

AFRL-RX-WP-TP-2008-4200

MILITARY AVIATION FLUIDS AND LUBRICANTS WORKSHOP 2006 (POSTPRINT)

Ed Snyder, Lois Gschwender, and Angela Campo

Nonstructural Materials Branch Nonmetallic Materials Division

JUNE 2006

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AIR FORCE RESEARCH LABORATORY MATERIALS AND MANUFACTURING DIRECTORATE WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7750 AIR FORCE MATERIEL COMMAND UNITED STATES AIR FORCE



Pall Aeropower Corporation

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June 10, 2008

Lois Gschwender Wright Patterson AFB 2941 P St., Suite 1 Wright Patterson AFB, OH 45433-7750

Subject: Data Rights Waiver for Pall Presentation dated June 20, 2006

Reference: Pall Total Contamination Management Workshop

Dear Ms. Gschwender:

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The report has been reviewed and we grant approval for public release, distribution unlimited.

Sincerely,

Joseph Hahn Sales Manager



Wedeven Associates, Inc

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June 12, 2008

Lois Gschwender AFRL/MLBT BLDG 654 RM 136 2941 Hobson Way Wright Patterson AFB, OH 45433-7750

Subject: Contract Number FA 8650-04-C-05034 Phase II SBIR

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Please feel free to contact me should you require any additional information.

Sincerely,

S.D. Weslesser

Lavern Wedeven President

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14. ABSTRACT					
				rious topics such as current lubricant	
the background of this topic was di				update on hydraulic fluid purification,	
				vy presented their data on the usage of	
MIL-PRF-32104 as a corrosion res					
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Military Aviation Fluids and Lubricants Workshop

Hope Hotel and Conference Center Fairborn, Ohio 20 – 22 June 2006

The following presentations are cleared for Public Release AFRL-WS 07-2067

Military Aviation Fluids and Lubricants Workshop

Hope Hotel and Conference Center Fairborn, Ohio 20 – 22 June 2006 <u>AGENDA</u>

Tuesday, 20 June 2006

0700 - 0800 Registration

0800 Session I Hydraulics, Ed Snyder Chair

- 0800 0815 Welcome and Introductory Remarks Mr. Robert Rapson, Materials and Manufacturing Directorate, Air Force Research Laboratory
- 0815 0830 Overview, Ed Snyder, AFRL
- 0830 0900 Air Force Lubricant Specifications and Conversions, Lois Gschwender, AFRL
- 0900 0915 Air Force Petroleum Office, Mel Regoli and Glenna Dulsky
- 0915 0930 Joint Service Hydraulics Manual, Megan Goold, NAVAIR
- 0930 1000 Elimination of Barium Containing Fluids in DoD Aircraft Systems, Lois Gschwender, AFRL

1000 - 1015 Break

- 1015 1045 US Army Hydraulic Contamination Control Program, Ken Wegrzyn, presented by Matthew Boenker, Avion, Army Aviation Command
- 1045 1115 Air Force Hydraulics Activity at Tinker AFB, Mel Louthan
- 1115 1200 Hydraulic Pump Health Monitoring, Shashi Sharma, AFRL/MLBT; and Bruce Pilvelait, Creare

1200 – 1315 Lunch

1315 Session II Hydraulic Fluid Contamination, Shashi Sharma, Chair

- 1315 1350 Overview, Al Herman, ASC Aging Aircraft Systems Squadron
- 1350 1405 Hydraulic Test Stand Modification at Eglin, Eddie Preston, Warner Robins ALC
- 1405 1420 Hydraulic Fluid Purification Decision Brief, Eddie Preston, Warner Robins ALC
- 1420 1440 Environmental Aspects of Hydraulic Fluid Purification (HFP), Don Streeter, ASC Pollution Prevention Branch
- 1440 1515 Analytical Data on Aircraft and Mule Hydraulic Fluid Samples, George Fultz, University of Dayton Research Institute
- 1515 1530 Break

1530 – 1600 Used Hydraulic Fluid Purification (UHFP), Capt John Yerger, AMC Battle Lab

- 1600 1615 Purifier Briefing, Gary Rosenberg, Pall Corporation
- 1615 1630 Purifier Briefing, Dave Sweetland, Malabar Corporation

1630 Adjourn

Wednesday, 21 June 2006

0730 - 0800 Registration

0800 Session III Hydraulic Fluid Purification, Lois Gschwender, Session Chair

- 0800 0820 HFP Requirements, Al Herman, ASC Aging Aircraft Systems Squadron
- 0820 0930 Service Evaluation Program, Kevin Hibbs, Randy Barnett

0930 – 0945 Break

- 0945 1005 Canadian Air Force Hydraulic Fluid Purification, Ghislain Boivin, Canadian Ministry of Defense
- 1005 1020 In-Line Hydraulic Fluid Contamination Multi-Sensor, Kenneth Heater, METSS Corporation
- 1020 1030 Air Sensor Program, Ed Snyder, AFRL
- 1030 1050 Cleaning Efficiency Study of Malabar and Pall Portable Fluid Purifiers, Ed Snyder, AFRL
- 1050 1115 F-15 Hydraulic System Fluid Contamination Prevention, Hugh Darsey, WR-ALC 330 FSG/LFEF, This presentation was not cleared for public release. It will not be included on the workshop CD.
- 1115 1145 HFP Implementation, AI Herman, ASC Aging Aircraft Systems Squadron

1145 – 1300 Lunch

1300 Session IV-A, AMC Hydraulic Maintenance Issues, MSgt Kurt Hinxman Chair

No Detailed Agenda

1300 Session IV-B, Engine Oils, Ed Snyder, Chair

- 1300 1345 Enhanced 5 cSt Oil Development for High Performance Gas Turbines, Lewis Rosado, Lynne Nelson and Nelson Forster, AFRL
- 1345 1430 Advanced Helicopter Transmission Lubricant, Eric Hille, NAVAIR
- 1430 1500 Engine Oil Requirements for Future Engines, Curtis Genay, Pratt & Whitney

1500 – 1515 Break

- 1515 1530 <u>Small Business Innovation Research Program, Gas Turbine Engine Oil</u> <u>Additives for Advanced Bearing Steel</u>, Lois Gschwender, AFRL
- 1530 1550 New and Innovative Gas turbine Engine Oil Additive Technology, Rich Sapienza/Bill Ricks, METSS
- 1550 1615 SBIR Phase II Additives for Corrosion Resistant Steels, Vern Wedeven, Wedeven Associates
- 1615 1645 Discussion

1645 Adjourn

Thursday, 22 June 2006

0730-0800 Registration

0800 Session V Greases/Solvents, Lois Gschwender, Chair

- 0800 0840 Development and Evaluation of Multi-Purpose, Moisture-Resistant, High Load Carrying Polyalphaolefin Based Grease, MIL-PRF-32014, Lois Gschwender
- 0840 0925 Navy Testing of MIL-PRF-32014, Chris Medic, NAVAIR
- 0925 0945 Screening Test Results for Low Cost Alternatives for the F100 Nozzle Actuator Grease, Angela Campo, AFRL
- 0945 1015 High Temperature Lubricant Phase II Status Report, Rich Sapienza and Bill Ricks, METSS

1015 – 1030 Break

- 1030 1050 The Future of Solvent Usage in the Air Force, Angela Campo, AFRL
- 1050 1130 PAO Coolant MIL-PRF-87252 Past and Current Activities, Lois Gschwender, AFRL

1130 Adjourn

Military Aircraft Hydraulic Fluids and Lubricants Workshop

Welcome and Introductory Remarks



Materials & Manufacturing Directorate Bob Rapson

Military Aircraft Hydraulic Fluids and Lubricants Workshop



- Purpose of Workshop
 - To bring together
 - Researchers
 - · Fluid and hardware manufacturers
 - Users
 - To provide an update on high interest topics
 - To provide a forum for discussion

Military Aircraft Hydraulic Fluids and Lubricants Workshop

- Challenge
 - New Aircraft More Demanding on System Materials
 - Aging Aircraft
 - More demanding missions
 - Modifications putting additional stress on systems
 - Changes in manufacturing processes for components
 - Fewer Military Specifications
 - Dilution of existing military specifications
 - Fluids and lubricants considered flight critical components will be maintained as MIL-Specs
 - Diminishing Fluids and Lubricants Tech Base in Companies due to downsizing and mergers



Where the Materials and Manufacturing (ML) Directorate Fits



AF Major Commands

- Air Combat Command
- AF Space Command
- AF Special Ops Command
- AF Materiel Command
- Air Mobility Command
- Pacific Air Forces
- USAF in Europe

AF Materiel Command

- AF Research Laboratory
- **Product Centers**
- **Test Centers**
- **Logistics Centers**
- **Specialty Centers**

AF Research Laboratory

- AF Office of Scientific Research
- **Air Vehicles**
- **Directed Energy**
- Human Effectiveness
- Information
- Materials & Manufacturing
- **Munitions**
- Propulsion
- Sensors
- Space Vehicles

Materials & Manufacturing **Directorate**

- Nonmetallic Materials
- Metals, Ceramics & NDE
- Manufacturing Technology
- Integration & Operations
- Survivability & Sensors Materials
- Systems Support
- Air Base Technologies



ML Mission / Vision



MISSION

Plan and execute the USAF program for materials and manufacturing in the areas of basic research, exploratory development, advanced development and industrial preparedness. Provide responsive support to Air Force product centers, logistics centers, and operating commands to solve system and deployment related problems and to transfer expertise





Aerospace materials and manufacturing leadership for the Air Force and the nation

Distribution Statement A: Approved for public release distribution is unlimited. (AFRL-WS 06-1402)



- Provide leadership for research, development and support for aerospace materials and manufacturing processes, and airbase and environmental technology
 - Be the best for selected technical areas
 - -- A first class in-house program
 - -- First class experts/consultants
 - Be "One Phone Call Away" from the best in other technical areas
 - -- A broad based contractual program
 - -- Active in the technical communities
- Exceed customer's expectations



Resources to Accomplish the ML Mission

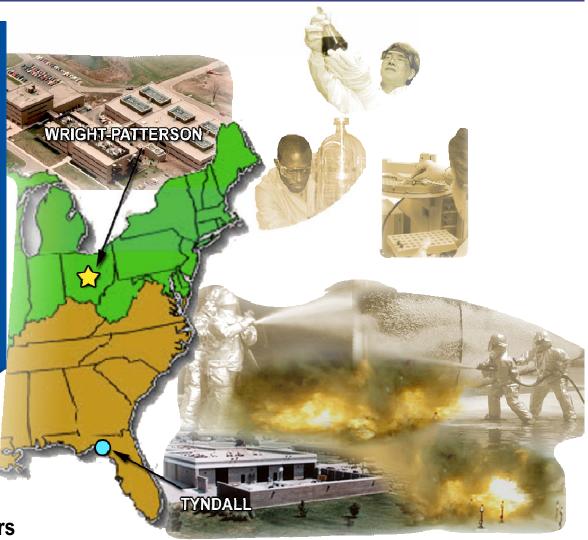


- Revenue \$378M /year
- People 1150 Gov't & Ctr
- 15/35 buildings (owned/occupied)
- 385,000 net square feet
- 215 Lab modules
- Designed specifically for aerospace materials, processes and airbase technologies R&D

LOCATIONS:

- Wright-Patterson AFB
- Tyndall AFB
- Program Offices in GA, OK, UT
- Collocates at TDs, SPOs, Centers







ML Unique Facilities & Equipment



Laser Deposition Tribology Laboratory	Non-destructive Evaluation (NDE) Research Laboratory
Confecul Brilloum Imaging Spectometer	Electron Optics Laboratory
Optical Measurements Laboratory	Laser Hardened Materials Evaluation Laboratory
Confocal Brillouin Imaging Spectometer	Secondary Ion Mass Spectroscopy (SIMS)
Fluid and Lubricant Development and Characterization Lab	ed Materials Evaluation Laboratory Electronic Failure Analysis Facility
Opto-Electronic Polymer Physics Laboratory	Materials Compatibility/Coatings Research Facility
Space Co-Waterials Processingarch	Systems Support Nondestructive Inspection Laboratory
Space Combined Environment Facility	pace Coatings Environment Test and Research
Mechanics of Composites Test Laboratory	Materials Test and Evaluation Laboratory
Morphology Laboratory	Product Affordability Realization Testbed
ondary ion Mass Spectroscopy (SIMS)	Coan Sual Beam Focused Ion Beam
Polymer Synthesis Laboratory	High Cycle Fatigue Laboratory
Polymer Processing and Characterization Laboratory	Coatings Technology Integration Office
Composites Processing Laboratory Cera Optical Crystal Characterization	Composites Characterization Facility Composite Prepreg
Experimental Materials Processing Laboratory	Electrostatic Discharge Control Laboratory
Blast Range and Fire Pit Robotics a	and Remote Transport
High Temperature Materials Laboratory	Materials Degradation Test Facility
Materials Characterization Facility Metallurgical Research Laboratory	Materials Processing Laboratory Virtual Reality for Materials Design Facility
Materials Behavior Research Laboratory	Electrical Characterization Facility
	abilities in One Place 📁



Materials / Processes to Enable Air Force Capability



Faster, farther, more survivable, more sustainable, more affordable.....



All Enabled By Enduring Materials/Processes Competencies



ML's Enduring Competencies Foundations of Our S&T Base

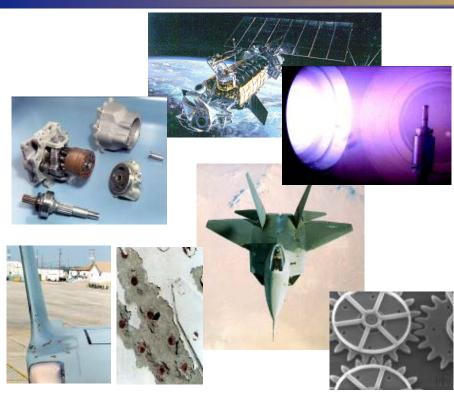






CTA 6 Tribology and Coatings





RECENT TECH HIGHLIGHTS:

- Rapid process gap/fastener filler transitioned to F-35
- Environmentally safe corrosion preventative primer transitioned to F-15 fleet
- Hydraulic fluid purification on flightline ground cart

- Advanced Fluids and Lubes Materials and Processes
- Fluids and Lubes Health Monitoring
- Solid Lubricants and Wear Resistant Materials and Processes
- MEMS and Nano Contact Lubrication
- Health Monitoring of Aircraft Components
- Space Protective Coatings
- Space Lubricant Technology
- Optical Characterization of Materials
- Multispectral Coatings for Signature Control
- High Performance Multifunctional Aircraft Coatings
- Corrosion Control and Pretreatment
- POSS polyimide coating formulated for space tethers
- Multi-environment, wear resistant coating under evaluation for JSF and launch vehicle applications

- MLBT Fluids and Lubricants Group Mission:
 - Research, development, and transition of new base fluids and additives to meet changing Air Force requirements
 - Provide quick reaction field support for fluids and lubricant and lubrication related problems
 - Maintain and Support
 - Fluids and lubricant military specifications
 - Non-government standards
 - MIL-handbook
 - TOs

<u>People</u>

- MLBT Fluids and Lubricants Group
 - Interdisciplinary team of mechanical and materials engineers
 - Long heritage in fluids and lubricants research, development and technology transition
 - Extensive experience in fluids and lubricants chemistry and performance
 - Developed large number of fluids and lubricants and transitioned them into DoD systems
 - Significant background in working fluid and lubricant related field problems

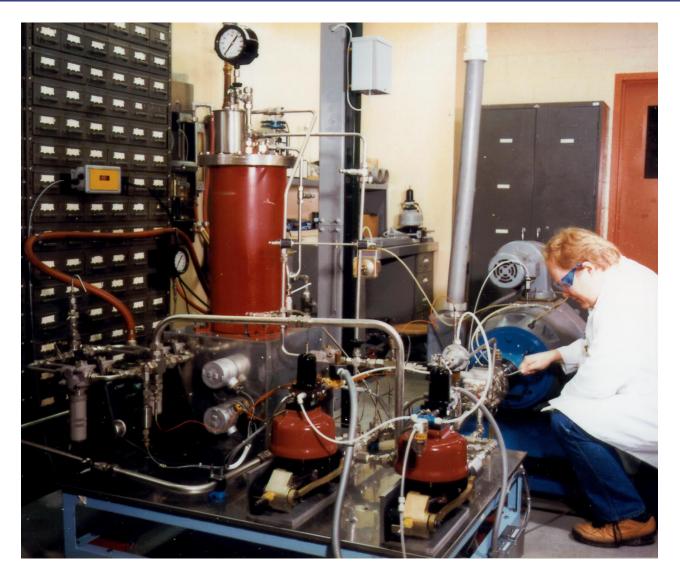
Capabilities

- MLBT Fluids and Lubricants Group Has Outstanding Analytical and Test Facilities
 - Unique Hydraulic Pump Test Facility
 - Unique Grazing Angle Infrared Microscope
 - High Speed Bearing Tester
 - Lubricity Test Equipment
 - Extreme Temperature Rheological Property Capability
 - In-House Fluid and Component Analysis Capability e.g., XPS, ICP, SEM, XRD, TEM



Pump Stand Slide Here

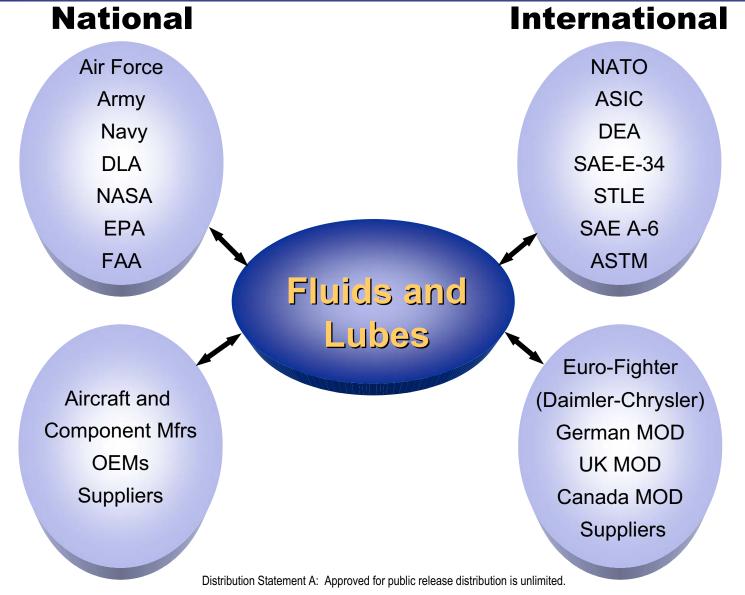




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Interactions

- MLBT Fluids and Lubricants Group Participates in Non-Government Standards Organizations and International Standardization Activities
 - American Society for Testing and Materials (ASTM)
 - Society of Automotive Engineers Aerospace Fluid Power and Control Technologies Committee (SAE A-6)
 - Society of Tribologists and Lubrication Engineers (STLE)
 - International Standards Organization (ISO)
 - North Atlantic Treaty Organization (NATO)
 - Air and Space Interoperability Council (ASIC)
- MLBT Fluids and Lubricants Group Works Collaboratively with Other Government Agencies
 - Army, Navy, NASA, DLA, FAA, International
- and Industry
 - Prime contractors, component designers and suppliers, and fluid suppliers



Military Aircraft Hydraulic Fluids and Lubricants Workshop

Value of the Workshop

- Provides opportunity for improved communication between AFRL/MLBT, the warfighter, program offices, other government agencies and industry
- Provides status of newer technology and an opportunity for feedback
- Provides opportunity to learn of new requirements, issues that would help the warfighter
- Provides opportunity to establish new and enhance existing relationships
- Provides awareness of skills and capabilities available at MLBT to provide support for field problems in fluid and lubricant technology

MLBT is DoD's One Stop Shop for Fluid and Lubricant Research, Development, Transition and Field Support

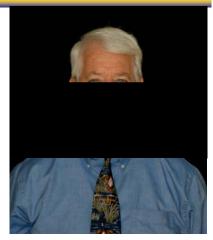
Use Good Science to Solve Field Problems



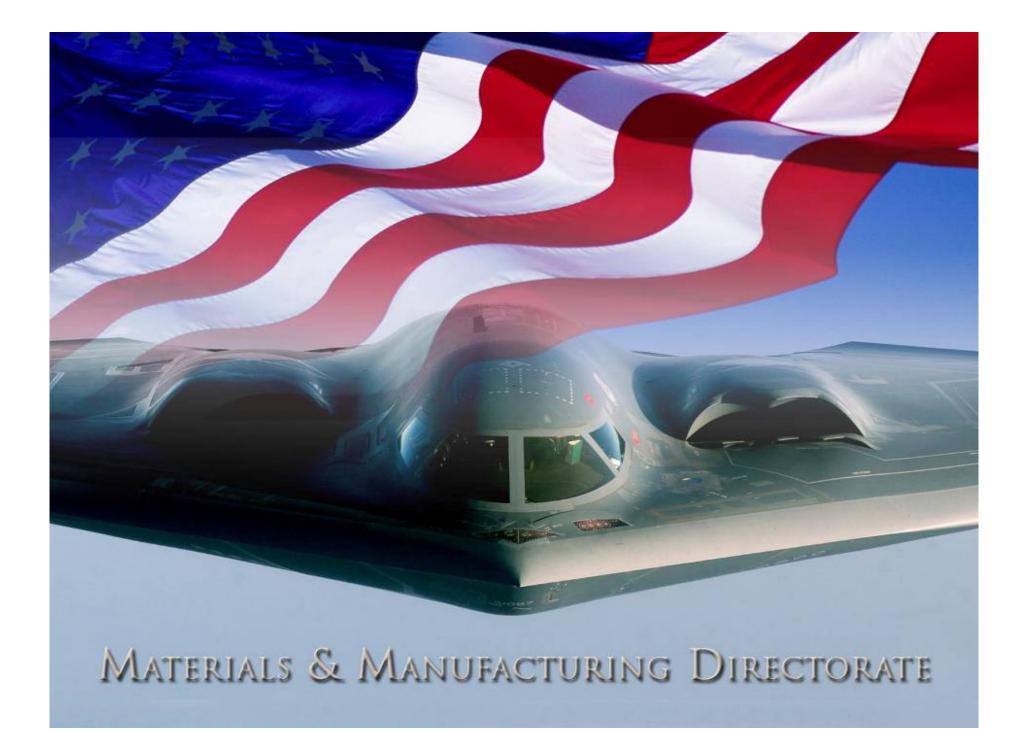
Carl "Ed" Snyder Scientific Achievement



- Leadership: Established ML as Fluids & Lubricants Center of Excellence
 - Fellow of Society of Tribologists and Lubrication Engineers
 - Chair of SAE Fluids Panel for Aerospace Power and Control Tech.
 - Provides US position related to F&L to NATO, allies, and the Air and Space Interoperability Committee
- Communication and Reporting
 - 15 patents; 150 publications; presentations at international venues
 - SAE LLoyd L. Winthrop Distinguished Speaker Award
- Technical Problem Solving
 - High Temp fluids and lubes; ultra-low volatility lubes for space
 - Fire resistant hydraulic fluids; stuck servo-valves; radar coolant
 - Grease for F-107 engine bearing; stuck servovalves in UH-1 helicopters
- Air Force Impact
 - His F&Ls are used in 98% of AF a/c and 100% of USA and USN a/c
 - His dielectric coolant for radar systems is used in 99% of AF and 100% of USN a/c
 - Reduced fire damage (~\$45M/yr savings); longer overhaul intervals



2006 AFRL Fellow





Air Force Research Laboratory Materials and Manufacturing Directorate Wright-Patterson Air Force Base, Ohio



- One Stop Shopping for Fluids and Lubricants in Air Force
 - Research
 - Development
 - Prepare and Maintain Specifications
 - Qualify Products to Specifications
 - Maintain Qualified Products Lists
 - Transition New Materials to the Field
 - Solve Field Problems



- Areas of Responsibility
 - Hydraulic Fluids
 - Purification
 - Greases

Aircraft and Spacecraft

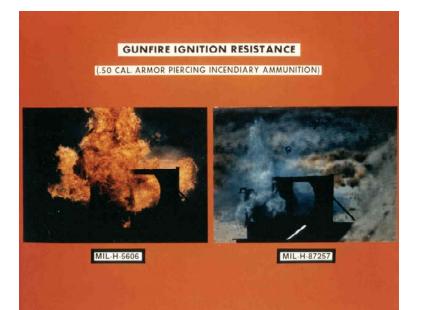
- Liquid Lubricants
- Coolants
- Solvents



- Personnel:
- Ed Snyder Team Leader
- Lois Gschwender Senior Research Materials Engineer
- Angela Campo Chemist
- Shashi Sharma Mechanical Engineer (1/2 Time)
- 5 On-Site Contractor Personnel
 - 3 Professionals
 - 2 Technicians
- External Contract With Phoenix Chemical Laboratory

Fire Resistant Hydraulic Fluids

- MIL-PRF-83282
- MIL-PRF-87257



ORCE RESEARCH LABOR



B-52 Hydraulic Fire

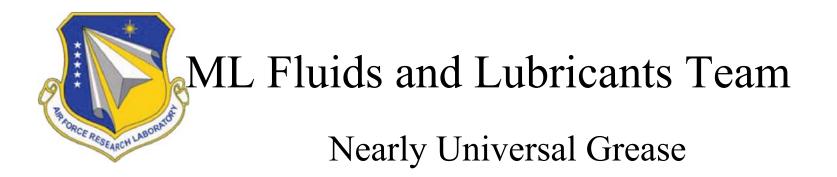


Hydrolytically Stable Coolant



Coolanol 25R (MIL-PRF-47220)

MIL-PRF-87252 (PAO)



Corrosion Rate Evaluation Procedure Coupons,

300M steel, distilled water, 45 min





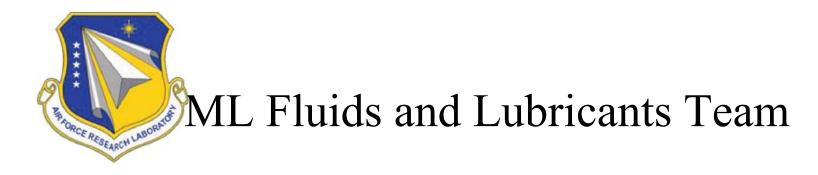


MIL-PRF- 32014 MIL-PRF-81322 Braycote 807RP



MIL-PRF-81322

MIL-PRF-32014



- New Fluids and Lubes Development
- Field Problem Solving
 - Stuck Servovalves
 - Prematurely Clogged Filters
 - Engine Oil Foaming
 - Hydraulic Fluid Contamination
- Fluid and Lubricant Specifications & QPLs
 - Hydraulic Fluids
 - Greases
 - Liquid Lubricants





Air Force Lubricant Specifications & Conversions

Lois Gschwender AFRL/MLBT June 20 2006



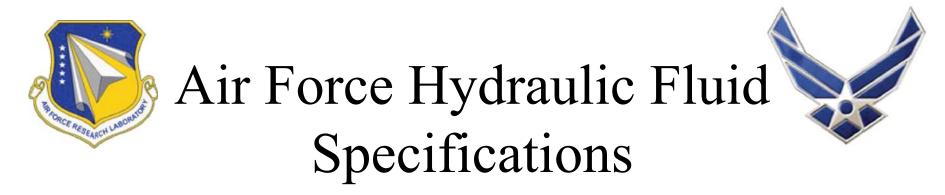
- Hydraulic Fluid*
 - MIL-PRF-27601 (hi temp PAO) One company qualified - EHA fluid?
 - MIL-PRF-87257 (PAO)
 - MIL-PRF-5606 (mineral oil)
- *Qualified Products List on these
- Available through ASSIST
 - http://assist.daps.dla.mil.quicksearch



- Coolant*
 - MIL-PRF-87252 (PAO, dielectric)
- Lubricating Oils*
 - MIL-PRF-6085 (instrument)
 - MIL-PRF-6086 (gear)
 - MIL-PRF-7870 (general purpose)
- Fastener Lubricant
 - MIL-L-87132 (cetyl alcohol)
- Thread compound
 - MIL-PRF-83483 (antiseize, MoS₂)
- * Qualified Products List on these



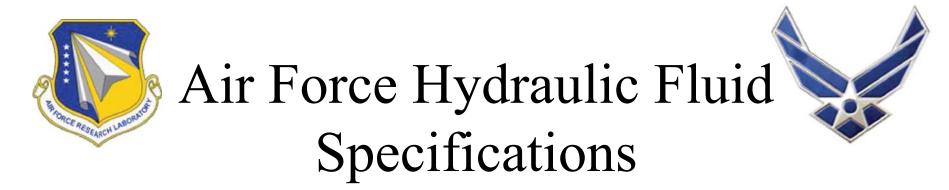
- Grease
 - MIL-PRF-27617* (perfluoropolyalkylether)
 - MIL-PRF-32014* (PAO, Li soap)
 - MIL-PRF-83261 (fluorosilicone, extreme pressure, antiwear)
 - MIL-PRF-83363 (extreme pressure antiwear helicopter transmission)
- * Qualified Products List on these



- MIL-<u>PRF</u>-5606H mineral oil hydraulic fluid extensive revisions but no change in basic materials or properties should be "invisible" to aircraft
 - Dated 7 June 2002
 - Remains inactive for new design
- Lots of re-qualification activity on MIL-PRF-5606 due to base stock supplier and quality changes
 - Base fluid properties problematic
 - Density
 - Seal Swell

- MIL-PRF-5606 extensive revisions including
 - Barium limit 10 ppm max, ASTM D 5185
 - Up to 3% antiwear additive allowed
 - Many test method changes (no effect on properties)
 Solvents, etc.
 - Interchangeability with other fluids statement
 - Notes section 6 more extensive

ESEARCHU



- MIL-PRF-5606 extensive revisions
 - Amendment 2
 - Lists MIL-PRF-87257 and MIL-PRF-83282 for new design
 - Adds rubber swell to list of conformance tests
 - Amendment 3 in tri-service coordination
 - Sampling plan eliminated (belongs in contracts, not spec)
 - Contamination
 - Delete filtration times
 - Go to polypropylene filters for gravimetric analysis better repeatability



- MIL-PRF-87257 extensive revisions in April 2004 but no change in basic materials or properties – should be "invisible" to aircraft
 - New requirements
 - Bulk modulus per ASTM D6793
 - Barium limit 10 ppm max
 - Biodegradability limit of Class I max
 - Format changes
 - Consolidated requirements and tables into comprehensive table I and revised table II
 - Hyperlinks in electronic version goes directly to footnotes in tables



- MIL-PRF-87257 extensive revisions
 - Changed requirements
 - Lowered flash point to 160°C due to use of automatic equipment that has a lower data bias
 - Added referee particle count method
 - Raised thermal stability test to 200°C and allowed use of test tube to conduct test
 - Changed temperature range in scope from "-54°C to 135°C" to "-54°C to 200°C" to allow use in EHAs

- MIL-PRF-87257 extensive revisions
 - Changed filter material in gravimetric procedure to polypropylene and added two stacked filter method – better repeatability
 - Changed limit in gravimetric particulate test to 1.0 mg/100 ml fluid max
 - Require only 1 gallon of final formulation additives on request only
 - Current fluids grandfathered



- MIL-PRF-27617 perfluoropolyalkylether based greases
 - Type I, –65-300°F
 - Type II, -40 to 400°F
 - Type III, -30 to 400°F
 - Type IV, -100 to 400° F
 - Type V, -100 to 450°F (none currently qualified)



- MIL-PRF-27617 is expensive ~\$200 to \$1000/lb
- Has some wear and corrosion issues
- Should only be used where hydrocarbon based greases are unacceptable
 - LOX & GOX
 - Extreme temperature
- Specification in pretty good shape, not high priority for revision



- MIL-PRF-32014 Multipurpose, Nearly Universal Grease
 - Currently working on extensive spec revisions
 - This grease currently in Cruise Missile F-107 engine, C-5 and C/KC-135 landing gear and C/KC-135 wheel bearings
 - Navy flight testing since Feb 2006
 - Nose wheel bearing
 - Rotodome
 - Nye Lubricants, Rheolube 374A and Air BP, Braycote 3214 qualified products on QPL





Air Force Coolant Specification

- MIL-PRF-87252 coolant, Amendment 1 Dec. 04
 - Changed to -54°C to 200°C temperature range due to advanced system predictions
 - All qualified products tested and passed 200°C, 100 hour thermal stability test

Air Force Specifications

- Qualified Product Lists
 - QPL-5606-31, 17 January 2003
 - QPL-6085-15, 6 January 2003
 - QPL-6086-13, 10 February 2003
 - QPL-32014-2, Amendment 1, 1 August 2003
 - QPL-27617-8 (perfluoropolyalkylether grease), 26 May 2004
 - QPL-87252, 6 January 2005
 - QPL-87257, 12 February 1996
 - Products requested to be re-qualified every 5 years





Air Force Specifications

• Any issues or concerns with military specifications we control, please contact AFRL/MLBT



Recent Conversions...

- MIL-PRF-87257 approved for use in B-52 aircraft
 - T.O.s and job guides changed
 - Flying on MIL-PRF-5606/MIL-PRF-87257 mixtures
 - Landing gear struts using MIL-PRF-5606
 - Recently changed from O-ring to T-ring seal design tested at Hill AFB
 - MIL-PRF-87257service testing on one aircraft LG
 - Expecting to convert landing gear ~ 1 year



- B-2 and trainers only aircraft using flammable MIL-PRF-5606
- MIL-PRF-32014 grease
 - Replaced MIL-PRF-81322 for main landing gear in C-5 and KC/C–135 aircraft
 - Looking for wheel bearing test
 - UK evaluating for military applications
 - Looking for new application opportunities

Air Force Petroleum Office

Developing, Fielding, and Sustaining America's Aerospace Fuels



AFRL FLUIDS & LUBES WORKSHOP June 2006

V. M. Regoli Det 3, WR-ALC/AFTT

Integrity - Service - Excellence



What We Do



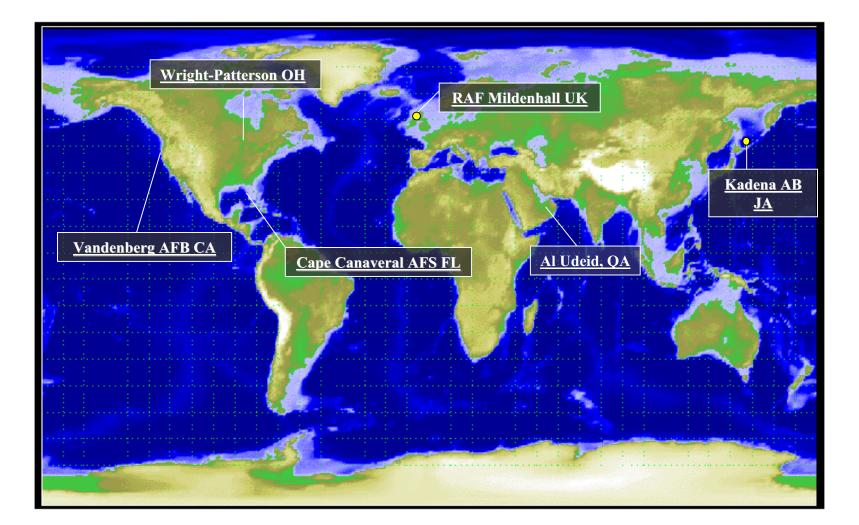
Strategically focus the efforts of the Air Force Fuels community to develop, mature and enhance core competencies in order to deliver state of the art technical support and service to the warfighter.

Maintain an Air Force Fuels Service Control Point (SCP) that is mission concentrated, agile, flexible and warfighter focused; which provides mission critical materiel, services and information with minimal infrastructure, manpower and costs.



Laboratory Locations









- Aviation product testing:
 - JP-5, JP-7, JP-8, JPTS, JP-10, Jet-A, RP-1, PF-1, aviation gas
 - Diesel fuel, heating fuel, mogas, E-85, biodiesel fuel
- Packaged petroleum products & chemicals
 - Lubricating oils
 - Hydraulic fluids
 - Greases
 - Corrosion prevention compounds
 - Aircraft cleaning compounds
 - Anti/Deicing fluids



Hydraulic Fluid (Responsibilities)



- T.O. 42B2-1-3, Fluids For Hydraulic Equipment
- Hydraulic Fluid Testing
- International Coordination







Scope

Cover the types, use, quality control, and disposition of used hydraulic fluids

Purpose

Clarify the use and disposition of hydraulic fluid used in the Air Force inventory





7

- Lot Acceptance (for DLA)
 - MIL-PRF-83282
 - MIL-PRF-5606
 - MIL-PRF-87257
- Shelf-Life Extension
 - DLA (SLES)
 - AF (Shelf-Life/Retest)
 - T.O. 42B-1-1
- A/C Incident / Mishap



Hydraulic Fluid Testing (Sampling)



- Results Only Good As Sample Received
 - Sampling is Critical
 - Sample Technique
 - Container Cleanliness
 - Questionable Receipts
 - Samples are received with fuel smell
 - Over packed in vermiculite





- Air and Space Interoperability Council (ASIC)
 - Air Std 15/03 Minimum Quality Surveillance Petroleum Products
 - Air Std 15/04 Allowable Deterioration Limits for Stored Fuels, Lubricants and Associated Products
 - Air Std 15/07 Guide Specifications for Petroleum Base (H515 & C-635) & Polyalphaolefin (H-537, H-538 & H-544) Aviation Hydraulic Fluids
 - Air Std 15/09 Interchangeability Chart of Standardized Aviation Furls Lubricants and Associated Products





- North Atlantic Treaty Organization (NATO)
 - STANG 1110 Deterioration Limits for NATO
 Armed Forces Fuels, Lubricants and Associated Products
 - STANG 1135 Interchangeability of Fuels, Lubricants and Associated Products used by the Armed Forces of the North Atlantic Treaty Nations







- DLA Privatization
 - Acceptance Testing
 - Shelf-Life
 - Depot Storage
 - USAF Storage
 - WRM
- Joint Tech Order
 - Aviation Hydraulics Manual



Joint Service Hydraulics Manual

Military Aviation Fluids and Lubricants Workshop 20-22 June 2006

Megan Goold AIR-4.9.7.2 Naval Air Depot Cherry Point NC

NAVAIR Public Release 06-0028, Distribution A – Approved for public release; distribution unlimited





Overview

- Purpose
- History
- Current/Future Events
- Final Product
- Points of Contact





Purpose

 Develop a Multi-Agency Joint Series Working Group to establish a multi-agency aviation hydraulics manual.









History

- February 18, 2005 Preliminary Plan of Action and Milestone (POA&M) sent to team members
- May 25-26, 2005 Joint General Series Working Group Meeting
- November 11, 2005 Preliminary draft of NAVAIR 01-1A-17 distributed for gap analysis





Current/Future Events

- May August 2006 : Data incorporation and final review
- September 2006: Publication and Distribution





Final Product

- Joint Service Hydraulics Manual
 - NAVAIR 01-1A-17
 - T.O. 42B-1-12
 - TM 1-1500-204-23-2
- 17 Work Packages

 Joint Packages
 Navy Use Only





Points of Contact

Navy Megan Goold, NAVAIR-4.9.7.2, Cherry Point, NC, 252-464-9767

Air Force

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Ed Snyder, AFRL/MLBT, Wright-Patterson AFB, Ohio, 937-255-9036

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ELIMINATION OF BARIUM CONTAINING FLUIDS IN DoD AIRCRAFT SYSTEMS

Lois Gschwender AFRL/MLBT WPAFB



ELIMINATION OF BARIUM CONTAINING FLUIDS IN DoD AIRCRAFT SYSTEMS

Outline The problem Background Program matrix Results Jar tests Pump tests Summary



The Problem

- DoD has traditionally used fluids containing barium dinonylnaphthalene sulfonate (BSN) for component storage.
 - Spent fluid is a hazardous waste
 - Documented problems of operational aircraft with BSN contamination
 - Army helicopters
 - Navy F-18s
 - Air Force T-38
 - Logistics/footprint







The Problem

- T.O. 42B2-1-3 formerly described storage and shipping with rust inhibited fluid and then flushing and draining with the operational fluid prior to use.
- Some parts cannot have all of the rust inhibited fluid drained.
- The fluids look the same so draining may not be done.



Background - Definition of Fluids

- The rust inhibited fluids contain $\sim 3\%$ BSN (1500 ppm Ba). Stability $\leq 225^{\circ}$ F.
- EPA limit is 100 mg/l (120 ppm) water soluble Ba for hazardous disposal (EPA Handbook CFR, 261.24)

Base stock	Non-inhibited	Rust inhibited		
Mineral oil	MIL-PRF-5606	MIL-PRF-6083		
PAO oil	MIL-PRF-83282	MIL-PRF-46170		



Background

- Aircraft components were stored with 4 different fluids at the start of program *
 - MIL-PRF-5606: B1B, C-130, C-135, E-3, E-4, E-6, F-5, P3C, U2R
 - MIL-PRF-83282: F-110 (F-16, actuator), F404, H60, H64, S60
 - MIL-PRF-6083: C-5A/B, F-117, F16
 - MIL-PRF-46170: AV8, C17, S3A, F15, E2C, F18, H53, H60, S60, V22
- * Information from Parker Aerospace



Other reasons to change

- No documented reason for using inhibited fluid
- Component inventory going down short shelf time for components
- Logistics two fewer fluids in AF inventory

 "Footprint" reduction
- Cost savings charges from component suppliers and overhaulers



Hypothesis

Operational fluids work fine as component storage fluids

No documented part corrosion with operational fluids

Laboratory tests indicated synthetic fluids more corrosion resistant than MIL-PRF-5606



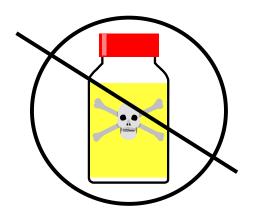
AF Suggestion - 1995

- F-22 will not use rust inhibited fluid in component/armament for less than one year storage
- Resistance in AF to eliminate storage fluid across the board
 - Concern about potential corrosion problems
 - No documented storage studies



Program

- Needed well planned storage program to validate hypothesis
 - Pollution Prevention program proposed and funded, FY00 to FY04





Program Test Matrix

- Queried MAJCOMs: HQ AMC, AFSOC/LG; SPOs, ASC, SSMs about test protocol
 - Real time storage, not heated to accelerate
 - Both rust inhibited and operational fluids
 - Submerged and drained parts
 - As received and water added to fluid
 - Room temperature and humidity monitoring
 - Component (pump) test after storage
- Two part program developed



- Selected corrosion- prone, 52100
 steel tapered bearings Timken
 Bearing Co.- and used F-16 pump
 pistons in jar storage
- Submerged parts
 - Two water levels
 - MIL-PRF-5606, 83282 and -87257 fluids, 100 & 350 ppm water
 - MIL-PRF-6083 and -46170 fluids, 220 and 400 ppm water
- Dip & drain parts
 - Higher water level only
 - Parts dipped, drained, then put into jars





Program Test Matrix, Part I

- Jar tests set up April 2000
 - Visual observations monthly
 - Jar with specific test conditions (fluid and water 200/400 ppm level) off yearly for three years
 - Dip and drain jars also observed





Program Test Matrix, Part II

- 3 year pump storage begun June and July 2000
- F-16 EPU pumps purchased for storage and then pump testing after storage
- Three fluids in stored pumps: MIL-PRF-83282, MIL-PRF-87257 and MIL-PRF-46170
- Water added to fluids, 300 ppm
- Constant measurement of temperature and humidity
- Post test examination, photography and analysis, as needed
- Pump tests conducted on certain pumps at 3 years



Results, Jar Tests



PART I JA	R TEST RE						
		Year					
Operational Fluids		1	2	3			
MIL-PRF-						Green = No change	
83282							
87257						Yellow = Slight stain	
5606							
						Red = Stain	
Storage Fluid	prage Fluids						
MIL-PRF-							
46170							
	Submerged						
	Dip & Drain				 		
6083							





MIL-PRF-46170, 215PPM WATER, STORAGE 2 YEARS



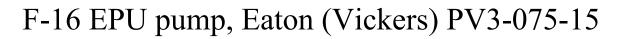


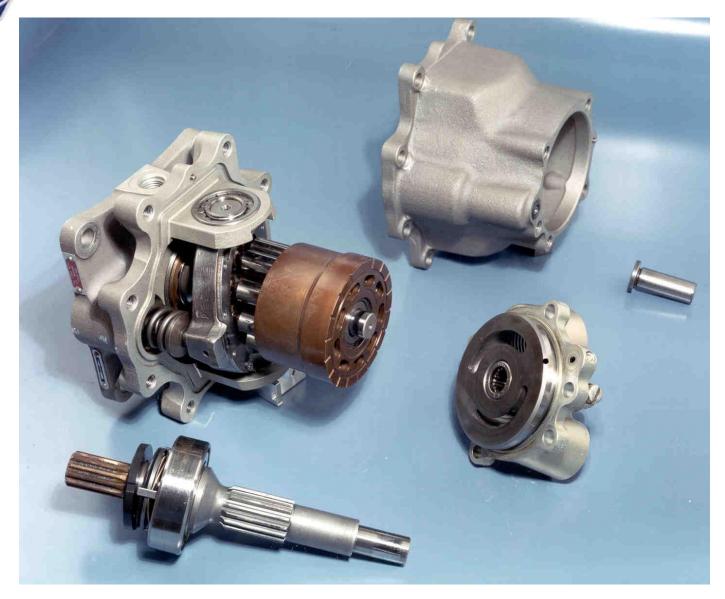
Jar Test Results Summary

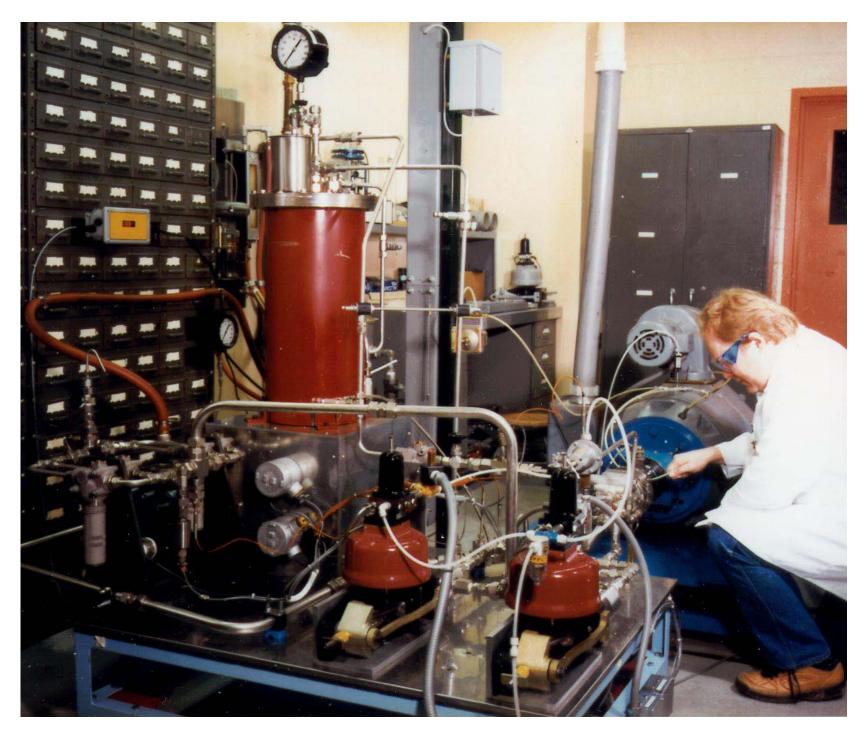
- Jar tests with
 - Operational fluid no changes
 - MIL-PRF-46170 staining
 - MIL-PRF-6083 no changes



Results, Pump Tests







Part II Pump Storage Results

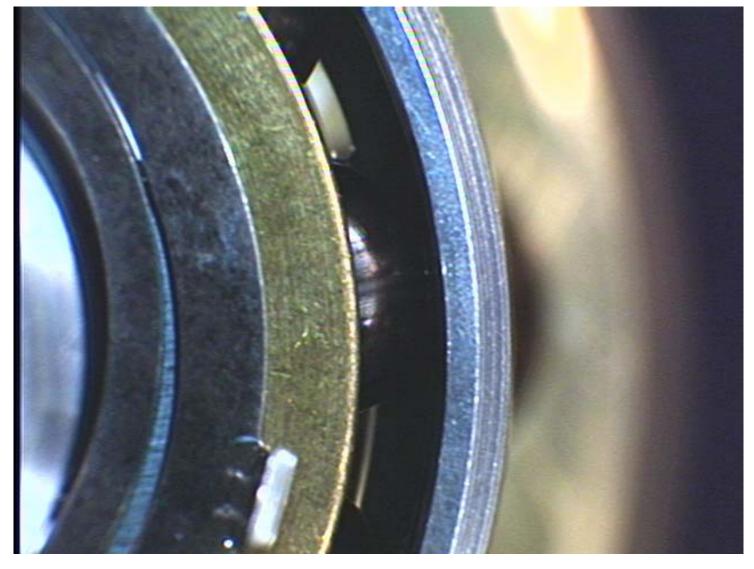
• 3 year pump storage begun June and July 2000 (300ppm water added)

PCE RESEARCH LABO

- Yearly inspection of MIL-PRF-83282 and MIL-PRF-87257 filled pumps - no changes
- Yearly inspection of MIL-PRF-46170 filled pump
 main bearing resisted turning, discoloration of metal, gel observed

MIL-PRF-46170 + 300 ppm water, 1 year storage





CHEMICAL REACTION MARKS ON SHAFT BEARING BALL



Part II Pump Results



- Pumps stored with 300 ppm water, drained and filled with fresh fluid
- MIL-PRF-83282
 - Run 500 hours
 - Teardown inspection showed little wear
 - Parts shiny



Part II Pump Test Results

- MIL-PRF-87257
 - Piston defect caused pump failure at 275 hours
 - No rust or other indication of fluid related problem
- Two more PV3075-15 pumps put into storage with MIL-PRF-87257 for 3 years to assure pump failure was an anomaly
- Since no corrosion was observed with MIL-PRF-83282 and MIL-PRF-87257, MIL-PRF-46170 stored pump was not tested



Pump Test Results

- Pump tests with
 - MIL-PRF-83282
 - Storage no change
 - Run 500 hrs, no corrosion
 - MIL-PRF-87257
 - Storage no change
 - Run 275 hrs, piston failure, no corrosion
 - MIL-PRF-46170
 - Storage, staining, rough turning, gel formed
 - Not pump tested



Summary

Expected Payoff / Summary

- Using operational fluid for component storage will
 - Reduce hazardous waste stream
 - Eliminate source of operational problems
 - Consolidate number of fluids used
- Storage program assures users that parts won't rust on the shelf
- Save charges passed on by component suppliers and overhaulers



Post Script



- Final technical report on storage program AFRL-ML-WP-TR-2004-4279
- Technical paper, <u>Trib. Trans.</u>, 1, 2006, by Gschwender, et al.
- Individual aircraft TO's are being changed
- Army and Navy also adopted use of operational fluid for component storage, based on ML work
- Specification for storage fluid MIL-PRF-46170, Type II has been cancelled – recommend using operational fluid when asked

US Army Hydraulic Contamination Control Program

Ken Wegrzyn HCCP Technical Lead & IPT Chair

In-Progress Report to USAF Hydraulic Contamination Workshop 21 June 2006



Hydraulics Contamination Test Evaluation Program

Objective of HHCP (initial):

- To understand the contamination control issues related to unexplained malfunctions of the controls and find a solution
- To reduce safety risk associated with malfunctions

Extended Objective:

- To improve mission readiness & reduce maintenance costs
- Reduce leakage rates which is one of the main reasons for aircraft downtime and maintenance activities based on 2410 data
- Improve the current 30+ year old MIL-F-8815 specification to include real operating conditions
- Update the current test procedures and insert state of the art technologies to insure repeatability of filter performance
- Develop Industry and Tri-service support to develop more robust filter element performance specs

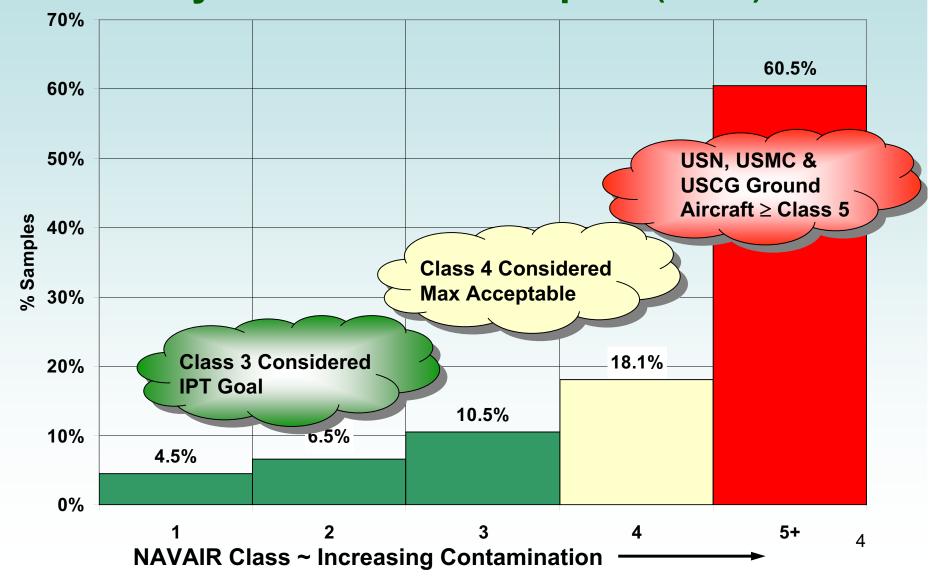


Plan of Attack

- Field sampling to assess the current condition of hydraulic fluid in aircraft
- Review aviation maintenance practices
- Review the current specs Mil-F-8815
- Review associated components that are sensitive to contaminants or affect the contamination levels in the system
 - Indicators
 - Servo valves
 - Filters themselves
 - Operating environment

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Army Helicopter Hydraulic Fluid Samples (FY01)





Field Induced Contamination





Contaminated Hydraulic Components

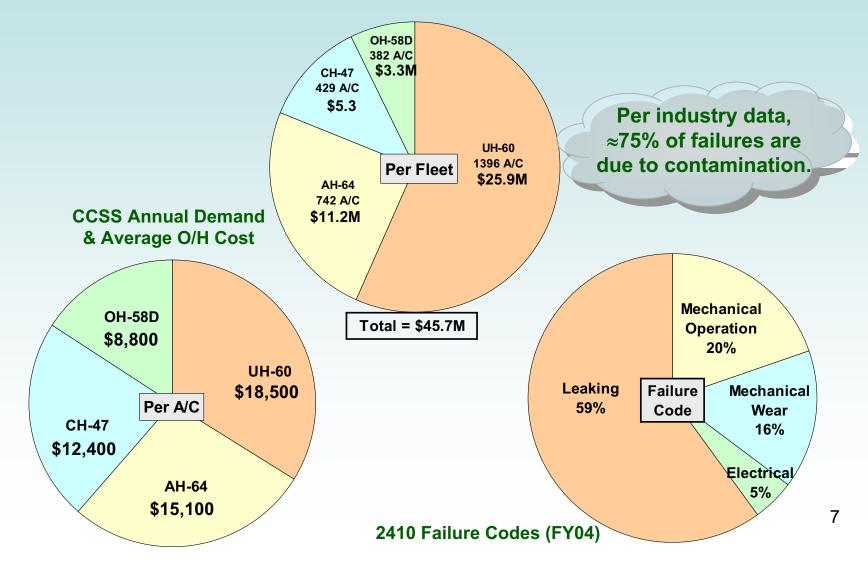


CH-47D Integrated Lower Control Actuator (ILCA) Components



Annual Helicopter Cost 26 Critical Hydraulic Parts

CCSS Annual Demand & Average Overhaul Cost (FY04)





Current Filtration is Ineffective

- Fiberglass element filters are effected by:
 - Changes in flow
 - Pump ripple
 - Filter Vibration/aircraft system induced
- These dynamic effects allow trapped contamination to re-enter flow stream.

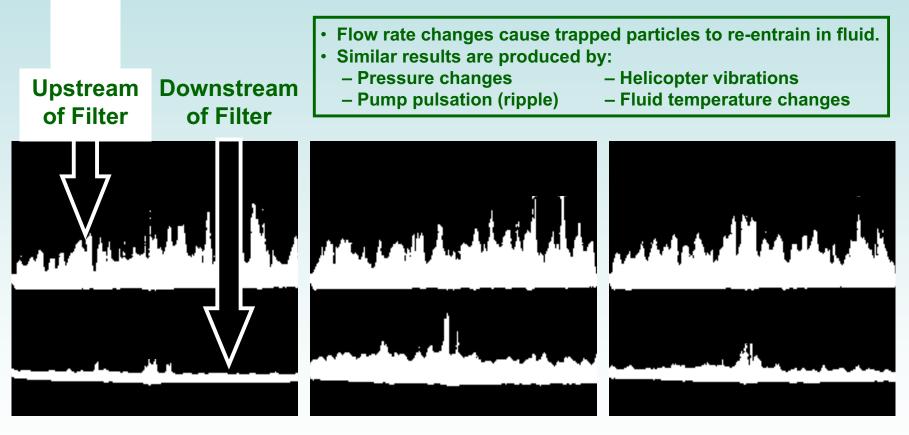
The smallest images displayed are 20 microns. Army helicopters have 5 micron 'absolute' filters.

CH-47D Sample (FY01)



Fiberglass Filters are Not Effective in Dynamic Environments

Dynamic Test at SSI (FY01)



Steady Flow (Nominal) Time: 0 - 30 Sec Increased Flow (1.5 x Nominal) Time: 40 Sec Steady Flow (1.5 x Nominal) Time: 80 Sec

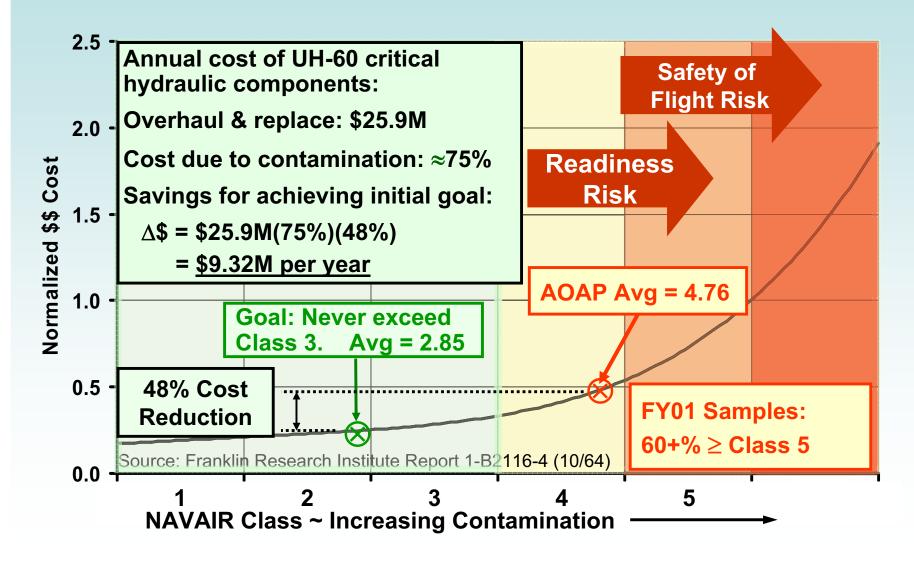


Characterizing Filters

Conducted Flight Test Contracted Testing & Acquired Hydraulic Test Instrumented CH-47D Hyd Sys Stand Actual Flight Conditions $\bigcirc \bigcirc \bigcirc \bigcirc \bigcirc \bigcirc$ Replicated Helo Filter Helo Hyd Sys Variations **Environment** – Pressure Varied Contamination – Flow Rate - Particulate - Ripple (Pulsation) - Water - Temperature – Air – Vibration **Quantified Benefits** Defined aircraft operating environment. Played back operating environment on test stands. Quantifying effectiveness. **Verifying Filter** • Determined potential ROI. Performance Monitoring performance of metal filters. (Metal vs Fiberglass) Pressure Flow Rate **Effectiveness & Trends** Ripple (Pulsation) Qualify Filter Fiberglass Filters Temperature Quantify Benefits Metal Filters Vibration



Safety and Economic Benefits of Improving Fluid Cleanliness





Actions Taken to Improve Fielded Aircraft Contamination Control

- Evaluated and implemented use of Pall hydraulic fluid purifier on CH-47.
- Evaluated, modified and demonstrated hand-pumped, filtered fluid dispensers (AGSE PM procured dispensers).
- Evaluated and demonstrated inline water monitor and particle counter (Monitored water and particulate contamination).





Actions Taken to Improve Fielded Aircraft Contamination Control

- Improved the cleanliness and serviceability of the Aviation Ground Power Unit.
- Evaluated and demonstrated AGPU end caps and 'runaround' block to keep hoses and fittings clean (AGSE PM procured aluminum fittings).
- Replaced 3 and 10 micron AGPU filters with 2 and 5 micron filter elements, respectively.







Hydraulics Contamination Test Evaluation Program

Objective of HHCP (initial):

- To understand the contamination control issues related to unexplained malfunctions of the controls and find a solution
- To reduce safety risk associated with malfunctions

Extended Objective:

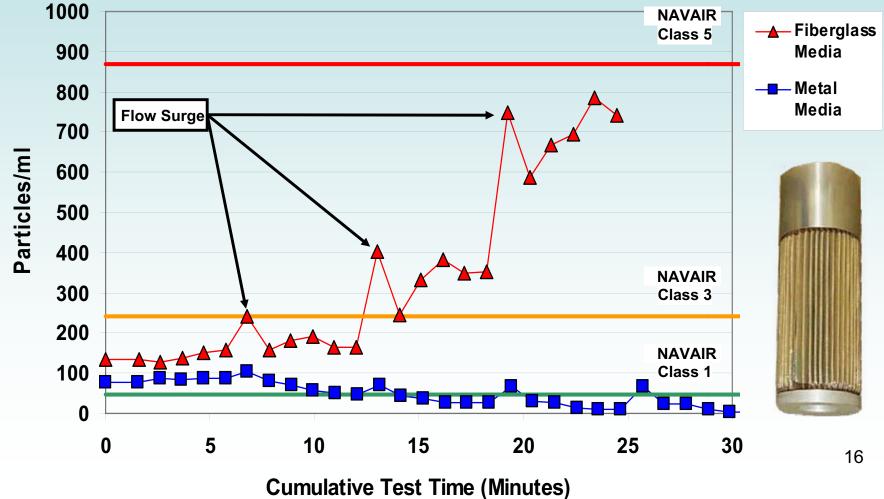
- To improve mission readiness & reduce maintenance costs
- Reduce leakage rates which is one of the main reasons for aircraft downtime and maintenance activities based on 2410 data
- Improve the current 30+ year old MIL-F-8815 specification to include real operating conditions
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- Develop Industry and Tri-service support to develop more robust filter element performance specs



Hydraulic Filter Testing

Particle Shedding Comparison of Fiberglass & Metal Filters NAVAIR Dynamic Test Results (FY02)

Downstream Particles Between 5 and 10 Microns





Hydraulic Filter Testing

- How well do the present filters perform using current specs?
 - All filters pass current MIL-F-8815 spec
 - We still have high usage rates on critical hydraulic components and issues with high leakage rates and high maintenance on pumps and actuators which are sensitive to contamination
- Some bench test data and field oil samples data suggest that we may have worse than normal cleanliness levels in aircraft during helicopter working conditions
 - Do we have bench test data?
 - Is there a more robust filter that is cost effective?
 - Can we separate more robust filters from non-robust filters using any approved /published test procedure?
 - If not, does it require a new test procedure?
 - Is there one test procedure available in the industry that truly replicates Army's environment?
 - Is the test procedure easily repeatable at other labs?
 - Do we rank filters based on realistic environmental test or assumed test conditions. Is this verifiable?

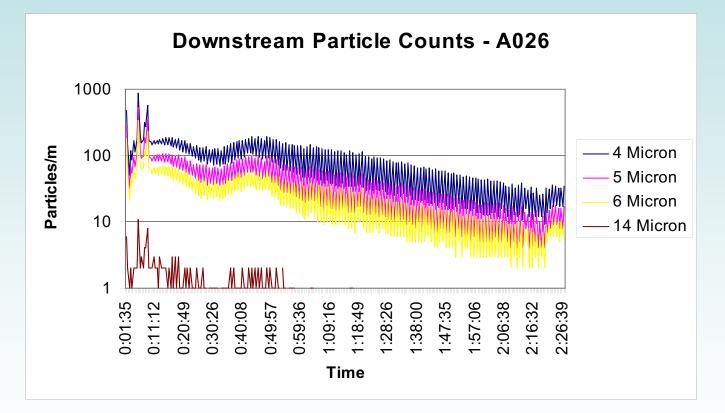


Tests Performed

- 628 Bubble Point Tests
- 231 Immersion Tests
- 155 Cold Start Tests
- 11 Flow Fatigue Tests
- 11 Collapse Tests
- 9 Media Migration Tests
- 34 ISO-23369 Cyclic Multi-pass Tests
- 18 ARP-4205 Dynamic Response Tests
- 46 DFE Tests
- Total Tests \rightarrow Over 1143

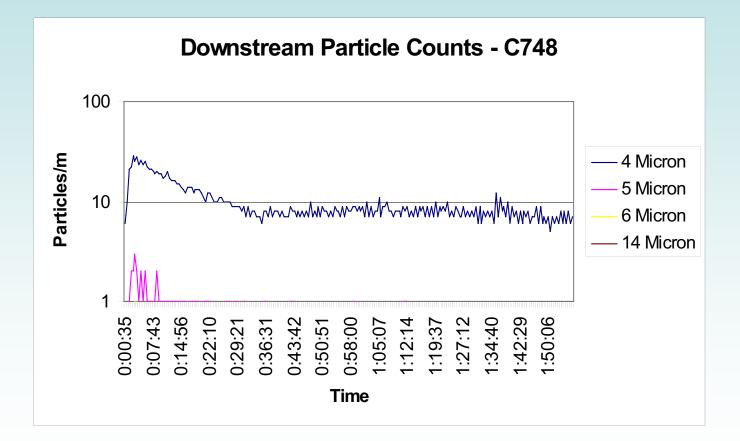


UH-60 Current Filter Performance



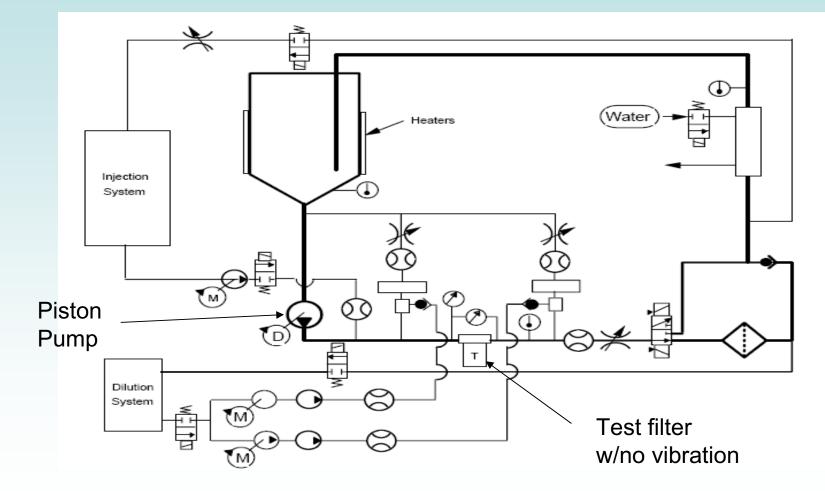


UH-60 Vendor 2 Filter Performance





DFE®-Dynamic Filter Efficiency Test



DFE trademark of SSI Labs,

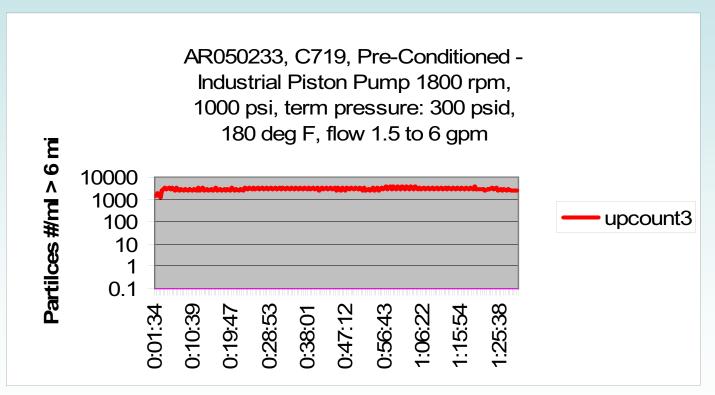
121



Upstream Challenge Maintained Constant For DFE Filter Test Duration

Upstream Counts vs Time

DFE Tests W/O Vibration

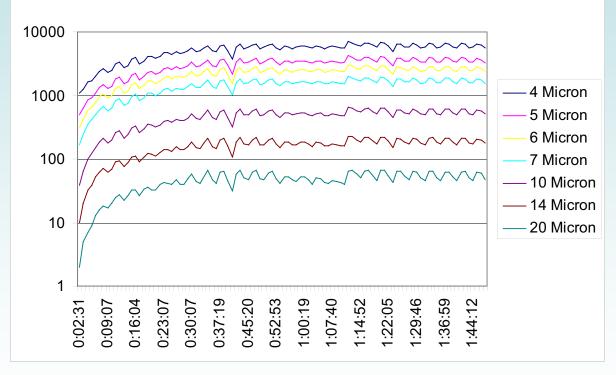




Validation DFE w/o Vibration Tests

Downstream Counts Follow 3mg/I Upstream Challenge 1.5 to 6 gpm, 1000 psi upstream, 300 psid,175 deg F

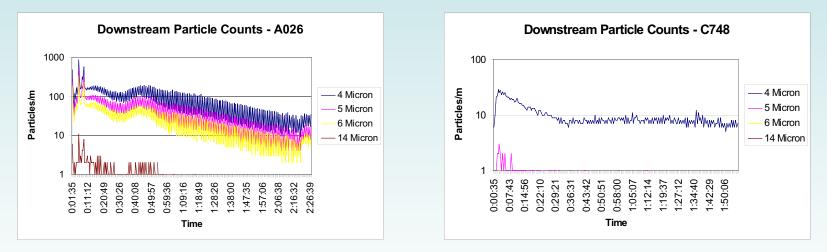
Downstream Particle Counts - Validation



AR050141



Comparison of DFE w/o Vibration Typical Results UH-60 Filters BM vs Robust Media



Bill of Material

Robust Media

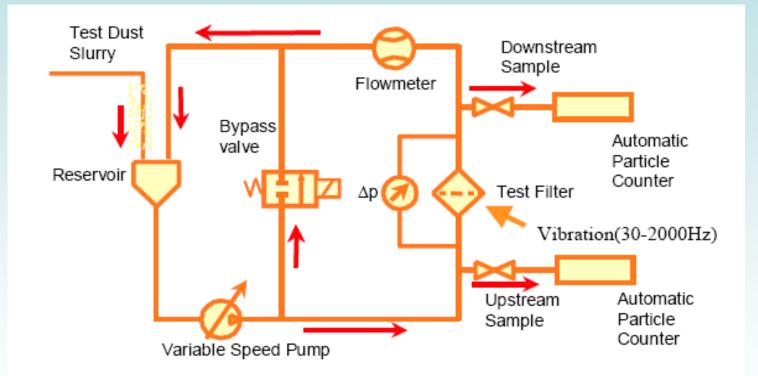


Courtesy SwRI



Cyclic Efficiency Test

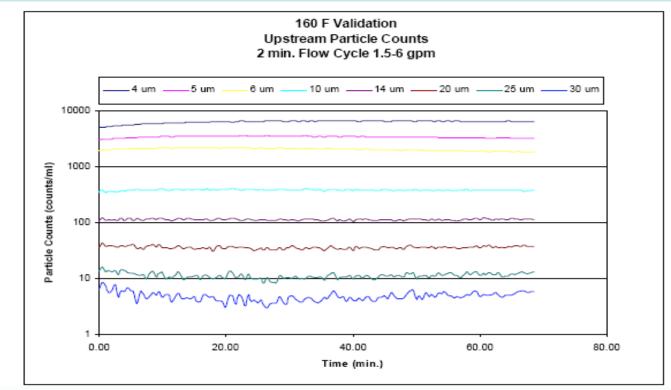
w/Vibration,160 Deg F, ISO-23369 & SAE-4205





Validation Under Dynamic Conditions ISO-23369 w/ Vibration And 160 Deg F Upstream Challenge Maintained Constant

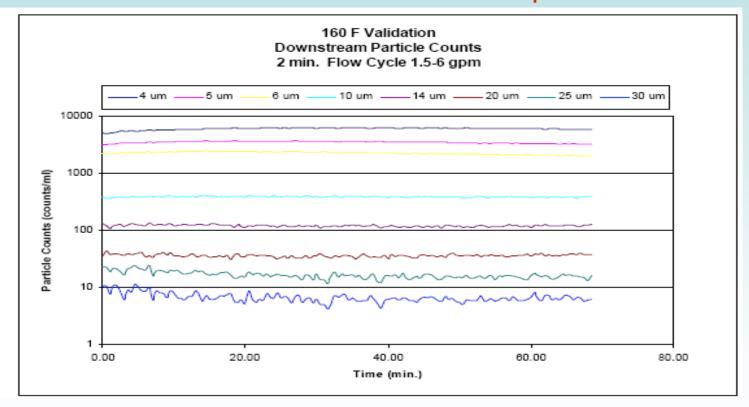
3mg/l - 1.5 to 6 gpm - 4 min cycle.



