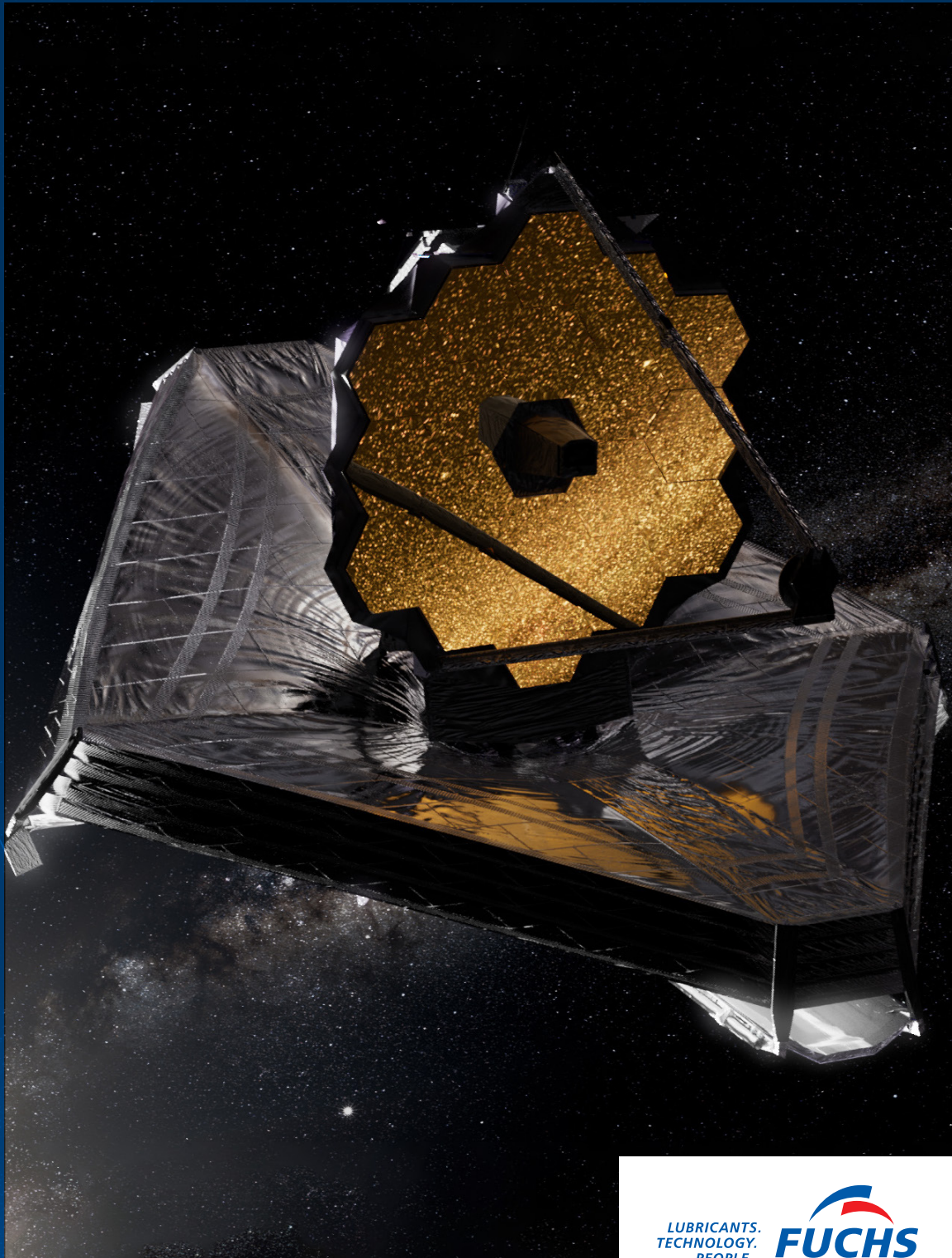


# Lubrication Solutions for Space Mechanisms



LUBRICANTS.  
TECHNOLOGY.  
PEOPLE.



