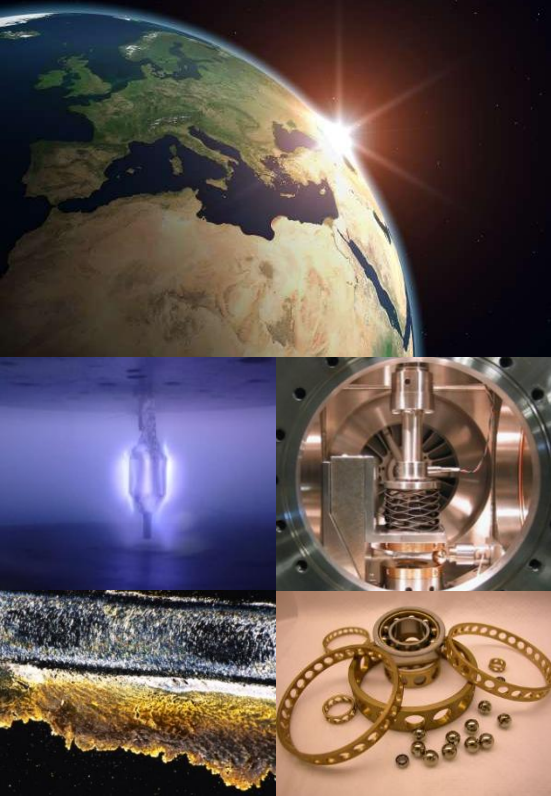




PFPE Lubricant Degradation – A New Method for its Assessment



M. Buttery

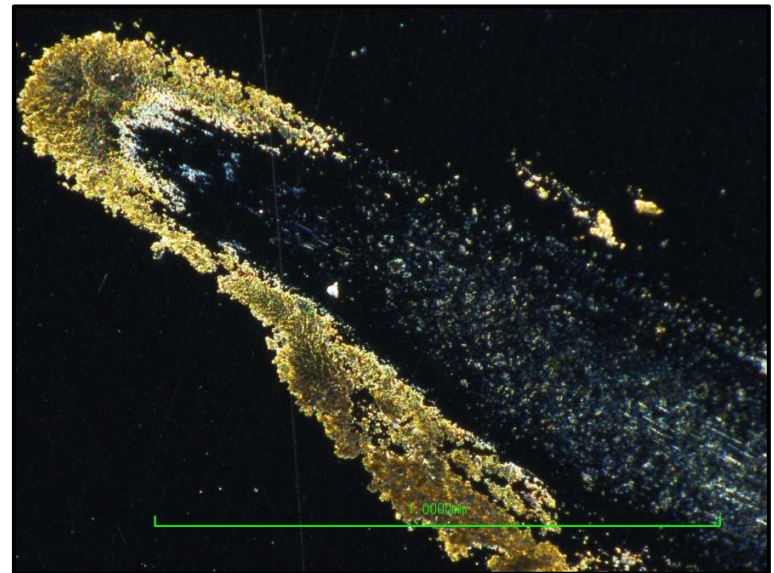
IMechE 22nd Mission of Tribology Research

December 4th 2013



Approach

- Brief background into space tribology
 - Leading to our lubricant choice
- The Spiral Orbit Tribometer (SOT)
 - A new facility for the testing of space lubricants under vacuum
- Degradation life of PFPE lubricants
 - How is the degradation life affected by contact stress and temperature?
- Understanding the degradation
 - In-situ residual gas analysis
- Auto-catalytic effect
 - Pin-on-disc tribology tests



Space Tribology



- In space tribology we encounter unique difficulties
 - High vacuum, zero-gravity, extreme temperature ranges, lack of moisture, radiation, and inaccessibility
- These conditions dictate and constrict our lubricant choices
- Often solid lubricants are selected
 - Molybdenum disulphide (MoS_2) and Lead are the most common
- However in some cases solid lubricants are inappropriate
 - High duty applications, low torque noise requirements, or minimal particulate contamination
- In such cases liquid lubricants must be selected
 - Key feature – low vapour pressure

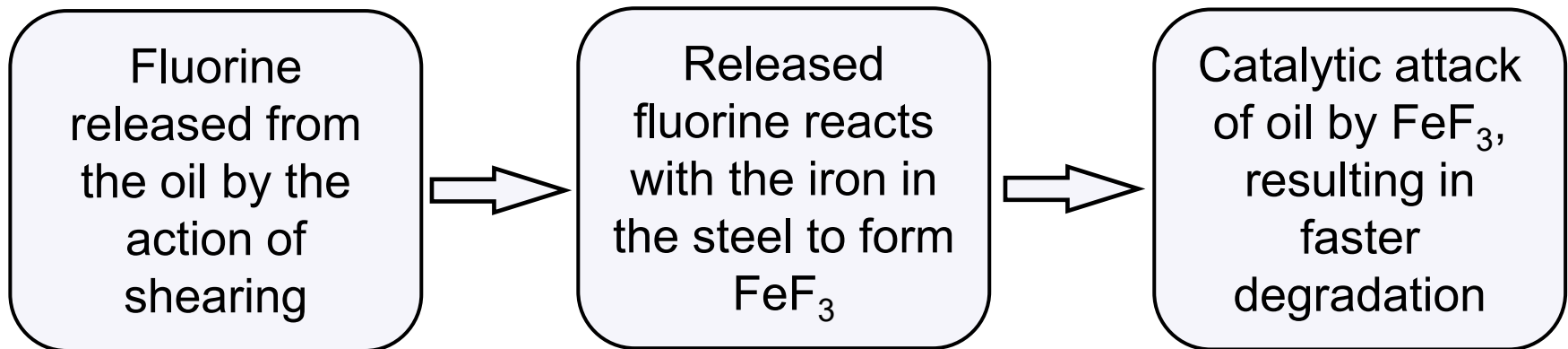
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PFPE lubricants

