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

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 Corporation

Pall Aeropower Corporation

10540 Ridge Road
New Port Richey, FL 34654 USA
727.849.9999 phone
727.815.3115 fax
www.pall.com

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
5072 West Chester Pike, P O Box 646
Edgemont, Pa 19028
Tel: 610-356-7161   FAX: 610-325-0687
www.wedeven.com

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

Dear Lois:

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

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

Sincerely,

L D Wedeven

Lavern Wedeven
President

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Nonmetallic Materials Division
Materials and Manufacturing Directorate
Wright-Patterson Air Force Base, OH 45433-7750
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14. ABSTRACT
The 2006 Military Aviation Fluids and Lubricants Workshop was comprised of various topics such as current lubricant research and conditions of lubricants in the field. This year there was an extensive update on hydraulic fluid purification, the background of this topic was discussed in detail along with field testing of purifiers that was ongoing at the time. Progress reports on the SBIR engine oil additive programs were presented. The Navy presented their data on the usage of MIL-PRF-32104 as a corrosion resistant grease. Current research in the coolant and solvent areas was also discussed.

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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
AGENDA

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

<u>Wednesday, 21 June 2006</u>
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, Al 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 Small Business Innovation Research Program, Gas Turbine Engine Oil Additives for Advanced Bearing Steel, 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

<u>Thursday, 22 June 2006</u>

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

THE AIR FORCE RESEARCH LABORATORY
LEAD | DISCOVER | DEVELOP | DELIVER

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

Air Force Research Laboratory

- Air Force
  - Provide air and space superiority to defend the nation against all enemy threats
  - Global vigilance, reach, and power
- Research Laboratory
  - Provide technology options to senior leadership
  - Develop technology for weapon systems
  - Spur innovation and rapidly provide solutions to current problems

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

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

Vision / Governing Philosophy

- **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

As of April 2006

ML Unique Facilities & Equipment

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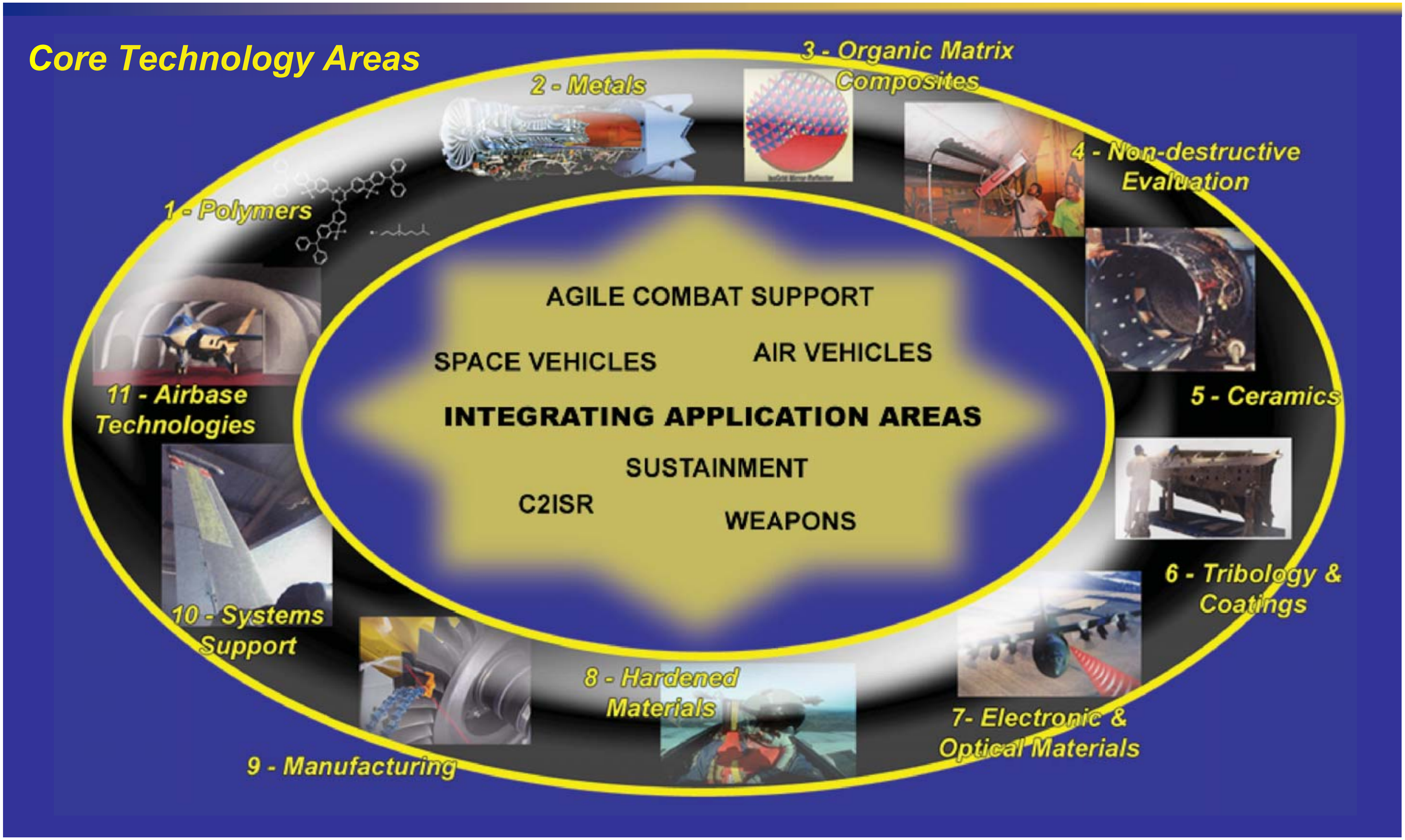
Materials / Processes to Enable Air Force Capability

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



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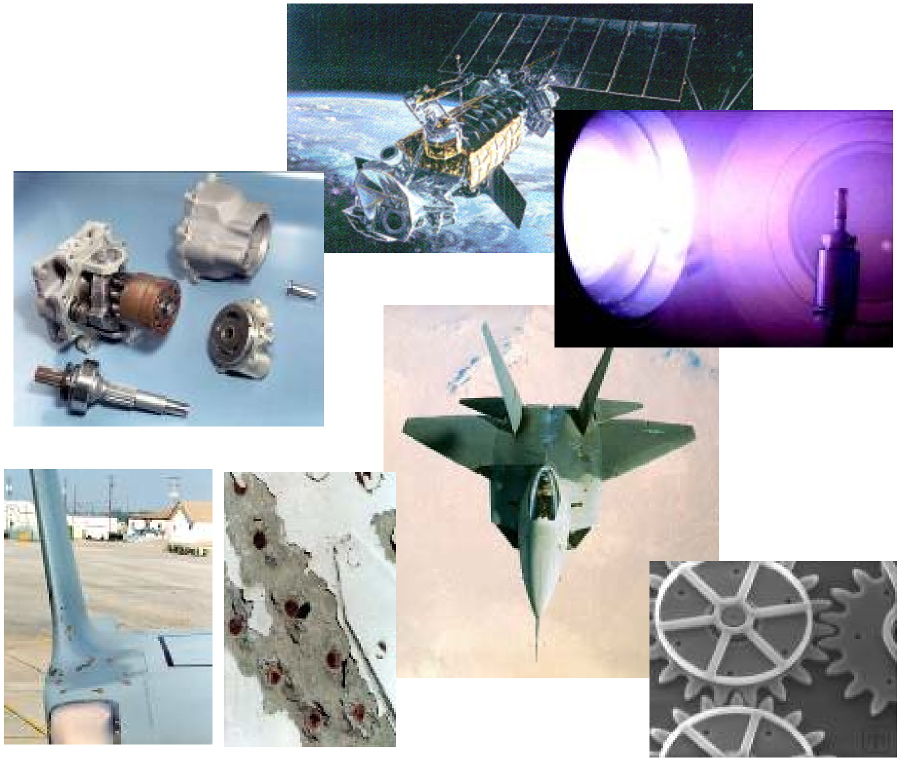
CTA 6
Tribology and Coatings



- 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

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
- 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

Military Aviation Hydraulic Fluids and Lubricants Workshop

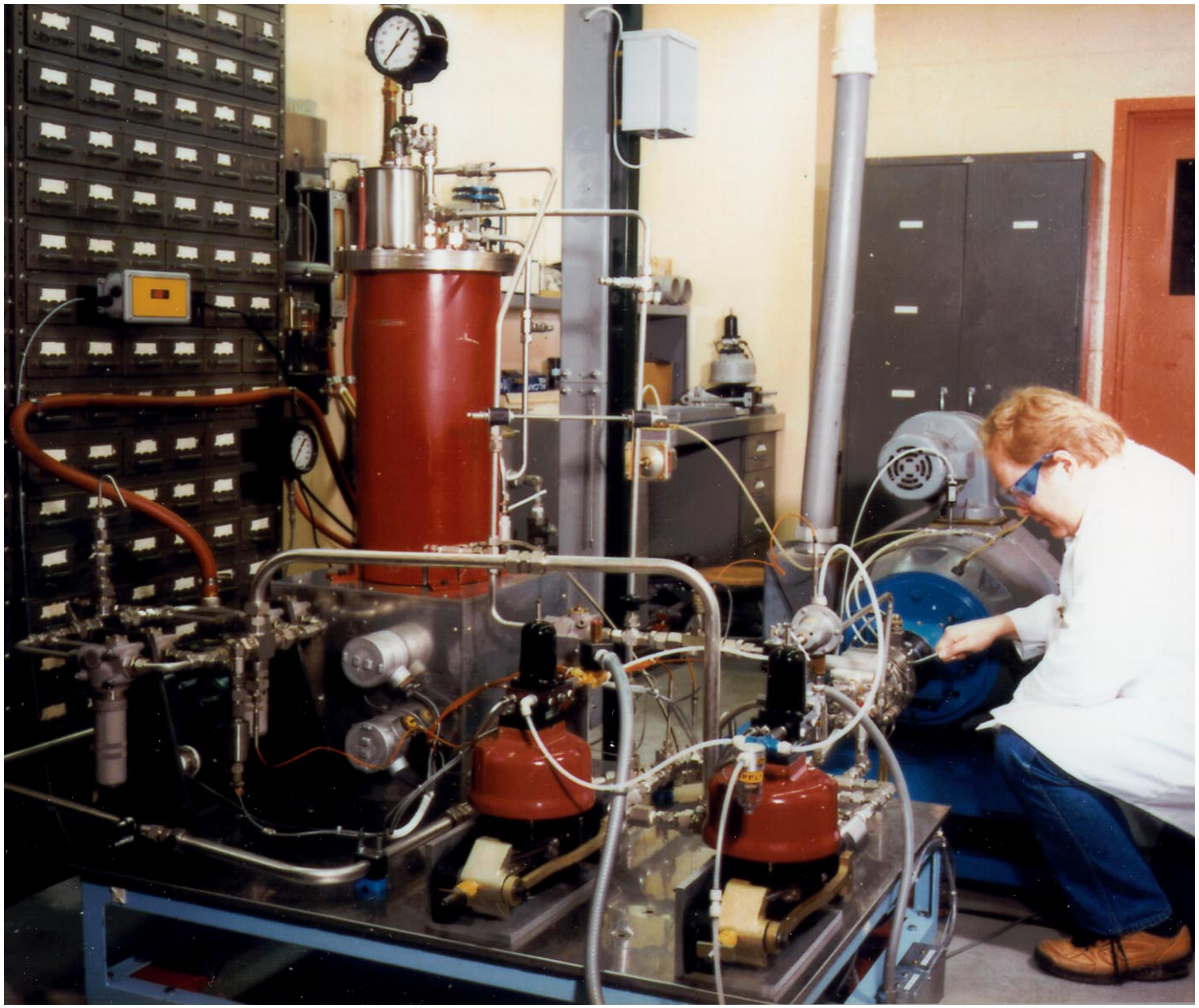
People

- 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 Aviation Hydraulic Fluids and Lubricants Workshop

National

Air Force
Army
Navy
DLA
NASA
EPA
FAA

Aircraft and Component Mfrs
OEMs
Suppliers

International

NATO
ASIC
DEA
SAE-E-34
STLE
SAE A-6
ASTM

Euro-Fighter (Daimler-Chrysler)
German MOD
UK MOD
Canada MOD
Suppliers

Fluids and Lubes

Distribution Statement A: Approved for public release distribution is unlimited.

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

2006 AFRL Fellow

- 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


MATERIALS & MANUFACTURING DIRECTORATE

Air Force Research Laboratory

Materials and Manufacturing Directorate

Wright-Patterson Air Force Base, Ohio

ML Fluids and Lubricants Team

- 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

ML Fluids and Lubricants Team

- Areas of Responsibility
  - Hydraulic Fluids
    - Purification
  - Greases
  - Liquid Lubricants
  - Coolants
  - Solvents

Aircraft and Spacecraft

ML Fluids and Lubricants Team

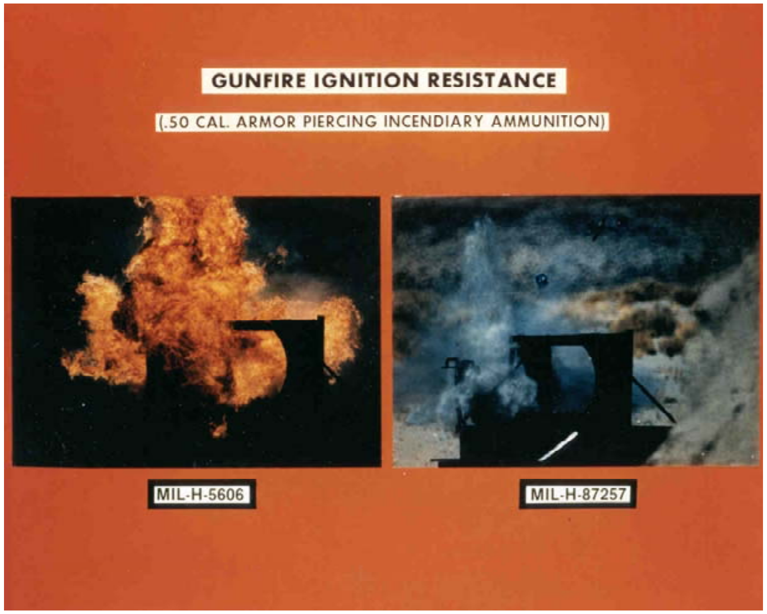
Personnel:

- 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

ML Fluids and Lubricants Team

Fire Resistant Hydraulic Fluids

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



B-52 Hydraulic Fire

ML Fluids and Lubricants Team

Hydrolytically Stable Coolant

Coolanol 25R (MIL-PRF-47220)

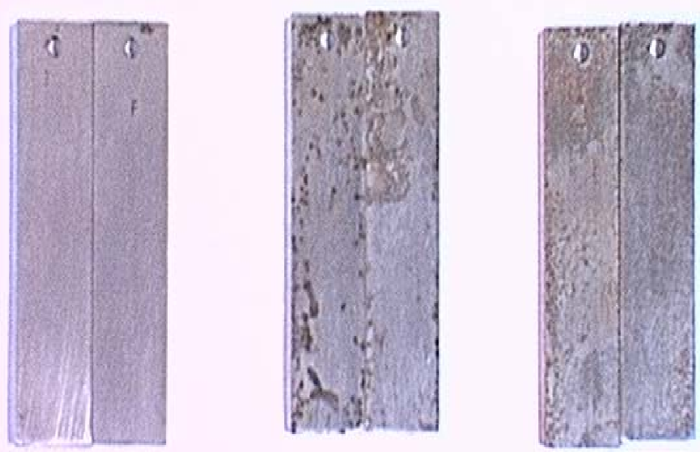
MIL-PRF-87252 (PAO)

ML Fluids and Lubricants Team

Nearly Universal Grease

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

ML Fluids and Lubricants Team

- 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

Specifications (AFRL/MLBT)

