NASA LESSONS LEARNED FROM LUBRICATED SPACE MECHANISMS

ROAMER PREDMORE
GODDARD SPACE FLIGHT CENTER
GREENBELT, MD

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SHORT-LIFE LUBRICATED MECHANISMS COMPLETE THEIR LIFE TEST QUALIFICATION REQUIREMENTS AFTER A FEW CYCLES

- SHORT-LIFE LUBRICATED SPACE MECHANISMS INCLUDE:
  - HINGES, MOTORS AND BEARINGS FOR DEPLOYMENT
  - RELEASE MECHANISMS
  - LATCHES
  - RELEASE SPRINGS AND SUPPORT STOPS
  - GEAR GIMBALS
- SHORT-LIFE MECHANISMS ARE OFTEN SINGLE POINT FAILURES FOR THE SATELLITE MISSION, I.E.,
  - SOLAR ARRAY DEPLOYMENT MECHANISMS
  - INSTRUMENT CONTAMINATION COVERS
- PERFORMANCE TESTING IS DIFFICULT AND EXPENSIVE BUT MUST BE ACCOMPLISHED, I.E., GALILEO HIGH GAIN ANTENNA
- LIFE TESTING CAN BE QUICKLY COMPLETED IN A FEW CYCLES

QUALIFICATION OF SATELLITE LONG-LIFE LUBRICATED MECHANISMS REQUIRES UP TO 5 YEARS OF LIFE TESTING OR 10 TO 100 YEARS OF SUCCESSFUL ORBITAL FLIGHT HERITAGE

- SPACECRAFT LUBRICATED MECHANISMS
  - REACTION WHEELS
  - MOMENTUM WHEELS
  - ANTENNA GIMBALS
  - SOLAR ARRAY DRIVES
  - GYROS
  - DESPIN MECHANISMS
- SATELLITE INSTRUMENT MECHANISMS FOR SCIENTIFIC AND EARTH OBSERVATIONS
  - SPATIAL SCAN MECHANISMS
  - SPECTRAL SCAN MECHANISMS
  - FOCUS MECHANISMS

HOW WELL DOES LIFE TESTING QUALIFY LONG-LIFE LUBRICATED MECHANISMS FOR SPACEFLIGHT?

A LIFE TEST MOMENTUM WHEEL PERFORMED SUCCESSFULLY FOR 3 YEARS, BUT THE SPACECRAFT WHEELS FAILED DURING GROUND TESTING

- THE SPIN AXIS OF THE LIFE TEST WHEEL WAS HORIZONTAL
  - GRAVITATIONAL LOADS DRAINED FREE OIL INTO THE BEARING RACES
- THE SPIN AXES OF THE WHEELS WERE PRIMARILY VERTICAL DURING SPACECRAFT TESTING
  - GRAVITATIONAL LOADS DRAINED FREE OIL OUT OF THE BEARINGS
- REDESIGN OF THE LUBRICATION SYSTEM RESULTED IN A SUCCESSFUL FLIGHT OF THE MOMENTUM WHEELS
- LESSONS LEARNED:
  - ORIENT THE WHEEL SPIN AXIS OF THE LIFE TEST LIKE THE SPACECRAFT DURING TESTING EVEN THOUGH THE THRUST LOADS EXCEED THE ORBITAL THRUST LOADS
  - ALTHOUGH LIFE TESTING IS THE BEST WAY TO QUALIFY A LONG LIFE LUBRICATED MECHANISM, GRAVITATIONAL EFFECT CANNOT BE FULLY COMPENSATED

THE TELDIX MOMENTUM WHEEL LIFE TEST EXCEEDED 10 YEARS AND THEY HAD HUNDREDS OF YEARS OF SUCCESSFUL ON-ORBIT PERFORMANCE, BUT GOES WHEELS FAILED IN ORBIT