Tested at SwRI @ 3 mg/liter



Validation Under Dynamic Conditions ISO-23369 w/ Vibration And 160 Deg F Downstream Follows Constant Upstream Challenge



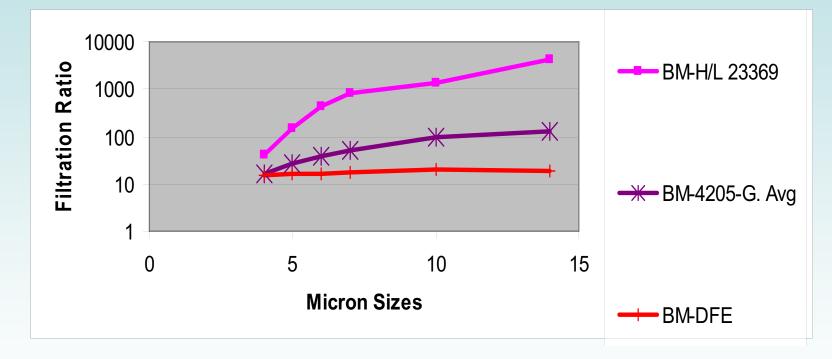
Tested at SwRI @ 3 mg/liter



Micron Sizes at 99.5 % and 99.9 % Efficiency ISO 23369 vs SAE 4205 vs DFE MIL-F-8815 (Current Filters)

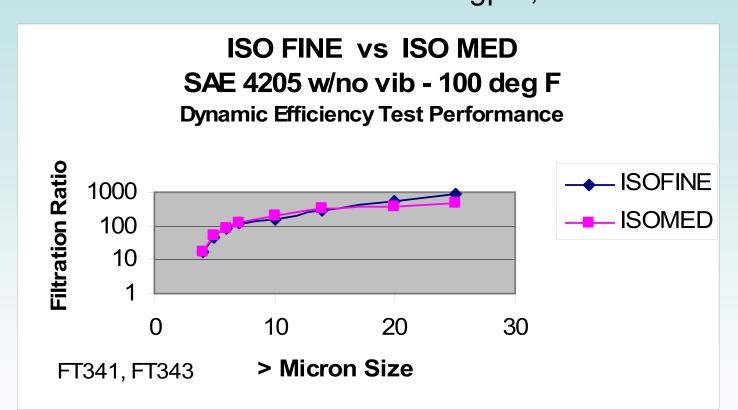
	SAE 4205	ISO 23369 w/Vibration			DFE w/no
Efficiency	w/vib	High to Low	Low to High	Avg. (Alpha)	vib
99.5%	15.88	5.27	4.68	4.35	14.42
99.9%	20.58	8.27	6.22	5.77	>20

Comparison of Test Methods 23369 w/vib vs 4205 w/vib vs DFE MIL-F-8815 Qualified Element



BM: Bill of Materials - Current Filters





No Measurable Efficiency Difference

Test Location: SwRi

BM: Bill of Materials



Future Action Plan

- Replace ISO Fine Test Dust with ISO Medium in SAE 4205. The answers are approximately the same with the more widely used ISO Medium dust
- Mil-F-8815 and Dynamic Test Procedures require some improvements - Army testing revealed deficiencies
 - Corrected them in Army testing
 - All of them can be improved w/o major cost penalty
 - All improvements have positive impact on repeatability
- Review the test procedures and conduct round-robin tests to zero-in on right test conditions for dynamic filter testing
- Vibration should be considered as a candidate in dynamic testing



Metal Media Filter Qualification Effort

- Completed Dynamic Filter Efficiency (DFE) Testing at Scientific Services, Inc. (SSI)
 - Test status & results being reviewed
- Completed Testing at Southwest Research Institute (SwRI)
 - MIL-PRF-8815D
 - ISO 23369
 - SAE 4205
- Performed Comparison of Filter Element Performance
 - Significant Improvement Shown with Robust Media Filter Elements
 - Plan to conduct field validation on selected robust filter elements to assess the improvement



Path Ahead

- Complete hydraulic test stand data analysis
- Qualify metal media filters for use in aircraft
- Obtain Flight Test Data at ATTC Ft. Rucker for new Robust media filters on UH-60/AH-64 and CH47
- Develop Mil Std or SAE spec for dynamic filter testing
- Update model to track HCCP O&S cost savings
- Quantify current HCCP cost savings
- Complete AED/RTTC hydraulic filter test stand (HFTS) validation/operation/performance
- Improve AGSE to include particle counters/water sensors



AED HCCP Opportunities

- Create an AED/RTTC Hydraulics Center-of-Excellence.
- Leverage in-house T&E capability to identify and implement improvements in hydraulic system cleanliness.
- Develop the infrastructure to support Army Aviation platform stakeholders in improving safety, readiness, and cost.
 - PMs
 - AED/HCCP IPT
 - Warfighter



Questions?



Army Tests

BACK-UP SLIDES





Air Force Hydraulics Activity Tinker AFB

Mel J. Louthan 848 CBSG/ENWH Tinker AFB OK

Tinker AFB Hydraulics Activities



- Depot Conversion to MIL-PRF-83282
- F-16 Hydraulic System Conversion to 5 Micron Filtration
- Engine-Driven Hydraulic Pumps
- Hydraulic Filter Testing

Tinker AFB Hydraulics Activities



- Depot Conversion to MIL-PRF-83282
 - Upon cancellation of MIL-PRF-46170 shop converted to MIL-PRF-83282
 - Most test equipment working with no noticeable change in performance
 - Hydraulic Pump Shop has three test stands that work the fluid very hard at high temperatures
 - Hydraulic fluid appears to "break down" and becomes discolored
 - Additional testing will be performed to determine what is occurring with the hydraulic fluid

Tinker AFB Hydraulics Activities



- F-16 Hydraulic System Conversion to 5 Micron Filtration
 - Hydraulic system originally had 15 micron elements
 - Condition of returned hydraulic components highlighted need to improve filtration
 - Study conducted to determine effects of reducing the filtration level to 5 microns
 - No adverse impact to the system was noted
 - After approval DLA initiated initial buy
 - No stock was on-hand of the 15 micron elements
 - Returned hydraulic assets after implementation show marked improvement in wear surfaces
 - Looking to Implement on other USAF platforms
 - Currently investigating F-15

Tinker AFB Hydraulics Activities



Engine-Driven Hydraulic Pumps

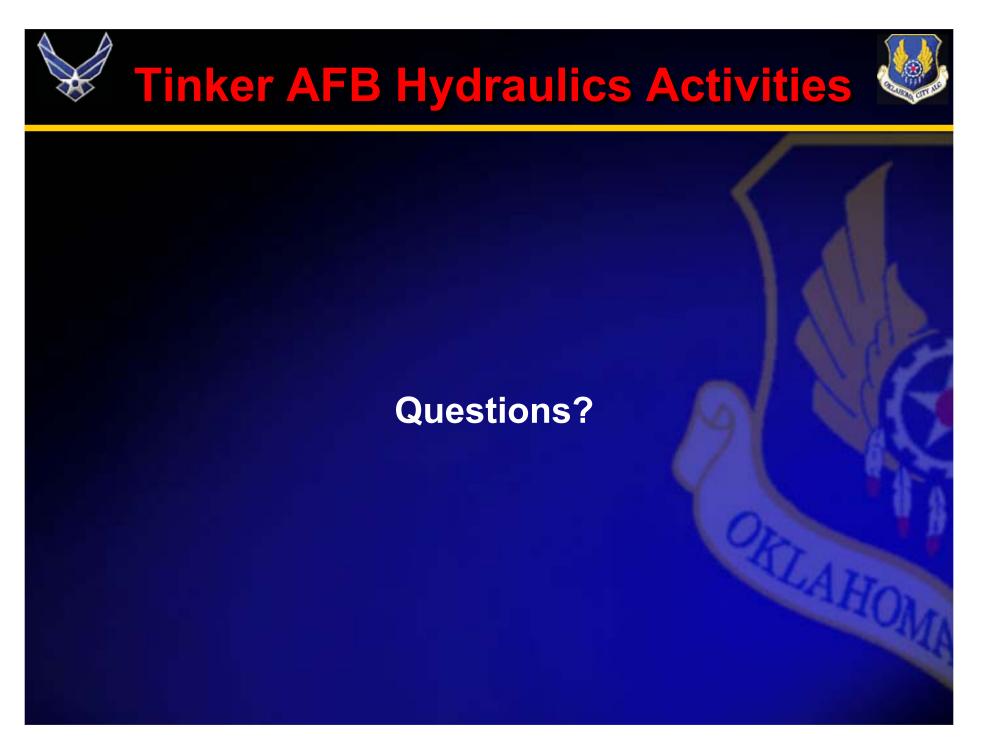
- Failure trend indicates three primary failure modes
 - Case Overpressurization
 - Cavitation
 - Pump Overheat
- Case Overpressurization
 - Front housing split
 - No change in material properties
- Cavitation
 - Piston Shoe exhibits evidence of cavitation damage
 - Cylinder Block occasionally has cavitation damage
 - Implementing case drain bleed process
- Pump Overheat
 - Some returned pumps exhibit evidence of heat discoloration

Tinker AFB Hydraulics Activities



Hydraulic Filter Testing

- Project is to determine new test media and test procedures for USAF performance specifications
- Efforts underway to equip an independent test facility (ARINC)
- Test plan is being developed
 - All currently qualified elements will be tested
 - Initial draft of test plan has completed review
 - Final test plan will be coordinated with industry
 - Test plan based on SAE variable flow testing document
 - MIL-PRF-83860, MIL-PRF-83861, and associated QPLs will be updated



An In-Line Aircraft Pump Health Monitoring System



Shashi K. Sharma, PhD

Air Force Research Laboratory, Wright-Patterson AFB Ohio, USA <u>Shashi.Sharma@wpafb.af.mil</u> (937) 255-9029

Bruce R. Pilvelait, PhD CREARE, Inc., Hanover, New Hampshire, USA brp@Creare.com (603) 643-3800

20 June 2006





Need for health monitoring of hydraulic pumps
 Concept Overview
 Pump Health Monitoring System (PHMS) status

 Initial development under Air Force SBIR Program
 Adaptation to Army pump

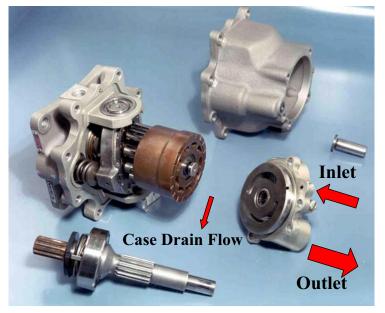
➤ Summary

Need for health monitoring of hydraulic pumps



3

- Hydraulic pumps are critical for aircraft safety
- Catastrophic pump failure can result in
 - loss of aircraft
 - contamination of entire hydraulic system
- Interval pump replacement results in unnecessary maintenance





Knowledge of impending pump failure will increase safety, reliability, & readiness and will reduce maintenance





> Noise

Vibrations

- Large amount of data needed to sort out various frequencies
- Placement/performance of sensors is an issue
- ➢ Oil Analysis particles, chemistry
 - Not very effective for hydraulic systems
- ► Variations in input signal





Motor current and voltage – limited to motor driven pumps

>Variations in output signal

Pressures, Flows, Temperatures





Symptoms of a failing pump

- Pump Noise
- Case drain flow increases
- Case drain temperature rises
- Pressure and flow fluctuations





Barrel Roller Bearing

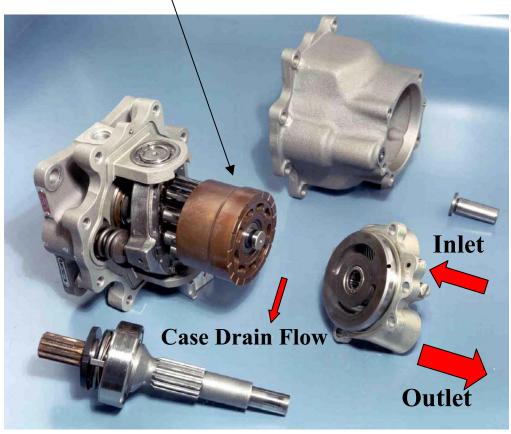


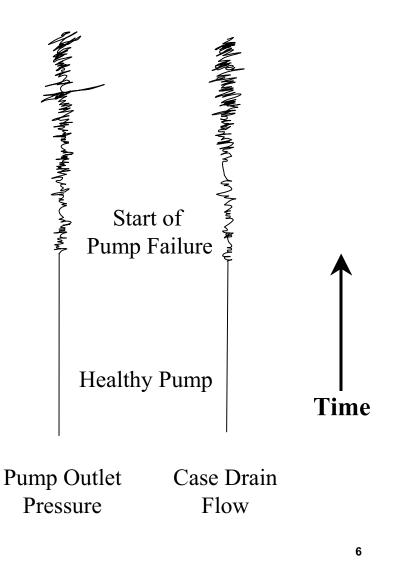
Ball Bearing





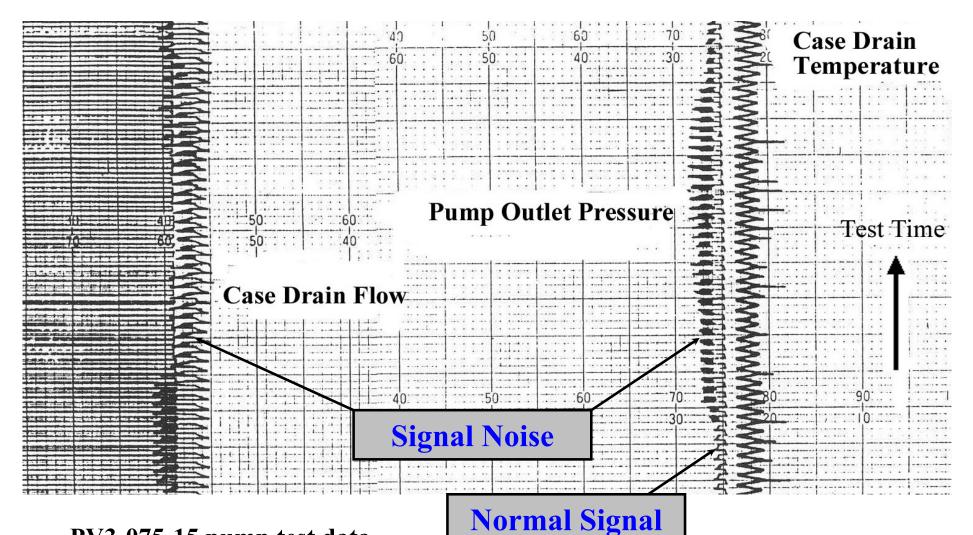
• When pump is nearing failure, case drain flow and pump outlet pressure signals exhibit **high frequency noise** - thought to be due to wobbly motion of the <u>shaft/cylinder-block</u>



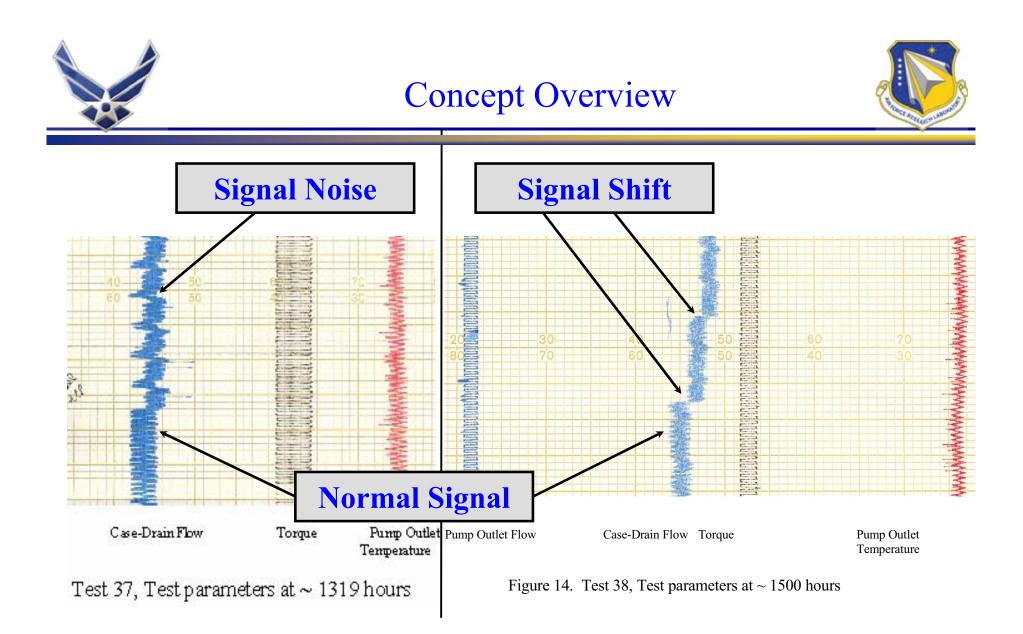




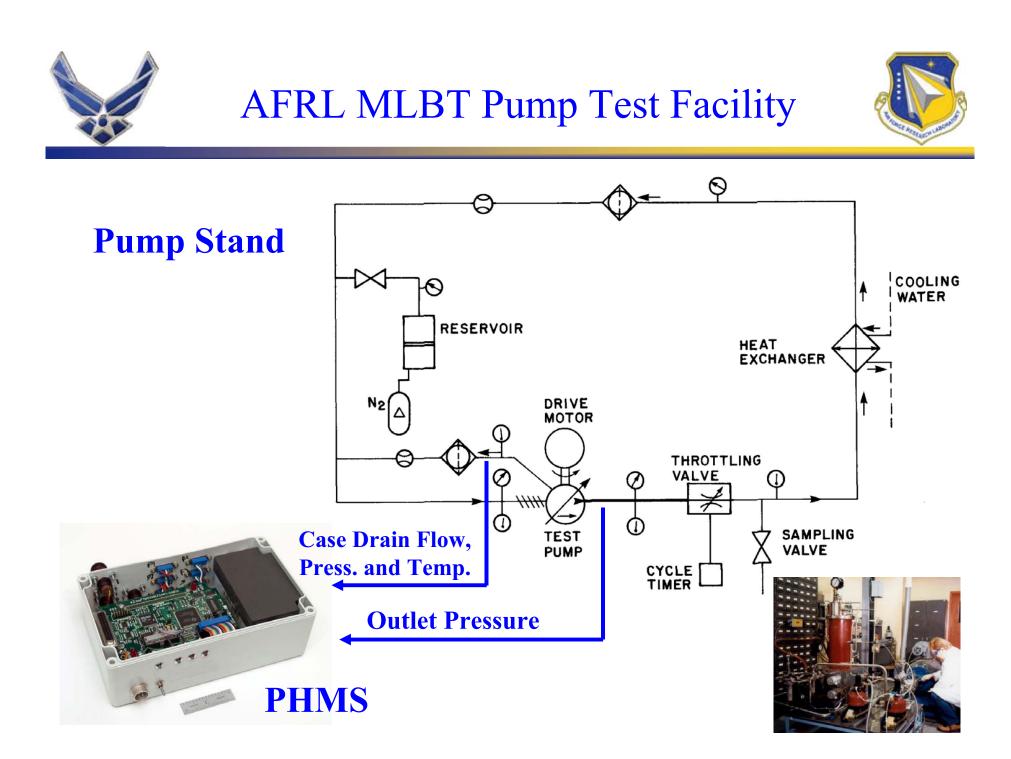




PV3-075-15 pump test data



ABEX model AP12V-17 test data

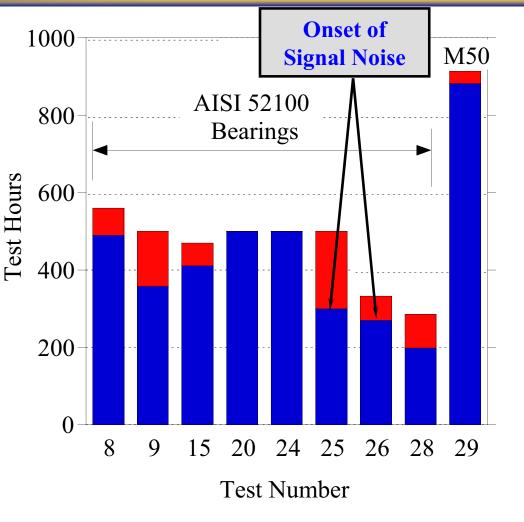






After the onset of signal noise, the pump still has ~10% of its remaining useful life

• In-line monitoring system being developed to predict pump failure based upon this concept



Onset of Bearing Failure in CTFE Pump Tests





Need for health monitoring of hydraulic pumps
 Concept Overview

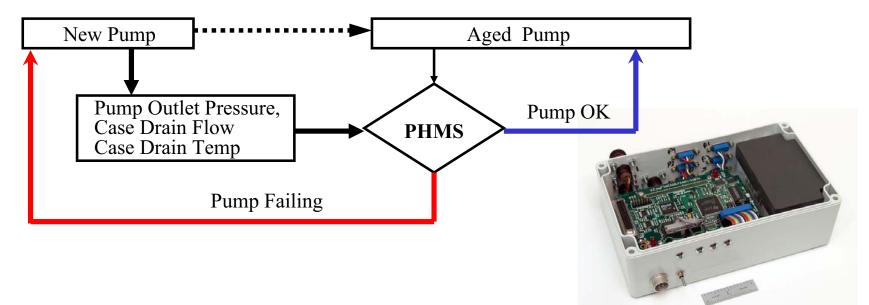
- Pump Health Monitoring System (PHMS) status
 Initial development under Air Force SBIR Program
 Adaptation to Army pump
- > Summary

Overview

- Goals of this program
 - Develop an in-line monitoring system (aircraft)
 - Utilize easy to observe signals
 - Diagnose failures in real time, in-situ
 - Allow for a future prognostic capability
 - Our approach
 - Demonstrate feasibility with simulations and a prototype (done)
 - Gather seeded fault data to refine prototype (done)
 - Use AFRL pump test data
 - Use commercial pump data
 - Finalize embedded prototype (final tests pending)
 - Evaluate a broader selection of pumps (in process)

1

Greate Initial Development



PHMS (Pump Health Monitoring System) acquires and stores the baseline characteristics of a new pump

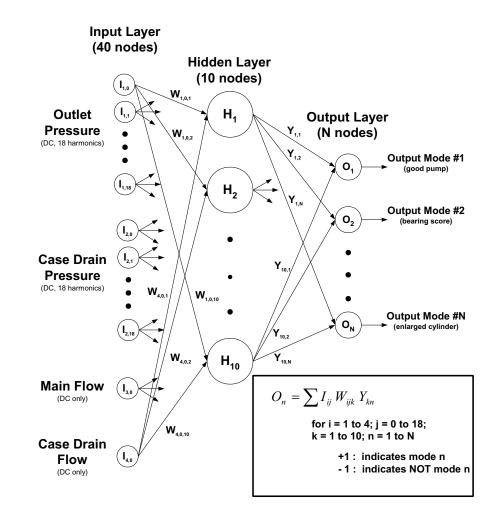
 \succ As the pump ages, PHMS algorithms continually compare the pump characteristics to the baseline and determine health of the pump

➤ Can be used as a stand-alone or integrated into the Vehicle Health Management System

157

2

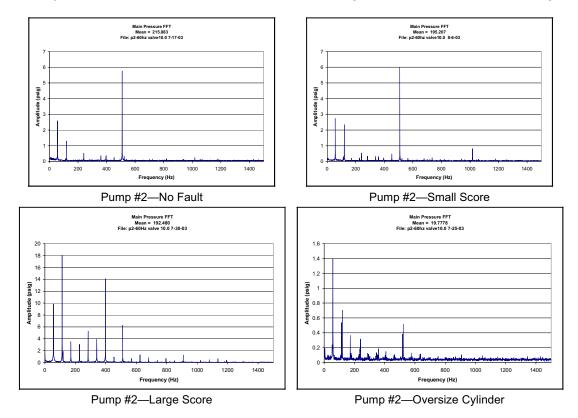
Initial Development: Software Algorithms



Initial Development: Phase II Results

- Parker Industrial Hydraulic Pump
 - PVP16 pump (3,000 psi, 8 gpm, 3,000 rpm, 17 hp)
 - Successfully classified bearing faults and cylinder erosion using seeded faults
 - Used these tests to establish algorithms
- Eaton Aerospace Aircraft Pump
 - Using MLBT test facility and PV3-075-15
 - Successfully classified bearing faults
 - Identified cavitation-induced erosion of port plate
- Parker-Abex Aircraft Pump
 - Pending: components and facility availability
- Developed embedded PHMS module
 - Sensors, hardware, software

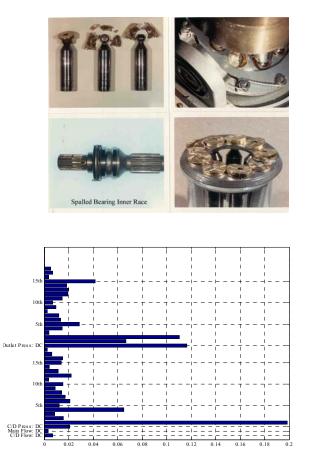
Typical Pump Data (83 Hz Drive)

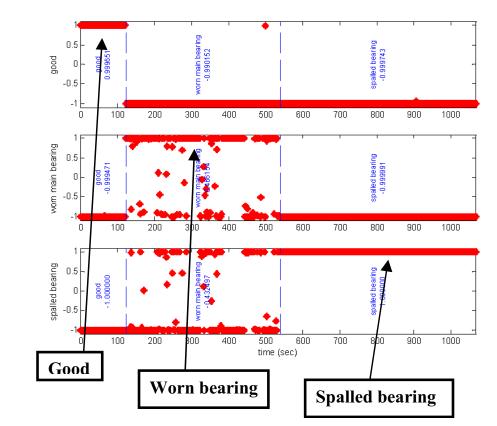


Rotational harmonic frequencies vary with pump state.

Greare & DEVELOPMENT

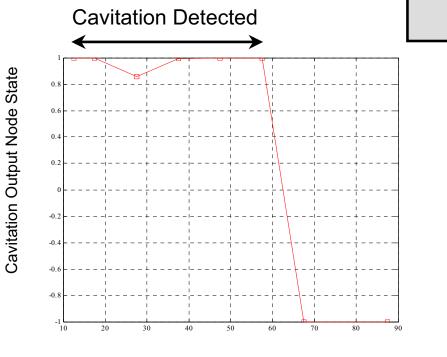
Eaton Aerospace (Vicker's) PV3-075-15





Training weights show important features

Eaton PV3-075-15 Pump Cavitation Detection



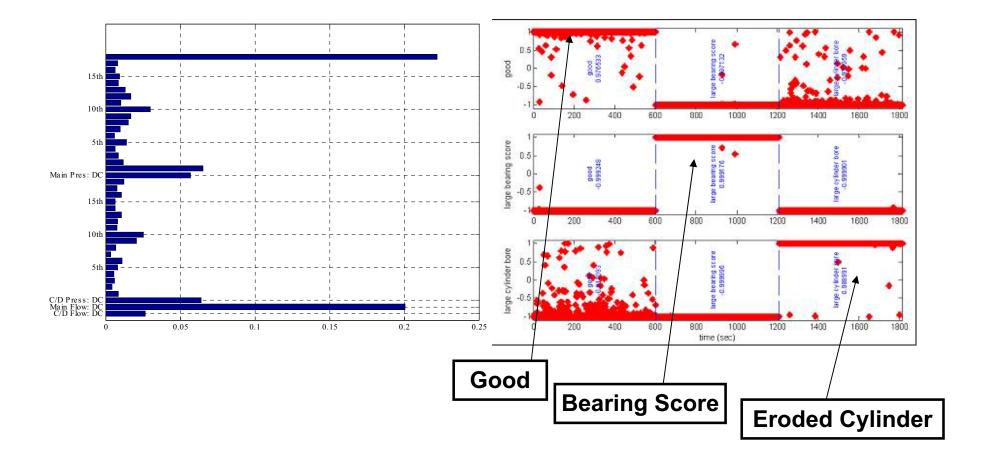
Inlet Pressure (psig)



PV3-075-15 Cylinder Block Face

Greare * DEVELOPMENT

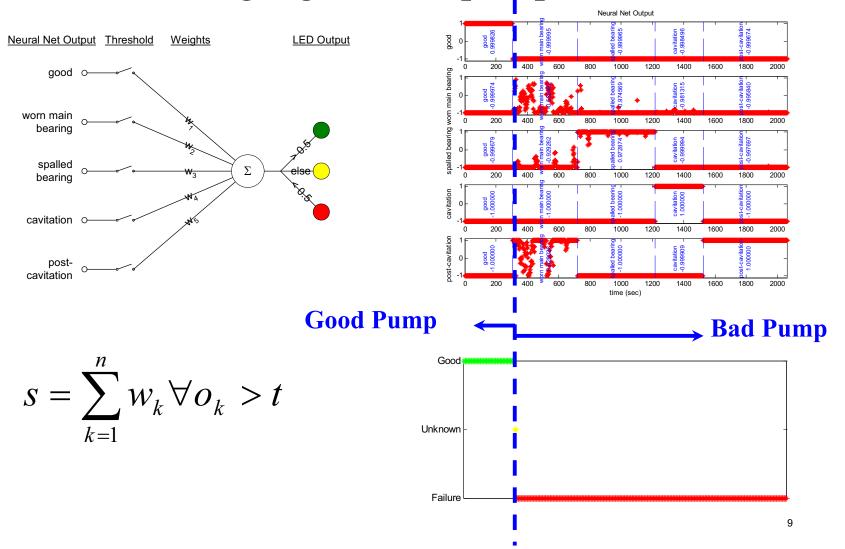
PVP16 Industrial Pump Results



8

Greare & DEVELOPMENT

Creating a good/bad pump classifier



Adaptation to Army Pump

- Co-funded by U.S. Army and Air Force OSD
- Investigating applicability to Army's PV3-075-20 pump
- PV3-075-20 is similar to PV3-075-15
 - Mounting hardware
 - Other changes to suit aircraft installation
- Thus far we have tested good and rebuilt pumps
- Results include:
 - PV3-075-15 algorithms work with PV3-075-20 pumps
 - Good and rebuilt pumps classified as good
 - Good and rebuilt pumps can be discriminated (if desired)

Further work on piston shoe and other failures pending

Greare & DEVELOPMENT

Phase II SBIR Follow-on Work

Output Node	Output Node Value
Good	+0.32
Worn Bearing	-0.99
Spalled Bearing	-0.97
Cavitation	-0.99
Post-Cavitation	-0.42

Output Node	Value
Good	+0.73
Worn Bearing	-0.99
Spalled Bearing	-0.83
Cavitation	-0.95
Post-Cavitation	-0.12

New PV3-075-20 Pump

Rebuilt PV3-075-20 Pump

Result #1: The **existing algorithms** correctly classify the **new** and **rebuilt** PV3-075-20 pumps as being similar to the **good** PV3-075-15 pumps.



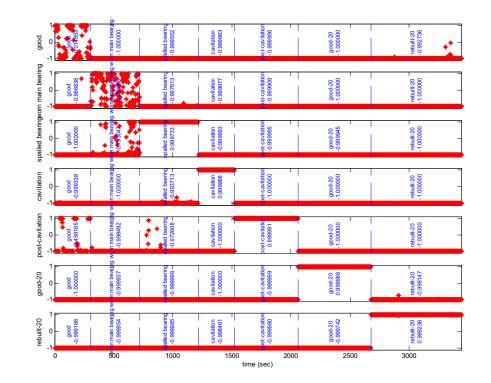
New (92 % Certainty)

Rebuilt (85 % Certainty)

Result #2: The optimizer provides a clear indication that the pumps are "good".

Greate a development

Phase II SBIR Follow-on Work



Result #3: New **algorithms,** with the new data included in the training, can now correctly classify all the PV3-075-20 and PV3-075-15 pump states.

Greare & DEVELOPMENT

Transition Path

• Two possible paths

≻Via airframe manufacturers or operators

➢Via pump manufacturers

• Possible output types

≻Annunciator

► Wireless/wired PHMS data to ground support

▶1553 bus data interface to VHM

• Other user applications

≻Piston pumps such as fuel pumps

≻Neural networks can be applied to other health monitors

Greare & DEVELOPMENT

Summary

• In-line health monitoring of aircraft hydraulic pumps

- > A concept based on pressure and flow fluctuations developed
- > Monitoring system under development using the SBIR contract
 - ✓ Bearing failures successfully detected
 - ✓ Adaptation to Army pump successful thus far (work ongoing)

• Impact

- Replace pumps for cause paradigm shift
- > Improved safety, reliability, readiness & maintainability
- > All systems impacted: DOD, Airlines and Industrial
- > Adaptable to other piston pumps (e.g. fuel pumps)

Aging Aircraft Systems Squadron

Dominant Air Power: Design For Tomorrow...Deliver Today

Hydraulic Fluid Purification OVERVIEW June 2006



U.S. AIR FORCE

Al Herman ACSSW/AASS/OB DSN 785-7210 Ext 3915 Email: Alan.Herman@wpafb.af.mil

Keep'em flying & Keep'em relevant



Overview



Dominant Air Power: Design For Tomorrow...Deliver Today

- Aging Aircraft Systems Squadron
- HFP Team / Background
- History
- Air Force Qualifications
- Purification Equipment
 - Pall
 - Malabar
 - Contamination Multi Sensor





Dominant Air Power: Design For Tomorrow...Deliver Today

Our Mission

The Aging Aircraft Systems Squadron develops and fields products that enhance USAF aircraft fleet availability and mission capability while reducing total ownership cost.

Our Objective

Our job is to develop, acquire, and field cross-enterprise materiel solutions that enhance fleet availability and mission capability. We deliver systems/products that provide the AF means to reduce total ownership costs.

Our Customers

ACC, AETC, AFMC, AFRC, AFSPC, AFSOC, AMC, ANG, PACAF, USAFE, and the ALCs





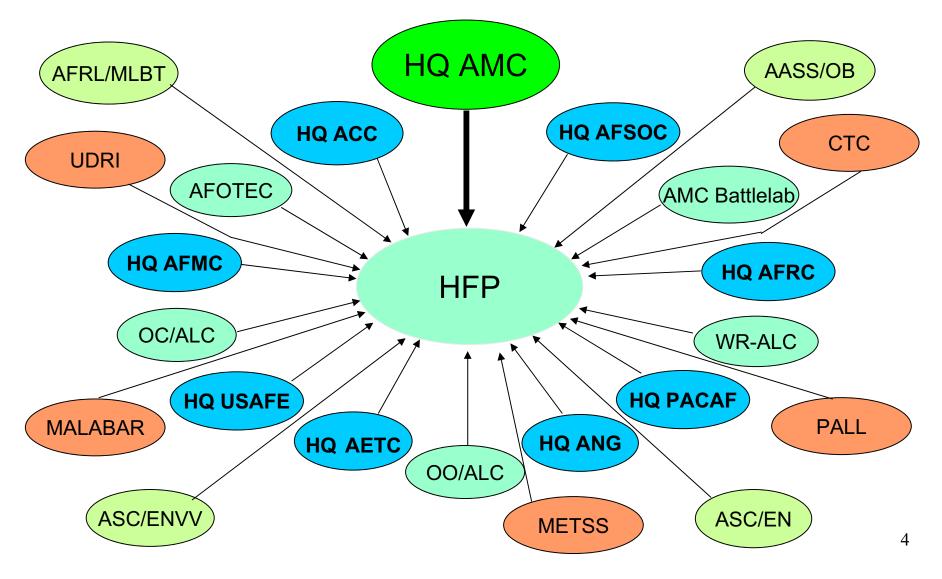








Dominant Air Power: Design For Tomorrow...Deliver Today

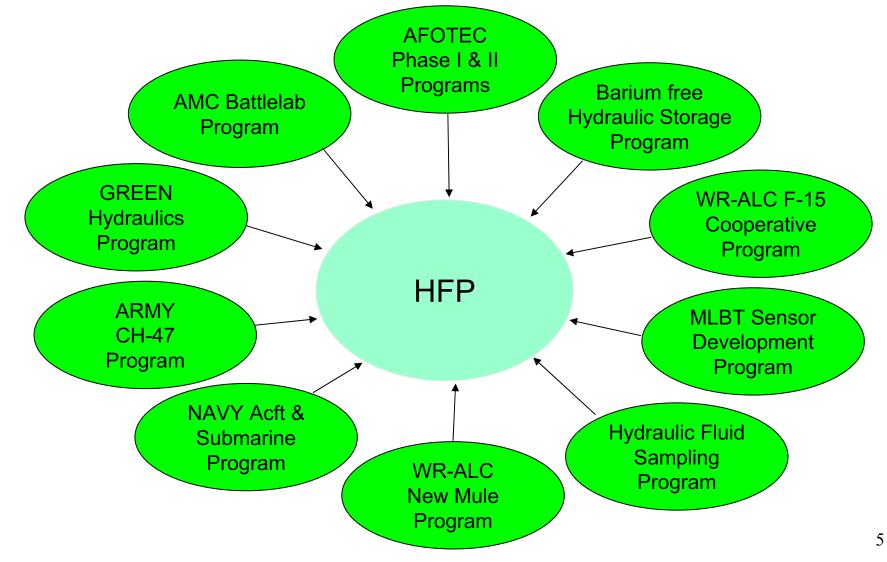




HFP Support



Dominant Air Power: Design For Tomorrow...Deliver Today





Background



Dominant Air Power: Design For Tomorrow...Deliver Today

- Initial Requirement:
 - Sep 1998 Executive Order 13101, Greening the Government through Waste Prevention, Recycling, and Federal Acquisition Section 101.

"It is the national policy to prefer pollution prevention, whenever feasible."

- AFMC-pollution prevention program
 - Reduce hydraulic fluid waste stream
 - Evaluate purification and demonstrate use in field



WHY HFP?



7

- Man-hours required to drain and flush
 - Contaminated systems require drain and flush to purge system
- Large Mobility/Supply Footprint
- Large Hydraulic Fluid Waste Stream
 - Pollution Prevention for Environment
 - High Cost of Waste Disposal
- Significant Cost Savings







- Savings in new fluid procurement (AF)/ALL FLUIDS
 - Estimated 0.9M gal X \$10/Gal X .90 = \$8.1M
- Savings in used fluid disposal cost
 - Estimated 0.8M gal X \$1.50/gal = \$1.2M
- Total savings = \$9.3M Annually
- 5 Year ROI ratio = 62:1 (9.3 X5 = 46.5/750K)
- Calculated savings does NOT consider savings as a result of component life extensions









- Purifying hydraulic fluid on equipment used to service Aircraft (F-14 / F-18)
- Many years of HFP on Submarines
 - Fluid disposal was an issue
 - Limited space to carry new and used fluid



Army HFP



Dominant Air Power: Design For Tomorrow...Deliver Today

CH-47 goes through phase every 18 months

- 480 CH-47s in the Army
- 480 X 0.667 = 307 = Number of aircraft in phase annually
- Prior to purification / 53 gals hydraulic fluid required per aircraft
- After purification / 1 gal hydraulic fluid required per aircraft
- 52 gallons saved per aircraft
- 307 X 52 = 15,964 Gals x \$10 Avg = \$159,640.00 Savings per year



HFP Program



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Phase I (Apr 00 – Jun 03)

- AFOTEČ, ASC/ENVV, AFRL/MLBT, HQ AMC, ASC/AAA
- Research and validate methods and procedures for HFP
- Phase II (Mar 04 Jun 04)
 - AFOTEC, ASC/ENVV, AFRL/MLBT, HQ AMC, ASC/AAA
 - Conduct Operational Utility Testing on existing Hyd Mules
 - Technical Order Change

• Phase III (Jan 04 – Sep 07)

- AFRL/MLBT, ALC's, MAJCOM, ASC/SPO's, AAA & ENVV
- Sampling program to determine purification standards
- Authorize use of purified fluid in aircraft via T.O. changes and letters of authorization
- Conduct field service evaluation

• SE Development and Fielding (Jan 00 – Sep 10)

- WR-ALC/LES, HQ-ACC/LGM
- Develop Malabar and T.O.s
- Field Malabar Mule as replacement
- Field Malabar and Pall Portables

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USAF Phase I



- AFOTEC Reviewed 13 test reports of Pall Portable Fluid Purifier (PPFP) conducted by:
 - US Army, US Navy, & US Air Force
 - 15 years of tests
 - Tests MIL-H-87257, 83282, 5606, & 46170
- Findings: AFOTEC & AFRL
 - Water reduction capability satisfactory in all tests
 - Particulate reduction capability satisfactory in all tests
 - Purification did not impact physical properties (i.e. viscosity, lubricity, fluid foaming)
 - Purification can bring fluid to spec standards in 2 to 4 hours (depending on contamination)



USAF Phase II (Mar 04 – Jun 04) **Det 1 AFOTEC**



- Conducted Operational Utility Evaluation
 - Used Mules from Kirtland AFB
 - 58th SOW
 - 150th FW
 - Mules were used to service F-16, H-53, & C-130



USAF Phase III (Jan 04-Sep 10)



- HQ AMC HFP Champion
 - Conduct Aircraft Sampling Program
 - -15 Different Aircraft
 - 53 Bases, 562 Samples
 - Aerospace Ground Equipment
 - 53 Bases, 216 Mule Samples
 - Develop Hydraulic Fluid Standards
 - Conduct Field Service Evaluations
 - AFRL, Aging Aircraft Systems Squadron (AASS), MAJCOMs & ALC Involvement



Purification Equipment



15

AIR FORCI

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Pall Hydraulic Fluid Purifier



- Purification
 - -- Particulate Reduction
 - Water Reduction
 - -- Free & Dissolved Air Reduction
 - -- Solvent Removal
 - -- Synergistic Effects

- Filtration

-- Particulate Reduction

Malabar Purification Unit



NSN 4920-01-380-7460, 3 System, Diesel Engine Driven.

NSN 4920-01-380-4744, 3 System, Electric Motor Driven.

NSN 4920-01-434-1081, 2 System, Diesel Engine Driven.

NSN 4920-01-434-3206, 2 System, Electric Motor Driven.



Hydraulic Fluid Purification



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How the purifiers work:

- Create large fluid surface area using a spinning disk or by misting
- Partial vacuum to remove volatiles
- High efficiency fine filter
- Some use absorption/adsorption to remove water

Effective in removing

- Particulate Contamination
- Moisture
- Solvents
- Air (Entrained and Dissolved
 - Spongy flight controls
 - Pump cavitation
 - Fluid over-temp

Portable and built-in configurations



Pall Portable Purifier



Malabar Portable Purifier



HFP Equipment (Cont'd)



Dominant Air Power: Design For Tomorrow...Deliver Today

Malabar Portable

- With Water Sensor
- Without Water Sensor
- In Use for Service Eval

P/N 885200-3

Commercial

Manual



MALABAR

Pall Portable

- With Water Sensor
- Without Water Sensor
- In Use for Service Eval

Air Force Without Water Sensor 4330-01-470-1855 P/N PE0107812H83 T.O. 35M15-2-9-1

Army With Water Sensor 4330-01-522-2007 P/N PE0107812HW83 Army Manual In Work



PALL







- Currently No Field Capability to Analyze Hydraulic Fluid for Water and Particulate Contamination
- Current Fluid Inspection is Visual Only
- Requires Sample sent to the Air Force Petroleum Lab at WPAFB
- Affects all aircraft, all platforms and all Mules
- Need on-site sensor for detection of water and particulate contamination in hydraulic fluids



Hydraulic Fluid Multi-Sensor



- Impact of no sensor
 - Sample analysis cost is about \$100 per sample
 - Shipping and analysis time causes equipment and aircraft down time
 - Hydraulic fluid purification initiative drives the need for the sensor technology
- MAJCOM Coordination:
 - HQ AMC/A44JS requested sensor



Sensor Solution



- Develop in-line, real-time, field-level multisensor
- Deliver Sensors with operating instructions
- Six (6) units to be delivered at completion of contract for field service evaluation
- Solution is cross-cutting on all Weapon Systems



Solution Approach



- Implementation issues
 - Additional units paid for by the user (\$3-5K each)
 - Operation manual will be provided with sensor
- What are the benefits?
 - Decreased analysis and shipping times will provide better aircraft/equipment availability (3-4 days saved)
 - Maintenance manhours are reduced by eliminating unnecessary drain and flush of Mules
 - Base level Hydraulic fluid contamination detection capability saves Lab analysis cost



Conclusion



- Tested Effectiveness of Purification
- Tested / Qualified Equipment Purification Capabilities
- Sampled Aircraft & Hydraulic Test Stands (mules)
- Authorized Use of Purified Hydraulic Fluid
- Service Evaluations in Process
- Multi-Sensor Development in Work
- READY FOR HFP IMPLEMENTATION



Hydraulic Fluid Purification





Hydraulic Test Stand Modification at Eglin

Presented by: Eddie Preston

Hydraulic Fluid Purification

- "Purity" can be measured in three areas:
 - Particulate
 - Water
 - Air

Achieving Purity

Can be achieved by two methods:

- Onboard purifier
- Stand Alone purifier

Achieving Purity

Onboard purifier

- On-board purifier is a good choice for new acquisition, poor choice for existing mules.
- Large dollar value (30k+ each) to add on-board purifier to existing mules.

Stand Alone purifier

- A good choice for the existing mules; however, existing mules need to be modified with connections. (1-1.5k each not including 3 micron filter change)
- One stand alone purifier can service multiple mules separately.

Maintaining Purity

Particulate

 Replace existing filters on the mules from current 5 micron hydraulic filters with 3 micron absolute filter elements

Water

Add a reservoir vent filter/dryer.

Air

- The only way to remove air is purify regularly.
- Modify mules with purifier connections.

Portable Hydraulic Stands Modified

4920-01-143-1203 3 System Diesel Engine Model Number TTU-228/E-1B 9 UNITS on hand total for the 33d AGE Flight Manufacturer- Hydraulics International Inc. One unit modified

4920-01-044-5926 3 System Electric Model Number A/M27T-2A 6 UNITS on hand total for the 33d AGE Flight Manufacturer- ACL FILCO One unit modified

3 System Diesel Mod for Purifier Attachments



Square Tank Method







3 System Diesel Mod Vent Dryer

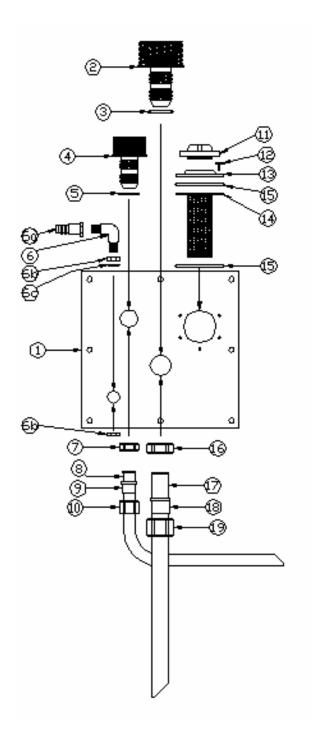


Unvented Filler Cap Vent Dryer Fitting





Vent Dryer Mounted On Inside Wall Of HTS Pall Purifier Hooked Up To HTS



Diesel Mod Preliminary Drawing

	Noun	P/N
1	Plate	Local Manufactured
2,	QD	155S4-16D
2a	dust cap # 16 (Not Shown)	155S7-16D
3	O-RING	AS287778-16
4	QD	015628S2-12
4a	dust cap # 12 (Not Shown)	155S7-12D
5	O-RING	AS28778-12
6	ELBOW	AS1038-0606
6a	ADAPTER PRESS LOCK	6LOL6FJX
6b	B-NUT	AN924-6D
6c	O-RING	MS29512-06
7	B-NUT	AN924-12
8	3/4" x 0.04? Wall x 10" long	ALUMINUM TUBE
9	SLEEVE	MS51533B12
10	NUT	AN818-12
11	CAP UNVENTED	A-100-X-G
12	SCREW	Retain for re-use
13	ADAPTER PLATE	A-100-Z
14	SCREEN	A-100-3
15	GASKET	A-100-4
16	B-NUT	AN924-16
17	1.00" x 0.04? Wall x 14" long	ALUMINUM TUBE
18	SLEEVE	MS51533-B16
19	NUT	AN818-16

3 System Electric Mod for Purifier Attachments



Existing End Cap



New Manufactured End Cap

Round Tank Method

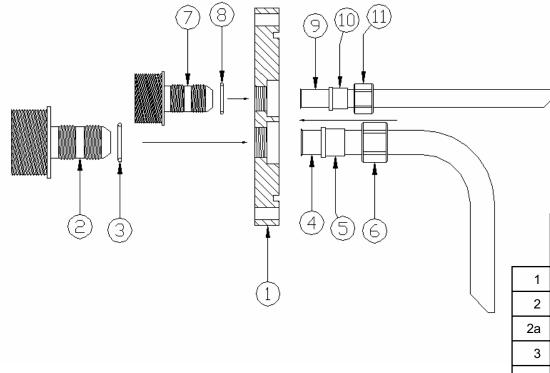


Hydraulic Reservoir End View End Cap Removed



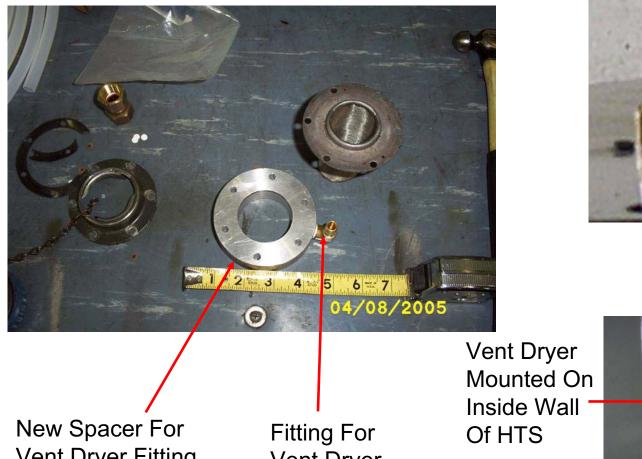
Hydraulic Reservoir End View New Manufactured End Cap Installed

Electric Mod Preliminary Drawing



	Noun	P/N
1	Plate	Local Manufactured
2	QD	155S4-16D
2a	dust cap # 16 (Not Shown)	155S7-16D
3	O-RING	AS287778-16
4	1.00" x 0.04? Wall x 14" long	ALUMINUM TUBE
5	SLEEVE	MS51533-B16
6	NUT	AN818-16
7	QD	015628S2-12
7a	Dust cap # 12 (Not Shown)	155S7-12D
8	O-RING	AS28778-12
9	3/4" x 0.04? Wall x 10" long	ALUMINUM TUBE
10	SLEEVE	MS51533B12
11	NUT	AN818-12

3 System Electric Mod Vent Dryer





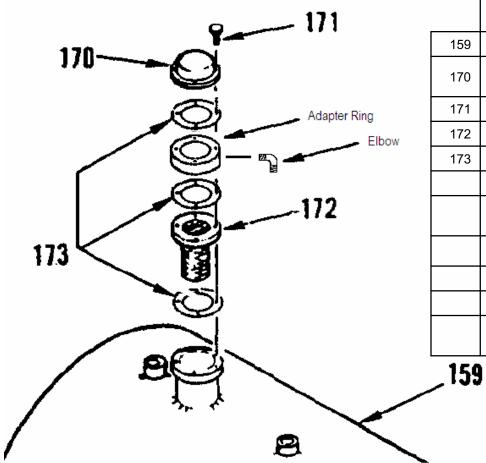
New Spacer For Vent Dryer Installed

Vent Dryer Fitting

Vent Dryer



Electric Mod Preliminary Drawing



	Noun	P/N
159	Reservoir	
170	Replace existing cap with un- vented cap	A-100-X-G
171	SCREW	Bench Stock
172	SCREEN	A-100-3
173	GASKET	A-100-4
	Adapter Ring	Local Manufactured
	90 Deg Elbow 3/8" NPT x 3/8" hose barb	TBD
	1/2" OD x 3/8" ID Hose (not shown)	polybutylene
	Pall Filter Vent (not shown)	TBD
	Pall Filter Vent Bracket (not shown)	TBD
	Pall Filter Vent Hose adapter (not shown)	TBD

Additional Requirements

- TCTO / IOS
 - Requires drawings and funding for parts and services.
 - VAL-VER of each TCTO / IOS.
 - Current TO's require new procedures and IPB changes.

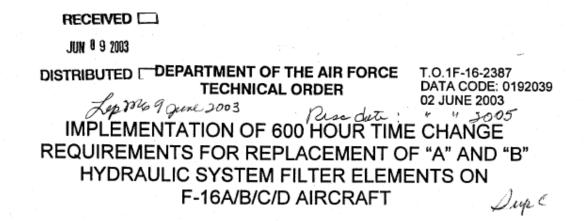
Hydraulic Fluid Purification Decision Brief

By: Eddie Preston

Overview

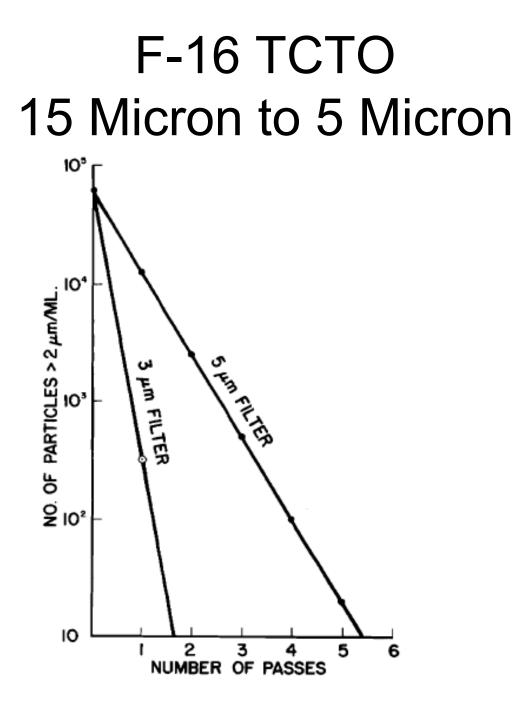
- Findings
 - Aircraft issues that justify a requirement
 - F-16
 - F-15
 - B-1
- Recommendations

F-16 TCTO 15 Micron to 5 Micron



NOTE

5 micron filter element part numbers listed below are the preferred part to be installed during accomplishment of the TCTO. However, supply may issue 15 micron filter elements until they are exhausted. They are considered a suitable substitute equivalent for the purposes of this TCTO.



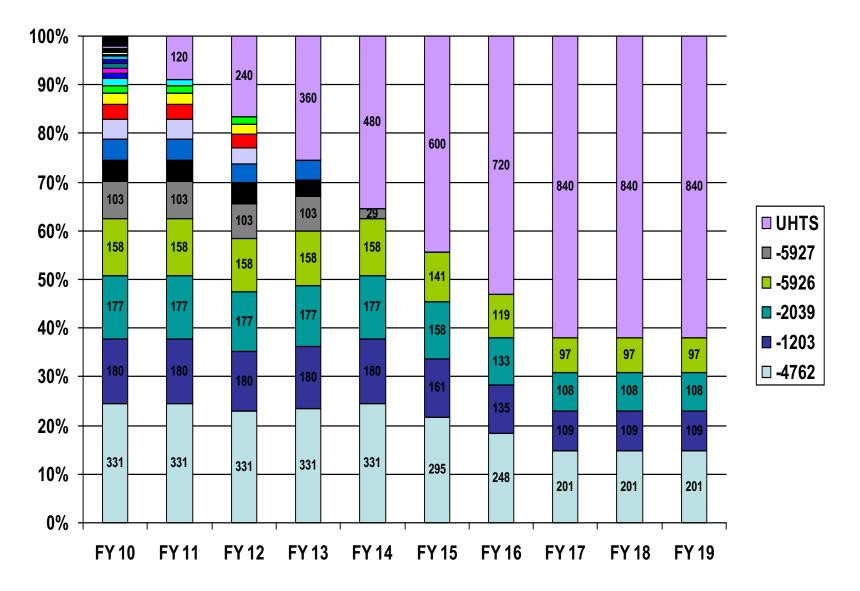
F-15

- High air content
- High Water
- High Particulate
- Recent concept demonstration performed successfully at Eglin AFB.

B-1 Issues

- Landing Gear Strut Contamination.
- B-1 found failed high pressure filters during mule inspection.
 - Ellsworth had 4 high pressure filters that were split apart.
 - AFTO 22 to have the filters changed every two years was disapproved by ACC.
- B-1 SPO inquired about the 1067 being submitted by F-15 SPO.

Mules in the Field



Recommendations

- Change 5 Micron HPF to 3 Micron HPF in top 5 legacy HTS.
- Fund Mod top 5 legacy stands w/ Purifier QD's.
- Allow SPOs to fund mod for other NSN's as requested.
- * Pall Purifier has been added to shop TA and several Aircraft TA's.





Hydraulic Fluid Purification Environmental Aspects

Mr. Don Streeter ASC/ENVV ASC HFP Environmental Manager <u>Donald.Streeter@wpafb.af.mil</u> DSN: 785-3550 Comm 937 255-3550



Why Hydraulic Fluid Purification (HFP)?



Drivers: DoDD 4715.1E/DoDI 4715.4, AFPD 32-70 /AFI 32-7086, HMRPP Need 530, Executive Order 13101, 40 CFR 279, T.O. 42B2-1-3

Description: Pollution Prevention Project Initiated to Evaluate Feasibility of Purifying and Reusing Hydraulic Fluid in the Most Effective Way Possible and to Reduce the Waste Stream as Much as is Feasible Without Significantly Increasing Ground Crew Demands or Degrading Aircraft Readiness, and Performance

Weapon Systems and Stakeholders: All SPOS/Wings that have Aircraft that Use and/or Dispose of Large Amounts of Hydraulic Fluid, All SPOs that want to Save Money and Improve Aircraft Hydraulic System, Ground Support Equipment and Ground Crew Performance



Hydraulic Fluid Purification Environmental History



Recycle of Working Fluids Project:

 Hydraulic Fluid Purification and Subsequent Reuse was included in this AFRL Early Research Project which was Initiated in 1994

• DoDD/I directed AF to issue AFPD 32-70 Environmental Quality and AFI 32-7086 Hazardous Waste Management Drove Hazardous Material Reduction Prioritization Process (HMRPP) Needs:

 Need 530 Part of 1995 Needs Assessment, Originally Submitted by SA-ALC Pneudraulics Repair Facility then at McClellan AFB CA (Now at Hill AFB UT)

 To Reduce Hazardous Waste Generation/Disposal, the Current Pollution Prevention (P2) Project was Initiated (PPPN Submitted) on 17 Dec 1999 by ASC/ENVV

Resulting Reduction in New Fluid Use also Supports AFPD 32-70 EQ
 Program Conservation Pillar



Hydraulic Fluid Purification Environmental History (con't)



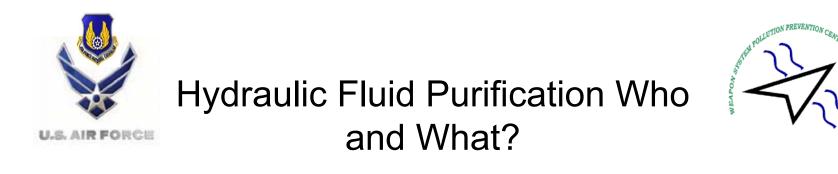
- Executive Order 13101 Greening the Government Through Waste Prevention Recycling and Federal Acquisition
 - Pollution Prevention and Source Reduction Preferred Whenever Feasible
 - Mandates Reuse/Recycle of Waste Materials Whenever Feasible
 - Disposal Employed Only as a Last Resort

• 40 CFR 279 Standards for the Management of Used Oil

- Comprehensive 25 page Code of Federal Regulations Document
 - Promulgates the Legal Standards for the Management of Waste Oil
- P2 Project Minimizes Need to Manage Unusable Waste Oil, Maximizes need to Properly Segregate/Manage Oil to be Purified and Reused

• T.O. 42B2-1-3 Hydraulic Fluid Standard Technical Order

 Document that was Changed 6 Jun 2004 to Allow Hydraulic Fluid Purification by Stating that Fluid Purified by Air Force Qualified Purifiers with Approval from the Responsible Wing/Program Office of Record for the Aircraft System using the Fluid



Stakeholders:

- Wings/SPOs that have Aircraft that Use and/or Dispose of Large Amounts (55 gal or Larger Drums/Tanks) of New/Waste Hydraulic Fluid,
- Wings/SPOs that have Aircraft (A/C) Hydraulic System and/or Ground Support Equipment (GSE) Contamination Problems
- Wings/SPOs that have Hydraulics (A/C & GSE) Maintenance Problems
 - Excessive Contamination, Component: Leakage, Failures and Subsequent Replacement
- Wings/SPOs that have A/C Hydraulic System Performance Problems
 - Erratic Flight Control Actuator, Brake or Landing Gear Operation
- The Product : Purified Hydraulic Fluid
 - All of the Above Stakeholders Require New MIL-SPEC Compliant or Purified Hydraulic Fluid to Resolve Above Problems



Hydraulic Fluid Purification Why Else? Not Just Environmental



Benefits

 Decreased Fluid Consumption and Reuse/Recycle of Fluid Usually Disposed of as Hazardous Waste Main Objective of ASC/ENVV HFP Environmental Initiative

Less Manpower will be Required to Manage and Handle Waste Materials

 Environmental Aspects only Part of Expected Savings, Other Benefits Include:

- Reduced Hydraulic System Maintenance/Extended MTBF for Hydraulic Systems
- Extended Hydraulic Component Life
 - Potential to Save Millions of \$ in Component Replacement Costs



Hydraulic Fluid Purification Why Else? Not Just Environmental (con't)



Benefits (con't)

- Improved Aircraft Performance
 - Smooth Operation of Hydraulic Components
 - Better Flight Control, Landing Gear, & Brake System
 Operation/Response
- Deployment Footprint is Minimized and Disposal Problems can be Greatly Reduced
 - Both New Fluid Carried In and Waste Fluid Carried Out can be Greatly Reduced if Purifiers are Deployed
 - Disposal Problems that are Worse in Foreign Countries than in the US can be Minimized as Well



Hydraulic Fluid Purification Environmental Aspects



Conclusion

- HFP is a Great Way to Comply with Current DoD and Air Force
 Environmental Policy and Should Be a Mandatory Air Force Requirement
- HFP Has Many Other Significant Benefits Which Go Way Beyond its
 Environmental Scope, and Will Make the Process Essential to the Warfighter

Analytical Data On Aircraft And Mule Hydraulic Fluid Samples

George Fultz University of Dayton Research Institute.



Shaping the technology of tomorrow

Hydraulic Fluid Sampling Program

• **Objective:** Analyze hydraulic fluid from operational aircraft and hydraulic test stands (mules) for particulate, water and chlorinated solvent contamination

- Primary purpose was to develop a realistic standard for maximum contamination levels in operational hydraulic systems
- This will serve as a guideline for establishing cleanliness standards for hydraulic fluid purification for both servicing equipment as well as aircraft
- Only current standard is for new hydraulic fluid not realistic for in-use hydraulic fluid

AIRCRAFT AND MULE SAMPLES

•Aircraft

•572 Kits Scheduled

•572 Kits Sent

•560 Received and Analyzed

•Mules

- 218 Kits Scheduled
- 218 Kits Sent
- 191 Received and Analyzed

HELICOPTER & MULE SAMPLES

•Helicopter

•86 Kits Scheduled

•73 Kits Sent

•52 Received and Analyzed

•Helicopter Mules

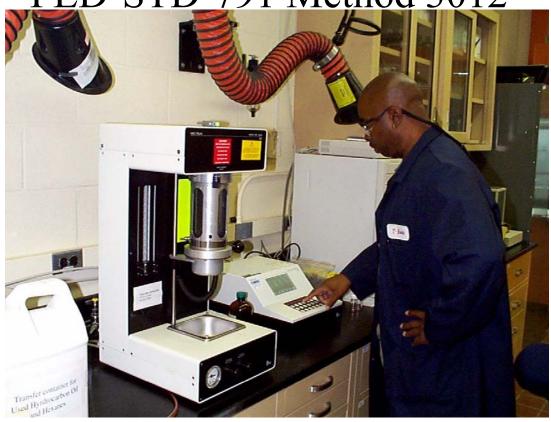
- 38 Kits Scheduled
- 38 Kits Sent
- 30 Received and Analyzed

DATA DETERMINED ON EACH SAMPLE

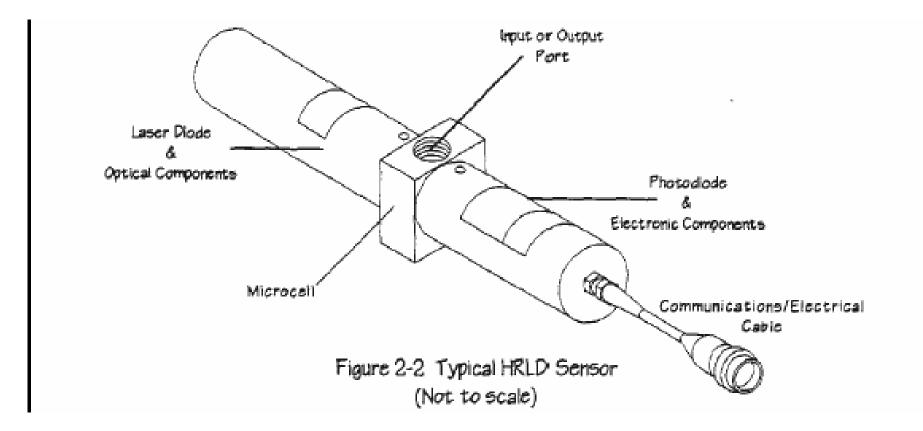
- PARTICULATE COUNT (FTM 791C 3012)
- WATER CONTENT ASTM D 6304
- BARIUM CONTENT ASTM D 5185
- CHLORINE

CAPILLARY GAS CHROMATOGRAPHY

PARTICULATE COUNT BY AUTOMATIC PARTICLE COUNTER FED-STD-791 Method 3012



Calibrated by Manufacturer Every Six Months



NAS 1638

MAXIMUM CONTAMINATION LEVEL OF 100 ML SAMPLES							
	Contamination Class						
Micron Range	00	0	1	2	3	4	5
5 -15	125	250	500	1,000	2,000	4,000	8,000
15 - 25	22	44	88	176	352	704	1,408
25 - 50	4	8	16	32	64	128	253
50 -100	1	2	3	6	11	22	45
>100	0	0	1	1	2	4	8
	Contamination Class						
Micron Range	6	7	8	9	10	11	12
5 -15	16,000	32,000	64,000	12,800	256,000	512,000	1,024,000
15 - 25	2,816	5,632	11,264	22,528	45,056	90,112	180,224
25 - 50	506	1,012	2,025	4,050	8,100	16,200	32,400
50 -100	90	180	360	720	1,440	2,800	5,600
>100	16	32	64	128	256	512	1,024

Coulometric Water Apparatus



REASONABLE LIMIT LESS THAN 300 PPM

ASTM D 6304 Coulometric Karl Fisher Titration

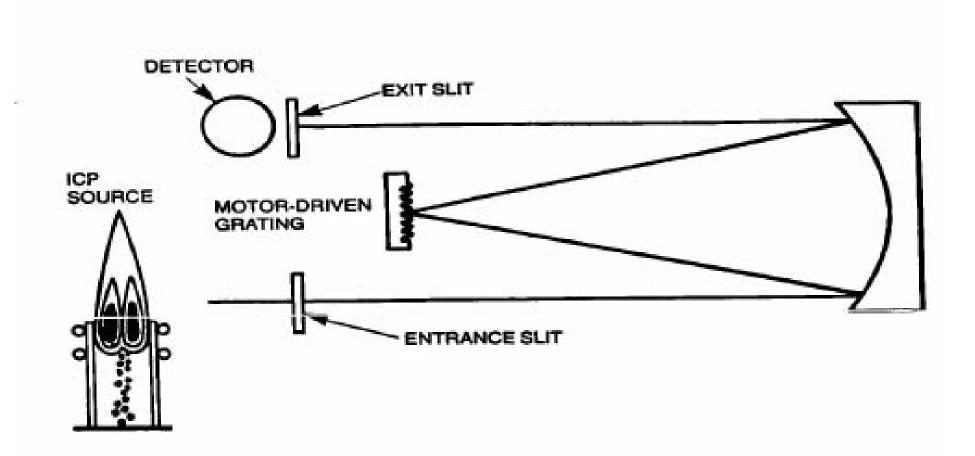
- Water in the range of 10 20,000 ppm
- A sample is injected into the titration vessel of a coulometric Karl Fischer apparatus
- Injection can be done either by mass or volume.
- Fisher reaction (pyridine and chloroform free) detected coulometrically.

BARIUM CONTENT BY ICP



REASONABLE LIMIT LESS THAN 20 PPM

ICP Source

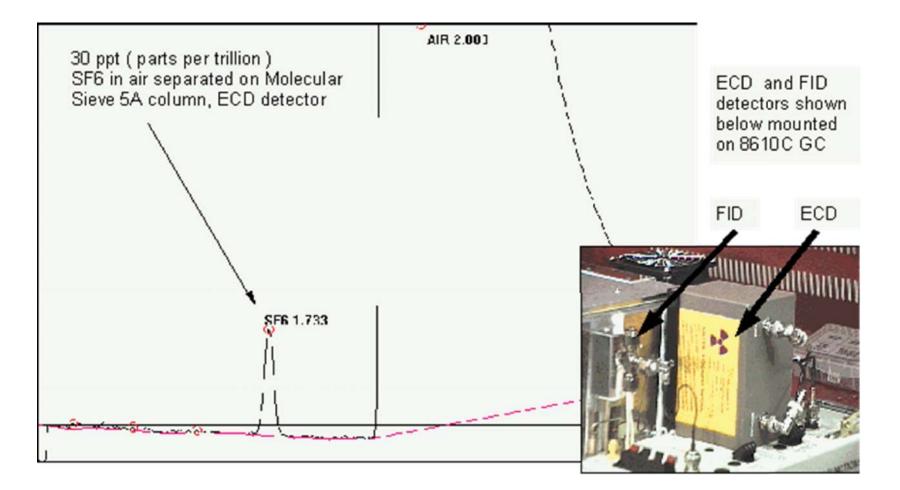


CHLORINE BY GAS CHROMATOGRAPHY

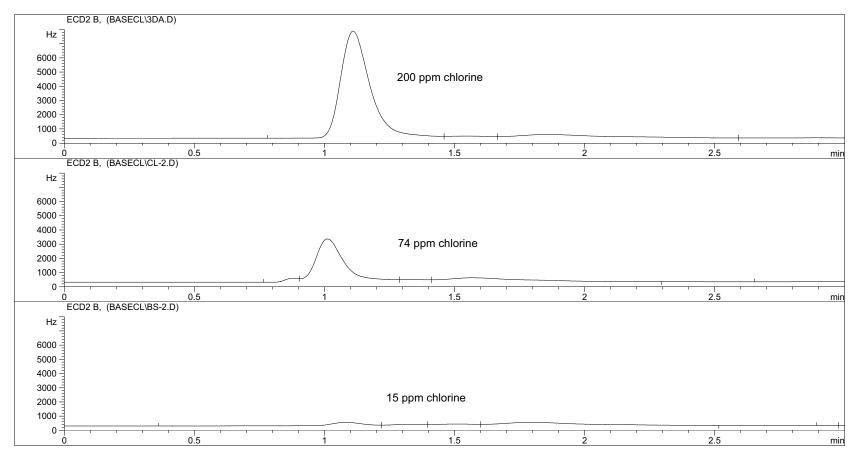


REASONABLE LIMIT LESS THAN 200 PPM

Electron Capture Detector (ECD)



Chromatograms of Chlorine (Freon)



Particle Counts, Water, & Barium Results From Various Groups of Aircraft & Associated Mules





The Air Force Academy "Mascot" and "Flash"

- From Wikipedia, the free encyclopedia & Steve Gunderson (UDRI)
- Multifunction Utility/Logistics and Equipment (MULE) vehicle is an autonomous ground vehicle developed by for the Lockheed-Martin





An aircraft hooked up to a mule (servicing cart), which is also hooked up to a purifier for a test.

