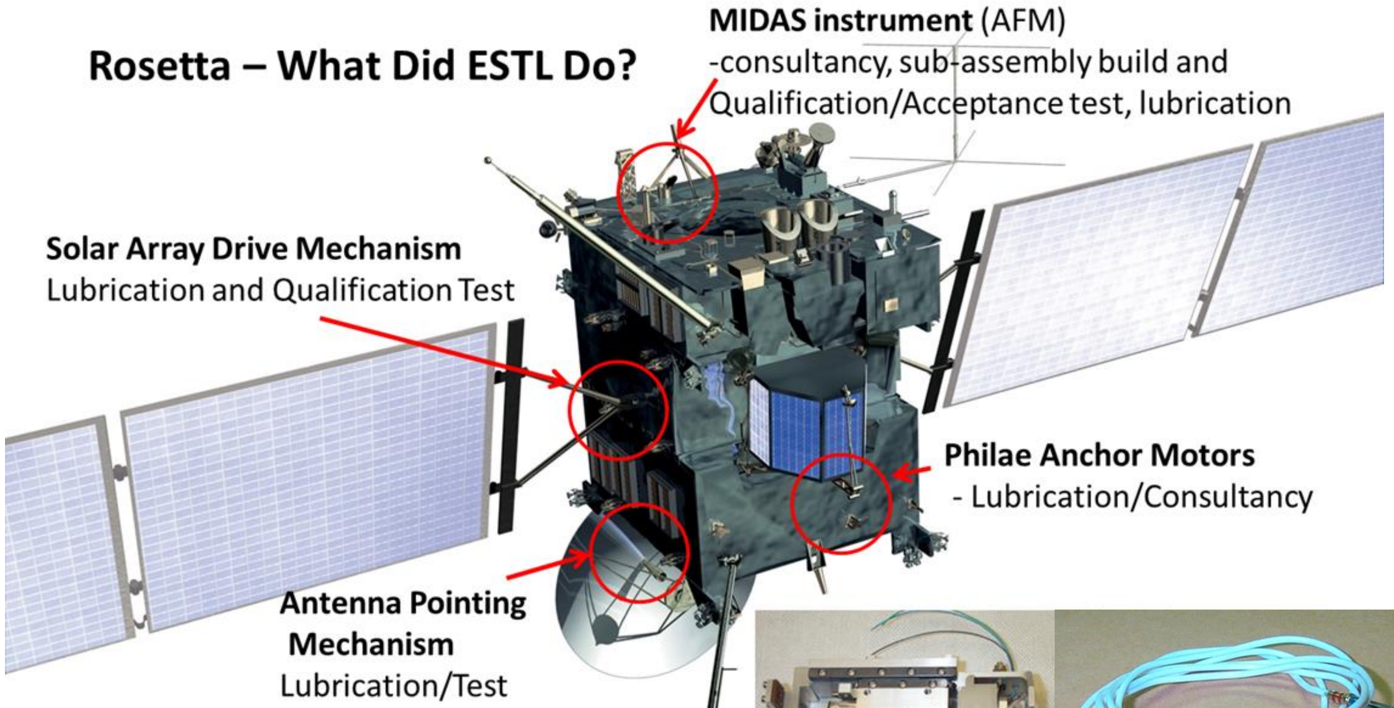
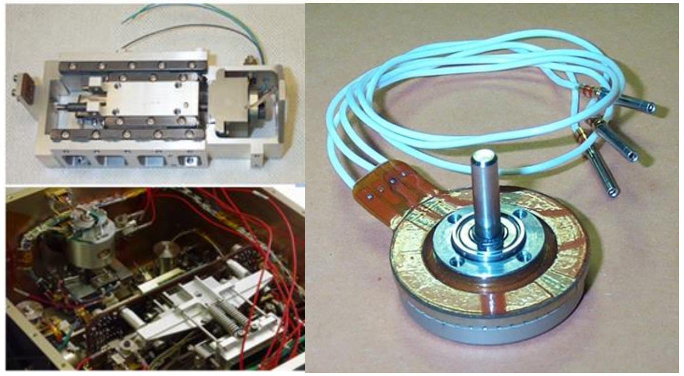
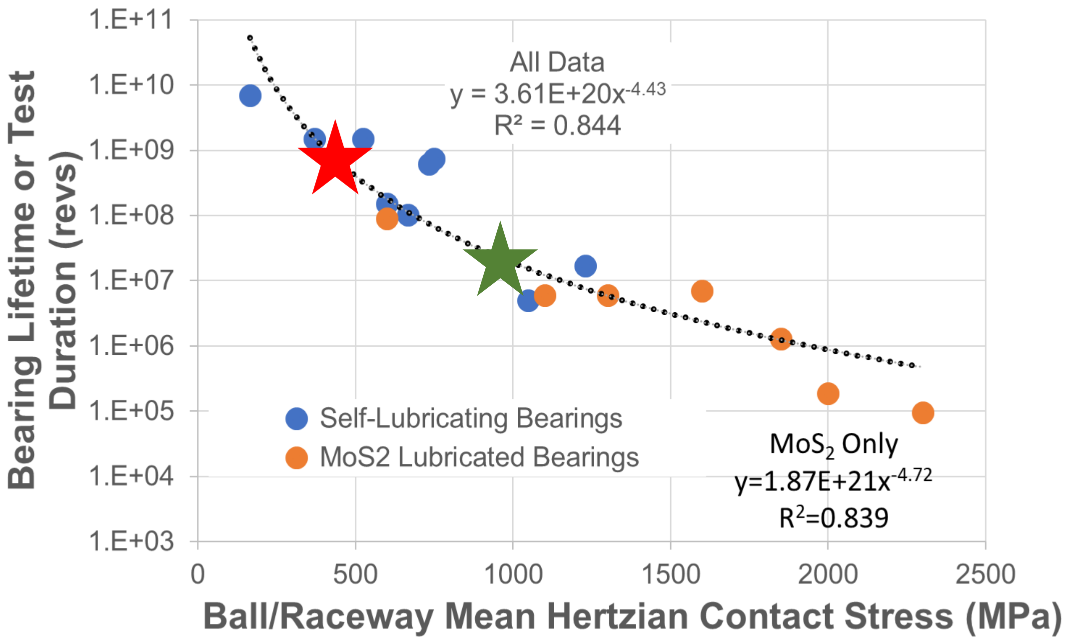