- USING HERITAGE AND LIFE TEST SUCCESS AS A CRITERIA FOR SPACEFLIGHT QUALIFICATION, TELDIX WHEELS SHOULD HAVE BEEN WELL QUALIFIED
- POOR ORBITAL PERFORMANCE SUGGESTED THAT TELDIX WHEELS HAD DRIFTED OUT OF QUALIFICATION
- RE-ESTABLISHING PROCESS CONTROL AND CONFIGURATION MANAGEMENT RESOLVED THE PROBLEMS
- MANY TELDIX WHEELS HAVE SINCE FLOWN SUCCESSFULLY
- LESSON LEARNED:
  - ESTABLISH WELL-DEFINED, DETAILED MATERIALS AND PROCESSES AND VERIFY THAT THEY ARE ALWAYS USED

HEN SURPRISE THERMAL FLUTTER OF THE HUBBLE SPACE ELESCOPE SOLAR ARRAY BOOMS CAUSED EXCESS WEAR ON THI RIPLE REDUNDANT FINE GUIDANCE FOCUS SYSTEMS (FGS), THE ECHANISMS SHOWED HIGH TORQUE, HIGH CURRENT AND XCESS BEARING WEAR

POST-LAUNCH ACCELERATED LIFE TESTING OF THE FGS MECHANISM BY LOCKHEED MARTIN DUPLICATED THE ON-ORBIT DATA

DISASSEMBLY OF THE LIFE TEST MECHANISM SHOWED THAT BRAYCO 815Z FLUOROCARBON OIL HAD TRIBOLOGICALLY POLYMERIZED TO A SOLID WHIC INCREASED THE BEARING FRICTION, TORQUE AND CURRENT

THE FGS THAT STOPPED IN ORBIT WAS REPLACED ON SERVICE MISSION 2, TESTED ON THE GROUND AND DISASSEMBLED

GROUND TESTING SHOWED HIGH TORQUE AND CURRENT BUT NOT THE STALL

DISASSEMBLY SHOWED THE BRAYCO 815Z OIL HAD POLYMERIZED LIKE THE LIFE TEST

LESSONS LEARNED:

- ACCELERATED LIFE TESTING DUPLICATED THE ORBITAL FAILURE AND IDENTIFIED THE CAUSE OF FAILURE
- REDUNDANT FGS MECHANISMS PERMITTED HST TO CONTINUOUSLY COLLECT SCIENCE DATA
- ON-ORBIT REPAIR CAN EXTEND SATELLITE LIFE AND EXPAND THE SCIENCE CAPABILITY

THE TROPICAL RAINFALL MEASUREMENT MISSION SATELLITE (TRMM) SOLAR ARRAY DRIVE LIFE TEST PASSED THE LIFE REQUIREMENT, BUT HARMONIC DRIVE GEAR DAMAGE WAS OBSERVED UPON DISASSEMBLY

TO ASSURE MISSION SUCCESS, REDESIGN OF THE DRIVE WAS UNDERTAKEN

LUBRICATION WAS IMPROVED BY ADDING GREASE TO OIL, GEAR TEETH WER HARD COATED, STIFFNESS WAS ADJUSTED AND TOLERANCE WAS IMPROVED

A LIFE RETEST WAS SUCCESSFULLY COMPLETED ON THE REDESIGNED DRIVE

DISASSEMBLY SHOWED NEITHER EVIDENCE OF GEAR WEAR OR DEGRADED C AND GREASE

THE TRMM SATELLITE HAS BEEN FLYING SUCCESSFULLY FOR SEVERAL YEAI AS WELL AS THE X-RAY TIMING EXPLORER SATELLITE WITH THE SAME DRIV

LESSONS LEARNED:

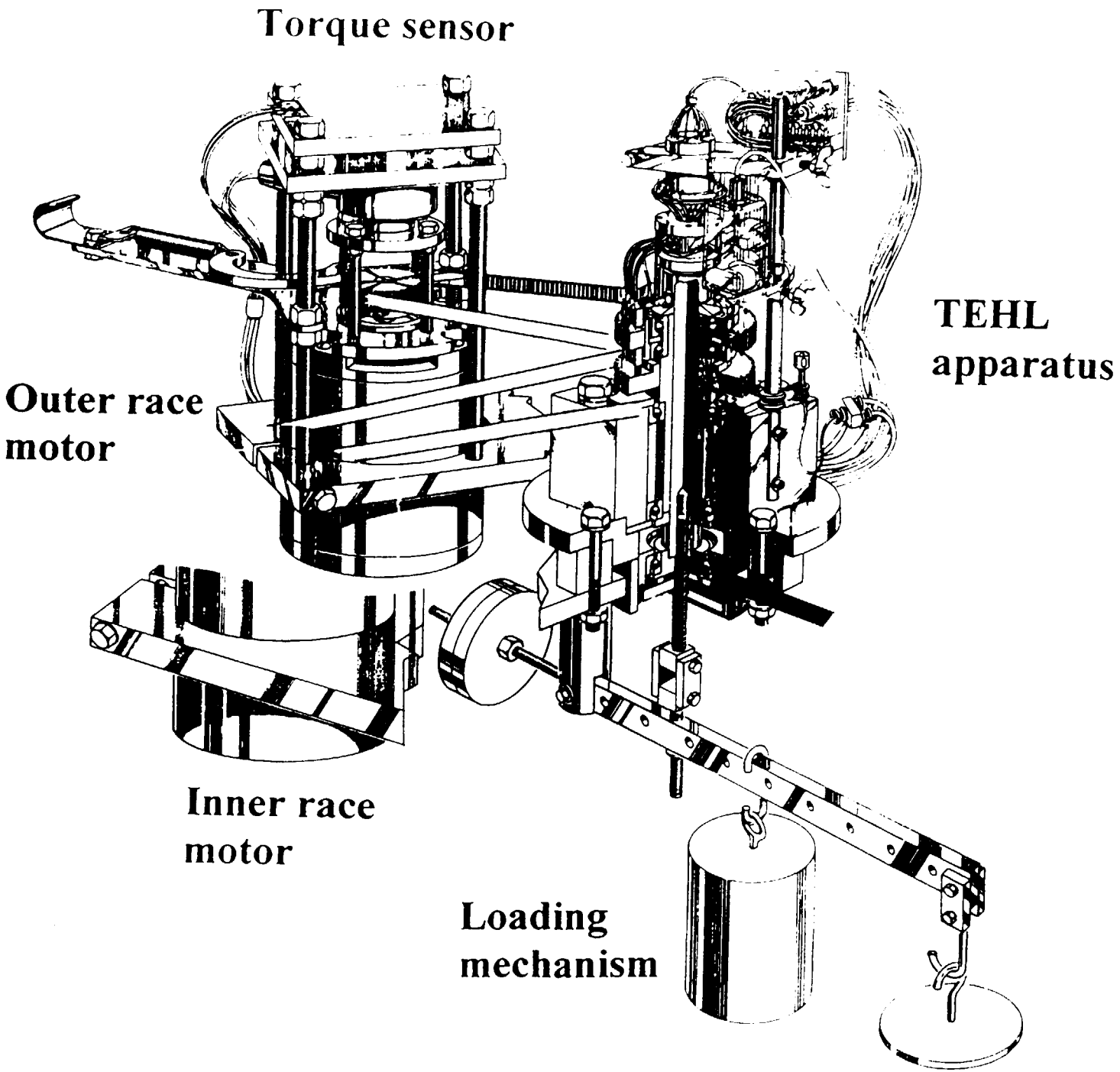
- THE LIFE TEST RESULTS DEMONSTRATED THAT THE SOLAR ARRAY DRIVI HAD TO BE REDESIGNED TO GUARANTEE EXTENDED SATELLITE LIFE
- LIFE TESTING OF ALL LONG-LIFE LUBRICATED SPACE MECHANISMS IS RECOMMENDED FOR ALL GODDARD SATELLITES BECAUSE OF MANY CAS HISTORIES LIKE TRMM