- 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

Specifications (AFRL/MLBT)

- 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, MoS_2)

* Qualified Products List on these

Specifications (AFRL/MLBT)

- 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

Air Force Hydraulic Fluid Specifications

- MIL-PRF-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

Air Force Hydraulic Fluid Specifications

- 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

Air Force Hydraulic Fluid Specifications

- 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

Air Force Hydraulic Fluid Specifications

- 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

Air Force Hydraulic Fluid Specifications

- 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

Air Force Hydraulic Fluid Specifications

- 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

Air Force Grease Specification

- 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)

Air Force Grease Specification

- 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

Air Force Grease Specification

- 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^{o}C to 200^{o}C temperature range due to advanced system predictions
    - All qualified products tested and passed 200^{o}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

Recent Conversions…

- 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

U.S. AIR FORCE

AFRL
FLUIDS & LUBES
WORKSHOP
June 2006

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

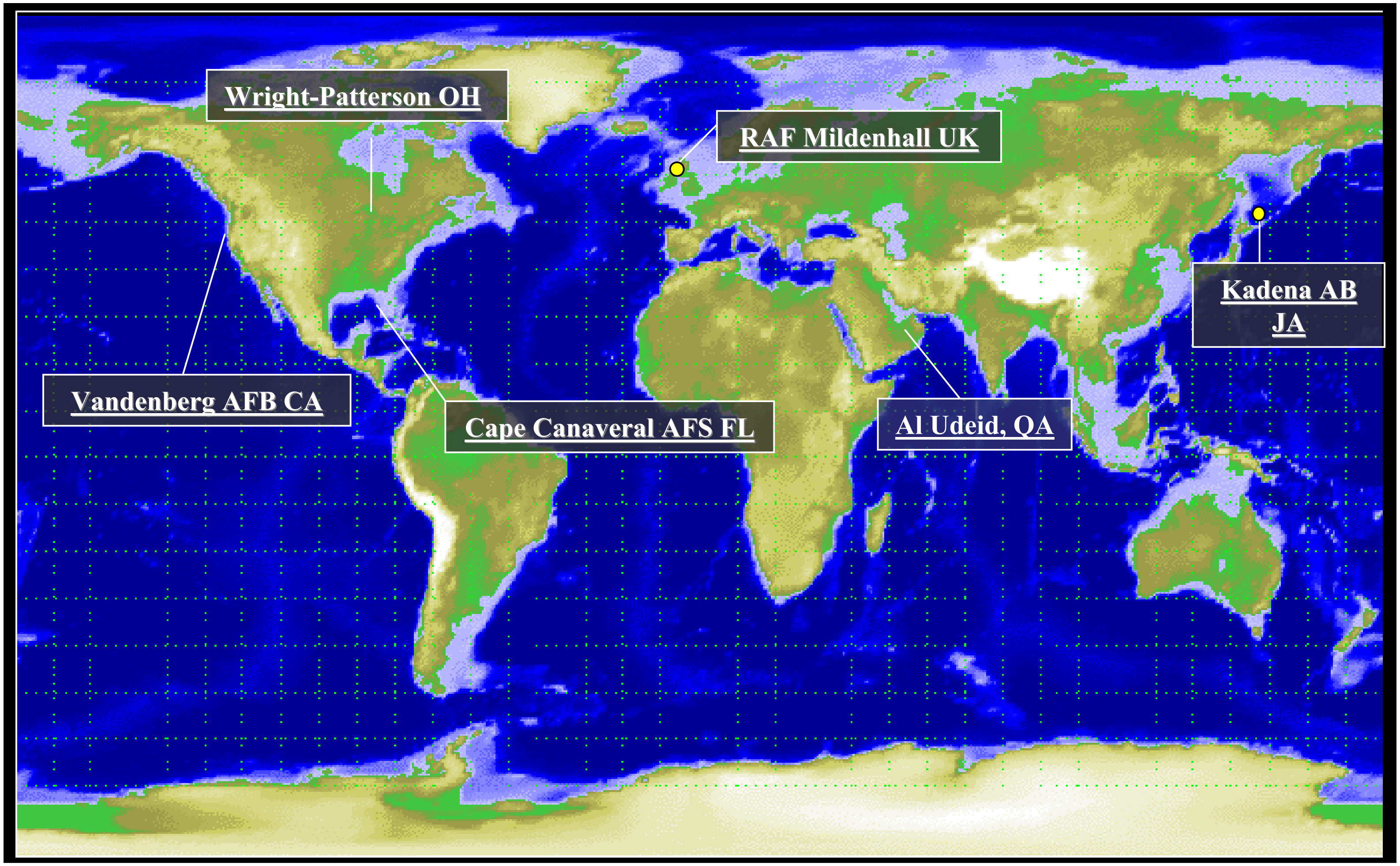
Integrity - Service - Excellence

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



Related Products

- **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

4

Hydraulic Fluid
(Responsibilities)

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

T.O. 42B2-1-3

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

Hydraulic Fluid Testing

- **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

International Coordination

AFMC

- **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**

International Coordination

- **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**

Change

- 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

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

<u>Navy</u>

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

<u>Air Force</u>

Lois Gschwender, AFRL/MLBT, Wright-Patterson AFB, Ohio, 937-255-7530

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

Conchita Allen, AF Petroleum Office, Wright-Patterson AFB, Ohio, 937-255-8038

MSgt Kurt Hinxman, Scott AFB, 619-229-2630

<u>Army</u>

Kenneth Wegrzyn, US Army, 256-313-9137

Questions

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 ~3% BSN (1500 ppm Ba). Stability $\leq 225^{o}F$.
- 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

Program Test Matrix, Part I, Jars

- 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 JAR TEST RESULTS

		Year				
Operational Fluids		1	2	3		
MIL-PRF-						Green = No change
83282						
87257						Yellow = Slight stain
5606						
						Red = Stain
Storage Fluids						
MIL-PRF-						
46170						
	Submerged					
	Dip & Drain					
6083						


MIL-PRF-83282, 352 PPM WATER, STORAGE 2 YRS


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


MIL-PRF-46170, 412 PPM WATER, DIP&DRAIN 2 YRS

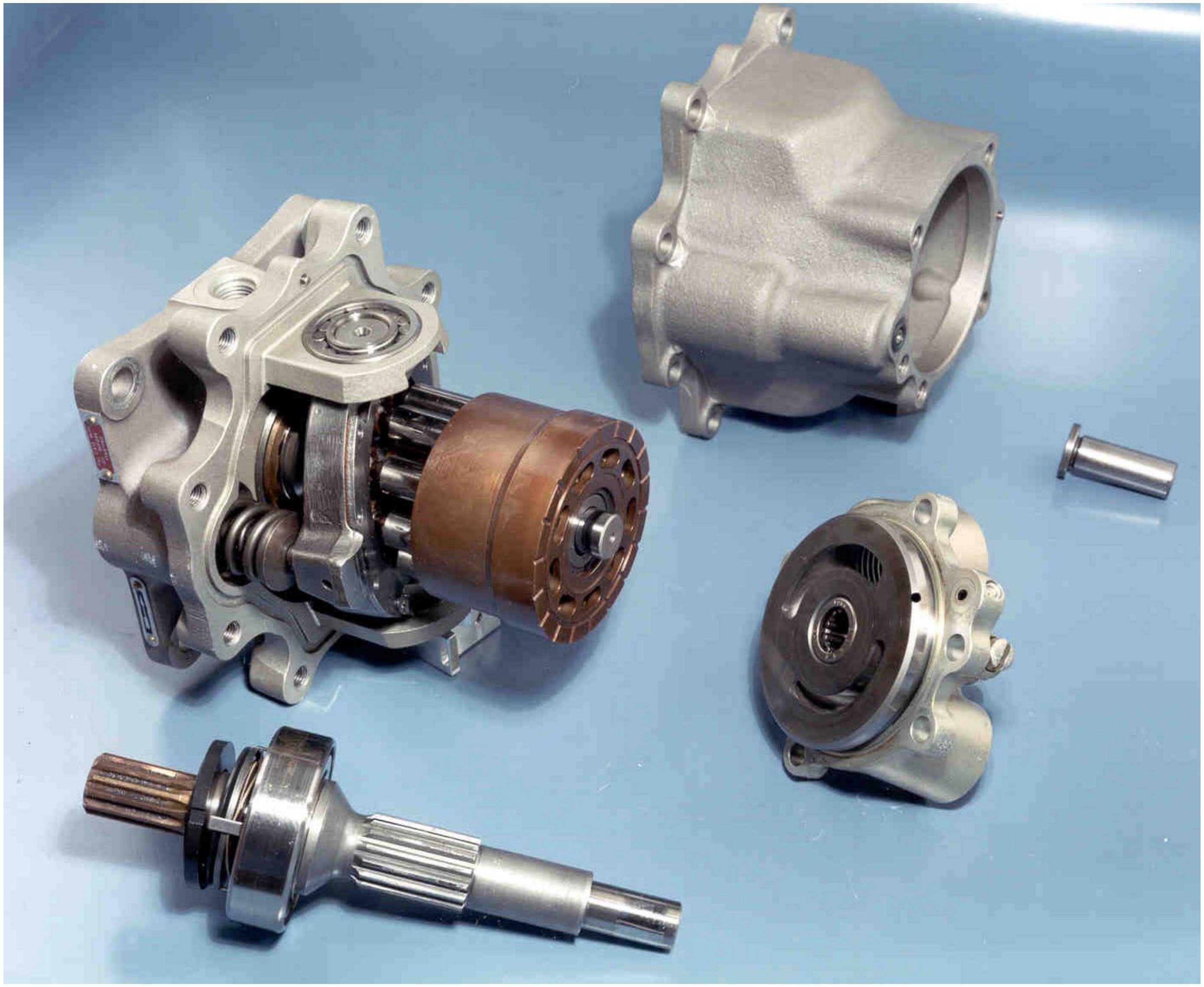

MIL-PRF-46170, 412 PPM WATER, STORAGE 2 YEARS

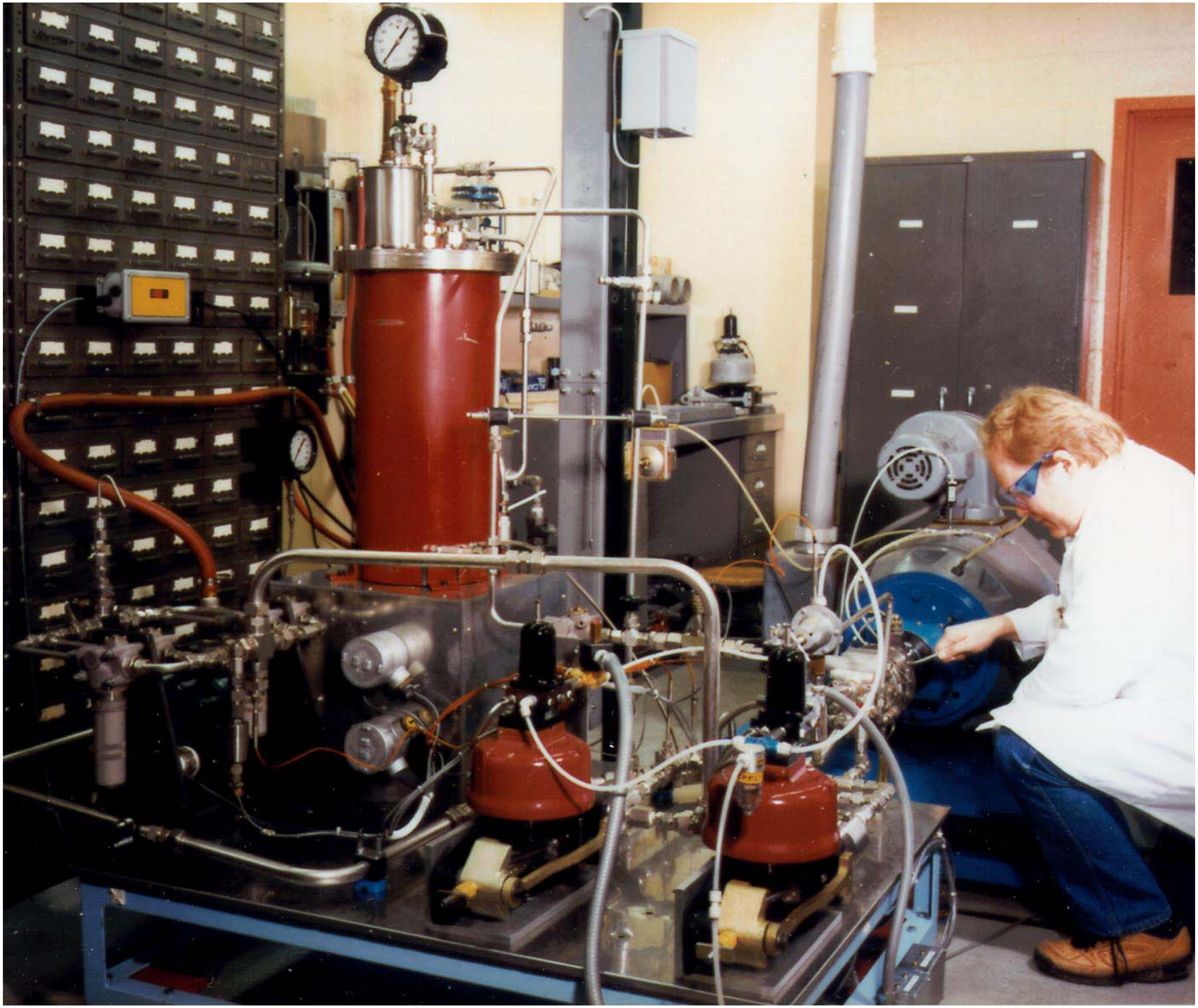
Jar Test Results Summary

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

Results, Pump Tests

F-16 EPU pump, Eaton (Vickers) PV3-075-15

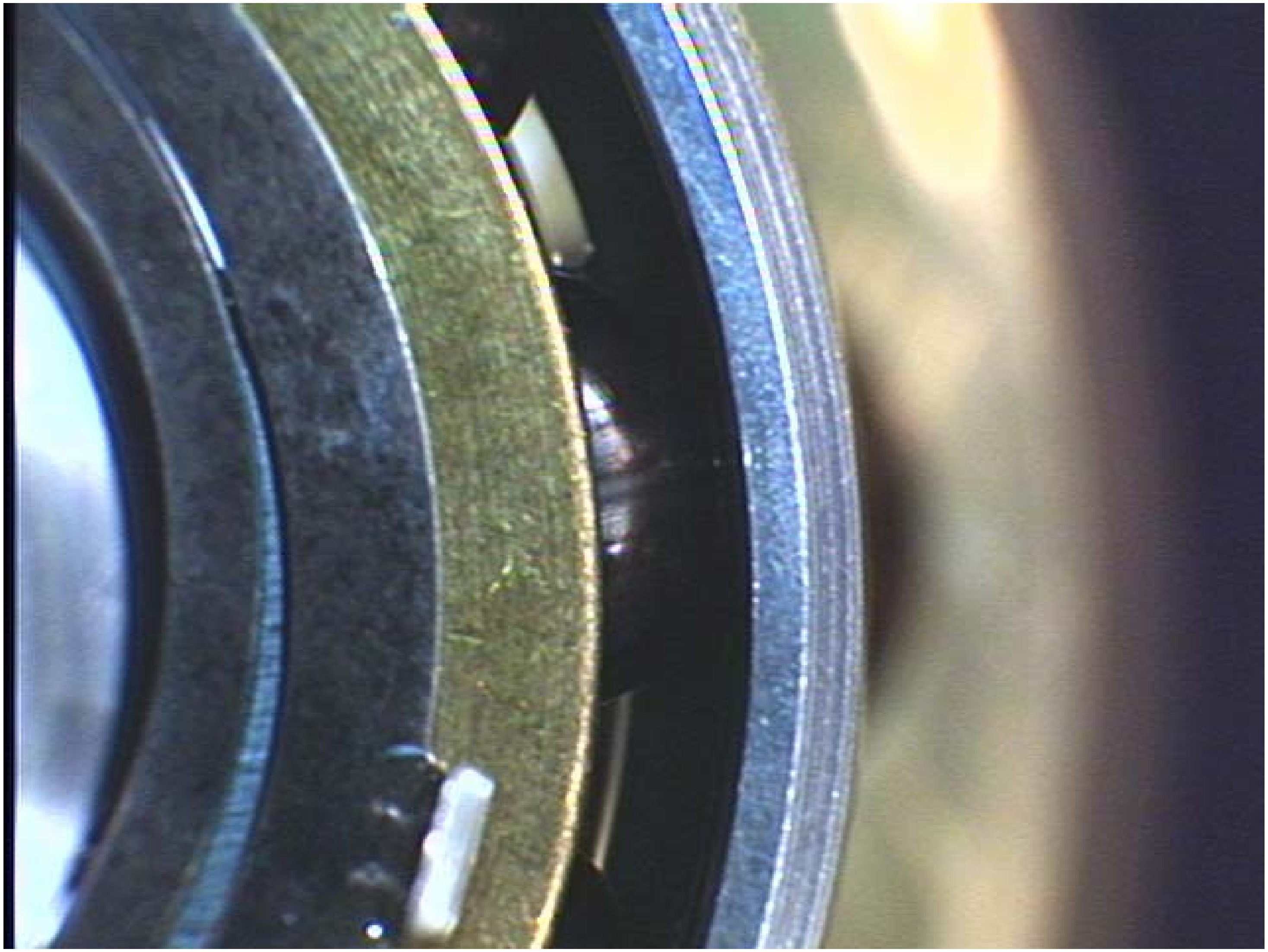




Part II Pump Storage Results

- 3 year pump storage begun June and July 2000 (300ppm water added)
  - 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, Trib. Trans., 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