Reaction Wheels
Kitting/Assembly Support
In-Flight Consultancy (Sept 2009)



GIOVE-A



Acceleration by load x 3.2

Acceleration by Speed x 3.3

Overall Factor ~ x10.4

Tribology at the Extremes…
Hot BepiColombo

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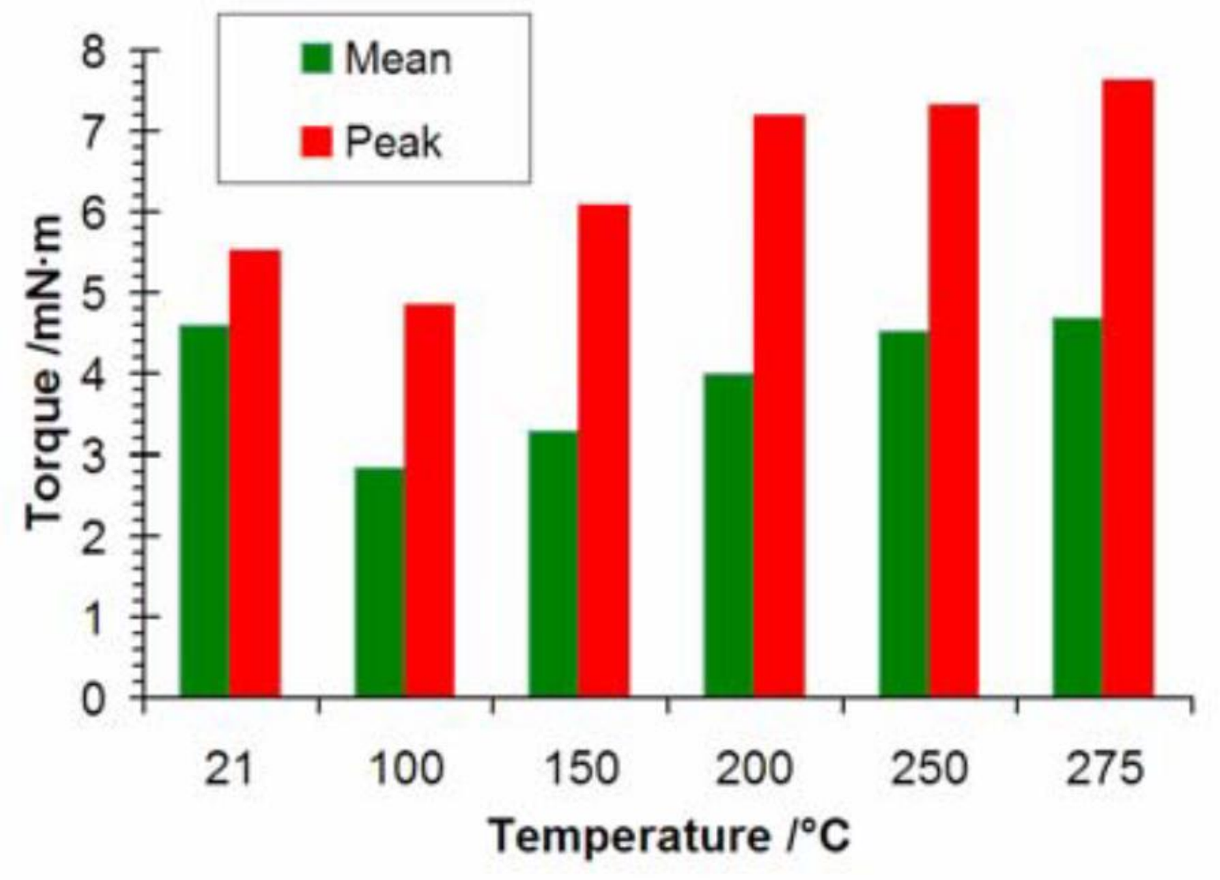