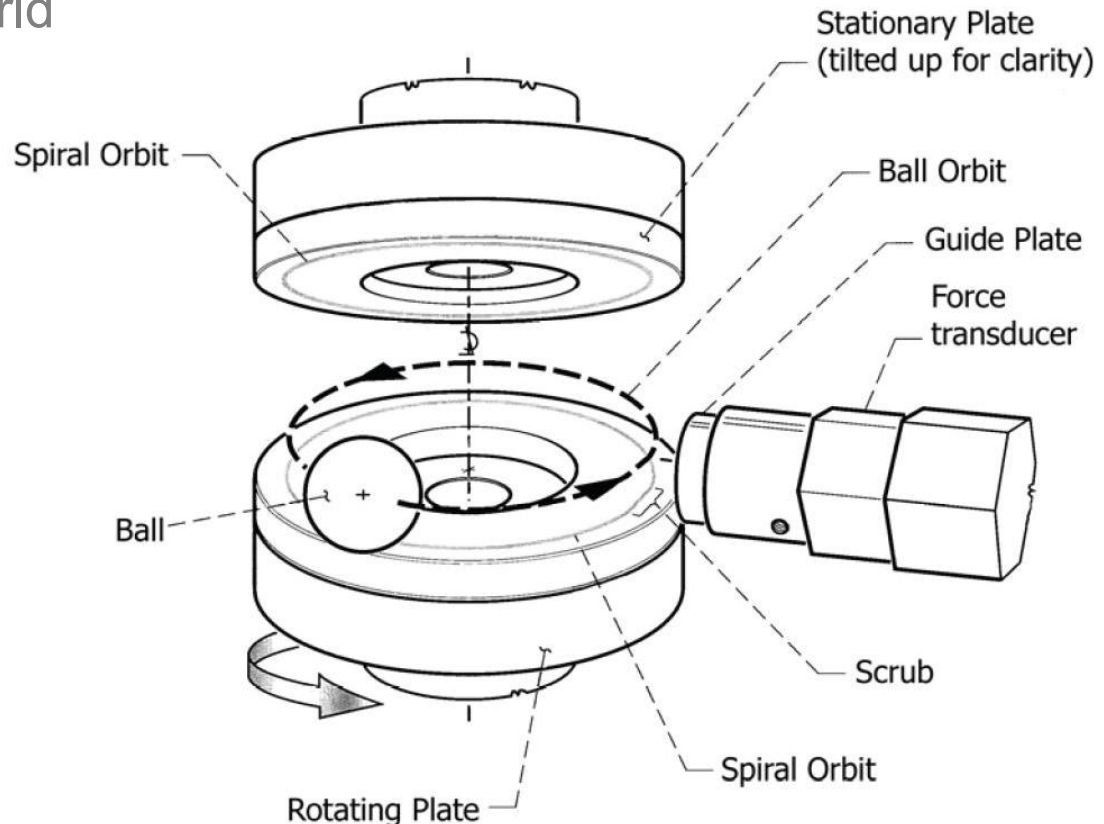
- Popular space oils due to their uniquely low vapour pressures
 - Long ‘evaporation’ lives
- Fomblin Z25 (oil), Braycote 601EF & Maplub PF100-b (greases)
- However their ‘degradation’ lives under operation are relatively short



- Particular concern for long operating-life spacecraft mechanisms

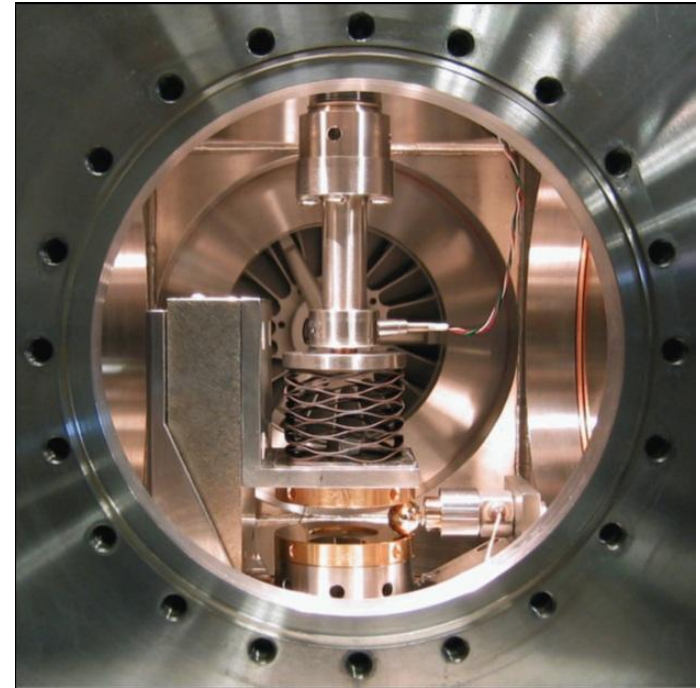
The Spiral Orbit Tribometer

- New test facility designed and built by NASA
 - Only three in the world
- Evaluates friction and degradation / consumption of lubricants
- Ball experiences sliding, rolling and pivoting motion



The SOT (cont.)