**MOVING YOUR WORLD**

## ***MOVING YOUR WORLD*** by reaching for the stars

Nye Lubricants, a member of the FUCHS Group, has formulated high-quality, lubrication solutions for the space industry for more than 65 years. We work with design engineers in the private, government, and military sectors to formulate specialty lubrication solutions for next-generation spacecraft. Launch vehicles, rovers, satellites, and applications involved in human travel and space exploration are just a few of the examples that require greases and oils that can withstand the demanding operating conditions of space.

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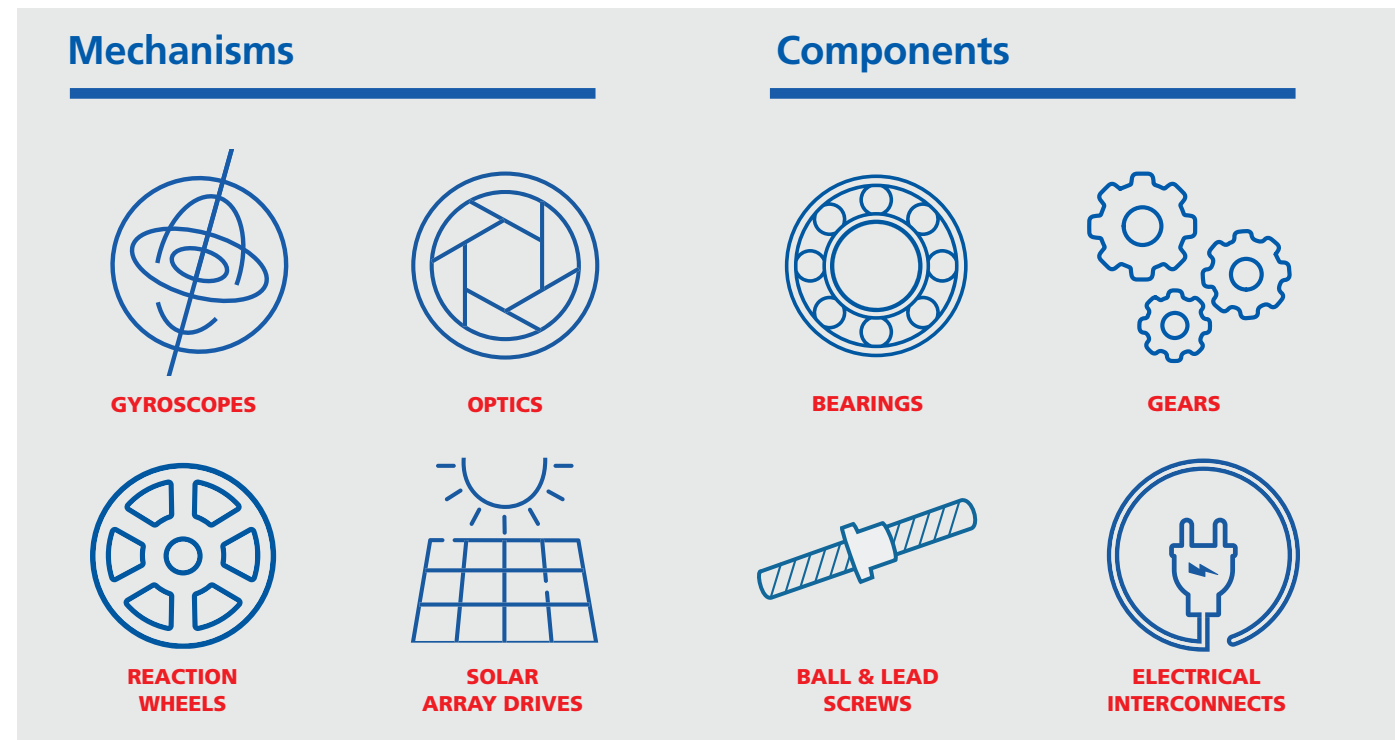
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Lubricants for Space Mechanisms

## Advantages of Specialty Lubricants for Space Mechanisms

The durability and reliability of all space mechanisms, including their lubrication, is critical to ensure the success of long-range missions. These missions will include exposure to ultra-high vacuum, radiation, and extreme temperatures, making higher performance and extended life lubricants a requirement.