Tribology at the Extremes… Cryo ISO to JWST

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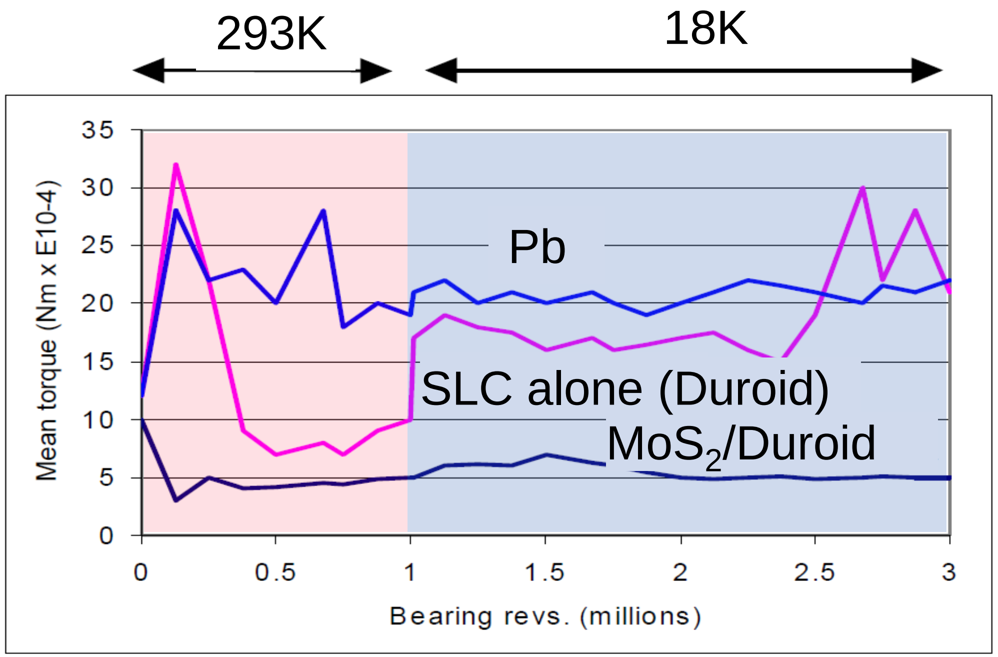

R&D Activities

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- A snapshot of R&D activities for 2021

Task	Title
7101	Gear Roadmap Phase 4 (2021) - Gear Procurement
7102	Gear Roadmap Phase 4 (2021) - Testing
7103	Space Industry Bearing Lifetest Database
7104	Next Generation MoS2 - Phase 2
7105	Bearing Lifetime with Next Generation MoS2 - Part 1
7106	Objective Tribological Criteria for Ball Bearing Tests
7107	Assessment of Low Temperature Fluid Blends
7108	Fundamentals of Grease Lubrication in Vacuum
7109	The Evaluation of ToFMS for Lubricant Degradation & Health
7110	Formulated Lubricants Based Upon Ionic Liquids
Non-TAP	Long Term Test Support
Non-TAP	Bearing Sizing Process Guidelines

What Have We Learned - Solids?