- Allows virtually unlimited material/lubricant combinations
- Tests performed using very small amounts of lubricant ($\sim 50\mu\text{g}$)
 - Short test times in comparison to bearing tests
 - Mode of lubrication is always boundary lubrication
- Allows for a more representative testing of a lubricant than conventional pin-on-disc testing, which only recreates sliding motion



Degradation Tests

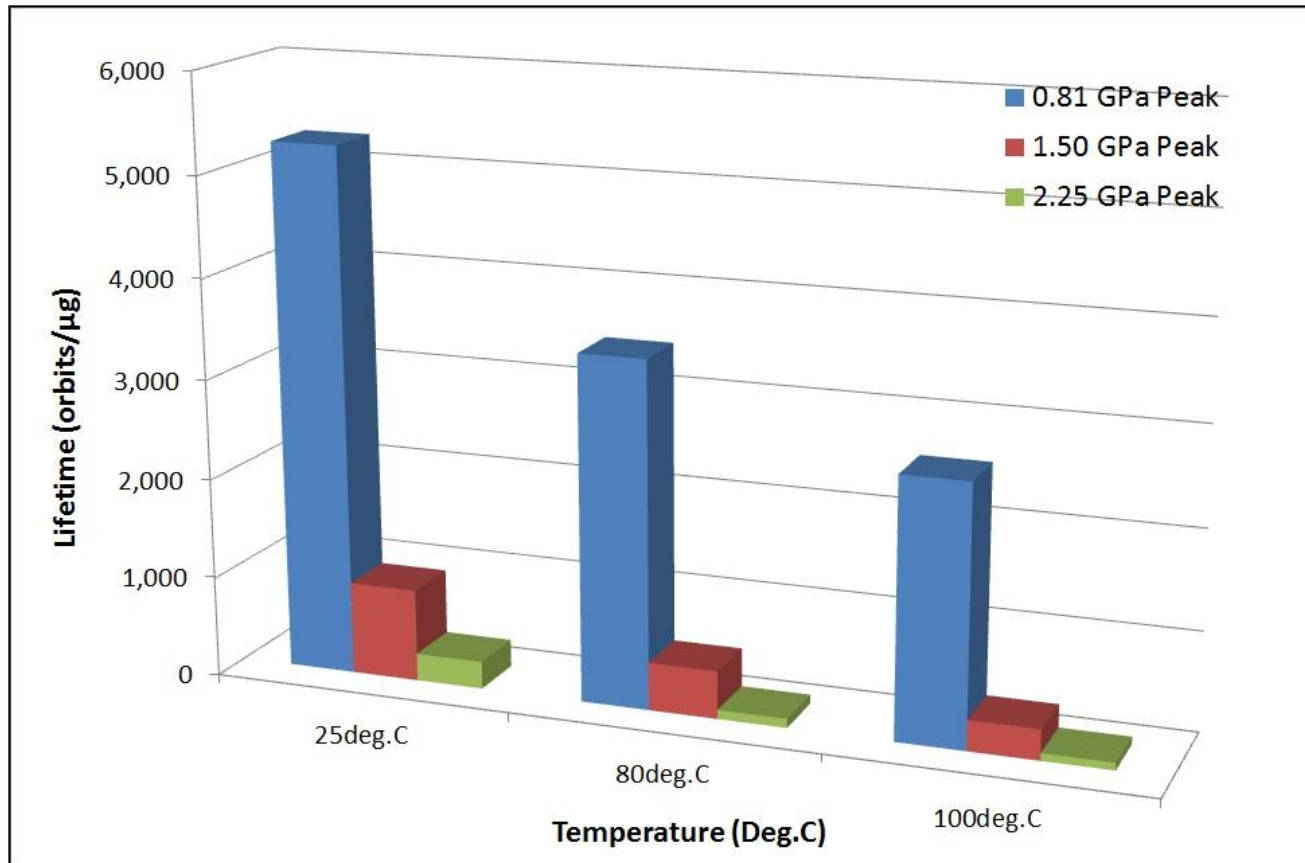
- Degradation tests performed to assess influence of multiple factors on life of Z25

- Temperature
- Contact stress
- (Speed)
- (Contact area)
- (Material)
- (Passivation)
- (Lube amount)

		Peak contact stress (GPa)			
		0.81	1.05	1.50	2.25
Temperature (°C)	25	✓		✓	✓
	60		✓		
	80	✓		✓	✓
	100	✓	✓	✓	✓

- All tests run until failure (rapid increase in friction coefficient)

Degradation Tests (cont.)