### Wide-Temperature Performance

Our lubrication solutions for space mechanisms can withstand extreme temperatures with minimal changes in viscosity. Our perfluoropolyether (PFPE) lubricants can withstand temperatures from  $-90^{\circ}\text{C}$  to  $+250^{\circ}\text{C}$ . Our multiply-alkylated cyclopentane (MAC) lubricants have an operating range of  $-50^{\circ}\text{C}$  to  $125^{\circ}\text{C}$  and offer an unmatched wear protection. If a space application requires the low outgassing and excellent wear performance of a MAC lubricant and the operating temperature is below  $-50^{\circ}\text{C}$ , some engineers add a heater to their design that raises the temperature into the operating temperature range of MACs.

### Improves Wear & Load Capacity

Lubricants with good film strength are recommended for space applications and ensure moving parts are coated to minimize contact and friction. MAC lubricants are known for resisting wear-related break down to protect components under heavy loads.

### Extends Component Life

Components in space mechanisms are expected to offer the highest reliability. As the ability to service or replace these components is limited or non-existent, lubricants must be able to protect components for the entirety of their intended life. We offer 'Lube-for-Life' lubricants, meaning that they have long-life performance to ensure reliability for the entirety of your mission.

### Reduces Outgassing

Outgassing is akin to evaporation; it is the release of small fractional molecules from a bulk liquid or solid material. Evaporation losses accelerate when operating in vacuum and compromise a lubricant's integrity over time. Low outgassing lubricants have a lower material loss to ensure longer-lasting lubrication.

Outgassed molecules can also condense on surfaces and adversely affect the optical or surface properties of the material onto which it condenses. Condensation on optical components like sensors, lenses, and solar cells can compromise mission performance. Lubricant outgassing is measured in total mass loss (TML) and collected volatile condensable materials (CVCM) per ASTM E595. The lubricants we offer for these components are tested to this standard and fall well below the acceptable outgassing limits determined by the space industry.

### Reduces Particle Generation

Dynamic particle generation happens when contaminants are created by being forced or expelled from a lubricated ball-screw, bearing, or gear system into the operating environment. These contaminants could include base oil constituents, thickener particles, additives, etc. and are freed from the grease through rolling, sliding, or a combination of both. Our proprietary test method and apparatus allows us to measure particle generation under these dynamic conditions.



## Aerospace Satellites

Our lubricants are designed specifically for satellite components that must survive the severe conditions of the space environment, where long life is critical for the success of the mission.

### 1. Camera Optics

To ensure contaminants from other lubricants do not creep onto the camera lens, NYEBAR® can be applied to multiple mechanisms on the camera mast. NYEBAR® creates a barrier film, holding the lubricating oil in place. Ultrafiltered MAC lubricants have low outgassing rates and superior anti-wear performance, making them ideal for components within or near a satellite camera. Lubricants with a lower particle generation count will ensure that optical components are not compromised.

**Bearings - RHEOLUBE® 2000LO & RHEOLUBE® 2004LO**  
**Camera Mast - NYEBAR® Barrier Film**

### 2. Reaction Wheel

By providing attitude control, reaction wheels are the control gyros for satellites. A medium viscosity MAC grease will operate through high-torque adjustments and can withstand extreme temperatures.

**Barrier Film - NYEBAR® Barrier Film**  
**Bearings - RHEOLUBE® 2000**

### 3. Scan Mirror Assembly

This system moves in a horizontal motion to scan targeted areas for imaging. Lubricating the bearings within the assembly will reduce vibration, and allow the system to move in a quick, smooth motion.

**Bearings - SYNTHETIC OIL 2001-3PBNP**

### 4. Spin Mechanism Assembly

This instrument supports and spins the satellite throughout the mission. The bearings within the assembly are in constant rotation and require a MAC grease fortified for friction reduction.