- TV testing - well understood throughout industry – new need for testing with dust and at cryo?

- High performance **solid lubricants –** available, structural and environmental impact on performance (including short-term storage) known (at least at tribometer level) – research into long-term storage ongoing

- Achievable **lifetimes of common components**, especially bearings, with these lubricants are known – but the situation regarding gears and some other components is less clear.

- The characteristics **of a range of lower cost solid lubricants** (e.g. spray bonded and other processes) suitable for lower precision, or lower duty applications are known

- Key properties of the **present generation of self lubricating polym**ers for use in bushes, gears and cages are known, but more work is needed.

What Have We Learned - Fluids?

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- The application and generic performance of key types (e.g. MAC and PFPE chemistries) is known and relative lifetimes in boundary regime well understood
- Considerable performance detail about specific products – but no agreed protocols for introduction of new fluid lubricant products.
- Partial understanding of cleaning, substrate materials, some aspects of environment and thermal effects.
- Performance of specific components (e.g. gears) with fluid is more limited – but work is ongoing.
- **For all lubricants** – detailed understanding of function is ongoing

Start Early – Tests May Be More Complex Than You Think

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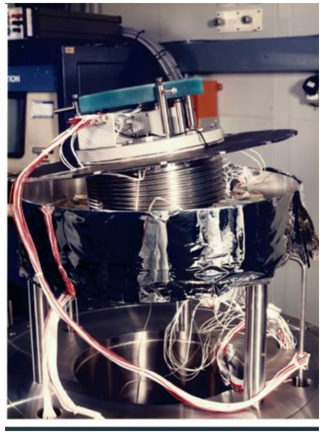
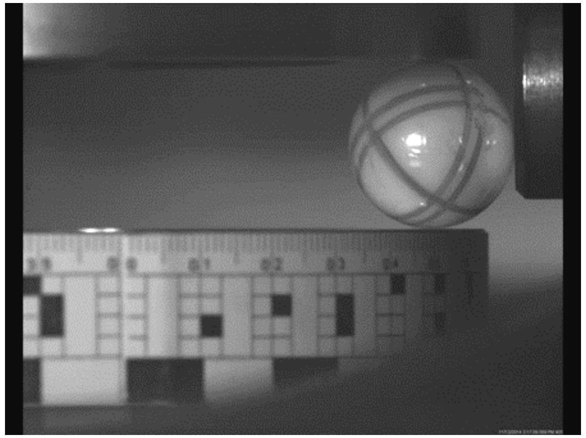
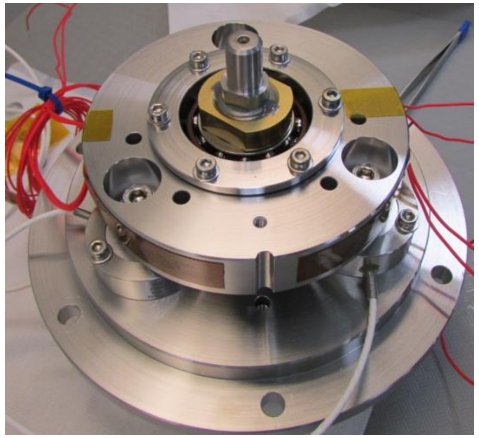
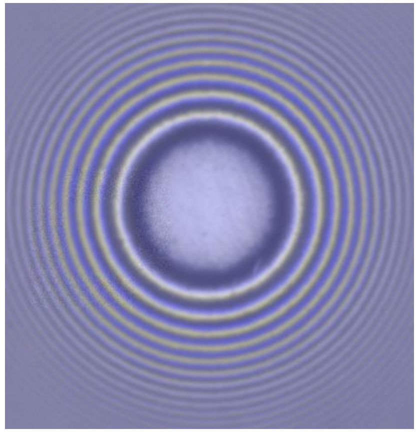
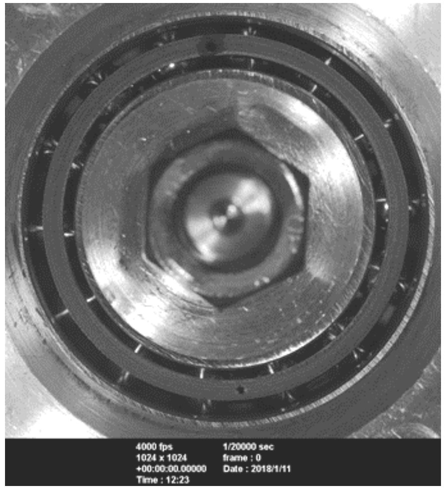
- New techniques or adaptation of rigs may be a pre-requisite