- Increasing contact stress gives significantly decreasing life
- Increasing temperature gives decreasing life
 - Not demonstrated before

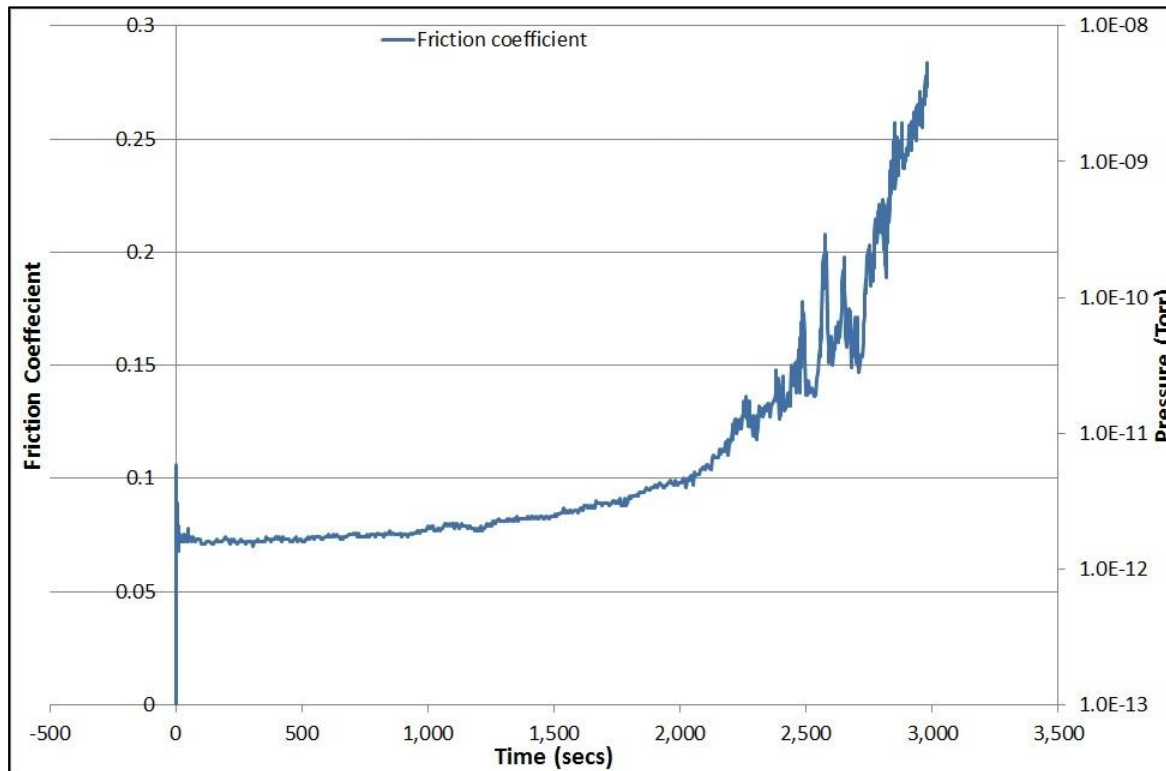
PFPE Degradation

- Degradation behaviour itself was then investigated using analytical techniques.
- Sublimation tests have demonstrated that cracking of the un-sheared oil occurs at high temperatures (250°C)
- Certain volatile gasses / oil fragments released during the test
 - Believed to be related to the degradation of the oil

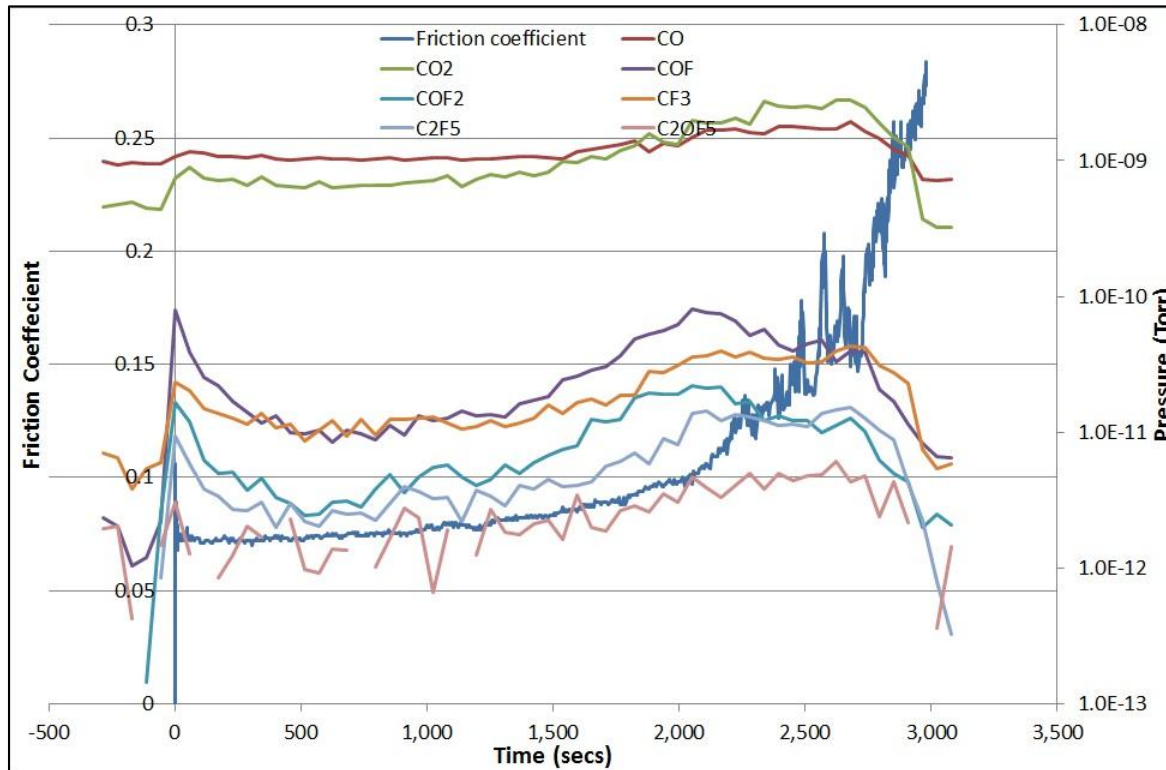
Gas	CO	CO ₂	COF	COF ₂	CF ₃	C ₂ F ₅	C ₂ OF ₅
AMU	28	44	47	66	69	119	135