THE GOES SOUNDER FILTER LIFE TEST PASSED A 6-YEAR LIFE TEST, YET GOES 8 & 9 SHOWED TORQUE ANOMALIES AND INTERMITTENT STALLING AFTER ABOUT 3 YEARS IN ORBIT

- THE GOES 8 & 9 SOUNDER FILTER WHEEL ORBITAL TEMPERATURE PROFILE WAS 15°C ABOVE THE LIFE TEST TEMPERATURE PROFILE
- DISASSEMBLY OF THE LIFE TEST SHOWED A PREFERENTIAL KRYTOX OIL EVAPORATION FROM THE LOWER BEARING NEAR THE EVAPORATION EXIT. THE LUBRICATION, BEARINGS, AND OTHER MECHANISM PARTS WERE FREE OF WEAR AND ANOMALIES
- LUBRICATION EVAPORATION ANALYSES SHOW THAT THE LOWER BEARING WOULD DRY OUT IN ABOUT 3 YEARS IF THE FILTER WHEEL WAS OPERATED 15°C ABOVE THE LIFE TEST TEMPERATURE
- BECAUSE OF A HIGH TORQUE MARGIN, TiC BALLS AND A ROBUST DESIGN, THE SOUNDER INSTRUMENTS HAVE PROVIDED CONTINUOUS WEATHER DATA EXCEPT FOR A FEW HOURS
- LESSONS LEARNED:
  - LIFE TESTING CAN PROVIDE SOLUTIONS TO ON-ORBIT PROBLEMS EVEN WHEN GROUND TEST CONDITIONS ARE NOT IDENTICAL TO ORBITAL TEST CONDITIONS

NUMEROUS GODDARD LONG-LIFE LUBRICATED MECHANISMS WERE CLEANED WITH OZONE-DEPLETING CHLOROFLUOROCARBON CFC-113 SOLVENTS. IN APRIL 1995, PRODUCTION OF CFC-113 WAS HALTED BY THE MONTREAL PROTOCOL OF 1992