What Next for Space Tribology?

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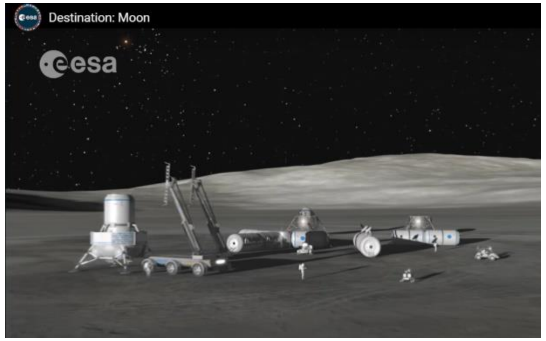
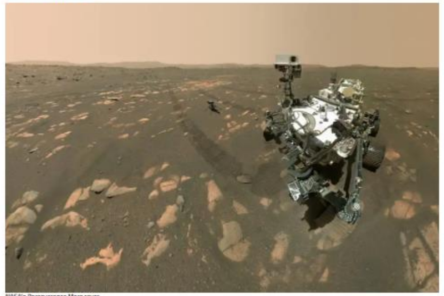
- Longer life solid Lubricants with fewer operational constraints
- New classes of fluid Lubricant – e.g. ionic fluids - combining low volatility and degradation resistance
- Cost reduction and process optimisation for tribo-components and lubricants
- New Space, New Players and New Mission Types/Requirements (In-orbit servicing, active debris removal, demisability, on-orbit assembly, (even larger) deployables)
    - Minimisation of tribological risks by availability of training, technical guides and close support regardless of company background, size or national experience.
- Condition Monitoring/Embedded Sensors/In-Situ Lubrication/Relubrication
    - Better sensors, derived from understanding of lubricant and contact behaviour, health warnings, and better decisions
- Environmental legislation here on Earth – prohibition of some materials or solvents
- New tribo-materials and products
- **… what about the lunar perspective?**




NASA's Perseverance rover has been hit by 100 'dust devils' on Mars

SPACE 16 September 2021

By Jonathan O'Callaghan

NASA's Perseverance Mars rover
NASA/JPL-Caltech/MSSS

NASA's latest Mars rover, Perseverance, encountered 100 dust devils in its first 90 days on Mars after landing in February.

Small whirlwinds on Mars, known as vortices, aren't uncommon. They can be tens of metres wide and several kilometres high, with wind speeds upwards of 100 kilometres per hour. Many have been detected by other missions on Mars, such as the Curiosity rover and InSight lander.

If these vortices lift up Martian dust, they can form so-called dust devils – dusty columns towering into