- SOT tests performed with in-situ RGA, scanning for above gas species

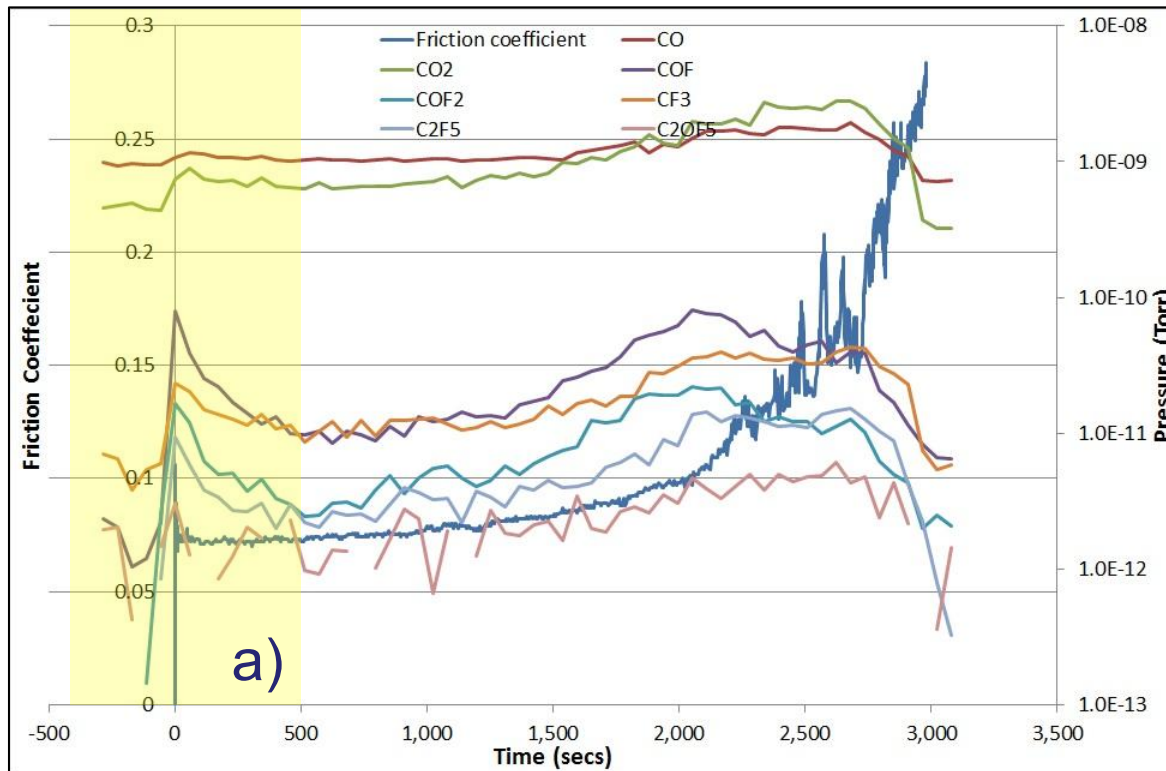
Mass Spec on the SOT



Mass Spec on the SOT