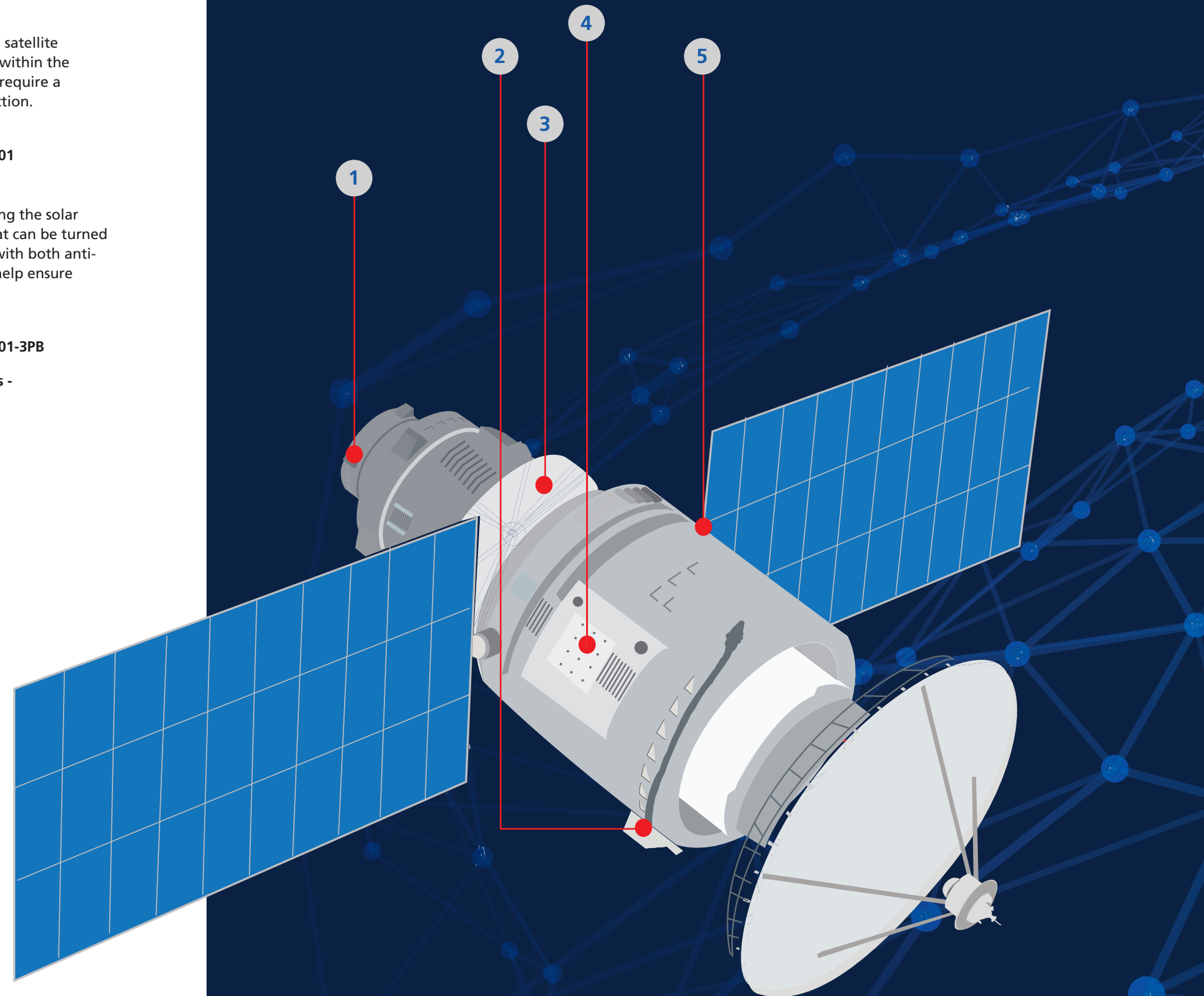
**Angular Contact Bearings -**  
**RHEOLUBE® 2000 & SYNTHETIC OIL 2001**

### 5. Solar Array Drive

This system is responsible for positioning the solar panels in order to harvest sun light that can be turned into energy. MAC lubricants fortified with both anti-oxidants and anti-wear additives will help ensure long life of components.