Space Mechanisms – Lunar Perspective

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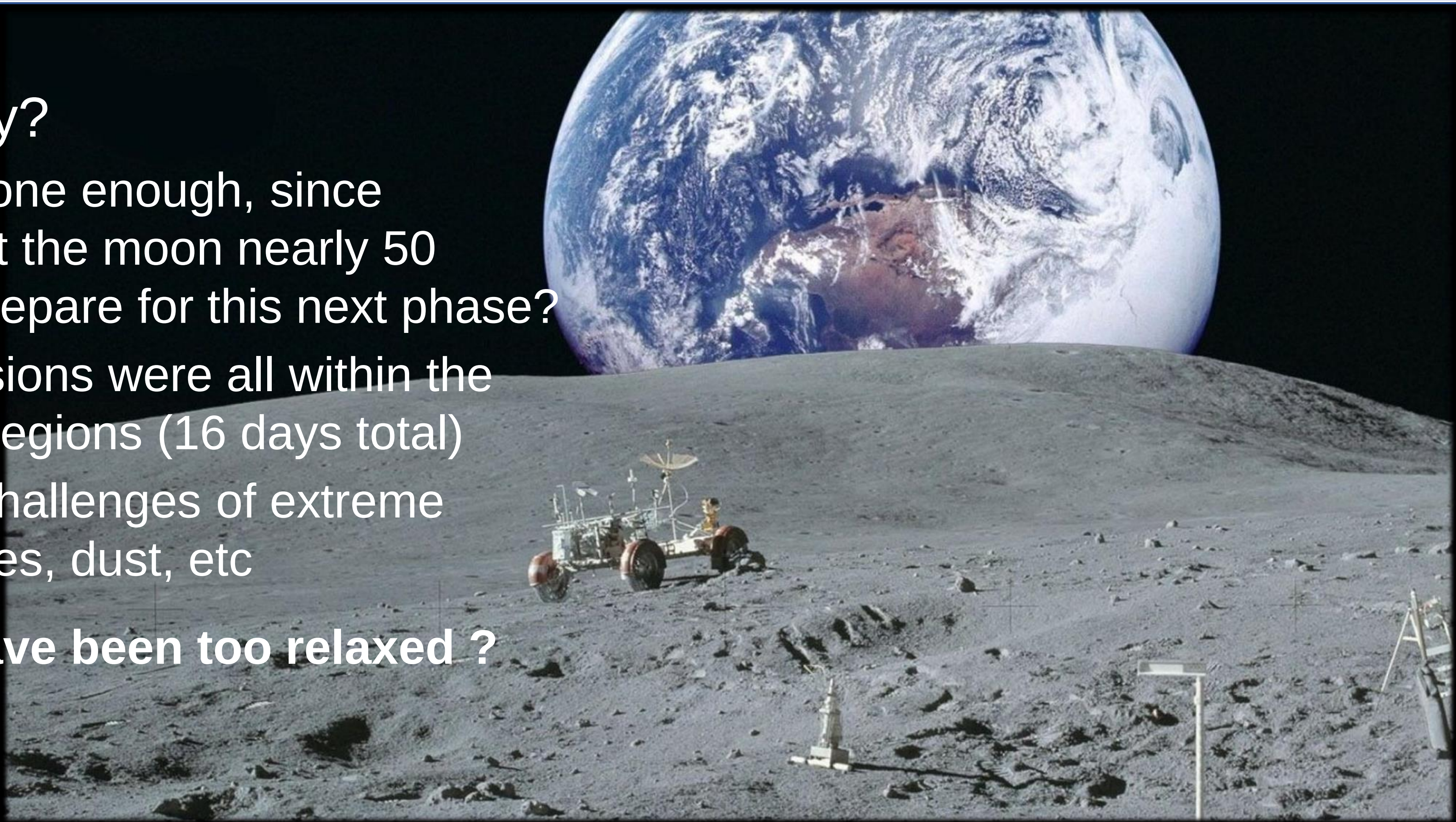
- Are we ready?
  - Have we done enough, since humans left the moon nearly 50 years, to prepare for this next phase?
  - Apollo missions were all within the equatorial regions (16 days total)
  - Immense challenges of extreme temperatures, dust, etc

…. **Could we have been too relaxed ?**



A New Start – ARTEMIS (twin of Apollo)