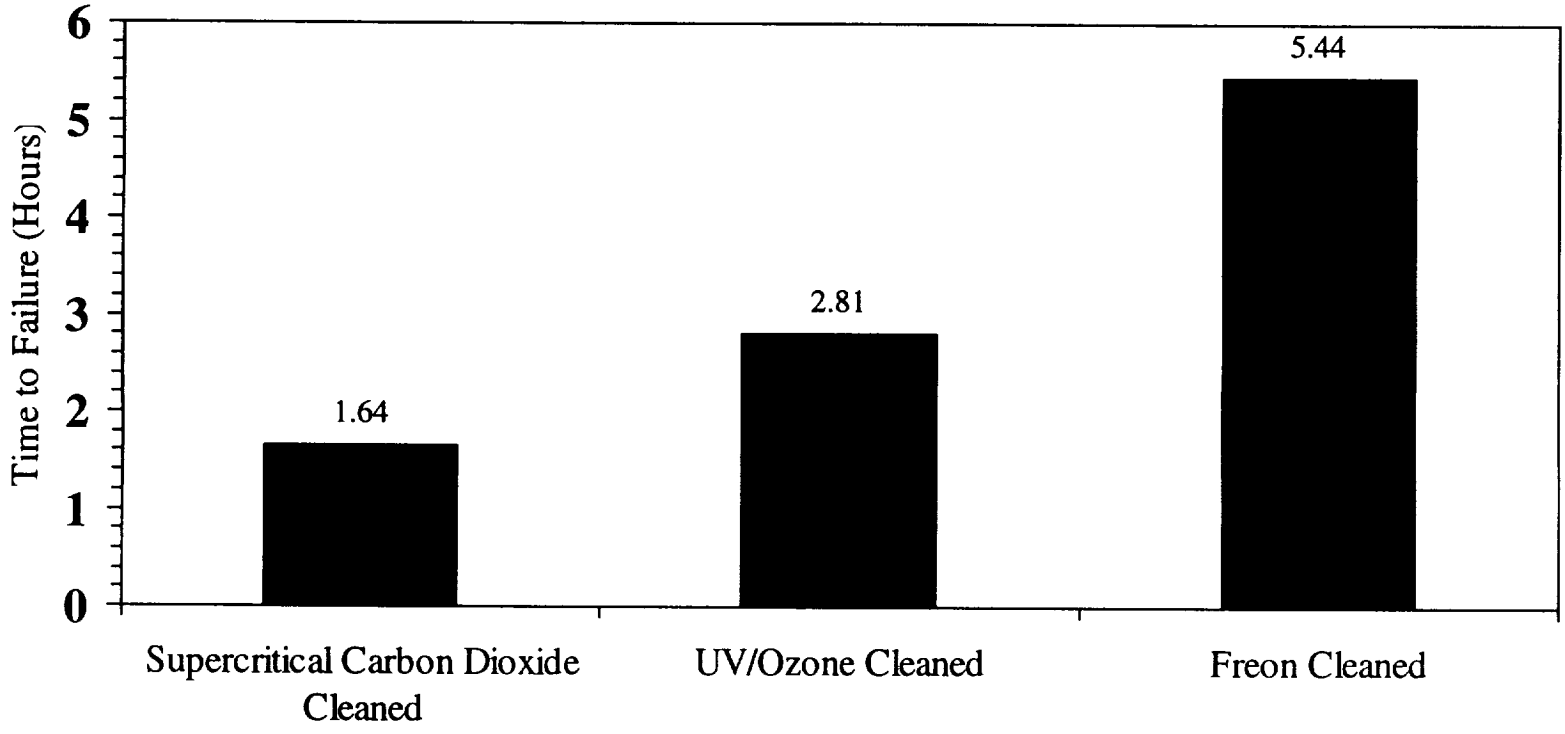
- IS THE MECHANISM LIFE REDUCED BY CLEANING BEARINGS AND MECHANISMS WITH REPLACEMENT SOLVENTS?
- ARE ALL LONG-LIFE LUBRICATED MECHANISMS REQUIRED TO BE REQUALIFIED BY REPEATING LIFE TESTS?



Overall TEHL Experimental Apparatus

ACCELERATED LIFE TEST OF KRYTOX 143AC FLUOROCARBON LUBRICATED BEARINGS

Parched Transient Elastohydrodynamic (TEHL) Apparatus
(Air, 4500 rpm, Room Temperature)



Ref: W. Jones, et al., The Effects of ODC-Free Cleaning Techniques on Bearing Lifetimes in the Parched Elastohydrodynam Regime, Second Aerospace Environmental Technology Conference, Huntsville, Alabama, August 1996

WITH CFC-113 PRODUCTION TERMINATED, ALL BEARING MANUFACTURER CLEANING SOLVENTS WERE SWITCHED FROM CFC-113 TO ODC-FREE SOLVENTS. ACCELERATED LUBRICANT LIFE TESTS SHOWED REDUCED LIFE. HOW COULD THE QUALIFICATION OF LONG-LIFE LUBRICATED MECHANISMS BE PROTECTED?