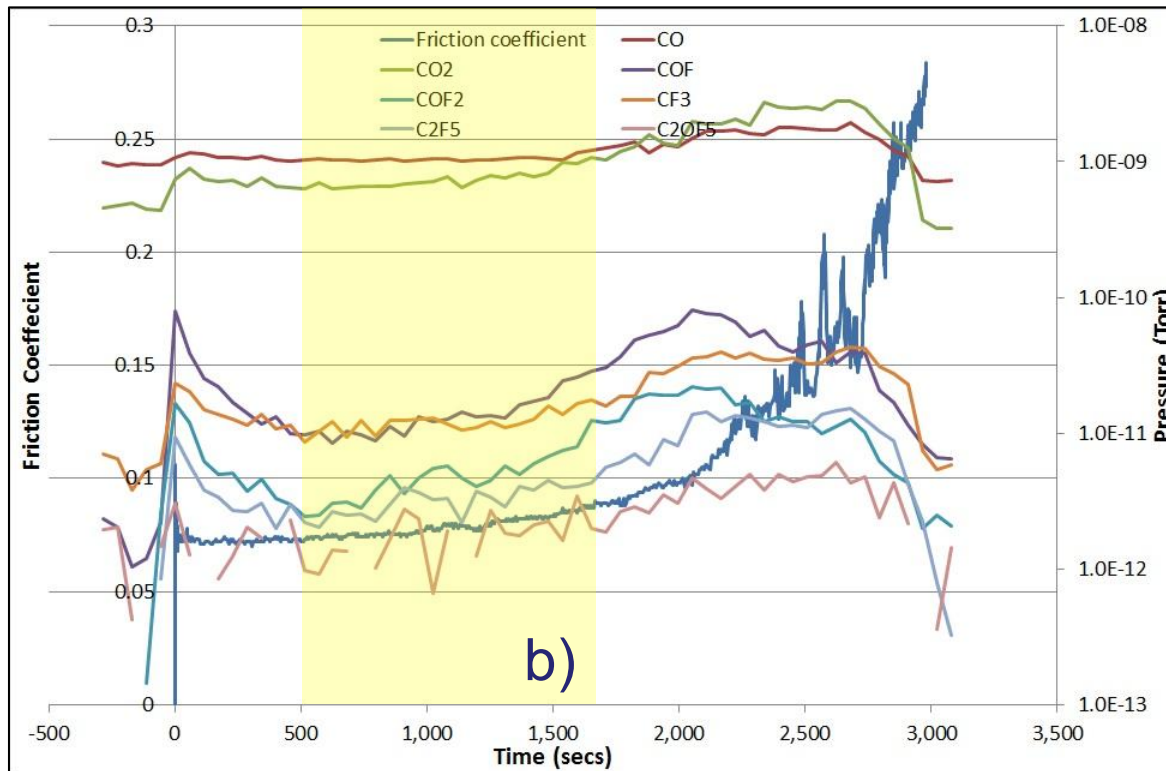


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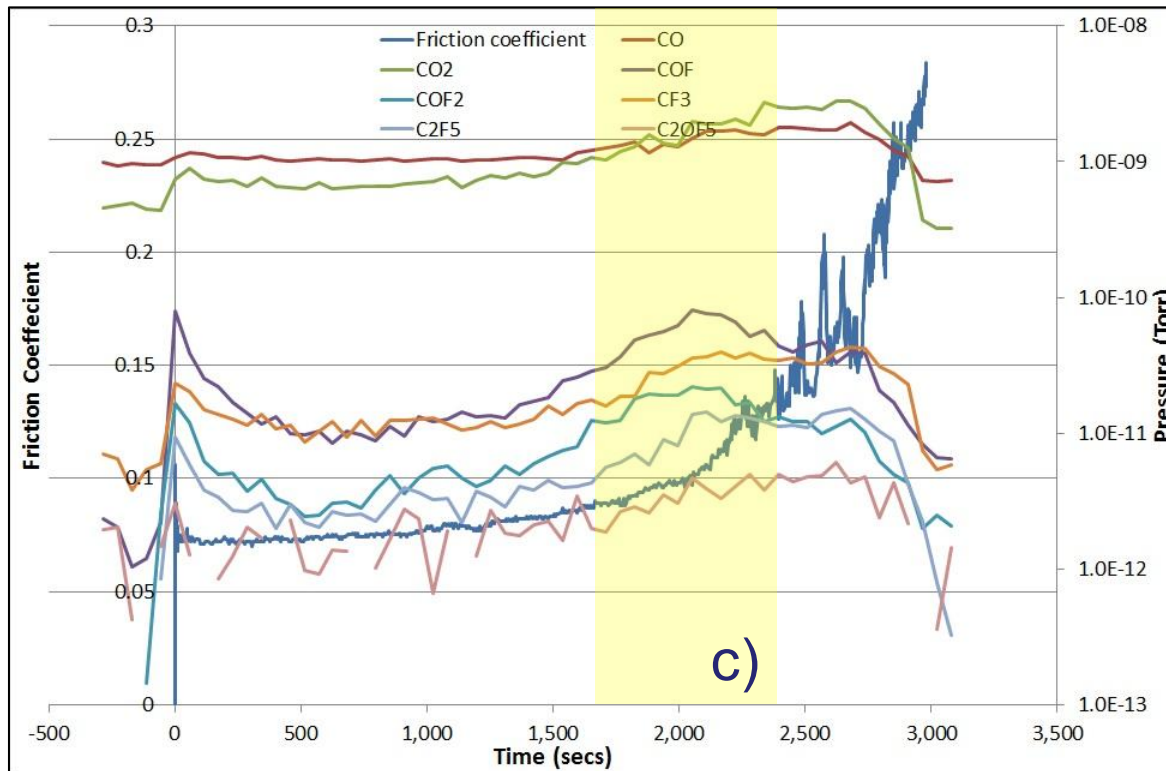
a) Initial rolling promotes initial step increase