10 B1 = 40 SAMPLES



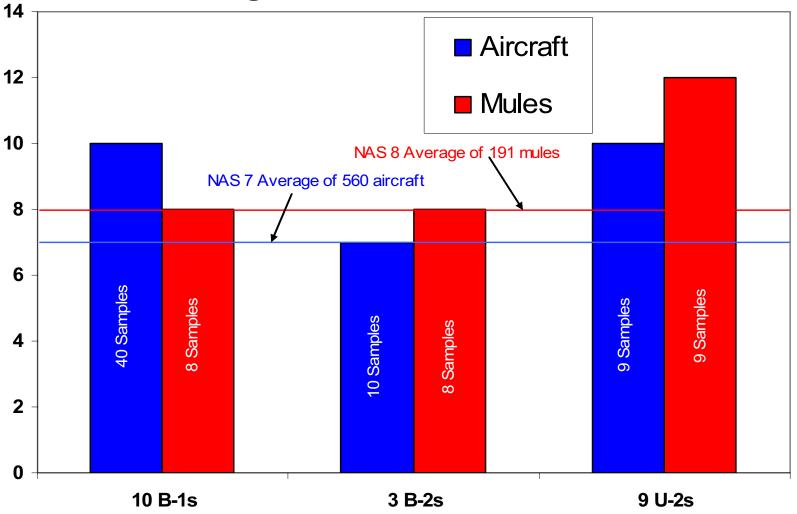
3 B-2 = 10 SAMPLES



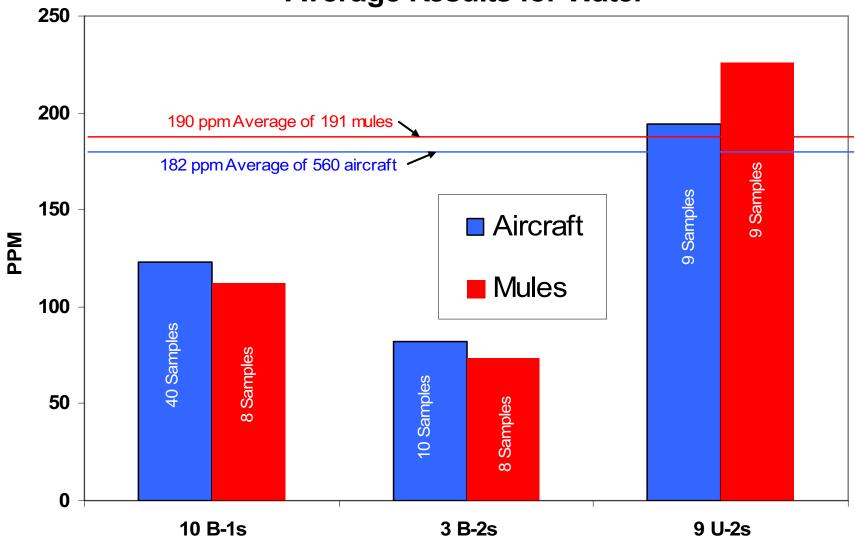
9 U-2 (NINE SAMPLES)



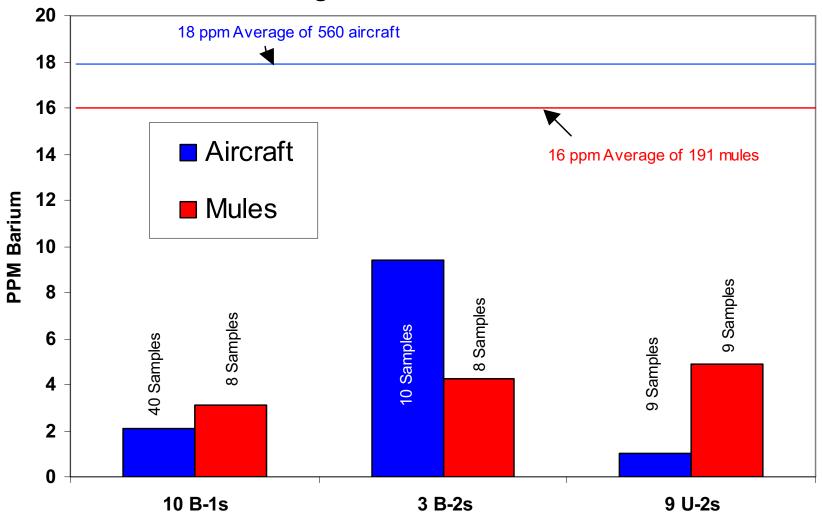
Bomber & U2 Aircraft + Mules Average Results for Particle Count



Bomber & U2 Aircraft + Mules Average Results for Water



Bomber & U2 Aircraft + Mules Average Results for PPM Barium



28 KC 135 (56 SAMPLES)



14 C-5 (56 SAMPLES)



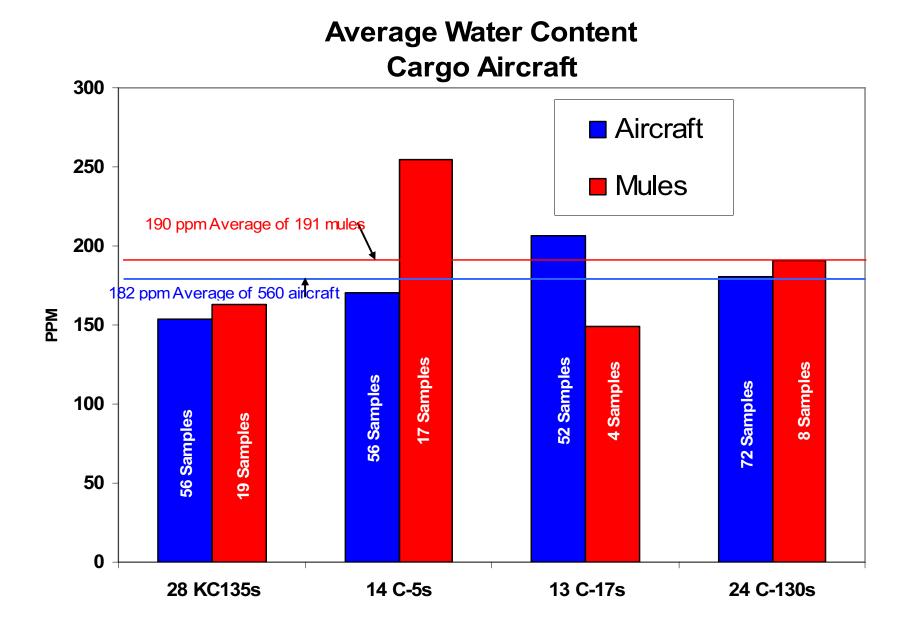
13 C-17 (52 SAMPLES)



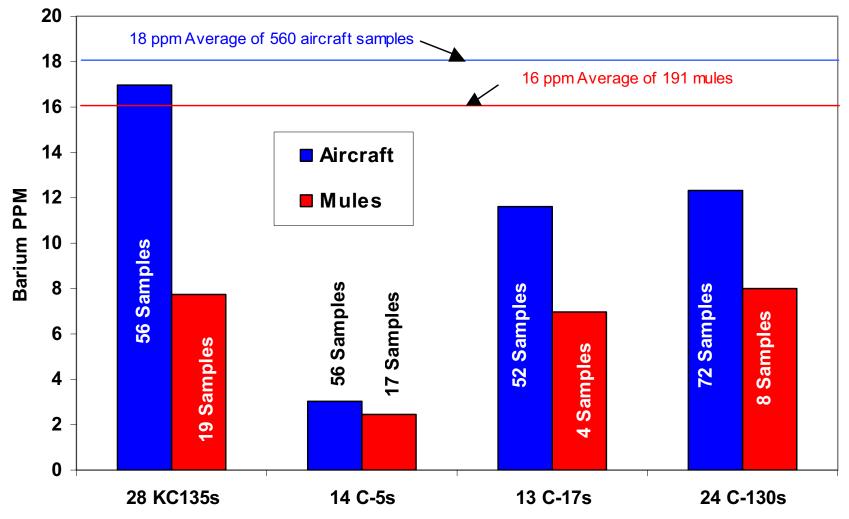
24 C-130 (72 SAMPLES)



Average Particle Count (NAS 1638) Cargo Aircraft 12 ■ Aircraft 10 Mules NAS 8 Average of 191 mules NAS 7 Average of 560 aircraft 8 6 52 Samples 72 Samples **19 Samples** 4 Samples 56 Samples 4 17 Samples 8 Samples 56 Samples 2 0 14 C-5s 13 C-17s 28 KC135s 24 C-130s



Average Barium Content Cargo Aircraft



16 A-10 (32 SAMPLES)



6 F-22 (12 SAMPLES)

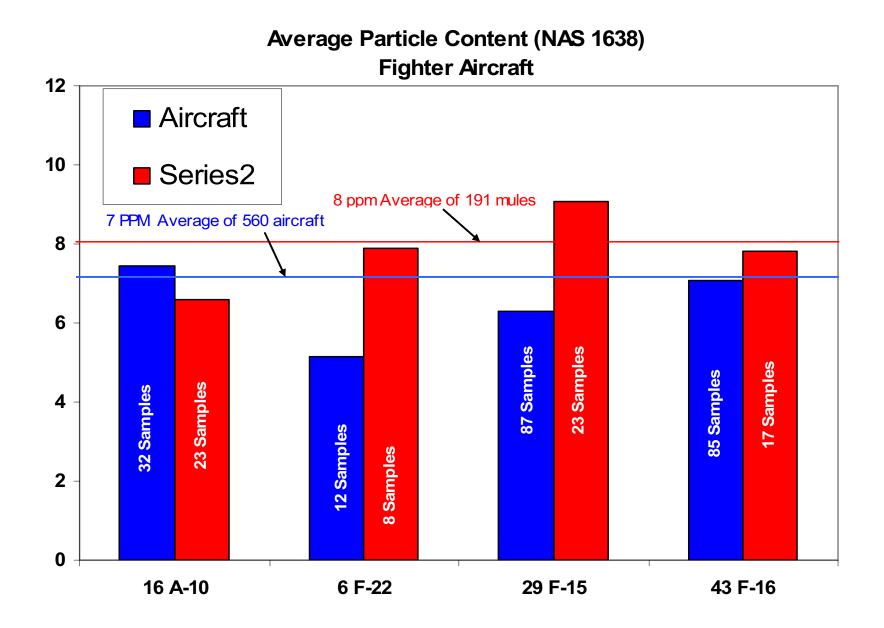


29 F-15 (87 SAMPLES)

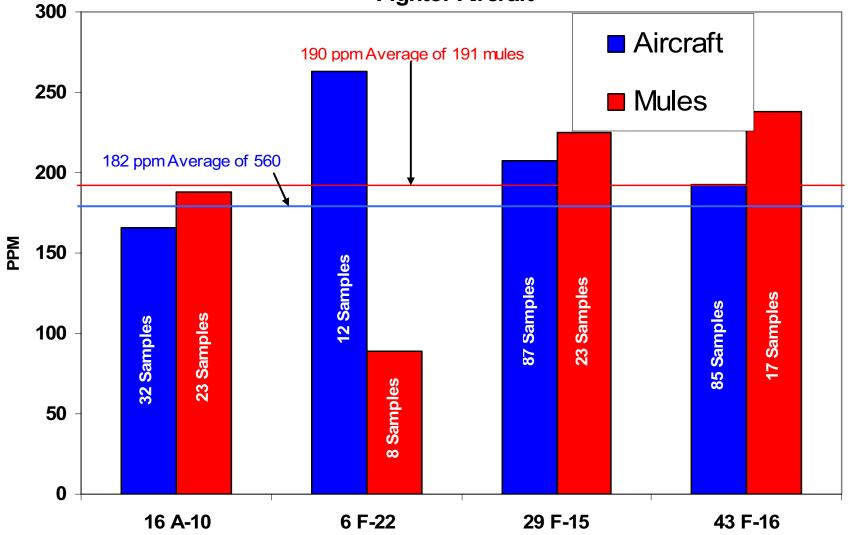


43 F-16 (85 SAMPLES)

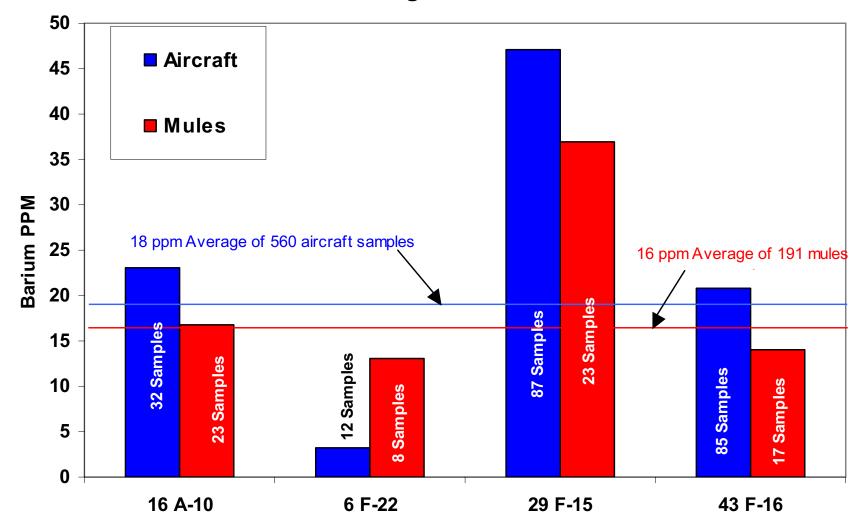




Average Water Content Fighter Aircraft



Average Barium Content Fighter Aircraft



14 UH-1 (28 SAMPLES)

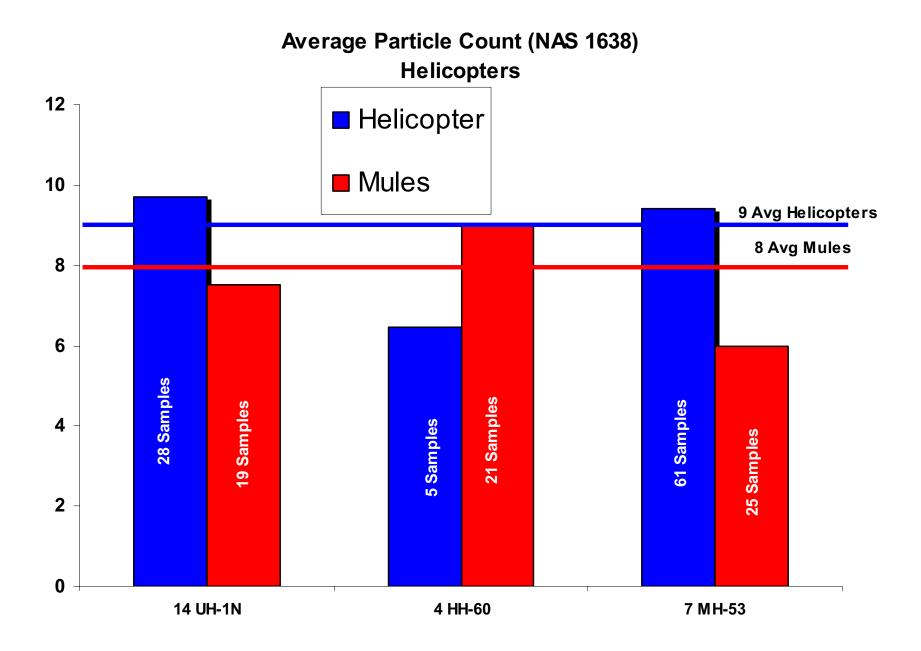


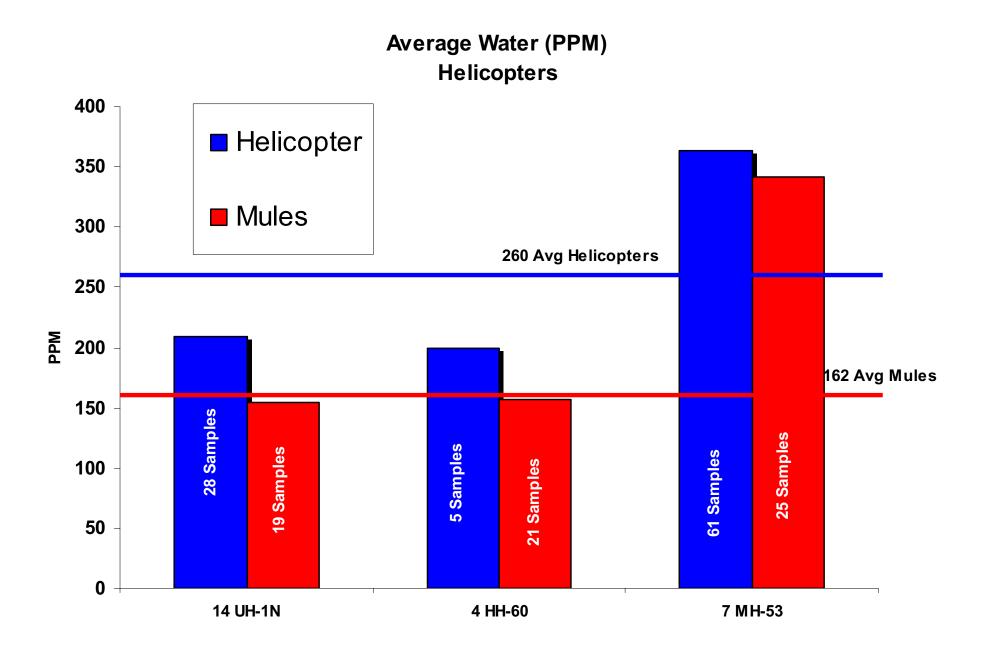
4 HH-60 (5 SAMPLES)

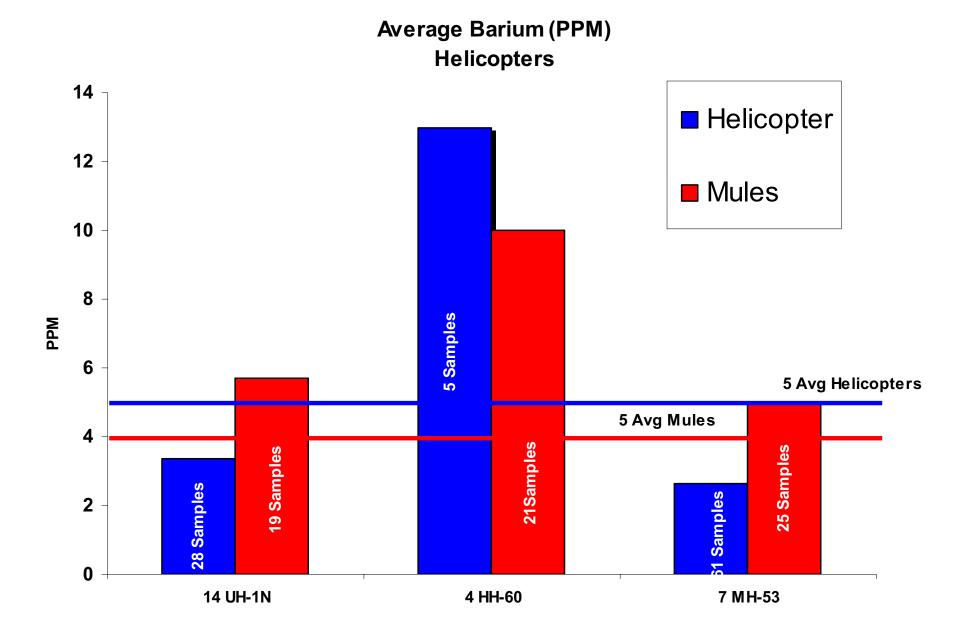


7 MH-53 (61 SAMPLES)





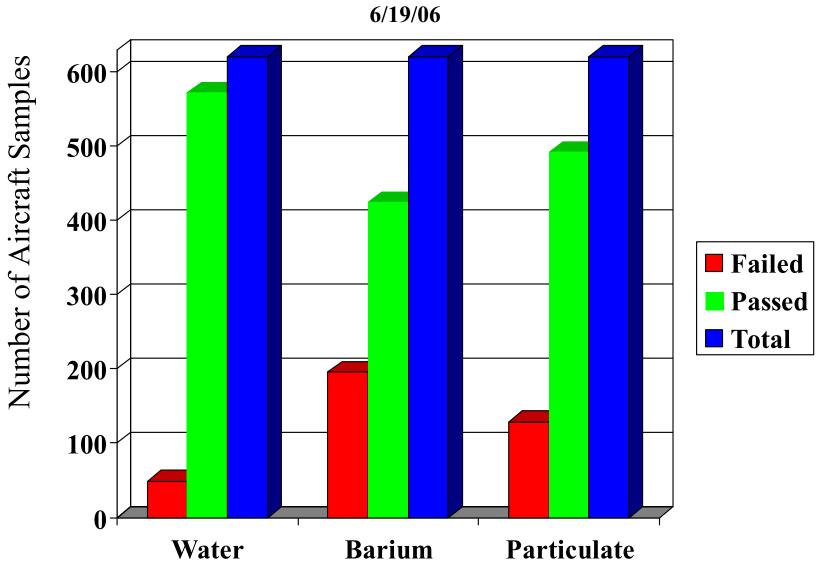




16 T-37 (16 SAMPLES)



AVERAGES PC = 10 WATER = 199 BARIUM = 2

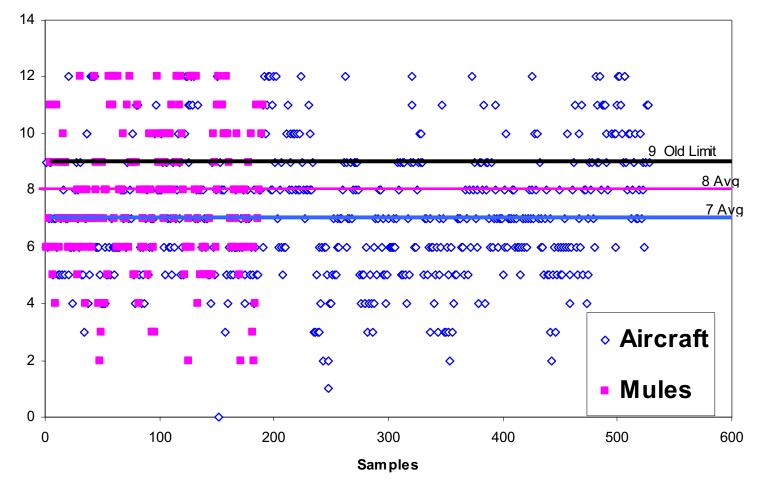


Aircraft Samples Using Previous Described Limits

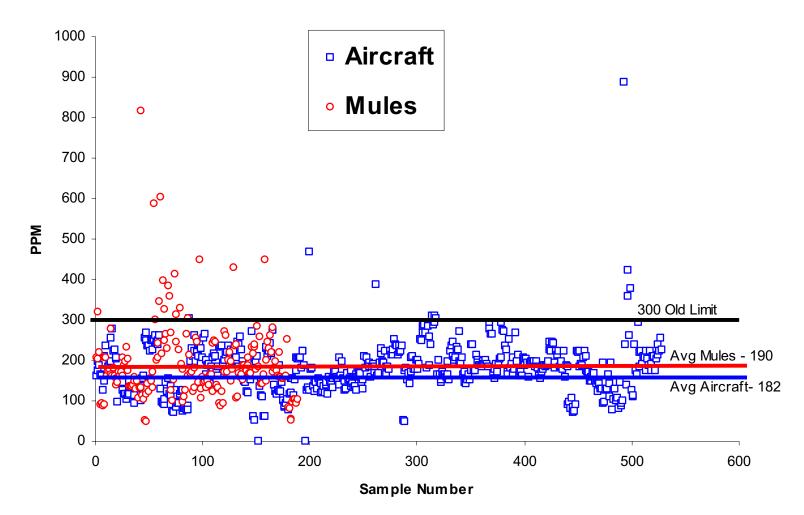
6/19/06 230 205 Number of Mule Samples 180 155 130 **Failed** 105 Passed 80 **Total** 55 30 5 -20+ Water **Barium** Particulate

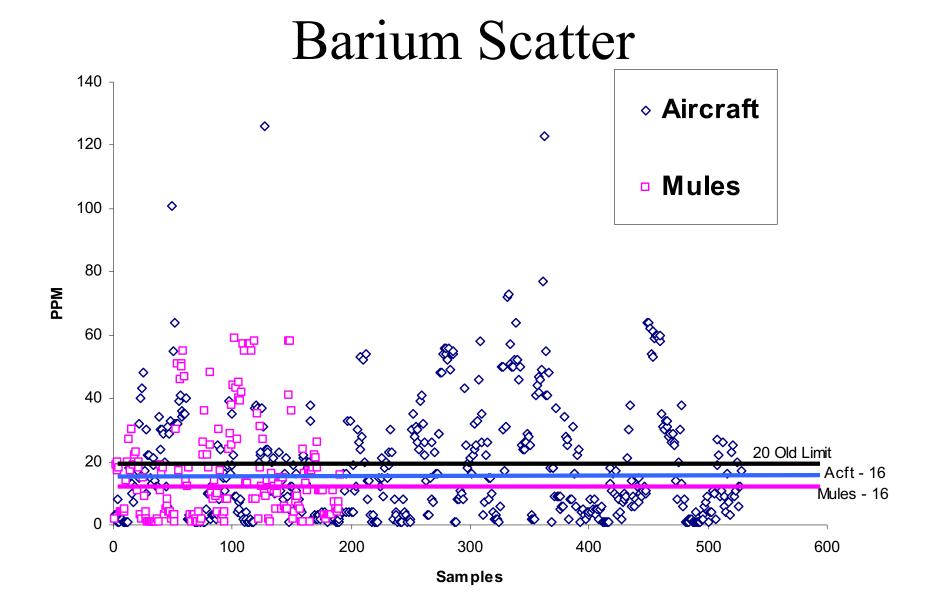
Mule Samples Using Previous Described Limits

Particle Count Scatter



Water Scatter





New Vs Old

All Aircraft Particle Count Water Barium **Original Limits** 9 300 20 7 Average 190 17 Std Dev 2 77 18

All Mules			
	Particle Count	Water	Barium
Original Limits	9	300	20
Average	8	186	15
Std Dev	2	92	15

Summary

- First broad range A/C and mule sampling program
- A lot of data scatter, but achieved meaningful statistics, because of number of samples (Over 800 samples from 14 different Aircraft and associated mules)
- Established a baseline for future purification work



Shaping the technology of tomorrow

Air Mobility Battlelab

Making Innovation Practical for Rapid Global Mobility



Used Hydraulic Fluid Purification (UHFP)

After Initiative Briefing

Capt John Yerger 22 Jun 06

DSN 650-7608

john.yerger@mcguire.af.mil



Overview

- Yesterday
 - How we came on board
- Today
 - Project results
- Tomorrow
 - Recommendations
- Awareness video

Note: Slide 5 is updated as of 21 Sep 06 to reflect completed CBA for Charleston AFB



Yesterday

3

Mission Statement: AMB will use commercially available purifying equipment to demonstrate the capability to collect, purify and return waste hydraulic fluid to aircraft operations

Objectives:

- Waste drum purification process
- Cost-benefit analysis
- Technical Orders and publications review for required changes
- Awareness video



Yesterday

4

Participants:

- USAF Hydraulic Fluid Purification IPT
- AFRL/MLBT
- National Defense Center for Environmental Excellence (CTC)
- OG-ALC, Hill AFB, UT (ALC)
- Selfridge ANG, MI (KC-135)
- Dover AFB, DE (C-5)
- Springfield AFB, OH (F-16)
- Charleston AFB, SC (C-17)

Methods of Securing Participation:

- SOW Concurrent Technologies Corporation
- MOA HFP IPT



Objective #1: Calculate life cycle costs/benefits of purifying waste hydraulic fluid

- AF wide, save ~ \$25M over 15-yrs (Case 3)
- ALC, Hill AFB, save ~ \$130,000 annually (Case 2)
 - ROI under 6 months
- Operational Unit, Charleston MXG, (Case 1)
 - ROI under 12 months
- AF procures 380,000 gal per year (MIL-PRF-87257,83282,5606)
 - Cost over \$3,000,000
- CBA included: equipment cost, maintenance, manpower
 - 13 parameters and assumptions

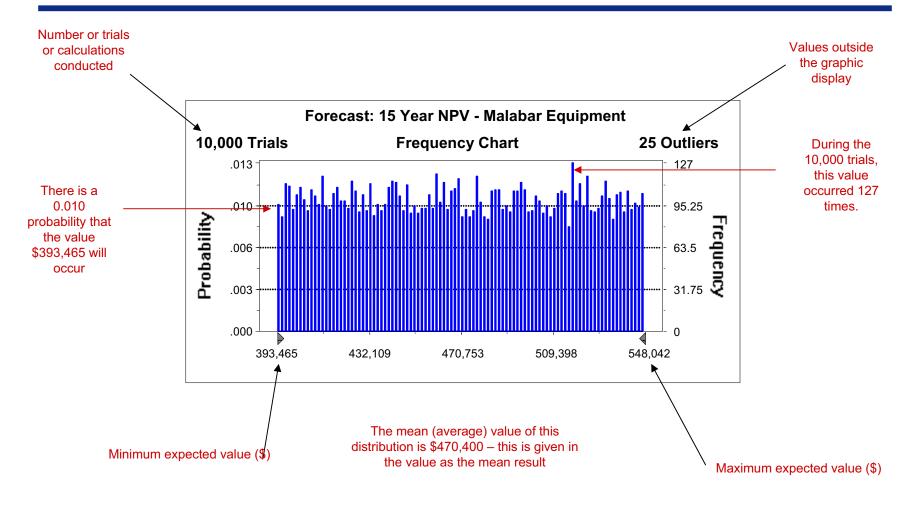
5



- UHFP Implementation Risk Areas
 - Fluid procurement requirements with UHFP (Scenario A)
 - Case 1 (AD Base level, Charleston C-17)
 - Case 2 (Depot level, Hill ALC)
 - Case 3 (AF-wide)
 - Future regulations prohibit burning of used fluid (Scenario B)
 - Fluid testing require to ensure proper segregation (Scenario C)
- Sensitivity Analysis using Monte Carlo Simulation
- Presented using standard financial indicators
 - Net Present Value: the sum of all costs and benefits resulting from UHFP during a 15 year period (in today's \$)
 - Payback Period: Time period required to recoup all UHFP equipment costs (due to annual operating savings)

6





Case 1 Scenario A: 15-Year NPV Probability Distribution for Malabar Equipment

7

Transforming today's technology into solutions for today's warfighter



Objective #2: Develop a waste hydraulic fluid purification process

- AFRL analysis validates both single barrel and barrel-to-barrel procedures purify fluid to acceptable mil-spec levels
- Used a Pall purifier and a 55 gallon drum with 83282; introduced a slurry of natural Arizona road dust; under ambient temperatures
- 5 different runs in total; 2 barrel-to-barrel, 3 single barrel
- Fluid preparation
 - Before test sampled 3 depths: ~2" from top, middle, ~2" from bottom
 - Determined baseline
 - Mixed in slurry; reached NAS 1638 Class 12
 - Added distilled water; middle sample read 600-700 ppm
 - Allowed to settle for 72 hours
 - Samples taken every 24 hours from 3 depths to document kinetics of settling process

8



- Barrel-to-barrel
 - Inlet/suction tube attached to collection barrel with QD's and pipe 32" in length, 1" in diameter, positioned ~2" from bottom
 - Outlet/discharge tube attached to clean drum with QD's and pipe 12" in length ¾" in diameter pipe
 - Purifier operated for 20 minutes, completing transfer
 - Samples taken from 3 levels upon transfer
 - Water and particulate reduced by ~ 50%
 - Inlet/suction pipe cleaned and moved to second barrel
 - Purifier operated with samples take every 15 minutes for first hour, then every hour until minimum requirements met (NAS 1638 Class 5 for particulates and/or <1.0 mg/mL and <100 ppm water)
 - Purifier met 2 hour time line
 - A second run was accomplished

9



- Single barrel
 - Additional 6 gallons added to replace fluid not transferred and fluid removed during sampling
 - Sample taken from middle of barrel, then contaminated and mixed
 - Purification began immediately with no wait time for settlement
 - Inlet/suction pipe and outlet/discharge same as previous test
 - Purifier operated with samples take every 15 minutes for first hour, then every hour until minimum requirements met (NAS 1638 Class 5 for particulates and/or <1.0 mg/ml and <100 ppm water)
 - Test repeated with outlet/discharge tube attached to pipes 18" and 24" in length; ~ 1 gallon of new fluid required due to sampling loss
 - Purifier met 2 hour timeline



- Captured used hydraulic fluid can be purified
 - Either single barrel or barrel-to-barrel configuration
- Human control factors must be in place to mitigate contamination
- Testing of fluid should be completed prior to purification
 - Regardless of controls, contamination of open fluids is possible
 - This decision should be left to local commanders

11



Objective #3: Develop/recommend AFI/technical data procedure changes

- Research identified 36 applicable publications
- Review results recommend 7 publications for changes

Objective #4: Develop a USAF hydraulic purification training and education awareness program

- Video completed, focused on cradle-to-grave handling of hydraulic fluid as a resource and not as waste
- Video target audience will be aircraft maintenance annual block training and AETC maintenance school houses



Tomorrow - Recommendations

Integration:

- IPT members coordinate AFMC approval
- MAJCOM functionals coordinate implementation

<u>CONOPS</u>: Purifier item manager adopt developed procedures for waste drum purification

Possibly use Environmental Allowance Standards and Item Coding amended accordingly

Funding: Cost is under \$20K per unit

Most installations/units could only require a single unit housed in AGE

Awareness Video:

- Integrate into block training
- Integrate into AETC school houses



Awareness Video

14



"Sorry, no popcorn"

Transforming today's technology into solutions for today's warfighter

Air Mobility Battlelab

Making Innovation Practical for Rapid Global Mobility



Questions?

Capt John Yerger 20 Jun 06

DSN 650-7608

john.yerger@mcguire.af.mil



PALL

TECHNICAL PRESENTATION Total Contamination Management







Gary Rosenberg Marketing Manager Pall Aeropower Corporation June 20, 2006



Presentation Outline

- Hydraulic System Contamination
- System Contamination Sources
- Recommended Solutions
- Field Demonstrated Results



Contaminated Hydraulic Systems Reported in 2004:

Aircraft Sampling: Particulate Water Mule Sampling: Particulate Water

23% Class 9 or Above35% 200 ppm or Above

33% Class 9 or Above34% 200 ppm or Above

Hydraulic System Contamination Reduces Service Life.

Aerospace Hydraulic System Contamination

Contamination Impacts System Performance:









- Accelerated component wear or failure
 - Pumps, Motors, Actuators, Valves
- Accelerated bearing fatigue
 - Pumps, Motors
- Fluid breakdown
- Surface Corrosion
- Pump cavitation, increased fluid temperature
 Pumps, Motors, Actuators, Valves
- Fluid oxidation
- Reduced fluid stiffness

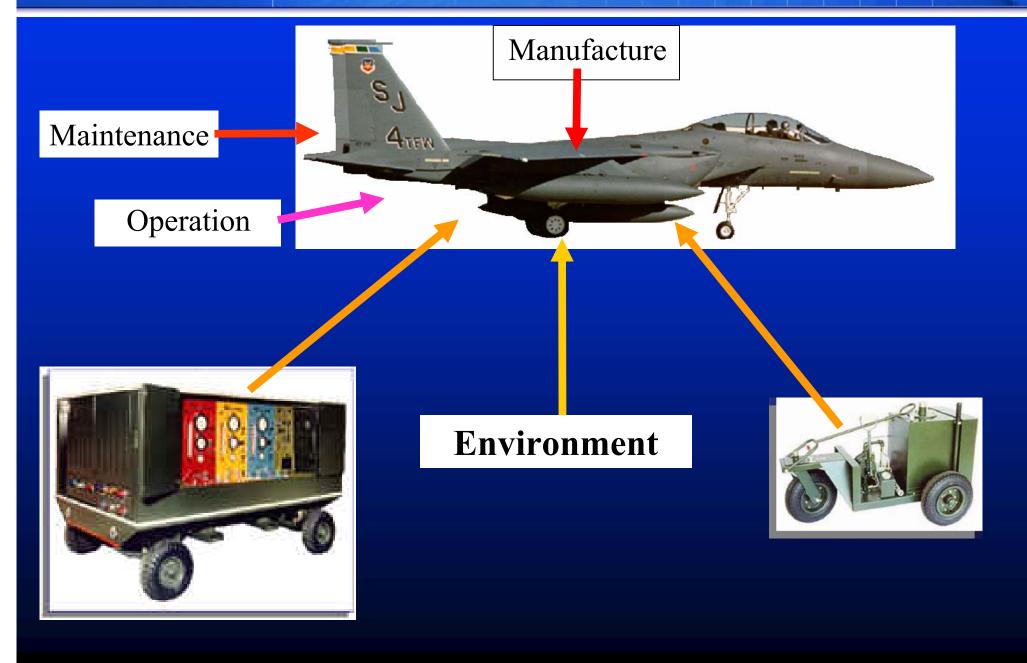


Field Surveys conducted at Robins AFB, Eglin AFB and Jacksonville National Guard Identified issues with:

- Aircraft In-System Protection
- Portable Hydraulic Test Stands
- Portable Service Carts
- Bulk oil distribution

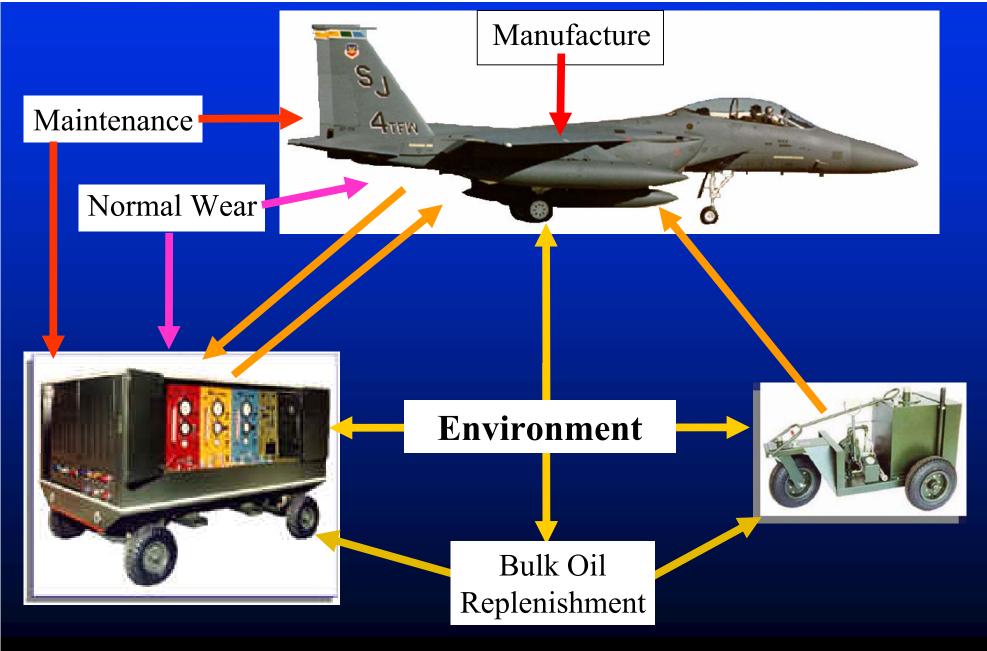


Sources of Aircraft System Contamination





All Sources of System Contamination





Aircraft Hydraulic System Filter Upgrade:



Replace: 15 Micron absolute

With: 5 Micron absolute ACC552F1605



–Flush system with ground cart fitted with MIL-F-81836 filtration prior to new filter installation
–Improve aircraft cleanliness to NAS1638 Class 5 or better





Existing Equipment



Open Reservoir Vent Water and Particulate

Existing Discharge Filter Particulate

MIL-F-27656 Non-Bypass 5 micron to 150 psid 18 micon to 4500 psid







Existing Equipment

Existing Discharge Filter Particulate

MS28720-12 50 psi Bypass 150 psid Collapse 30 micron





Open Reservoir Vent Water and Particulate





Improve Discharge Filter Control Particulate

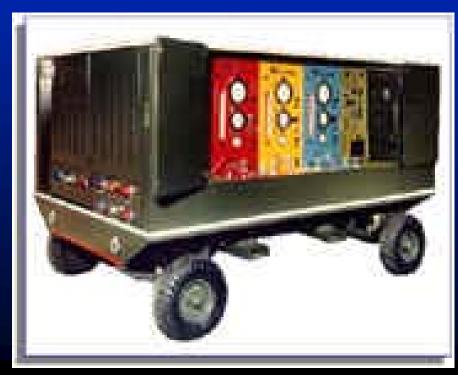
MIL-F-81836 Non-Bypass 3 micron to 5000 psid

Adapt to MIL-F-81836





Protect Reservoir Vent Control Water and Particulate





PROPRIETARY TO PALL AEROPOWER CORPORATION









Upgrade Discharge Filter Control Particulate

MS28720-12 Envelope Non-Bypass 3 micron filter 5000 psi Collapse Protect Reservoir Vent Control Water and Particulate









Portable Fluid Purifier

Water, Air & Particulate Removal



40 Years of Oil Purification Experience

- Small, light-weight, energy efficient and highly mobile
- Designed to maximize ease of use, economy, reliability, and maintainability
- Operates unattended for extended periods of time with built-in safety features
- Can be used to clean:
 - Portable Test Stands
 - Service Carts
 - Back-shop Test Benches
 - Bulk Oil Distribution

Portable Fluid Purifier

Tested & Certified

Aerospace

- Removal of contaminants without the degradation of the working properties of the fluid being purified
- Does not use any fluid damaging processes:
 - High Vacuum
 - High Temperature
 - Desiccant Materials







Portable Hydraulic Test Stands and Stationary Test Benches

Protect vents from ambient contaminants



Reservoir Vent Filter/Dryer NSN: 4330-01-287-4060

•Upgrade GSE High Pressure Filters:

using Adapter:



•Monitor system for water contamination

3 micron MIL-F-81836

NSN: 4330-01-047-1118

NSN: 4920-01-046-8190

Water Sensor NSN: 9390-01-508-6464







PROPRIETARY TO PALL AEROPOWER CORPORATION





Portable Hydraulic Service Carts





Reservoir Vent Filter/Dryer NSN: 4330-01-287-4060

•Replace Discharge Filter Assembly: Non-bypass Filter Housing with 3 micron M81836/4-8 Filter Element

•Monitor system for water contamination

Water Sensor NSN: 9390-01-508-6464



•Use a Pall Portable Fluid Purifier to: Remove Air, Water, Particulate and Solvents NSN: 4330-01-522-2007

PROPRIETARY TO PALL AEROPOWER CORPORATION







TCM of GSE was demonstrated at Eglin AFB with the following aircraft system results:

Particulate:NAS1638 Class 5 or BetterWater:100 PPM or LessAir:75% Reduction by Volume



Improved Support Equipment

Integrated Fluid Purifier and Portable Test Stand:







Integrated Purifier and Test Stand



Includes:

- Upgraded
- Filter Elements
- Reservoir Vent Filter Dryer
- Fluid Purifier

Integrated Test Stand operated for the Hydraulics IPT at Robins AFB

Aircraft Systems

erospace

- Use GSE which has been upgraded with vent protection, MIL-F-81836 filtration and has been cleaned with a portable fluid purifier.
- Flush aircraft system to remove manufacturing and assembly debris as well as air prior to initial aircraft operation
- Upgrade filters from 15 micron to 5 micron



Practice Total Contamination Control

GSE Systems:

Aerospace

- Protect reservoir vents from water and particulate
- Use non-bypass filter housings
- Use 3 micron filter elements IAW MIL-F-81836
- Monitor and service filter elements as required
- Use fluid purifier to clean fluid and reservoir
- Control bulk oil contamination levels







FLUID PURIFICATION BRIEFING

Military Aviation

Fluid & Lubes

Workshop

20 - 22 June, 2006

Hope Hotel

Wright-Patterson AFB



Our History . .

Established in 1935 as "Malabar Machine Co." in East Los Angeles, we were considered at quality Machine Shop attracting business from several large aviation firms. In a couple short years, our relationship with Lockheed Aircraft Company in Burbank produced the first Aircraft "Tripod" Jack and Patented Locknut. Malabar was very busy during the War Years manufacturing a variety of Aircraft Jacks for B-29's, B-24's, DC-3's, DC-4's, etc.

After WWII, we spent a short time as a Division of MENASCO Manufacturing Company and added Railroad and Automotive Jacks to the product line. The early 1950's started a series of changes in ownership and a relocation to the Bay Area.



INTERNATIONAL FLUID PURIFICATION BRIEFING; 16-18 November 2004

In 1968 MALABAR was acquired by E.D. Sweetland ("Gene") of the Sweetland Company a west coast distributor of hydraulic and pneumatic components.

In 1978, MALABAR moved to Simi Valley, California, our current location.

In 1993, Gene passed away, with E. D.Sweetland Jr ("Dave") assuming responsibility as Chairman & CEO.

MALABAR expanded its facility in 2001 for production of an anticipated 600 of the HTS units. We have added a total of 25,000 Sq. Ft. which includes new administration offices, HTS Test Cell, and increased space for inventory and assembly activities. Malabar International is fully staffed "In-House " for all Manufacturing, Engineering, Test, Contract Administration, Quality Control, and Sales/Marketing Requirements.



MALABAR INTERNATIONAL FLUID PURIFICATION BRIEFING; 16-18 November 2004



Welding and Fabrication Area with Full Overhead Crane Capability.

Machine Shop Area which includes CNC and Manual Machine Tools of varying Vertical and Horizontal capability.



MALABAR

INTERNATIONAL FLUID PURIFICATION BRIEFING; 16-18 November 2004

Test Facilities





225 Ton Dynamic Hydraulic Jack Test Fixture

HTS Test Cell

MALABAR

INTERNATIONAL FLUID PURIFICATION BRIEFING; 16-18 November 2004

USAF Automated Hydraulic Test Stand

 In 2000 Malabar was awarded a contract for approximately 600 test stands with purification systems.





Each test stand includes a purification system to comply with Executive Order 13101 "Greening the Government"

MALABAR

INTERNATIONAL FLUID PURIFICATION BRIEFING; 16-18 November 2004

FLUID PURIFICATION CAPABILITY

- Vacuum Distillate Process
- Fluid is sprayed under pressure into a vacuum chamber and circulated through a 2µ absolute particulate filter.
- Fluid Contaminants are removed and fluid is returned to "Original" Properties.

MALABAR

FLUID PURIFICATION PROCESS

- Remove dissolved air to less than 8% from 12%
- Remove dissolved water to less than 100 PPM* from 600 PPM *ref: MIL-PRF-5606 fluid
- Remove chlorinated solvents to less than 50 PPM from 300 PPM
- Remove particulates to ISO 16/14/11 (NAS 5) from ISO 22/20/17 (NAS 11)
- Test sample: 40 gallons of contaminated fluid
- Test run: 8 hours at WP-AFRL

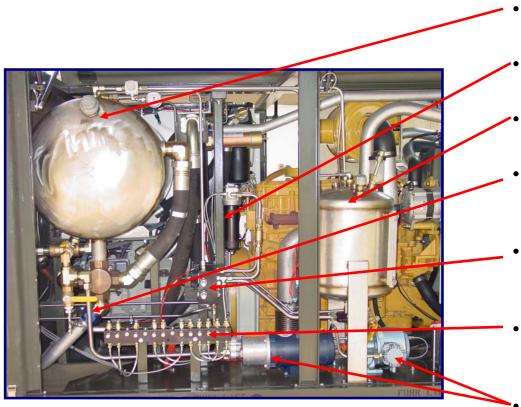
MALABAR

HTS Control Panel



MALABAR

HTS Purification Subsystem



- MAIN RESERVOIR
 - FILL/PURIFICATION FILTER
 - VACUUM RESERVOIR
 - FILL/PURIFICATION SUCTION LINE
 - FILL/PURIFICATION VALVE MANIFOLD
 - PRESSURE TRANSDUCER MANIFOLD
 - FILL/PURIFICATION PUMP and MOTOR, VACUUM PUMP

MALABAR

MALABAR Model 8852 Stand-Alone Fluid Purification Unit

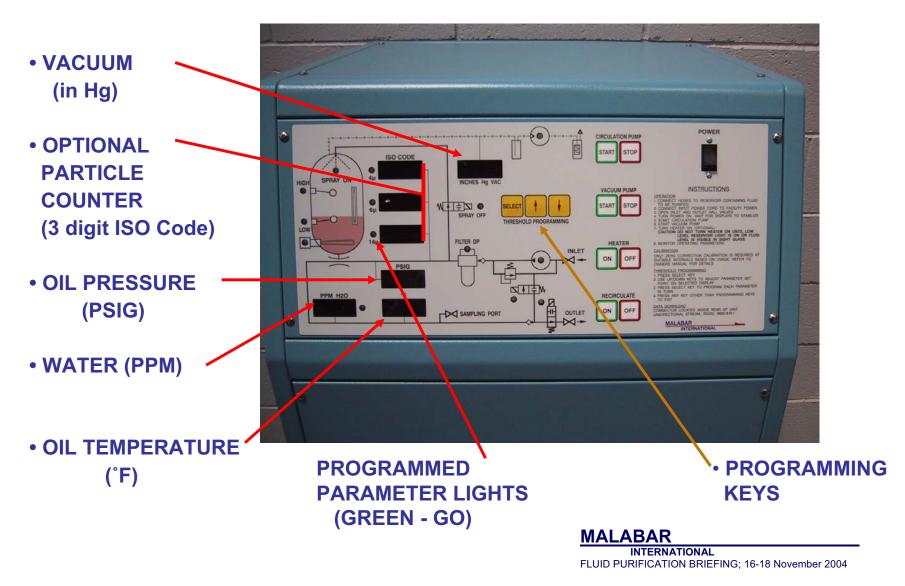
Current Users:

- Lockheed Martin
 -MIL-PRF-83282
 -MIL-PRF-87257
- NASA -MIL-L-23699
- WP-AFRL -2 test units



MALABAR

Model 8852 Control Panel



Model 8852 Specification:

FEATURES:

- Rugged and compact construction
- Available in three configurations:
 - Stationary
 - Portable (with 4 inch casters)
 - Mobile (with tow handle and 10 inch foam filled tires rated for 20 MPH)
- Multiple fluid pass operation
- Multi-fluid capability:
 - Aircraft hydraulic fluids
 - Lubricating oils and industrial fluids
- Low watt density heater
- Microprocessor control including:
 - Digital displays
 - Transducers
 - Start-up and safety shutdown protocols
 - Programmable go/no go set points
- Automatic level, flow, temperature and vacuum control
- Audio and Visual alarms
- Dual power choices:
 - 120/240 VAC, 1 phase or 12/24 VDC
- Limited warranty: 1 year

SPECIFICATIONS

- Flow Rate : 4 GPM
- Process Rate : 1 GPM
- Operating Pressure : 100 PSIG
- Ambient Temperature : -20°C to +55°
- Maximum Viscosity : 2500 SSU
- Power Consumption : 2.5 KW
- Power Supply Options : 120V, 50/60 Hz, 1 Ph 230V, 50/60 Hz, 1 Ph 24 VDC
- Fluid Immersion Heater : 1000 watt (15 watts/sq. in)
- Vacuum System : 27.5 in. Hg maximum
- Processing Reservoir : 8 gallons, stainless steel
- System Alarms : Filter condition, Low vacuum, High pressure and High temperature
- Electrical Compliance : Stationary NEMA 4
 Portable NEMA 4 and
 NEC article 513

MALABAR

Air Force Research Laboratory Testing

- PUMP TEST
- Completed January 2002
- Confirmed Malabar Process does not degrade Fluid Properties

- PURIFICATION
 TESTING
- Completed July 2003
- Validated Contamination Removal
- Met or Exceeded WR-ALC Purchase Description Requirements.

MALABAR

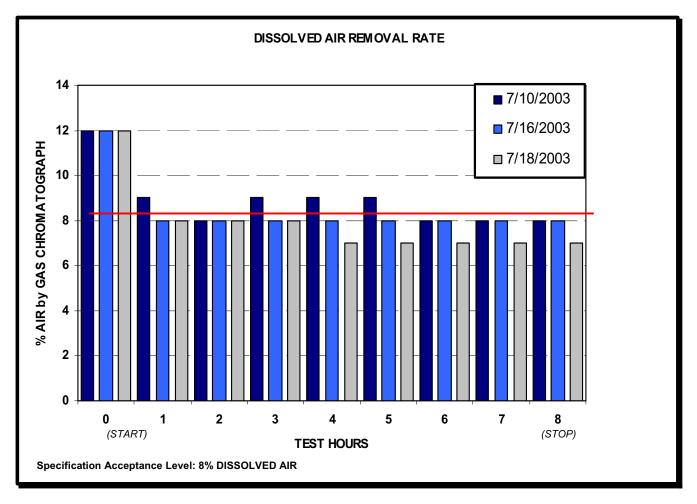
WPAFB AFRL Purification Testing – JULY 2003

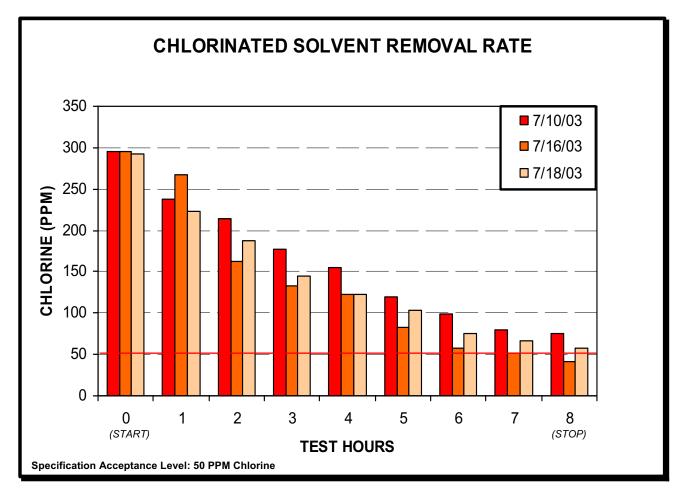


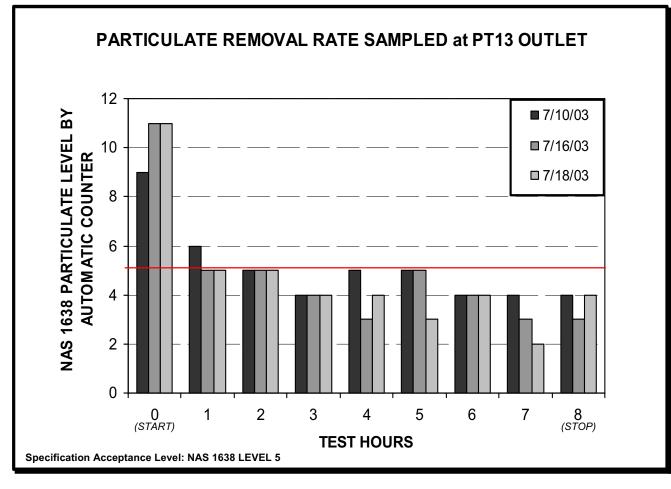


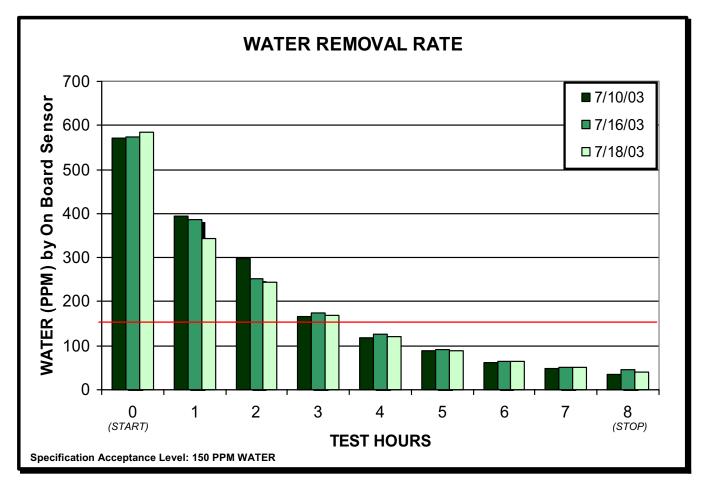


MALABAR









MALABAR TEST STAND ANALYTICAL DATA

7/10/2003

TEST HOURS	WATER (PPM)		CHLORINE ppm		% AIR	PARTICULATE NAS 1638		
	METER	KF	(PPM)	(PPM)*	by GC	PT12	PT13	OUTLET
0	570	513	399	236,252**	12	10	9	10
1	395	302	309	198,208**	9	9	6	6
2	297	219	267	162	8	7	5	7
3	167	160	227	127	9	7	4	5
4	119	122	204	106	9	7	5	8
5	89	98	153	85	9	7	5	5
6	63	84	141	57	8	5	4	5
7	49	71	114	45	8	5	4	5
8	36	69	101	51	8	6	4	4

*Rerun using different gas chromatograph after samples stored in refrigerator for several days

** Chlorine was determined on these two samples that were setting out of refrigerator

7/16/2003

TEST HOURS	WATER (PPM)		CHLORINE ppm			% AIR	PARTICULATE NAS 1638		
	METER	KF	RUN 1	RUN 2	AVG	by GC	PT12	PT13	OUTLEI
0	573	464	295	296	295	12	11	11	11
1	387	346	290	245	268	8	4	5	5
2	253	243	160	164	162	8	3	5	5
3	174	139	132	135	133	8	5	4	5
4	125	126	126	120	123	8	-4	3	6
5	90	90	80	84	82	8	4	5	5
5	65	66	57	58	58	8	4	4	5
7	51	56	51	51	51	8	5	3	5
8	45	44	40	44	42	8	5	3	5

7/18/2003

TEST HOURS	WATER (PPM)		CHLORINE ppm			% AIR	PARTICULATE NAS 1638		
	METER	KF	RUN 1	RUN2	AVG	by GC	PT12	PT13	OUTLET
0	584	455	293	293	293	12	11	11	11
	342	334	226	221	223	8	5	5	6
2	245	237	192	184	188	8	4	5	6
3	169	171	146	145	145	8	4	4	5
4	120	117	123	120	122	7	5	4	6
5	89	90	105	101	103	7	4	3	6
6	65	69	76	75	76	7	4	4	4
7	52	44	69	63	66	7	2	2	3
8	40	46	60	54	57	7	2	4	3

USAF

WPAFB - AFRL Materials and Manufacturing Directorate

Test Dates: 7/10, 7/16, 7/18, 2003

MALABAR



INTERNATIONAL

220 West Los Angeles Avenue Post Office Box 367 Simi Valley, California 93062 USA PHONE: (805) 581-1200 FAX: (805) 584-1624 EMAIL: sales@malabar.com WEBSITE: www.malabar.com

MALABAR





Hydraulic Fluid Purification Requirements

June 2006



Al Herman ACSSW/AASS/OB DSN 785-7210 Ext 3915 Email: Alan.Herman@wpafb.af.mil

Keep'em flying & Keep'em relevant



HFP IPT REQUIREMENTS



- Purpose
- Objectives
- Operation
- Membership
- Goals
- Service Evaluation







• Purpose

The Hydraulic Fluid Purification (HFP) Integrated Process Team (IPT) was established to take the common commercial practice of HFP, and conduct a formal three-phase USAF evaluation effort as a pollution prevention project in order to validate HFP and implement purified hydraulic fluid use in USAF aircraft and aerospace ground equipment (AGE)



HFP IPT



• Objective

Bring together those parties responsible for pollution prevention, aircraft/AGE engineering authority, aircraft hydraulic fluid specification, and aircraft/AGE maintenance to evaluate, discuss, and implement HFP

Reduce the second largest fluid waste stream in the USAF by providing timely, thorough, and factual data to the USAF aerospace community to support and implement aircraft/AGE hydraulic fluid purification







- Operation Principal Members
 HFP IPT Manager
 - Lead Command Executive Agent
 - Air Force Research Lab
 - MDS Aircraft Engineering Authority



HFP IPT Duties



Dominant Air Power: Design For Tomorrow...Deliver Today

•HFP IPT Manager

- Chair HFP IPT meetings at mutually agreed upon location
- Provide HFP IPT progress reports on action items
- Present the HFP program to the aircraft/AGE SPOs
- Lead Command (AMC) Executive Agent
 - Assist the IPT manager and interface with MAJCOMs
- Air Force Research Lab (AFRL)
 - Provide Technical Support for hydraulic fluid sampling/analysis
 - Provide Technical Support for purification equipment evaluation/qualification
- Each MDS Aircraft Engineering Authority
 - Provide feedback and assistance to ensure the IPT addresses their concerns, to expedite implementation of fluid purification on their MDS
 - Provide endorsement/declination letters to show support/non-support for the HFP program







- Membership
 - Voting Members Of The HFP IPT
 - AASS/OB
 - MAJCOM Functional Managers
 - AFRL/MLBT
 - ASC/ENV
 - WR-ALC/LESG
 - AMWC/WCB Air Mobility Battlelab
 - Aircraft System Wings



HFP IPT



Dominant Air Power: Design For Tomorrow...Deliver Today

Advisory Agencies

Aircraft System Program Offices

- WR-ALC/LTEM (C-5/C-141)
- WR-ALC/LBRSM (C-130)
- ASC/VFM and WR-ALC/LFEF(F-15)
- ASC/YCE (C-17)
- OC-ALC/LCRM (KC-135)
- ASC/YPV (F-16)
- ASC/YFABU (F/A-22)
- OC-ALC/PSBEF (B-1)
- OC-ALC/PFLR (B-2)
- OC-ALC/LHRH (B-52)
- OO-ALC/LCEM (T37/38)
- WR-ALC/LUH (MH-53/HH-60/H-1)
- NAVAIR (CV-22)



HFP IPT



- Specific Goals
 - Evaluate HFP equipment/process
 - Evaluate contamination levels in aircraft, AGE hydraulic test stands (HTS) and hydraulic servicing carts
 - Educate and inform the USAF aerospace community



HFP IPT



- Evaluate HFP equipment/process
 - Ensure the HFP process effectively removes contamination
 - Ensure the HFP process does not degrade fluid properties
 - Qualify specific HFP equipment for authorized use by the USAF
 - Ensure future AGE compatibility for purification equipment interface
 - Improve mission capable rates, war fighting capability, and flight safety
 - Reduce maintenance burden
 - Reduce overall hydraulic fluid procurement and disposal costs



HFP IPT



- Evaluate operational (in-service) hydraulic fluid contamination levels in aircraft and AGE hydraulic test stands (HTS) and hydraulic servicing carts
 - Determine operational contamination levels.
 - Determine a baseline for purification
 - Establish an in-service fluid cleanliness standard for aircraft, HTS, and other applicable AGE
 - Quantify expected overall cleanliness improvement gained through HFP
 - Minimize HFP manpower impact



HFP IPT



- Educate and inform the USAF community
 - Provide HFP information to: pollution prevention office, aircraft program engineering, MAJCOM aircraft hydraulic functional managers, and aircraft maintainers
 - Disseminate findings from laboratory research and testing
 - Perform field demonstrations of purification equipment



HFP IPT



- Establish HFP guidelines and procedures
 - General T.O.s
 - AGE T.O.s
 - Applicable AFIs
 - Weapon system specific technical orders
 - Identify TAs



Service Evaluation Plan



- Complete a 2 Year Service Evaluation
 - Use portable purifier to purify mules
 - Sample Mules and Aircraft before and after purification is implemented
 - Purify all mules upon receipt of portable purifiers and after use on aircraft
 - Purify after major hydraulic component change (WUC tracked in MDC)
 - Purify whenever contamination is suspected (in lieu of drain & flush)



Service Eval Goal



- Our Goal is to evaluate:
 - Reductions in waste stream by implementing HFP
 - Reduction in new fluid procurements
 - Impact on maintenance workload as a result of HFP
 - Improvements in component life
 - Improvements in hydraulic system performance



Field Requirements



- Request Field Units complete the following:
 - Provide a record of prior hydraulic fluid procurements (One year prior to purification)
 - Provide a record of prior waste disposal (One year prior to purification)
 - Track and report replacement of serially controlled hydraulic components
 - Track and record new hydraulic fluid procurements
 - Track and record disposal of waste hydraulic fluid







- Request Field Units complete the following:
 - Provide feedback on ease of use and maintenance of the portable purifier
 - Provide feedback on parts required for the portable purifier
 - Provide feedback on functionality and usefulness of the portable purifier
 - Provide feedback on the impact on maintenance man-hours of hydraulic systems



Field Requirements (Cont'd)



- Cost savings initiative:
 - Track Hours to operate purifiers
 - Materials or supplies requirements
 - Fluid life extension
 - Increase/Decrease in aircraft O&M \$\$\$\$ (if possible)



Lessons Learned



- Document implementation experiences
- Processes Developed
- Identify T.O. Changes
- Share lessons learned with USAF



Service Evaluations





Hydraulic Fluid Purification

927 ARW Aircraft Charts



KEVIN HIBBS 927 MXG DSN: 273-5179

OVERVIEW

- Procedures
- Particle and water count
- Aircraft and Mule Results



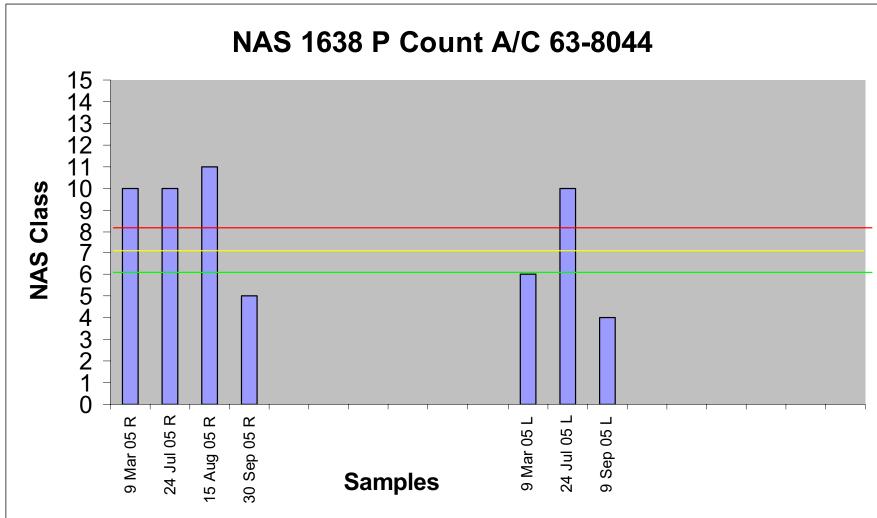
- Results of initial samples indicate some samples may have been improperly taken. Or Mule contaminating our aircraft.
- Easy to contaminate sample when taken
- Shop Test Stand
- Barrel Sampling

Aircraft purification Procedures

- Purifying minimum of two hours:
- Fluid level to twenty-five gallons:
- Best course of action:
- Initial purification procedures:

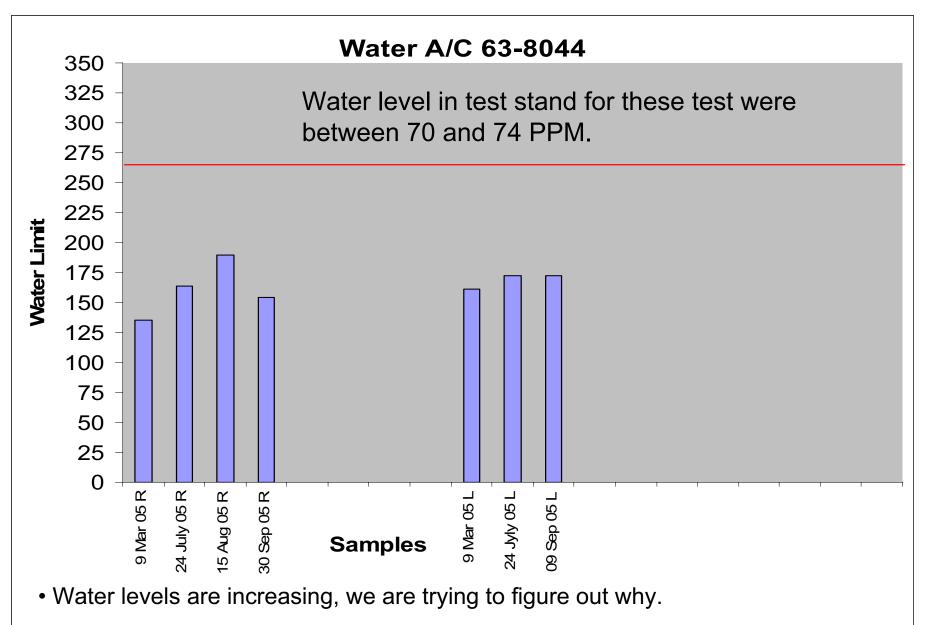
Tracking

- AFTO form 22 submitted:
- Landing gear sample results
- Mule Samples
- Aircraft Samples
- Waste Drum Samples

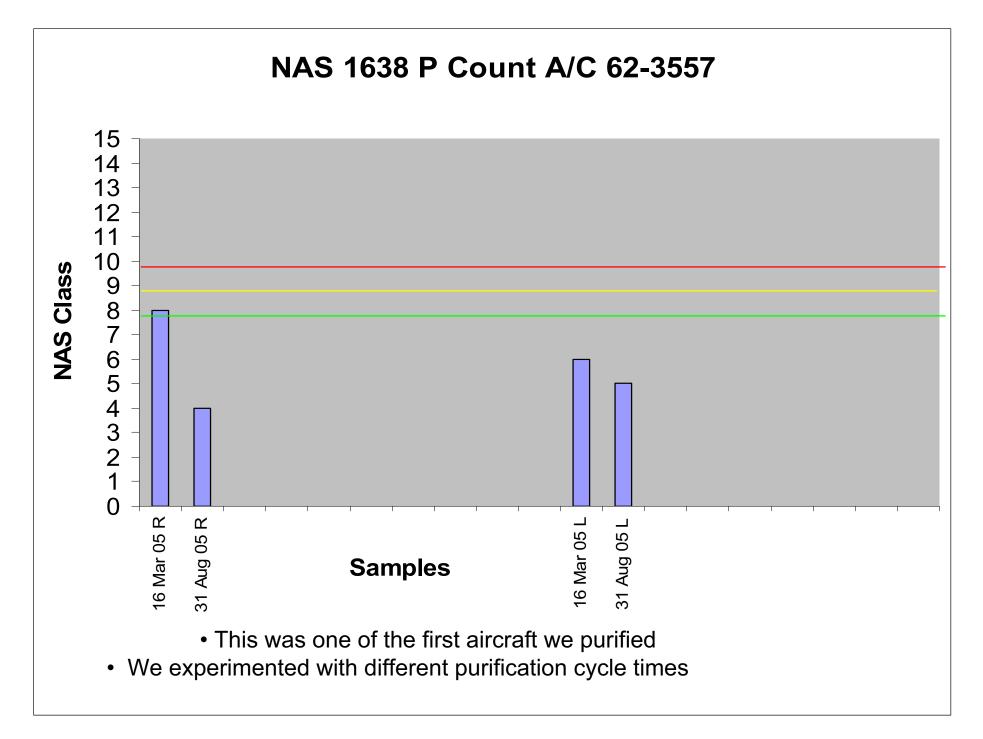


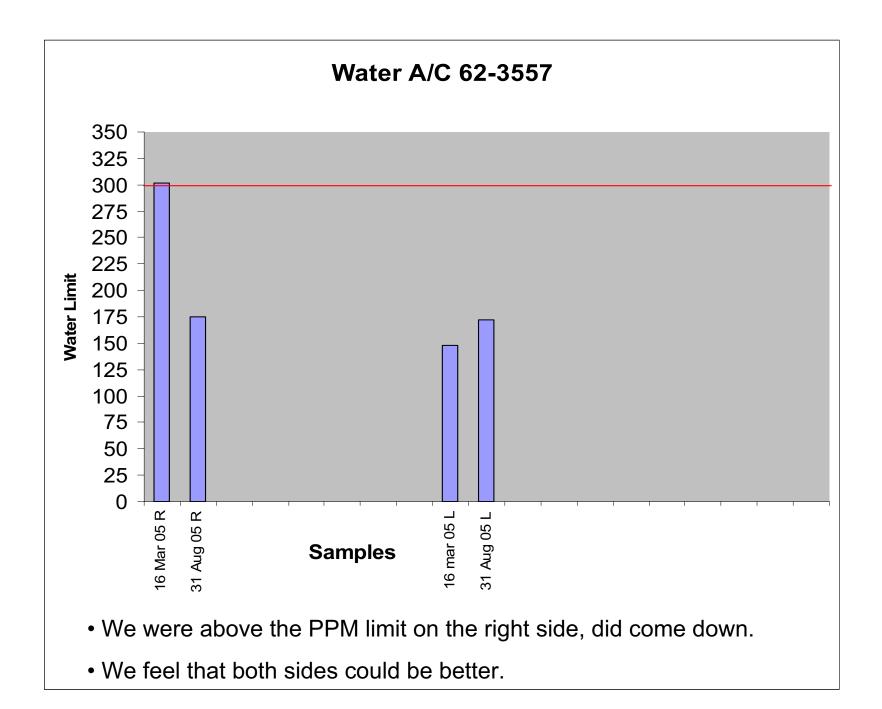
• Right System particle level high, Multi sensor would have been a great benefit.

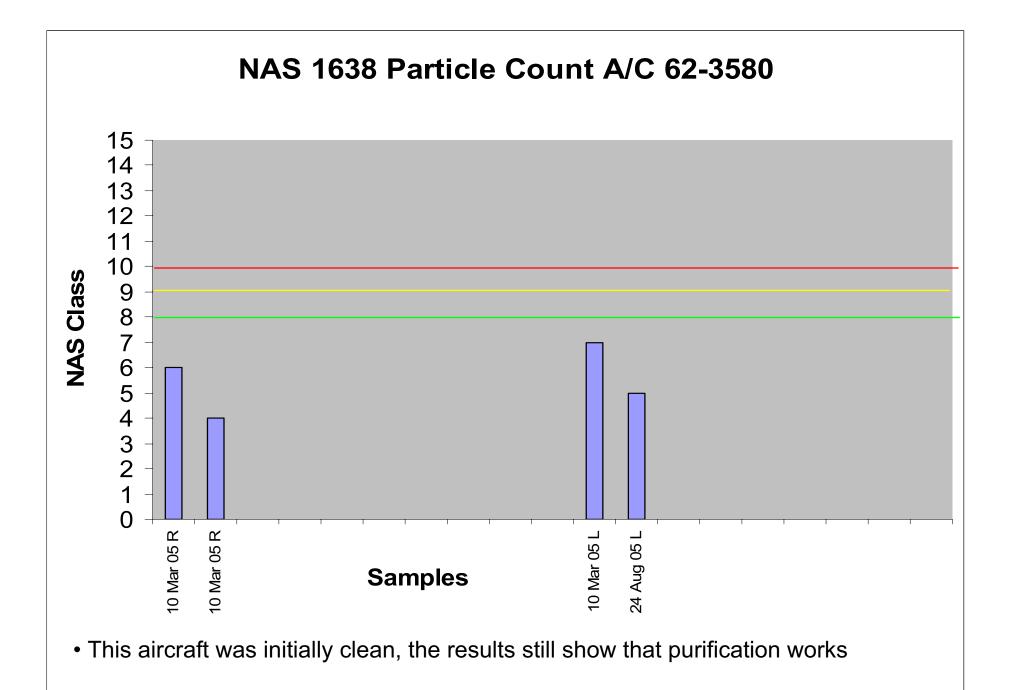
• Second samples may have been contaminated during sampling or contaminated by the mule

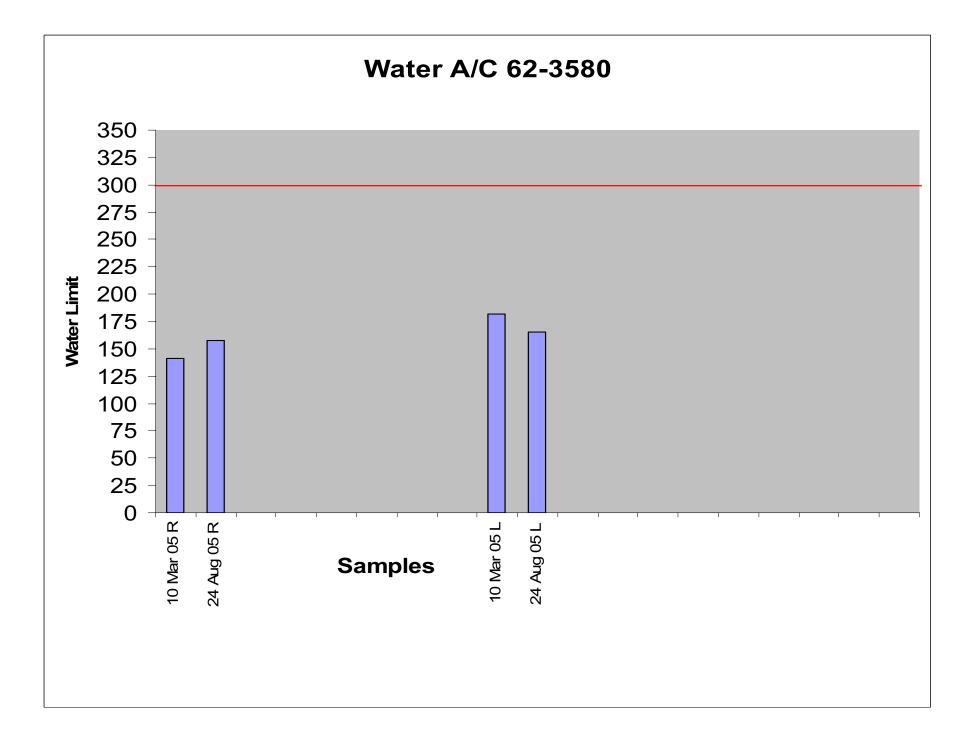


• Levels remain well within acceptable levels.