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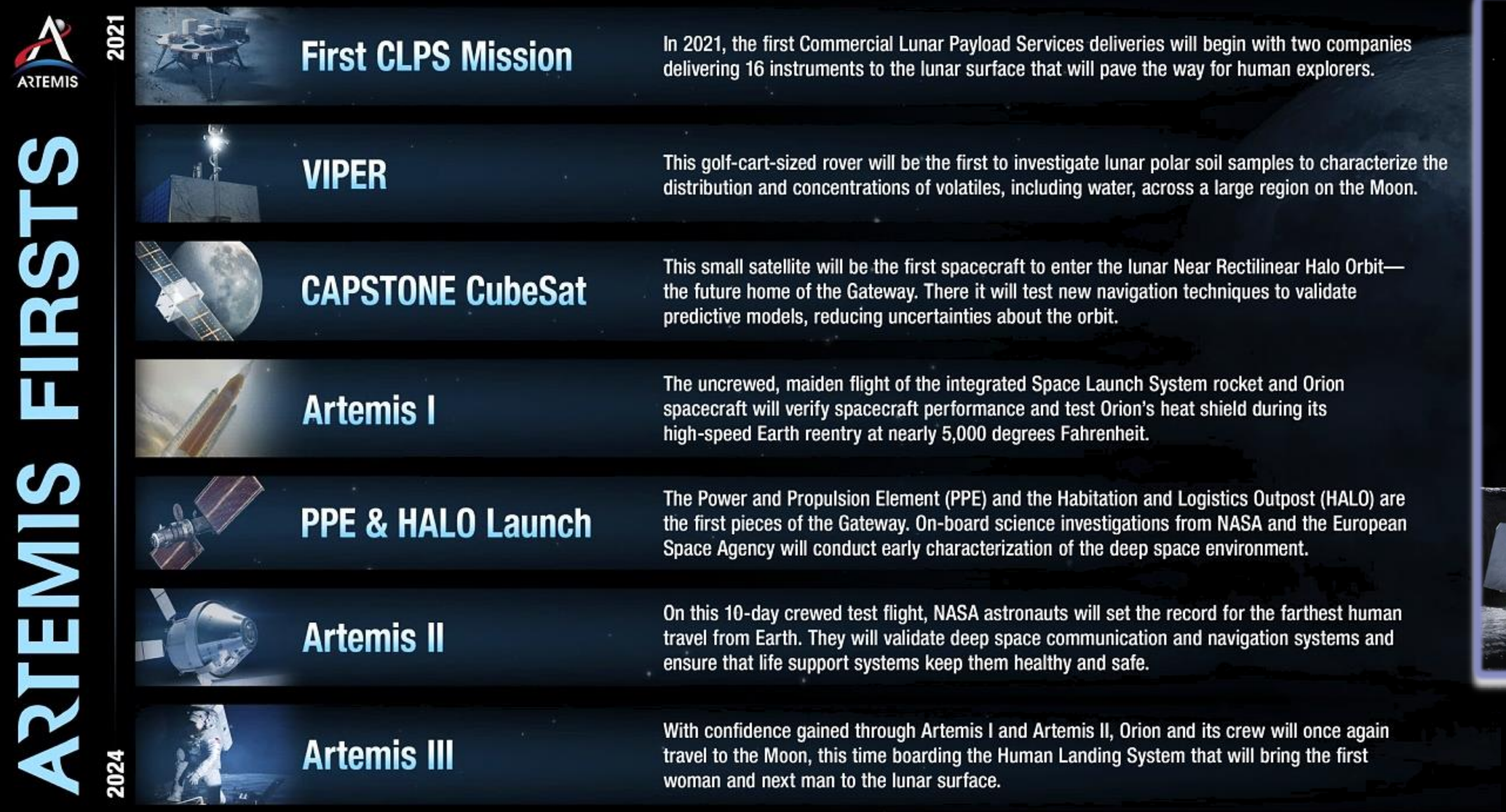
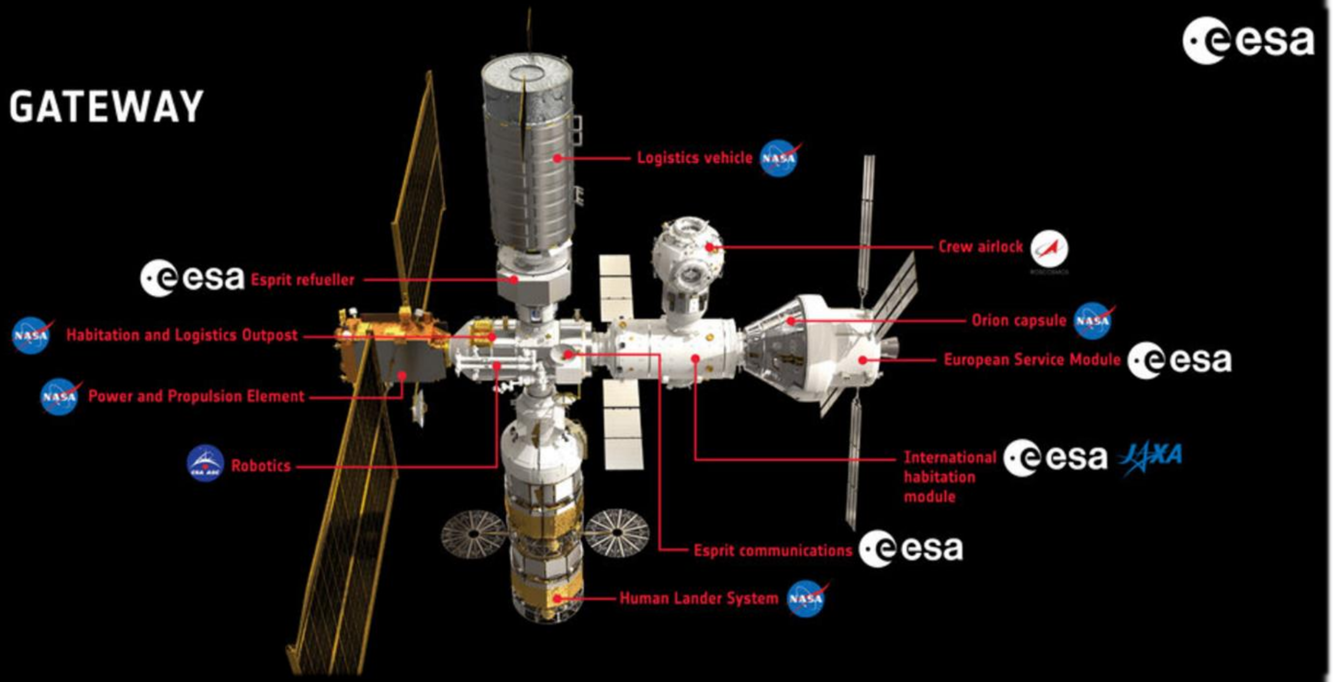
- *From NASA Lunar Exploration plan Sep.2020*