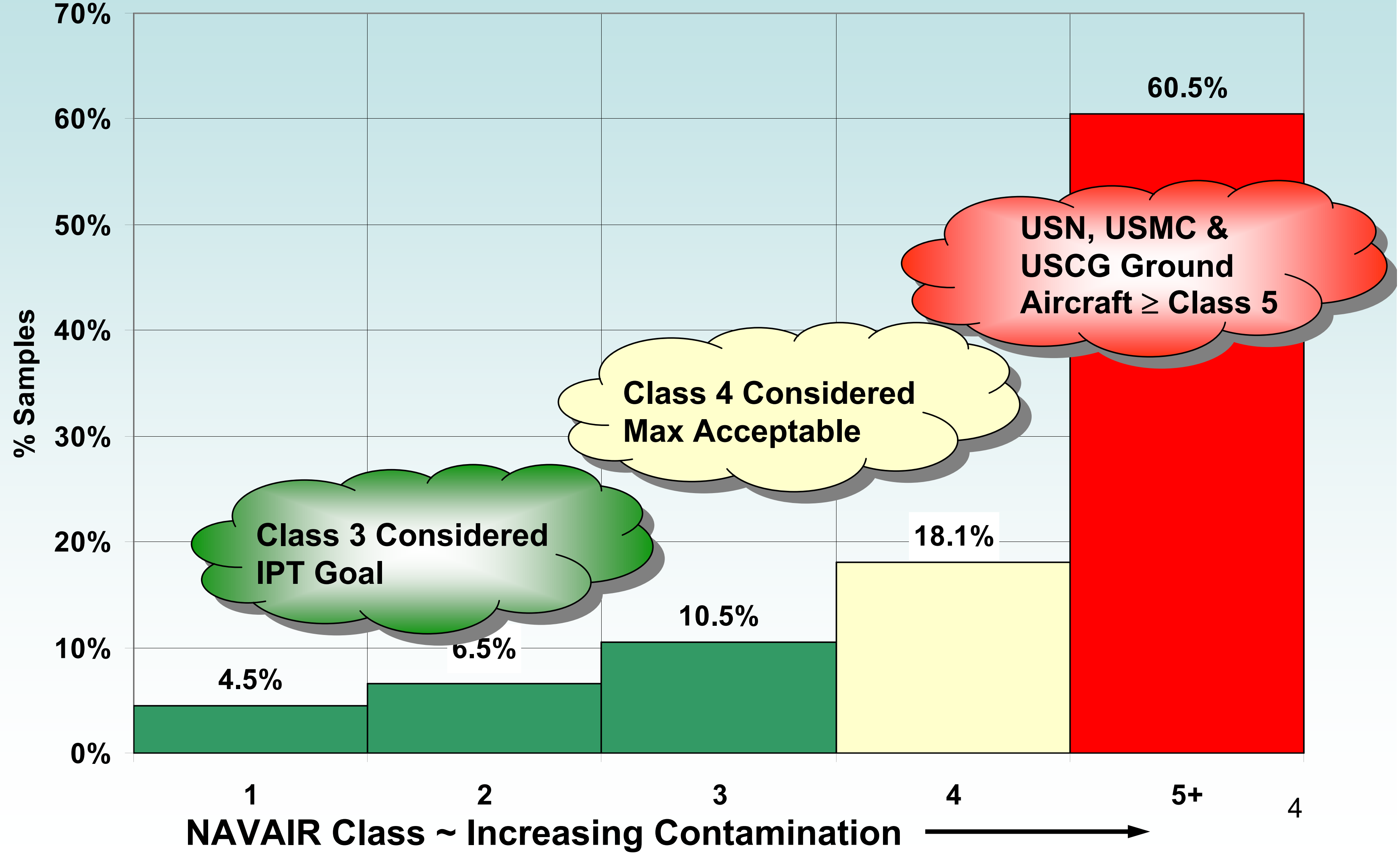
2

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

3

Army Helicopter Hydraulic Fluid Samples (FY01)



4

Field Induced Contamination

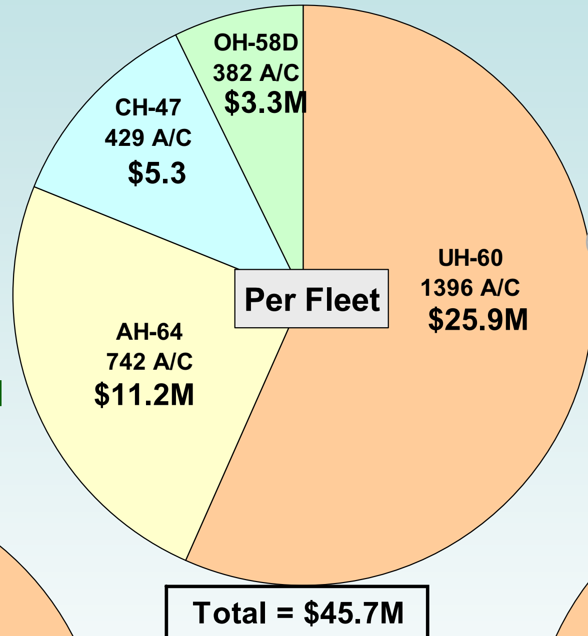
5

Contaminated Hydraulic Components

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

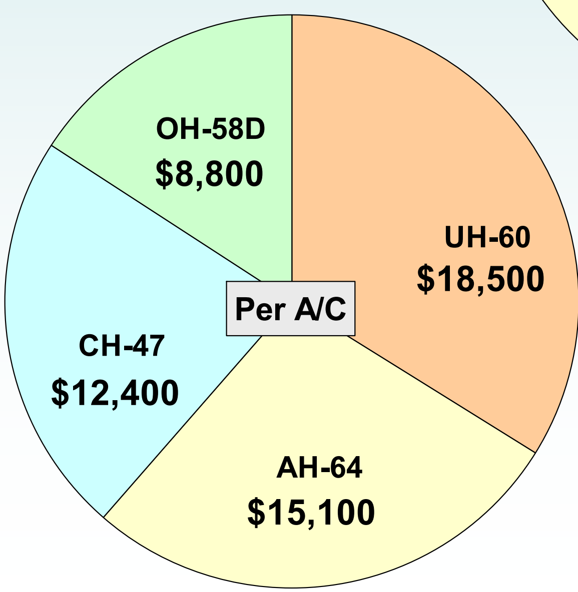
6

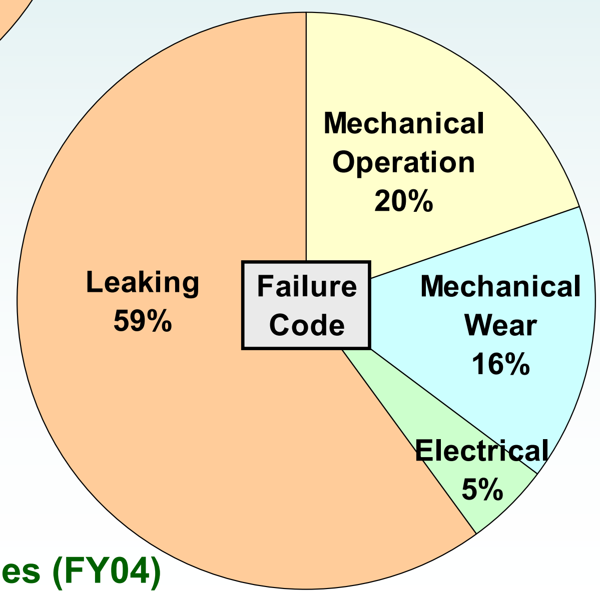
Annual Helicopter Cost
26 Critical Hydraulic Parts
CCSS Annual Demand & Average Overhaul Cost (FY04)



Per industry data, ≈75% of failures are due to contamination.

CCSS Annual Demand & Average O/H Cost





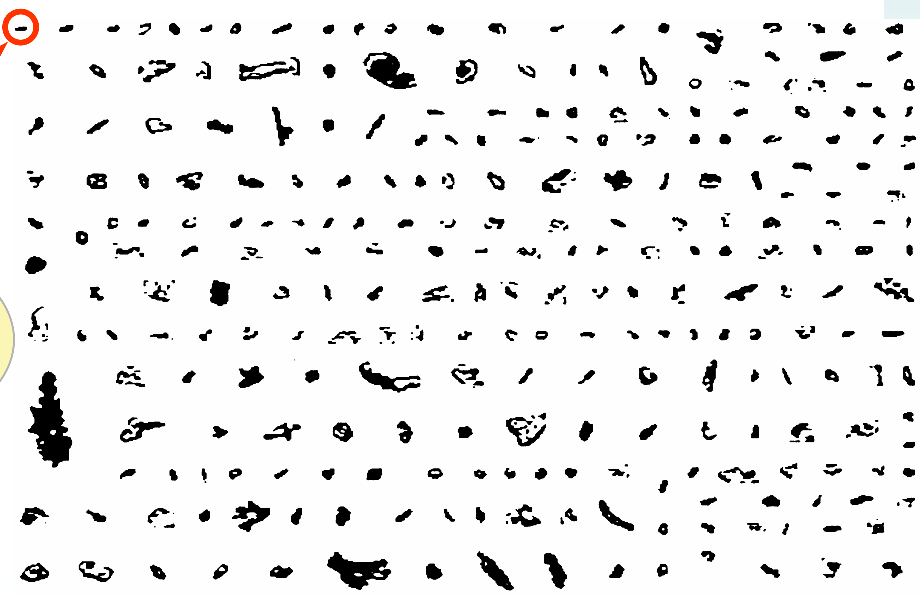
2410 Failure Codes (FY04)

7

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.



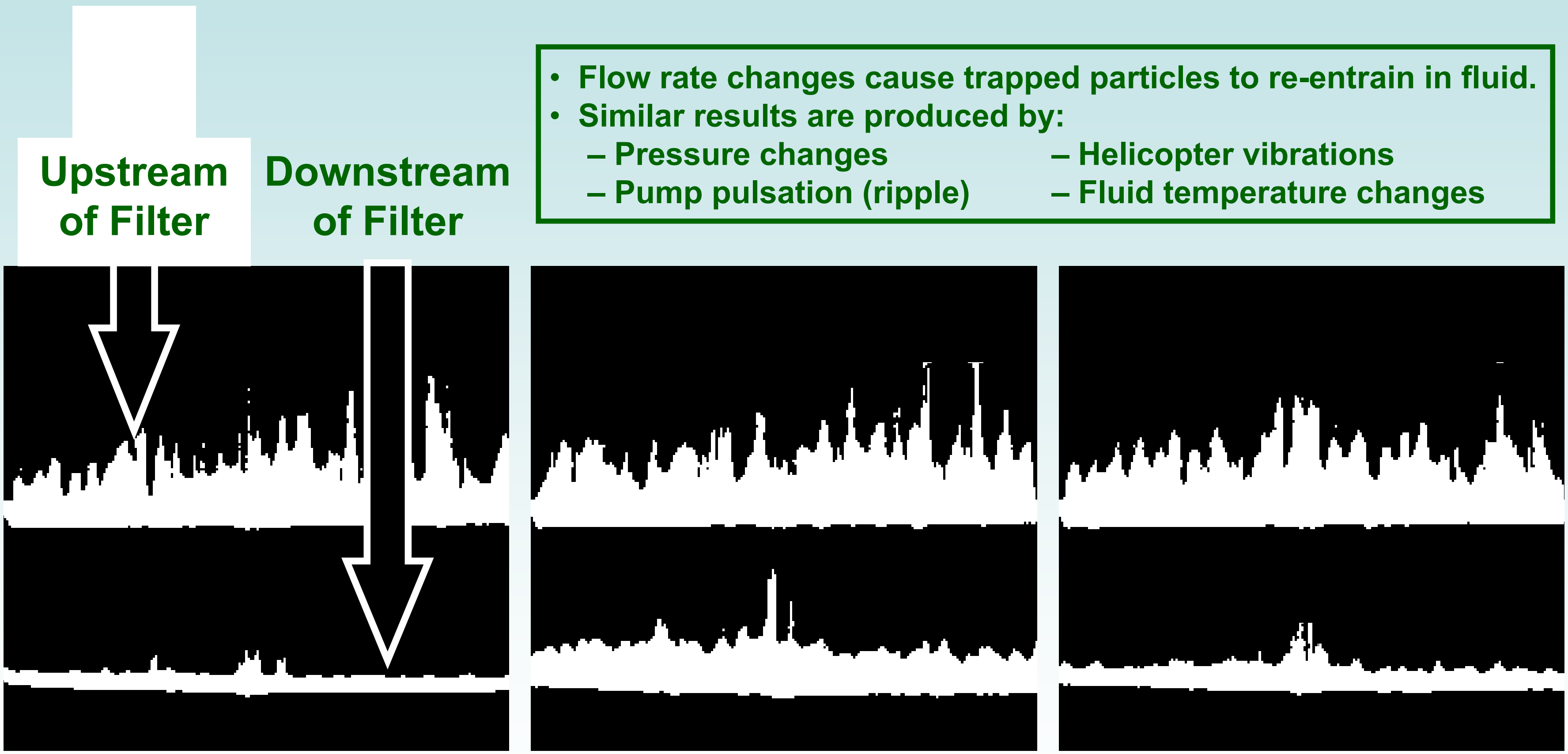
CH-47D Sample (FY01)

8

Fiberglass Filters are Not Effective in Dynamic Environments

Dynamic Test at SSI (FY01)

- Flow rate changes cause trapped particles to re-entrain in fluid.
- Similar results are produced by:
  - Pressure changes
  - Pump pulsation (ripple)
  - Helicopter vibrations
  - Fluid temperature changes



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

9

Characterizing Filters

Conducted Flight Test
- Instrumented CH-47D Hyd Sys
- Actual Flight Conditions
- Helo Hyd Sys Variations
  - Pressure
  - Flow Rate
  - Ripple (Pulsation)
  - Temperature
  - Vibration