Aircraft Summary

- Our aircraft do not look to bad.
- If we keep our mules clean we should be able to maintain clean aircraft.
- We believe that an NAS class of 6 or better on each aircraft is possible.
- The increases in our water PPM levels is still in research and testing

Aircraft Summary (Cont)

- Component life enhancement will come using purified fluid
- Life extension results will not be seen for some time
- Particle sensor is needed to give real time indication when fluid is purified

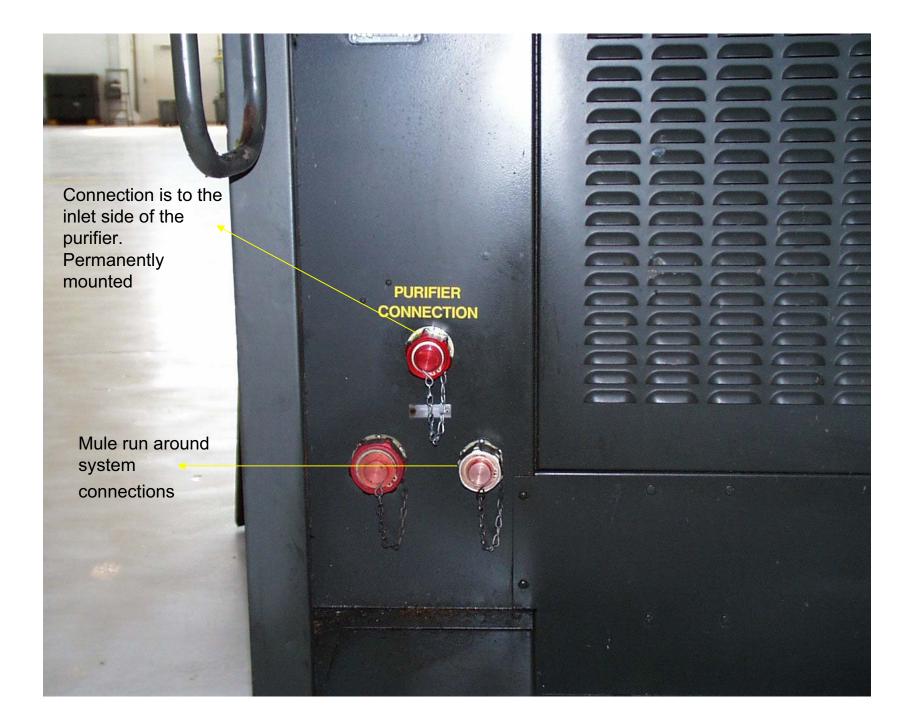
Test Stand Samples (Mule)

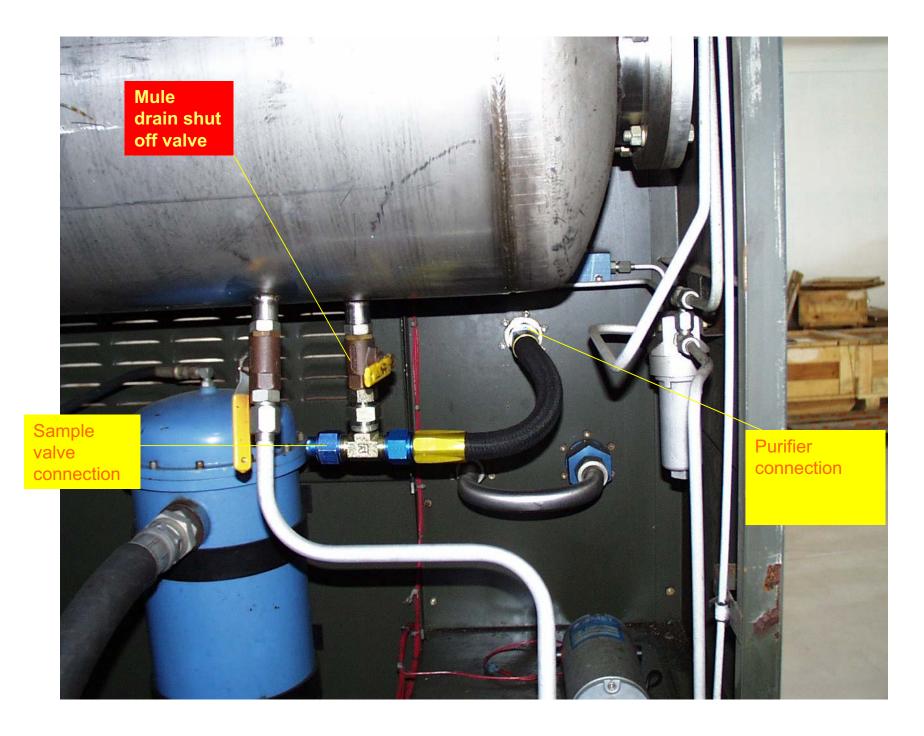
Single system units Two Diesel, one Elect

Particle and Water count

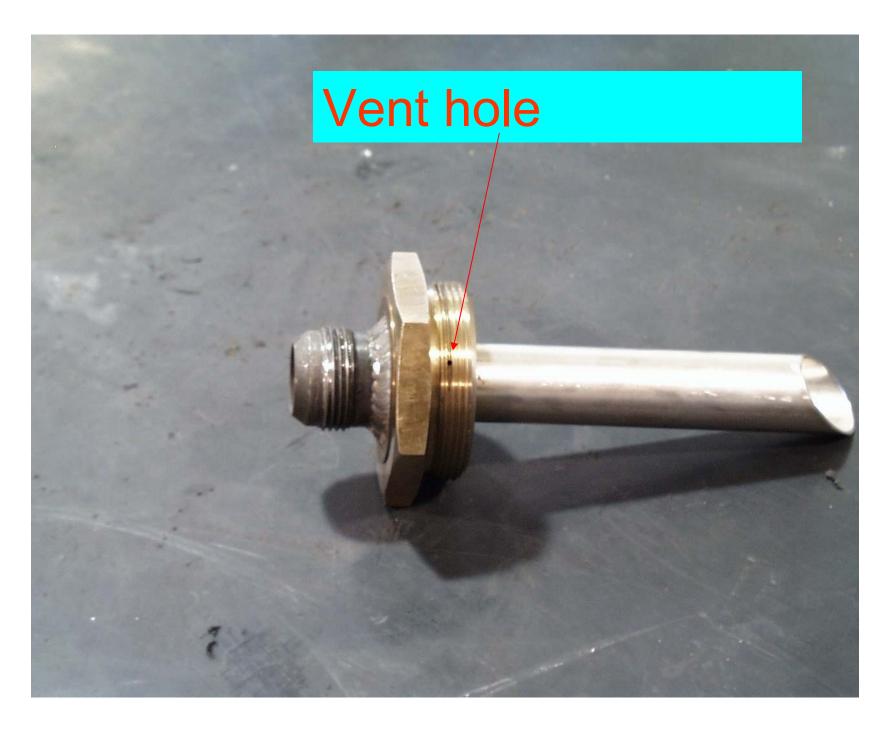
Introduction

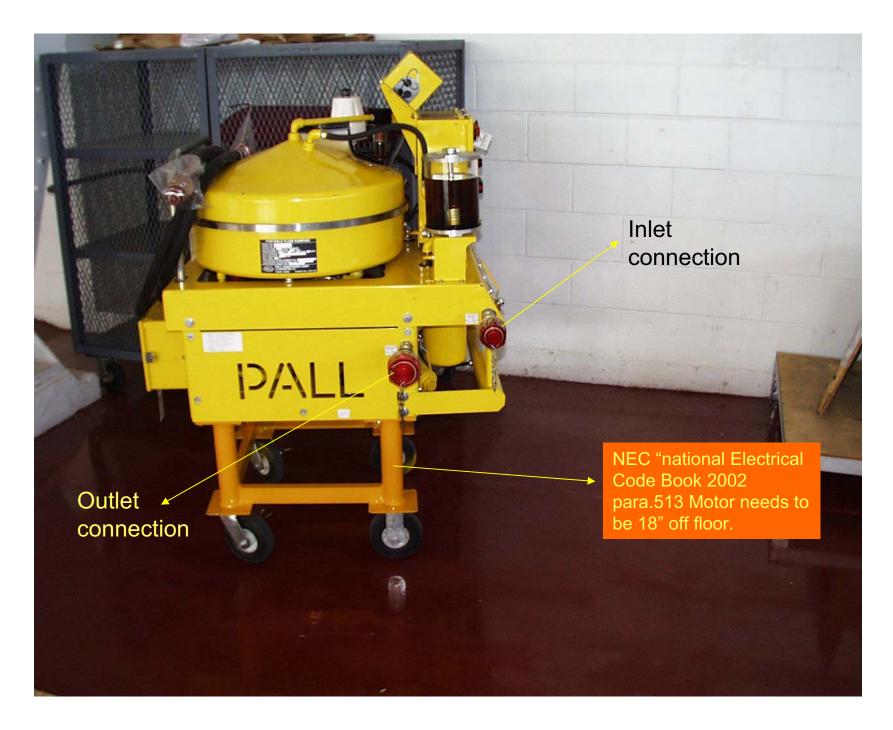
- How we modify the mules?
- How we connect to the purifier?
- How long did we purify test stands?
- Different methods?













This is the inlet connection to the purifier unit from the elect mule Item goes into the reservoir fill neck.



Also connection for drum purification if ever authorized.



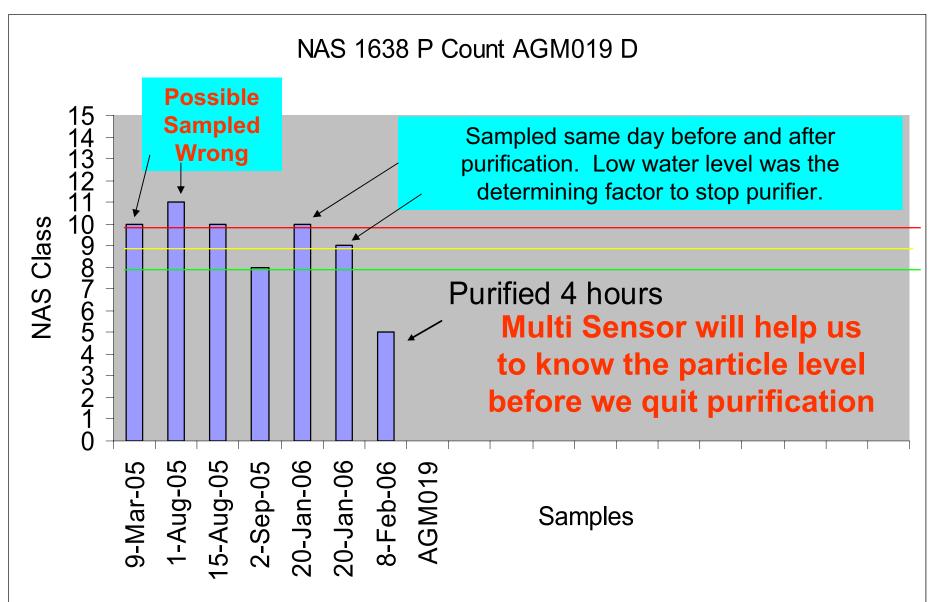
Elect Mule connections proposed





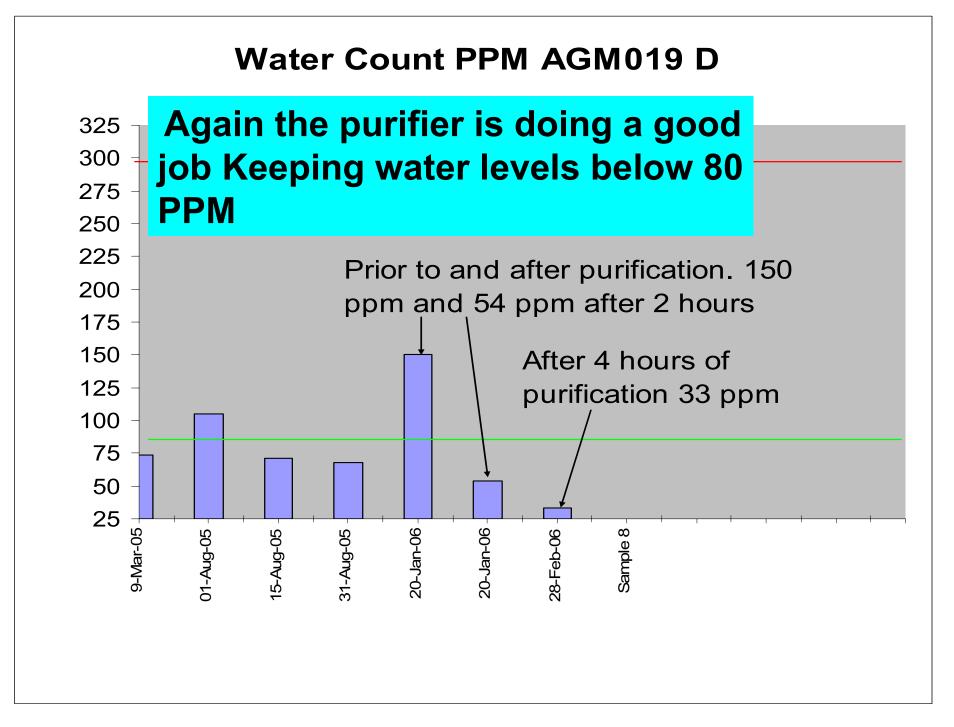
Elect Mule purification connections proposed

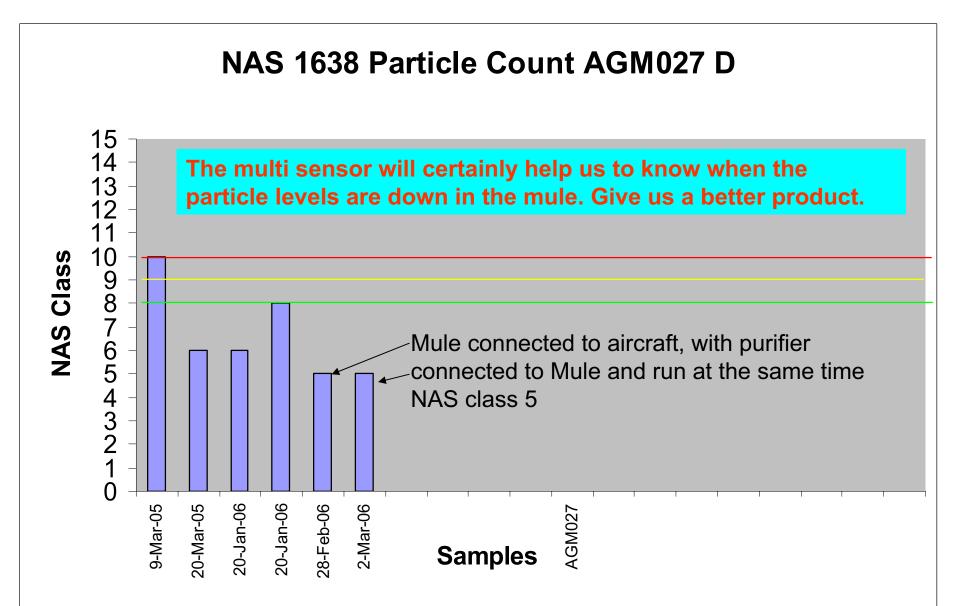




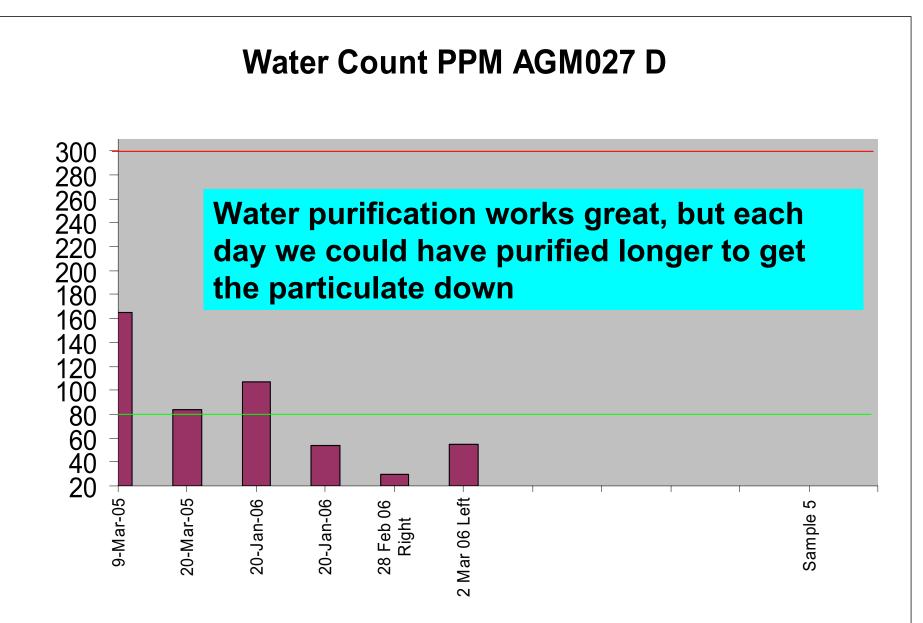
• Particle count remaining high with 2 hour purification

• Switching to using the runaround system for 15-20 minutes prior to and during the purification process.

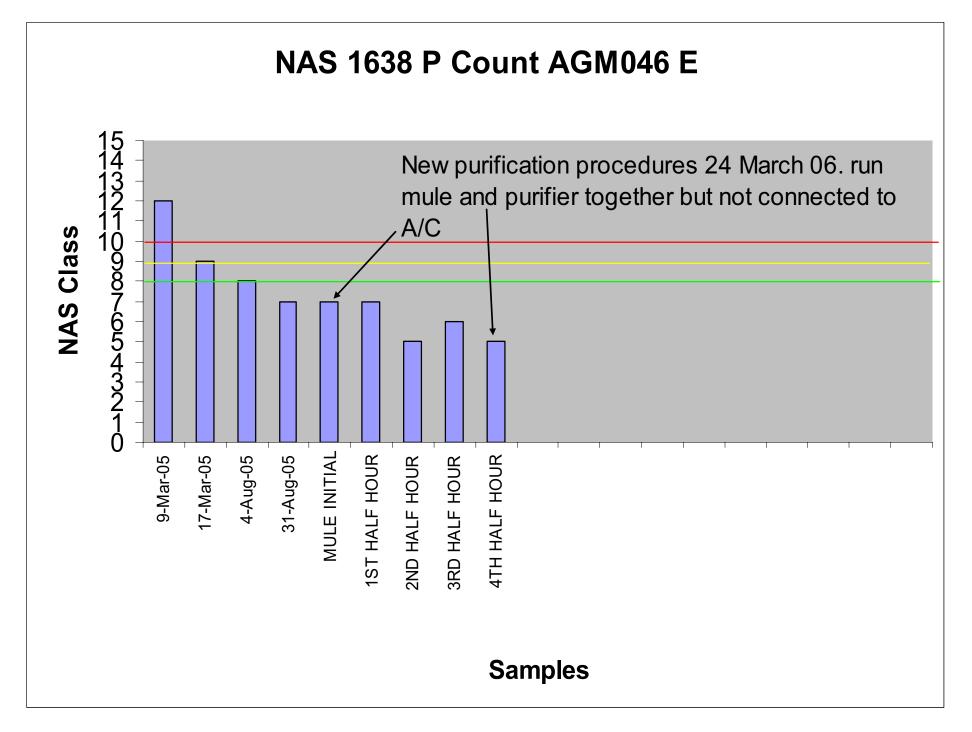




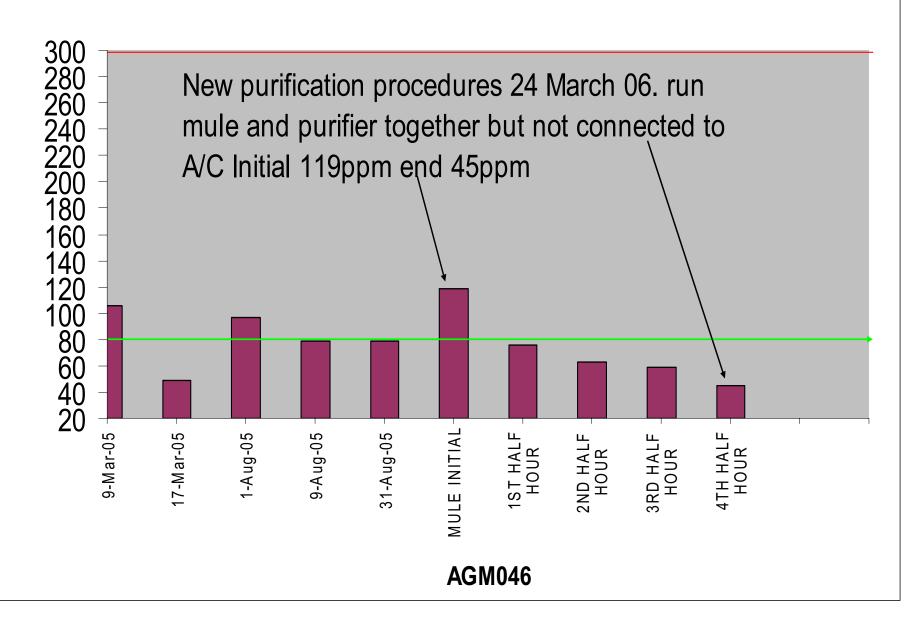
This is a diesel mule, we were having better luck on keeping it clean at two hours. The last two results were with using the runaround system with purification for the first time.



- The last two results were with using the runaround system with purification.
- The water PPM is 30 and 55 respectively.



Water Count PPM AGM046 E



Mule Summary

- Lessons learned?
- What we would like to do?
- How could things be easier/better?

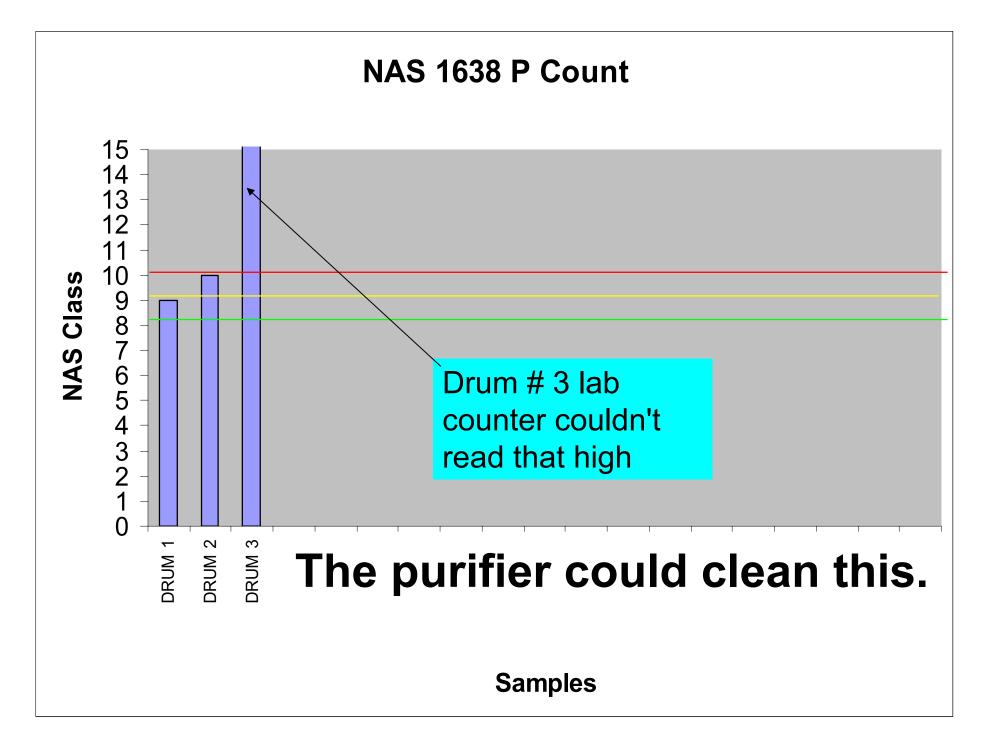
Hydraulic Shop Test Stand

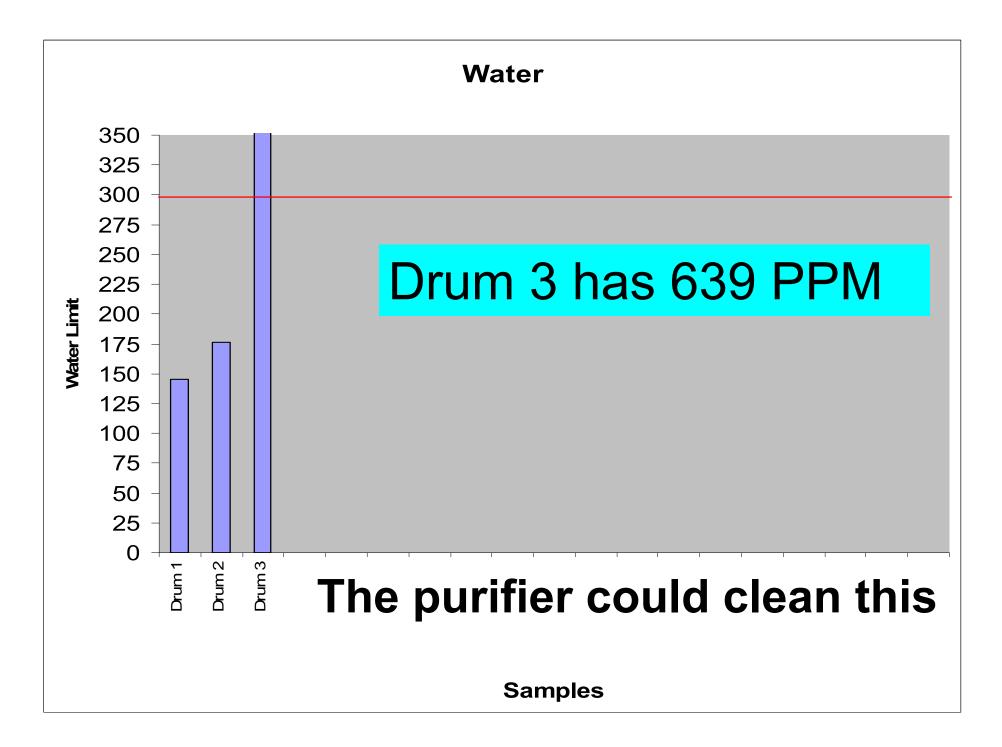
Particle and water count

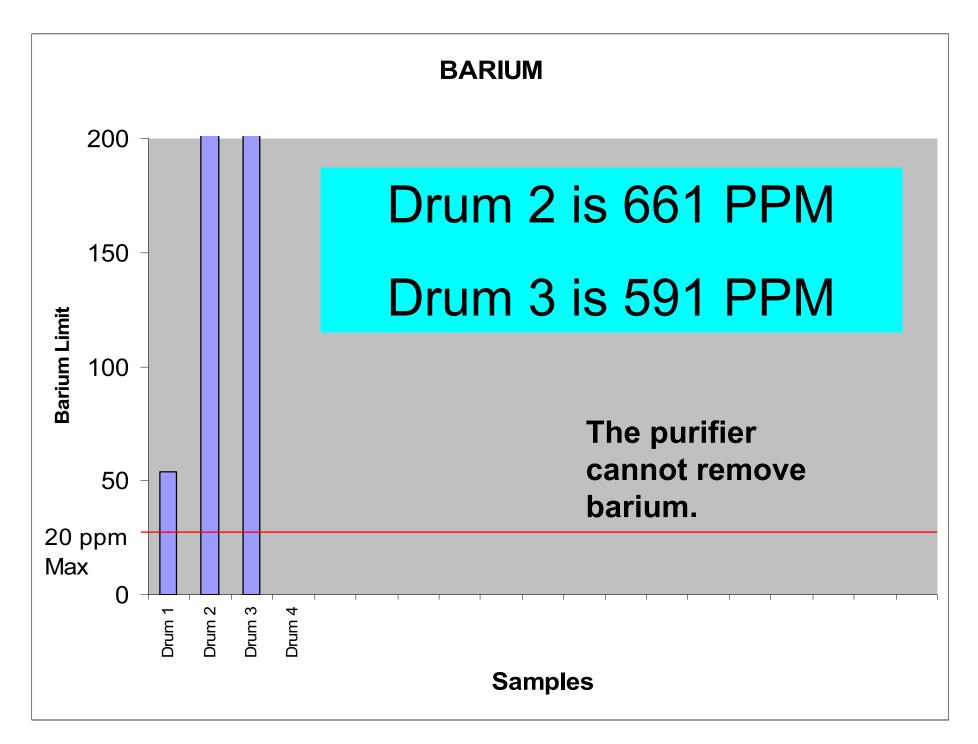
Waste Drum

Particle, Water and Barium Count

- 1) We wanted to see if our drums were purifiable.
- 2) How well we were doing on keeping the fluid in our drums segregated with other fluids. We are doing a great job on the segregating of oils and fuels.
- 3) Our water and particle count does not really matter due to the fact that the purification unit will remove it.
- 4) Our drums are not purifiable because of the high counts of barium.
- 5) We suspect that the fluid from our landing gear struts is the cause of the high barium count. We have taken samples to see if this, in fact, is the cause.





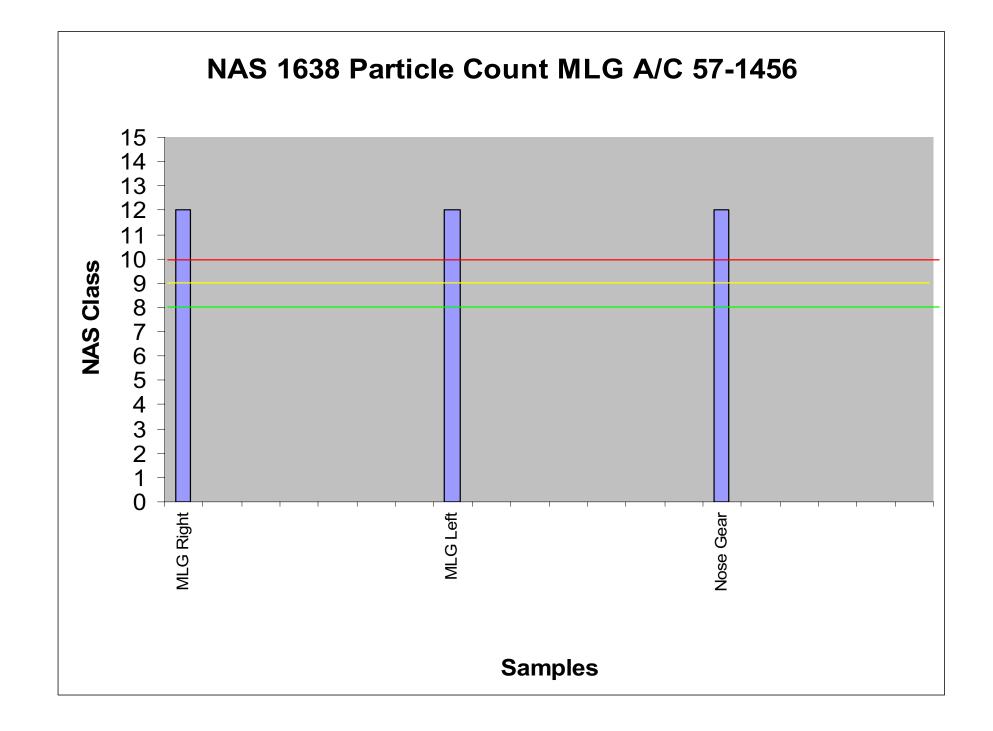


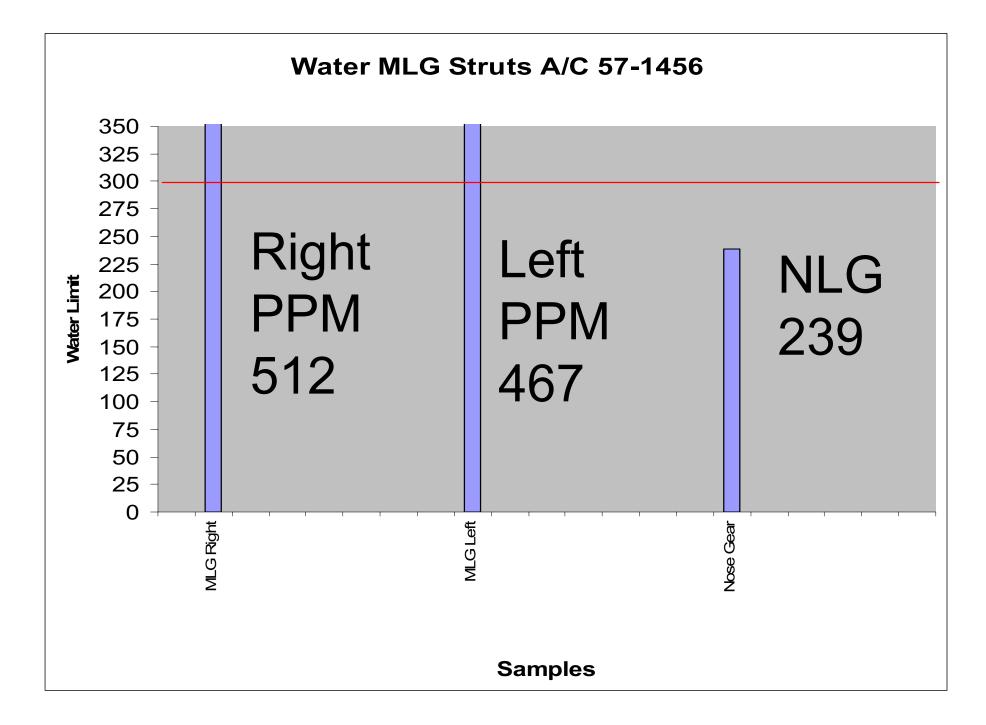
CONCLUSION

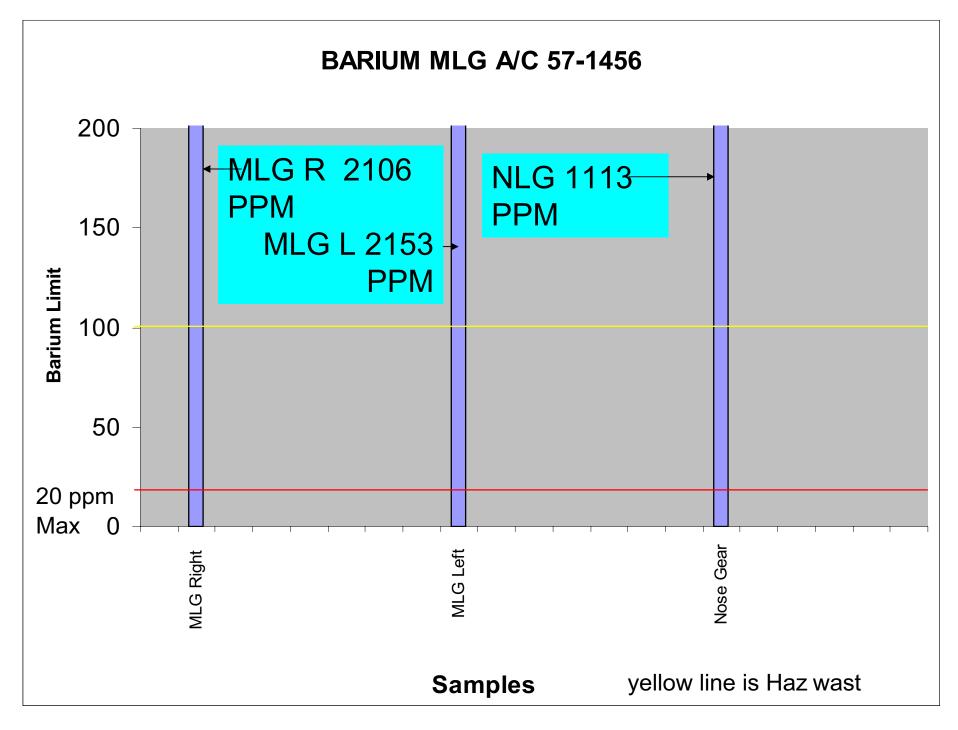
- Barium is coming from MIL-PRF-6083.
 located within our landing gear hydraulic struts, and components.
- If we can control the use of 46170 and 6083 we could control the drum fluids and purify them.

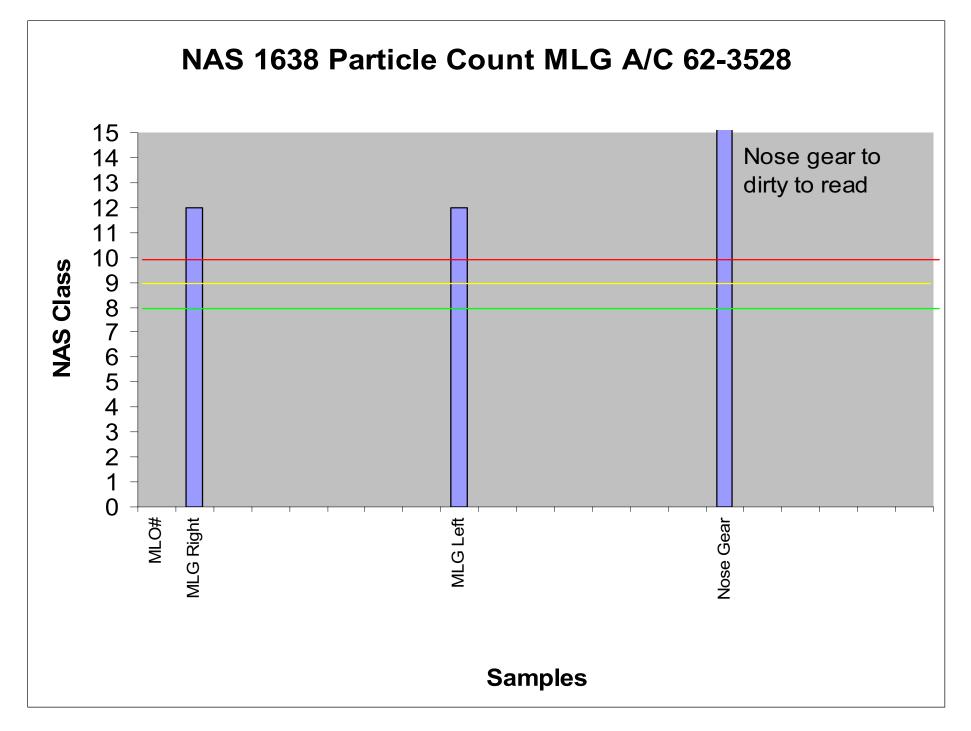
- We must drain components that are serviced with 46170 and 6083.
- We have to get the depots to stop using 46170 and 6083. Received two struts dated Mar 06 with 6083 fluid in them.

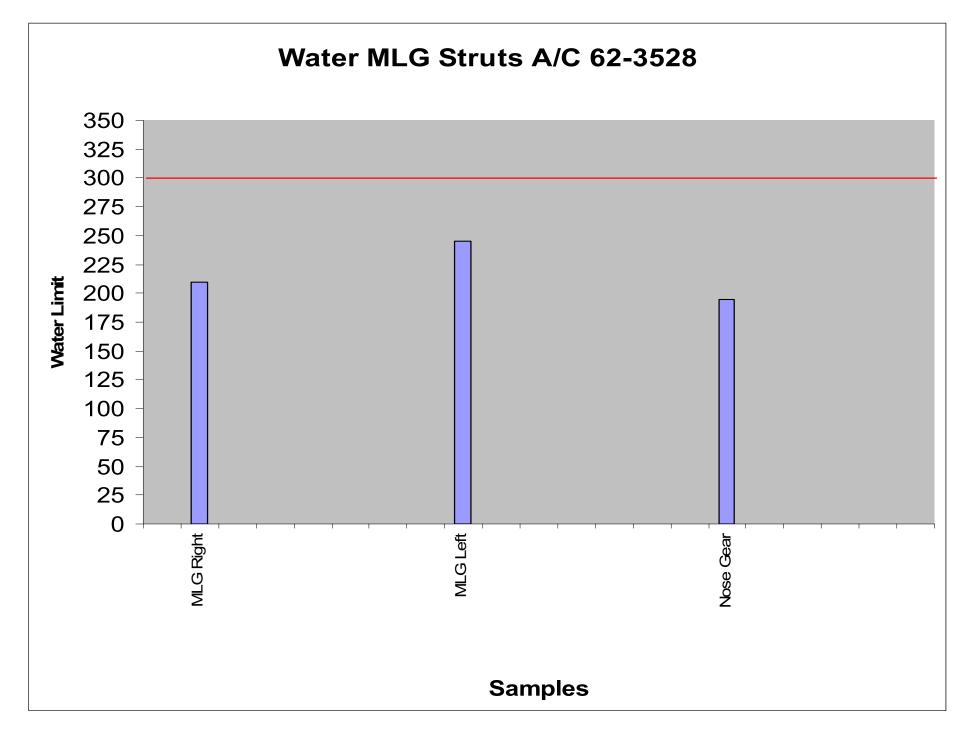
LANDING GEAR SAMPLE RESULTS.

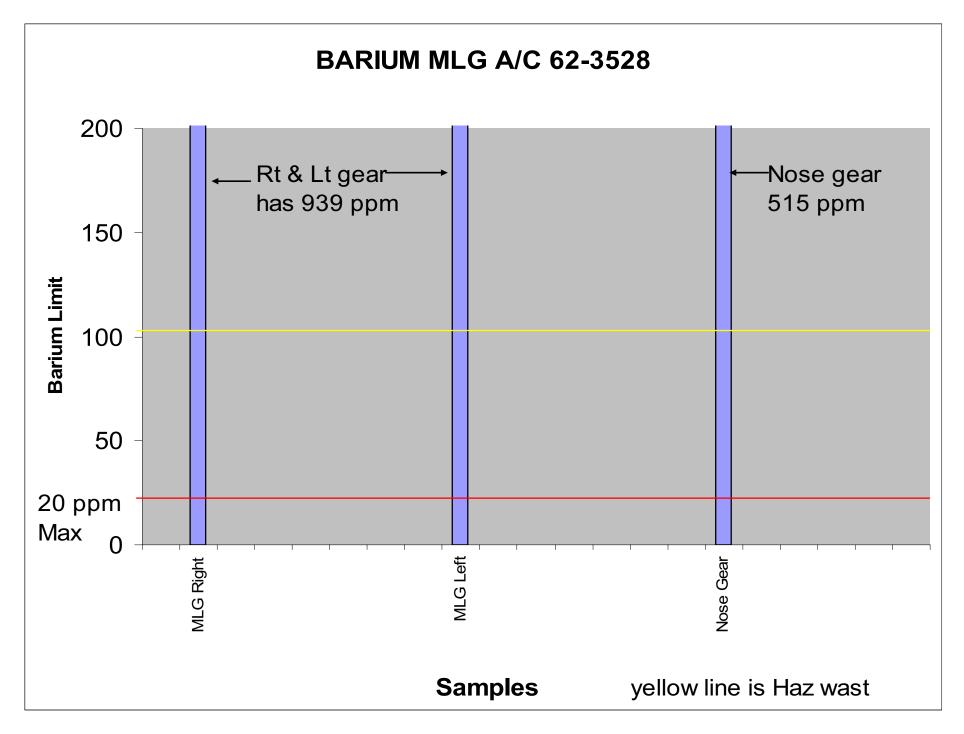


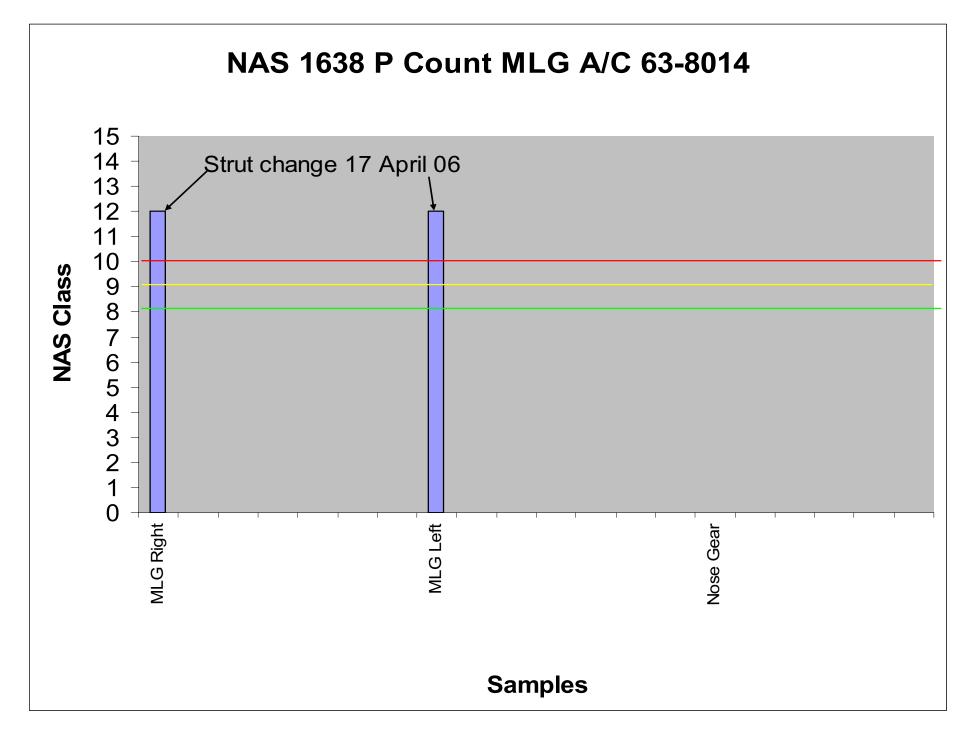


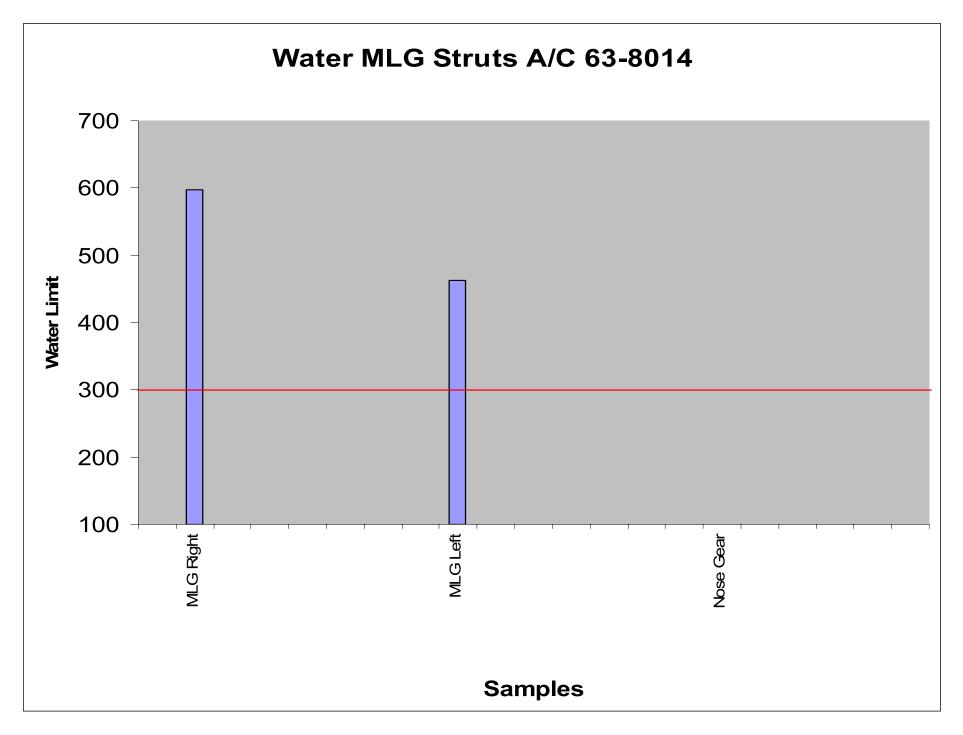


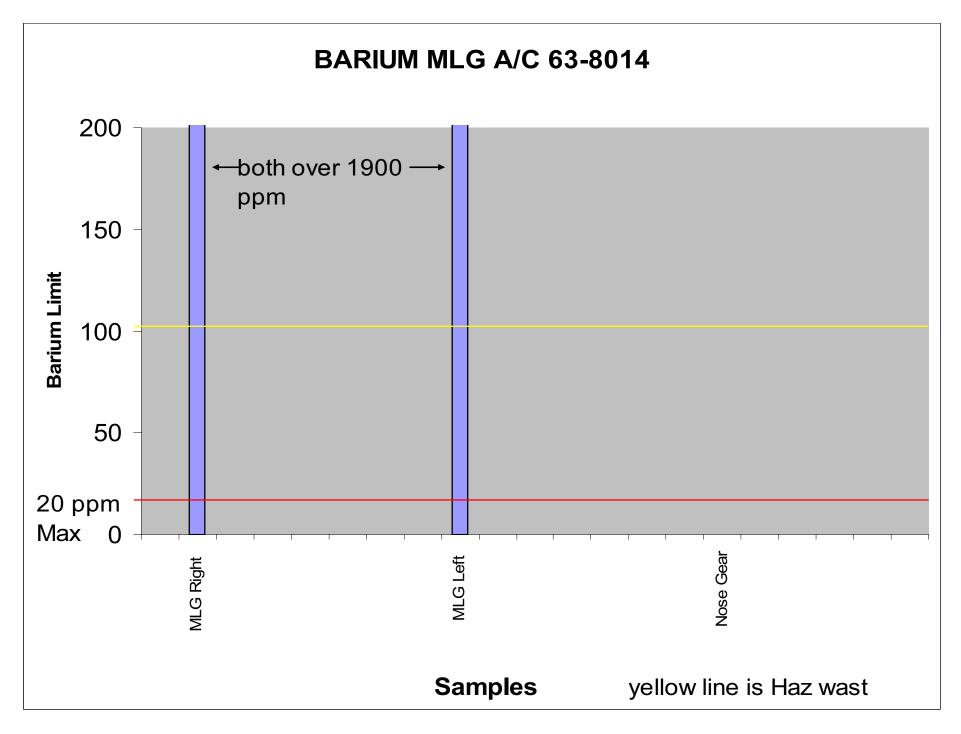












CONCLUSION

- During our ISO inspections. We must drain all landing gear struts for the KC 135. When draining and refilling our struts with 87257 fluid, we seem to be getting the 6083 fluid levels down but not eliminated. We still have high counts of Barium within the landing gear system.
- 6083 and 46170 fluid is not purifiable and has to be rendered as a waste fluid.
- We now need to segregate our hydraulic fluids from our landing gear and aircraft system until we get rid of 46170 and 6083 form all components, and out of the struts and Air Force aircraft and component systems.

- By eliminating 6083 and 46170 fluid, this will reduce our hydraulic fluid waste stream.
- There is no written guidance that we can find on acceptable barium percentages within the aircraft hydraulic system.

QUESTIONS ???



Aircraft purification Procedures

We started these procedures by first purifying the test stand for a minimum of two hours, never going over four hours, maintaining the test stand water PPM below 100 PPM before terminating procedures. We purify the day prior to using the test stand on the aircraft, if possible. We always purify the test stand after each use on any aircraft system. We have noted that we may have been doing our test stand purification procedure improperly. We were not mixing the test stand reservoir fluid prior to purifying. We were under the impression that when we connected to the bottom of the reservoir, that we were in fact at the bottom. We have since learned that there is a stand off pipe of one inch, this is not letting us get all the particles or water off the bottom test stand reservoir. It seems that the purification unit does not mix the fluid as well as we were anticipating. So we are having to mix the fluid with the runaround system on the test stand as we purify or prior to purification.

Our initial test stand set up was to set the test stand reservoir fluid level to twenty-five gallons. This would allow us to drain the aircraft reservoir into the test stand without overfilling. By draining the aircraft reservoir into the test stand reservoir, we increase our total fluid quantity to thirty gallons. By allowing us to drain the aircraft reservoir directly into the test stand, on certain procedures, we are reducing our hydraulic fluid waste stream. This can cause another problem with the overfilling of the test stand reservoir on certain occasions, if the fluid level within the test stand is not properly set.

We determined that our initial best course of action was to take initial samples of all aircraft prior to purification, then go through and purify and sample all aircraft again. Look at the results, re-accomplish any aircraft that was an NAS class eight or higher or with a water count above 200ppm. One thing we did forget to look at the test stand sample results. This could have caused some of our aircraft to have increased particle and water counts. We then proceeded to purify all aircraft during their ISO inspection, and anytime we connect to an aircraft we will drain the aircraft reservoir into a purified test stand, then run our operational check on the affected system only. Then we refill the aircraft reservoir and re-purify the test stand prior to its reuse. We had some problems with this, due to improperly educating our counter parts on the flight line of the proper sequence of events that needed to be followed.

The actual procedures we use to run the aircraft for initial purification process was to hook up and operate two purified test stands one to the right system and the other to the left system. We would cycle the following system through five times, flaps, inboard and outboard spoilers, brakes, rudder, boom hoist, boom telescoping, forward and aft AR pumps for five minutes each and simulated gear retraction, using 3000psi at 10 to 20 GPM. Initially it only took twenty minutes to run each system. We felt that this was not enough time, so for the initial purification process, we ran each hydraulic system for one hour, not to exceed operating limits of each sub system.

One of our standard practices that we set up was to take a sample from the aircraft when we drained the aircraft reservoir into a purified test stand, then ops check aircraft system and re-fill system reservoir. This sample would be taken after the aircraft next flight.

We do not track which test stand we use on which aircraft. We have considered cross contamination as a condition that could result with this action, especially if we do not purify the test stand after each use when draining the aircraft reservoir into the test stand.

Tracking

We are currently tracking our waste disposal, fluid procurement, component failures/replacements and drum fluid quality (mixing of compatible oils within the drum). From 2004 thru 2005 we found that since starting our purification process we have reduced our purchase of hydraulic fluid by 162 gallons and reduced our waste stream by 83 gallons. We are tracking component failures by the quarter but don't expect any real or true results until well after this test has been concluded.

AFTO Form 22 & 1067 submitted and status

We found that within the KC135 job guide, the current particle count table for hydraulic fluid, did not match the recommended NAS class 1638 particle count. We have submitted an AFTO form 22 and was approved to change to align with the NAS table. Initially we had no procedures or SPO approval to drain the aircraft reservoir into the test stand and reuse this fluid. We have submitted an AFTO form 22 and it was approved, to allow use of this fluid without purifying the fluid prior to reusing it on a different aircraft. We also submitted AFTO form 22 on both style of test stands, on how to purify the mule prior to it's use and a test stand purification procedure. Along with that we also submitted an AF form 1067 on permanent test stand connections needed to allow hook up of the purifier and purification of our mules. We have not heard back on these items as of today.

We are taking samples of our waste drums to see how well we were doing on segregation of our oils and fuel from our waste hydraulic fluid. According to the lab we are doing a fine job of keeping all of our waste drums oil segregated, and indeed we would be able to purify our drums but we also found out something that we were not expecting on the drums and I will discuss this information later in the briefing.

Mule information

We saw how the test stands were initially being connected. We felt that having to connect and disconnect every time you wanted to purify the test stand would not work. We wanted something that was going to be quick and easy, it needed to be able to attach to the aircraft and purifier without having to add or disconnect any plumping, it also had to be versatile so if we can purifier drums we would be able to connect to them with zero effort. So we came up with the following connections, (show next five slides) each quick disconnect is the same style and size used on the KC135 aircraft. Initially we used the return hose on the test stand as the return from the purifier unit and it worked great, but when we went to purifying and run the test stand on an aircraft at the same time, that set up would not work. So we came up with the reservoir cap idea. This was the cats meow, we could not ask for anything better, other than another permanent connection on the front of the test stand going back into the reservoir. There were some initial problems with the cap design, at first we did not have an extension pipe attached, so it would leak fluid out of the vent hole when we were running. We figured that the incoming fluid was to close to the vent hole and the air was catching and forcing the fluid back out. So we added a six inch tube and this corrected the problem.

We also used the same type connections on the purifier unit. Our connections were in place and we're moving forward looking for better things. Initially we started purifying the test stands for four hours, this proved to be not working as we are finding out with our samples. We were also not using the runaround system prior to purification. As you will be able to see on our next few slides we were having problems keeping the test stands clean. We had two different methods of connecting the purifier unit to the test stand. Since we had no connection mounted onto the elect test stand we had to remove the cap and metal screen, we then used the connection made for the drum purification process for the inlet to the purifier unit and the return line on the test stand for the return. This worked great, only concern was the time it took to remove and reinstall cap and screen, due to it has seven bolts that needed to be removed and reinstalled each time. On the diesel test stand we used a connection that was mounted onto the test stand as the inlet for the purifier unit and the return line on the test stand for the return. We did seem to get a better cleaning job on the elect test stand than with the diesel test stands.

Earlier this month we tried a different purification method, we used a diesel test stand for this test. We needed to find out if we could in fact bring down the water within our aircraft systems, we proceeded to connect the test stand to the aircraft, then connect the purifier unit to the test stand, (this is where we ran into the problem with the return connection and went to the reservoir cap return) we ran the test stand and cycled the fluid, we turned on the purifier unit at the same time to get the water level down below 70ppm, then ran the aircraft system watching the water level on the purification unit making sure that it did not go above 100ppm. We took test stand samples prior to and after purification, we also will be taking samples of the aircraft system after it's next flight. The sample information received back on the test stand is very encouraging. We also have the complete procedures on this if you would like to review them.

Mule conclusion

- We have learned that water and particles are not removed at the same rate, a particle / water counter is definitely needed for field operations.
- Circulation of fluid; We were not aware that there is a stand off pipe of one inch connected to the drain valve where we made our connections to hook the inlet of the purifier to, we're not getting to the sludge or particles from the bottom of the test stand reservoir. We need to use the runaround system for the mixing of the fluid in the mule reservoir each time we purify the test stand. It seems that the purifier unit will not mix the fluid enough for the short amount of time (4 hours) we run the system. We need to add in the tech-orders, that if you are not purifying the test stand at the same time you are using test stand to run aircraft systems, then you need to use the runaround system for 15-20 minutes while purifying test stand. Or something like that.
- We needed to have a better understanding of how the test stand actually worked. I was under the impression that every time we ran the test stand on the aircraft that we were actually mixing the fluid within the two reservoirs, found out I was wrong and had to re-accomplish purification on one aircraft.
- Definitely need permanent hook up connections on the test stand, and a permanent sample port connection.
- We needed to keep better records, like recording initial and ending water PPM from the start
- Things we are looking to do or concluded that it's not practical for the KC135 aircraft;

1. we are going to try to find out how long we need to run the purifier unit and the runaround system. We will take an initial water reading and sample of the test stand, run the runaround system for 15 minuets at the same time we are purifying it, stop the purifying process at thirty minutes take a water reading and another sample, restart the purifier unit and run for another thirty minutes, take another water reading and sample. continue this process for a total of two hours and check our results. Then connect to another test stand and perform the same checks until all mules are at a NAS class 5 or better.

2. We were looking at trying to hook the purifier directly to the aircraft reservoir, we have come to the conclusion that using the purifier in this manner would not give us our best results, due to we would only be cleaning approximately seven gallons of fluid out of twenty seven.

3. We also look at the possibility of purifying our landing gear struts due to the high water and particle samples. We have determined that it is indeed needed, but is not practical due to the struts would have to be redesigned. We have no way of getting the fluid out and back into the struts.

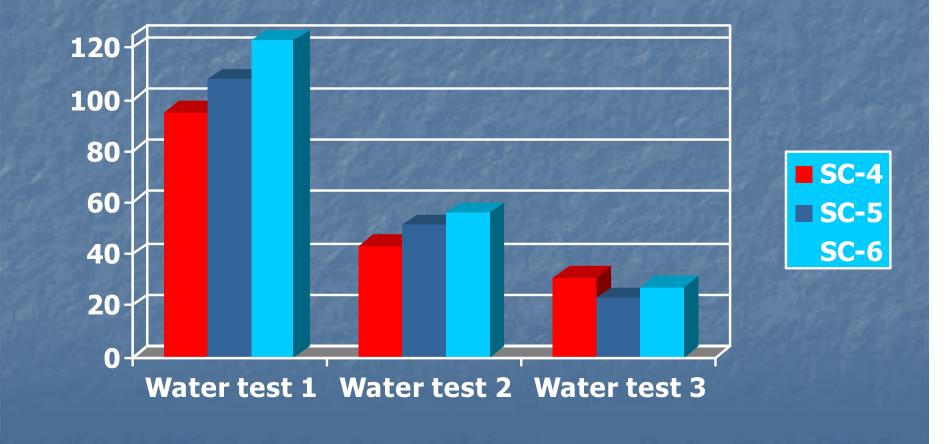
178th Fighter Wing MXS/MXMG



Hydraulic Fluid Purification As Of December 2006

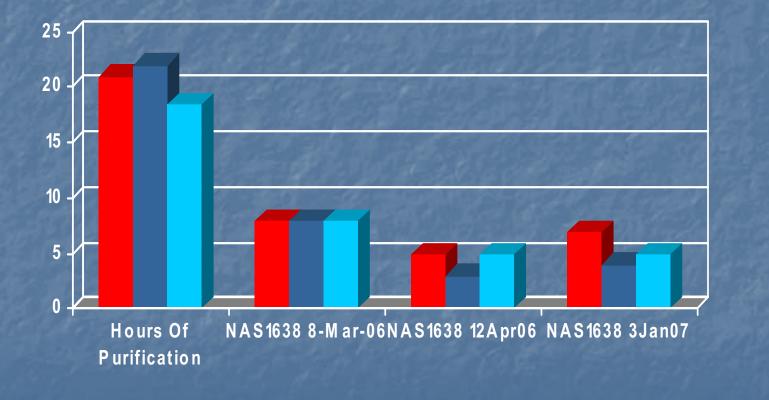
Hydraulic Service Carts

• Water



Hydraulic Service Carts

Particulate
 Hours of Purification



SC-4

SC-5

SC-6

Hydraulic Mules Water Hours of Purification 200 **T**-1 150 **T-2 T-3** 100 T-4 **T-5** 50

Test 4

Test 5

Hours

Test 3

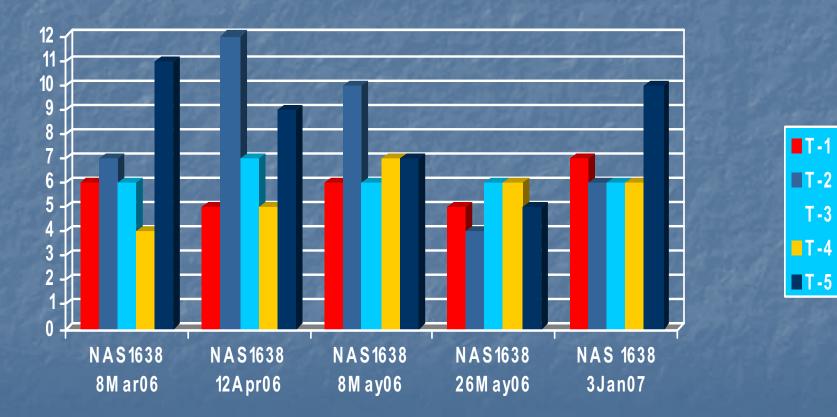
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Test 1

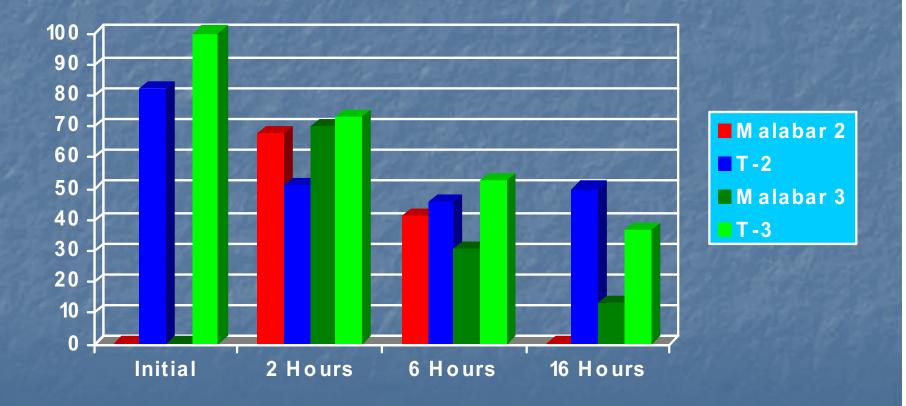
Test 2

Hydraulic Mules

Particulate

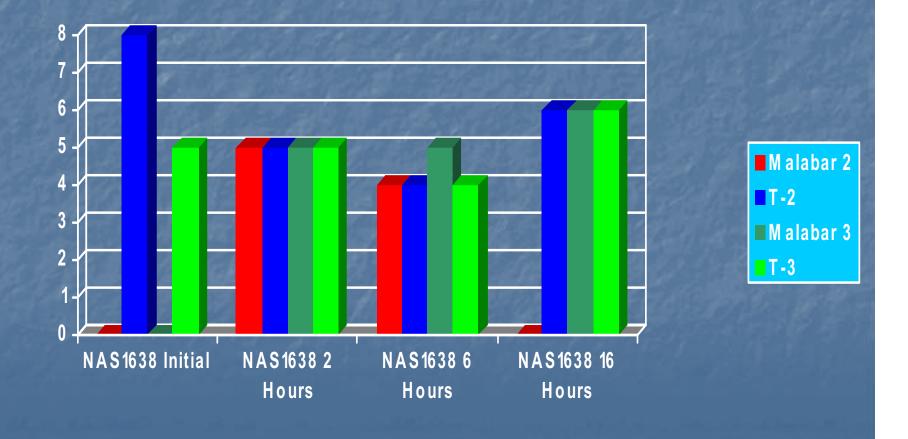


Hydraulic Mules & Malabar Samples Water Hours of Purification

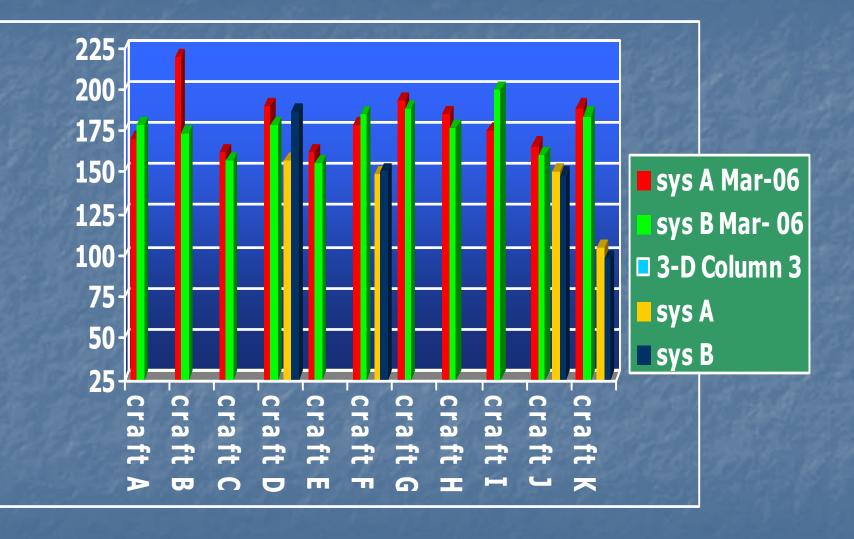


Hydraulic Mules & Malabar Samples

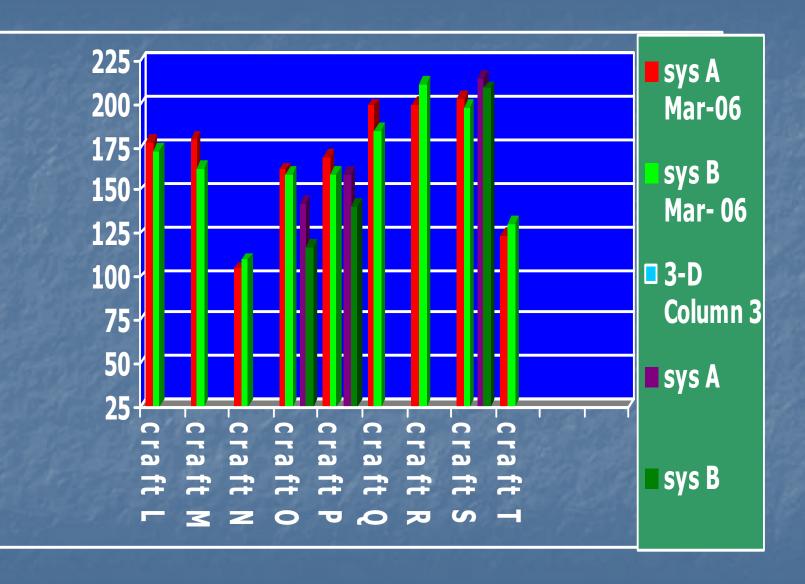
Particulate
 Hours of Purification



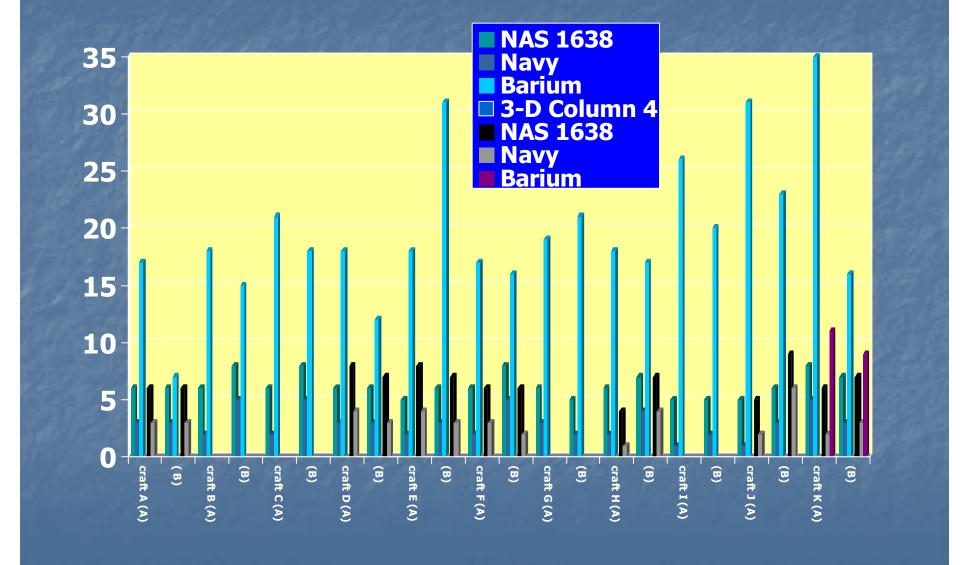
Aircraft F-16 Water Content



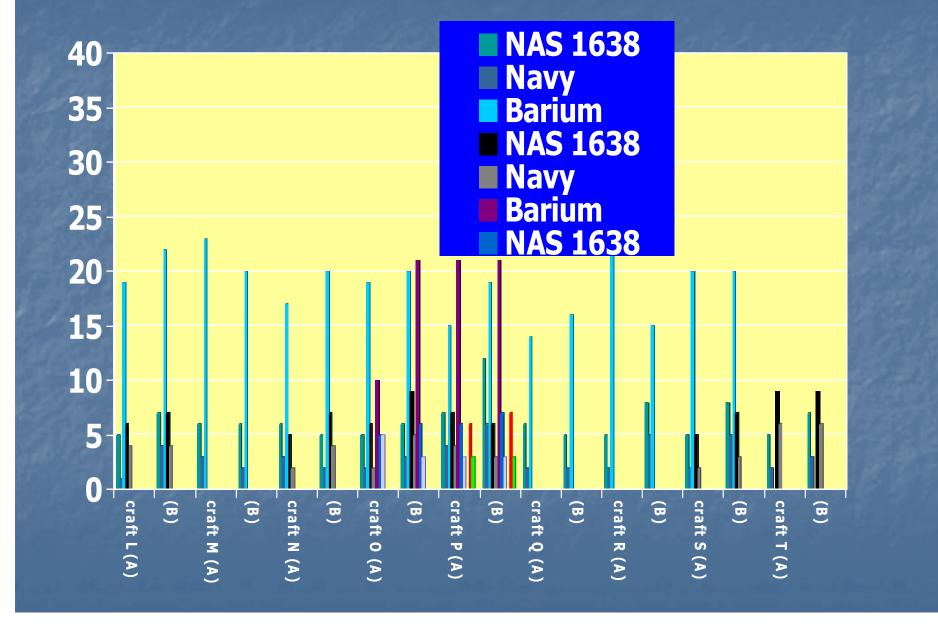
Aircraft F-16 Water Content



Aircraft F-16 Particulate & Barium



Aircraft F-16 Particulate & Barium



- Received Hydraulic purification system on 14 March 2006
- Unit needs to be marked with outlet and inlet
- Bigger casters and tow handle
- Unit Elect. Pump needs to be 18" or more from the ground for safety in hanger.
- Emergency switch to shut down the system if unit over fills.
- Unit manual needs more information on the operation and calibration procedure, and a theory of operation for trouble shooting purposes.
- Unit needs real time for the particulate count I.A.W. NAS1638 (currently has ISO). Spoke with Malabar they said there is a conversion chart.
- We have found that the water ppm is fairly accurate.

- Personnel in the phase docks have been stating that they are getting the flight controls and gear swings done in half the time.
- After around 320 hrs. of operation the low level switch was sticking, we called and Malabar sent a new switch no other problems after replacement.
- After around 350 hrs. of operation the ISO indicators on the control panel started reading "99" and would not reset back to "0" so we could get some type of indication on how dirty the fluid was, talked to Malabar and was told to follow calibration instruction in the book but the book is not clear on how to fix the problem.
- On June 14 2006 after 396.25 hrs. of operation the vacuum pump stopped working all of the relays are working and there is power going to the capacitor and the motor, the motor is not locked up but it does not work. We talked to Al and he is getting with Malabar to bring a lap top for trouble shooting and recalibration to correct the problem.
- In July of 2006 the problem with the vacuum pump was found to be a loose wire at the vacuum relay it was repaired and purification resumed.
- As of December 19 2006 the purifier has 814.50 hrs.
- Testing of hydraulic fluid from five mules and three hydraulic service carts was sent to the lab on Dec. 19 testing on the f-16 aircraft will resume Jan. 2007 and all power point slides will be updated as we receive the test results back from the lab.

Quality Engineering Test Establishment (QETE)

Hydraulic Fluid Purification



G. Boivin June 06

Hydraulic Fluid Purification

- Background
- Objective
- Pall Purifier
- Implementation Plan
- Additional Benefits

Background

- The CF consumes 19,000 liters of hydraulic fluid per year
- \$130,000 in procurement per year
- Reasons for Fluid Disposal
 - Contamination (Water, Particulate)
 - Maintenance
 - Aircraft 2nd line
 - HTS Scheduled maintenance
- 100% of used hydraulic fluid is disposed of as waste
- Thousands of Base dollars spent on disposing of HazMat (>50% of the procurement cost)

Background

Hydraulic Fluids used by the CF:
Mil-PRF-5606
Mil-PRF-83282
AS 1241
Hydraulic Fluid Contamination Limits:
Particulates from NAS class 6 to 9
Water from 100 ppm to 3000 ppm

Objective

Determine the most suitable way to implement the fluid purifiers without compromising the Ground Support Equipment and aircraft systems airworthiness by using purified fluid.



Pall Purifier



431

Implementation Plan

•Baseline GSE and aircraft hydraulic systems to determine the state of the fluid in service by sampling 50% of the GSE and 15-20 aircraft (at one selected location).

•Identify the most suitable way of using the fluid purifiers

•Optimize maintenance practices to minimize fluid losses during maintenance activities

•Purify systematically all GSEs

•Establish a monitoring program to quantify the impact of the purification units on the hydraulic fluid condition.