Lunar Programmes – European Roles

- In-Orbit
  - Lunar Gateway (science, communications)
    - Orbiting Outpost - providing essential support for long-term human return to surface (ESA funding habitat module and communications and refuelling module)
    - Staging point for lunar descent and deep space exploration
  - Orbiting spacecraft for Communication & Navigation Links, resource identification



- HERACLES = Lander + Rover
- Transport to Ground
  - Humans (via Orion, powered by ESA service module)
  - Transport of Supplies (EL3 – Large Logistics Lander)

- On-Surface
  - Rovers, Mobility platforms
  - Infrastructure:
    - Habitats, ISRU (PROSPECT), Communications
  - Science from Surface including Observatories

Lunar Programmes – Mechanism Needs

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- Lunar Gateway (robotics, communications)
  - Much more autonomous compared to ISS
- Orbiting Spacecraft
  - Comms & Navigation Links (optical and RF)
- Landers
  - ESA aiming for truly global lunar access, leads to thermal challenges (requires active control)
- Rovers/Mobility Platforms
- Habitats (recent CDF Moon village study)
  - Crane, berthing mechanism, louvred radiators
- ISRU (PROSPECT in polar regions)
  - Drills, thermal equipment, processing materials
- Observatories & Science Instruments

EL3 Lander being unloaded – ESA artwork

Specific Lunar Tribology Challenges

- Extensive characterisation of dust effects and related mitigations required (plumes from lander, rover movement)
- Temperatures will require that lunar mechanisms rely heavily on solid lubricants to reduce heater power, so lifetime improvements will be demanded for longer-term presence
- Gateway requires highly reliable devices for autonomous robotics and to support human missions
- To limit transported mass, future demands may involve new structural and tribological materials – if 3D printed parts were to be developed, maximising use of local resources

Concluding Remarks

- We are a conservative industry, we only use something new if we REALLY have to – tribologically, maybe that time is coming for various reasons

- Critical importance of early involvement or tribological experts in test, education and a partnership development approach
  - risk reduction, mechanism optimisation and programmatic success

- Importance of state-of-the art test facilities and centre of expertise approach – close to both industry and ESA


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Thank You