Mass Spec on the SOT



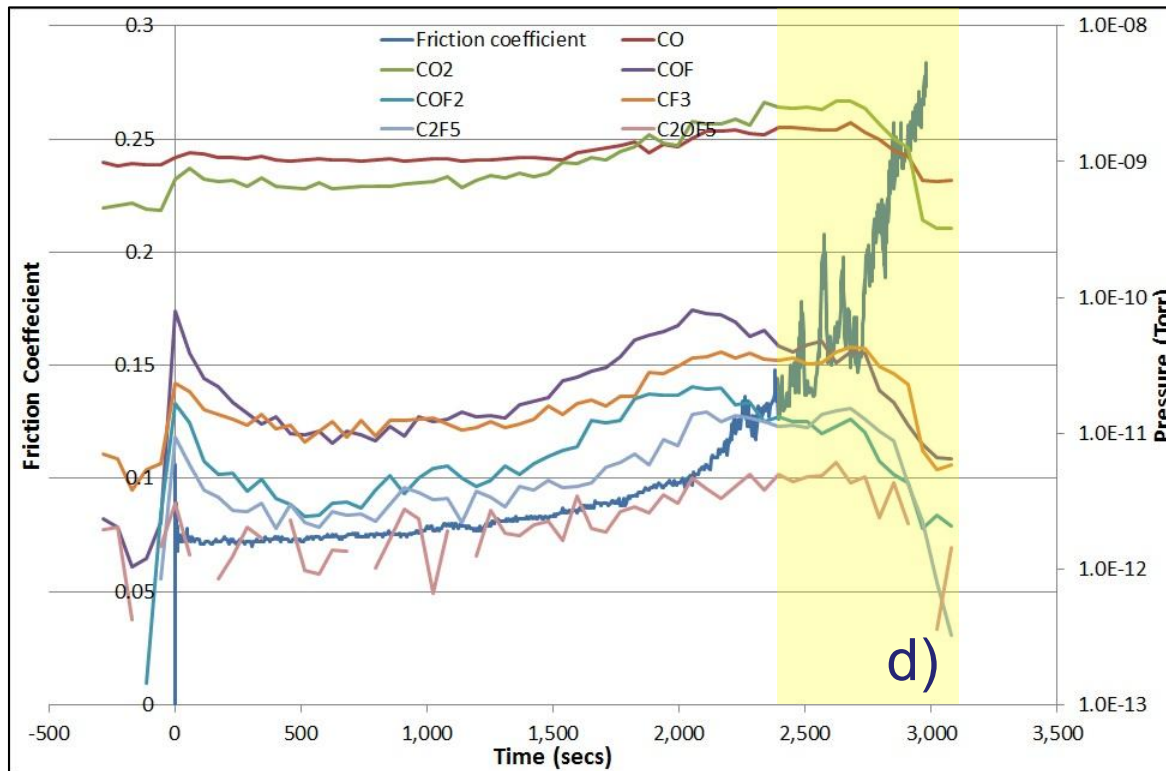
- a) Initial rolling promotes initial step increase
- b) Steady state, constant gas pressure

Mass Spec on the SOT



- a) Initial rolling promotes initial step increase
- b) Steady state, constant gas pressure
- c) Maximum volatile gas production before significant increase in friction

Mass Spec on the SOT

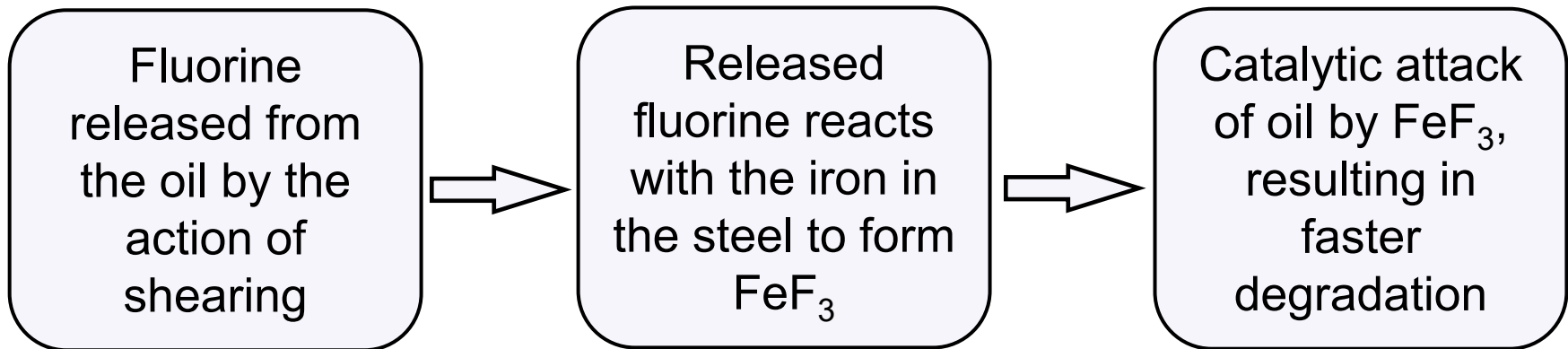


- a) Initial rolling promotes initial step increase
- b) Steady state, constant gas pressure
- c) Maximum volatile gas production before significant increase in friction