Fluid Base lining

- To determine fluid condition prior to purifying
- Sample 50% of the Base Mil-PRF-83282 HTS' in service
- Sample 15 aircraft (CF18)
- Analyze Fluid:
 - Properties:
 - Viscosity
 - Acidity (TAN)
 - Lubricity (4-Ball)
 - Contaminants:
 - Water
 - Particulate

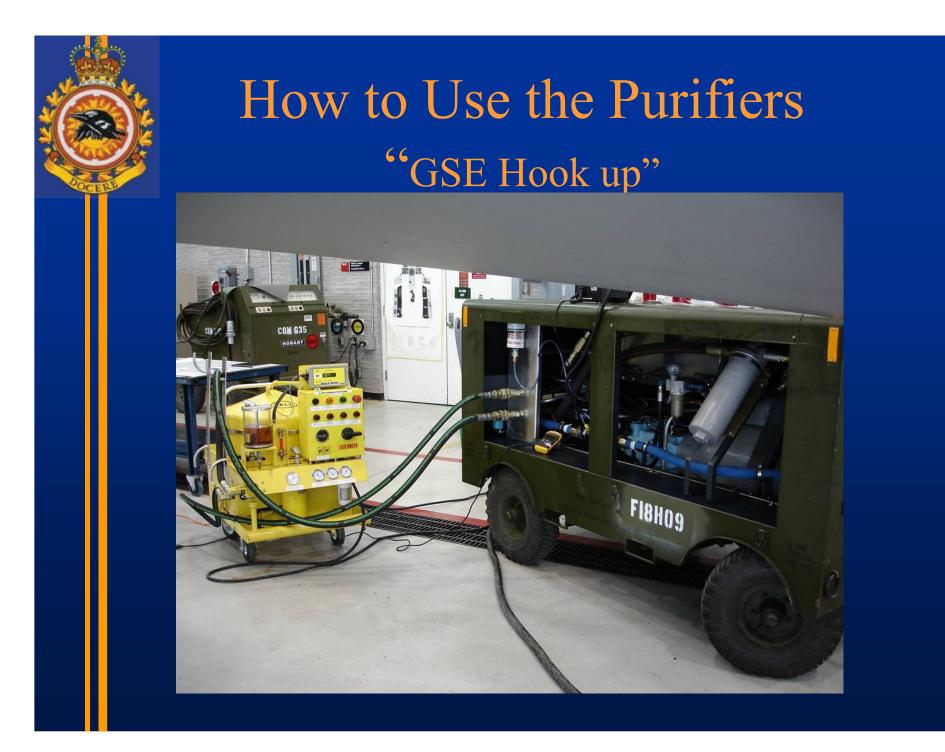
HTS - Fluid Base lining

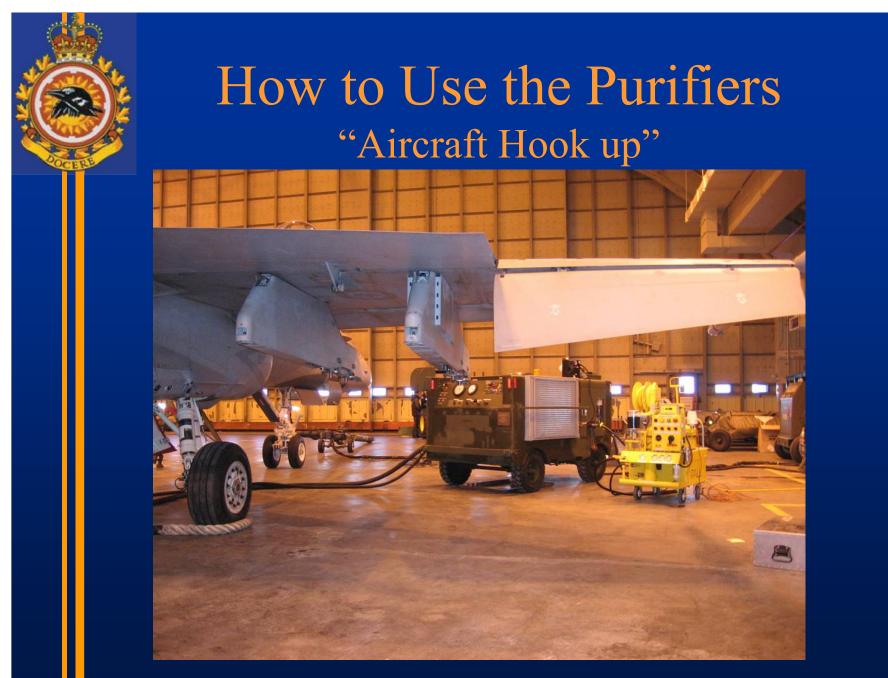
Serial #	Item	PC (NAS 1638)	Water (ppm)	Viscosity @40C (cSt)	TAN Mg KOH/g	
		6 Max	150 Max	14 Min	0.2 Max	
GE-5046	HTS 400	6	151	15.96	0.013	
GE-5240	HTS 400	5	199	15.92	0.021	
GE-5044	HTS 400	4	132	16.75	0.007	
GE-5270	HTS 400	5	163	15.81	0.025	
GE-5068	HTS 500	4		15.51	0.019	
GE-5280	HTS 400	5	184	16.22	0.029	
GE-5246	HTS 400	4	147	15.73	0.025	
GE-5248	HTS 400	2	182	15.77	0.023	
GE-5244	HTS 500	5	154	16.27	0.024	
GE-5313	HTS 500	4	190	16.37	0.02	
Aircraft Baselining in Progress						

When to Use the Purifiers

- Suspected HTS contamination
 - Water level >200 ppm or cloudy
- At scheduled HTS maintenance prior to returning HTS into service
- During aircraft periodic
- During major hydraulic component (s) replacement
- Before HTS and aircraft deployment

Not during routine HTS operation



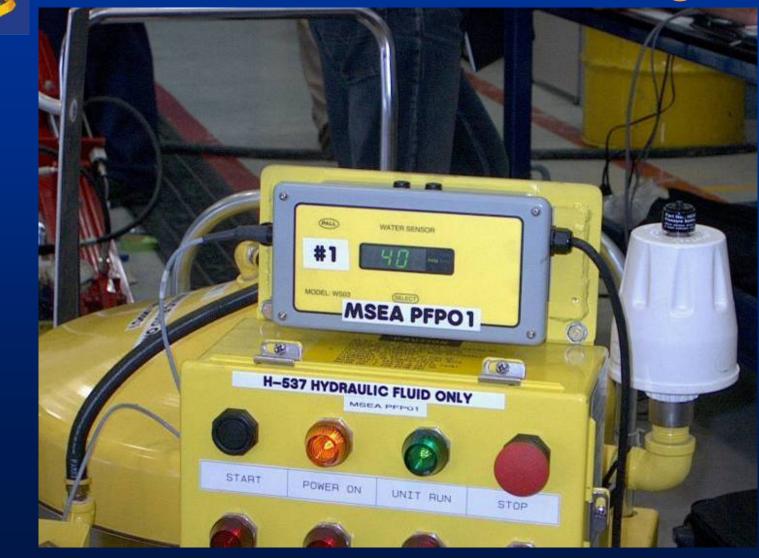


Not authorized to connect directly Purifier to aircraft hydraulic system (s)

Particulate Content Monitoring



Water Content Monitoring



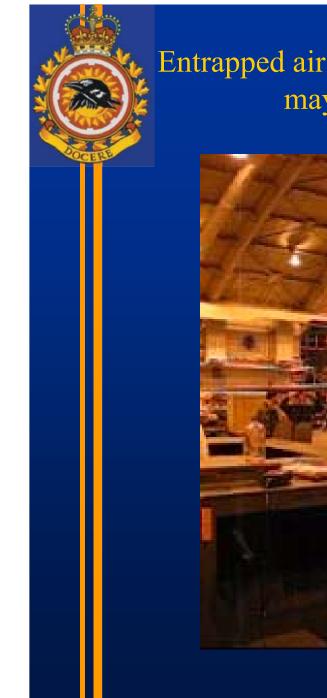
Fluid Monitoring Program

- Pre and Post purification results will be tracked to monitor additive and properties degradation over time
- From this data a top up rate will be established to maintain optimum fluid performance (if required)



Additional Benefits Air Removal





Entrapped air in aircraft hydraulic systems after maintenance may require up to 2-3 days to be purged.







Air Content Monitoring

Quantification of entrapped and dissolved air (Bulk Modulus)
Modifications of GSE to optimize air removal:

Improve diffuser in reservoir to reduce turbulence
Place reservoir under partial vacuum (trial)
Increase reservoir capacity

Use of Pall Purifiers (20-22 in of Hg vacuum)







Way Ahead

• Complete Base Lining of aircraft

- Complete GSE modifications to hook up Purifiers
- Introduce Purifiers at 2nd CF18 Base
- Consider other fleets/other fluids for purification



Quality Engineering Test Establishment



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In-Line Hydraulic Fluid Contamination Multi-Sensor Phase II Enhancement Program

METSS Corporation 300 Westdale Ave Westerville, OH 43082

Kenneth Heater

METSS CORPORATION

Problem Statement

- Condition of aircraft hydraulic fluids is critical to maintaining hydraulic fluid systems
 - detrimental effects to systems and components
 - can lead to premature failure and flight risks
- Hydraulic fluid purification program implemented to maintain fluid integrity and eliminate waste
- Current condition monitoring techniques require sampling and off-site analysis
 - Time delays
 - Sampling errors
 - Costly

New methods are needed to support field purification.

Program Objective Development of Hydraulic Fluid Contamination Multi-Sensor

- Field monitoring capability to support flight-line use and pre-flight analysis
- In-line contamination monitor for ground support equipment, including next generation hydraulic fluid purification systems

Both capabilities will ensure aircraft hydraulic fluid is of sufficient quality to support flight operations in a safe and effective manner.

Multi-Sensor Requirements

- Simple to use
- Real-time feedback
- Compact and able to integrate with existing fluid purifier systems
- Operational fluid temperature range of –40°F to 130°F
- Easy to calibrate and maintain
- Affordable (\$3500-\$5000)
- Robust & reliable

Impurity Targets

Particulate Matter

- Classify particulate contamination according to NAS 1638 specifications (5 to 100+ μ m)

Water Content

- 100 ppm requirement
 - » Allowable water concentration of MIL-PRF-5606 and MIL-PRF-87257 are 100 ppm and 300 ppm, respectively
- Match laboratory analysis performance
- Entrained Air Sensor
 - Possible integration of 3rd party sensor



- Take advantage of proven technologies
 - Decrease risk to DoD
 - Faster technology development
 - Technology transfer faster and easier
 - Commercial pathways easier to define/support
- Technologies Employed
 - Water Content

MEISS CORPORATION

- » FTIR Spectroscopy
- Particulate Matter
 - » PAMAS joint development/qualification effort based on adaptation of existing prototype based on light extinction principles

METSS CORPORATION

First Generation HFMS Prototype



Multi-Sensor Prototype Technical Specifications

Particle Sensor:

- Orifice: 500 μm x 500 μm
- Max. concentration @ 7% coincidence: 24,000 parts/ml
- Max. pressure: 250 bar
- Water Sensor:
 - Orifice: 1270 μm
 - Max. concentration >500 ppm
 - Max. pressure: ~14 bar

Electrical power supply:

- 120VAC approx. 10W
- Hydraulic supply:
 - Oily liquids
 - Viscosities up to 1000 cSt
 - Temperature -20°C to 100°C
 - Oil compatible with Viton seals and polyamide hoses



First Generation Water Sensor Prototype





Nicolet 800 FTIR & Raman

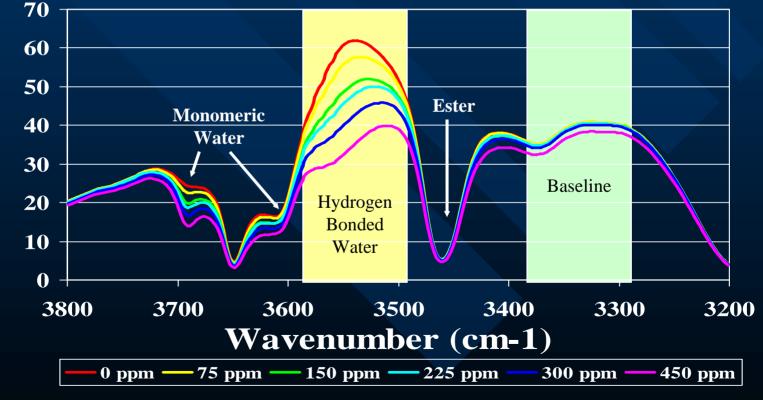
Miniaturized Water Sensor

METSS CORPORATION

% Transmission

Basics of Operation

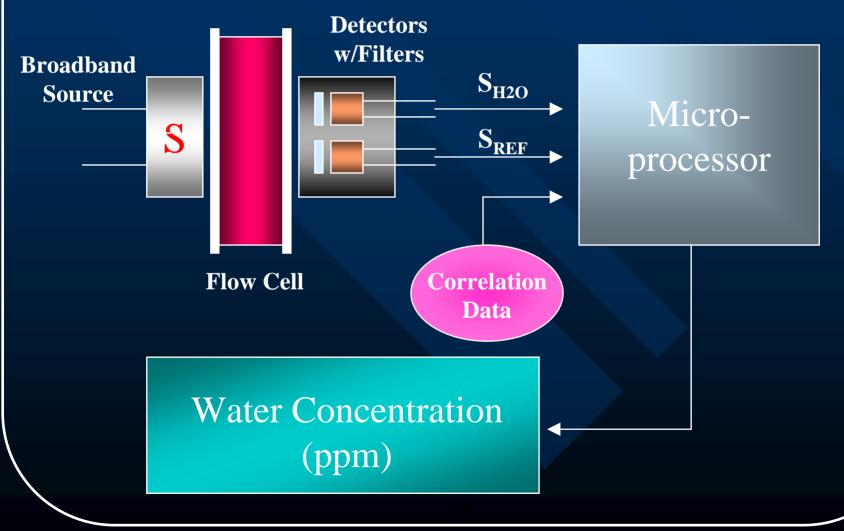
Transmission Spectra of MIL-PRF-83282 Containing Water



METSS Corporation

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Water Sensor Prototype – Basic Concept

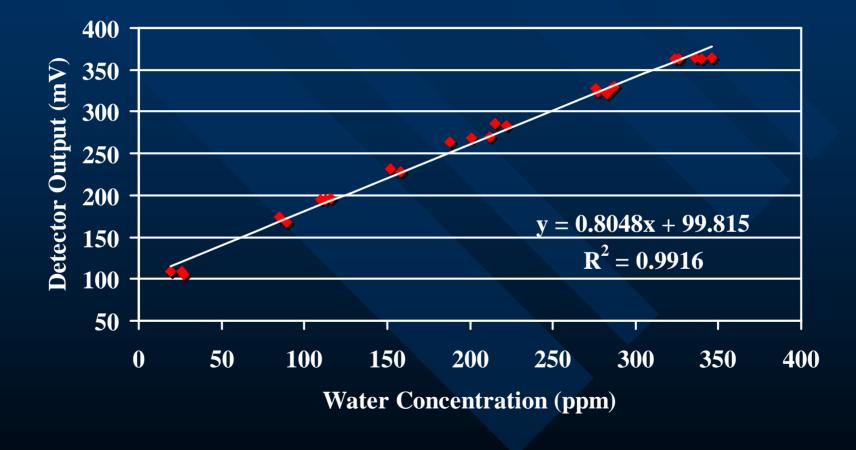


Water Sensor Performance Calculated vs Actual (Royco 782)

Sample ID	Calculated Concentration (Sensor)	Actual Concentration (KF Analysis)	Δ Conc.
CC-373	140 ppm	141 ppm	-1 ppm
CC-374	84 ppm	103 ppm	-19 ppm
CC-375	237 ppm	241 ppm	-4 ppm

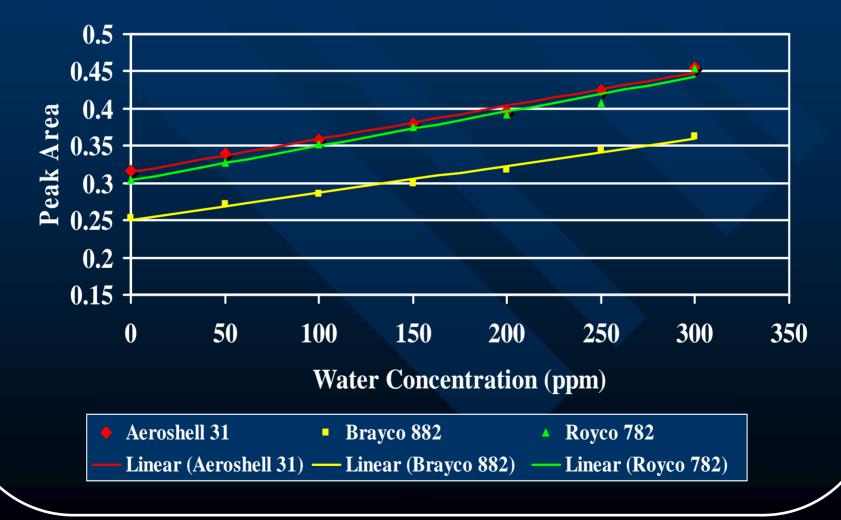


Multi-Sensor Prototype Water Sensor Detector Response





Multi-Sensor Prototype Projected Water Sensor Response



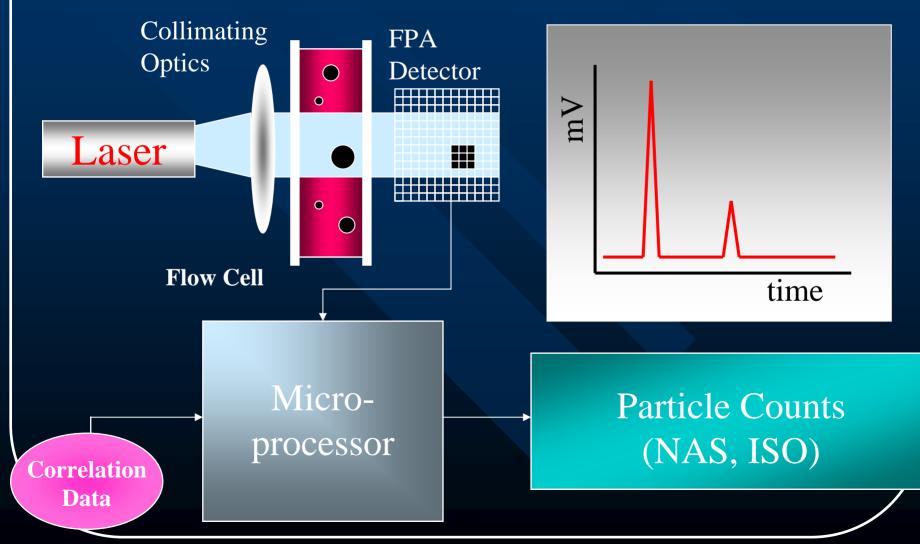
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First Generation Particle Sensor Design



MEISS CORPORATION

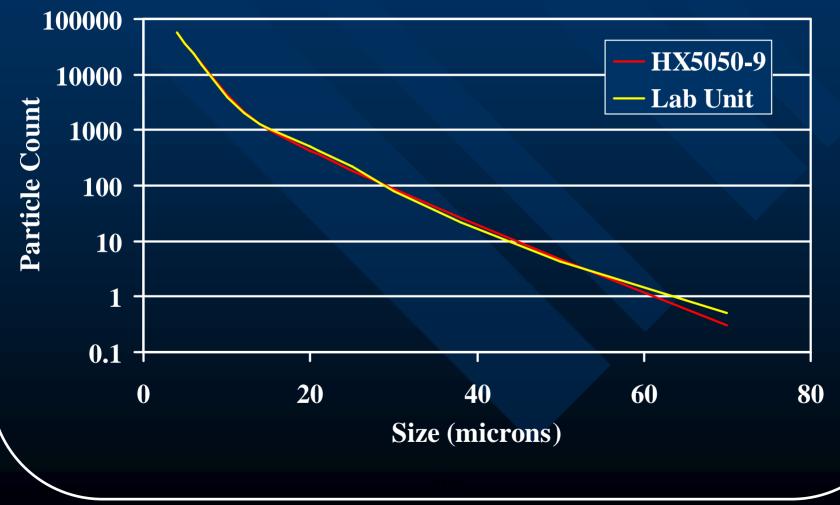
Particle Counting Basic Concept



Comparison of ISO, NAS and SAE Classes

Unit	ISO 4406:1999			NAS 1638	SAE/AS4059D					
	ISO 4µm	ISO 6 µm	ISO 14 µm	NAS	SAE A	SAE B	SAE C	SAE D	SAE E	SAE F
Lab Unit	20	18	14	10	10	10	8	9	7	5
HX50 50-9	20	18	14	10	10	10	8	9	7	5

Particle Counter Performance Pamas Calibration Suspension



Enhancement Objective



Portable Fluid Purifier





Enhancement Program Overview

Water Sensor Improvements
Particle counter Integration
Field Prototype Development
Field Testing and Evaluation
Additional Sensor Improvements
Commercial Manufacture of Units

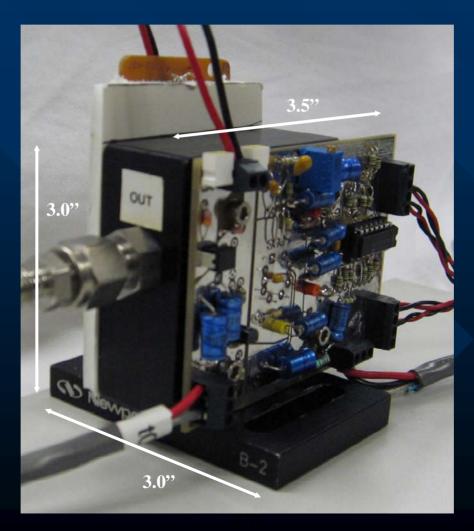
Water Sensor Development

Four filters/detectors

- More sophisticated algorithms which will compensate for variability between fluid types and electronic drift
- Automatic temperature compensation within detectors
- 10x improvement in source output
- Rugged flow cell with fixed path-length
- Reduced size and complexity

MEISS CORPORATION

Second Generation Water Sensor

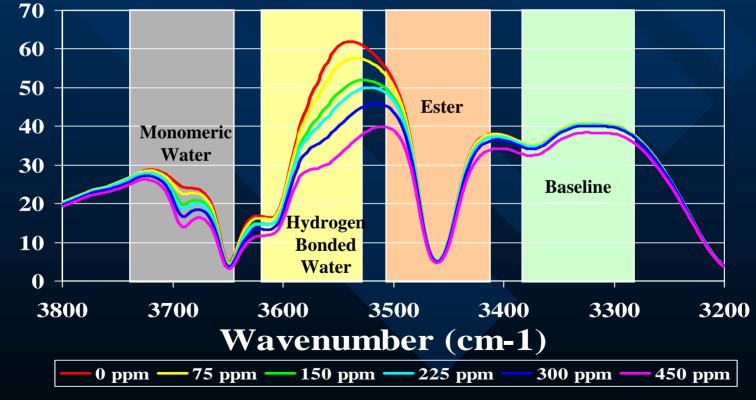




% Transmission

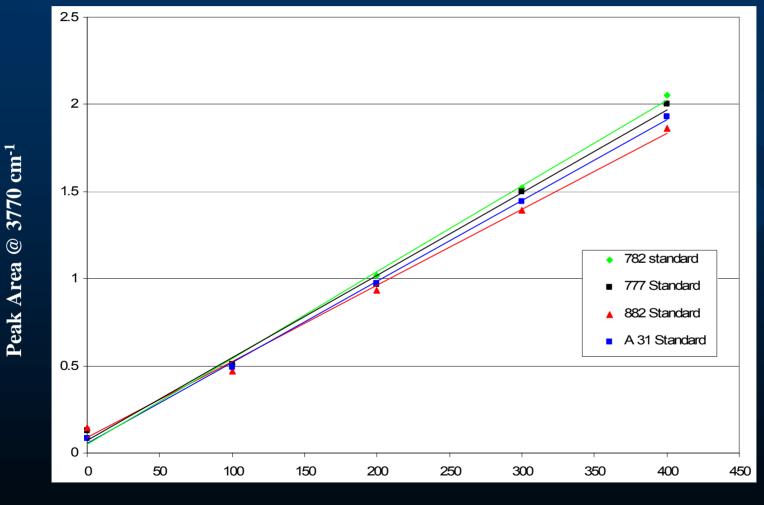
Second Generation Water Sensor - Operation

Transmission Spectra of MIL-PRF-83282 Containing Water



METSS CORPORATION

Water Sensor - Projected Output



Target Water Concentration (ppm)

PAMAS Particle Counter

Flow rate compensation

- Input flow rate can be variable within 5 to 50 ml/min
- Support variable system integration requirements
- Integrated circuitry
 - Circuit design modified to support integration with HFMS design

METSS CORPORATION

System Integration

- Sensor integration
 - Water sensor
 - Particle counter
 - Environmental sensors
 - RS232 and analog inputs for other sensors
- Output
 - Real-time display
 - Automatic data logging
 - Removable flash memory card for data storage
 - Automatic system check at power up
- Mechanical/Electrical
 - 110 V AC operation
 - Fittings for input/output
 - Sample collection
 - Robust design and footprint

METSS CORPORATION

Field Prototype





Status

- System board design completed
 - Currently being populated
- Display menus programmed
- User interfacing programming completed
- Sensor modules built and ready for integration
 - Fine tuning water content algorithm
 - Testing to be initiated at WPAFB in June
- Integration and testing by end of June
- 6-month field testing
- Integrate user feedback
- Commercial deployment

Thank You.



Sensor for Measurement of Air in Hydraulic Fluid

FY06 SBIR Topic

Air Sensor for Hydraulic Fluids

- Many operational aircraft have problems with excessive air trapped in the hydraulic systems. Excessive air causes spongy flight controls, cavitation of hydraulic components and overheated hydraulic fluid.
- Purifiers are used effectively to remove air and other contaminants but there is currently not a sensor to determine the level of air in hydraulic fluids.





 This program will investigate technology to provide an inline air sensor for use with purifiers or test stands.



Air Sensor for Hydraulic Fluids

- Three phase I SBIR contracts recently
 awarded
 - 3 different approaches
 - All show great promise
 - Plan to integrate into multi-sensor currently under development by METSS
 - Initially will be a hand held stand-alone sensor
 - Could be installed on purifiers or test stands later



Cleaning Efficiency Study of Malabar and Pall Portable Fluid Purifiers

Ed Snyder and Lois Gschwender AFRL/MLBT George Fultz and Tim Jenny University of Dayton Research Institute



Portable Purifiers – Cleaning Efficiency Study

- Two major requirements for hydraulic fluid purifiers
 - Not harm fluid quality
 - Remove harmful contaminants
 - Particulate
 - Water
 - Air



- Both the Malabar and the Pall Portable Fluid Purifiers were found by extensive hydraulic pump tests to not adversely affect hydraulic fluid quality as a result of repeated purification cycles
- Baseline cleaning effectiveness studies had not been conducted
- This study was to investigate the ability of each purifier to remove particulate, water and air

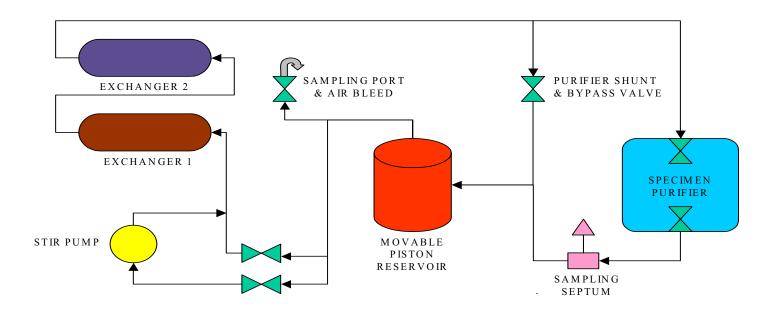


Portable Purifiers – Cleaning Efficiency Study

- The objective of the program was to determine the time required to reduce:
 - Particulate from NAS 1638 class 12 to ≤ 5
 - Water from 600 ppm to <100 ppm
 - Air from 12% to $\leq 8\%$
- Also studied was the ability of the purifiers to remove JP-8 fuel
- The efficiency was studied for both vented and unvented systems



Schematic of Pumping Loop





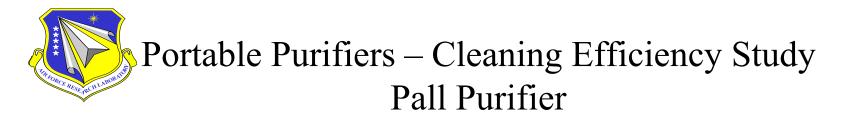
Portable Purifiers – Cleaning Efficiency Study

- Fluid Quantity: 25 gallons
- Fluid: MIL-PRF-83282
- Particulate contamination: NAS 1638 Class 12
- Water Content: ~600 ppm
- Air Content: $\sim 12\%$
- Time: 5 Hours

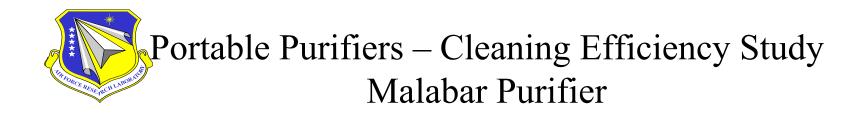


Portable Purifiers – Cleaning Efficiency Study

• Unvented (Closed) System



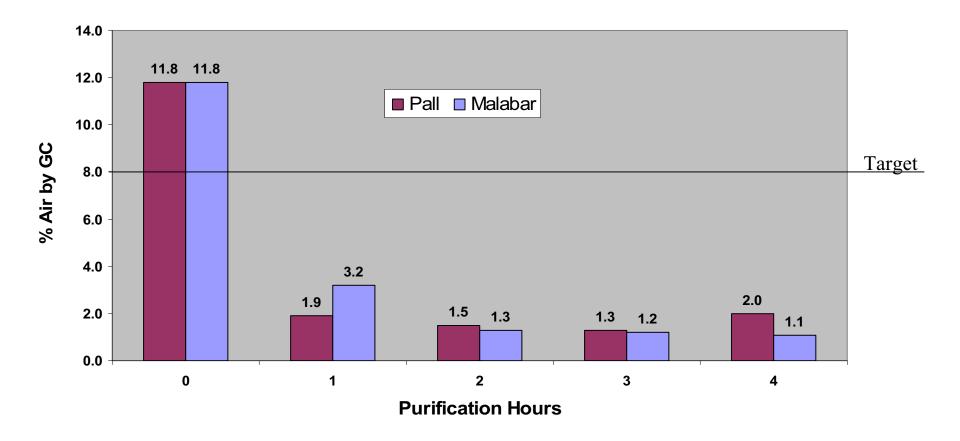






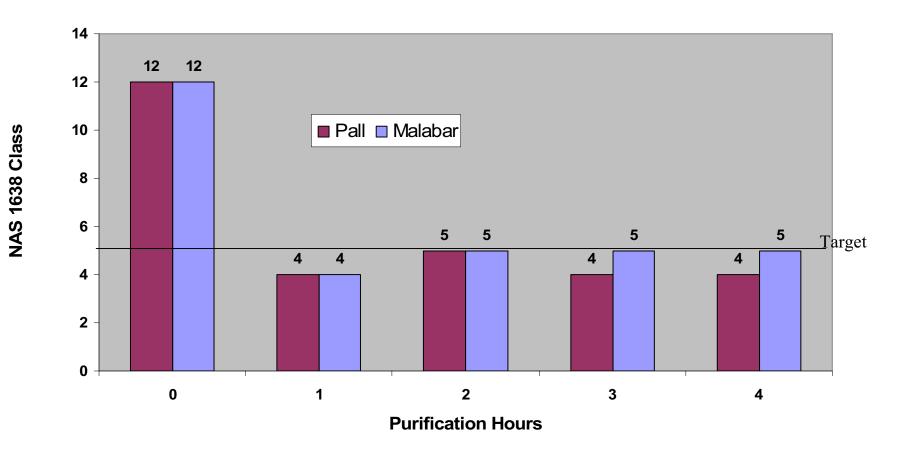


Dissolved Air Removal - Closed System



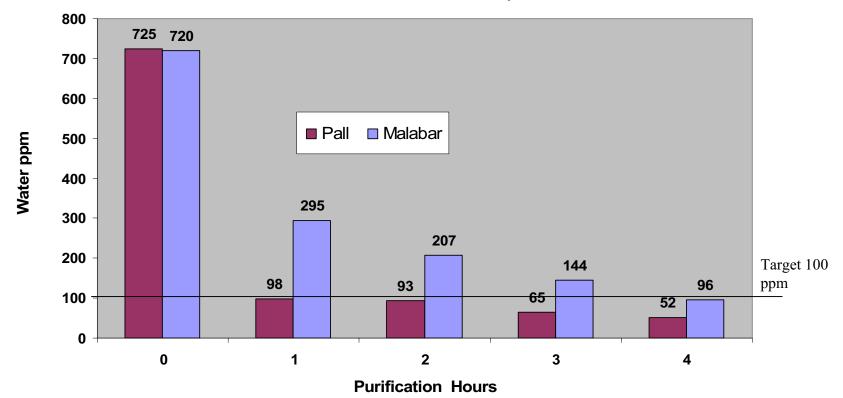


Particulate Removal - Closed System





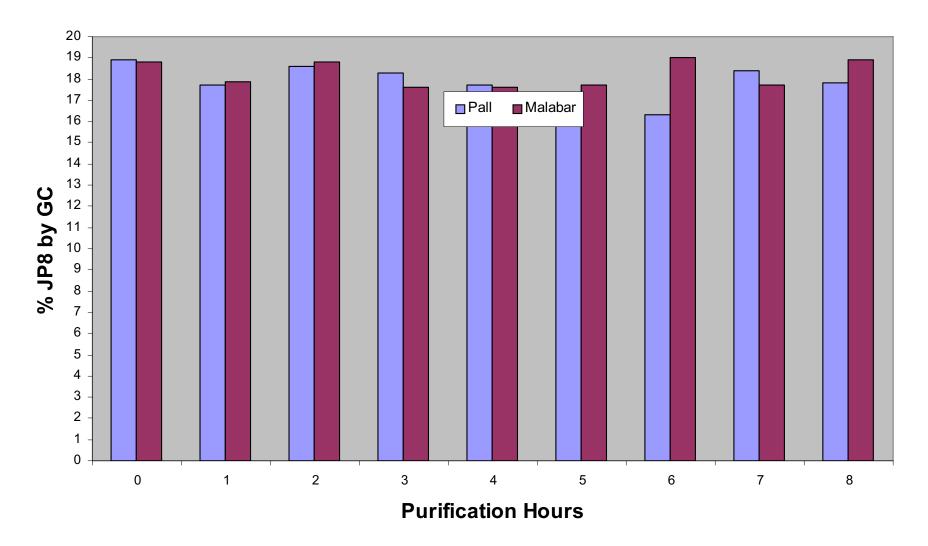
Water Removal - Closed System



492



JP8 Removal





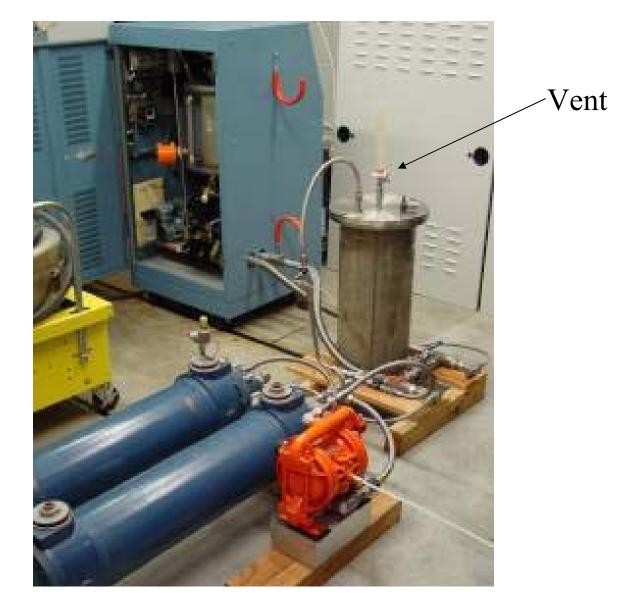
• Vented System







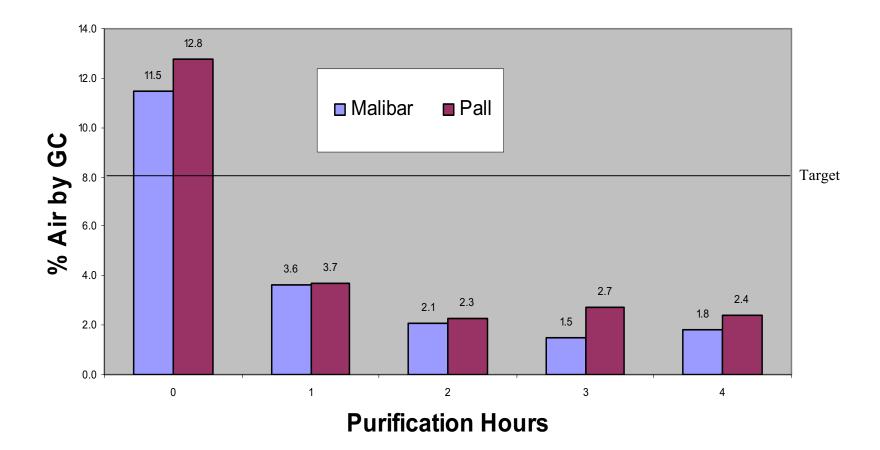
Portable Purifiers – Cleaning Efficiency Study Malabar Purifier





Portable Purifiers – Cleaning Efficiency Study

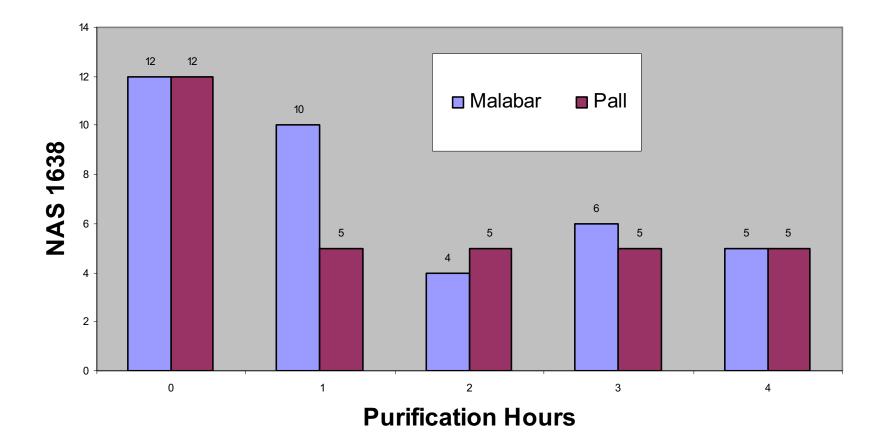
Dissolved Air Removal - Vented System





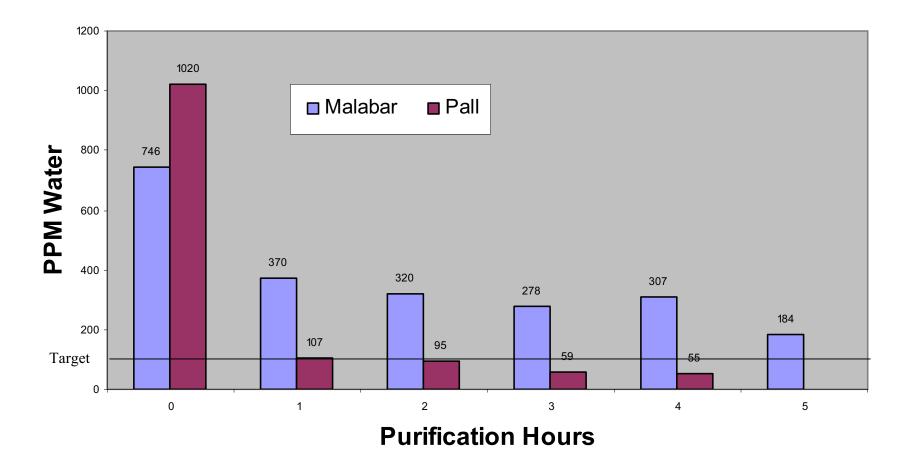
Portable Purifiers – Cleaning Efficiency Study

Particulate Removal- Vented System





Water Removal - Vented System





Portable Purifiers – Cleaning Efficiency Study Conclusions

- Both the Malabar and the Pall fluid purifiers removed air, particulate and water from contaminated MIL-PRF-83282
- Neither purifier was effective at removing JP-8 fuel
- For air, both purifiers reduced the air content of the hydraulic fluid from $\sim 12\%$ to $\leq 4\%$ in 1 hour for both vented and unvented conditions
- For particulates, both purifiers reduced the particulate levels from NAS 1638 Class 12 to \leq Class 5
 - Unvented Systems Both within 1 hour
 - Vented Systems Malabar 2 hours; Pall 1 hour



Portable Purifiers – Cleaning Efficiency Study Conclusions

• For water removal, the Pall purifier was much more efficient than the Malabar purifier for both the vented and unvented systems

• The Pall purifier reduced the water content to ≤ 100 ppm within 1 hour for both vented and unvented systems

• The Malabar purifier required 4 hours to reduce the water content to ≤ 100 ppm for the unvented system and over 4 hours for the vented system

Portable Purifiers – Cleaning Efficiency Study Conclusions

- While both the Malabar and Pall purifiers remove air and particulate equally well, the Pall purifier is superior in water removal
- This presentation is included on the AASS/OB web-site along with the list of approved portable hydraulic fluid purifiers for Air Force use.



Aging Aircraft Systems Squadron Ominant Air Power: Design For Tomorrow...Deliver Today



Dominant Air Power: Design For Tomorrow...Deliver Today

Hydraulic Fluid Purification Implementation **June 2006**



U.S. AIR FORCE

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Keep'em flying & Keep'em relevant



Overview



- Authorization to Use Purified Fluid
- Status:
 - General Hydraulic T.O.
 - Aircraft T.O.
 - Table of Allowance
 - Equipment Availability, Mod, Use
- Implementation Issues
- Sample Analysis
- Improvements



Steps To Field



- 1. Aircraft SPO approve use of purified fluid
- 2. Add purifier to Applicable Table of Allowance
- 3. Purchase Purifiers
 - Unit Funded
 - MAJCOM Funded
- 4. Modify hydraulic mule to add quick disconnects to connect purifier
- 5. Add purification procedures and frequencies to the hydraulic mule T.O.



HFP Authorization & Use Status



(MIL-PRF-5606, MIL-PRF-83282, MIL-PRF-87257)

Dominant Air Power: Design For Tomorrow...Deliver Today

- Status on authorization to use purified hydraulic fluid on ALL USAF aircraft
 - 1. Hydraulic General T.O. Authorizes Use Provided
 - Applicable aircraft SPO approved use
 - Only approved purifiers are used (Pall & Malabar)
 - 2. Aircraft Status





Malabar Mule



4



HFP AUTHORIZED



- Use of purified hydraulic fluid has been authorized for most aircraft in the Air Force.
- Those aircraft that currently have not approved use of purified hydraulic fluid are evaluating for benefits.

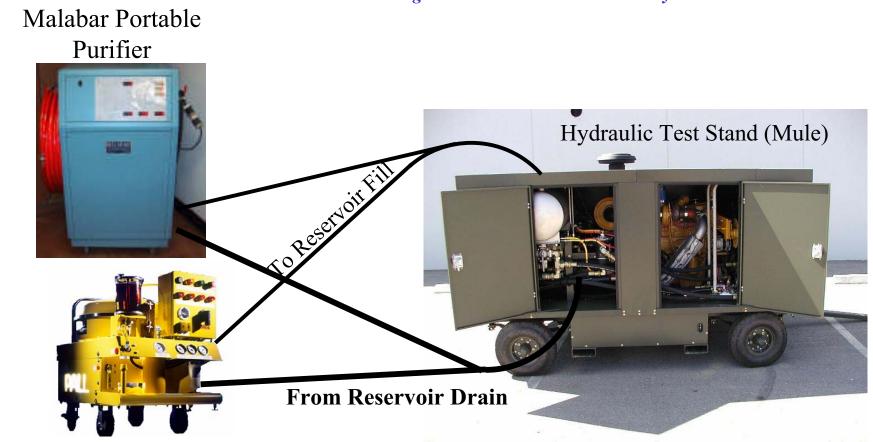


Mule Purification Process



6

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Pall Portable Purifier



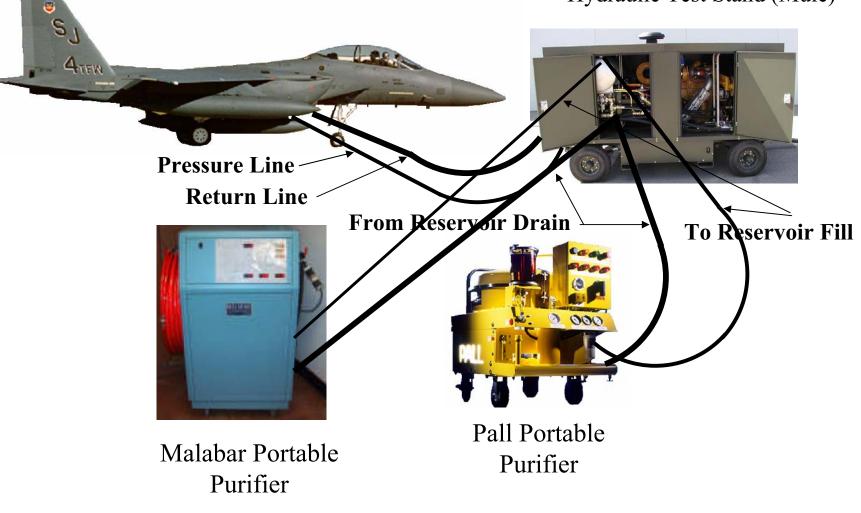
Aircraft Purification Process



7

Dominant Air Power: Design For Tomorrow...Deliver Today

Hydraulic Test Stand (Mule)





Purifier Table of Allowance



- Table of Allowances (TAs) has been updated to allow field purchase of portable purifiers
 - TA 772 AGE
 - TA 355 AIRCRAFT
 - Unit queries AFEMS to add purifier to their applicable organization ID



Purifier Purchases



- Purchase portable purifiers
 - Field Units fund / Immediate
 - MAJCOMs fund / Immediate
 - WR-ALC fund / 2-3 years (POM)



Mule Modification



- Technical Order Change Required by Warner Robins 542 SEVSG/GBZFA
 - Identify how to modify mules to allow connection of portable purifier and identify purification frequency
- Modification schedule dependent on method of implementation
 - TCTO
 - WR-ALC POM for funding support (2-3 year delay)
 - Completion in 90 days after funding
 - Field funded TCTO
 - Operational Supplement
 - Field funds the modification (immediate implementation)
 - Completion driven by purification decision
 - May be limited by CNC capability



HFP Implementation Issues



Dominant Air Power: Design For Tomorrow...Deliver Today

- AF Form 1067 from HQ ACC to identify need for mule modification
- WR-ALC 330 FSG/LFMS completing 1067 for HQ ACC
- HQ ACC will review and approve 1067 and submit to 542 SEVSG/CC
- 542 SEVSG/GBZFA change mule T.O. as follows:

–Identify how to modify mules to allow connection of portable purifier (quick disconnects)

–Modification is proposed to be a field level TCTO to be funded by the field units

–Add purification procedures and frequencies in the mule technical orders

• Portable Purifier T.O. required (Pall with water sensor)

•Army tasking Manufacturer to put commercial manual in MIL SPEC format (Mar-Apr 06 completion)

•Air Force T.O. number will be assigned to Army Manual (May 06 completion)

•Training minimal pending HQ manual review







- FY06 provisioned quantities for stock
 listed purifier low
 - Procurement requires MIPR direct to Army
 Item Manager for direct buy from manufacturer
- Currently field lacks capability to analyze hydraulic fluid
 - Aging Aircraft Systems Squadron and AFRL developing Multi Sensor to provide field level analysis capability



HFP Sample Support



- Sample analysis required to support service evaluations and implementation until multi sensor is available
 - Selfridge ANGB / Apr 05 Apr 07
 - Jacksonville ANGB / Dec 05 Dec 07
 - Springfield ANGB / Mar 06 Mar 07



HFP Improvements



- Multi sensor OT & E will be completed at existing service evaluation locations
 - Sample Analysis Support / Jun 06 Nov 06
 - Stand alone Multi Sensor available for procurement (Jun 07)
 - Incorporate multi sensor in Malabar mule production models (WR-ALC/LESGS) (Jun 07)
 HQ ACC will need to fund this
 - Incorporate multi sensor in all mules undergoing overhaul (WR-ALC/LESGS) (Jun 07)
 - Incorporate multi sensor in portable purifiers



Hydraulic Fluid Purification





Enhanced 5 cSt Oil Development for High Performance Gas Turbines

Military Aviation Fluids and Lubricants Workshop, Fairborn, OH June 21, 2006



Lewis Rosado, Ph.D. Lynne M. Nelson Nelson H. Forster, Ph.D.

Propulsion Directorate

Air Force Research Laboratory



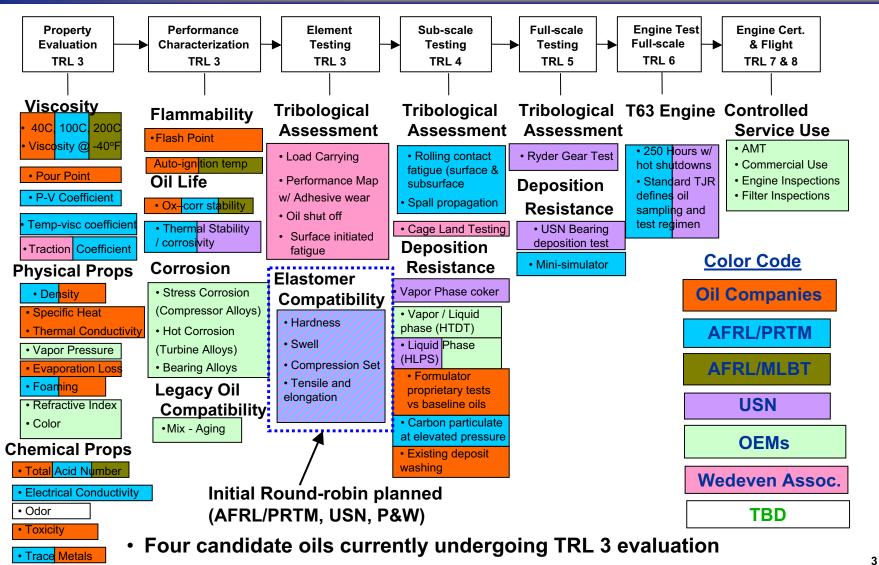


- The objective of this program is to restore the performance margin for the next generation aircraft engine lubricants
- Candidate oils should have thermal stability equal to HTS + boundary lubrication equivalent to MIL-PRF-23699 STD oils, or better, with current and new generation of materials:
 - M50, P675, 9310, P53
- Introduce no issues in the engine (e.g. fully compatible with existing elastomers)
- Both CI and non CI oils are desired for evaluation
- Maintain a 13,000 cSt / -40 F oil requirement for full compatibility with legacy systems



Comprehensive Oil and Material Qualification Plan - Developed by P&W & USAF





• AFRL/PRTM has received one 55 gal drum of one candidate



Elastomer Testing



More Comprehensive Elastomer Evaluation:

Generic Type	Specification	Trade Name	Part Number	Test Temperature
Fluorocarbon	AMS 7276 (AMS- R- 83248)	Viton-A ™	Parker V1164-75	175 +/- 2 C ¹
Fluorocarbon	AMS-R-83485	Viton GLT ™	Parker V0835-75	200 +/- 2 C
Perfluoroelasto mer	AMS 7275	Kalrez™	TBD ²	TBD
Fluorosilicone	AMS 3383		TBD	121 +/- 2 C
Nitrile	AMS-R-25732		TBD	135 +/- 2 C

¹Revised temperature from 200°C to 175°C since last SAE E-34 presentation ²Dupont-Dow planned for initial testing

•Swell (ASTM D471), tensile strength/elongation (ASTM D412 and D1414), compression set (ASTM 395), hardness (ASTM D1415)

•70, 240, 500 hour tests



- Elastomer Round Robin began Mar 06
 - Phase I : 70 hrs, 175° C
 - utilizing C&O glassware
 - Viton A elastomers
 - BP 2197, MJO 254, MJO II, Reference Oil 300
 - 240 and 500 hr phases to be run by Oct 2006; test method finalized in Nov 06.
- Selection of reference Viton-A and GLT materials
 - Material should be available to anyone
- Database generated will be used to establish limits in the Draft Oil Requirements and eventual Specification

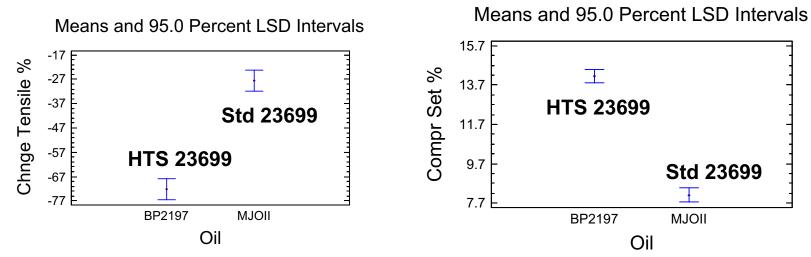
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Preliminary ANOVA Results

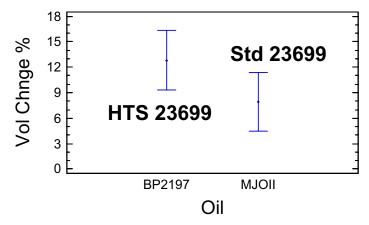
Std vs HTS Oil

UDRI Results

(AF o-ring source, AF data & compressed O-rings only)





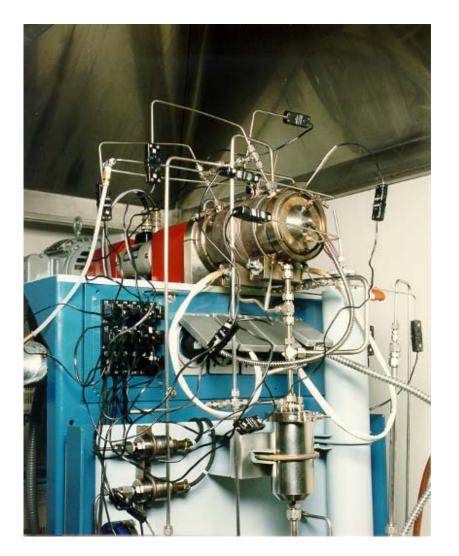


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Oil Deposition -Mini-Simulator Rig





Test ConditionsOil Flow rate: 400 ml/minOil capacity: 2000 ml

Test Temps (°F):SumpBearingHot Spot428527572

Test Duration: 100hrs

Overall Rating	<u>Test 1</u>	<u>Test 2</u>
MJO II	55.7	63.5
Higher Coking	129	116.6
Grade 3 oil		

Switch to stainless steel test heads - Apr 06







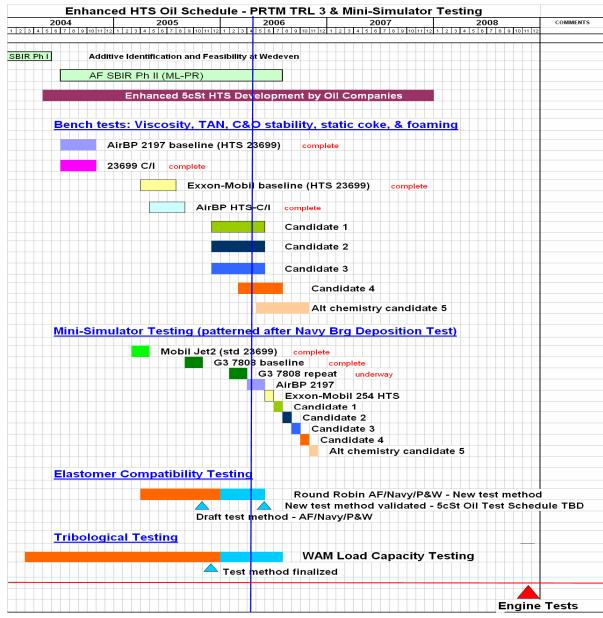
Tribology/Load Capacity:

- WA Scuffing Load Capacity using Modified Test Protocol, Min value load stage is 22 (consistent with STD 23699 oil)
- WA testing will use M50 and M50 NiL baseline, P675 and P53 as advanced materials

Ryder Gear Testing:

 Target is consistent with a high load gear oil, minimum is consistent with STD 23699 oil

TRL 3 Oil Qualification Testing



Four candidate oils currently undergoing TRL 3 testing

AFRL/PRTM plans to complete properties testing/C&O by May 06

CHARACTERISTIC	REQUIREMENT	Baseline Oil	P&W	OIL COMPANY	USAF/P RTM	USAF/ MLBT	USN
VISCOSITY (ASTM D2532) @ -40C (-40F), Max	13,000 cSt, Max	11,990	N/A	10,981	11,524	?	N/A
Percent Change After 72 Hrs @ -40C (- 40F)	+/- 6%, Max		N/A	1.2 (3 hr)	0.27 (3 hr)	?	N/A
VISCOSITY (ASTM D445) @ 40C (104F)	23.0 cSt, Min	26.71	N/A	26.53	26.67	?	N/A
@ 100C (212F)	4.90 to 5.40 cSt	5.23	N/A	5.21	5.24	?	N/A
@ 200C (392F)	REPORT cSt		N/A	N/A	N/A	?	N/A
POUR POINT (ASTM D97)	-54C(-65F)	-57	N/A	-57	N/A	N/A	N/A
PRESSURE - VISCOSITY COEFFICIENT (WAM)	REPORT		N/A	N/A	?	N/A	N/A
TRACTION COEFFICIENT (WEDEVEN)				WEDEVE	N ASSOCIAT	ES	
DENSITY (ASTM D891B)	REPORT	0.9957	N/A	0.9957	?	N/A	N/A
	5 Pts From	150 to 300 C mm H	g N/A N/A N/A			N/A	
	150C	2.5	2.7	N/A	N/A	N/A	N/A
	175C	4.0	4.0	N/A	N/A	N/A	N/A
	200C	6.5	6.5	N/A	N/A	N/A	N/A
VAPOR PRESSURE (ASTM D2879)	225C	9.0	10.0	N/A	N/A	N/A	N/A
	250C	13.7	16.8	N/A	N/A	N/A	N/A
	275C	21.6	27.9	N/A	N/A	N/A	N/A
	300C	31.1	37.4	N/A	N/A	N/A	N/A
EVAPORATION LOSS (ASTM D92) 6.5 Hrs @ 204C (400F)	10% (weight), Max	1.99	N/A	1.53	N/A	N/A	N/A

FOAMING (ASTM D892) 5 Minutes Aeration @ 24C (75F)	25 mL, Max	5	N/A	5	5	N/A	N/A
1 Minute Settling @ 24C (75F)	0 mL, Max	0	N/A	0	5	N/A	N/A
5 Minutes Aeration @ 93.5C (200F)	25 mL, Max	5	N/A	5	1	N/A	N/A
1 Minute Settling @ 93.5C (200F)	0 mL, Max	0	N/A	0	2	N/A	N/A
5 Minutes Aeration @ 24C (75F) [After Test @ 93.5C Above]	25 mL, Max	5	N/A	10	?	N/A	N/A
1 Minute Settling @ 24C (75F)	0 mL, Max	0	N/A	0	?	N/A	N/A
REFRACTIVE INDEX (Visual Exam)	REPORT		?	N/A	N/A	N/A	N/A
COLOR (Visual Exam)	REPORT		6.5	N/A	N/A	N/A	N/A
TOTAL ACID NUMBER (SAE ARP 5088)	0.75 mg KOH/g, Max	0.35	N/A	0.41	0.34 (D664)	?	N/A
		pS/m, Report		N/A	N/A	N/A	N/A
ELECTRICAL CONDUCTIVITY (ASTM	22C	1400	1170	N/A	N/A	N/A	N/A
D2624)	70C	5100	6300	N/A	N/A	N/A	N/A
	100C	15000	9220	N/A	N/A	N/A	N/A
COBRA (Equipment Manual)	Unitless, Report	1	1	N/A	N/A	N/A	N/A
ODOR (MSDS Evaluation)	Report		?	N/A	N/A	N/A	N/A
TOXICITY (MSDS Evaluation)	Report		N/A	See MSDS	N/A	N/A	N/A

TRACE METAL CONTENT (Oil Co - ASTM D5185 and P&W - Rotrode A.E.) Fe (Rotrode in parenthesis)	2 ppm, Max	0.14 (<1)	<1	?	N/A	N/A
AI	2 ppm, Max	0.07 (<1)	<1	?	N/A	N/A
Cr	2 ppm, Max	0.07 (<1)	<1	?	N/A	N/A
Ag	1 ppm, Max	0.08 (<1)	<1	?	N/A	N/A
Cu	1 ppm, Max	0.09 (<1)	<1	?	N/A	N/A
Sn	11 ppm, Max	1.39 (4)	3	?	N/A	N/A
Mg	2 ppm, Max	0.35 (<1)	<1	?	N/A	N/A
Ni	2 ppm, Max	0.09 (<1)	<1	?	N/A	N/A
Ti	1 ppm, Max	0.18 (1)	1	?	N/A	N/A
Si	2 ppm, Max	2.28 (1)	1	?	N/A	N/A
Pb	TBD ppm, Max	0.12 (<1)	<1	?	N/A	N/A
Zn	TBD ppm, Max	1.01 (<1)	<1	?	N/A	N/A
FLASH POINT (ASTM D92)	246C (475F), Min	261	N/A	?	N/A	N/A
AUTOGENOUS IGNITION TEMPERATURE (ASTM E659)	350C (662F), Max		N/A	?	N/A	?
THERMAL STABILITY & CORROSIVITY (FED STD 791C Method 3411) Viscosity Change	TBD %, Max	-0.22	N/A	N/A	?	N/A
Total Acid Number Change	TBD mg KOH/g, Max	1.29	N/A	N/A	?	N/A
Metal Weight Change	TBD mg/cm2, Max	-0.17	N/A	N/A	?	N/A

SEDIMENT AND ASH (FED STD 791C Method 3010) Visual Undissolved Water	0, Max	0	N/A	?	N/A	N/A	N/A
Sediment Through 1.2 Micron Filter Membrane	10 mg/L, Max	0.96	N/A	?	N/A	N/A	N/A
Total Ash Content	1 mg/L, Max	Not Run	N/A	?	N/A	N/A	N/A
STRESS CORROSION (MCL E205) Compressor Alloys	metallographi c cross section		?	N/A	N/A	N/A	N/A
HOT CORROSION (PWA 36700) Turbine Alloys	< / = 2 tenths of a mil attack @ 500X	PASS - All Results <0.2mil	PASS - All Results <0.2mil	N/A	N/A	N/A	N/A
BEARING CORROSION (EIS)	Report Method Under Development		?	N/A	N/A	N/A	N/A
MIX - AGING TESTS (FTM 3403 Mod 3) MIL-PRF-23699 Class STD (2)	REPORT, Volume of Sediment		?	N/A	N/A	N/A	N/A
MIL-PRF-23699 Class HTS (2)	REPORT, Volume of Sediment		?	N/A	N/A	N/A	N/A
MIL-PRF-23699 Class C/I (2)	REPORT, Volume of Sediment		?	N/A	N/A	N/A	N/A
MIL-PRF-7808 Grade 4 (1)	REPORT, Volume of Sediment		?	N/A	N/A	N/A	N/A
Enhanced Ester Candidates (4)	REPORT, Volume of Sediment		?	N/A	N/A	N/A	N/A
LOAD CARRYING	Load Stage		WEDEVEN ASSOCIATES				
PERFORMANCE MAP W/ ADHESIVE WEAR			WEDEVEN ASSOCIATES				
OIL SHUT OFF			WEDEVEN ASSOCIATES				
SURFACE INITIATED FATIGUE			WEDEVEN ASSOCIATES				

CHARACTERISTIC	REQUIREMENT	Baseline Oil	P&W	OIL COMPA NY	USAF/PRT M	USAF/M LBT	USN
LIQUID PHASE COKING - HLPS (SAE ARP 5996) 375C @ 20 Hours @ 40 Hours	REPORT TBD mg, Max	0.22, 0.37	?	?			?
VAPOR PHASE COKING - VPC (SAE ARP5921) @ 371C	REPORT TBD mg, Max	225	?				?
CARBON PARTICULATE @ 625F, 125psig, 12 Hours	REPORT TBD mg, Max	?	?	?			?
HIGH TEMPERATURE DEPOSITION TEST - HTDT Alcor HTDT	REPORT TBD mg, Max	0.2					
FORMULATOR PROPRIETARY TESTING CYCLIC COKER MISTER	REPORT TBD mg, Max	0.21, 0.23					



T63 Engine Testing



Increasing thermal stress cycles and total run time for oil qualification based on USN HTS T63 test procedure:

- Previous 131 cycles 80 minute duration
- New requirement 200 cycles 75 minutes duration
- Previous total engine run time 175 hours
- New requirement 250 hours

Sample Temperatures

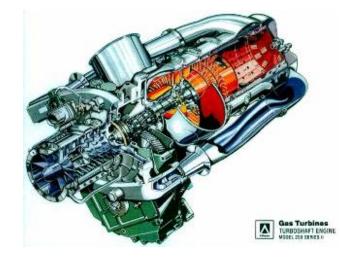
•Oil in 300°F

•Cruise condition - No 6 & 7 brg 385°F, No 8 brg 375°F

•Soak back - No 6 & 7 brg 670°F, No 8 560°F

<u>Status</u>

127 hrs on rerun of BP 2197; will begin T63 test on 1^{st} enhanced candidate ~ Jun 06



T63 Test Schedule

Enhanced HTS Oil - T63 Engine Test Schedule									
2004	2005		2006	2007	2008	COMMEN TS			
1 2 3 4 5 6 7 8 9 10 11	12 1 2 3 4 5 6 7 8 9 10 11 12	1 2 3 4	5 6 7 8 9 10 11 12	1 2 3 4 5 6 7 8 9 10 11	2 1 2 3 4 5 6 7 8 9 10 11 1	2			
SBIR Ph I Add	litive Identification and Feasil	oility at W	edeven						
AFS	SBIR Ph II (ML-PR)		Wedev	ven Enhanced Additive De	velopment (5cSt basestock)				
	Enhanced HTS Develo	opment b	y Oil Companies						
	T63 E	ngine Te	sting (250 hours/te	st) **					
	Baseline AirBP 2	197 HTS	oil Complete						
		Baselin	e Exxon-Mobil 254	Complete					
			Repeat bas	seline 2197					
				Candidate #1					
				Candidate	e #2				
					HTS-C/I candidate #3				
					Alt Chemistry candidate #	4			
					HTS-C/I can	didate #5			
** Oil Samples w	ill be drawn daily for UDRI an	alysis: v	iscosity, TAN, COE	RA, wear metal analysis					
					Engine Tes	VAATE-I Denzos			

40 mm Bearing Testing - Beyond Target Requirements



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- Prior research by Nixon et. al., and Trivedi et. al., indicate lubricant antiwear additives can have a significant negative or positive effect on bearing life
- In addition to fatigue life, new anti-wear additives should be checked for the effect on spall/crack propagation



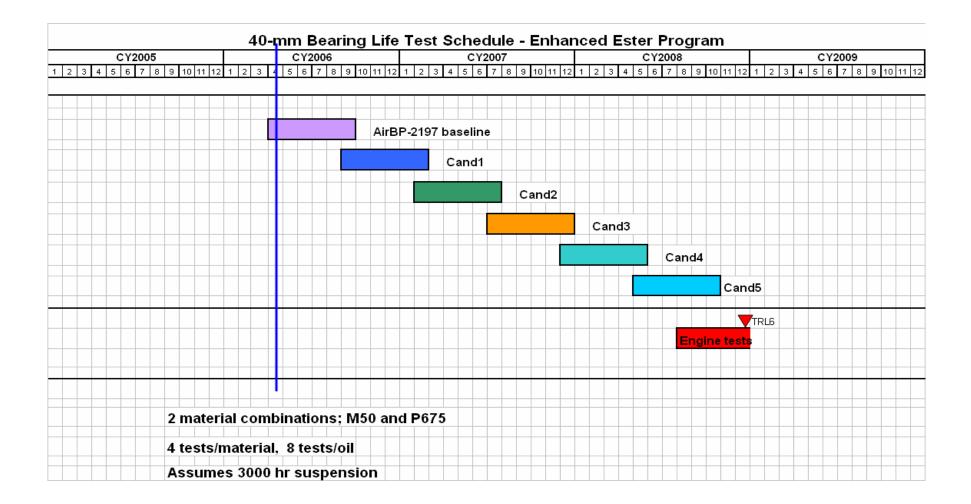
Six additional test heads added to existing 8 Will be used for oil-bearing life testing



Bearing test heads with insulated head and oil supply lines for high temp operation

- 10,000 rpm
- 450 ksi max Hertzian stress
- Test Temperatures
 - 375°F (191°C) bearing temp
 - 350°F (177°C) oil in temp
- Suspend at 3000 hrs
- Currently running AirBP2197 baseline with M50 and P675 hybrid bearings

40 mm Bearing Test Schedule







- TRL 1 3 testing complete with 4 initial candidates August 2006
 - O/C, coking, basic oil properties completed by May 2006 (WA load capacity
 Aug 06; elastomer screening Oct 06)
- TRL 4 6 testing planned for Jun Dec 2006; requires a 55-gallon drum of sample; working to line up additional candidates
 - 40 mm bearing life and spall propagation, Deposition in vapor and liquid phase, Ryder gear, bearing deposition testing, T63 engine testing
 - RR/LW F136 engine gearbox testing CY07
- TRL 7 Engine demos
 - P&W XTC68/LF1 (4th Q CY08) & GEAE-RR/LW XTE78/LF1 (4th Q CY08)
- TRL 8
 - Oil Spec 2007 2009
 - Transition the oil to the field 2008 2010 with wide distribution to military engines/aircraft



"Advanced Helicopter Transmission Lubricant"

NAVAIR Report at Wright-Patterson AFB June 2006

Eric J. Hille Naval Air Systems Command AIR - 4.4.2.2



- Our Business Card -

- NAVAIR, Propulsion & Power Group, Patuxent River MD
 - Doug Mearns 301.757.3421
 - Fuels and Lubricants Head
 - Eric Hille 301.757.3414
 - AHTL Development and Tribology
 - Lubricants and Gas Path Cleaner Fleet Support
 - Jim McDonnell 301.757.3413
 - MIL-PRF-23699 Qualification
 - Lubricants Fleet Support
 - Oscar Meza 301.757.3409
 - ESDP ("Engineer & Scientist Development Program")
 - Lubricant Deposition Methods and Testing





Propulsion Systems Evaluation Facility







Navy Lubes Group - Background

MIL-PRF-23699 and DOD-PRF-85734

- In-house product qualification (QPL's) for turbine and gearbox oils
- Service performance and Fleet support
- Development of new product performance requirements

Full Spec Testing Capabilities

- Physical, chemical, analytical analysis
- Bench test simulators and T63 turboshaft engine test

Ties to DOD / Industry / Allied Militaries

- Common specification goals
- Identifying emerging technologies
- Development of new test methods





Gearbox Oils - Historical

• Prior to 1986...

- Navy helicopter transmissions operated on gas turbine engine oils (MIL-PRF-23699, MIL-PRF-7808 types)
- Marginal performance in relation to these oils' deficient degree of load carrying capabilities

In 1986...

- Navy implemented DOD-PRF-85734 class of oils
- Viewed as an "interim" oil to increase operating life
- Provided MIL-PRF-23699 type oils with enhanced additives
- Relieved recurring fleet problems (e.g. AH-1T upper mast bearing *micro pitting*)
- "Optimum" oil envisioned, target properties investigated



9-Feb-0



"AHTL"

• Advanced Helicopter Transmission Lubricant, aka:

- "AHTL"
- "Nine centistoke oil (9 cSt)"
- "Optimum oil"

Intentions:

- Replace 5 cSt DOD-PRF-85734 oil for all Navy power drive systems with oil intended to further extend gear and bearing life
- Reduce high temperature "engine oil" features to allow for an oil tailored specifically for helicopter systems
- Maintain compatibility with MIL-PRF-7808, MIL-PRF-23699, MIL-PRF-85734, hardware, elastomers
- Provide design parameter for future drive systems





Slide 6

AHTL Development

• Properties:

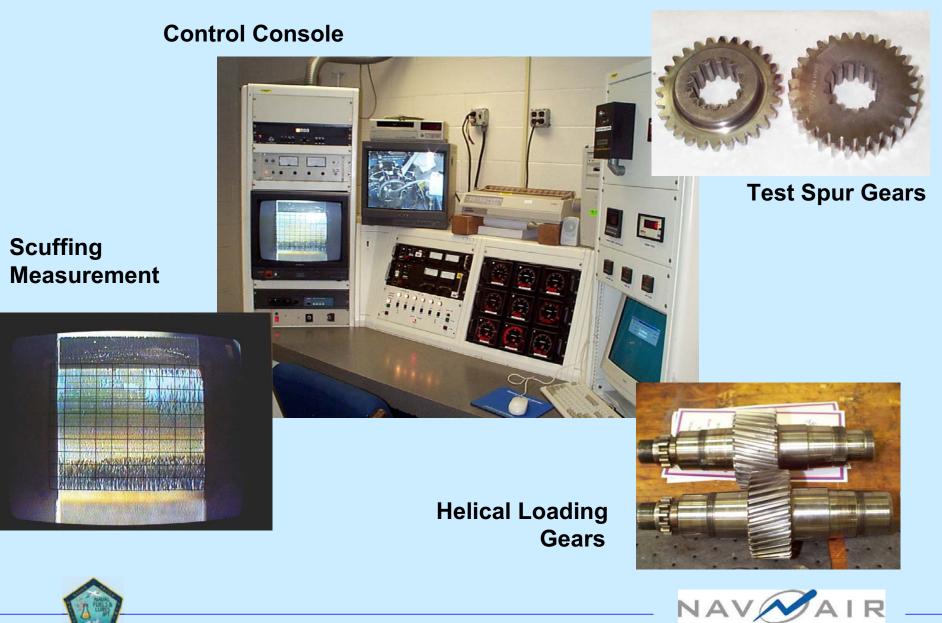
- Higher viscosity, 9 cSt versus 5 cSt measured at 100 deg C
 - suitable for use in normal gearbox operating ranges
- Good to -32 deg C (13,000 cSt)
 - Coincides with Army limit
 - Tradeoff from -40 deg C (5 cSt), -60 deg C (3 cSt)
 - But, additional benefits at upper end of viscosity / temp chart
- Corrosion inhibition
- Substantial increase in load carrying capacity as measured by the Ryder Gear test...