**Harmonic Gear Drive -**  
**RHEOLUBE® 2004 & SYNTHETIC OIL 2001-3PB**

**Slip Ring in Power Transfer Assemblies -**  
**RHEOLUBE® 2001**



# Success Stories: Lubricants in Space

**International Space Station (ISS)**  
 Devices: Multiple Mechanisms  
 Products: Various products including RHEOLUBE® 2000  
 Multiple devices for positioning and control;  
 Vibration Isolation Systems for Advanced Resistance  
 Exercise Equipment.



250 MILES

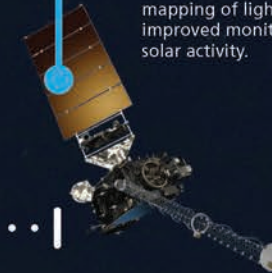
**MetOp-SG A & B**  
 Devices: Multiple Instruments  
 Product: SYNTHETIC OIL 2001A  
 This partnership between ESA and EUMETSAT  
 is developing the next generation of  
 weather satellites.



516 MILES

22,300 MILES

**GOES-R Series**  
 Devices: Reaction Wheels & Solar  
 Array Drives  
 Products: SYNTHETIC OIL 2001-3PB  
 and RHEOLUBE® 2000 & 2004  
 This joint effort between NASA  
 and the NOAA, aims to provide  
 more accurate forecasts, real-time  
 mapping of lightning activity, and  
 improved monitoring of  
 solar activity.



**Mars Curiosity & Perseverance Rover**  
 Device: Mast Camera  
 Product: NYEBAR® Barrier Film  
 Mars Rover Curiosity has provided photos  
 along with data concerning climate and  
 geology since August 2012.

The Mars Perseverance Rover will provide  
 opportunities to gather knowledge that  
 addresses the challenges of future human  
 expedition to Mars.



160 MILES

34 - 249,000,000 MILES

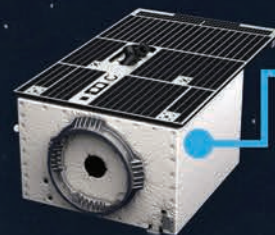
438 MILES

**Thermal Infrared Sensor (TIRS)**  
 Device: Angular Contact Bearings  
 Products: RHEOLUBE® 2000 & SYNTHETIC OIL 2001  
 The Thermal Infrared Sensor located on the Landsat Data  
 Continuity Mission (LDCM) measures land surface temperature.

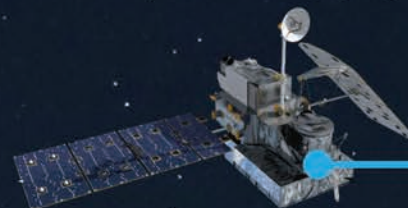


405 MILES

**EnMap**  
 Device: Shutter Calibration Mechanism Gear  
 Product: RHEOLUBE® 2000  
 This German hyperspectral satellite mission aims  
 to monitor and characterize the Earth's  
 environment on a global scale.



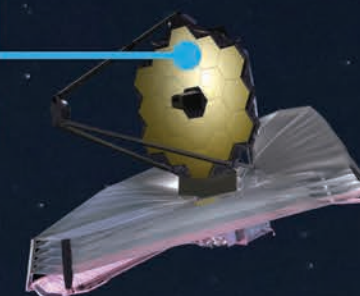
**Global Precipitation Measurement (GPM)**  
 Device: Harmonic Drive Gear  
 Products: RHEOLUBE® 2004 & SYNTHETIC OIL 2001-3PB  
 Global Precipitation Measurement is a joint mission  
 between JAXA and NASA that records precipitation  
 characteristics on Earth.



253 MILES

1,000,000 MILES

**James Webb Space Telescope (JWST)**  
 Devices: Multiple Mechanisms  
 Product: Custom Pennzane™ Oil  
 The James Webb Space Telescope will be a  
 large infrared telescope with a 6.5 meter  
 primary mirror. The telescope will be launched  
 on an Ariane 5 rocket from French Guiana.