- SHORT-TERM SOLUTIONS
  - STOCKPILE CFC-113 FOR USE ON GSFC MECHANISMS
  - CONDUCT SEVERAL TYPES OF ACCELERATED LUBRICANT LIFE TESTS
- LONG-TERM SOLUTIONS
  - FOR NEW MECHANISM DESIGNS, CLEAN THEM WITH SOLVENTS THAT DO NOT DEPLETE OZONE AND QUALIFY BY LIFE TESTING
  - REPEAT LIFE TESTS ON MECHANISMS THAT ARE CLEANED WITH ODC-FREE SOLVENTS
  - MEASURE LUBRICANT LIFE IN SPACEFLIGHT-QUALITY BEARINGS CLEANED WITH ODC-FREE SOLVENTS

EFFECT OF ODC-FREE SOLVENT CLEANING ON BRAYCO 815Z LIFE IN INSTRUMENT BEARINGS

SOLVENT	CYCLES TO FAILURE (MILLIONS OF CYCLES)	
FREON (CFC-113)	10.1	12.6
AQUEOUS	15.0	35.6
3M PF5052	40.5	33.1
DUPONT VERTREL XF	26.1	108.2

REF: S. LOWENTHAL, LIFE OF PENNZANE AND 815Z-LUBRICATED INSTRUMENT BEARINGS CLEANED WITH NON-CFC SOLVENTS, PROCEEDINGS OF THE 8TH EUROPEAN SPACE MECHANISMS AND TRIBOLOGY SYMPOSIUM, TOULOUSE, FRANCE, SEPT. 29, 1999

CONCLUSIONS:

- NON-CFC SOLVENTS INCREASE LUBRICANT LIFE IN INSTRUMENT BEARINGS
- LONG-LIFE MECHANISMS LUBRICATED WITH BRAYCO 815Z OIL RETAIN THEIR QUALIFICATION WHEN CLEANED WITH NON-CFC SOLVENTS

MECHANISM CASE HISTORIES REVEAL MANY LESSONS LEARNED

- REVIEW OF THE LESSONS LEARNED DURING MECHANISM DESIGN WILL PREVENT MOST PROBLEMS
- ROBERT FUSARO'S NASA STUDY OF CASE HISTORIES, LESSONS LEARNED AND DESIGN HANDBOOK IS THE PLACE TO START
  1. NASA TECH. MEMO 107046, "VOL. I - SUMMARY, SPACE MECHANISMS LESSONS LEARNED STUDY," W. SHAPIRO, F. MURRAY, R. HOWARTH, AND R. FUSARO, SEPT. 1995
  2. NASA TECH. MEMO 107047, "VOL. II - LITERATURE REVIEW, SPACE MECHANISMS LESSONS LEARNED STUDY," SEPT. 1995, AUTHORS - SEE 1
  3. NASA/TP-1999-206988, "NASA SPACE MECHANISMS HANDBOOK," R. FUSARO, EDITOR, JULY 1999
     - INTERNATIONAL TRAFFIC IN ARMS REGULATIONS (ITAR) EXPORT CONTROLLED
     - FOR COPIES
       - ROBERT FUSARO 216-433-6080
       - E-MAIL: Robert.L.Fusaro@grc.nasa.gov

WHEN PURCHASING SATELLITES OR INSTRUMENTS, HOW CAN MECHANISM PROBLEMS BE AVOIDED?

- MECHANISM PERFORMANCE AND TEST SPECIFICATIONS; WHEN ALLOWED BY PROCUREMENT LAWS
- EXPERT REVIEW OF SUPPLIER'S DESIGN AND TEST PLAN; WHEN ALLOWED BY PROCUREMENT LAWS

- GODDARD SELECTS CONTRACT REQUIREMENTS FROM: 300-PG-7120.2.2, MISSION ASSURANCE GUIDELINES (MAG) FOR TAILORING TO THE NEEDS OF GSFC PROJECTS
  - http://gdms.gsfc.nasa.gov/gdms/plsql/menu
  - MAUREEN BARBER 301-286-4494 FOR QUESTIONS
- WHEN APPROVING LUBRICATION AND MATERIAL USAGE FOR SATELLITES, THE MATERIALS TIPS WILL BE USEFUL
  - 115 CASE HISTORIES OF LUBRICATION AND MATERIALS USAGE PROBLEMS
  - FOR A COPY:
    - Roamer.E.Predmore.1@gsfc.nasa.gov
    - 301-286-5953