Contracted Testing & Acquired Hydraulic Test Stand
- Replicated Helo Filter Environment
- Varied Contamination
  - Particulate
  - Water
  - Air

Verifying Filter Performance (Metal vs Fiberglass)
- Pressure
- Flow Rate
- Ripple (Pulsation)
- Temperature
- Vibration

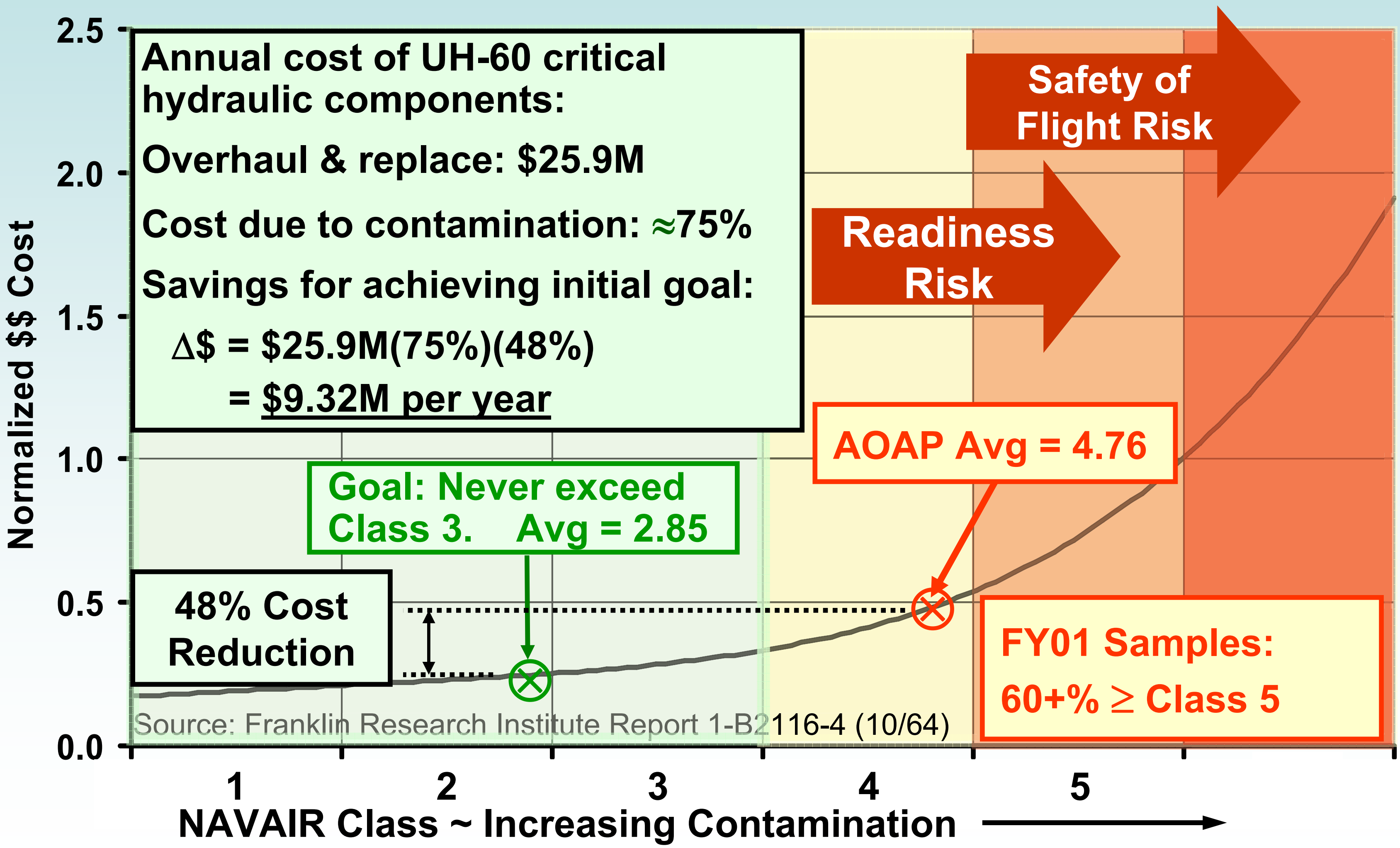
Effectiveness & Trends
- Fiberglass Filters
- Metal Filters

Quantified Benefits
- Defined aircraft operating environment.
- Played back operating environment on test stands.
- Quantifying effectiveness.
- Determined potential ROI.
- Monitoring performance of metal filters.

✓Qualify Filter
✓Quantify Benefits

10

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).

12

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
- 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

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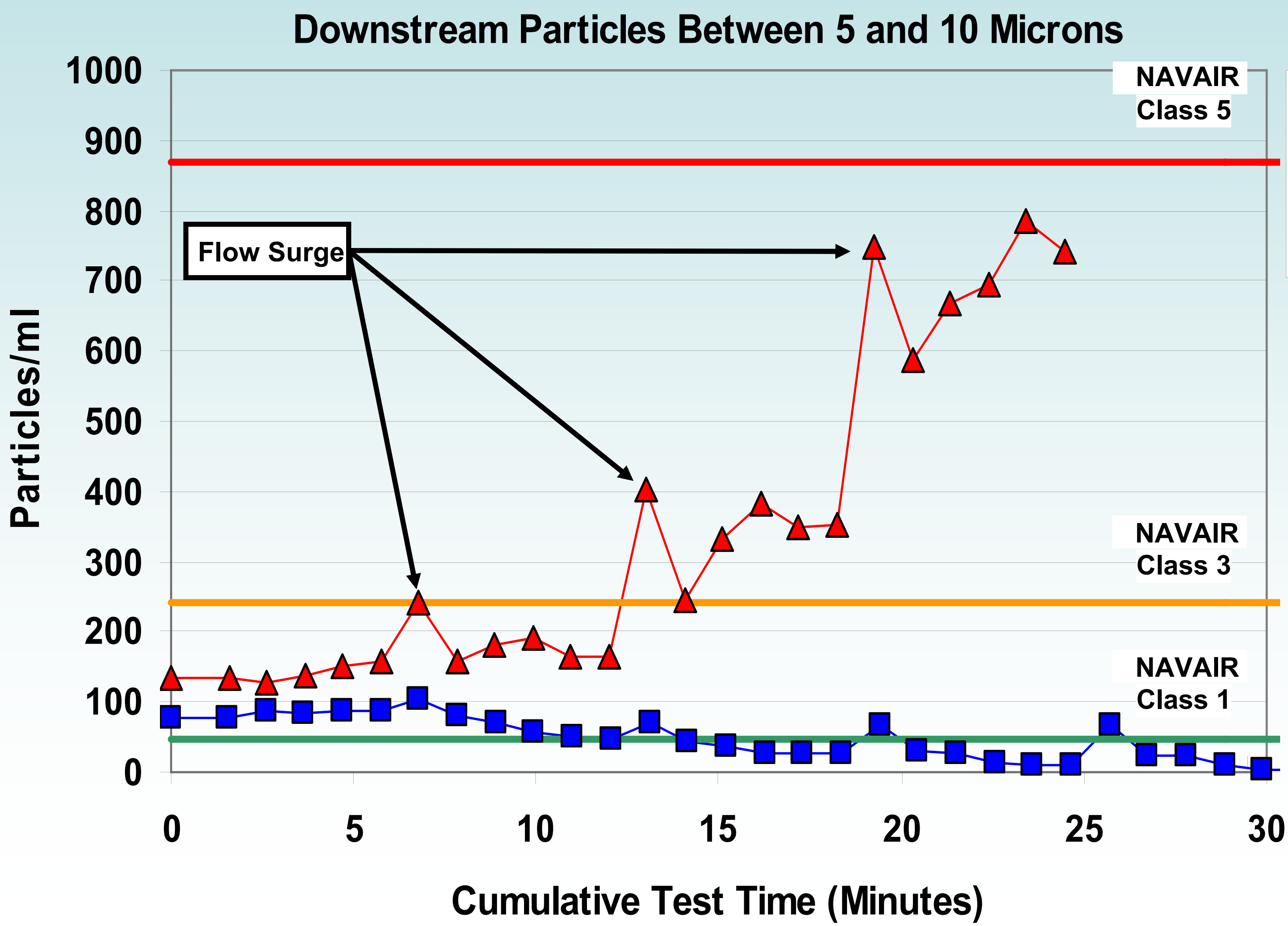
Hydraulic Filter Testing

15

Particle Shedding

Comparison of Fiberglass & Metal Filters

NAVAIR Dynamic Test Results (FY02)



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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

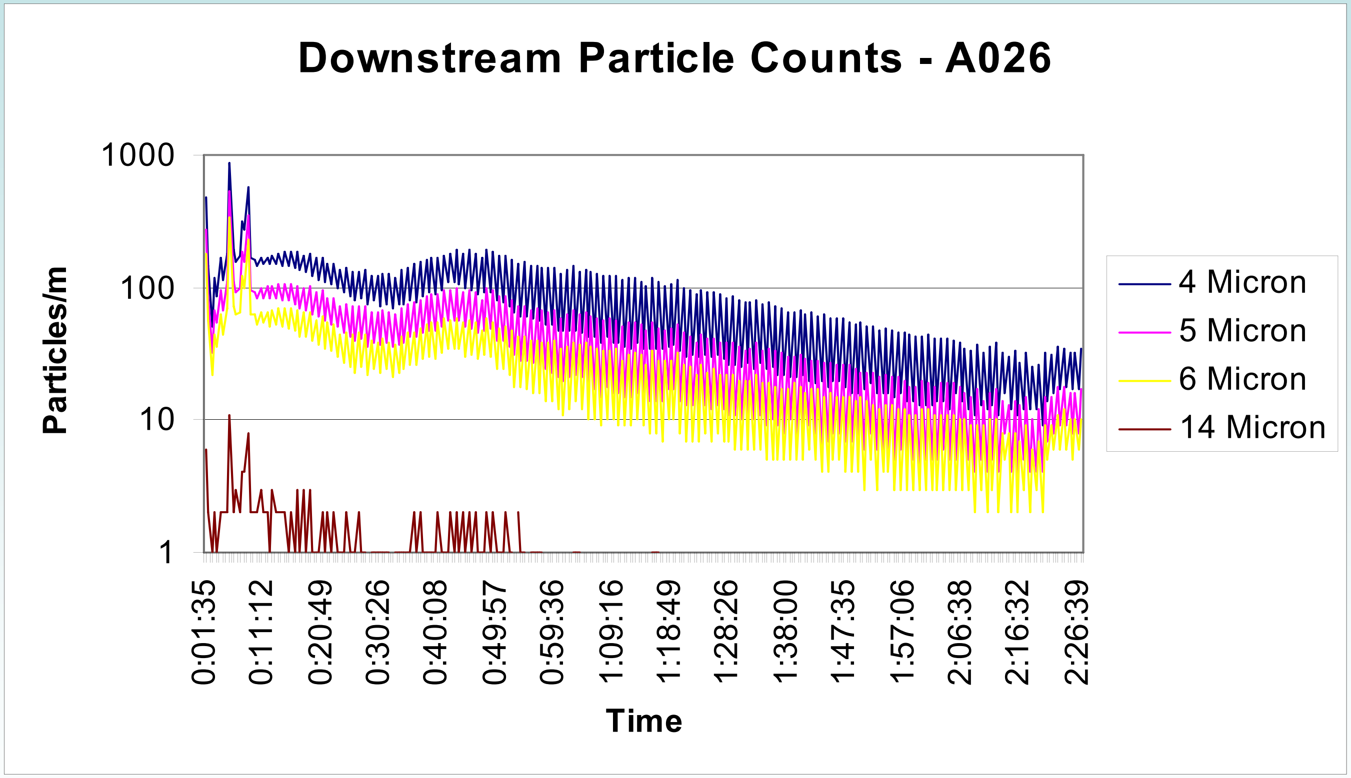
- Some bench test data and field oil samples data suggest that we may have worse than normal cleanliness levels in aircraft during helicopter working conditions