**Mars Climate Sounder (MCS)**  
 Device: Actuator  
 Product: SYNTHETIC OIL 2001A  
 The Mars Climate Sounder observes the  
 temperature, humidity, and debris content  
 of the Martian atmosphere.



55 - 217 MILES

**CubeSats/NanoSats**  
 Device: Reaction Wheels  
 Products: Pennzane™ Formulations & NYEBAR® Barrier Film  
 The reaction wheels located on CubeSats/NanoSats  
 provide an efficient, high performance solution for  
 attitude control.



## Testing Capabilities

Our lubrication solutions for space are tested and validated for their performance in our state-of-the-art laboratory dedicated to in-vacuum testing. In this laboratory lubricants can be tested under simulated environmental operating conditions (i.e., vacuum, extreme temperatures) and provide our customers with performance data that helps them understand how our lubricants will perform in their application. Ultimately, this service helps our customer make the most informed lubricant choice.

## Friction & Wear

### SRV Tribometer

The SRV (Oscillating, Friction & Wear) test rig can run custom tests with options that include: rotational and linear oscillatory motion, tests up to 2,000 N load, 2,000 RPM, and a maximum temperature of 180 °C. Specimens include ball on disc, pin on disc, cylinder on disc, and custom geometries.

### Mini Traction Machine (MTM)

The Mini Traction Machine (Figure 2) measures friction in a mixture of rolling/sliding contacts to simulate applications like rolling element bearings and gears. The MTM allows for the speed element to be a combination of sliding and rolling speed to produce the entrainment speed. The MTM provides a very good testing method for scuffing and galling of metal surfaces by allowing for the ball and disc to be driven in different directions (contrarotation). This produces a tribological test that can operate with high sliding / rolling speeds and low entrainment speed.

## Relative Life

### Spiral Orbit Tribometer

Originally developed by NASA, the Spiral Orbit Tribometer (SOT) produces relative lifetime calculations based on the number of orbits made below a friction level which is normalized to the amount of lubricant on the ball bearing. The testing (Figure 1) is done in ultra-high vacuum and simulates a thrust bearing. The results indicate the lubricant consumption, degradation, and life.

### Vacuum Bearing Test Rig

Data from the Vacuum Bearing Test rig can determine the life expectancy of our lubricants on angular contact bearings in high vacuum environments. This rig can support customer supplied bearings to simulate how a lubricant will perform in a specific application. Our high vacuum test can assess performance at temperatures up to 200 °C and determine mass loss under specific operating conditions. The rig also uses electrical resistance across the bearing to determine which lubrication regime (boundary, mixed or elasto-hydrodynamic) our products qualify under, given the test parameters.

## Cleanliness

### Particle Generation

The Dynamic Particle Generator is used to classify lubricant particle generation into ISO and Federal cleanliness levels. It utilizes an ISO 3 clean air system, precision ball screw, and particle counter to characterize the number of particles down to 0.1 micron produced by various greases as the test is run.

### Outgassing

Outgassing testing (per ASTM E595 Vacuum Stability) screens materials for volatile contamination. This test provides percent Total Mass Loss (TML) and percent Collected Volatile Condensable Materials (CVCM) data for our lubricants. Residual Gas Analysis can be used to determine the elemental species contained in the outgassing material. This testing provides customers with an understanding of the stability of our materials in a static vacuum environment and identifies which materials are outgassing.

### Vapor Pressure

The Knudsen method is used to determine a lubricant's vapor pressure (VP) and requires a very small sample, reducing testing costs and efficiency. The sample is placed in a small, capped cell with an orifice in the cap of known diameter. The cell is then placed in one of the vacuum chambers, at a desired temperature and duration. The mass loss from the lubricant is factored into the Knudsen equation, along with the other known variables of temperature and time, to calculate the Knudsen VP of that material at that temperature.