d) No un-degraded oil remaining, volatile gas species removed

The Auto-Catalytic Effect

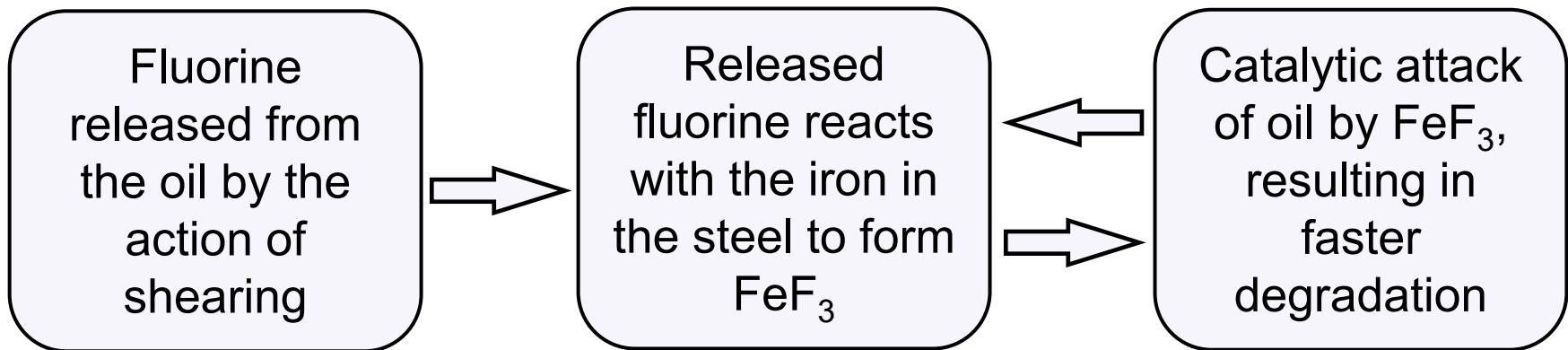
- It has been observed that when exposed to extended periods of dwell under vacuum, following running, PFPE lubricated mechanisms have displayed significantly higher torque on re-start
- Believed to be related to the catalytic attack of the oil by the FeF_3



- Attack continues when shearing action is halted – Auto-catalysis
 - Potentially a significant problem for flight hardware & qualification

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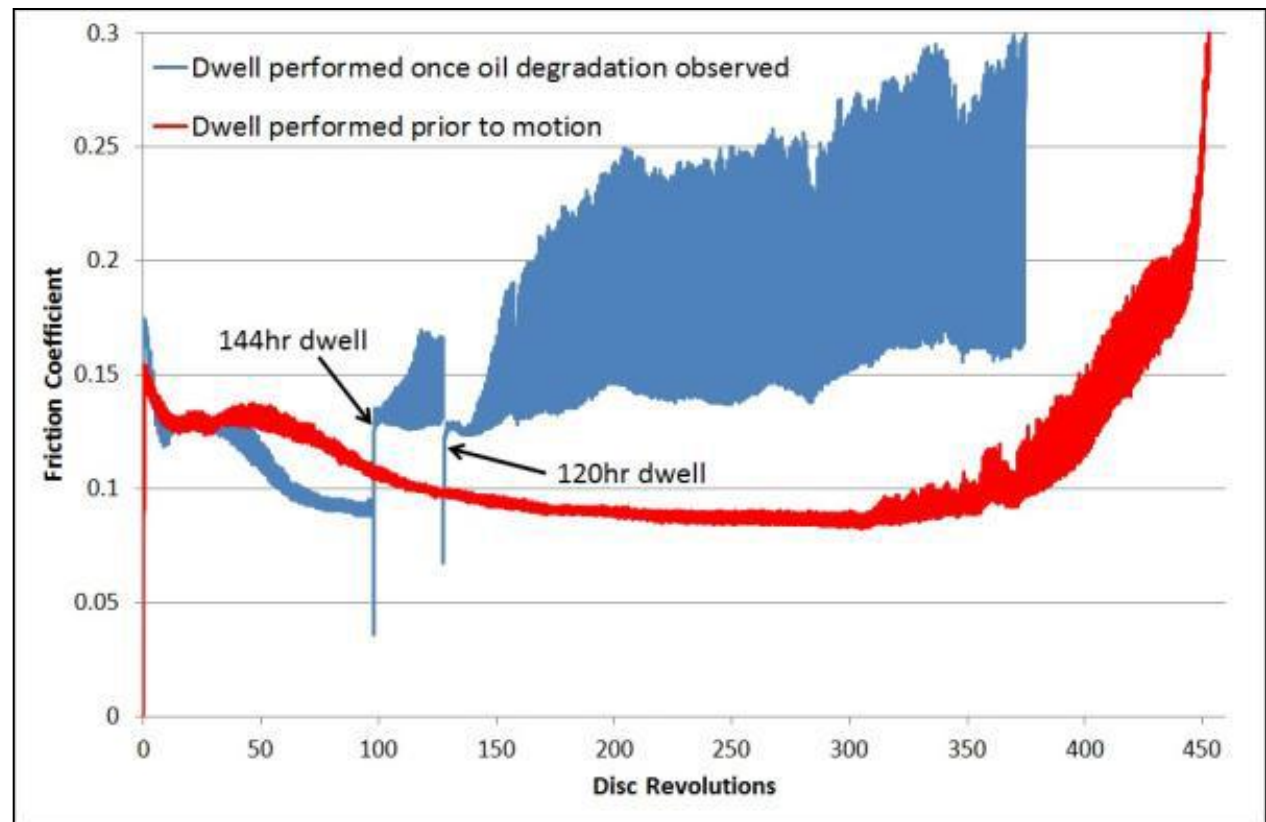


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Auto-catalysis on the POD

- Dwell tests performed on a vacuum pin-on-disc tribometer, temperature 100°C, Fomblin Z25 oil

- Tests show increase in friction following 6-day dwell, only when degradation of oil initiated through sliding
 - I.e. FeF_3 produced



Conclusions



- Lubricant consumption through degradation!
- Tribological lifetime of Fomblin Z25 is particularly sensitive to contact stress and temperature
- Failure of the lubricant can be predicted before significant increase in friction (on the SOT) through the monitoring of certain gas species related to the oil degradation – conditional monitoring
- Evidence of the auto-catalytic effect has been seen in a tribological context (at high temperature...)

Thank you for listening
Any questions?