Slide 7

U. S. Navy Ryder Gear Test



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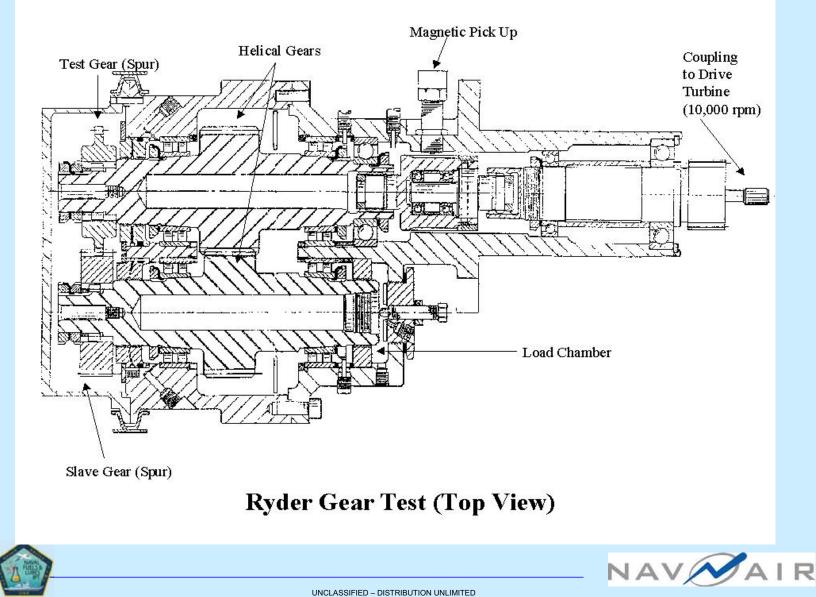
U. S. Navy Ryder Gear Test





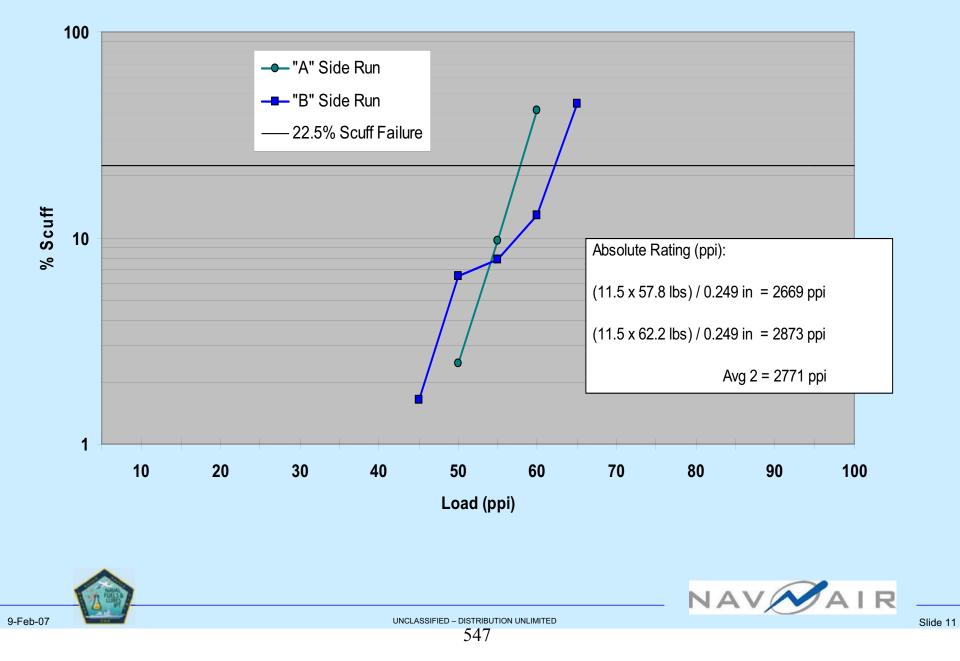
UNCLASSIFIED – DISTRIBUTION UNLIMITED

U. S. Navy Ryder Gear Test

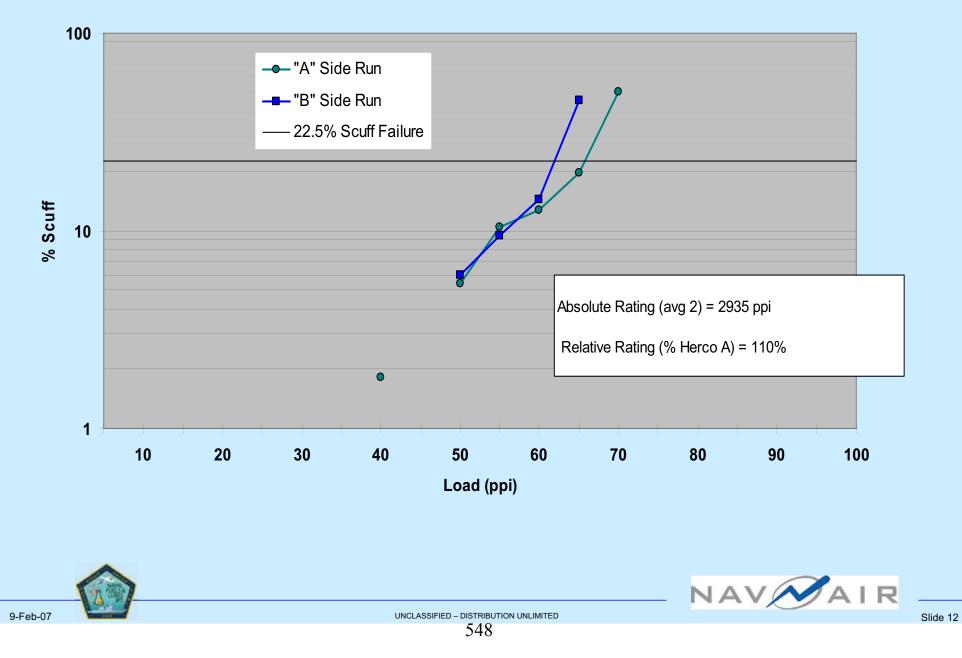


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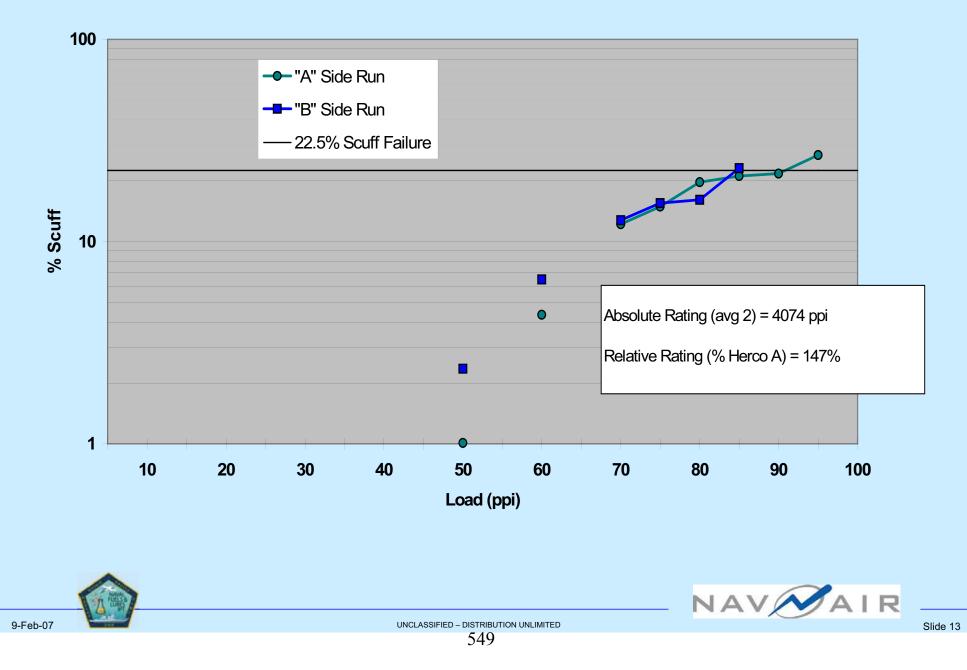
U. S. Navy Ryder Gear Test Results for Selected Herco A, Batch 4 Gears



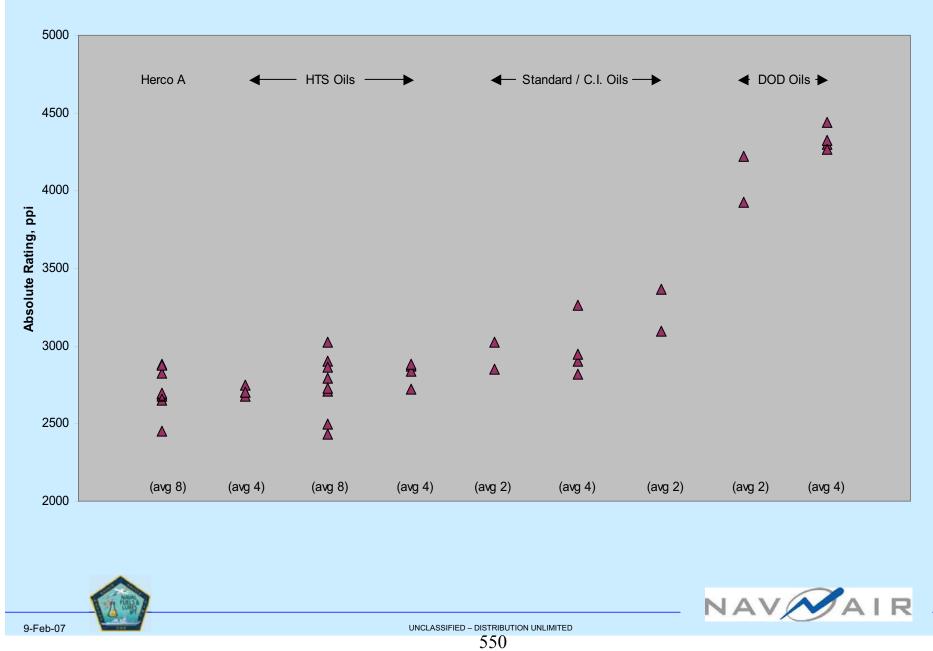
U. S. Navy Ryder Gear Test Results for Selected MIL-PRF-23699, Batch 4 Gears



U. S. Navy Ryder Gear Test Results for Selected DOD-PRF-85734, Batch 4 Gears

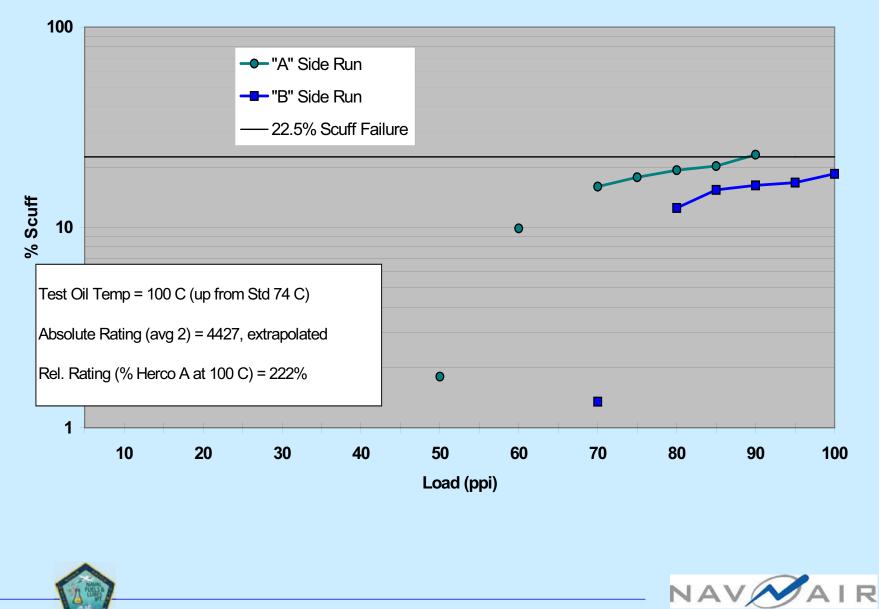


U. S. Navy Ryder Gear Test Summary, Tifco "Batch 4" Gears



Slide 14

U. S. Navy Ryder Gear Test Results for Selected AHTL, Historical Data



9-Feb-07

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Slide 15

Additional AHTL Testing

- Long-Term Fatigue Testing...successful
 - NASA Spur Gear Testing 8X life improvement over DOD oil
 - Timken Tapered Roller Bearing Fatigue Testing equal life
- Component Ground Tests...operationally successful (temperatures / pressures)
 - CH-46 fwd / aft transmission at Cherry Point
 - SH-60 Main transmission at Pensacola
 - CH-53 nose / tail rotor / intermediate gearboxes at Pax River
 - Boeing CH-47 engine transmission test (combining gearbox)
 - Bell M412HP (UH-1N type) main trans / 42 degree gearbox / tail rotor





AHTL Flight Test Status

• Flight evaluation continues with one CH-53E at Pax

- Initiated in December 02
- Switched to 2nd "qualified" lubricant in March 05
- About 350 hours of total flight time on each of six gearboxes
- No detergency issues







Slide 17

AHTL Flight Test Status (Cont'd)

Filtration Evaluation

- Finalized Flight Test Plan to convert Main GB's 10 micron oil filter to a newer 3 micron upgrade used for fleet aircraft
- Verify suitable oil system operations (temps, pressures)
- Brief ground/flight test is imminent

Expanded CH-53E flight evaluation

- Follows successful 3 micron evaluation
- 5 additional aircraft at Pax
- "drop-in" conversion
- Monitor lubricant performance under fleet flight training profile
- One year evaluation...then...first steady customer?



9-Feb-0



"AHTL" Current Status

Specification / Qualified Products List

- Still a draft Navy specification
- No MILSPEC designation until customer emerges in the Fleet
- Two-product draft QPL
- Spec parameters were streamlined with U.K.'s and published as an ASCC Air Standard 15/19 dated 18 July 2002

Further AHTL Implementation

 U. S. Army's H-60 contract with Sikorsky now underway to evaluate higher viscosity effects on oil system (e.g. thermal lockouts, bypasses), suggest oil system modifications, will lead to "qualifying" AHTL for H-60 model





In Closing...

• The AHTL will provide substantial cost savings...

 a Sikorsky cost benefit analysis estimates an overall 16% reduction in the per-flight-hour cost of maintaining the transmission and drive systems for all U. S. Navy and Marine Corps helicopters.







The Need For A Synergist Approach For The Development Of Advanced Aerospace Lubricants

Curtis Genay Lubricants Technologist Pratt & Whitney





Mechanical System Design Issues

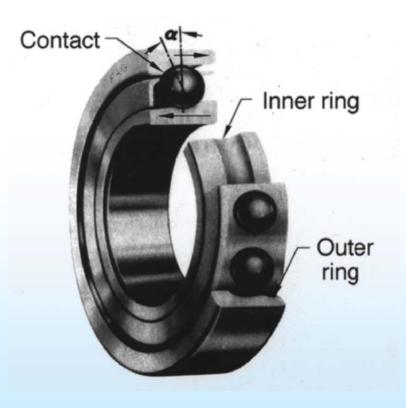
→ Bearing Materials Development

→ Future Lubricant Requirements

= Need For Synergistic Approach

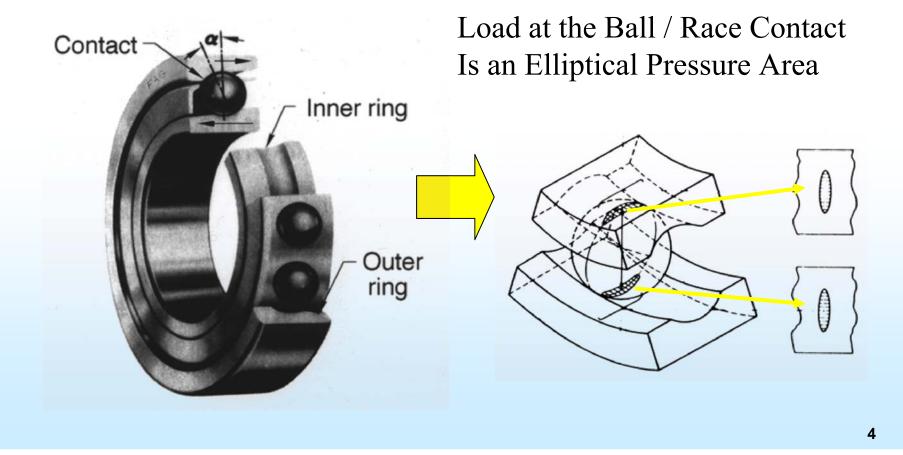


A Bearing Is Not a Component → It Is a System !



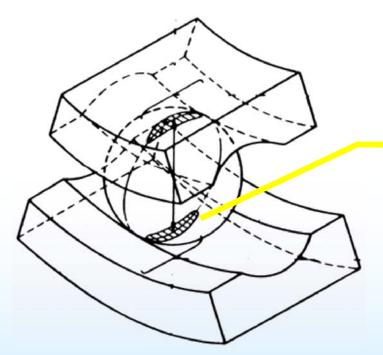


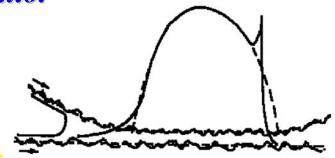
Bearing Contact Ellipse Is Where All the Action Occurs





The Tribology of a Bearing: Synergy Between Material, Lubricant & Design - λ Ratio.





Interacting Surfaces & Lubricant:

 λ Ratio = $\frac{\text{Thickness of Lubricant Film}}{\text{Thickness of Surface Associated}}$

Thickness of Surface Asperity

 λ Ratio > 1 Full EHD Lubrication λ Ratio < 1 Boundary Lubrication **USAF FLUIDS WORKSHOP 2006**

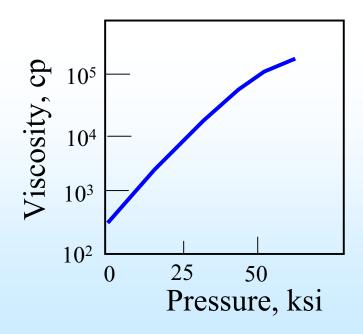
The Bearing / Lubricant System



Lubricating Characteristics

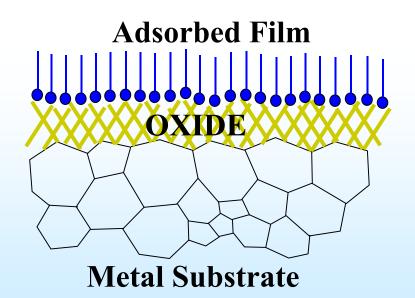
<u> Pressure - Viscosity:</u>

The Secret to Load Bearing Capability



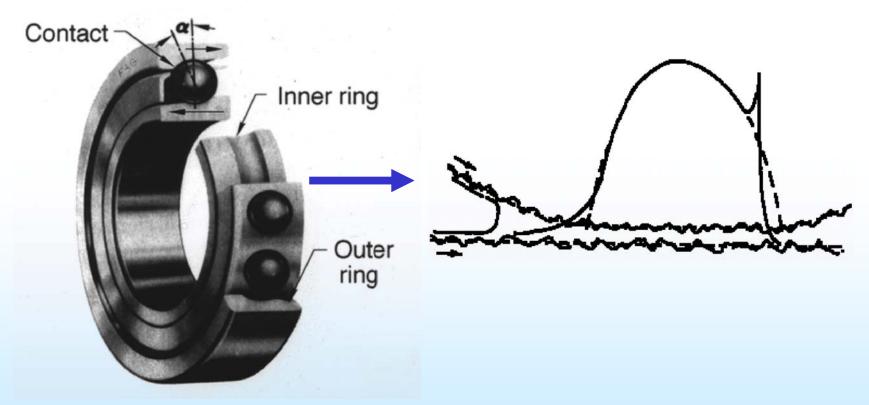
Anti-wear Additive:

The Secret to Boundary Lubrication





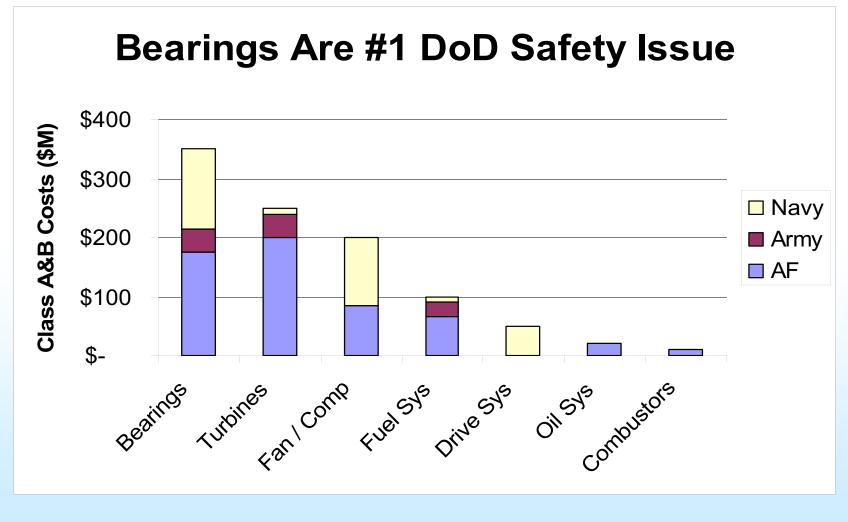
So, A Bearing Is Not A Component → It Is A System.



And Thus, There Is Much to Consider...



Solutions Needed to Address Safety and Durability Issues



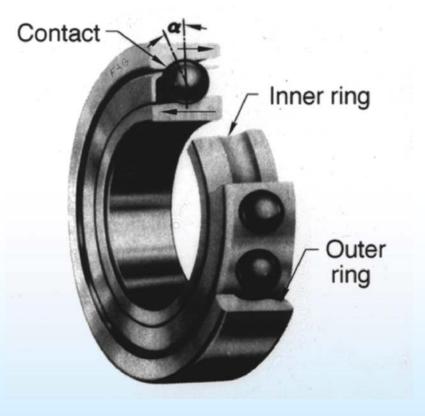


The Bearing / Lubricant System



Bearing Material Needs:

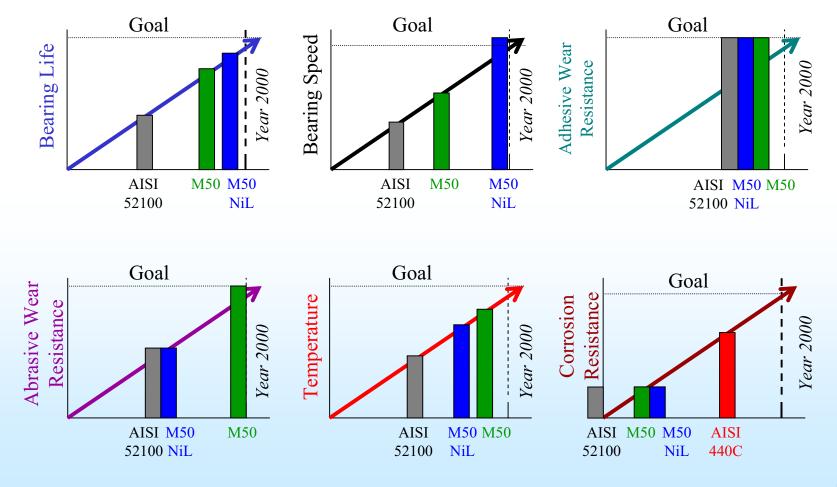
- Hardness
- Strength
- Toughness
- Corrosion Resistance
- Wear Resistance
- Temperature Capability



~ 90% of All Bearing Failures Today are Surface Related (Corrosion, Debris, & Handling Damage)



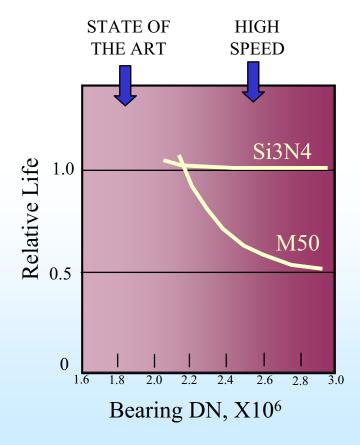
Bearing Material Requirements Into the Next Millennium





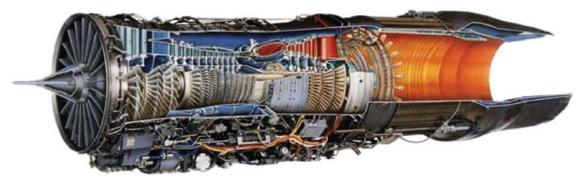
Pyrowear 675 / Si₃N₄ Full Scale Bearing Successfully Ran at 675°F (357°C)

Si₃N₄ Lowers Ball Centrifugal Loads & Frictional Heating





Gas Turbine Challenges For Ester Based Lubricants



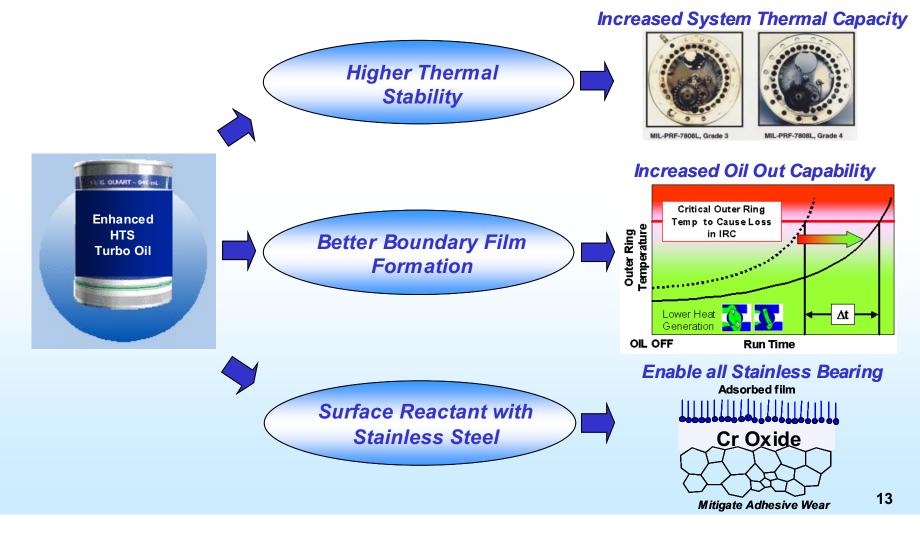
Advanced Aircraft Engine Designs Require Improved Performance And "Life" (Higher – Hotter – Faster):

- Higher Compression Ratios
- Higher Combustion Temperatures
- Higher Turbine Inlet Temperatures
- Reduced Cooling Air
- Higher Rotor and Gear Speeds

Consequence: Increased Thermal and Tribological Demands on the Engine Lubrication System \rightarrow Challenges For Formulators

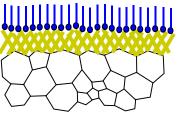


Enhanced Oils Needed to Meet Demanding Requirements





Adhesive Wear Defended by Boundary Lubrication



- Occurs During: Start-up, Shut-down & High G Maneuvers
- Molecular Boundary Layers Form Last Line of Defense
- Influenced by Materials, Surface Treatments & Roughness

Anti-wear Additive Used to Mitigate Adhesive Wear

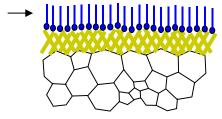
- Additive Chemically Reacts With Bearing Surface to Form Chemically Adsorbed Film
- Required When Bearing Contact Areas Preclude the Formation or Maintenance of Effective Lubricant Film (EHD)
- Additive Film Protect Bearing Surface From Excessive Wear



TCP In All Currently Approved Aircraft Lubricant Formulations

Properties/Characteristics:

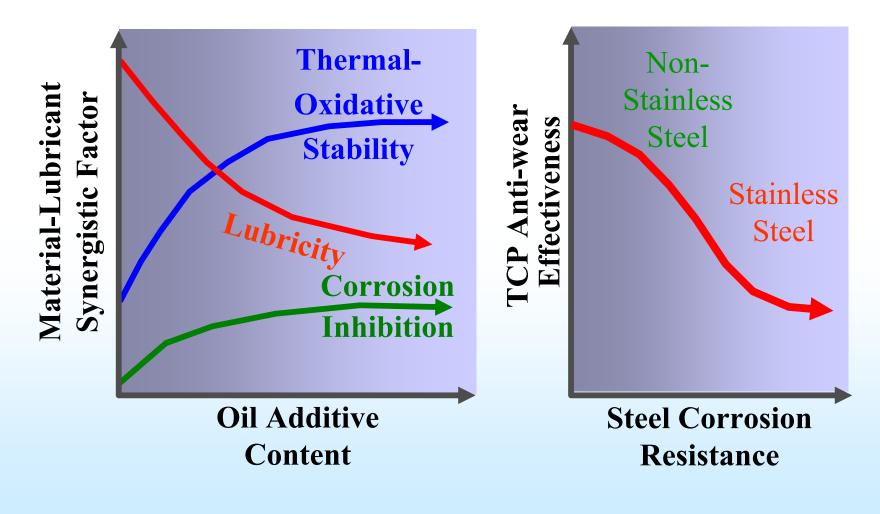
- > Practically Colorless, Odorless Liquid
- > Boiling Point 420°C (788°F)
- > Non-volatile, Combustible
- > Typically Blended in Oil at 1-3 Wt. %



TCP

- > Reacts Readily With Current Bearing Steels (M50, etc.)
- > Does Not React Easily With Stainless Bearing Steels
- > Other Chemistries Being Investigated Under a USAF SBIR





USAF FLUIDS WORKSHOP 2006

Critical Properties Of The Lubricant

Viscosity & Density

Vapor Pressure

Foaming Characteristics

- Heat Generation
- Lubrication System Pressure
- Component Size & System Weight
- Pump-ability
- Compartment Pressure & OperabilityFluid Losses
- Pump Performance
- Engine Pump Operability (Cavitation)
- Tank Size
- Component Speeds
- Lubricant Cooling Capacity

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Specific Heat & Thermal Conductivity - Heat Exchanger Size

Auto-Ignition Temperature

Bearing Compartment Operating TemperatureSystem Weight

Elastomer / Material Compatibility - System Integrity



Enabling Technology Required For Improved Bearings:

Boundary Lubrication of Corrosion Resistant Bearing Steals

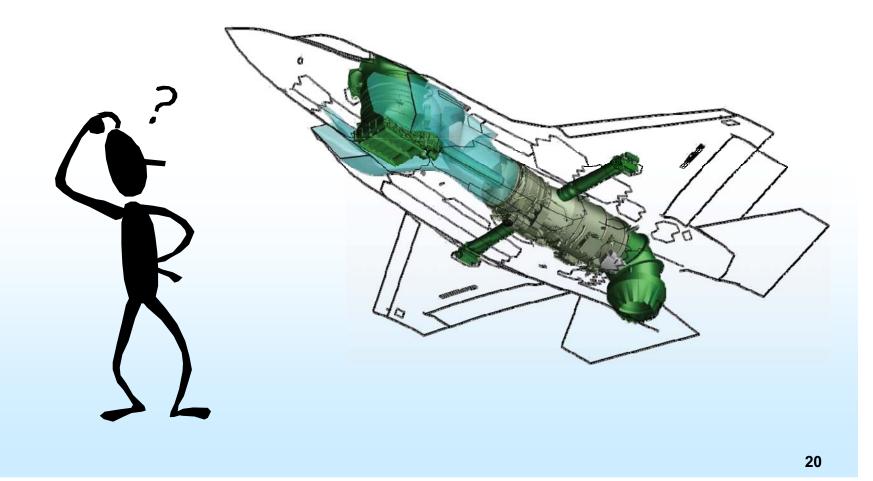
Potential Approaches:

- ➤ Use Si₃N₄ Rolling Elements Hybrid Bearings
- > More Chemically Reactive Anti-Wear Additives
- > Bearing Surface Treatments To Increase Reactivity To TCP

Synergy Between Bearing Material and Lubricant Tribological Properties a Necessity for Advanced Aircraft Gas Turbine Engine Mechanical Component Systems Into the Next Millennium !



Questions??



Small Business Innovative Research Program, "Gas Turbine Engine Oil Additives for Advanced Bearing Steel"





June 2006

Lois Gschwender, Program Manager Air Force Materials Directorate, Materials Laboratory, Wright-Patterson AFB 937-255-7530, lois.gschwender@wpafb.af.mil



Gas Turbine Engine Oil Additives for Advanced Bearing Steel

 Unique opportunity to make significant advancements in anti-wear additives for new steels for a variety of GTO applications

Gas Turbine Engine Oil Additives for Advanced Bearing Steel

- Program focused on Pyrowear 675
- These additives must be effective as lubricity additives while not increasing the deposit-forming tendencies of the lubricant formulations when they experience high temperatures in gas turbine engines nor adversely effect the oil stability
- They must remain in solution at effective concentrations over the desired operational temperature range of the GTO and, in general, allow the formulation to meet existing military GTO specifications (backwards compatible)



Gas Turbine Engine Oil Additives for Advanced Bearing Steel

 Phase I: Included the initial demonstration of novel additive technology for use in high temperature GTOs with advanced bearing steels. Candidate additives and formulations from industry were explored. The formulations demonstrated good performance in boundary lubrication compared to baseline, currently used MIL-PRF-7808 Grade 4 with M50 steel.

Gas Turbine Engine Oil Additives for Advanced Bearing Steel

- Phase I SBIR
- Tier 1 Contractors requested samples from industry – focus on wear properties
 - Additives New and developmental
 - Base fluids Used to blend the new additives
 - Formulations Candidates for the requirements
- Phase II SBIR
 - METSS Corp. and Wedeven Associates were invited to and prepared Phase II proposals
 - Both awarded



- Two Phase II contractors
 - METSS Corp.,
 - PI Dr. Richard Sapienza, Mr. William Ricks, 614-797-2200
 - Wedeven Associates, Inc.,
 PI Dr. Vern Wedeven, 610-356-7161
- Industry support

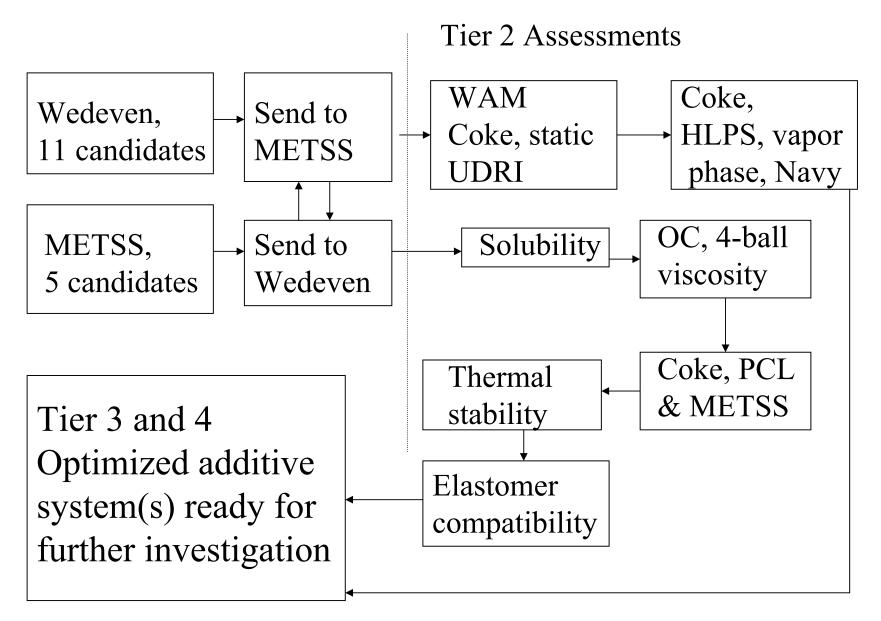
Gas Turbine Engine Oil Additives for Advanced Bearing Steel

- METSS Corp. strengths are in chemical additive synthesis and tribological additive/steel chemical mechanisms of reactions
- Wedeven Associates strengths are in tribological testing, lubrication regimes and close ties with bearing /engine companies
- Both strengths are needed to provide successful technology development and transition

Gas Turbine Engine Oil Additives for Advanced Bearing Steel

- Phase II SBIR
 - Tier 2 formulation assessments
 - Stability, coking and all other critical performance tests (down select)
 - Tier 3
 - Subject successful formulations to boundary lubrication and rolling/sliding lubrication and compared to currently-used steels.
 - Bearing tests with new bearing steels

Flow chart for Phase II additive down-selection





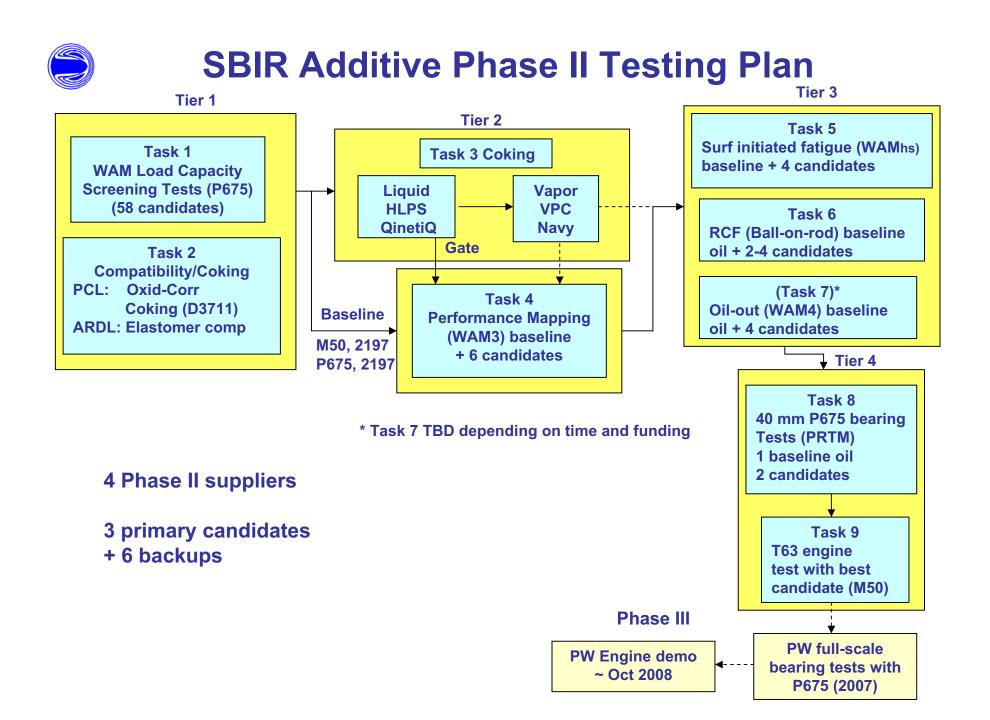
Gas Turbine Engine Oil Additives for Advanced Bearing Steel

- Program issues
 - Lack of corrosion-resistant new steel for test specimens
 - 440C has served well as a substitute
 - P675 is a moving target, but finally have samples
 - Test methods
 - Fidelity to real application not proven
 - Deposition tests several methods
 - Poor reproducibility (lab to lab agreement)
 - Elastomer
 - Oxidation-Corrosion
 - Are amines acceptable due to potential silicone/fluorosilicone interaction?



Gas Turbine Engine Oil Additives for Advanced Bearing Steel

- Program Issues
 - Base stock issues
 - Phase I used a 4 cSt base stock with anti-oxidant additives, but not stable enough to pass the oxidation corrosion test
 - Another 4 cSt base stock with AO selected to down-select from 16 candidates from Phase I
 - PRTM/NAVAIR decided to focus on high thermal stability (HTS) 5 cSt GTO for most future engines
 – Reformulation in 5 cSt oil accomplished
 - In general anti-wear additives in different ester base oil viscosity grades behave similarly



FY06 Phase I SBIR Contracts – Novel Additives for Perfluoropolyalkylethers for Silicon Nitride Bearing Elements

- Phase I contractors
 - METSS Corporation
 - Luna Innovations, Inc.

New and Innovative Gas Turbine Engine Oil Additive Technology

Richard Sapienza William Ricks METSS Corporation

> June 21, 2006 Work done under

Air Force Contract No. FA8650-04-C-5029



The Problem

- Advanced high-chrome steels in engine bearings should provide:
 - higher operating temperatures
 - higher speed capabilities
 - improved corrosion
 - fatigue resistance
- However, they have experienced significantly shorter life than anticipated in performance tests conducted using current gas turbine engine oils (GTOs) which utilize synthetic polyol ester basestocks.
- Their chemistry does not interact in the same way with the lubricious coating additives.





GTO Lubricant Development Requires

- The gas turbine engine oil is required to lubricate not only the engine bearings but also other engine components such as the gears that may be made out of conventional steels. Thus, the development of successful new GTO lubricant additives requires
 - an understanding of the chemical and physical properties of the material to be lubricated or which will interact with the lubricant
 - an understanding of lubricant basestock and additives; their interactions and synergies
 - a well-defined strategy for testing and evaluating the candidate materials relevant to the performance requirements of the fluid



Carbon and Chromium Effects

- The chromium is crucial in promoting the formation of a Cr-rich passive film on the surface of stainless steels
- With increasing chromium, the steels become increasingly resistant to aggressive solutions
- The carbon is added for the same purpose as in ordinary steels to make the alloy stronger
- Carbon and Chromium are less chemically reactive than iron surface



Reaction of Antiwear Additives

On Conventional Low Chromium Steels

- antiwear additives react chemically with the iron surface
 - a lubricious coating on steel surfaces under boundary lubrication
- produce soft films of inorganic metallic chlorides, sulfides and phosphides.
 - films shear easily where any asperities meet and thus protect the base metal.

On advanced steels

 It has been postulated that the high-chromium content does not provide the proper reactive iron surface necessary for interaction with the aryl phosphate (TCP) to form an ironphosphorus surface film





METSS Concept for High Chrome Steel Additives

- There are different "active sites" for additive interaction
- Based upon the poisoning characteristics of conventional iron/chrome oxide high temperature water-gas shift catalysts
 - catalyst is strongly deactivated by sulfur
 - alkaline materials promote phosphorus poisoning
 - Some nitrogen was also found to be deposited



Idea was poisoning for the catalyst occurs due to strongly coordinated species at active sites could this insight help select additives that would bond similarly with high chrome steels.

METSS Program

- Identify needs, evaluate existing fluids
- > Select candidate alternative materials
- Develop testing and evaluation program
- Conduct iterative formulation, testing, and optimization
 - tiered approach to testing
 - simple screening tests to eliminate poor performers
 - more advanced tests to optimize formulations
 - final qualification tests to select best performers
- Partner with Manufacturers provide max feedback ; Work with AFseek max information
- Transition technology to military and commercial market applications.



Goal - Identify several candidates that exhibit better antiwear properties than either the current TCP additive or the current finished fluid.

Lubricant Materials Selection

- METSS obtained samples of two base fluids from ExxonMobil :
 - Fluid A. MCP 2433, a synthetic polyol ester basestock fluid containing no additives.
 - used as primarily the carrier for the candidate lubricant additives
 - one control was Fluid A with current tricresyl phosphate antiwear additive.
 - Fluid B. RM284A, a MIL-PRF-7808 Grade 4 fluid, fully compounded with all additives, including the aryl phosphate.
 - Fluid B was used as one of the controls
- METSS found suppliers and additive technology to prepare fluids.



Lubrication performance with M-50 steel served as baseline comparison of the additives. 440C steel used to simulate advanced high-chrome bearing steels.

Typical Elemental Composition of Selected Bearing Steels

Material	Carbon %	Nitrogen %	Silicon %	Chromium %
52100	1.00	-	0.25	1.45
M50	0.80	-	0.25 max.	4.00
440C	1.10	-	1.00 max	17.0
Pyrowear 675	0.07	-	0.40	13.0
Cronidur 30	1.08	0.38	0.40	15.2



Industrial Participants

- Acheson Colloids
- Akzo Nobel
- Albemarle
- Chevron Texaco
- Ciba-Geigy
- Crompton
- Dover Chemical
- Elco Corporation
- Ethyl Corporation

- ExxonMobil
- Great Lakes Chemical
- King Industries
- Lockhart Chemical
- Lubrizol Corporation
- Nyco America
- Hatco Corporation
- Rohm & Haas
- RT Vanderbilt
- Uniqema



Additive Chemistry Summary

- The lubricious coating additives of current gas turbine engine oil (GTOs) chemistry do not interact with advanced high-chrome steels in engine bearings in the same way as conventional steels.
 - Different "active sites" for additive interaction
 - from Surface Analysis No P was found with TCP
- Lower oxidation state P chemistry is effective in alkaline environments in providing high-chrome steel surface reaction.
 - Large anti-wear improvements measured.
- An anti-oxidant anti-wear additive synergism demonstrated.
 - Amines act as phosphate conversion coating accelerators
 - Anti-oxidant functionality reduces acid formation



- An optimize corrosion-oxidation stability of the new additive systems is needed to meet the mil-spec requirements.
 - Phosphorus-nitrogen complexes show high effectiveness on high chrome steels
 - However adverse effects of amines or amino-functionality on fluorocarbon and fluorosilicone elastomers found.

Development Steps

Grade 4 GTO with aryl phosphate additive Low chrome-content bearings based on 52100 and M-50

Phase I

Type 4 with advanced additives MIL-PRF-7808 testing basis ExxonMobil RM284A standard Readily available high-chrome steel - 440C

Phase II

Grade 5 GTO with developed additives MIL-PRF-23699 testing ABP 2197 standard Advanced high-chrome steel Pyrowear 675 and silicon nitride bearings



Testing and Evaluation - Tier 1

- Physical and Chemical Properties
- Mixture Compatibility
- Low Temperature Stability and Viscosity @ -40°C
- Four Ball Wear Testing
 - ASTM D4172 relative antiwear properties
 - determination of coefficient of friction
 - test matrix include friction and wear testing with M50 and 440C steel balls,
 - ball-on-disk configuration to evaluate the friction wear properties of the candidate lubricant formulations on disks fabricated from advanced steel.



Testing and Evaluation - Tier 2

- Corrosion-Oxidation Stability (ASTM D4636)
 - Determines the ability to resist oxidation and tendency to corrode various metals
 - Measure changes in fluid viscosity, acid number, sludge, metals appearance and weight change
 - 40 hours @ 220°C with dry air flow
- Elastomer Compatibility (FTM 3604 and 3432)
 - Measure changes in elastomer volume, hardness, tensile strength and elongation after fluid exposure.
 - NBR-H aged 168 hours @ 70°C
 - FKM aged 72 hours @ 175°C
 - FVMQ aged 72 hours @ 150°C



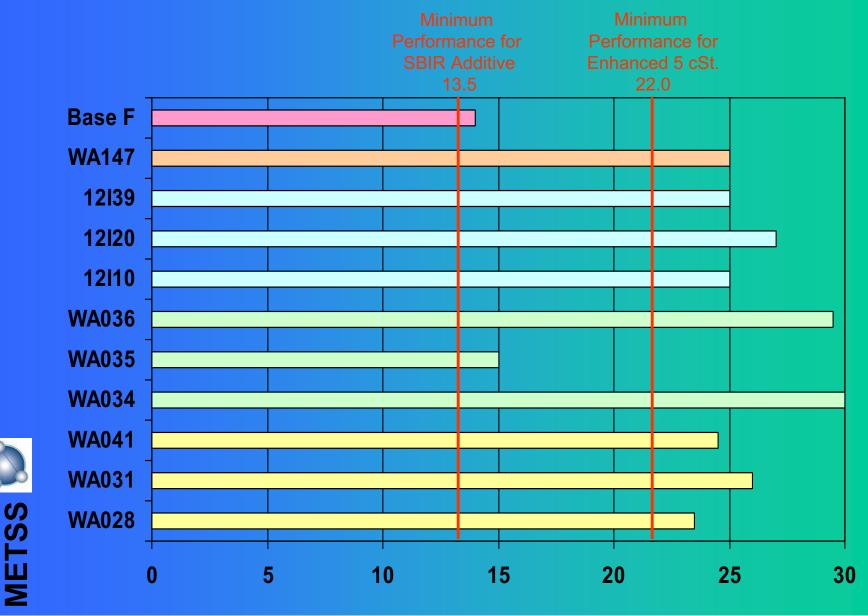
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Testing and Evaluation - Tier 2 (continued)

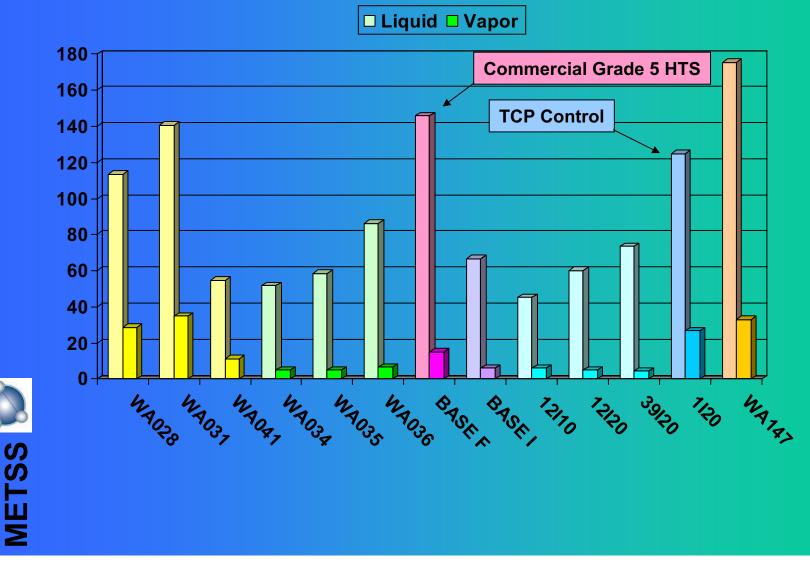
- Coking Tendency(ASTM D3711)
 - Determines the tendency to form coke deposits for both liquid and vapor contact with surfaces at elevated temperatures
 - 100 ml aged 5 hours @ 300°C with 50 ml/min flow
- Thermal Stability & Corrosivity (FTM 3411)
 - 96 Hours @ 274°C in sealed evacuated glass tube with steel
 - Measure changes in fluid viscosity & acid number, metal weight change.
- Additional Tribology Testing
 - an attempt at correlating laboratory friction and wear performance with anticipated performance in the field
 - WAM Testing Load Stage Failure

METSS

WAM Load Stage Failure

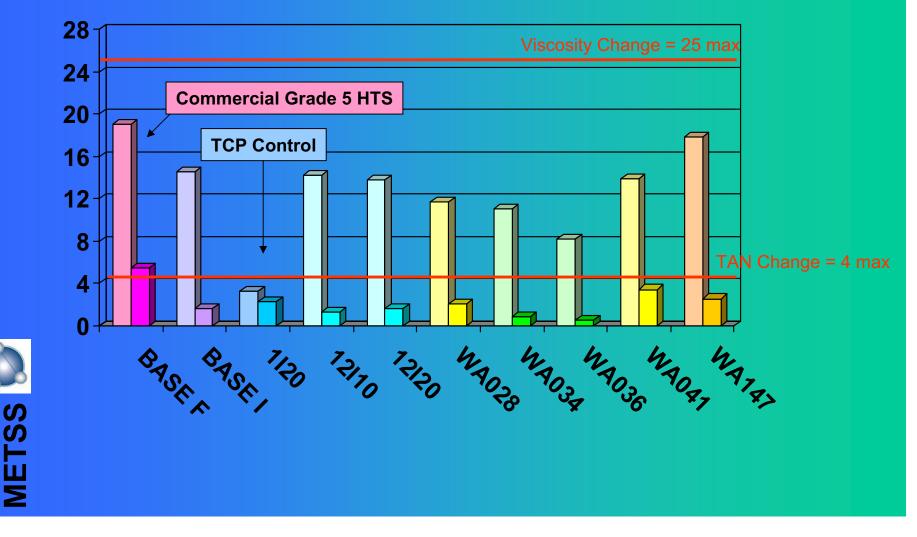


D3711 Coking Tendency - Gross Deposit, mg

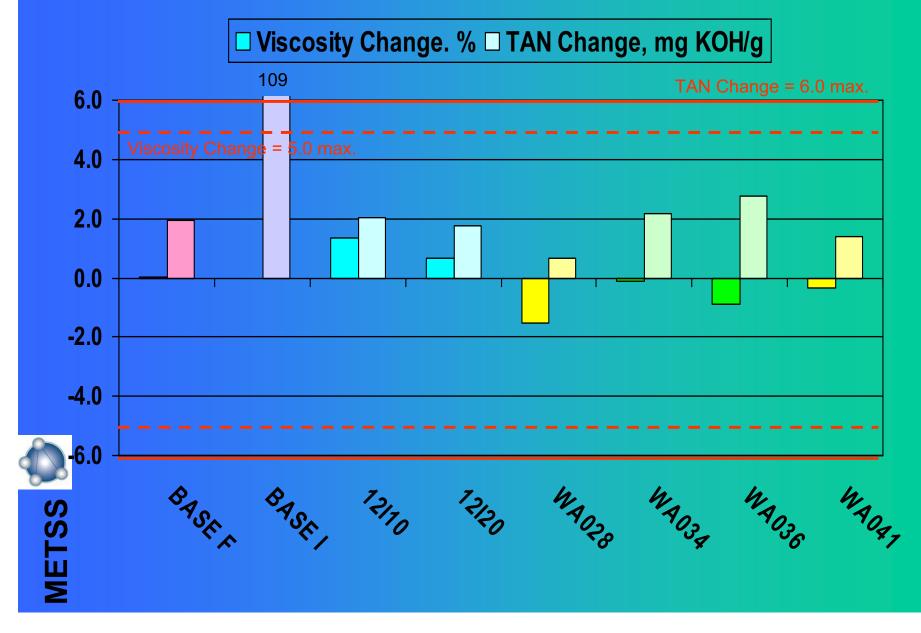


Corrosion-Oxidation Stability Test Results

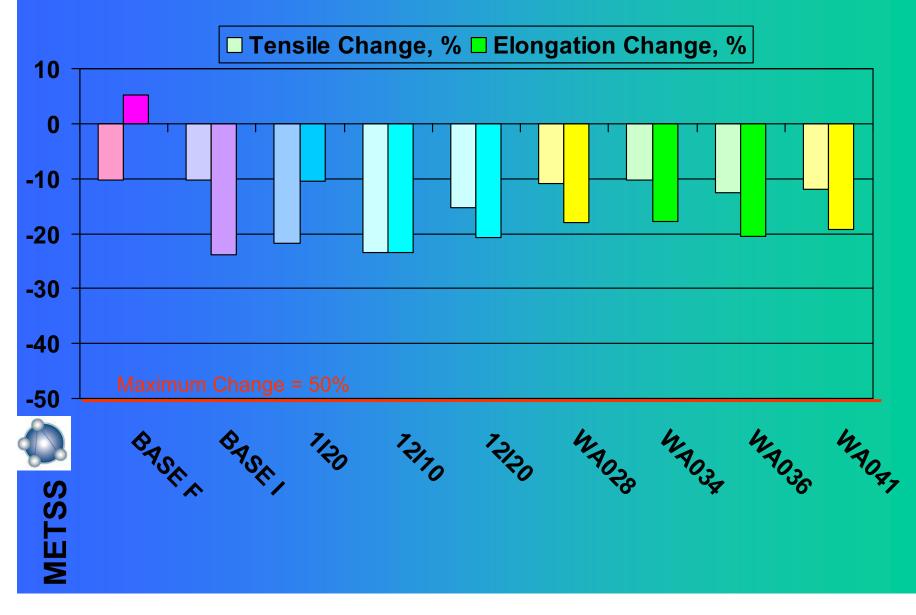
□ Viscosity @ 40C Change, % □ TAN Change, mg KOH/g



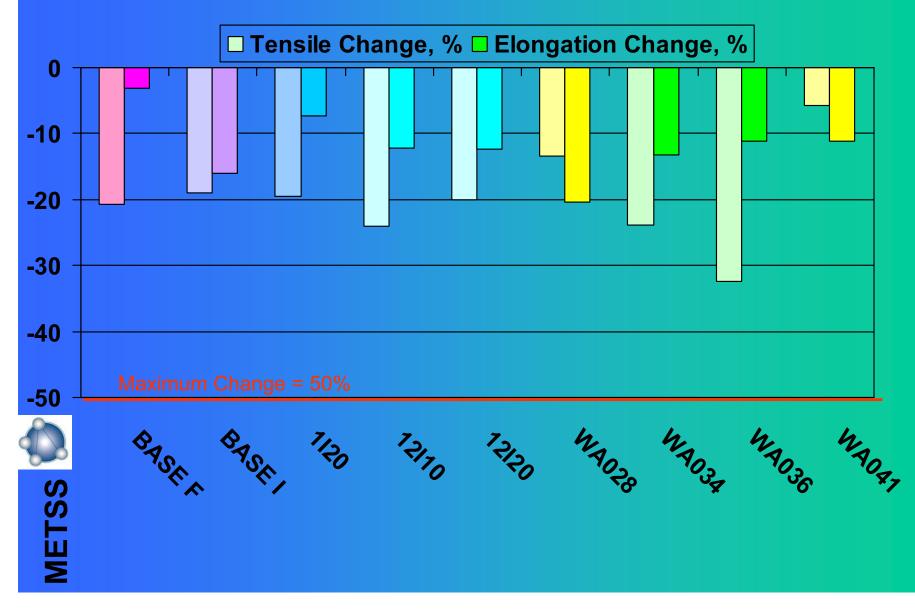
Thermal Stability & Corrosivity



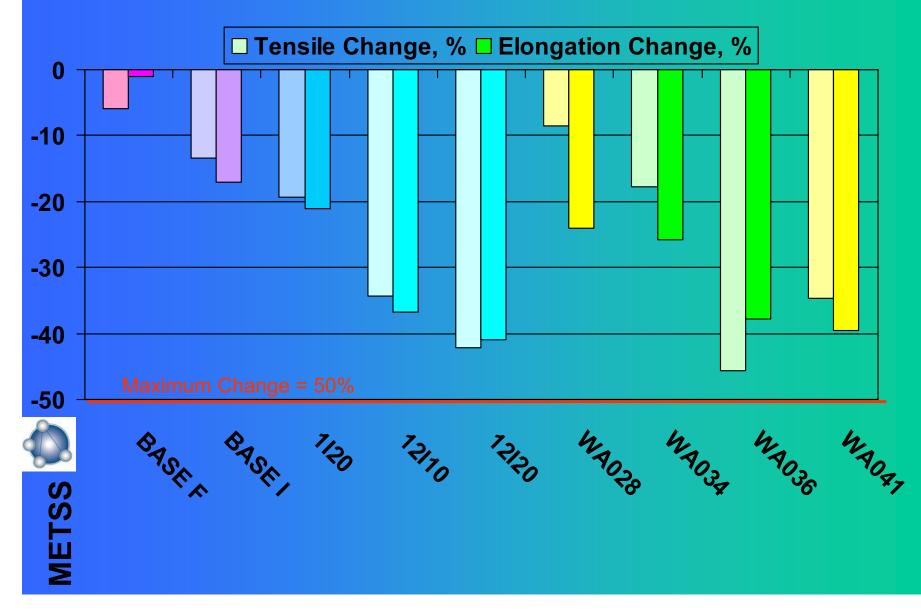
NBR-H Elastomer Compatibility



FKM Elastomer Compatibility



FVMQ Elastomer Compatibility



Summary of Progress

- New and innovative gas turbine engine oil additive technology is being developed to achieve the greatest benefit from the performance advantages provided by the advanced bearing steels.
- The new lubricant formulations have demonstrated performance comparable to baseline data obtained for the current MIL-PRF-7808 Grade 4 GTO.
- The new lubricant anti-wear additives are effective on both advanced Pyrowear 675 as well as conventional steels and have demonstrated high temperature stability.
- The new additive formulations are suitable for MIL-PRF-23699 Type 5 fluids with enhanced antiwear performance.





Down Selection

- Work with AF Propulsion and Materials to establish a relative weighting system for fluid test parameters.
 - Most important parameters receive highest weight factor
 - Least important parameters receive lowest weight factor.
- Rate candidate fluids according to test results and weight factors to achieve an overall score for each.
- Assist in selection of best candidate technologies for subsequent T-63 engine testing program.



Thanks and Acknowledgements

- METSS
 - Bill Ricks; Joe Sanders; Ann Banks
- SBIR program technical partners
 - Timken Technical Services
 - Wedeven Associates
 - POC: L. Gschwender and Ed Snyder , AFRL/MLBT
- SBIR program commercialization partners
 - Nyco America
- Outside testing laboratories
 - Phoenix Chemical
 - UEC
 - NAVAIR
 - UTC
 - AFRL





SBIR Phase II Additives for Corrosion-Resistant Steels

Vern Wedeven Wedeven Associates, Inc. Air Force Contract No. FA8650-04-C-05034

Status Briefing for Military Aviation Fluids and Lubricants Workshop

Hope Hotel and Conference Center Fairborn, OH

21 June 2006



SBIR Phase II Additives for Corrosion-Resistant Steels

Outline

- Project Scope
- Testing approach
- Tribology Performance Targets
- Additive Tribology Screening
- Down-selections
- Tribology Performance Mapping Status
- Contact Fatigue
- Coking Test Results

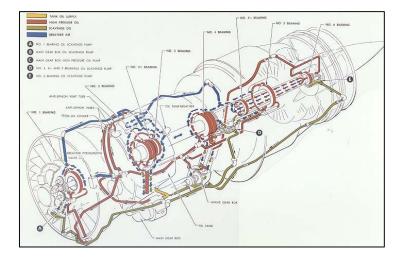


SBIR Additive – Objective



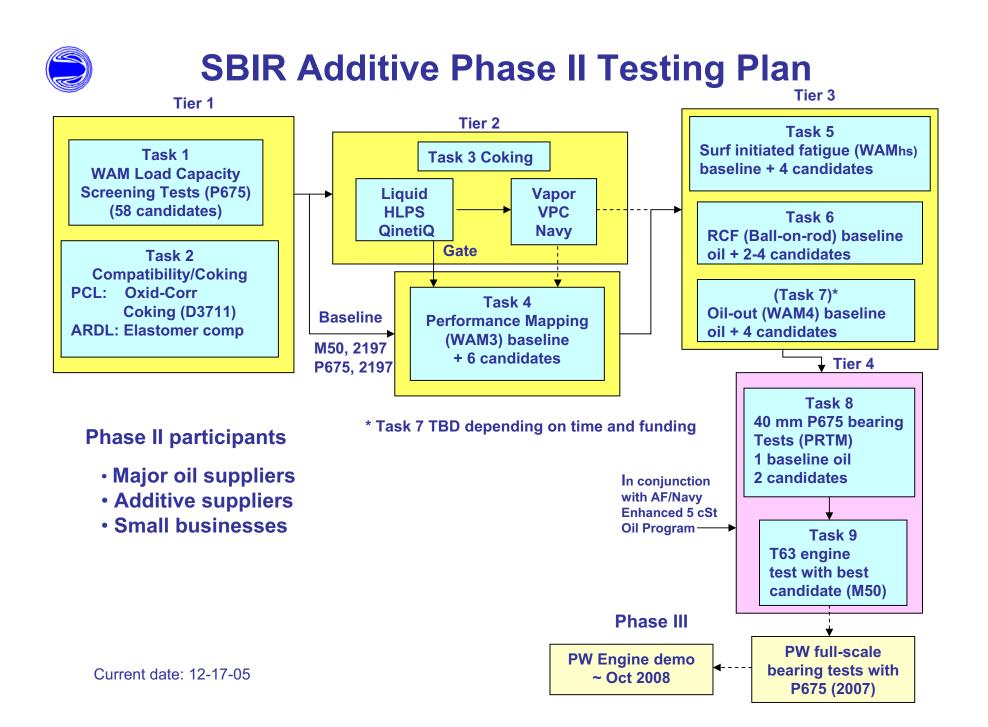
Objective: significant boost in tribology for corrosion resistant steels with no loss in coking or compatibility attributes (HTS type)







Liquid Vapor Mixed HLPS QinetiQOxid-Corr Elastomer O-C Navy PhoenixThermal stability PhoenixScuffing MearWear Fatigue WAM8 WAM8 WAM8 RCF WA, Inc.Surface Fatigue	Coking	Compatibility	Tribology
	HLPS VPC D3711	O-C D471 stability	WAM8/9 WAM8 WAMhs RCF





Tribology Strategy



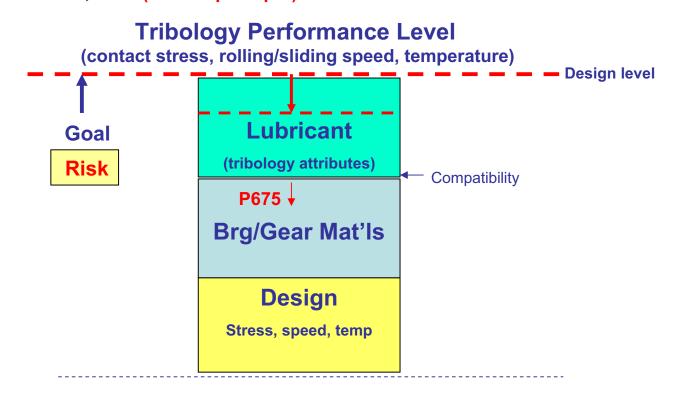
9310, Pyrowear 53, P675 (low temp temper)

• Wear

- Scuffing
- Surf fatigue



M50, M50NiL Pyrowear 675





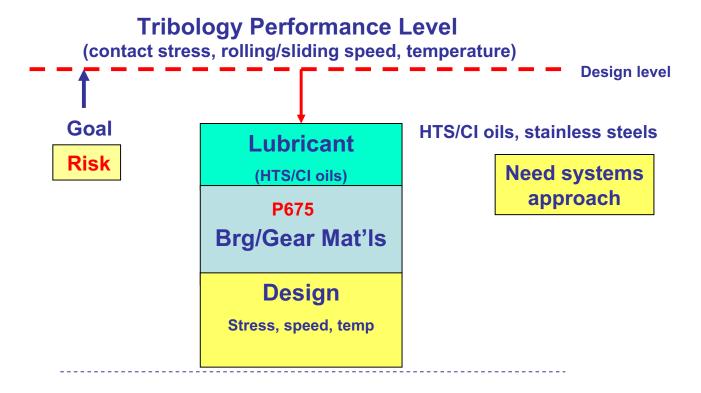
Tribology Strategy



9310, Pyrowear 53, P675 (low temp temper)

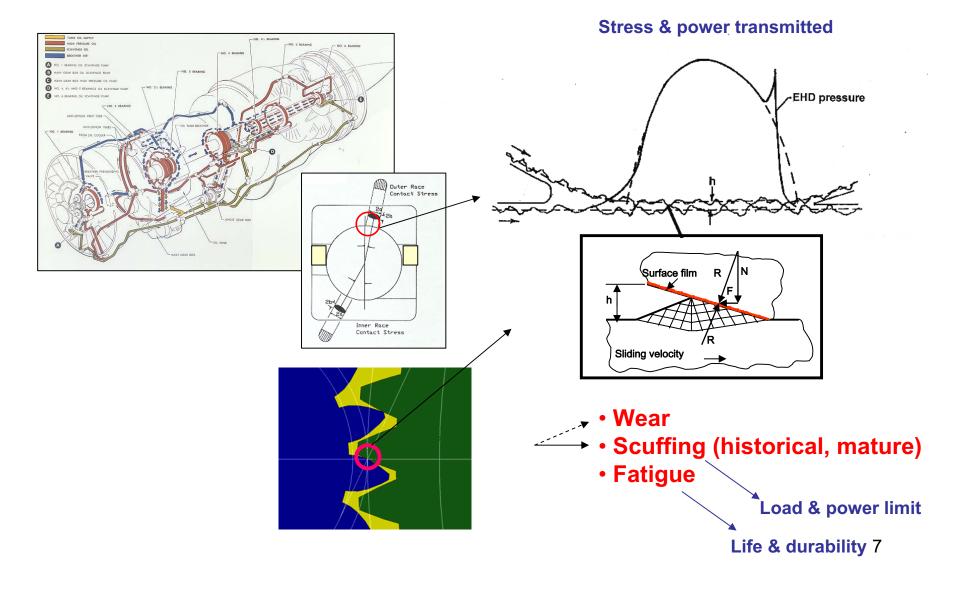


M50, M50NiL Pyrowear 675

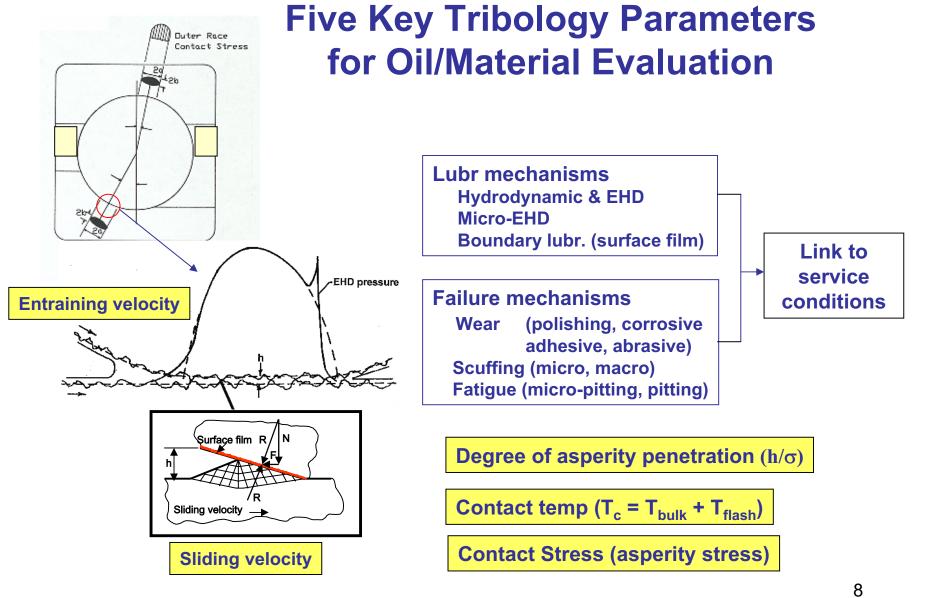




Baseline Tribology Testing – Approach



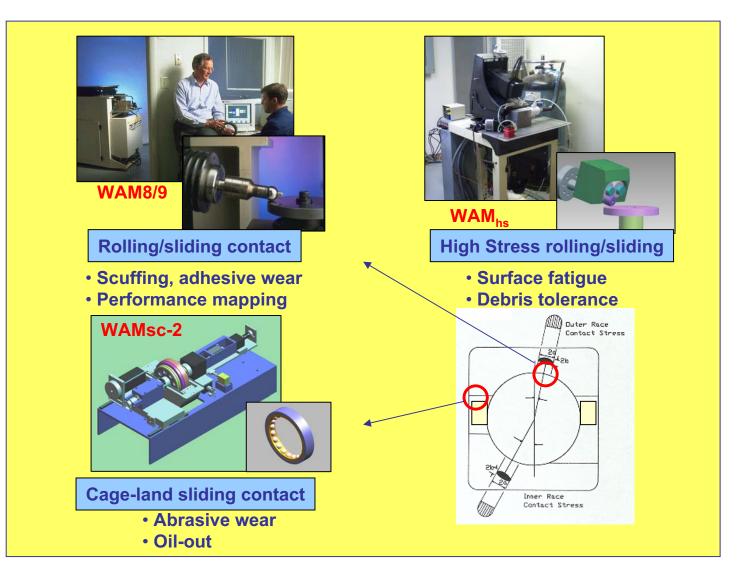






Tribology Testing

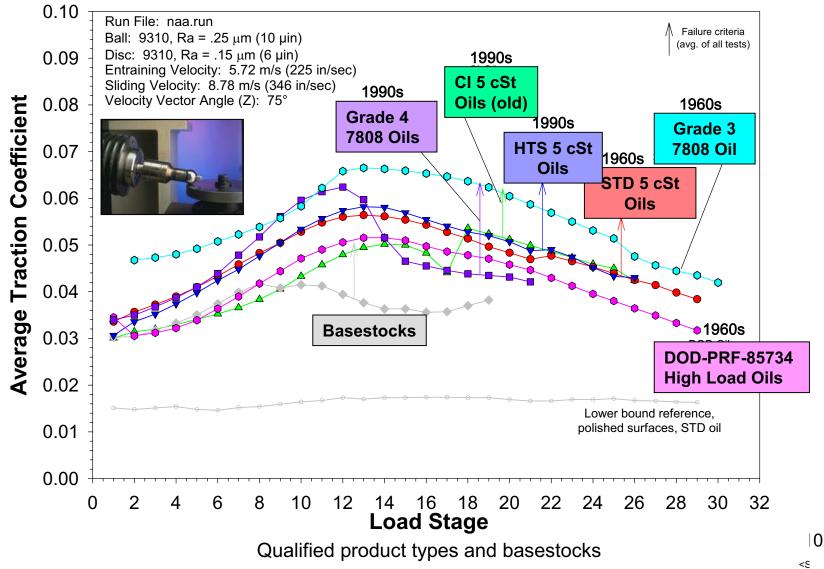
Suite of three types of machines cover current test methods





Master Chart for Oil Scuffing Performance

Historical trends in oil lubricating performance

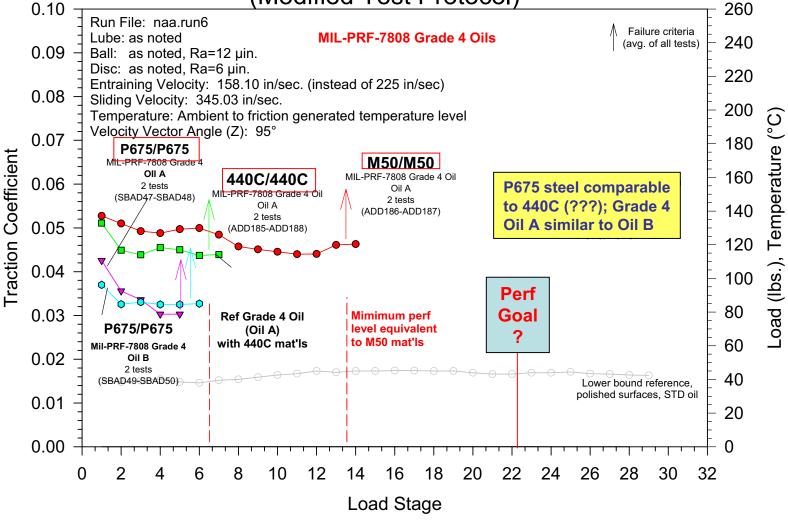




Baseline Testing – Minimum Performance

WAM High Speed Load Capacity Test Method

(Modified Test Protocol)



W/Testing/SBIR-Add/Project/WAMLCC/AVG/RM284A M50 & 440C.jnb



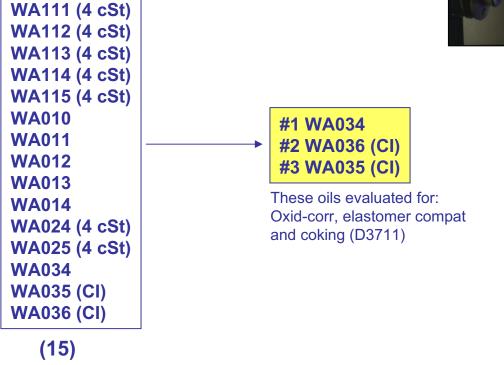
WAM Screening Tests with Timken Optimized P675



Supplier A Formulations and Down-Selections

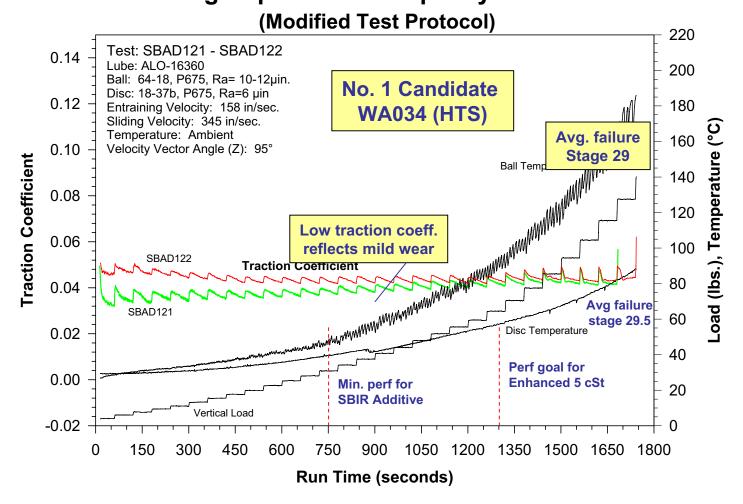
WAM load capacity screening tests





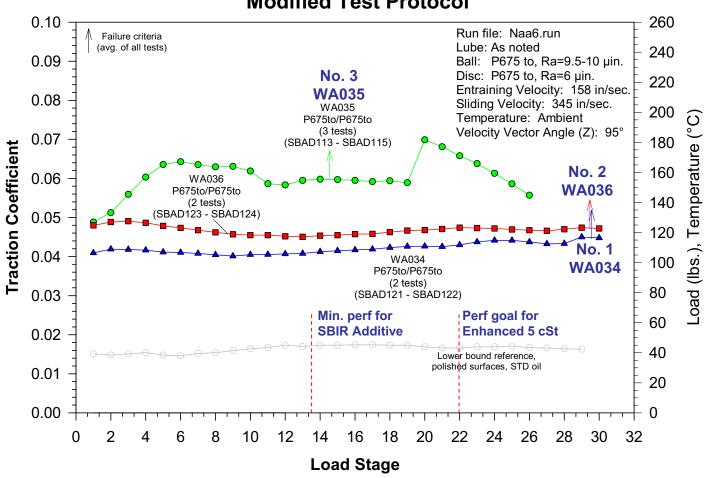
WAM Screening Tests with Timken Optimized P675

WAM High Speed Load Capacity Test Method



WAM Screening Tests with Timken Optimized P675

Supplier A Priority Candidates



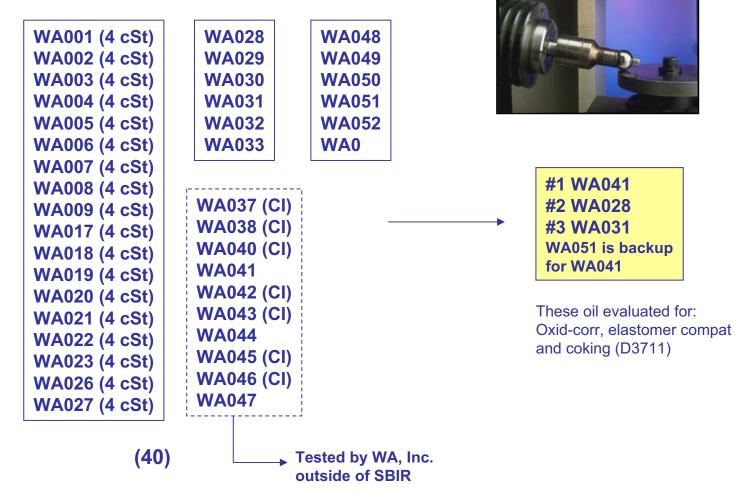
WAM High Speed Load Capacity Test Method Modified Test Protocol