Figure 1: Spiral Orbit Tribometer



Figure 2: Mini Traction Machine



## Synthetic Oil & Greases for Space Mechanisms

### MAC vs. PFPE

Our space oils and greases are formulated using two different base oils: Perfluoropolyethers (PFPE) and multiply-alkylated cyclopentanes (MAC), each offering specific benefits.

#### MAC

We hold the exclusive distribution rights to Pennzane™ MAC fluids. Unlike other lubrication solutions on the market, Pennzane lubricants alone offer the unique combination of extreme wear protection, low outgassing, and additive compatibility for optimal performance in space applications.

#### PFPE

If your application requires low outgassing and an extremely wide operating temperature range but does not require the extreme wear performance or specialized additives of a MAC lubricant, a PFPE from our NYETORR® or NYECLEAN® product line is recommended.

We have developed PFPE lubricants using the most advanced technology available, like NYETORR® 6350EL, which offers significantly improved load-carrying ability and much longer operating life versus heritage PFPE technology.

## Synthetic Oil for Space Mechanisms

Product Name	Temperature Range (°C)	Base Oil Chemistry	Base Oil Viscosity ASTM D445 (cSt)			Pour Point (°C)	Evaporation CTM-2 (24 h, 100 °C) (wt%)	Vacuum Stability ASTM E595 (125 °C, 7 x 10-3Pa, 24 hrs) (wt%)		Vapor Pressure Knudsen (25 °C) (Torr)	Density (g/cc <sup>3</sup> )	SRV Coefficient of Friction & Wear ASTM D5707 (100N, 50Hz, 1 stroke, 2 h, 40 °C)		Particulate Cleanliness Levels* IEST-STD-CC-1246D
			-40 °C	40 °C	100 °C			TML	CVCM			CoF	Wear Scar (mm)	
			SYNTHETIC OIL 1001	-50 to 125	MAC			24,910	55			8	-59	
SYNTHETIC -OIL 1001A	-50 to 150	MAC	26,070	56	9	-63	0.02	0.25	0.242	1.27 x 10 <sup>-11</sup>	0.85	0.16	0.62	Level 50
SYNTHETIC OIL 1001-3PB	-50 to 125	MAC	24,910	56	8	-59	0.06	0.30	0.066	2.45 x 10 <sup>-10</sup>	0.85	0.14	0.91	Level 50
SYNTHETIC OIL 2001	-45 to 125	MAC	80,494	107	14	-55	0.04	1.39	0.700	1.88 x 10 <sup>-10</sup>	0.84	0.11	0.43	Level 50
SYNTHETIC OIL 2001A	-45 to 125	MAC	80,500	108	15	-55	0.00	0.12	0.013	4.50 x 10 <sup>-11</sup>	0.84	0.19	0.80	Level 100
SYNTHETIC OIL 2001B	-45 to 125	MAC	80,500	108	15	-55	0.10	0.94	0.574	8.18 x 10 <sup>-12</sup>	0.86	0.11	0.43	Level 50
SYNTHETIC OIL 2001-3PB	-45 to 125	MAC	80,500	108	15	-55	0.10	0.33	0.293	1.27 x 10 <sup>-10</sup>	0.86	0.11	0.48	Level 50
NYETORR® 6201	-45 to 150	MAC	80,500	108	15	-55	0.00	0.11	0.010	6.91 x 10 <sup>-11</sup>	0.84	0.18	0.80	Level 50
NYETORR® 6301	-75 to 250	PFPE	5,818	187	56	-80	0.00	0.00	0.002	2.79 x 10 <sup>-12</sup>	1.83	0.08	0.84	Level 25
NYETORR® 6351	-65 to 250	PFPE	13,380	186	45	-69	0.04	0.00	0.000	4.43 x 10 <sup>-13</sup>	1.84	0.10	0.64	Level 25