  - 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 → Over 1143**

UH-60 Current Filter Performance



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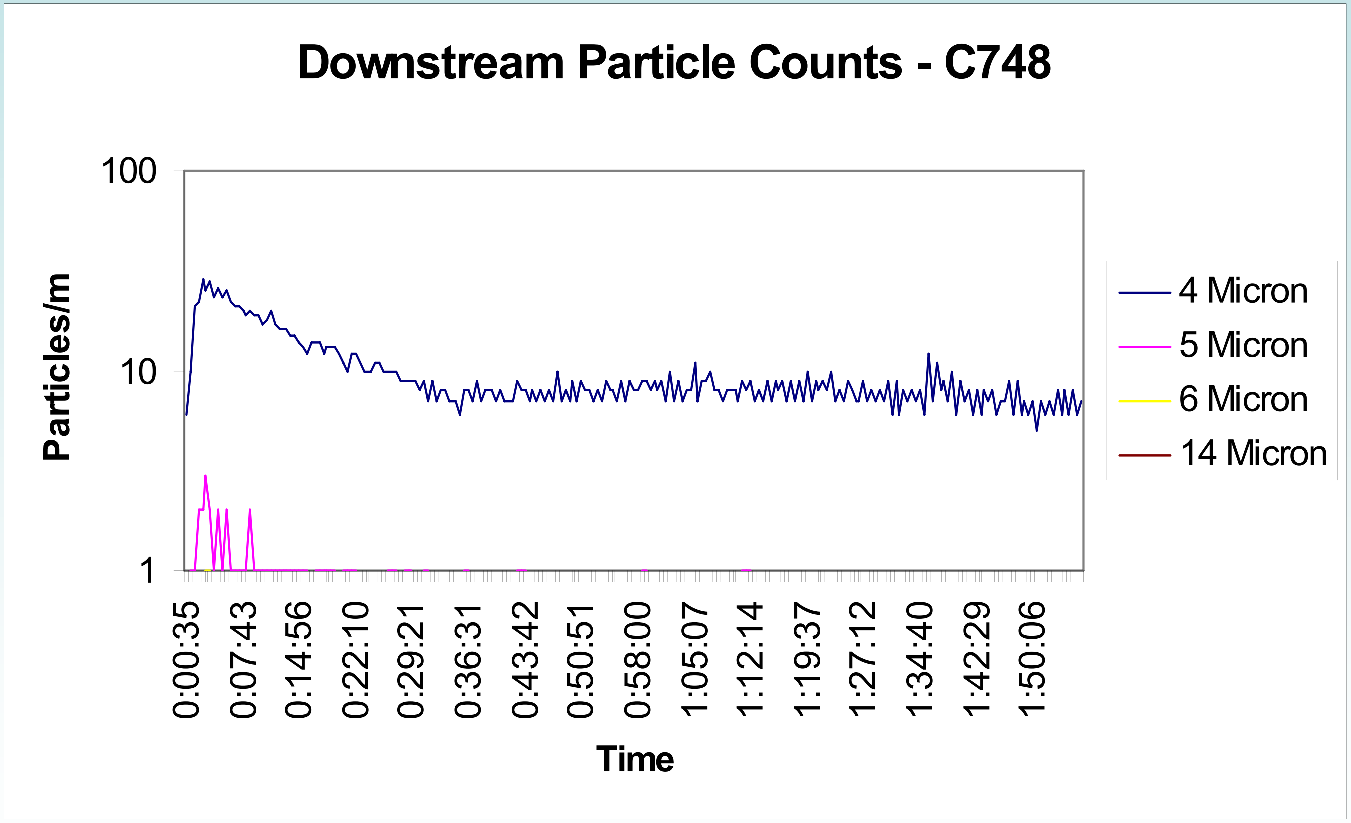
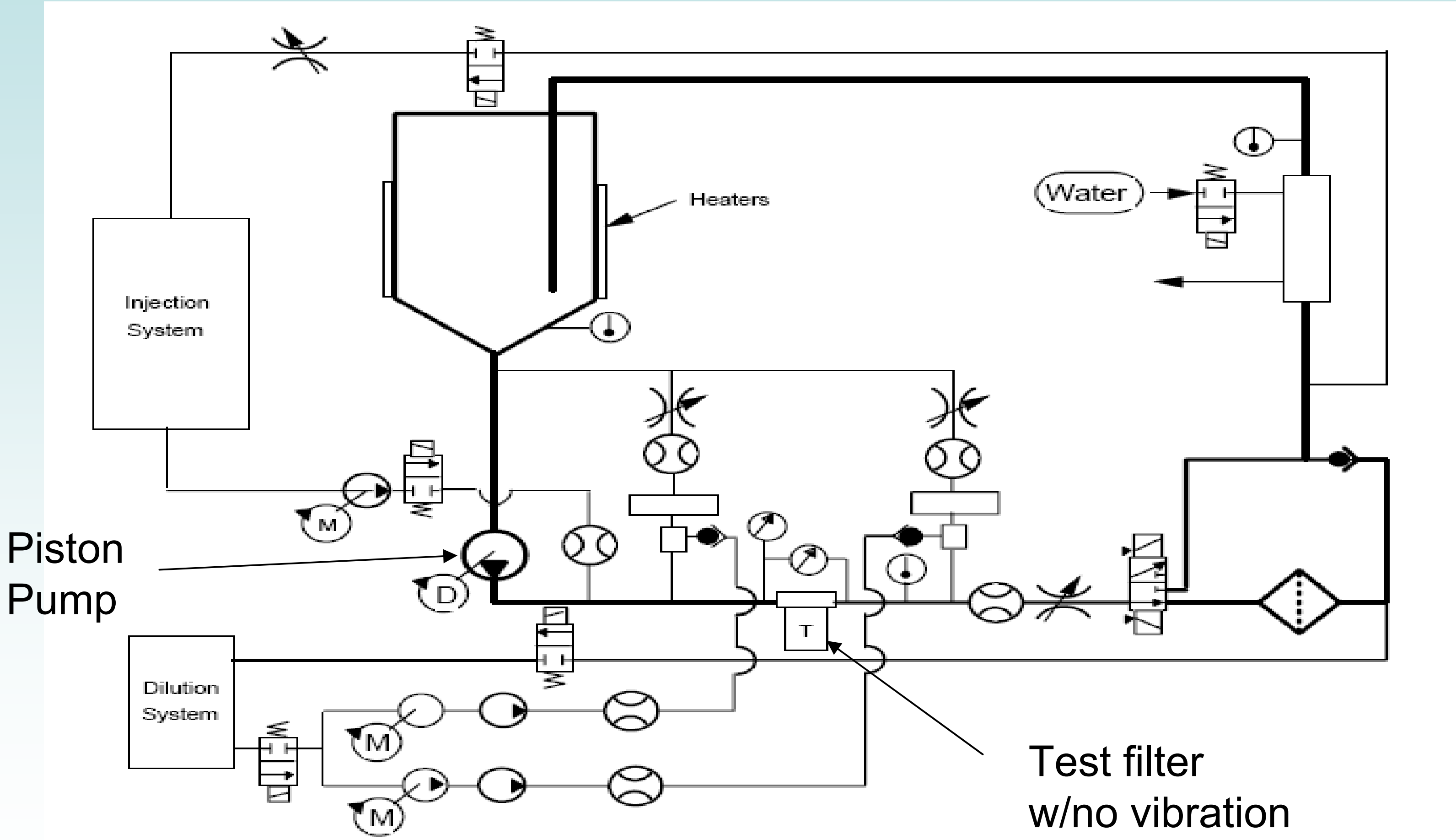
UH-60 Vendor 2 Filter Performance



20

DFE®-Dynamic Filter Efficiency Test



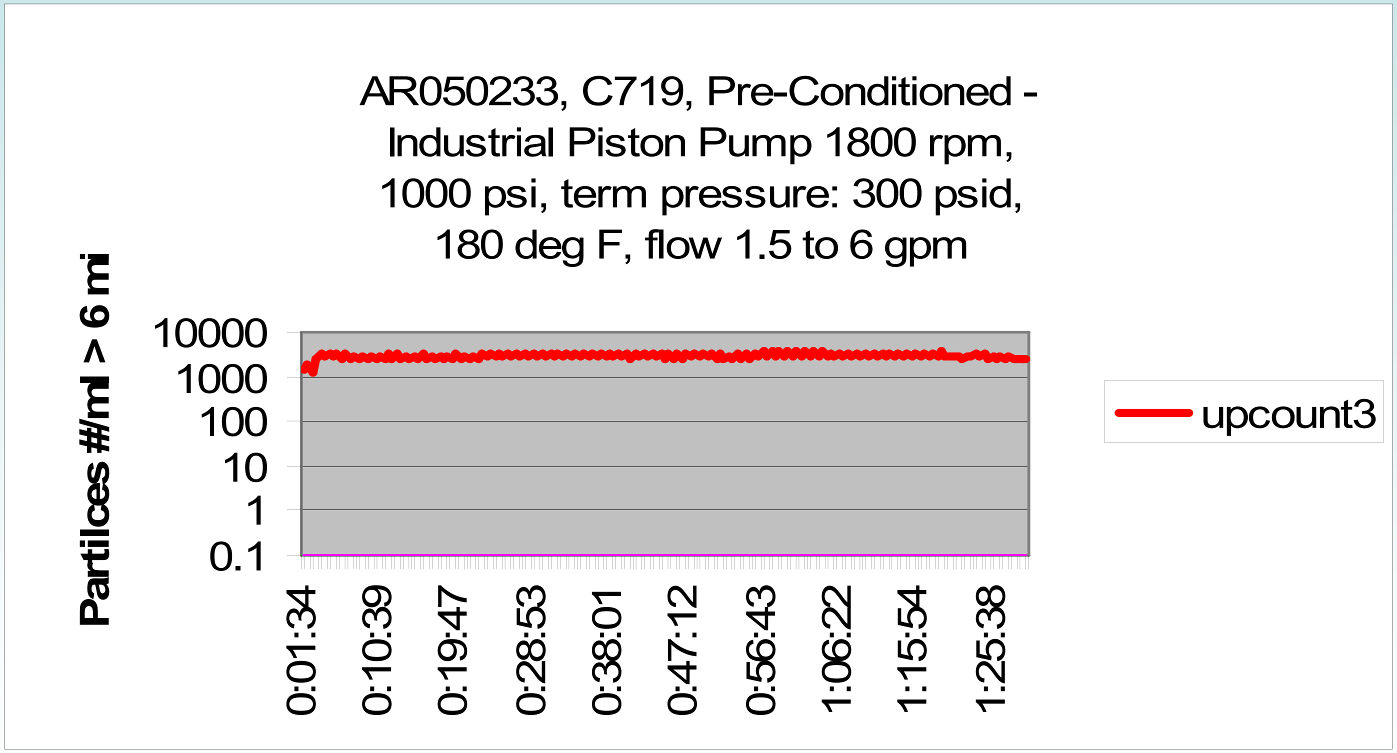
21

DFE trademark of SSI Labs,

Upstream Challenge Maintained Constant For DFE Filter Test Duration

Upstream Counts vs Time

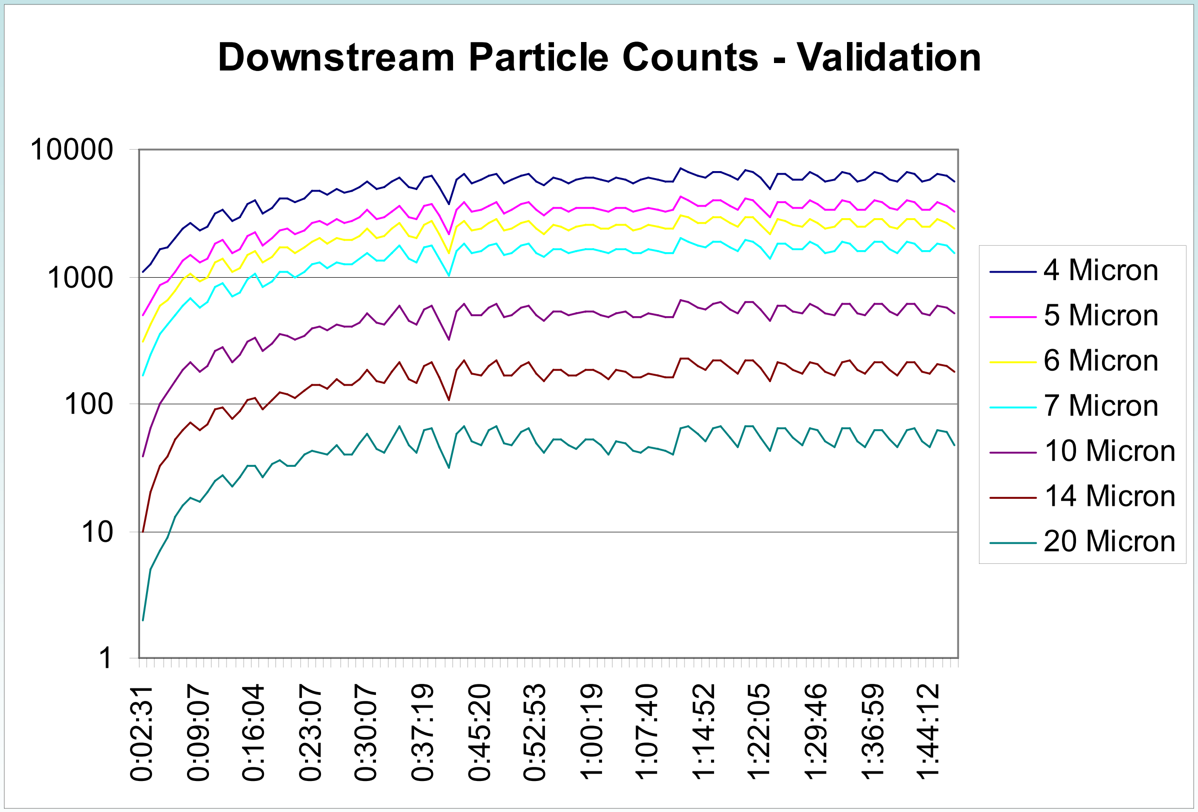
DFE Tests W/O Vibration



22

Validation DFE w/o Vibration Tests

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

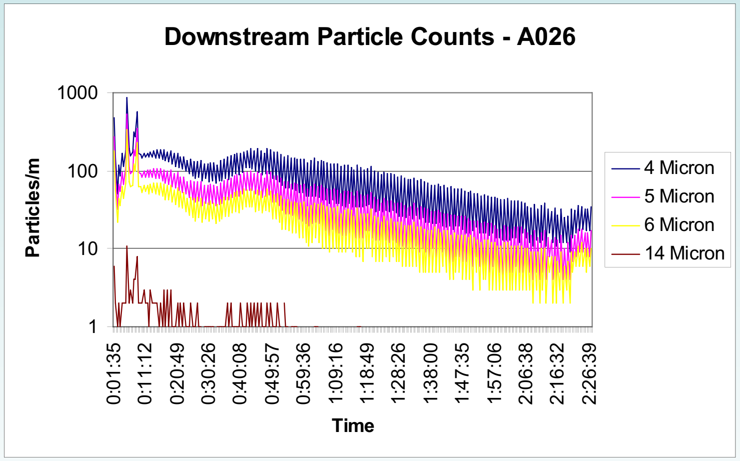


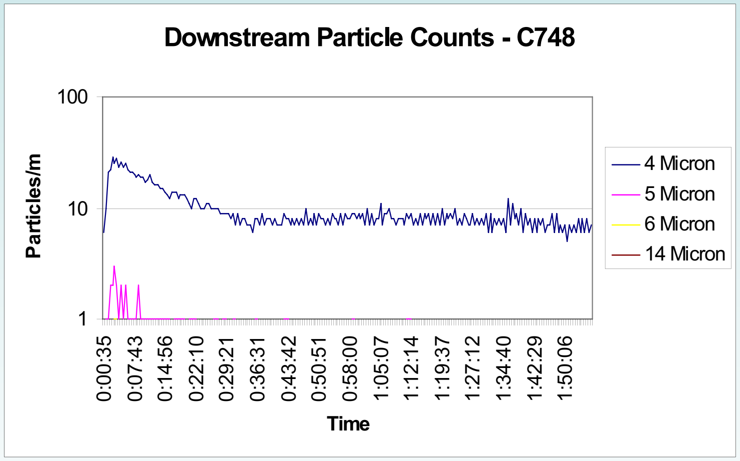
AR050141

Comparison of DFE w/o Vibration Typical Results

UH-60 Filters

BM vs Robust Media





Bill of Material

Robust Media

DFE: Registered trademark of SSI

Shaker Table Arrangement at SwRI

Courtesy SwRI

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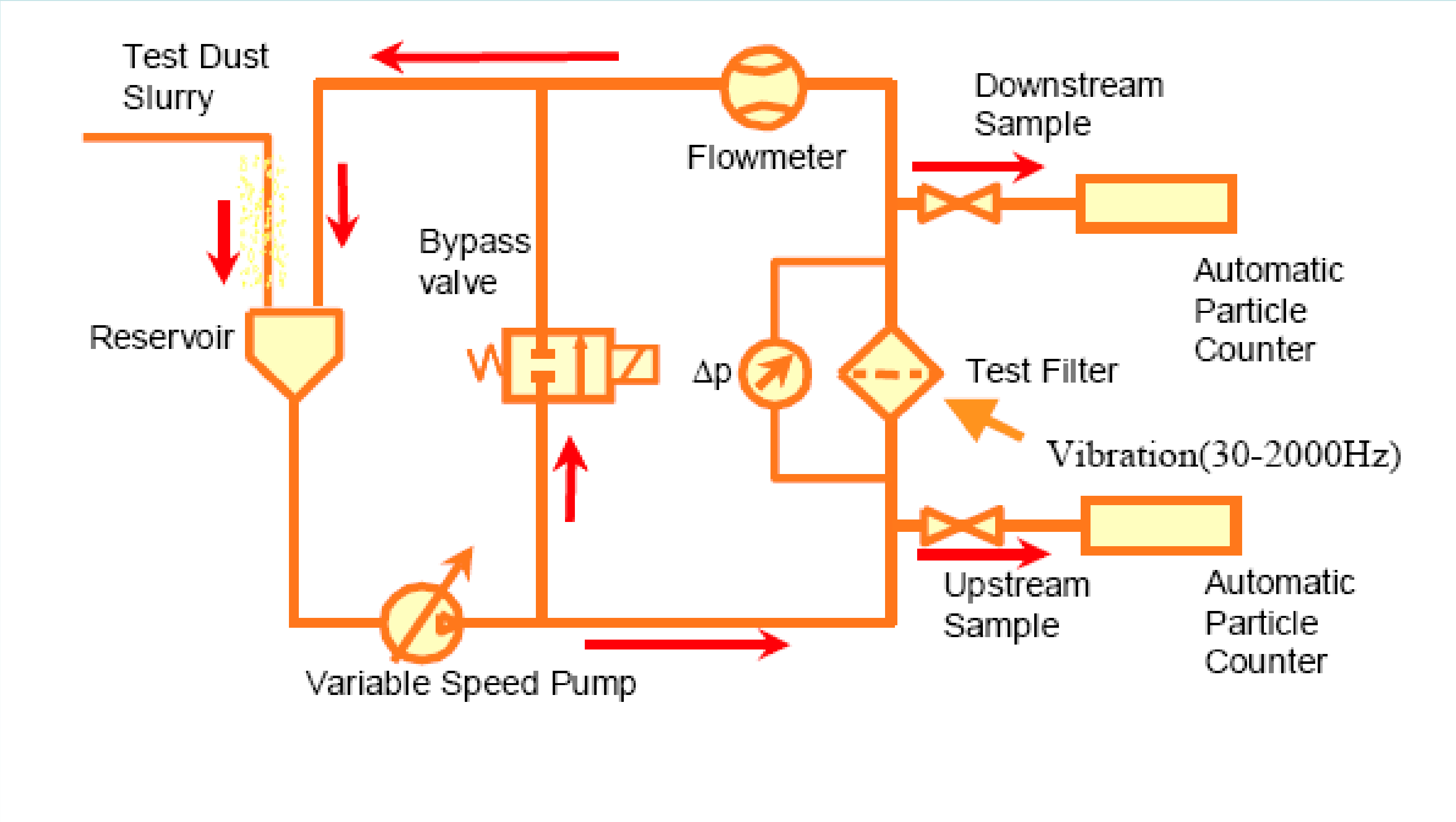
Cyclic Efficiency Test