W/Testing/SBIR04-05/Project/WAMLCC/.jnb



Supplier B Formulations and Down-Selections

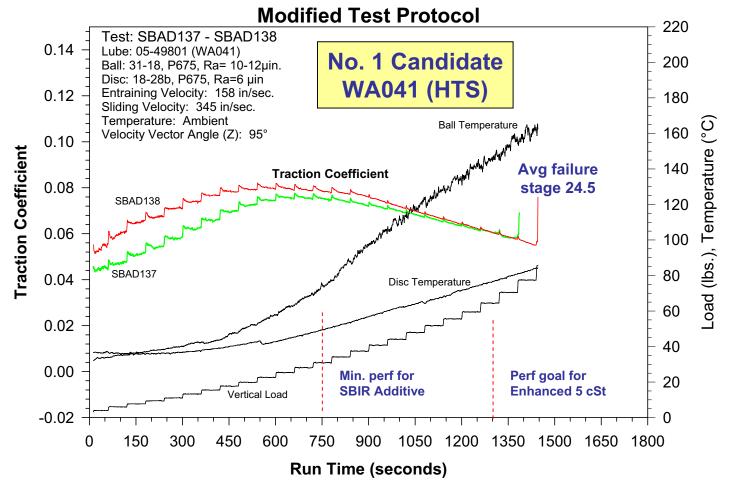
WAM load capacity screening tests





Supplier B Priority Candidates

WAM High Speed Load Capacity Test Method



17

w/testing/sbir-ADD/Projest/LCCjnb



Supplier B Priority Candidates

Modified Test Protocol 0.10 260 Run file: Naa6.run Failure criteria (avg. of all tests) WA041 Lube: As noted 240 0.09 P675to/P675to Ball: P675 to, Ra=9.5-10 µin. WA031 (2 tests) Disc: P675 to, Ra=6 µin. 220 P675to/P675to (SBAD137 - SBAD138) Entraining Velocity: 158 in/sec. (2 tests) 0.08 Sliding Velocity: 345 in/sec. SBAD129 - SBAD130 200 Temperature: Ambient ΰ Velocity Vector Angle (Z): 95° 0.07 180 **Traction Coefficient** No. 3 Temperature A041 **WA031** 160 0.06 WA051 140 0.05 (backup) 120 No. 2 Load (lbs.), **WA028** 0.04 WA028 WA051 100 P675to/P675to P675to/P675to (2 tests) (2 tests) (SBAD125 - SBAD126) 80 (SBAD157 - SBAD158) 0.03 Min. perf for Perf goal for 60 Enhanced 5 cSt 0.02 **SBIR Additive** 40 Lower bound reference. polished surfaces, STD oil 0.01 20 0.00 0 20 22 24 0 2 6 8 10 12 18 26 28 30 32 Δ 14 16 Load Stage

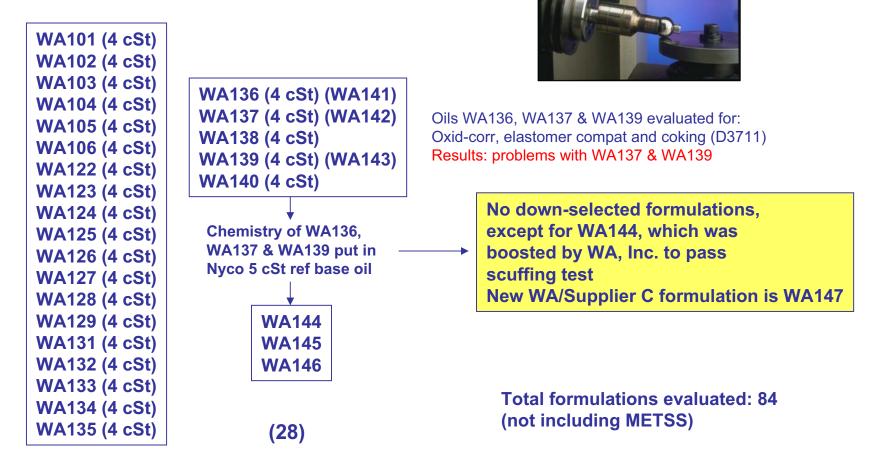
WAM High Speed Load Capacity Test Method

W/Testing/SBIR04-05/Project/WAMLCC/.jnb



Supplier C Formulations and Down-Selections

WAM load capacity screening tests

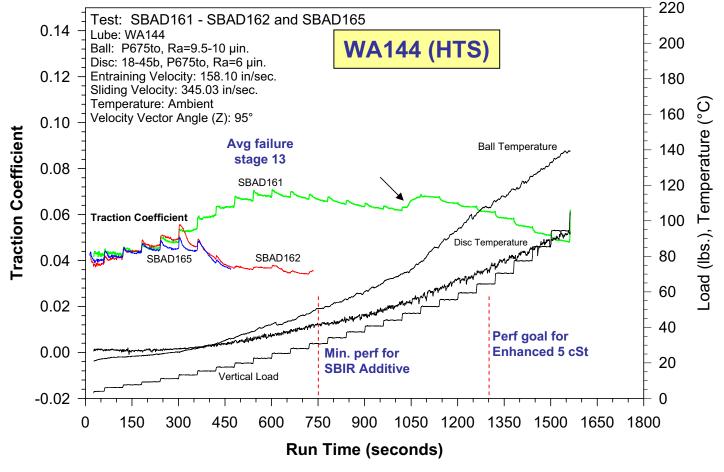




Supplier C Candidate

WAM High Speed Load Capacity Test Method

Modified Test Protocol

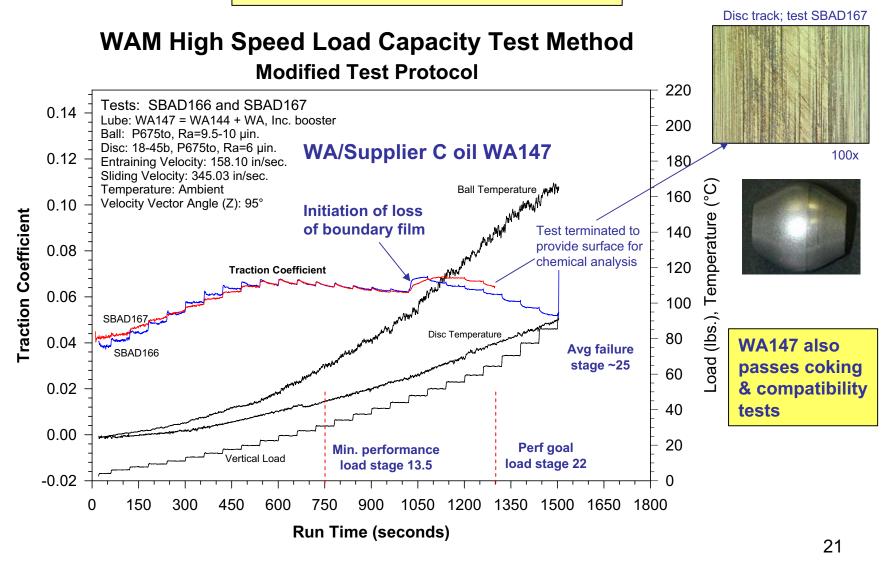


wamlcc/sbir-add/modifiedtestprotocol/DOD.jnb



WAM Screening Tests with Timken Optimized P675

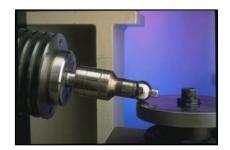
WA, Inc./Supplier C Candidate

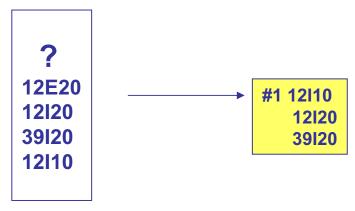


wamlcc/sbir-add/modifiedtestprotocol/DOD.jnb

METSS Formulations and Down-Selections

WAM load capacity screening tests



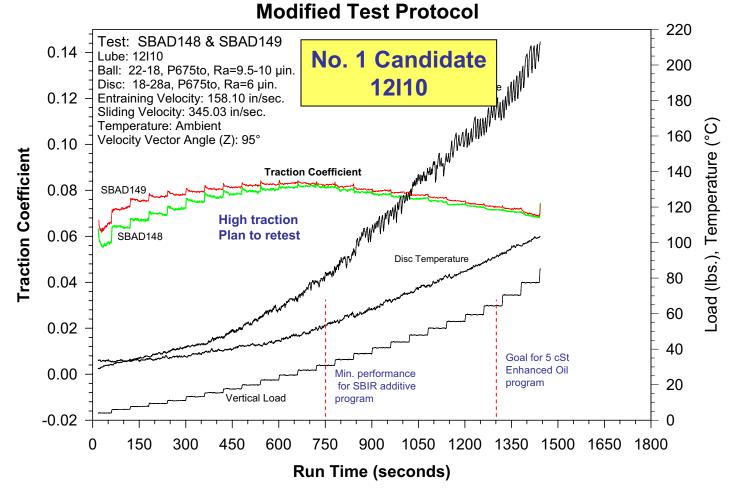


These oils evaluated for: Oxid-corr, elastomer compat and coking (D3711)



METSS Candidates

WAM High Speed Load Capacity Test Method

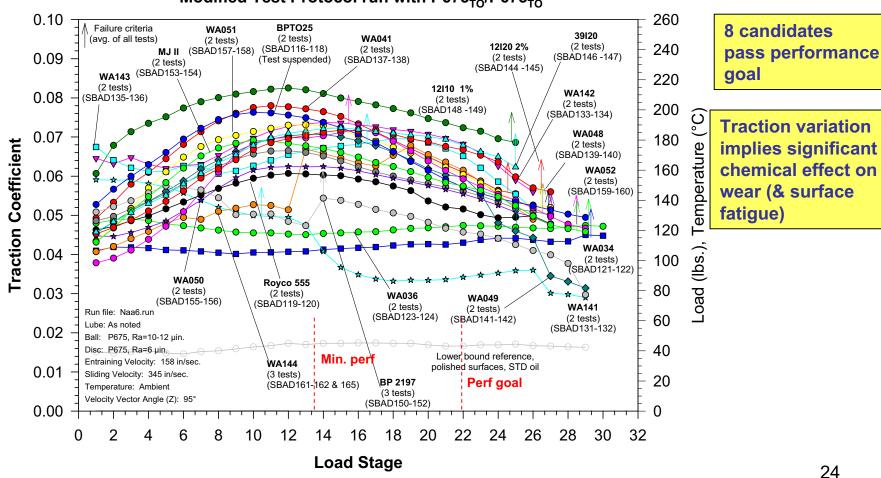


wamlcc/sbir-add/modifiedtestprotocol/DOD.jnb



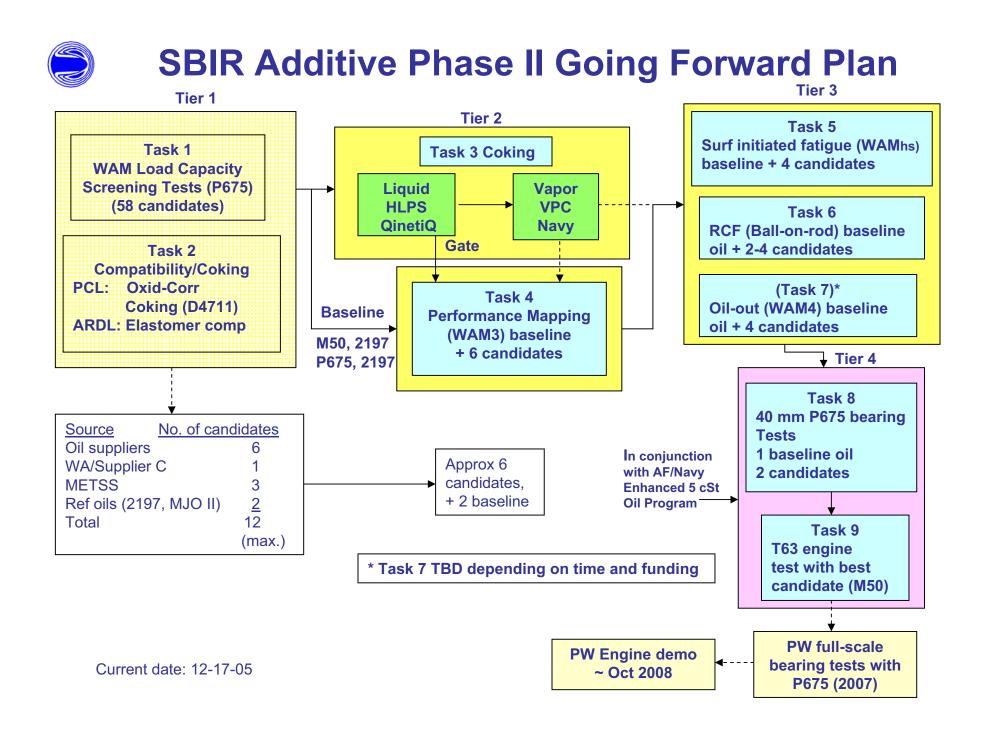
Monster Graph – All oils tested with P675_{TO}

WAM High Speed Load Capacity Test Method



Modified Test Protocol run with $P675_{TO}/P675_{TO}$

W/Testing/SBIR04-05/Project/WAMLCC/.jnb

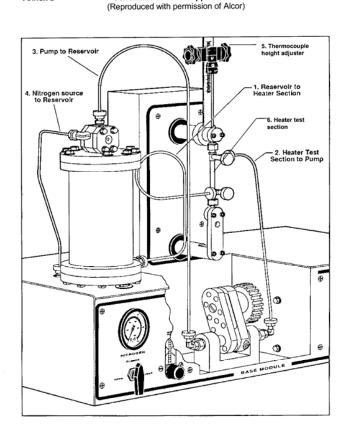




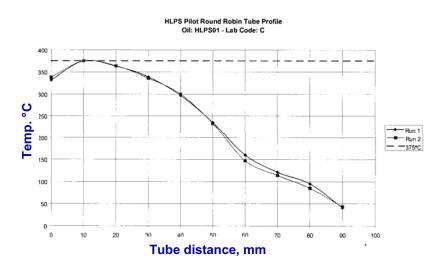
Annex D

Coking Tests at QinetiQ

HLPS – liquid phase



Schematic of HLPS Apparatus

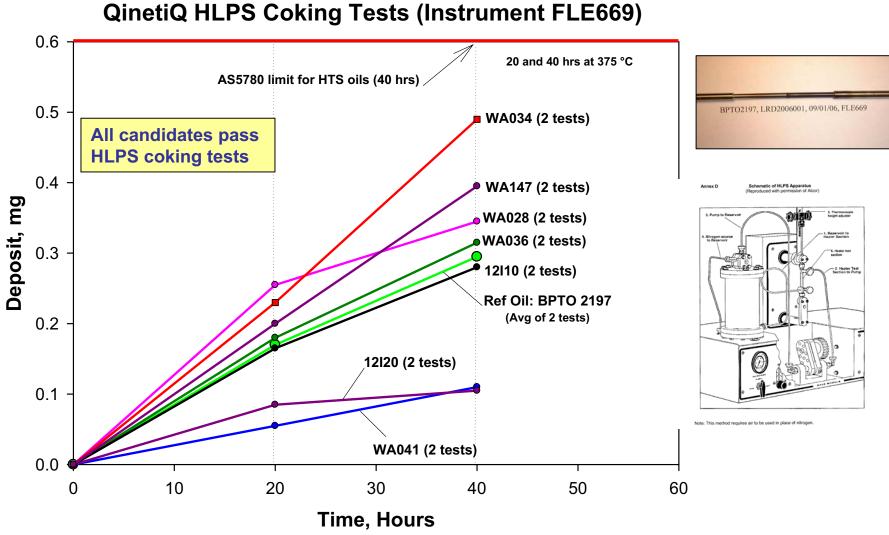


Note: This method requires air to be used in place of nitrogen.

HLPS 320 Instrument



Coking Tests at QinetiQ



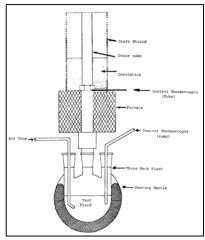
Current date: 6-12-06



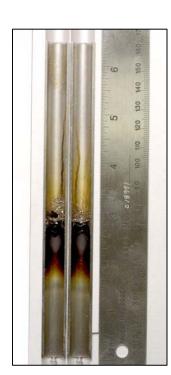
Coking Tests at U.S. Navy

Vapor Phase Coking

343 °C nominal tube temperature data









U.S. Navy Vapor Phase Coking Tests

Wedeven SBIR Additive Project Air Force Contract No. FA8650-04-C-05034 May 22, 2006

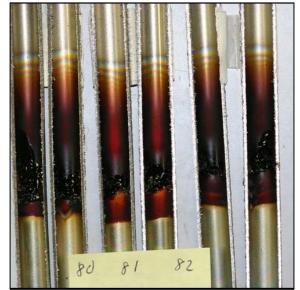
343 °C nominal tube temperature data

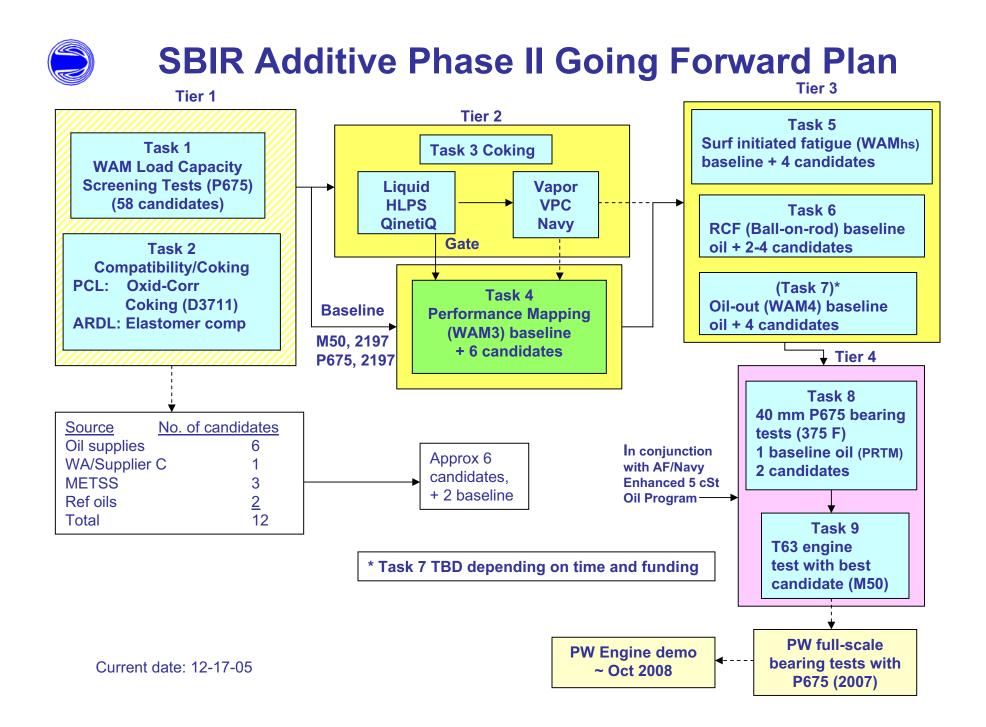
<u>Test Oil</u>	A <u>vg. deposit (3 tests), mg</u>	
Air BP 2197 (ref HTS)	212	
23699 "Dirty Oil" (DLA04-1075)	332	
12 10	305	
12120	355	
WA034	172	
WA036	178	
WA041	206*	
WA028	224	

* Red deposits on flask not counted in this number

Four of six oils tested so far pass

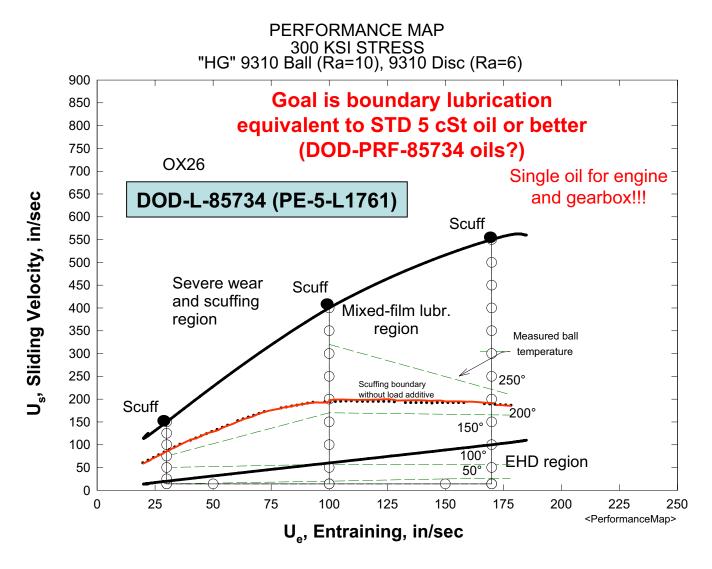






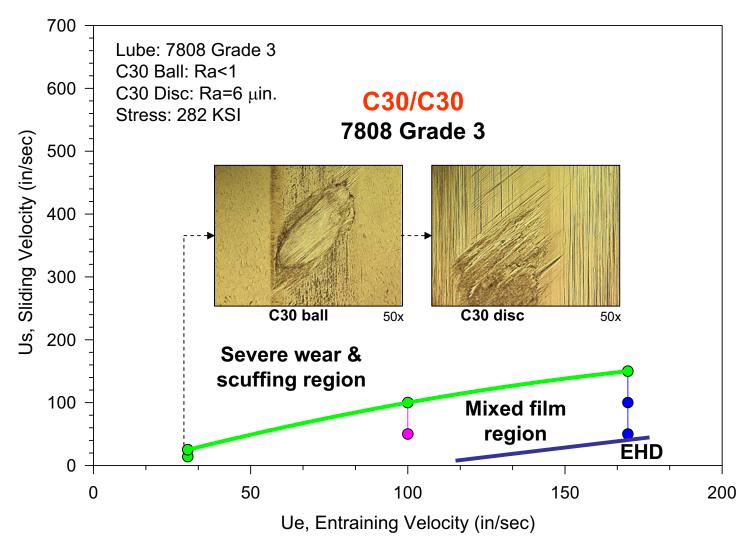


Performance Mapping





Impact of Corrosion Resistant Materials on Boundary Lubrication



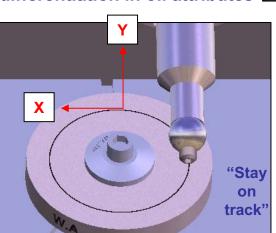


WAM3 Upgraded for • Design and manufacture of parts under SBIR Test Method contract F33615-01-C-2118

• Final assembly and checkout under SBIR Additive contract FA8650-04-C-5034

WA, Inc. designed & fabricated WAM System Control Board

- Upgraded electronics
- High precision positioning (x-y mode)
- WinWAM software
- Significant savings in test time
- Greater differentiation in oil attributes





WAM8

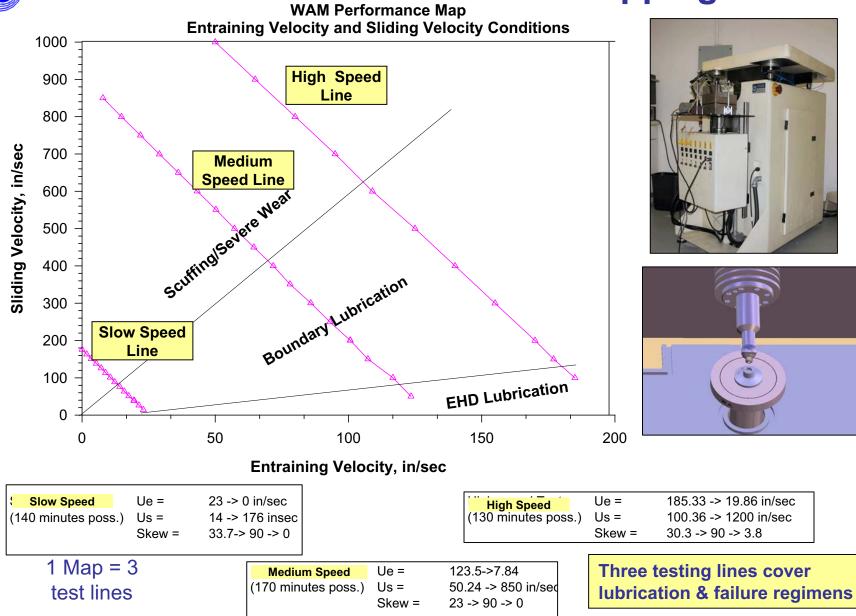


- XY control
- Stiffer mounts and linkages
 Linear encoders for position feedback

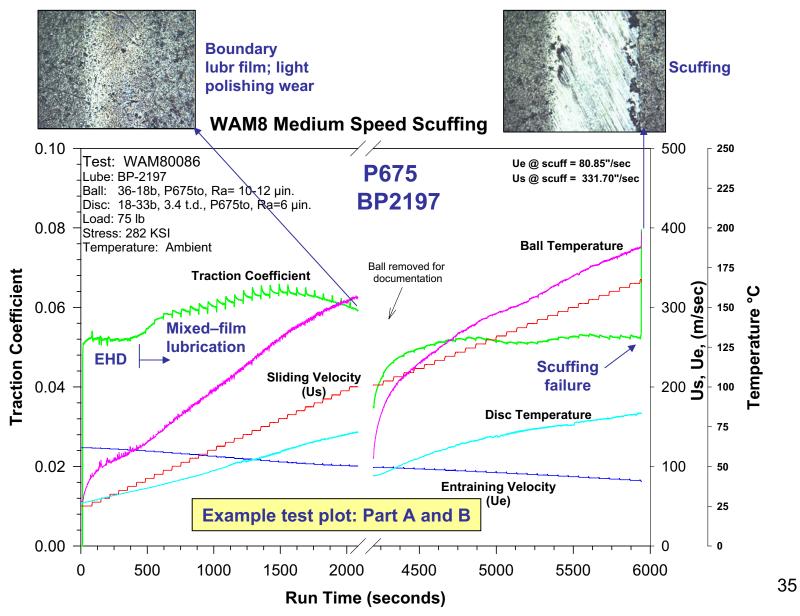


Simplified and robust electronics



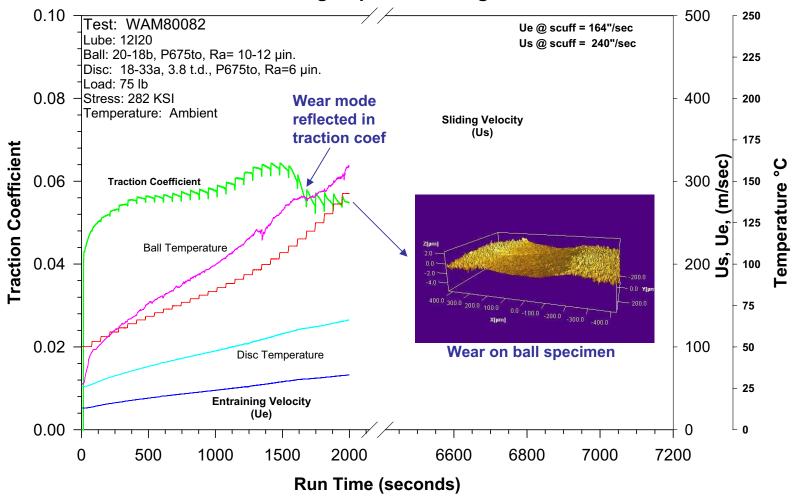






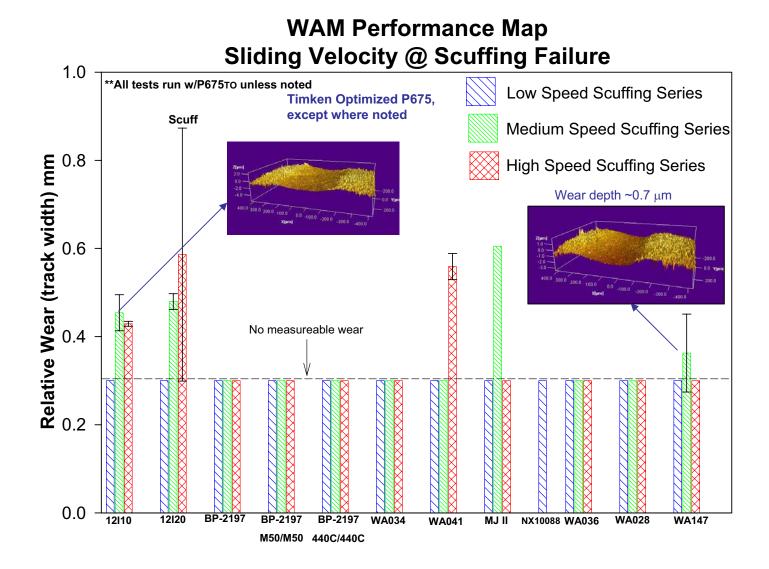


WAM8 High Speed Scuffing





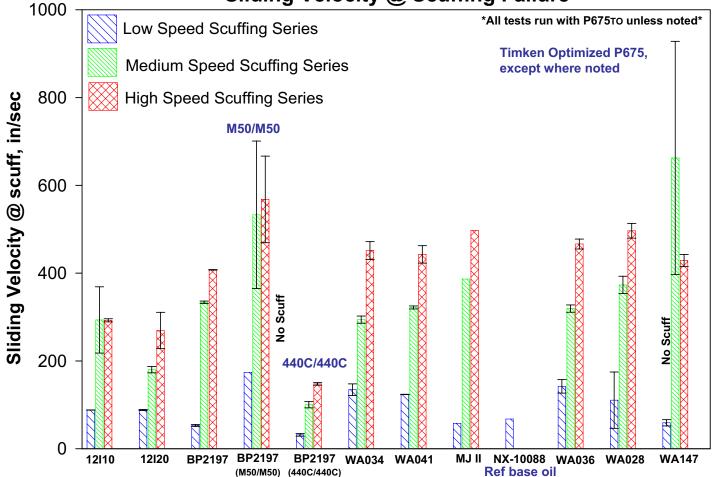
First part of test evaluates wear performance

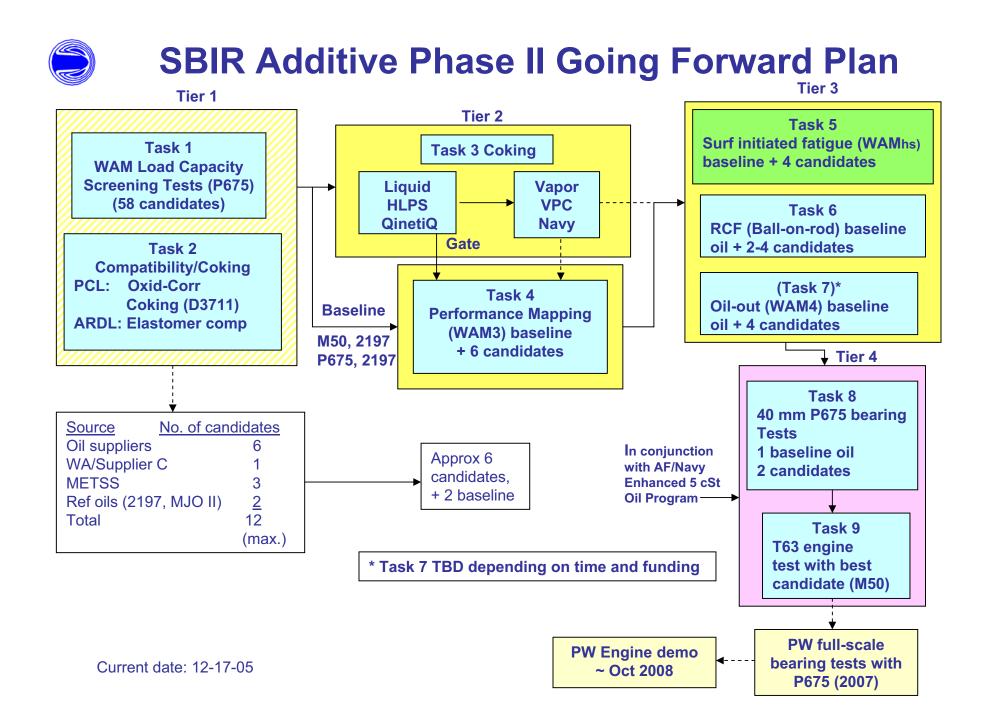




Second part of test evaluates scuffing performance

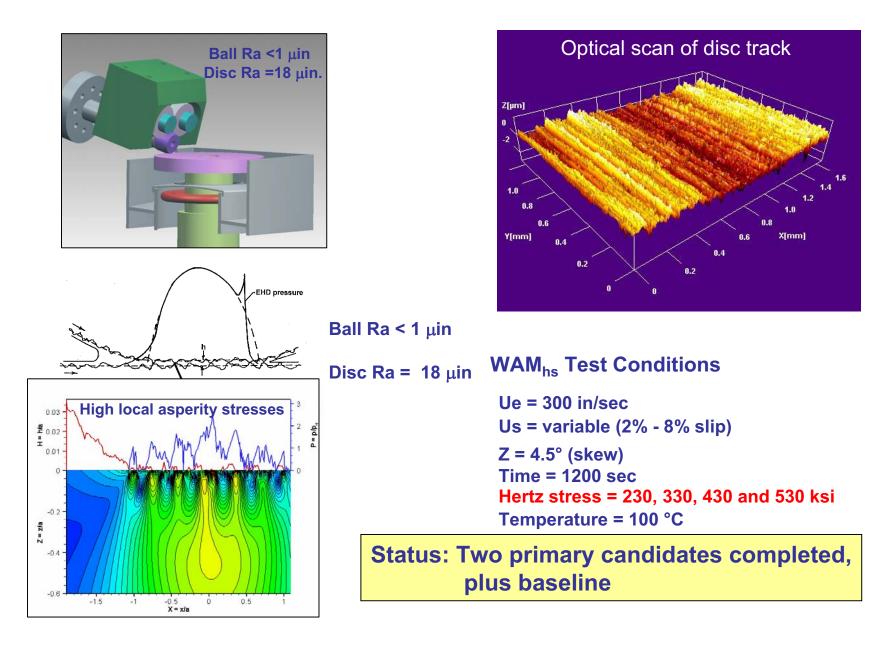
WAM Automated Performance Map Sliding Velocity @ Scuffing Failure





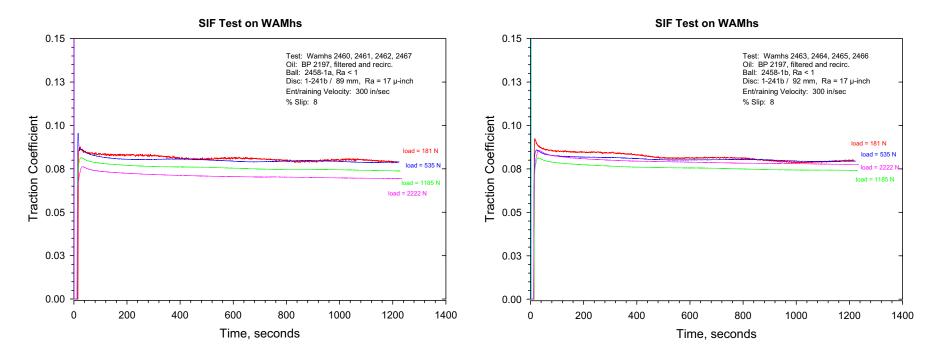


WAM_{hs} Test – Surface Initiated Fatigue



Progressive Loading SIF- M50 Traction Behavior

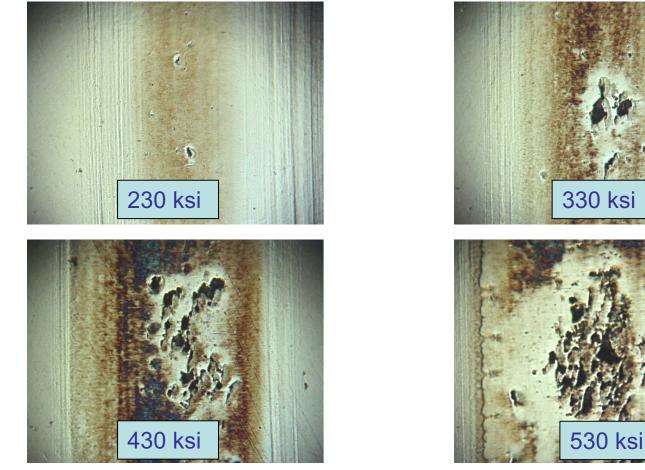
Test temperature: 100° C Test oil: BP2197



Progressive Loading SIF- M50

Test temperature: 100° C Test oil: BP2197

Ball 2458-1a



Fatigue initiates at 330 ksi. Small "spots" at 230 ksi are most likely pre-existing finishing marks in M50 ball.

Progressive Loading SIF- M50

Test temperature: 100° C Test oil: BP2197

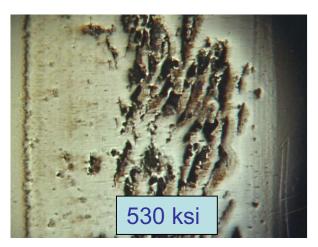
Ball 2458-1b







*repeat

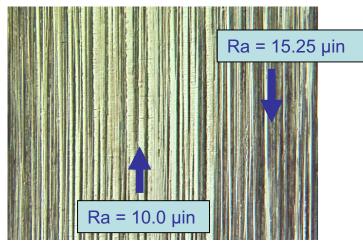


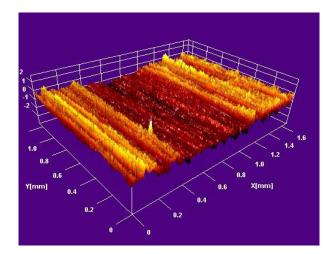
Fatigue initiates at 330 ksi. Small "spots" at 230 ksi are most likely pre-existing finishing marks in M50 ball.

Progressive Loading SIF- M50

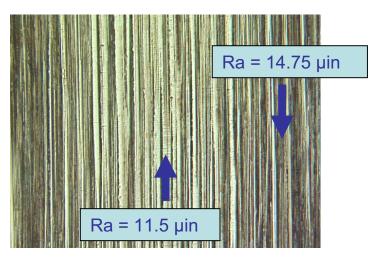
Test temperature: 100° C Test oil: BP2197

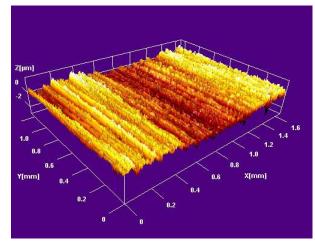
Disc 1-241b / 89mm





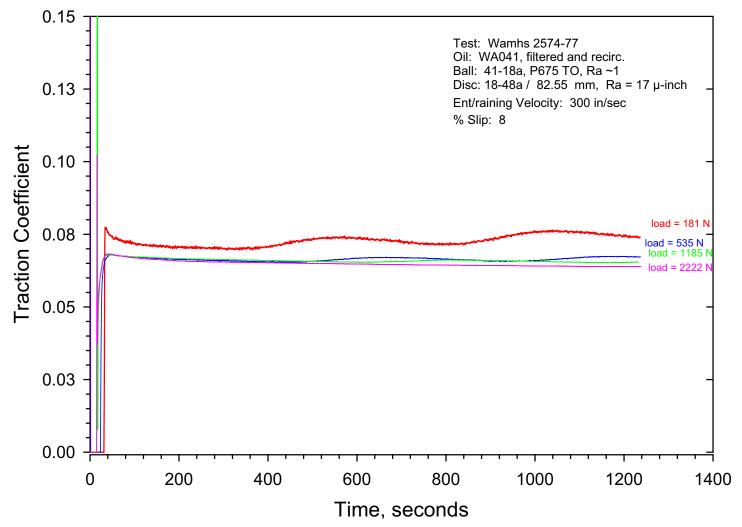
Disc 1-241b / 92mm





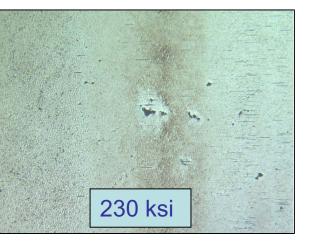
Progressive Loading SIF- P675 Oil: WA041 (100 C)

SIF Test on WAMhs



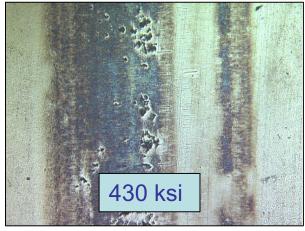
Progressive Loading SIF- P675то Oil: WA041 (100 C)

Prominent chemical surface film

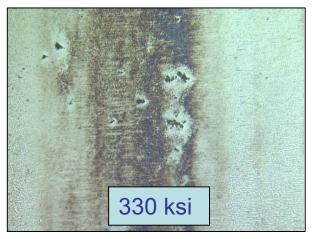


Ball 41-18a

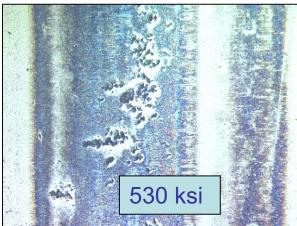
100X



50X



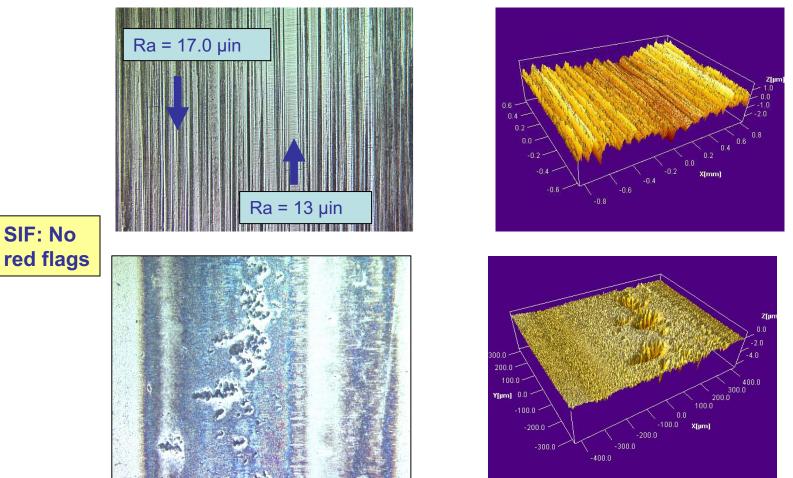
100X



46

50X

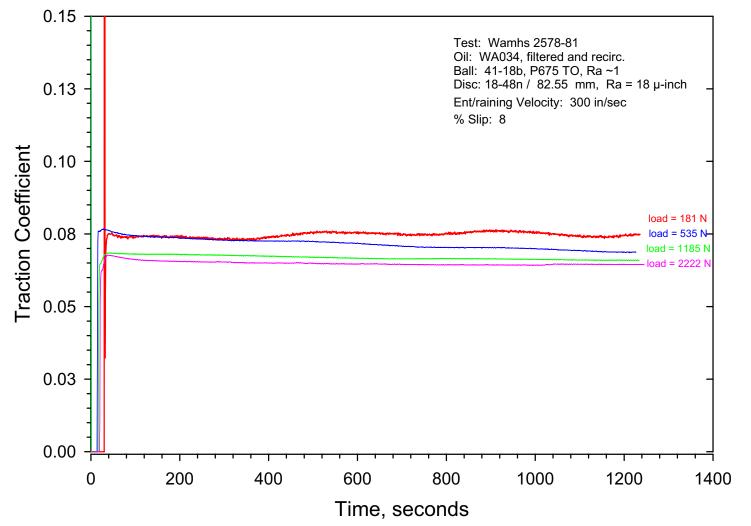
Progressive Loading SIF- P675то Oil: WA041 (100 C)



Ball and disc specimens after final stage of SIF test (530 ksi) with P675 specimens and WA041 oil. Typical depth of surface damage on ball is ~ 4 micron. Disc shows polishing wear and a reduction in Ra from 17 μ -inch to 13 μ -inch.

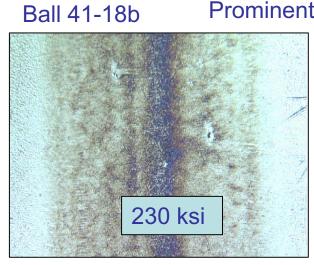
Progressive Loading SIF- P675 Oil: WA034 (100 C)

SIF Test on WAMhs



Progressive Loading SIF- P675то Oil: WA034 (100 C)

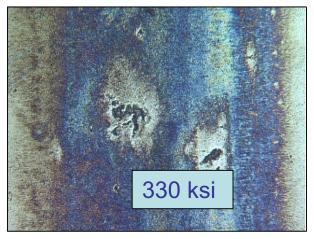
Prominent chemical surface film



100X



50X



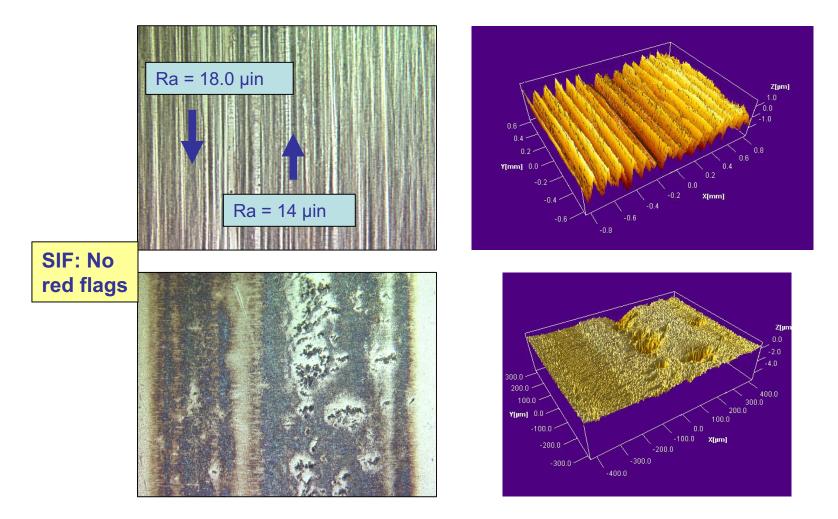
100X



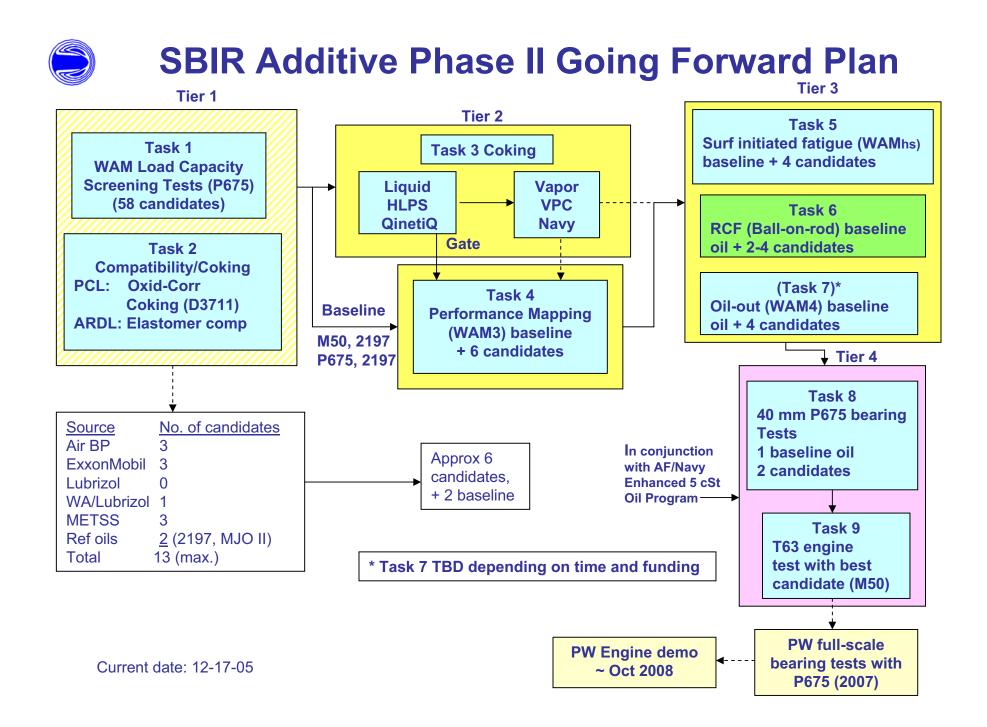
49

50X

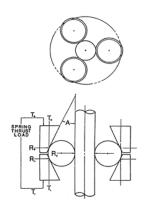
Oil: WA034 (100 C)



Ball and disc specimens after final stage of SIF test (530 ksi) with P675 specimens and WA034 oil. Typical depth of surface damage on ball is ~ 4 micron. Disc shows polishing wear and a reduction in Ra from 18 μ -inch to 14 μ -inch.







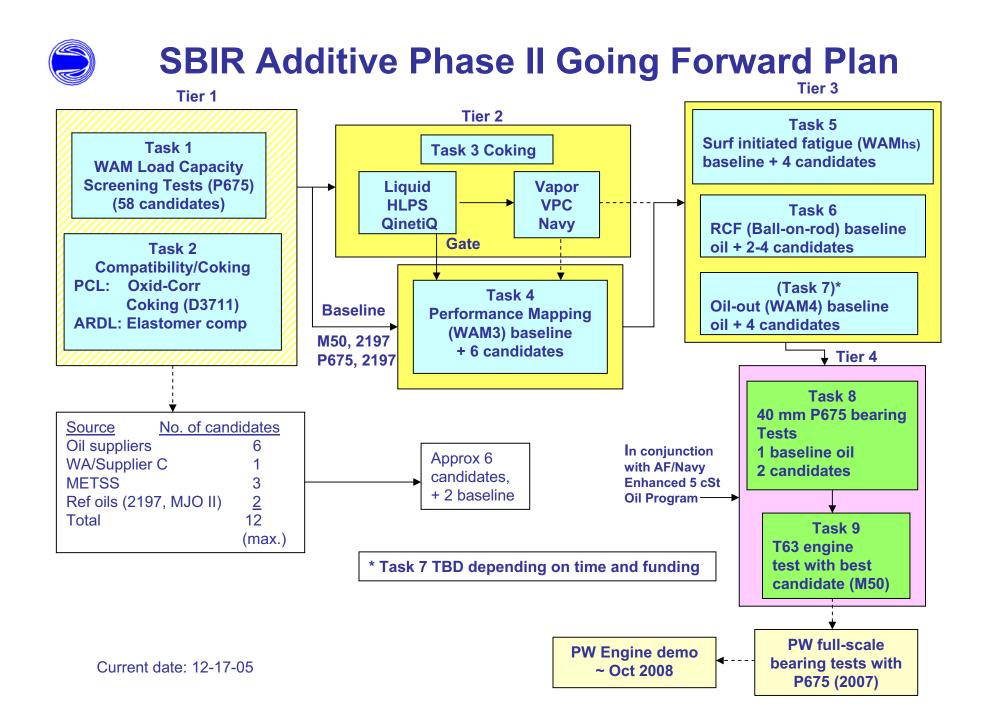
• PO with UES

RCF Tests by UES





- Ball mat'l: Si3N4 (instead of M50)
- Contact stress: 800 ksi
- P675 rods (3/8-inch dia) limited supply (Timken optimized)
- Temperature: 350 °F
- Run until spall detected or suspend at 300 hrs
- Run 16 tests to spall or suspension (Weibull analysis)
- Run two tests to limited times (TBD) for fatigue progression & chem anal.
- P675 rods and balls to be shipped to WA, Inc. for documentation
- Baseline oil: 2197
- No. of candidates from SBIR Additive program: 3
- Selected data to be shared with P675 supplier (Timken)
- Compare data with WAM surface initiated fatigue





Conclusions

- Tribology, compatibility and coking tests show approx. six potential candidates oils with HTS and enhanced tribology properties
- Additional fatigue tests and coking tests are required to select two primary oils for 40 mm bearing tests with follow-on T63 engine test with one oil
- Good potential for successful next generation engine/gearbox oil



Acknowledgements

U.S. Air Force Monitor:

Lois Gschwender (and Ed Snyder) Oil suppliers Additive suppliers Engine OEMs

Think Systematic Tribology

CE RESEARCH LABOR Development and Evaluation of Multi-Purpose, Moisture-Resistant, High Load Carrying Polyalphaolefin Based Grease, MIL-PRF-32014 By

Lois Gschwender



Outline



- Cruise Missile Problem
- Grease Attributes
- Selected Properties
- Test Methods
- Other Grease Issues
 - Compatibility Data
 - Introduction of New Greases
- Qualification Status
- Summary



Cruise Missile Problem

- F107 Cruise Missile engine
 - Missile stored for 18 months- requirement
 - Williams Engine Co. could not guarantee
 - In #1 bearing, the grease, Andok 260, reacted with air moisture and bled out of bearings
 - Overhauls to re-grease costly
 - New grease needed

MIL-PRF-32014 R&D

- Rigorous grease requirements
 - High temperature ~175 to 225°C
 - High load ~135 Kg
 - High speed ~30,000 rpm
- Andok 260
 - Mineral oil base fluid
 - Sodium soap thickener
 - Additives
- Andok 260 met operational requirements but sodium soap hydrolyzed and released oil - dripped out of bearings

MIL-PRF-32014 R&D

- AFRL with AMOCO under contract developed improved grease
 - Synthetic polyalphaolefin base oil desired repeatable and reliable source, minor cost increase
 - Several thickener systems were candidates
 - Candidate grease had to meet or exceeded all operational requirements
 - Last 6 months in high humidity storage
 - Pass 30,000 rpm 203 bearing test after storage
 - New test methods had be be devised

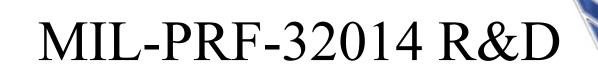


- Base Oil mixture of 6 and 40 cSt polyalphaolefin
- Thickener: Methyl 12-hydroxy stearate and lithium hydroxide monohydrate
- Antioxidants
- Antiwear
- Antirust
- Metal deactivator



- Base oil is repeatable unlike mineral oil
- Lithium soap thickener is water insoluble, non-hygroscopic and does not react with water, unlike sodium soap thickener
- Has the latest state-of-the-art performance improving additives
- Non-proprietary
- Low cost



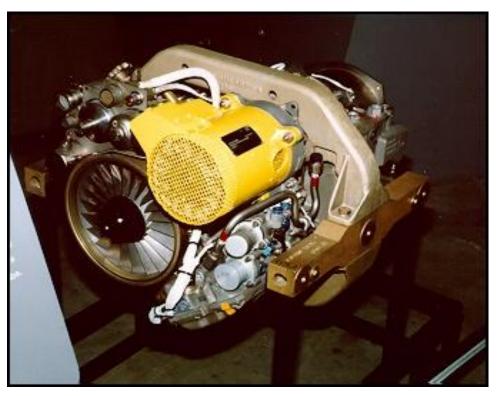


- Grease properties and test methods approved by
 - Joint Cruise Missile Program Office
 - Williams Engine Co.
 - Air Force Propulsion System Program Office
 - Navy Air Propulsion Center
 - Naval Air Development Center



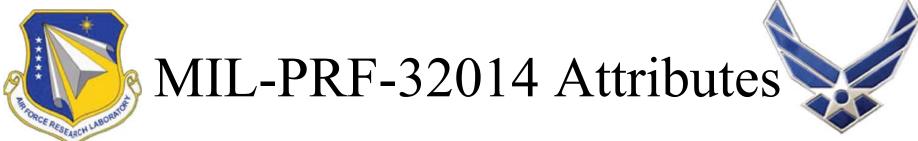
MIL-PRF-32014 R&D

- Final validation
 - Engine test
 - ->\$1M
 - Overhaul extended to60 mo., bearings reusedmost often



F-112 Advanced Cruise Missile Engine

• Williams Engine Co., "We can't fail this grease!" Using in other #1 engine bearings.



- Excellent water washout resistance
- High load carrying
- High temperature
- High speed
- Corrosion resistant
- Low cost
- Available
 - Two qualified sources
 - No "Vanishing Vendor"



MIL-PRF-32014 Selected Properties



	Target	Typical
Dirt particles, max		
25-125 micrometers	1000	144
>125 micrometers	none	0
Water resistance, max %	15	2.75
Dropping point, ^o C, min	200	395



MIL-PRF-32014



Wear Properties

		Target	Typical
Fretting wear, mg max		6	1.3
Four bal	l wear, mm max	0.65	0.41
Falex sp	indle 204 bearing, hi	rs max 500	pass
High speed 203 bearing, hrs max		max 25	pass
High spe	ed 203 bearing, hrs	max	
<u> </u>	nonths storage in h chamber		pass

High humidity oven for 6 mo. storage test





High-speed 203 bearing test 4 hr at room temp, 21 hr at 115°C, 1769 N load, As received grease and after 6 mo. storage at 71°C and 98-100% RH



Comparative Testing

- Three laboratory tests were performed to compare corrosion protection, water resistancy, and load capacity of MIL-PRF-81322 and MIL-PRF-32014
 - SRV
 - CREP
 - Water Washout (including salt water)



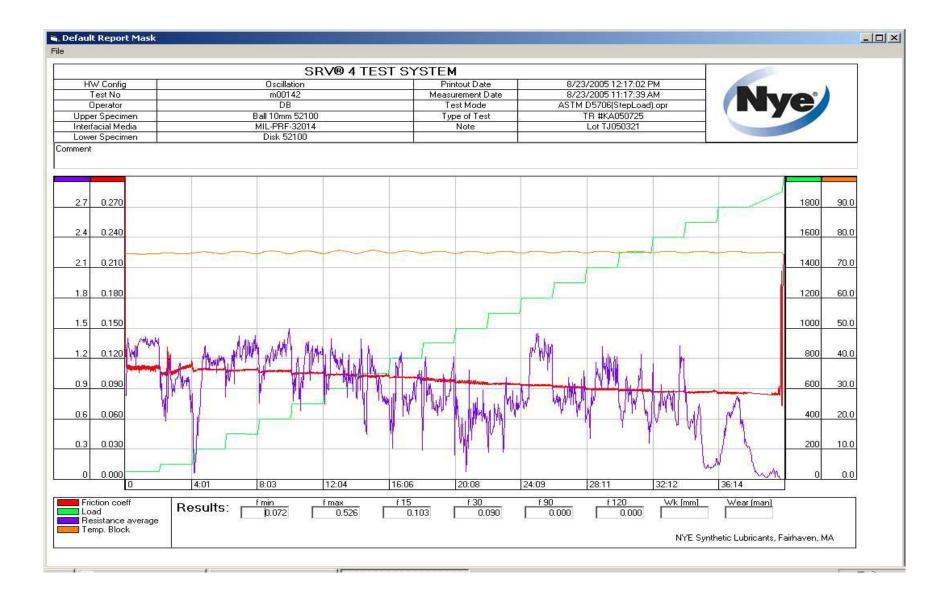


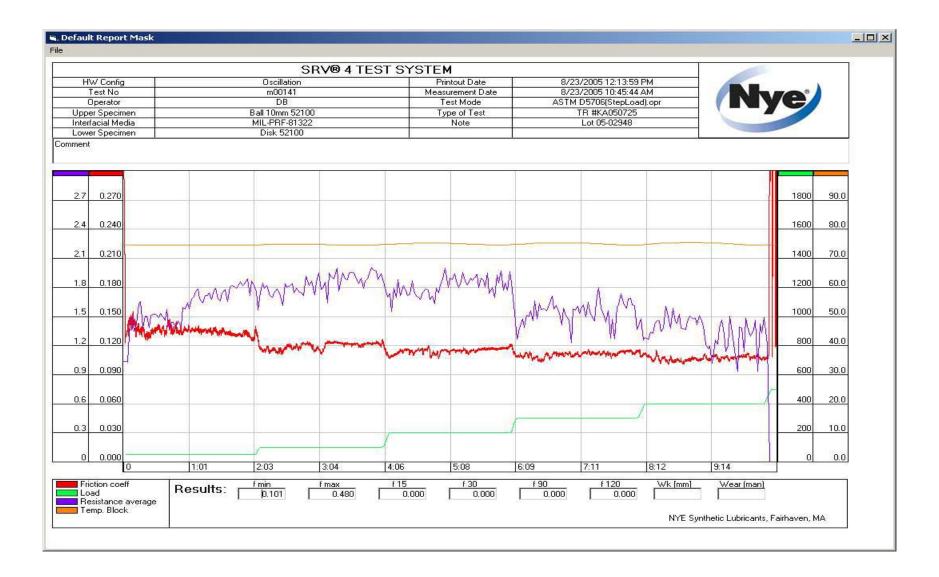
Comparative Testing

MIL-PRF-81322	MIL-PRF-32014	
	(Rheolube 374A)	
ΡΑΟ	ΡΑΟ	
5.4	16.6	
31.5	121	
-62	-48	
Clay	Lithium Simplex	
Red	Tan	
305	267	
>260	273	
0.45	3.3	
0.2	0.29	
0.56	0.44	
	PAO 5.4 31.5 -62 Clay Red 305 >260 0.45 0.2	



- SRV linear oscillating device, applying normal force and measuring friction
- 52100 steel used for ball and plate
- Displacement 1mm / Frequency 50 Hz
- Increase in 100N increments, failure at CoF 0.2 above steady state
- Protocol per ASTM D 5706









Comparative Testing - SRV

- MIL-PRF-32014
 - 2 runs, 1900N and >2000N (max load)
- MIL-PRF-81322
 - 2 runs, 400N each





Comparative Testing - CREP

- CREP Corrosion Rate Evaluation Procedure
- Fast, inexpensive way of examining corrosion inhibition
- 45 mins, 100C, distilled water, 300M steel





Corrosion Rate Evaluation Procedure Coupons, 300M steel, distilled water, 45 min.



Comparative - Water Washout

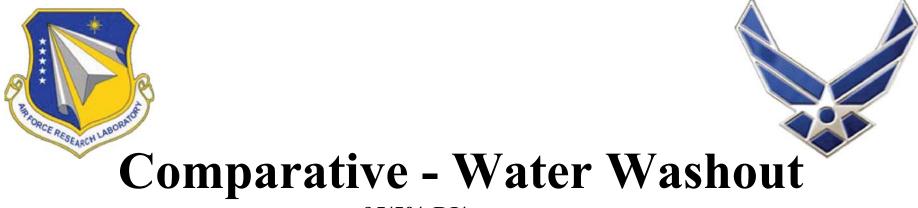
- Run per ASTM D 665
- First run with 100% deionized water
- Also used 95/5% DI / syn. sea water
 - Incorporates corrosion and any washout differences
 - Must use new bearing each time





Comparative - Water Washout

	100% DI water Run 1 / Run 2	Condition of Bearing	95/5% DI/sea water Run 1 / Run 2	Condition of Bearing
MIL-PRF-81322	1.8 / 1.5	No	1.3 / 2.3	Corrosion
Lot# B87890	(1.7 average)	corrosion	(1.8 average)	in raceway
MIL-PRF-32014	2.3 / 2.7	No	1.2 / 0.8	No
Lot# TJ050321	(2.5 average)	corrosion	(1.0 average)	corrosion



95/5% DI/sea water



MIL-PRF-81322

MIL-PRF-32014



Grease Compatibility



- Greases with different thickener systems may not be compatible
 - MD-80 crash initially suspected cause was jack screw failure from mixing of clay and soap thickened greases. (Later deemed improper maintenance.)
- Grease users are very concerned about grease compatibility
 - Not always possible to remove old grease prior to use of new grease



- Grease A = MIL-PRF-81322
- Grease B = MIL-PRF-32014
- Grease C = Brayco 807 RP
- 50/50 Mix of A and B
- 50/50 mix of B and C
- 50/50 Mix of A and C

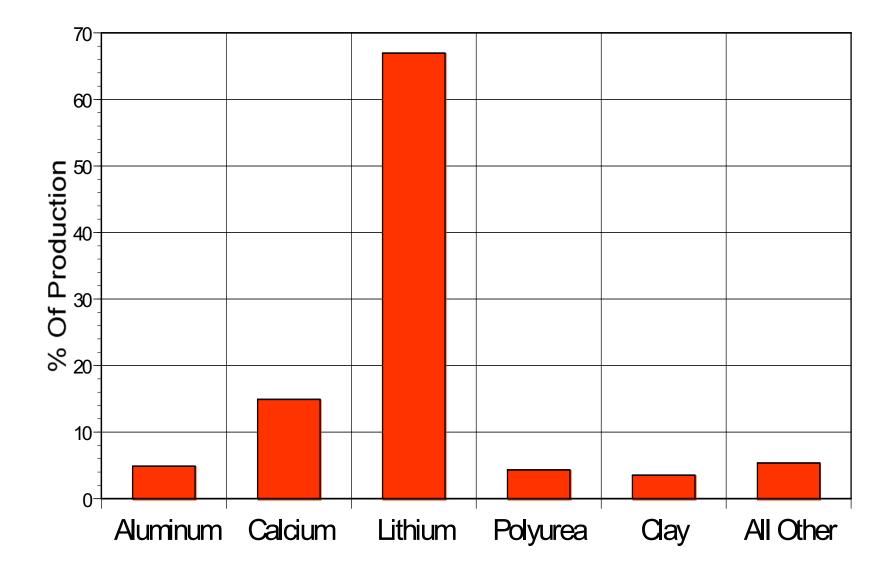


- Test conducted-
 - Evaporation
 - Worked penetration, 60 & 100,000 strokes
 - Oil separation
 - Four ball wear
 - Copper strip corrosion
 - Dropping point
- No compatibility problem in mixture tests

Other current grease issues

- Older greases were clay thickened
 - Newer grease are thickened in-situ with soap based thickeners superior properties
 - More stable-less oil bleed
 - Better lubrication
 - Military Technical Orders assure product quality for DoD systems, but do not make changing to newer greases easy because TO changes are difficult

NLGI 1999 Grease Production By Thickener







Qualification Status

- Two greases qualified to MIL-PRF-32014 specification
 - Nye Lubricants, Rheolube 374A
 - AirBP, Braycote 3214
- Specification being updated to reflect test method issues



DJ Marosok OO-ALC/LILEN DSN 777-5039 david.marosok@hill.af.mil



C-5 Landing Gear Struts ready for final assembly



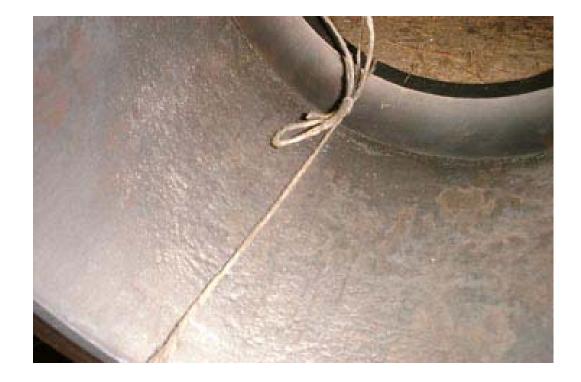
Landing Gear parts are given cadmium, IVD, phosphate, and paint for protection against corrosion.



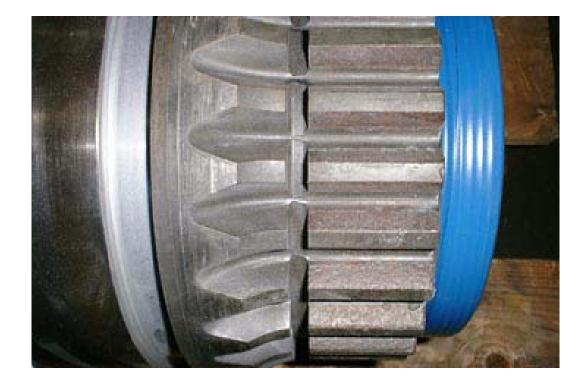
MLG Bogie PN 4G12011 \$206,359.63



Brake Collar PN 4G12031



Gudgeon Bearing PN 4G13406



Splined Tube PN 4G13413

\$13,574.78



Forward Axle PN 4G12030



Roll Pin PN 9510447 \$11,582.40



Ball Screw Nut Bearing Balls PN BB562-1



Crosshead Area C from partially disassembled gear



Wheel Bearing Rollers



Yoke-Side Brace Attach Lugs

\$65,488.00

C-5 Landing Gear Flight Test



C-5 Landing Gear Flight Test

- This aircraft landing gear was very susceptible to corrosion
 - Low alloy steel and corrosive environment
 - Significant rework cost and loss of service
- MIL-PRF-81322 was specified lubricant
 - Synthetic hydrocarbon base oil thickened with clay

C-5 Landing Gear Fight Test

- Side-by-side flight testing performed
- Components cleaned, inspected and photographed
- One side of gearing lubed with MIL-PRF-81322 and other with MIL-PRF-32014
- After 2725 flight hours (1217 landings), gears re-inspected

C-5 Landing Gear Flight test

- No corrosion was observed on gears lubricated with MIL-PRF-32014
- Technical Orders were changed to MIL-PRF-32014 for both C-5 and C/KC-135 for main landing gear







Applications



- Approved applications
 - F-107 Cruise Missile engine bearing
 - C/KC-135 and C-5 main landing gear
 - C/KC-135 wheel bearing
 - JSF low temperature engine bearing
- Potential applications
 - Army helicopter swash plate
 - A/C wheel bearings
 - UK military grease
 - Navy A/C with sea water corrosion issues



Summary



• MIL-PRF-32014 grease could become a multi-purpose military grease replacing many others, in some cases perfluoropolyalkylether greases



Navy MIL-PRF-32014 Grease Study Airframe Bearings Fleet Focus Team







Chris Medic NAVAIR Pax River Military Aviation Fluids and Lubes Workshop June 22, 2006





Fleet Driver for an Improved Grease

Poor corrosion/washout resistance of the current MIL-PRF-81322 lubricant is resulting in numerous corrosion failures, effecting safety, readiness, and increased cost.

Navy Specific Requirements

- Steam Catapult
- Shipboard Stow (Wing/Tail Fold)
- Saltwater Environment/Frequent Wash Cycles



Planned Resolution

- The Navy, in conjunction with the Air Force, will perform extensive testing on the proven grease MIL-PRF-32014.
- Testing will consist of various bench and flight tests on numerous aircraft including the F-18, E2/C2, C-5, AHE, and JSF.
- Successful testing will result in qualification of MIL-PRF-32014 grease as a recommended substitute for MIL-PRF-81322 either across the board or for specific applications.





ABFFT Improved Grease Team

National Leadership

Brian Weber (PAX Co-lead) Chris Medic (PAX Co-lead)

Logistics/Cost Team

Tresmarie Wolfe

Air Force Research Lab

Lois Gschwender Ed Snyder David Marosok Dr. Shashi Sharma

Engineering POC's

George Franco (NI E2/C2) Mike Chabot (NI E2/C2) Brian Carr (NI E2/C2) Sal Piu (LKE F-18 LG) Dirk Dessel (NI F-18) Chrys Starr (NI F-18) Mike Cocca (PAX LG) Todd Standish (PAX Materials) Aldo Arena (NGC E2/C2) Joe Troutman (NAVICP) Edelia Correa (DSCR) Ned Pruitt (DSCR)



E2/C2 Potential Savings

Component P/N	Component Cost	Usage per	Matl cost per
		year	year
GRD5628	\$36,921.00	21	\$775,341
123SAM121-7	\$10,710.00	16	\$171,360
123WM0483-611	\$52.09	25	\$1,302
18720	\$7.76	881	\$6,836.00
L507949	\$25.65	286	\$7,336
18790	\$16.47	1464	\$24,112
123WM10476-511	\$231.82	7	\$1,623
123WM10476-513	\$1,044.22	5	\$5,221
123WM10475-1	\$55.60	21	\$1,167
123WM10478-611	\$39.76	12	\$477
123WM10482-511	\$110.86	14	\$1,552
123WM60010-1	\$35,799.30	8	\$286,394
123WM60010-2	\$90,140.72	4	\$360,562
123WM10011-601	\$8,692.87	2	\$17,385
123WM10011-602	\$12,336.03	3	\$37,008
TOTAL			
COST/YEAR			\$1,697,676

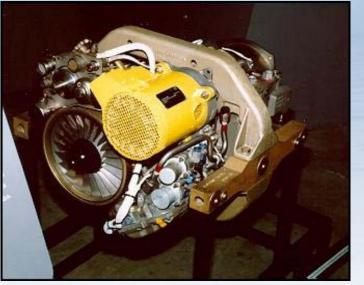
NAVAL AVIATION TECHNOLOGIES





Air Force Grease Study

- AFRL with a grease manufacturer under contract developed improved grease for use in the F-107 cruise missile engine bearings
- Rigorous requirements long storage in uncontrolled environment would bleed oil out of grease
- Bearings now have 5 times the life (60 months) than what was originally achievable
- Saved more than \$60 Million over life of the engine



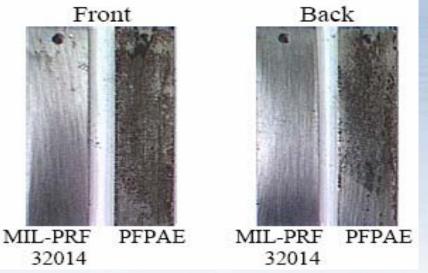




CE RESEARCH LABOR

Improved Grease Composition

- Synthetic Polyalphaolefin base oil
 - mixture of 6 and 40 cSt (reliable)
- Lithium Soap Thickener (non-hygroscopic)
 - Methyl 12-hydroxy stearate and lithium hydroxide monohydrate (in-situ)
- Corrosion inhibitors
- Antioxidants
- Antiwear
- Metal Deactivator





Grease Comparison

	MIL-PRF-81322 (Current)	MIL-PRF-32014 (Proposed)
Color		
Thickener	Inorganic Clay	Lithium Soap
Evaporation	10% weight loss (max)	5% weight loss (max)
Water Resistance	20% loss (max)	15% loss (max)
Steel on steel wear	0.8 mm (max)	0.65 mm (max)

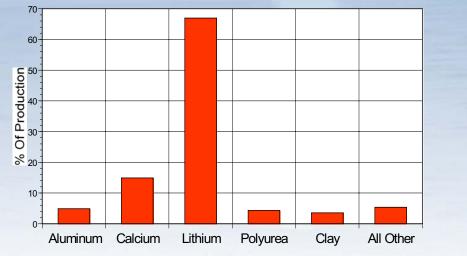
NAVAL AVIATION TECHNOLOGIES



AVIATION TECHNOLOGIE

MIL-PRF-32014 Attributes

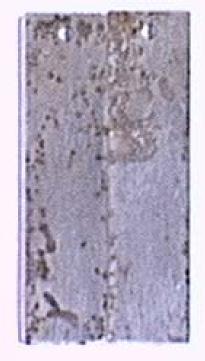
- Excellent water washout resistance
- Low cost (\$44/lb at low volume/low dirt)
- High load carrying (135 Kg)
- High temperature (225°C)
- High speed (30K rpm)
- Corrosion resistant
- Available (2 vendors)
- Non-proprietary
- Compatible

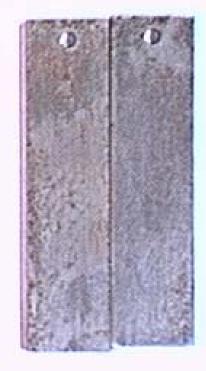


NLGI 1999 Grease Production By Thickener

Corrosion Rate Evaluation Procedure Coupons, 300M steel, distilled water, 45 min







MIL-PRF-32014

MIL-PRF-81322

MIL-PRF-27617



C-5 Landing Gear Test



- Dover AFB installed 32014 grease on 2 left side MLG against control 81322 on 2 right side MLG
- Tested in service for nearly 3 years









C-5 LG Test Results

- AF approved 32014 for use in all C-5 and C-135 Landing Gear
- AF plans to qualify for use in F-16 LG as well



NAVAL AVIATION TECHNOLOGIES



Navy Fleet Drivers



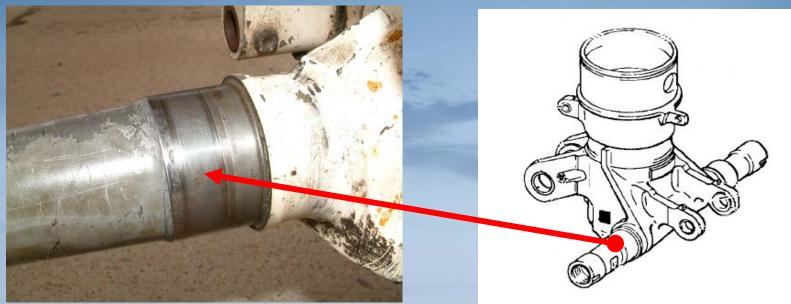
E2 Rotodome Bearings



- Water runs down pylon shaft through X-bearing and lower support bearing and settles in gearbox.
- The grease hydrolyzes and the bearings fail
- Failure of spur gear bearing causes eccentric rotation of spur gear which cuts through housing.