## Synthetic Grease for Space Mechanisms

Product Name	Temperature Range (°C)	Base Oil Chemistry	Base Oil Viscosity ASTM D445 (cSt)			Thickener Type	NLGI Grade ASTM D217	Oil Separation ASTM D6184 (24 h, 100 °C) (wt%)	Evaporation (24 h, 100 °C) (wt%)	Vacuum Stability ASTM E595 (125 °C, 7 x 10-3Pa, 24 hrs) (wt%)		Vapor Pressure Knudsen (25 °C) (Torr)	Density (g/cc <sup>3</sup> )	SRV Coefficient of Friction & Wear ASTM D5707 (100N, 50Hz, 1 stroke, 2 h, 40 °C)		Low Temperature Torque ASTM D1478 (g.cm, -40 °C)		Ultrafiltration Cleanliness Levels* (10-34 µm, particles/cc)	Dynamic Particle Generation CTM-094	
			-40 °C	40 °C	100 °C					TML	CVCM			CoF	Wear Scar (mm)	Starting	10-min run		1200 RPM	2400 RPM
			RHEOLUBE® 1000	-50 to 125	MAC					24,910	53			8	Sodium Soap	2	0.3		0.20	2.307
RHEOLUBE® 1000-3PB	-50 to 125	MAC	24,910	53	8	Sodium Soap	2	1.4	1.90	1.820	0.208	1.02 x 10 <sup>-9</sup>	0.89	0.11	0.53	4,793	658	< 500	ISO 4.0	ISO 6.0
FLUOROCARBON GEL 1000F	-50 to 150	MAC	24,910	53	8	PTFE	2	1.3	0.22	1.587	0.401	TBD	1.10	0.11	0.45	840	287	TBD	TBD	TBD
RHEOLUBE® 2000	-45 to 125	MAC	72,000	110	15	Sodium Soap	2	3.3	0.10	2.461	0.729	1.79 x 10 <sup>-10</sup>	0.89	0.11	0.41	265	126	< 500	ISO 4.0	ISO 6.0
RHEOLUBE® 2000B	-45 to 125	MAC	72,000	110	15	Sodium Soap	2	5.0	0.10	2.117	0.647	8.18 x 10 <sup>-12</sup>	0.89	0.11	0.40	2,581	601	< 500	ISO 4.0	ISO 6.0
RHEOLUBE® 2004	-45 to 125	MAC	72,000	110	15	Sodium Soap	2	0.1	0.10	1.873	0.104	8.46 x 10 <sup>-10</sup>	0.89	0.11	0.51	4,941	778	< 500	ISO 4.0	ISO 6.0
RHEOLUBE® 2004LO	-45 to 125	MAC	72,000	110	15	Sodium Soap	2	0.1	0.10	0.772	0.268	2.45 x 10 <sup>-10</sup>	0.89	TBD	TBD	TBD	TBD	< 500	TBD	TBD
RHEOLUBE® 3000-3PB	-10 to 125	MAC	N/A	2,082	202	Sodium Soap	2	1.0	TBD	TBD	TBD	TBD	0.89	TBD	TBD	TBD	TBD	TBD	TBD	TBD
NYETORR® 6200	-45 to 150	MAC	77,000	108	15	PTFE	1	3.5	0.00	0.058	0.025	2.44 x 10 <sup>-11</sup>	1.05	0.12	0.46	1,135	599	< 300	ISO 3.6	ISO 4.3
NYETORR® 6300	-65 to 250	PFPE	5,818	187	56	PTFE	2	4.8	0.02	0.036	0.006	2.79 x 10 <sup>-12</sup>	1.89	0.11	0.68	221	125	< 300	ISO 4.2	ISO 5.1
NYETORR® 6350EL	-80 to 250	PFPE	13,380	200	47	PTFE	2	6.3	0.06	0.060	0.008	5.76 x 10 <sup>-12</sup>	1.89	0.16	0.76	545	271	< 400	ISO 3.9	ISO 4.5

\*CTM = Company Test Method \*Level 25 = 1 25µm particle max. Level 50 = 1 50µm particle max. Level 100 = 1 100µm particle max\*CTM = Company Test Method



# FUCHS Lubricants

## Innovative lubricants need experienced application engineers

Every lubricant change should be preceded by expert consultation on the application in question. Only then the best lubricant system can be selected. Experienced FUCHS engineers will be glad to advise on products for the application in question and also on our full range of lubricants.

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