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



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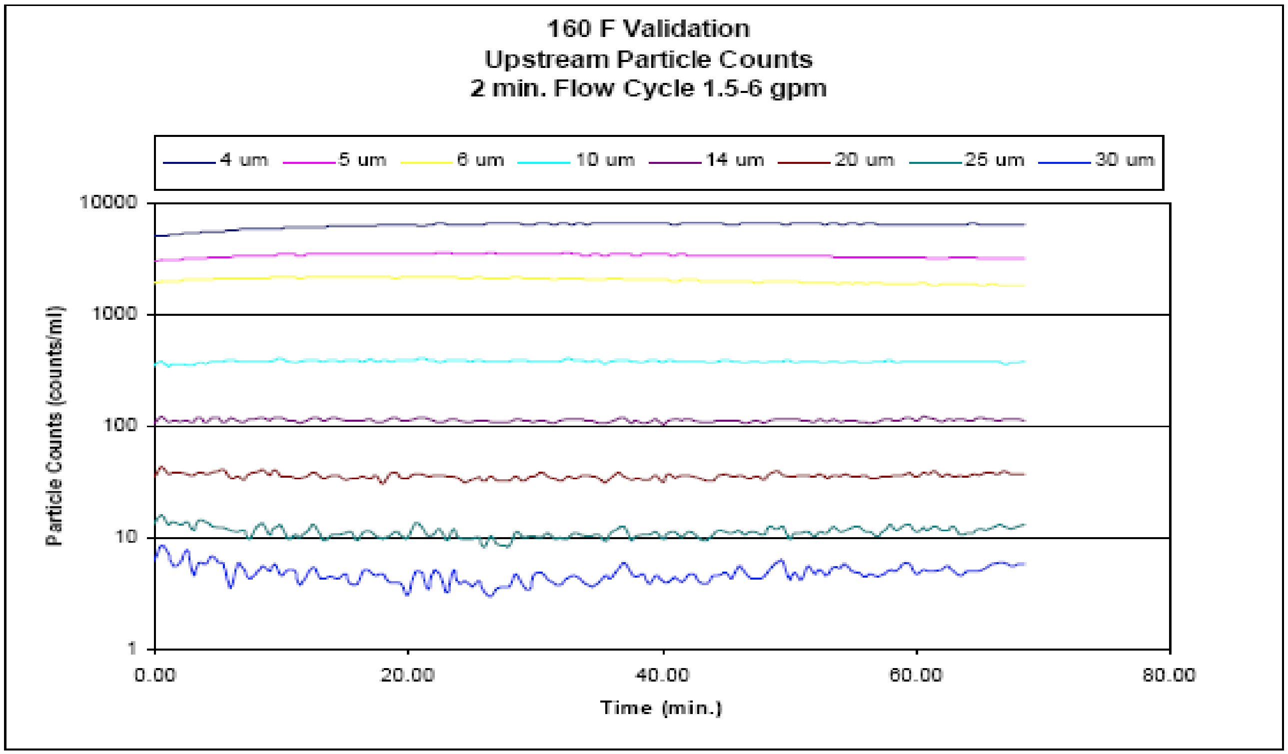
Validation Under Dynamic Conditions ISO-23369 w/ Vibration And 160 Deg F

Upstream Challenge Maintained Constant

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



Tested at SwRI @ 3 mg/liter

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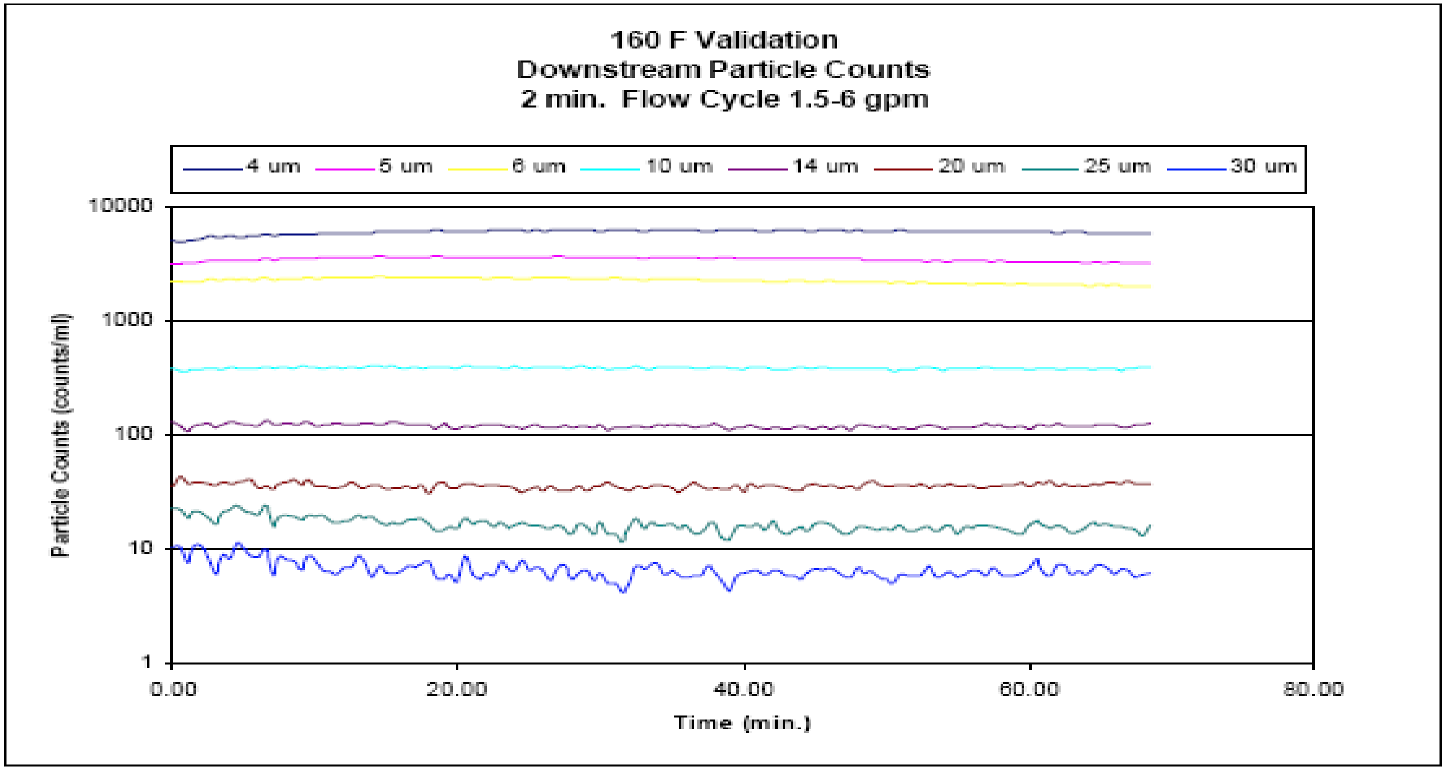
Validation Under Dynamic Conditions ISO-23369 w/ Vibration And 160 Deg F

Downstream Follows Constant Upstream Challenge



Tested at SwRI @ 3 mg/liter

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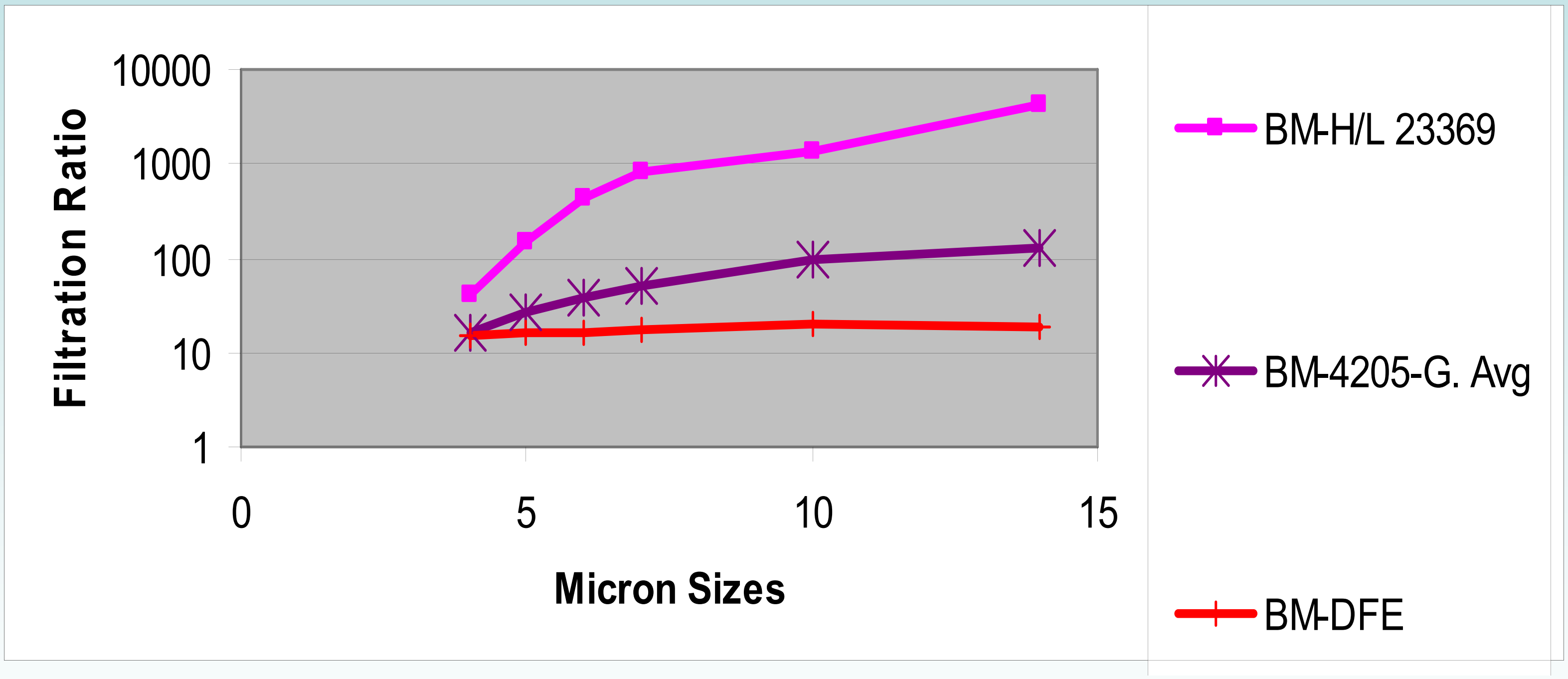
Micron Sizes at 99.5 % and 99.9 % Efficiency ISO 23369 vs SAE 4205 vs DFE MIL-F-8815 (Current Filters)

Efficiency	SAE 4205 w/vib	ISO 23369 w/Vibration			DFE w/no vib
		High to Low	Low to High	Avg. (Alpha)	
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

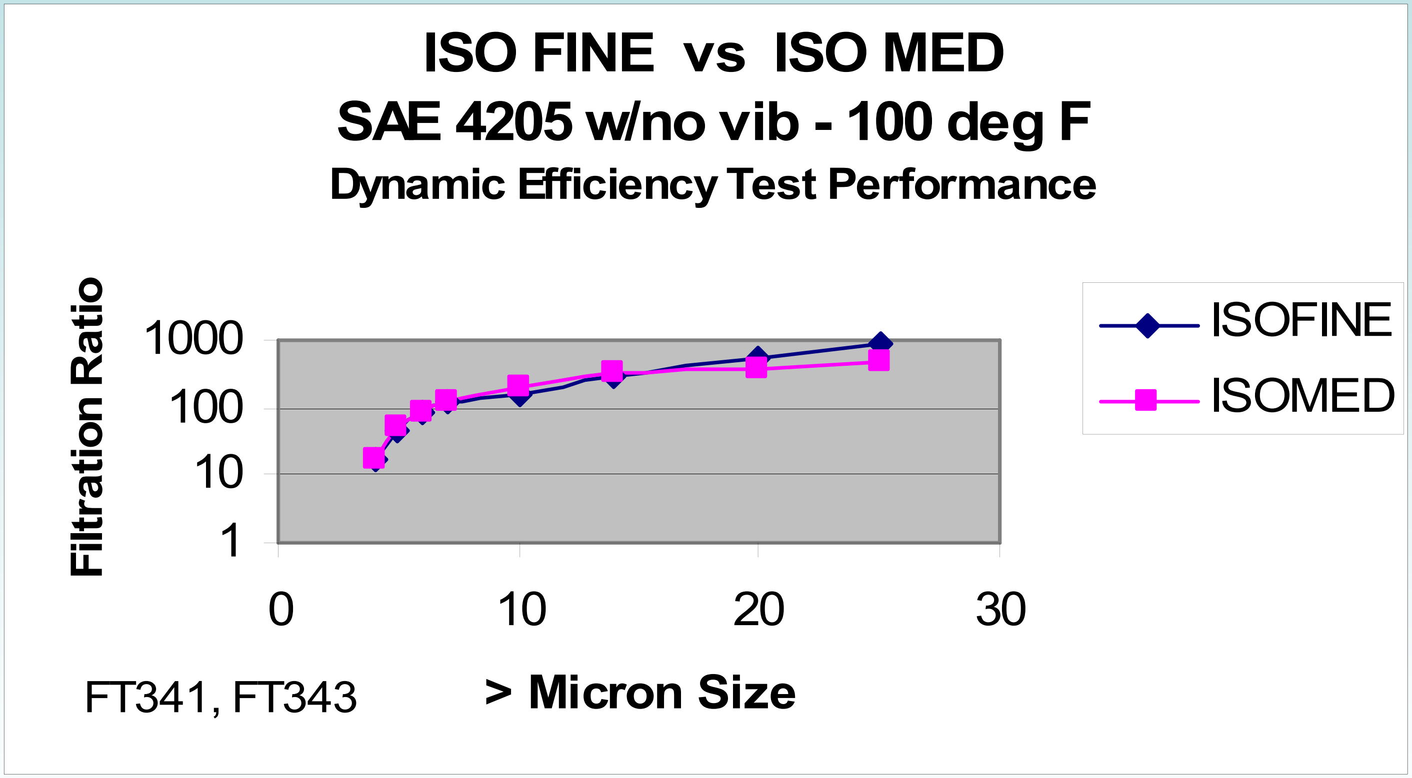


BM: Bill of Materials - Current Filters

30

ISO Fine vs ISO Med

SAE 4205 Dynamic Efficiency Test – 100 deg F
AH-64 - BM -1.5 to 6 gpm, 0.1 HZ



No Measurable Efficiency Difference

Test Location: SwRi

BM: Bill of Materials

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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

Tinker AFB Hydraulics Activities

Questions?