E2/C2 Caster Barrel



- High pressure steam from the catapult purge grease from the wheel bearings.
- The bearings seize and the spun inner bearing race on the axle can cause irreparable damage.
- Components are scrapped prior to reaching full service life.



E2/C2 Wing Fold Hinge Cracking



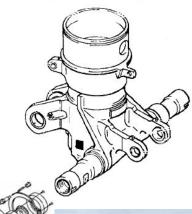
- In stow, fold joints are exposed to environment and often high pressure wash without covers.
- The grease is purged and/or hydrolyzes.
- The bolt seizes in the bushing causing heavy galling and contributes to cracks in wing fold hinge.



Stage 1: Field Testing

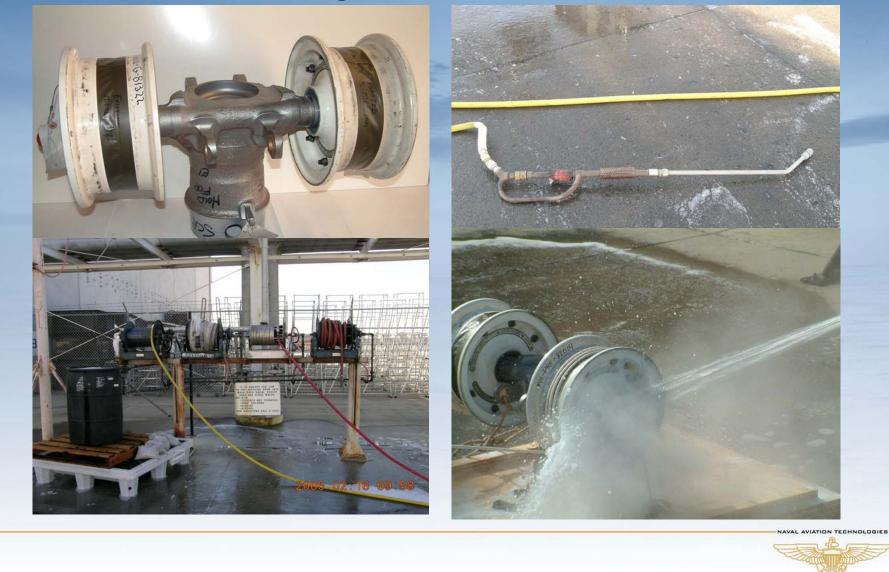
- E2/C2 Nose Landing Gear wheel bearing assembly
 - Spray wash test
 - Steam wash test
 - 100 psi for 10 minutes. Repeated 3 times and held for 10 days
 - Salt Water Immersion
 - 300 hr immersion of coated bearing cups in salt water







Spray Wash Test









Material Tests

- GC (Gas chromatography) and FTIR (Fourier-Transform Infrared)
 - Establish molecular structure and characteristics of lubricant
 - MIL-PRF-32014 "Fingerprint"
 - Identifies change in physical properties
- Karl-Fischer Titration (ASTM D1744)
 - Determines water content in PPM

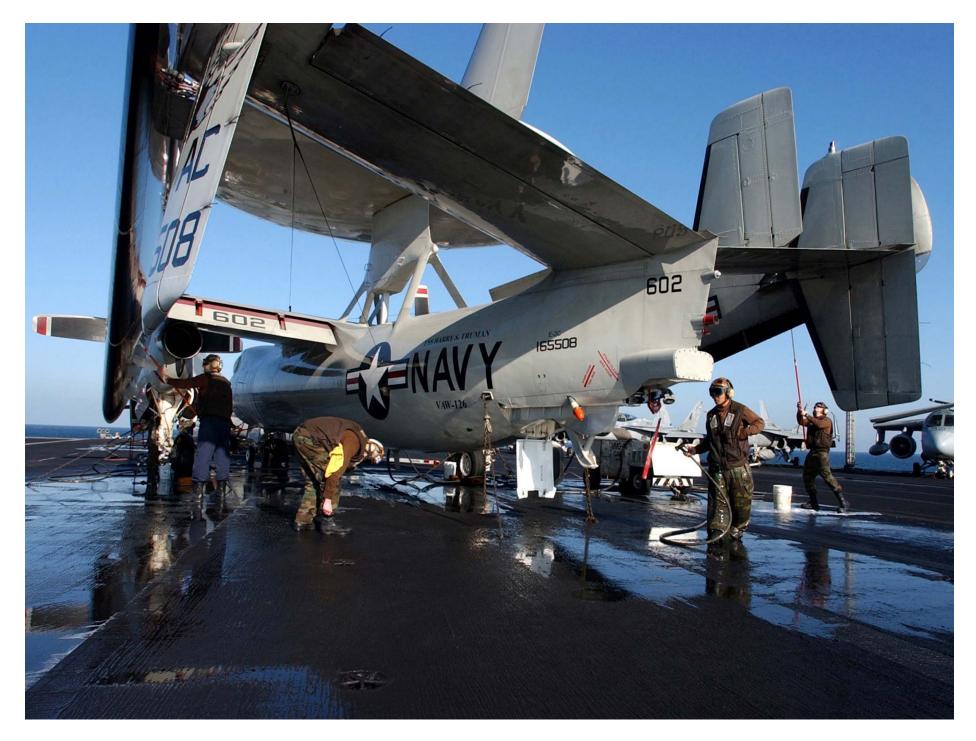


Side by Side Test results

Test	MIL-PRF-32014 Results	MIL-PRF-81322 Results
High Pressure Spray Wash	No corrosion No water absorption	Deep corrosion on cup and rollers 2% water absorption
High Pressure Steam Wash	No corrosion 1% water absorption	Deep corrosion on inner race and outer cage 2% water absorption
Salt Water Immersion	No corrosion Still serviceable	Corrosion cells formed Deep corrosion pits from .025 to .040" deep

NAVAL AVIATION TECHNOLOGIES







Stage 1: Field Testing

- E2 Cold Soak Torque Tests (–40F)
 - Rotodome Pylon Ball Bearing (14" Dia. double bearing set, 440 CRES)
 - Rotodome double "X" bearings (14" dia crossed roller bearing)
 - Rotodome Gearbox Assembly (Input drive, pinion gear, idler gear, and output spur gear)







NAVAL AVIATION TECHNOLOGIES





Cold Soak Torque Test Results

Component	Lubricant	Torque at 70°F (in-lbs)	Break-Out Torque at -40°F	Running Torque at -40°F
Pylon bearing	81322	10.9	58.0	33.0
Pylon bearing	32014	14.5	43.5	36.3
X bearing	81322	6.8	67.5	27.0
X bearing	32014	13.5	81.0	40.5
Gearbox	81322	0	0.5	0.5
Gearbox	32014	0	1.5	1.5

- MIL-PRF-32014 performed well with a negligible increase in torque at low temp (gearbox input torque is throttled to 20 in-lbs)
- More torque sensitive components may need to be evaluated on a case by case basis



Stage 2: Operational Flight Testing

- E-2C Test aircraft will be carrier deployed and tracked for a 18 month period with MIL-PRF-32014 applied to
 - Rotodome pylon shaft bearings
 - Rotodome gearbox assembly
 - RH Wing fold hinge lug bushings
- C-2A Test Aircraft from local squadron VRC 30 will be monitored every 4 months or 40 CATS for a 12 month flight test with MIL-PRF-32014 applied to the
 - RH Nose wheel bearings
 - RH Wing fold hinge lug bushings and locks





E-2D Advanced Hawkeye

- Lower Pylon Self Aligning Bearing (new design)
- Rotodome Gearbox (new design)
- EMIRS Deployment System
- Landing Gear Components









Additional Fleet Applications

- T-34/44 Catastrophic Wheel Bearing failures due to corrosion
 - Engineering Investigation identified possible grease deficiency
 - Proposed change to MIL-PRF-32014
- JSF Upper Lift Fan Bearing and Components









Potential Applications

- H-60 Swashplate and Tail Rotor Drive Shaft Disconnect Bearings
- H-53 Swashplate and Tail Rotor Drive Shaft Disconnect Bearings
- F-18 Landing Gear







ATION TECHNOLOGIE

Summary

It is vital that the Navy aggressively attack the Corrosion problem. Though this grease study is only a small piece of the puzzle, the potential benefits are huge. The ABFFT is dedicated to the ongoing

effort to reduce corrosion failures that effect fleet safety, readiness, and cost.



Screening Tests Results for Low Cost Alternative F100 Nozzle Actuator Greases

Angela Campo Fluids and Lubricants Group Wright-Patterson AFB



- Brief introduction
- Screening tests
- Details of each screening test and their results
- Cost of candidate greases
- Conclusion
- Recent updates

Introduction

- There was a need for a grease that was 50% of the cost of the NYE Uniflor
 - Initially, cost was the main factor in choosing a new grease. But new actuator design and technology called for a better performing grease
- A test matrix was developed to narrow the grease candidates from 56 to 8 samples
 - 2 Standards (NYE Uniflor and Braycote 602EF)
 - 1 In-house, the best candidate
 - 4 companies' best candidates
 - MIL-PRF-32014 (hydrocarbon based-high risk, high payoff)

Screening Tests

Cameron Plint Tribology
Evaporation – High Temperature Stability
WAM Tribology (Wedeven Associates Machine)

Cameron Plint





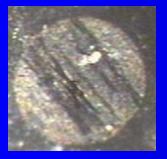
Cameron Plint Test Conditions

- 150°C sample temperature
 <u>3% relative humidity of sample chamber</u>
- 20N load for 5 min., then 250N for 2 hours
- 52100 steel disc and ¹/₄ inch ball
- 1 gram of sample
- 3 Hz frequency
- 9mm Stroke

Formulation	Average	Standard	
	Scar Area	Deviation	
	(mm^2)	(mm^2)	
MIL-PRF-32014	0.15	0.01	
MLO-02-311	0.38	0.00	
MLO-02-358	0.58	0.02	
NYE Uniflor	0.71	0.10	
MLO-03-008	0.78	0.03	
MLO-03-007	1.02	0.14	
In-house	0.72	0.02	
candidate			
Braycote 602EF	1.23	0.10	

Comparison of Wear Scar

MIL-PRF-32014



0.15mm²



0.71mm²

Evaporation Study

- The test was conducted at 232°C for 72 hours
- Most candidates still maintained their grease texture, but one did not. MIL-PRF-32014 hardened and changed color from light tan to black
- Duplicate tests

Evaporation Data

Formulation	Average % Loss	
MIL-PRF-32014	49.5	
MLO-02-311	8.43	
NYE Uniflor	10.03	
MLO-03-008	10.60	
MLO-03-007	3.17	
In-house candidate	1.85	
Braycote 602EF	1.37	

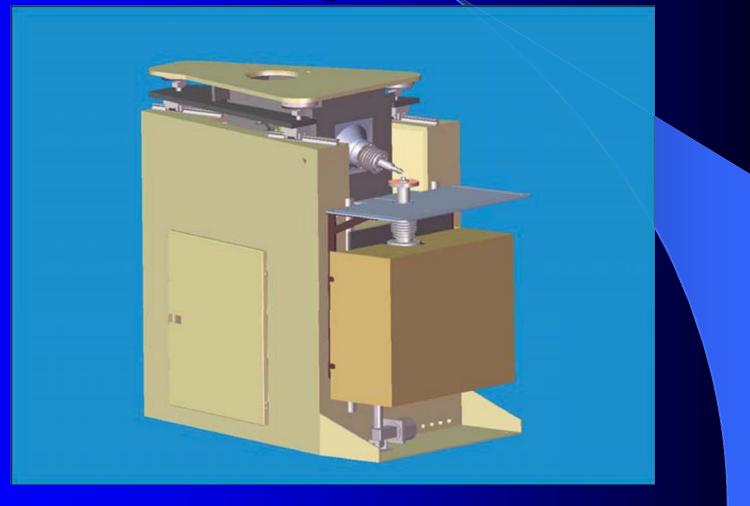
WAM Tribology

- Test consists of six cycles
- A cycle consists of an acceleration period, steadystate period, and a deceleration period
- Greatest tribological activity occurs in the transitions
- Braycote 602EF and NYE Uniflor used as baseline greases
- Metal test specimens are phosphated and coated with MoS₂

Explanation of a WAM Cycle

- Specimens are coated with sample and heated to 100°C
- Surface speeds are set to zero
- The load is set to 20lbs
- Roller and disc specimens are accelerated to 570in/sec &220 in/sec respectively
- Steady-state for 125 seconds
- The roller is decelerated to -570 in/sec and the disc is decelerated to -220 in/sec respectively
- Roller and disc are then decelerated to zero in/sec

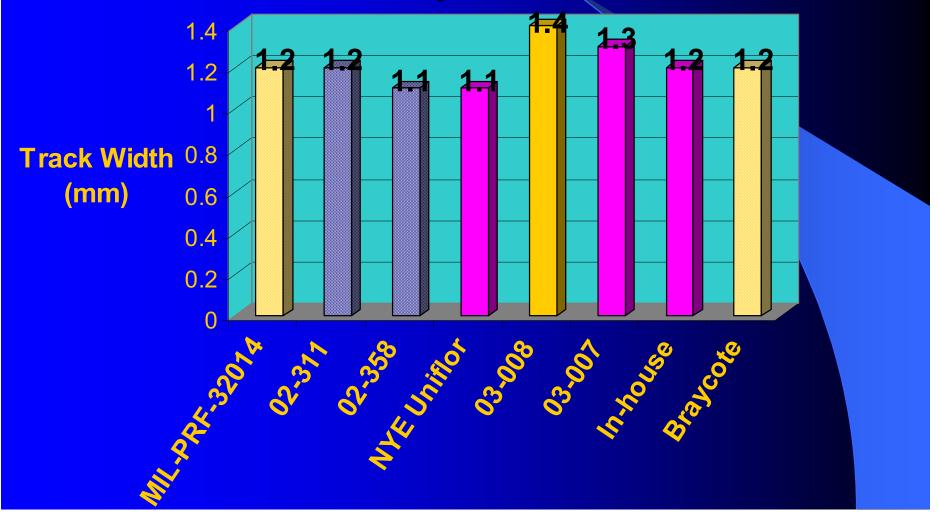
WAM Testing Machine Diagram



WAM Ball and Disc Arrangement



WAM Average Track Width Comparison





Microcracking

Pitting

MLO 03-7 In-house

> Nye Uniflor

MLO 03-8

Braycote 602EF

MLO 02-311

MLO 02-358

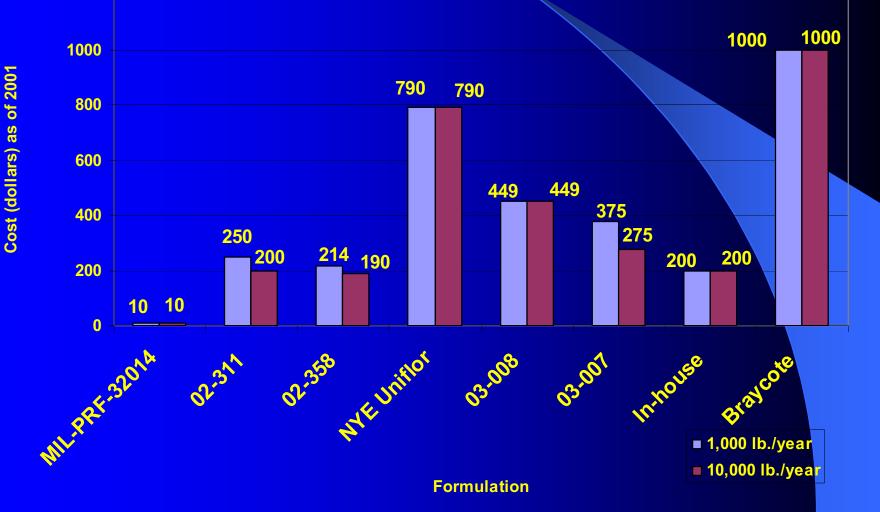
MIL-PRF-32014

Candidate Ranking

	Cameron Plint	Evaporation	WAM	Total
MIL-PRF-32014	8	1	3	12
MLO 02-311	7	5	4.5	16.5
Braycote 602 EF	1	8	2	11
NYE Uniflor	5	4	8	17
In-house candidate	4	7	7	<mark>18</mark>
MLO-02-358	6	n/a*	4.5	10.5
MLO-03-7	2	6	6	14
MLO-03-8	3	3	4	10

*Small supply of MLO-02-358, not enough to run evaporation.

Which Candidate is More Cost Effective?



Results and Conclusion

- Candidate, low cost greases have been developed that appear to meet the performance and price goals of the program.
 - While none of the greases exceed the performance of the NYE Uniflor grease in WAM testing, some did outperform the NYE Uniflor grease in the Cameron-Plint Tribometer and in the high temperature evaporation test.
 - All of the candidate greases were below the cost requirements of the program (<\$500/lb)

Results and Conclusions – cont'd

- The only problem with the program to date is that we were unable to identify a clearly superior candidate.
 - This is due to the similarity in performance in the WAM Tribometer which is supposed to be able to discriminate between acceptable and unacceptable greases.
 - It makes it difficult to select only one grease to have tested in the actuator.
- If there was a way to run the component test on more than one candidate, that may identify the best low cost grease for this application.
 - If they still perform similarly, we could have multiple suppliers a very desirable situation

Recent Updates

- The nozzle actuator test was performed on the in-house candidate and it did very well
 - But the base stock for this grease is no longer available
- Temperature test strips have been placed to record the max temperature of the nozzle actuator.
 - Depending on the results, MIL-PRF-32014 may be an excellent alternative grease for this application





High Temperature Lubricant Phase II Status Report

METSS Corporation 300 Westdale Avenue Westerville, OH 43082

June 22, 2006

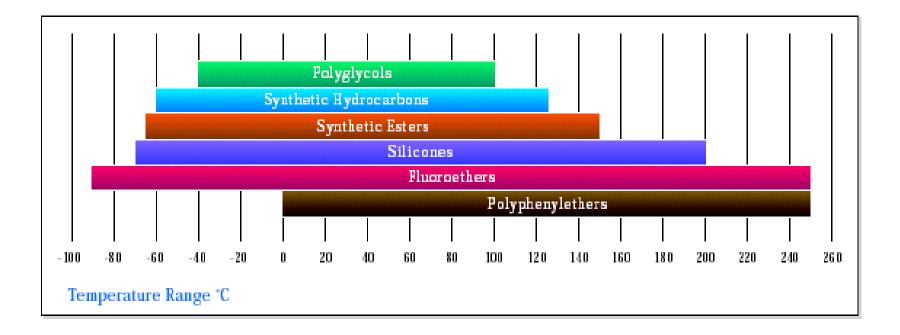
Navy Contract No. N68335-05-C-0077

Advanced Lubricant Requirements

- Projected operating temperatures of advanced gas turbine engines and their accessories require a lubricant grease that
 - Can endure extreme operating temperature range of roughly -40° F to $+625^{\circ}$ F
 - Can remain chemically stable with no performance degradation for ~4,000 hours
 - Must allow easy movement of corrosion resistant stainless steel as well as ceramic roller elements.

Current lubricants used cannot maintain viscosity throughout the entire range of operation.

Operational Temperature Ranges for Several Classes of Synthetic Lubricants



High Temperature Greases

Phase I

- 14 PFPAE Grease Candidates
 - Nye
 - DuPont

Phase II

- 15 PFPAE Grease Candidates
 - DuPont
 - Daikin
- 8 Ionic Liquids
 - Merck & Covalent
 - METSS thickened these with BN to prepare IL greases.
- 2 Polyphenyl Ethers
 - 5P4E and 6P5E fluids obtained through AFRL.
 - METSS thickened these with BN to prepare PPE greases.

Dupont Krytox® XHT Greases

- Fluorinated synthetic base oils, thickeners, and additives
 - perfluoropolyether (PFPE) greases thickened with boron nitride with additives for antirust, antiwear, or extreme pressure performance
- Useful temperature ranges up to 360°C (680°F) for continuous use
- Resistant to oxygen, and inert to virtually all chemicals.
 - insoluble in most solvents
- The chief limitation is limited availability of soluble additives *METSS is working closely with DuPont in the evaluation*

Other Materials

• Ionic Liquids

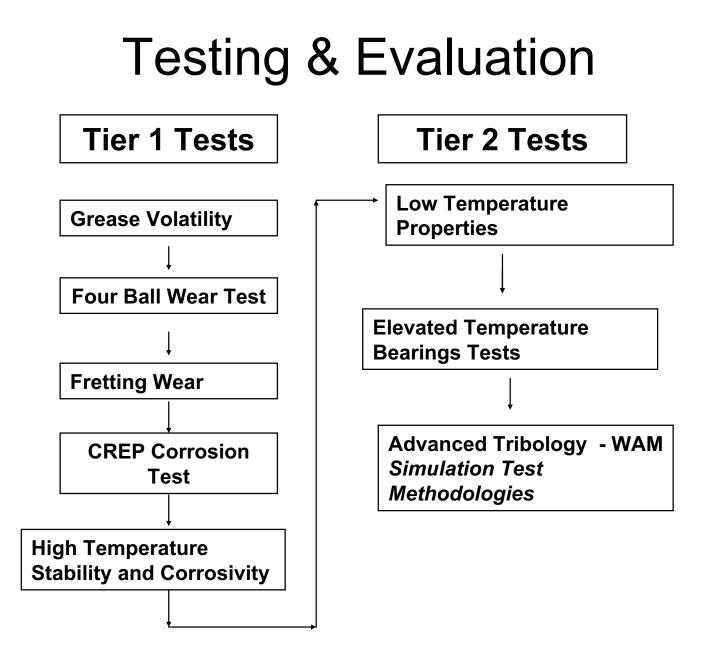
- Possible alternatives to PFPAEs as extreme temperature lubricant basestocks.
- Reported to have good high and low temperature properties.

• Polyphenyl Ethers

- Possible alternatives to PFPAEs as high temperature lubricants.
- Reported to have good high temperature properties but low temperature use is limited. (Similar to Pendent PFPAEs).

• Interaction of PFPAEs with Hi Temp Coatings

- Under a separate SBIR, Arcomac is developing surface coatings and has developed laboratory test equipment with extreme operating temperatures and loading conditions.
- METSS, DuPont and Arcomac have signed a 3-way confidentiality agreement.
- Plan to exchange samples of lubricants and metal test specimens (balls and disks) for testing and evaluation.



Primary Screening Tests

- Weight Loss
 - 2-3 grams of grease in Petri dishes
 - 22 Hours @ 300 and 330C in muffle furnace
- TGA
 - Isothermal @ 290C and 330C
 - Grease Alone and with Pyrowear Rust Contamination
- CREP Rust
 - SAE 1010 Carbon Steel
 - 2 Hours, 98C, DI Water
- Four Ball Wear (D4172)
 - Dry Air (RH \leq 5%)
 - M50/M50, 440C/440C, Si₃N₄/440C, Si₃N₄/Pyrowear 675

METSS is using the MIL-PRF-27617 specification for several different types of PFPE based greases as a performance guideline

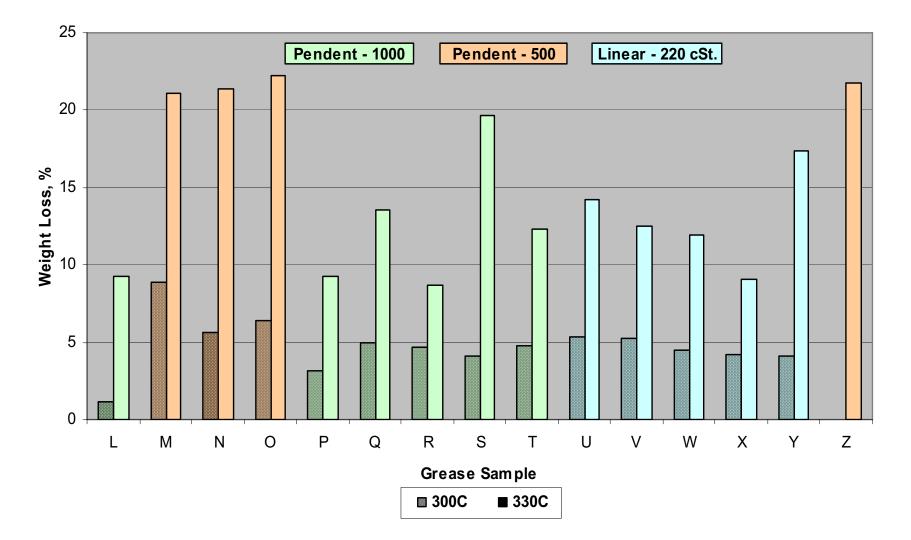
PFPAE Grease Formulation Variables

- PFPAE Fluid Types
 - Linear vs. Pendent
- Fluid Viscosity
 - 220, 500, 1000 cSt.
- Thickeners
 - PTFE, BN, Graphite/MoS₂
- Additives
 - Dispersed (Insoluble)
 - Disodium Sebacate DSS
 - Sodium Nitrite NaNO₂
 - Calcium Hydroxide Ca(OH)₂
 - Soluble
 - Fluorinated Benzene Sulfonic Acid, Sodium Salt
 - Fluorinated Diphenyl Ether (DPE)

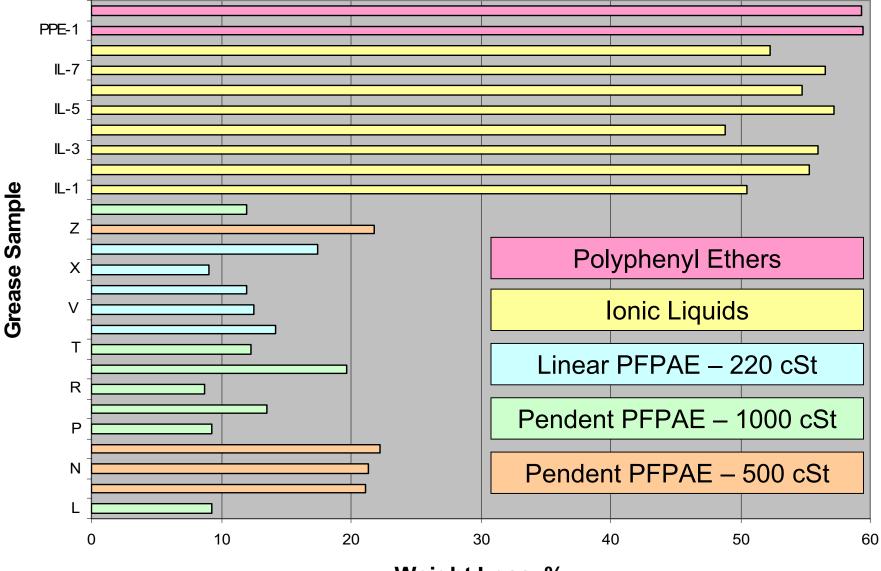
Candidate Grease Chemical Composition

METSS Code	Fluid Type	KV @ 40C, cSt.	Thickener Type	Corrosion Inhibitor	Co-Additive
L	Pendent PFPE	1000	BN	5% Ca(OH) ₂	
М	Pendent PFPE	500	Graphite	5% Ca(OH) ₂	MoS ₂
Ν	Pendent PFPE	500	BN		
О	Pendent PFPE	500	BN	5% Ca(OH) ₂	
Р	Pendent PFPE	1000	BN		
Q	Pendent PFPE	1000	Graphite	5% Ca(OH) ₂	MoS ₂
R	Pendent PFPE	1000	BN	2% KBSANa	
S	Pendent PFPE	1000	Graphite	2% KBSANa	
Т	Pendent PFPE	1000	Graphite	2% KBSANa	MoS ₂
U	Linear PFPE	220	PTFE		
V	Linear PFPE	220	BN		
W	Linear PFPE	220	BN	5% Ca(OH) ₂	
Х	Linear PFPE	220	BN	2% KBSANa	
Y	Linear PFPE	220	Graphite	5% Ca(OH) ₂	MoS ₂
Z	Pendent PFPE	500	BN	2% KBSANa	
LR1	Pendent PFPE	1000	BN	2.5% Ca(OH) ₂ 1% KBSANa	

Grease Evaporation Loss 22 Hours @ 300°C and 330°C



Grease Evaporation Loss After 22 Hours @ 330C



Weight Loss, %

High Temperature and PFPAE Base Stocks

- The real "Achilles heel" of any PFPAE is its increased tendency to degrade when in contact with active metals.
- The formation of metal fluorides of aluminum, iron, titanium, etc. are thermodynamically favored over the fluorine-carbon bond, and their high free energy of formation limit the potential performance of PFPAEs at temperatures above 300°C.
- The oxidative stability of base PFPAE's in the presence of metals has been vastly increased with Carburized Pyrowear 675®.
- PFPAE has been reported to react with silicone nitride binders

Grease TGA Experiments

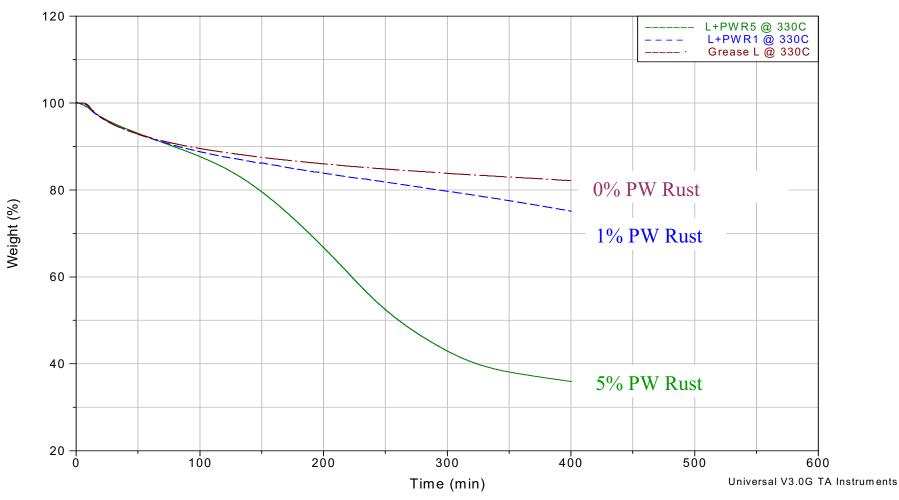
- Conducted isothermal testing a elevated temperatures to determine percent mass loss vs. time.
- Initial experiments conducted were isothermal at 290C. Subsequent testing at 330C provided better differentiation.
- Addition of Pyrowear 675 corrosion product provided further separation of candidates.

PW Pyrowear 675 Corrosion Product XRF*

XRF - PW Pyroware 675 Corrosion Product

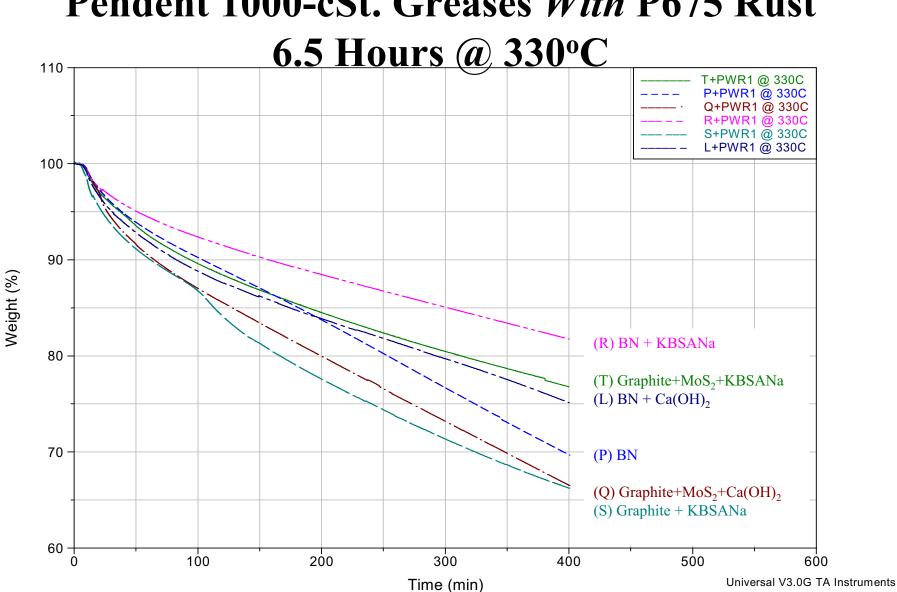
Z	wt%	Ζ	wt%	Z	wt%
Sum Be - F	nd	29 Cu	nd	52 Te	nd
11 Na	nd	30 Zn	0.07	53 I	0.020
12 Mg	nd	31 Ga	nd	55 Cs	0.038
13 AI	nd	32 Ge	nd	56 Ba	0.055
14 Si	0.63	33 As	nd	Sum La - Lu	0.530
15 Px	0.04	34 Se	nd	72 Hf	nd
16 Sx	0.00	35 Br	nd	73 Ta	nd
17 CI	0.50	37 Rb	nd	74 W	nd
18 Ar	0.03	38 Sr	nd	75 Re	nd
19 K	nd	39 Y	nd	76 Os	nd
20 Ca	nd	40 Zr	nd	77 Ir	nd
21 Sc	nd	41 Nb	nd	78 Pt	nd
22 Ti	0.02	42 Mo	0.16	79 Au	nd
23 V	0.01	44 Ru	nd	80 Hg	nd
24 Cr	0.86	45 Rh	nd	81 TI	nd
25 Mn	0.30	46 Pd	nd	82 Pb	nd
26 Fe	89.64	47 Ag	nd	83 Bi	nd
27 Co	4.99	48 Cd	nd	90 Th	nd
28 Ni	2.27	49 In	nd	92 U	nd
		50 Sn	nd	94 Pu	nd
*Data provided courtesy of DuPont.		51 Sb	nd	95 Am	nd

Effect of PW P675 Rust Concentration on Grease L at 330°C

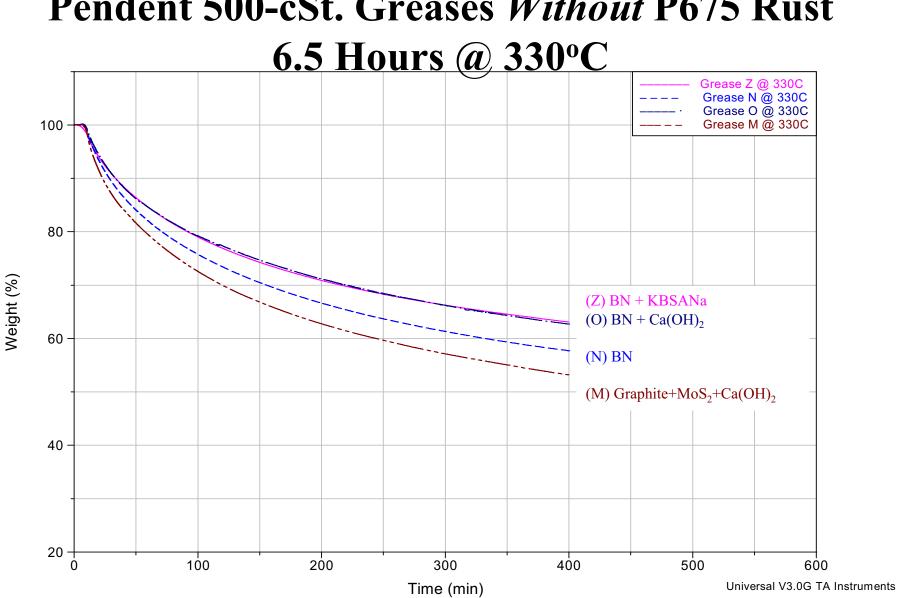


6.5 Hours @ 330°C 110 Grease T @ 330C Grease P @ 330C Grease Q @ 330C Grease R @330C Grease S @ 330C Grease L @ 330C 100 90 Weight (%) (R) BN + KBSANa (T) Graphite+MoS₂+ BSANa (L) $BN + Ca(OH)_2$ 80 (P) BN (S) Graphite + KBSANa (Q) Graphite + MoS₂ + Ca(OH)₂ 70 60 -200 500 300 Ò 100 400 6Ó0 Time (min) Universal V3.0G TA Instruments

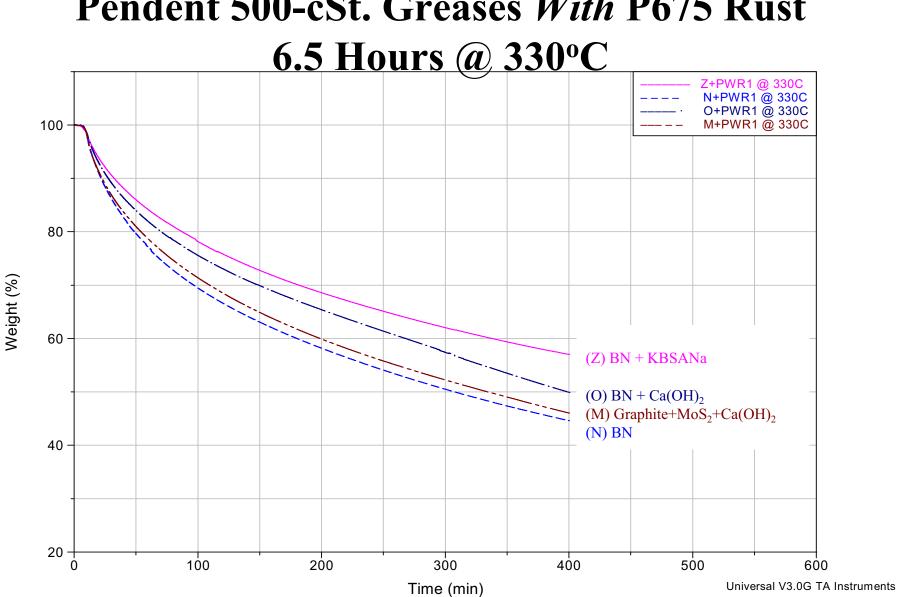
Pendent 1000-cSt. Greases Without P675 Rust



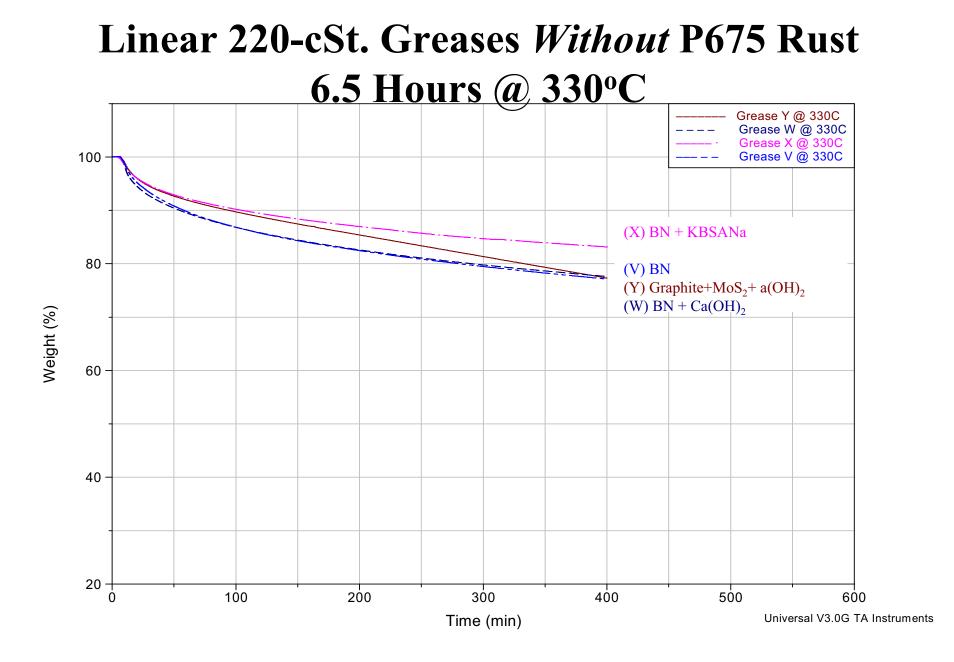
Pendent 1000-cSt. Greases With P675 Rust

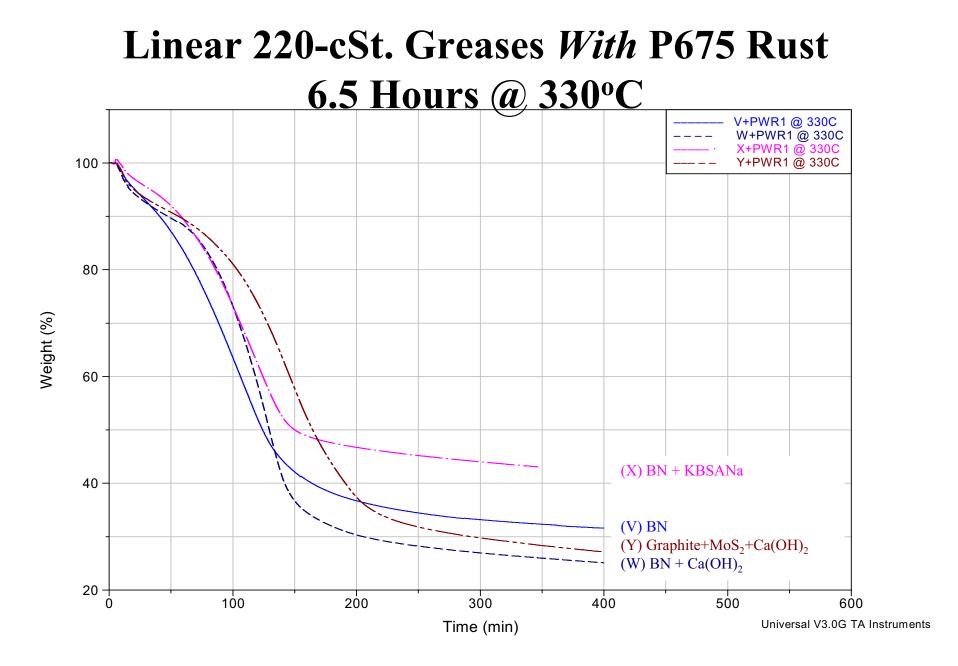


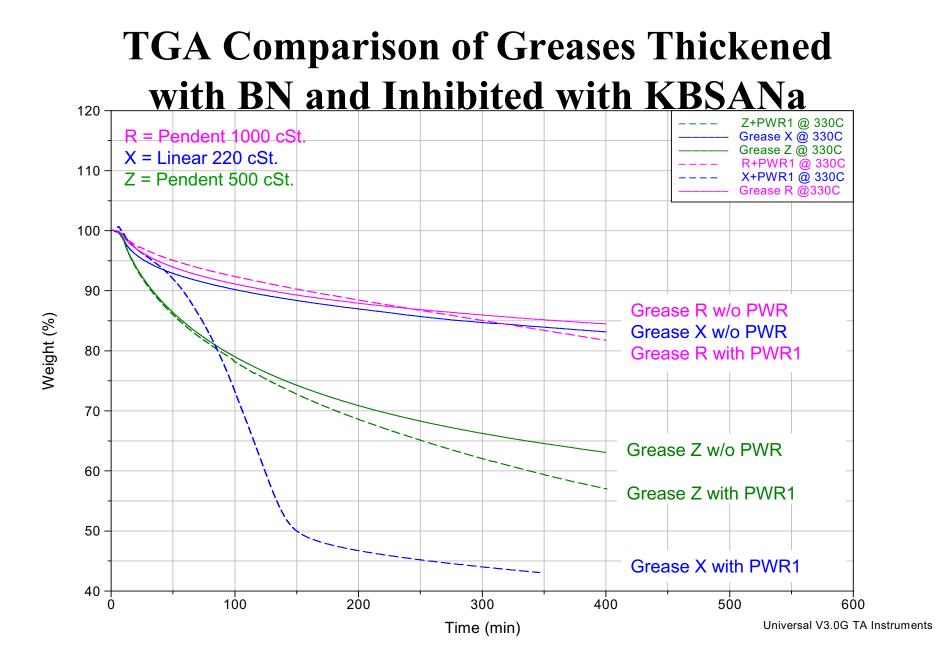
Pendent 500-cSt. Greases Without P675 Rust



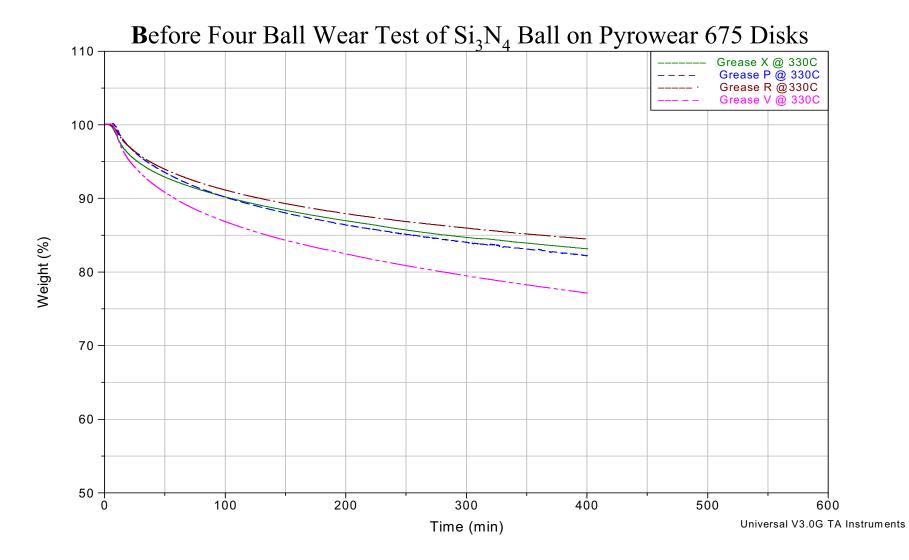
Pendent 500-cSt. Greases With P675 Rust



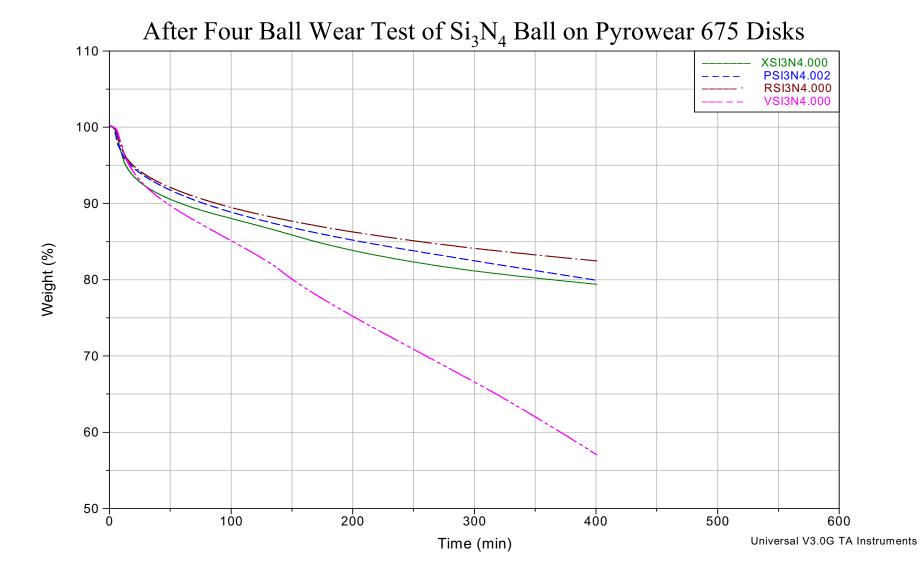




Isothermal TGAs (6.5 Hours @ 330C) of Fresh Grease Samples Obtained



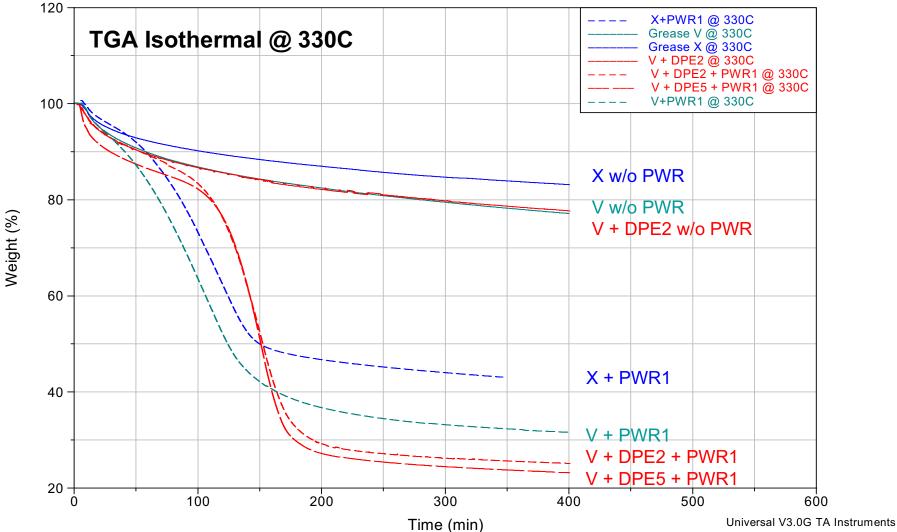
Isothermal TGAs (6.5 Hours @ 330C) of Aged Grease Samples Obtained



Attempts to Improve the Thermal Stability of Linear 220 cSt - BN Thickened Grease

- Obtained sample of Fluorinated Diphenyl Ether (DPE) from AFRL.
- Added to Grease V (Linear 220 cSt + BN) at 2% and 5% treat levels.
- Ran TGAs on Grease V+DPE with and without PW Pyrowear Rust. Compare with data obtained for Grease X (Linear 220cSt + KBSANa).
- Ran TGAs on DPE alone.

Effect of Soluble Fluorinated Additives KBSANa And DPE in Linear 220 cSt Greases

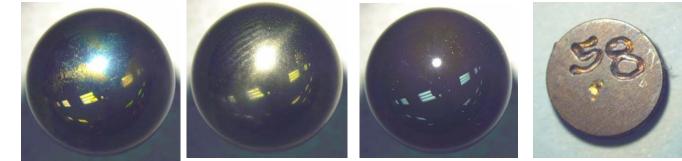


Thermal Stability & Corrosivity Test

- Modified DuPont procedure for Fluids
- Immerse metal Test Specimens in Grease
- ➢ 96 Hours @ 330°C
- Visual Evaluation for Corrosion
- ➢ Rating Scale
 - 1 = Shiny, no evidence of corrosion.
 - 2 = Shiny, but discolored.
 - 3 = Slight evidence of corrosion .
 - 4 = Pitting on half of surface.
 - 5 = Pitting on most of surface.
 - 6 = Corrosion flaking off ball.



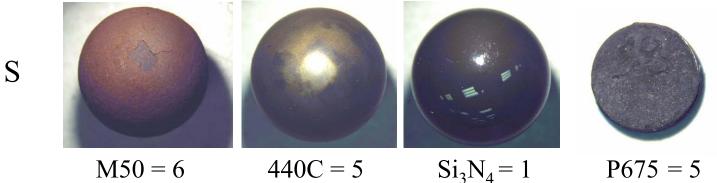
Thermal Stability & Corrosivity Test Results



M50 = 2

440C = 2 $Si_3N_4 = 1$

P675 = 2



Grease S

Grease R

Rust Preventive Characteristics Phoenix Chemical CREP Test

Grease Sample	Corrosion Inhibitor	Number of Tests	Average Time To Failure, min.	Coupon Rating at End of Test
L	5.0% Ca(OH)2	3	120	Slight Rust
R	2.0% KBSANa	3	3	Medium Rust & Stain
LR1	2.5% Ca(OH)2 1.0% KBSANa	3	9	Medium Rust & Stain
LR2	5% Ca(OH)2 2.0% KBSANa	3	120	Slight Rust

Accomplishments to Date

- METSS has identified 2-3 candidate greases better thermal and wear properties on conventional as well as high-chrome steels than the current formulations.
- A clearer understanding of the interactions of the grease components has emerged allowing more scientific formulation strategies.
- The results of the program clearly demonstrated the technical feasibility of developing product formulations to meet the program requirements.

Conclusions to Date

Basestocks

- Pendent provides better thermal stability than linear in the presence of PW Pyrowear 675 rust.
- Pendent basestock thermal stability: 1000-cSt. better than 500-cSt.
- Low temperature performance may be an issue.
- Ionic fluids and polyethers need more work

• Thickeners & Additives for PFPAEs

- $Ca(OH)_2$ reduces wear in four ball test.
- $Ca(OH)_2$ is best for rust protection in high humidity.
- Dupont's KBSANa is best for thermal stability and corrosivity.
- Combinations of KBSANa and $Ca(OH)_2$ provide the best characteristics.
- KBSANa may be an effective inhibitor for the thermal breakdown of linear PFPAE in the presence of P675 wear debris.
- DPE is too volatile to be effective HMW analogs needed to be tested

To Do List for HT Lube Phase II Program

Formulation Chemistry

- Blends of Linear and Branched PFPEs?
- Inorganic Base To reduce acid formation and enhance stability
- Inorganic Fluorides Nanotribology
- Soluble Fluorinated Additives
- METSS to do more work in Phase II utilizing 3-roll mill for grease formulation.

Surface Characterization

- Micropitting PFPE decomposition
- Surface Analysis Fluorides, Acid leaching
- ASTM F2094-03a Standard Specification for Silicon Nitride Bearing Balls

Additional Tests

- evaluate performance of greases in ball bearings operating at elevated temperatures.
- An aggressive material corrosion test designed to assess effects of salt and moisture under long-term conditions.

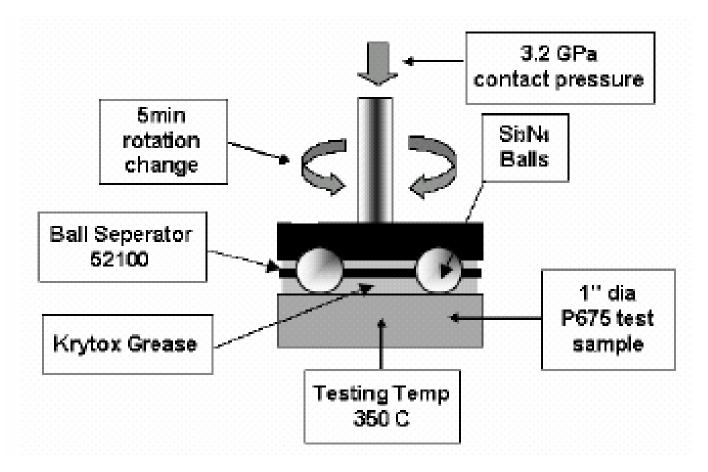
Formulation Technology and Technical Support

- Jon Howell, and Carl Walther of DuPont
 - Volatility limits have been lowered
 - Known impurities have been removed

Arcomac Testing

- METSS plans to send samples of some of the better candidates (L, P, R, LR2) to Arcomac for testing under conditions of high load and high temperature in a thrust bearing ball-on-disk test fixture.
- Samples are based on XHT-1000 + BN containing
 - No rust inhibitor
 - Ca(OH)2
 - KBSANa
 - Ca(OH)2 + KBSANa
- Candidate greases will be evaluated with and without the Arcomac coating.
- Thus far, all of Arcomac's testing has been with DuPont's XHT-BDX grease: a 750 cSt Pendent PFAE thickened with BN and containing no additional additives. The planned tests will allow METSS to look at additives effects and their interaction with the coating.

Schematic of Arcomac Thrust Bearing Ball-on-Disk test Fixture Used for High Temperature PFPAE Lubricant Compatibility Testing



The Future of Solvent Usage in the Air Force

Environmentally friendly replacements for commonly used solvents

Angela Campo Fluids and Lubricants Group Wright-Patterson AFB

Solvents 101

- Solvents are chemical compounds that dissolve, suspend, or extract materials without changing the chemical composition of the solvent or the material.
- Good cleaning solvents are the following:
 - Inert to the material being cleaned
 - Can dissolve the desired contaminants
 - Easily removed
 - Low surface tension

Why we need new solvents

- The US signed the Montreal Protocol in 1989, which banned the use of chlorofluorocarbons (CFC) like Freon 113
- Later amendments set deadlines for other solvents, such as hydrochlorofluorocarbons (HCFC).

Why do CFC's cause ozone depletion?

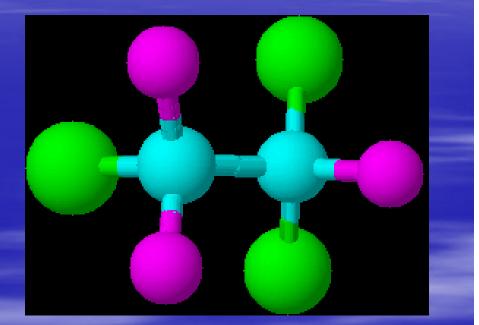
- Ozone (O₃) absorbs ultraviolet light in the atmosphere and breaks down into O₂
- O_2 can then react with O and form O_3 again.
- CFC's interfere the ozone cycle by reacting with O₃ which forms products that in turn destroy more ozone molecules.
- As the concentration of CFC's increase in the atmosphere, it become less likely for the remaining ozone to effectively absorb ultraviolet light.

The Search for New Solvents

- "Like dissolves like"
- Hard to find a good solvent that is ecofriendly and non-toxic
- New solvents must be comparable in price
 Same ease of use, in other words a "drop in" replacement

Background on Freon 113

- Boiling point = 48°C
- Non-flammable
- Low reactivity
- Low toxicity
- Was used to degrease parts and also for LOX cleaning applications
- Contributes to ozone depletion



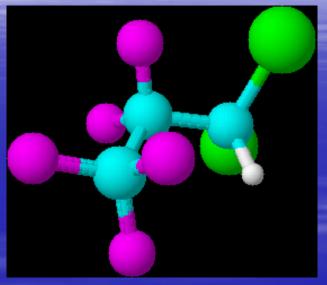
Could HCFC's replace Freon 113?

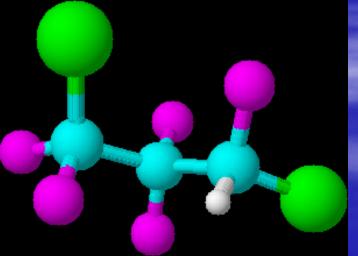
HCFC = Hydrochlorofluorocarbons
Low reactivity, but not as low as Freon 113
Will dissolve less material than Freon 113
Will be banned in 2030 due to adverse effects on the ozone layer
Until then, they can be used as a short term

Until then, they can be used as a short term solution only.

AK 225

- AK 225 is a mixture of two HCFC solvents. It performed very well in cleaning tests₁
- Boiling point = 54°C
- Low toxicity
- Currently in the tech order for cleaning LOX equipment
- Can contribute to ozone depletion, but to a much lesser degree than Freon 113





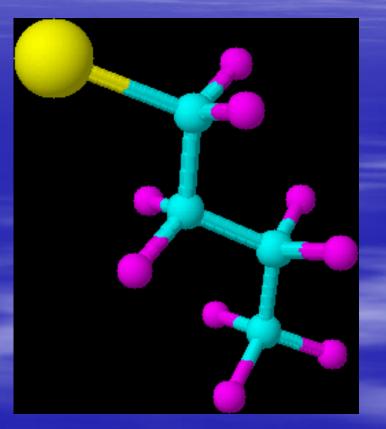
Candidate to replace Freon 113

- Perfluorobutyl lodide, PFBI
- Performed very well in cleaning tests₁
- Initial toxicity studies₂ were encouraging, a more in-depth toxicology study is currently underway
- Safe for the environment, non-ozone depleting
- Would be a drop in replacement for Freon 113



Boiling point = 54°C

- Does not contain chlorine
- Does not react with ozone
- Currently is priced similar to AK 225₃
- Can be a dark pink in color



The next step

- Send a purified sample for repeat LOX Compatibility testing
 - The first LOX test was completed during the initial study with fluid that was not highly purified, which can alter the results of the test
 - PFBI passed at the 2nd highest load stage (60lb), this is considered acceptable in most cases. With purification it is expected to pass at the highest load stage.
- Find multiple commercial sources that can produce PFBI in large enough quantities.

Conclusions

 CFC's are great solvents that have proven to be difficult to replace

AK 225 is the best replacement that is currently available, but it is a short term solution <u>only</u>

 PFBI, pending toxicity testing results, has the potential to be a drop in replacement for Freon 113 for all cleaning applications

References

- AFRL-ML-WP-TR-2003-4040 "The Wipe Solvent Program" Marcie Roberts (UDRI), Lois Gschwender, Ed Snyder
- 2. <u>International Journal of Toxicology</u> Vol.23 Number 4/July-August 2004 p. 249-258 Darol E Dodd, Gary Hoffman "Perfluoro-n-Butyl Iodide: Acute toxicity, sub chronic toxicity, and genotoxicity evaluations
- 3. "Lubricant Cleaning and Compatibility Study for Candidate CFC and HCFC Solvent Replacements" Marcie Roberts (UDRI), Carl E Snyder (AFRL), Lois Gschwender (AFRL) Tribology and Lubrication Technology Feb 2004 p. 34-41

PAO COOLANT - MIL-PRF-87252- PAST AND CURRENT ACTIVITIES

Lois Gschwender AFRL/MLBT, Wright-Patterson AFB 22 June 2006



Outline

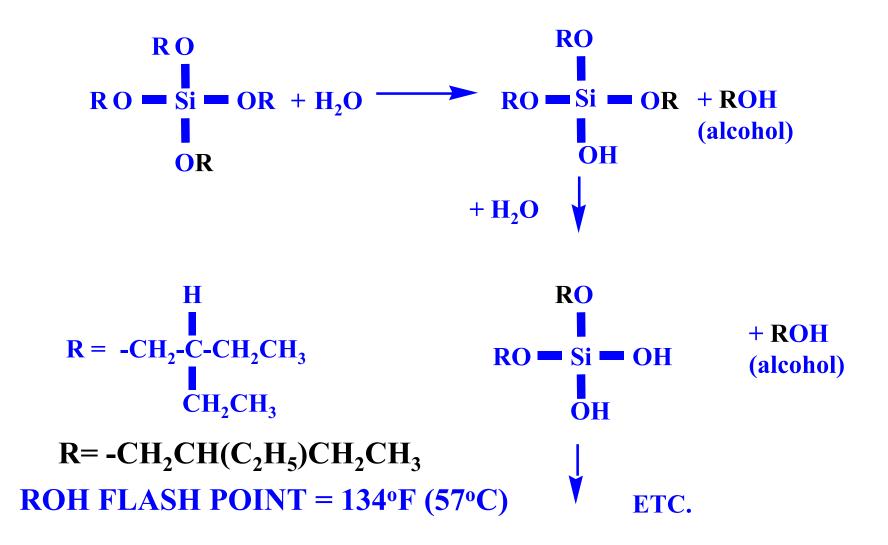
- Problem with silicate ester coolants
- PAO coolant development
- PAO coolant validation/flight tests
 - B**-**1
 - US Navy
- AF conversion status
- New interest
 - High pressure switches
 - New system
- Conclusions



Problem

- Silicate ester dielectric coolants (Coolanol 25R/40, MIL-C-47220) had developed serious problems in the field
 - React with water to produce a gel, which clogs cooling systems, and alcohol
 - Gel is also an arcing source
 - Alcohol is a fire hazard
- Problem first appeared in the Air Force in the SR-71 (1979, Coolanol 40) and in the F-15 (1985, Coolanol 25R) and in numerous Navy systems

2-ETHYLBUTYL SILICATE ESTER HYDROLYSIS





Solution - PAO Coolant

- Materials Directorate and Naval Air Development Center developed the polyalphaolefin coolant that
 - Is not sensitive to water
 - Has a stable flash point (less flammable)
 - Is lower cost
 - Has an Air Force military spec, MIL-PRF-87252
- MIL-PRF-87252 now standard for DoD and has commercial applications

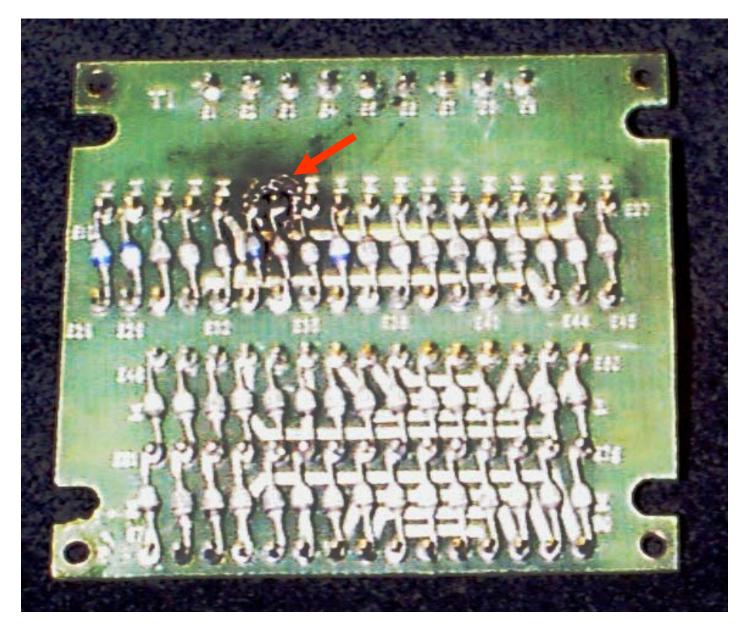


Hydrolysis study: MIL-PRF-87252 vs. silicate ester



Chronology of Development

- SR-71 had corona discharge and gelling problems with Coolanol 40 (a higher viscosity, higher use temperature silicate ester fluid)
 - 1979-82: Remedial actions with Coolanol 40 & new PAO coolant developed
- Numerous systems identified problems with Coolanol 25R: F-4, F-15, F-14, F-18
 - 1985: ASD task force
 - 1986: ASD program (Hughes: F-15, F-14)



Arced electrical board failure from silicate ester system



Chronology of Development (con't)

- Flight testing
 - 1987 88: B1-B program (PRAM/SAC)
 - 1987 88: P-3 ← program (Navy/TI)
 - 1988 92: F-14/F-18 (NAVAIR)
- Most aircraft converted by analogy



SR-71 Problems with Coolanol 40

- No longer available (later reversed)
- Black plague (arcing)
 - Possible causes for arcing
 - Fluid contamination
 - Free water
 - Particulate
 - System
 - Fluid Hydrolysis
 - Alcohol lowers dielectric strength
 - Gel provides arcing path





Silicate Ester Replacement Difficulties

- Requirements only partially known
 - Coefficient of thermal expansion
 - Electrical properties
 - Other requirements "fuzzy"
- Commercial functional fluids contain
 - Many polar additives increase conductivity, reduce power factor



Critical Properties for a High Performance Fluid

- Material Compatibility
 - System materials
 - Existing coolant
- Electrical properties
 - Dielectric strength
 - Resistivity
 - Power factor
- Hydrolytic Stability*
- Hygrospopic tendency

Foaming tendency Lubricity Viscosity/temperature Flash point stability* Thermal stability Commercial availability* Cost*

*Critical important PAO improvements over Coolanol 40

Search for a Replacement Fluid

- Motivation No long term Coolanol 40 supplier & poor performance
- Replacement fluid development approaches considered:

Mineral oil Silicone MIL-H-83282 Silahydrocarbon

Polyalphaolefin

Modified silicates -Cluster silicates - Olin Corp. -Additives - Monsanto Halogenated fluids -Fluorinerts - 3M -Freon E - DuPont -Chlorotrifluoroethylene



- Stability high
- Very inert towards metals, boards and elastomers
- Electrical properties high
- Coefficient of thermal expansion low
- Miscible and compatible with silicate esters
 - conversion plus



SR-71 New PAO and Coolanol 40 Evaluation

Compatibility (for simple retrofit) Low temperature circulation Electronic component cooling Full electronic system evaluation Low foaming

Full system conversion approved for SR71



- Evaluation for radars of F-15, F-14 and other fighters, "F-15 R&M PAO Coolant Study," 1 Mar 88, ASC-TR-97-5003, AD B221926
- Results
 - Compatibility with other electronic component materials and with Coolanol 25R (retrofit)
 - Full up radar system tests

- Low temperature performance
 - -45°F
 - -65°F issue (1200cSt vs. 300cSt at -65°F)



B-1B Problems Observed

- Silica gel formation
 - ICL system
 - ACL system
 - Ground support equipment
 - Cass
- Black particulate
- Free water





B1-B Problems in Practice

- Radar system coolant related failures occurred every 200 hours
- Flash point fluid sampling results unacceptably low
- At any one time, 40% of B-1Bs were grounded with silicate ester related failures
- Filter replacement and system cleaning after failure cost \$40K each incident



B-1 Flight Test

- Three phase program
- Completed & fully successful
- Conversion successful
- Cost of conversion paid for in first year use





PAO Coolant Transition

- PAO mil-spec MIL-C-87252 issued 2 Nov. 1988
- B-1B flight test sampling support
- Coordinate progress with other DoD agencies -Army, Navy, DGSC (and industry)
- Survey of potential users (DGSC, Kelly AFB)
- Future support activities B-2, F-16/B-1
- Spec amended Dec 2004 Revision C with amendment
 - Qualified product list has 8 companies



Navy Coolant Issues

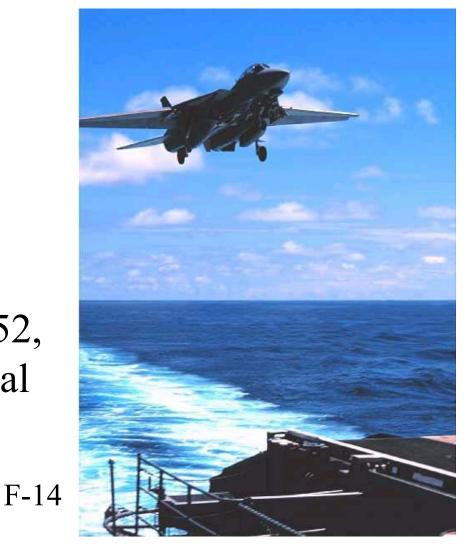
- F-18 and F-14 are high voltage dielectric applications
- High humidity environment
- F-18, F-14 and F-15 radar fluid sampling alarmingly low flash points





Navy Coolant Issues

- Converted successfully
- Concerned about lower dielectric strength test results with MIL-PRF-87252, but not an operational problem



846



Key MIL-PRF-87252 Features

- Hydrolytically stable
- Better heat transfer
- Better lubricity
- Less foaming (faster servicing)
- Availability
 - PAOs are made from readily available ethylene
 - Military fluid suppliers (e.g., Anderol, AirBP) formulate & package



- Availability (con't)
 - PAO is readily available at low cost ~\$15/gal vs >\$400/gal for Coolanol
- Handling
 - Toxicity very low (use normal shop procedures)
 - Fluid less hygroscopic
 - Recycling/reclamation Pall Corp. fluid purifiers used successfully
 - Disposal can be sold as a hydrocarbon fuel oil supplement
 - Biodegradable ASTM D5864 Class I
 - **Key features lead to lower life cycle cost**



- <u>Now</u>
 - B-1 and F-18 converted
 - Projected life cycle cost savings:
 - B-1 \$947M F-18 \$ 70M



\$1.017B



PAO Coolant Transition Systems Using Coolant

- Air Force
 - B-1B F-14
 - EF111* F/A-18**
 - EC-130
 - F-15
 - F-16 (block 60 foreign sales)
 - F-22 (base-lined)
 - JSF (base-lined)

- P-3 - E/A6B

- S-3

• Navy

- AV-8B
- Mark 92 mod
-)



PAO Coolant Transition Systems Using Coolant (con't)

- Weapons
 - PAVE
 - LANTIRN***
 - SPIKE
 - ALQ-119 Pod
 - Phoenix
 - Joint Stars*

- Army
 - Ground radar
 - Missile systems





- *EF111 and Joint STARS
 - Changed to conductive hoses (carbon impregnated)
 because PAO caused electrical streaming that did not occur with Coolanol
- **F-18
 - changed low temperature flow switches
- ***LANTIRN
 - Converting by attrition, but gel from residual silicate ester coolant (5-9%) caused leakage pathway
 - Solution: Drain and fill to 100% PAO at overhaul



New System Interest

- New system coolant lines anticipated to be routed in high temperature area
- MIL-PRF-87252 originally tested at 175°C/100 hours to meet the specification
- All products on Qualified Product List were tested at elevated temperatures
- Specification changed to require 200°C/100 hours thermal stability test. Current materials "grandfathered" i.e. did not have to re-qualify.



Status of silicate ester users

• F-16 and B-1 (isolated loop) - No plans to convert





Status of silicate ester users

- B-2 Reconsidering conversion ASC SBIR contracts to investigate alternate coolants began FY06
- Two Phase I SBIR contractors
 - METSS Corporation
 - InfoSciTex



- High pressure switching technology for directed energy High Power Microwave (HMP) applications
- AFRL/PR sponsored research at University of Missouri at Columbia and The Boeing Company, St. Louis Mo
- Prototype switch successfully developed



High Pressure Switches Program goals

- Voltage
- Current
- Rise-time
- Charge transfer
- Jitter
- Pulse repetition rate
- Pulse width
- Switch lifetime

200 - 1000 kV

20 - 250 kA

< 50 ns

 ~ 0.5 Coulombs/pulse

<< 50 ns

50 - 100 pps

50 - 500 ns

 $10^{7} - 10^{8}$ pulses

High Pressure Switching Technology

- MIL-PRF-87252 breaks down to carbon and hydrogen during arcing
- Increased pressure (1000 to 2000 psi) helps reduce arc-induced bubbles
- Dielectric flow helps remove bubbles, carbon and ablated electrode material from electrode stressed area
 - Filtering removes carbon particles
 - H₂ gas generation has not created a hazard
- Current Univ of Missouri Columbia's Capabilities
 - -150 kV, 70 ns pulses into 4.2 Ω
 - 100 pps operation

Proposed Program: Characterization of Fluids for HMP Switch

Opportunity: Establish fundamental understanding of fluids' breakdown characteristics for use in High Power Microwave (HPM) sources

Approaches: Evaluate different chemical classes of fluids, alone and with various concentrations of polar additives, for dielectric strength, with respect to temperature and pressure



Newly deployed PR prototype oil-filled high voltage switch



Other information

- PAO coolant has many commercial spinoffs - e.g., computer coolant, automobile shock absorbers
- MIL-PRF-87252 is a Class I biodegradable fluid (best) by ASTM D 5864



Conclusions

- PAO coolant MIL-PRF-87252 overcomes most of the difficulties with silicate ester coolants and has many other benefits
- Most military liquid cooled systems use MIL-PRF-87252