An In-Line Aircraft Pump Health Monitoring System

Shashi K. Sharma, PhD
Air Force Research Laboratory,
Wright-Patterson AFB Ohio, USA
Shashi.Sharma@wpafb.af.mil
(937) 255-9029

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

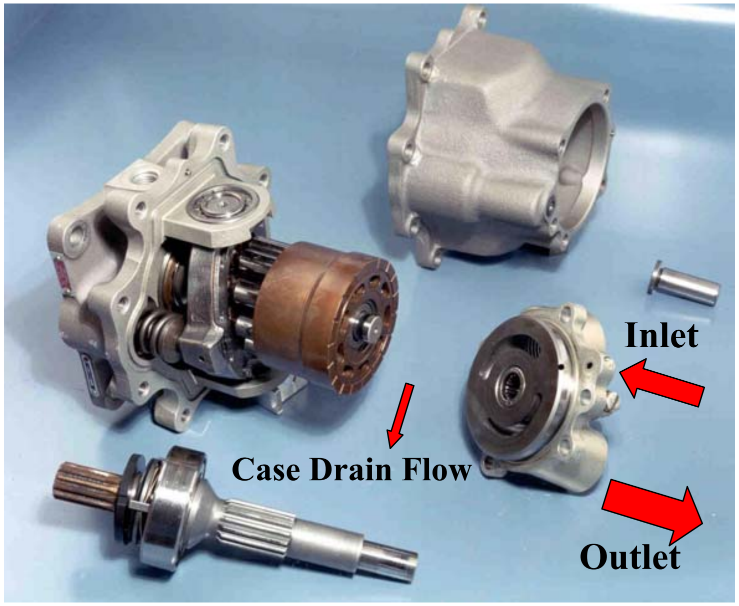
20 June 2006

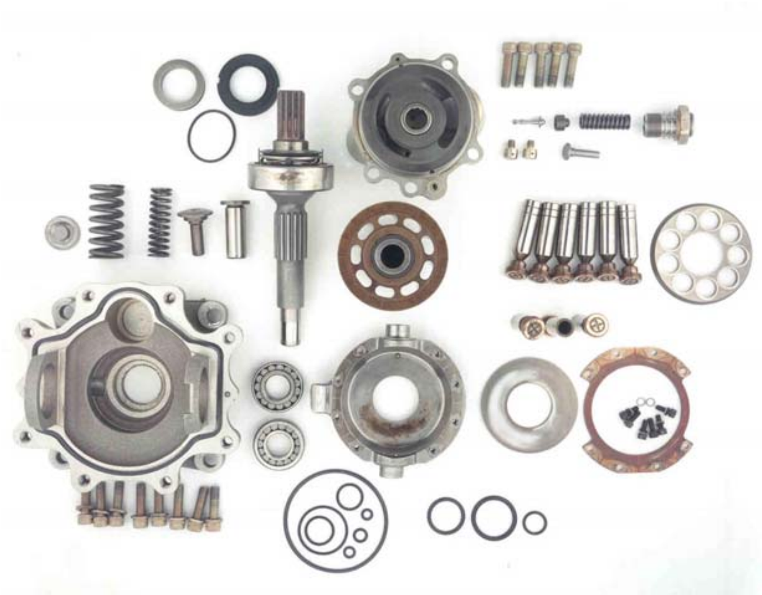
In-Line Health Monitoring System for Aircraft hydraulic Pumps

- 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

- 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

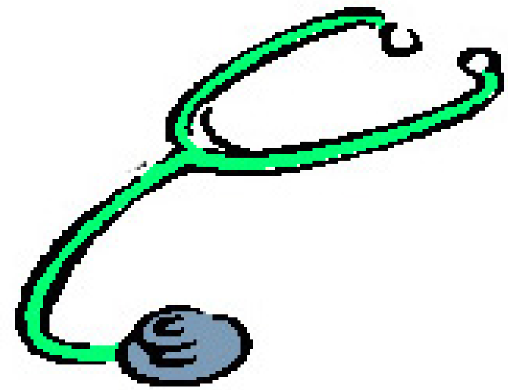


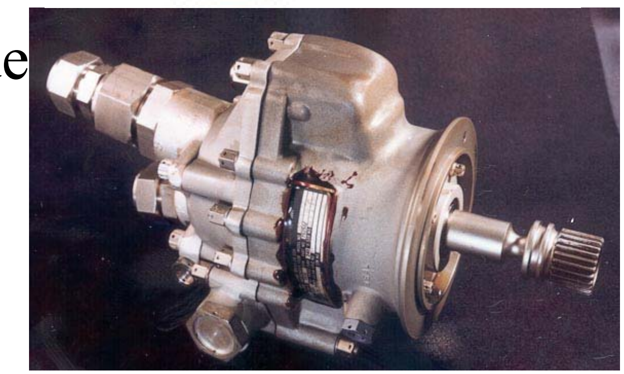


Knowledge of impending pump failure will increase safety, reliability, & readiness and will reduce maintenance

Concept Overview

- ➢ 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***

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Concept Overview

Symptoms of a failing pump

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

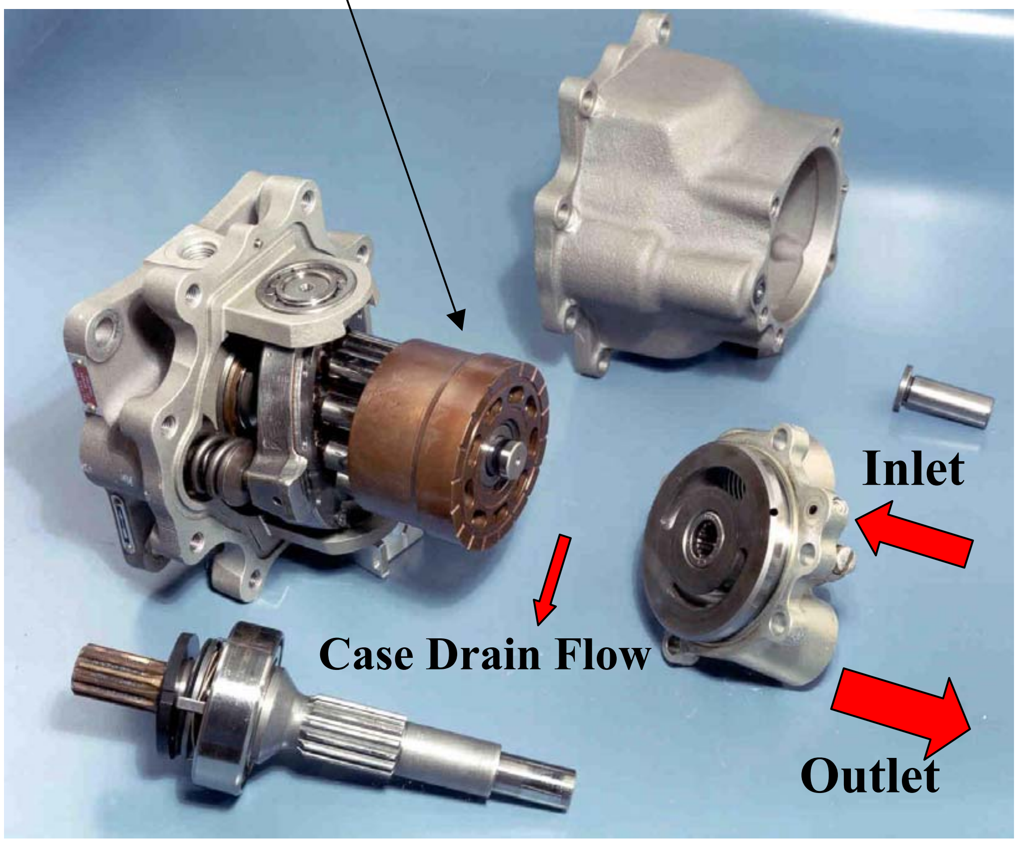
Barrel Roller Bearing

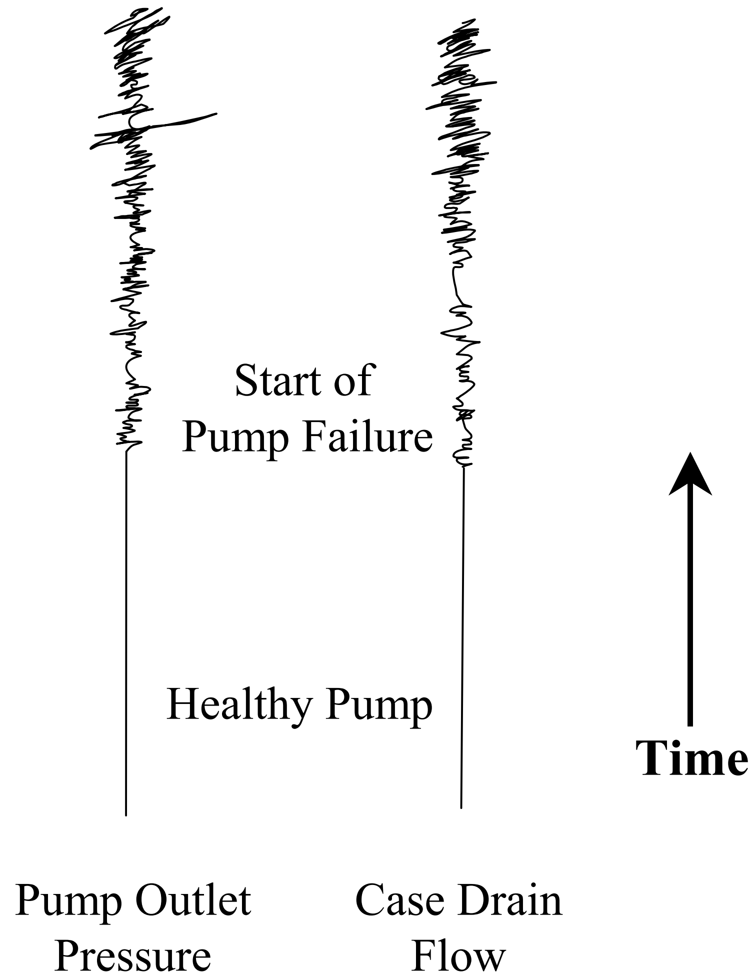
Spalled Bearing Inner Race

Ball Bearing

Concept Overview

- 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 shaft/cylinder-block





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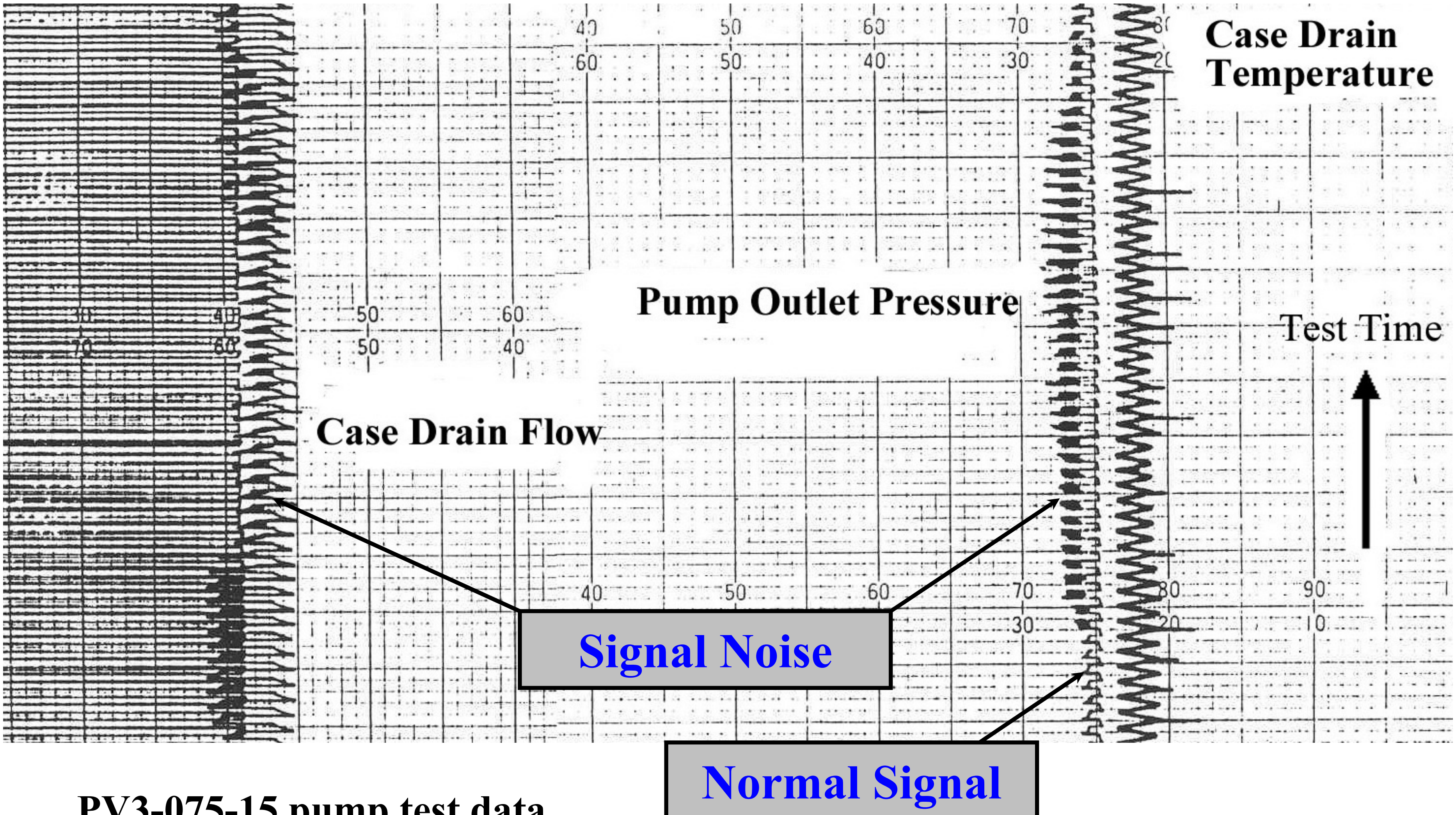
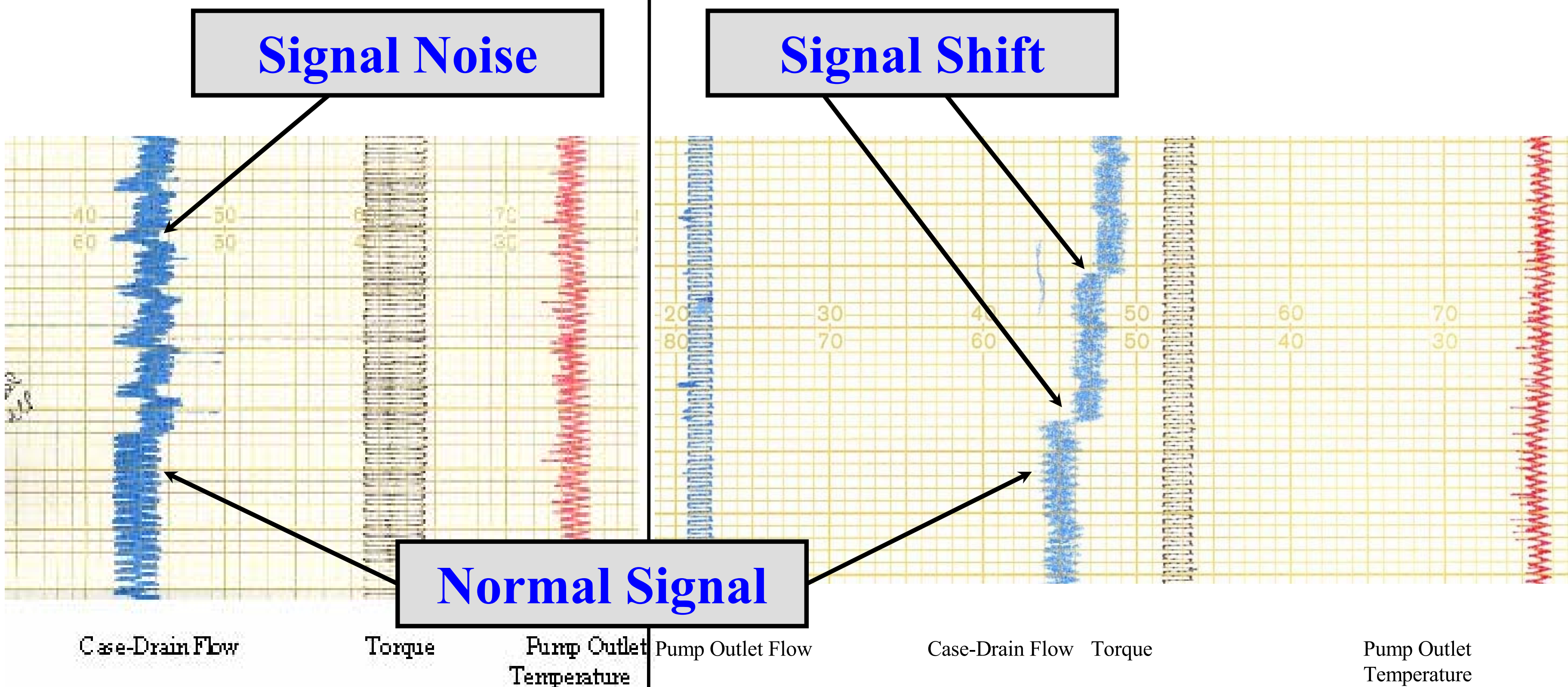
Concept Overview



PV3-075-15 pump test data

Concept Overview



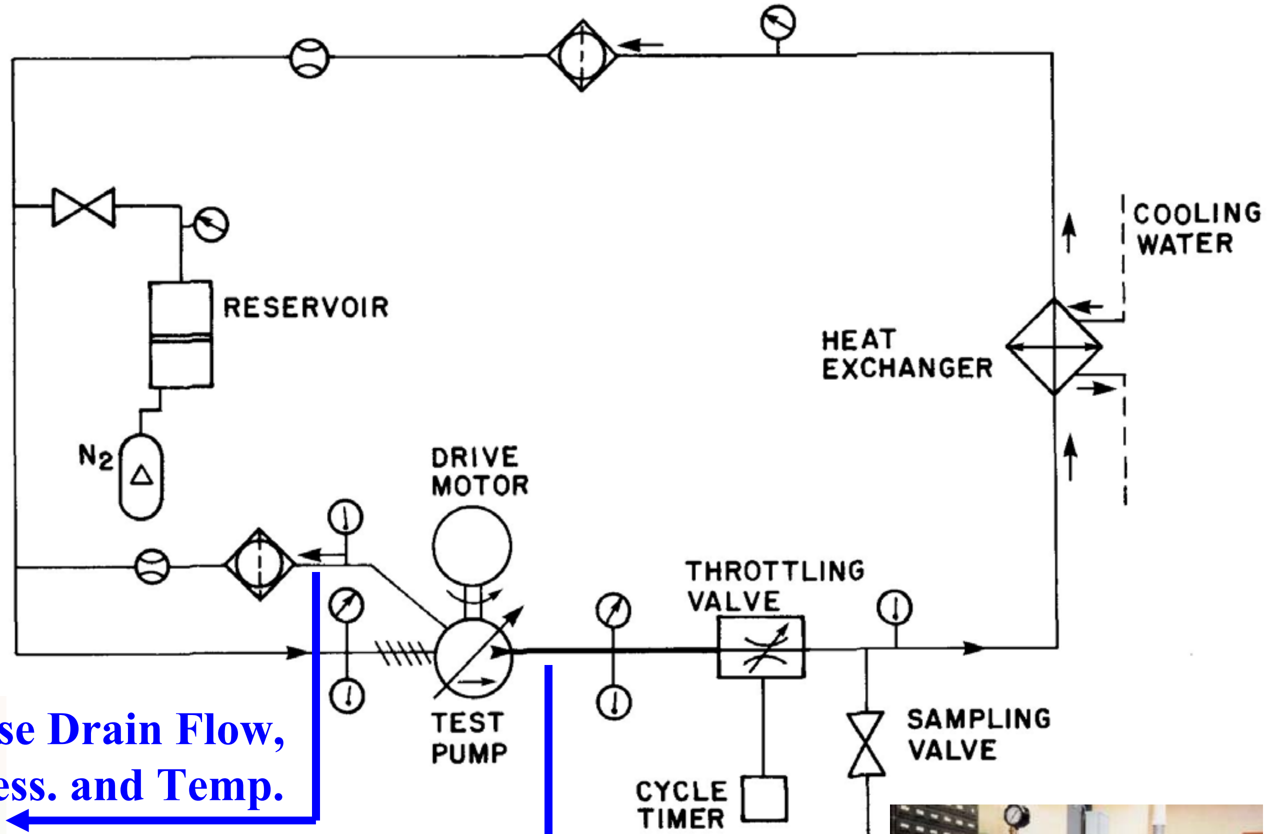
Test 37, Test parameters at ~ 1319 hours

Figure 14. Test 38, Test parameters at ~ 1500 hours

ABEX model AP12V-17 test data

AFRL MLBT Pump Test Facility

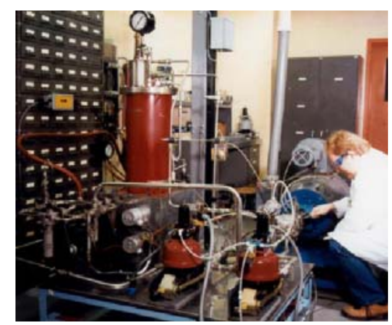
Pump Stand



Case Drain Flow, Press. and Temp.

Outlet Pressure

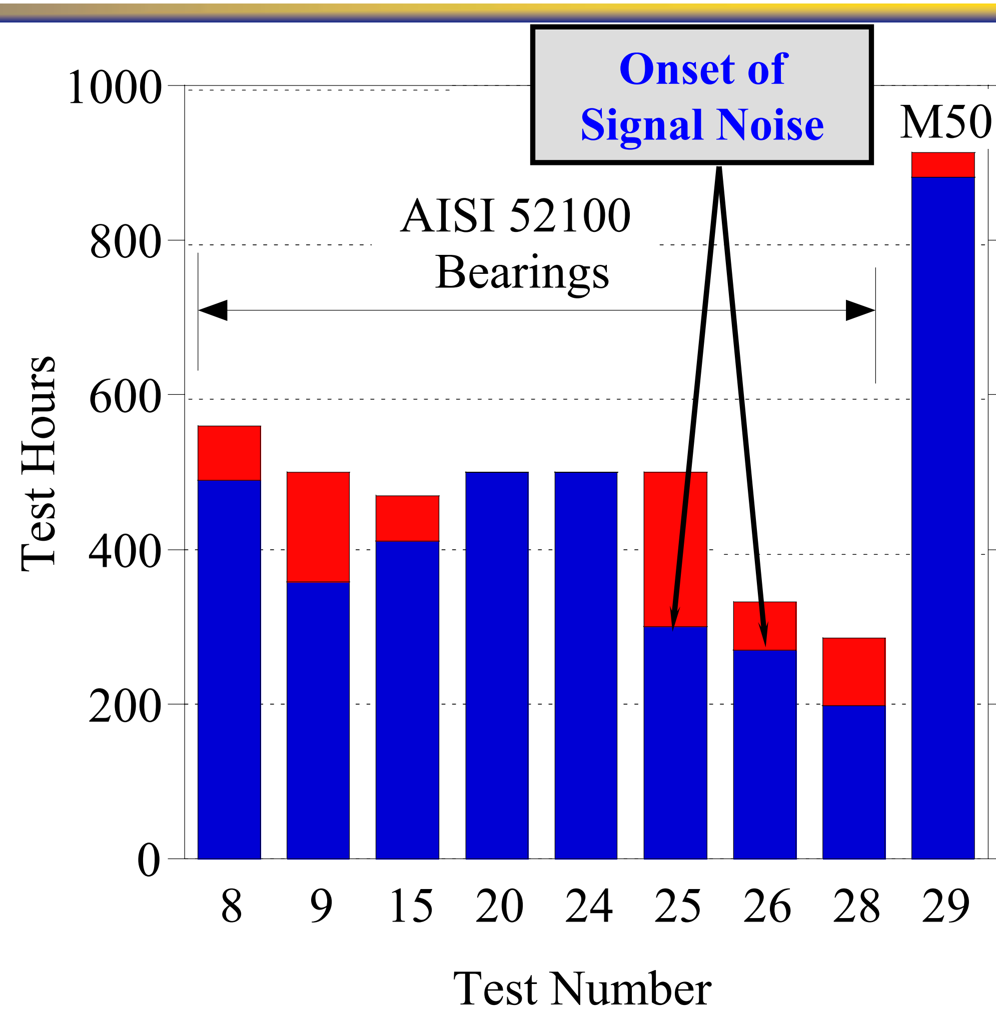
PHMS



Concept Overview

- 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

An In-Line Aircraft Pump Health Monitoring System (PHMS)

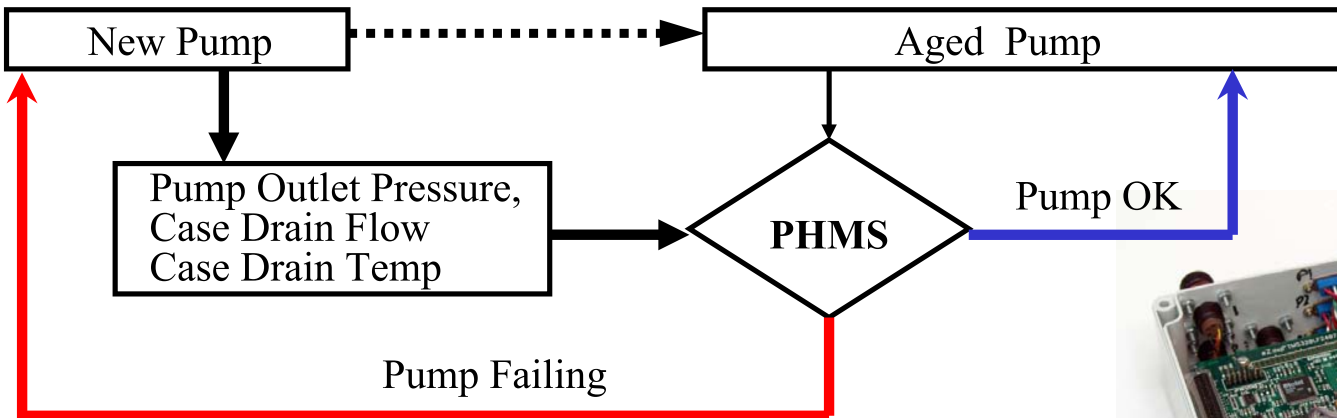
- Need for health monitoring of hydraulic pumps
- Concept Overview
- **Pump Health Monitoring System (PHMS) status**
  - -Initial development under Air Force SBIR Program
  - -Adaptation to Army pump
- Summary

RESEARCH & DEVELOPMENT Creare

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)***

Initial Development



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

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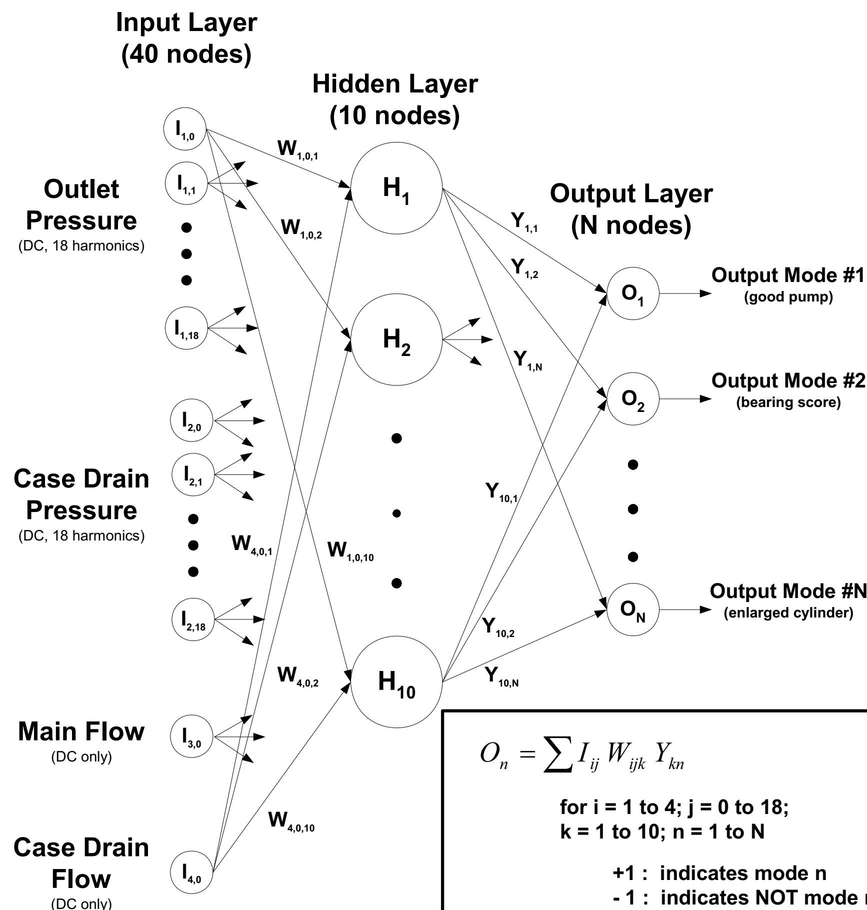
Initial Development: Software Algorithms



$$O_n = \sum I_{ij} W_{ijk} Y_{kn}$$

for i = 1 to 4; j = 0 to 18;
k = 1 to 10; n = 1 to N

+1 : indicates mode n
- 1 : indicates NOT mode n

3

RESEARCH & DEVELOPMENT

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***

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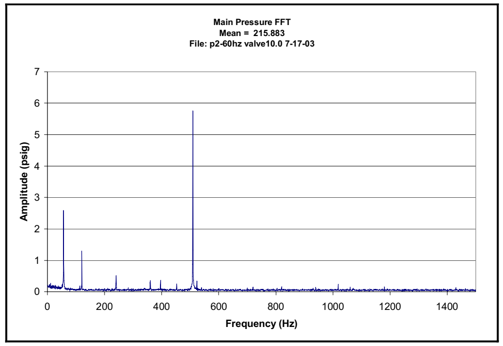
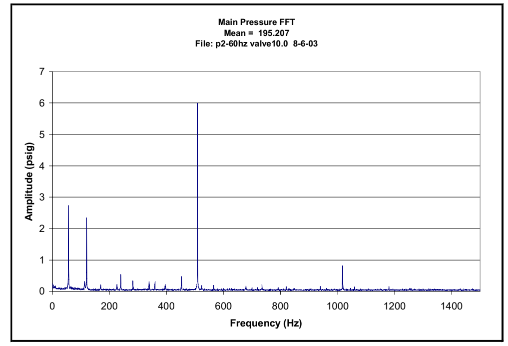
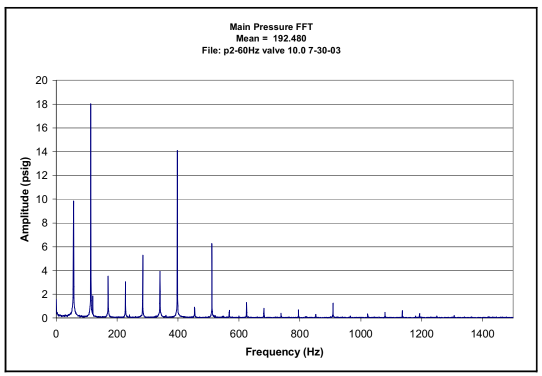
Typical Pump Data (83 Hz Drive)



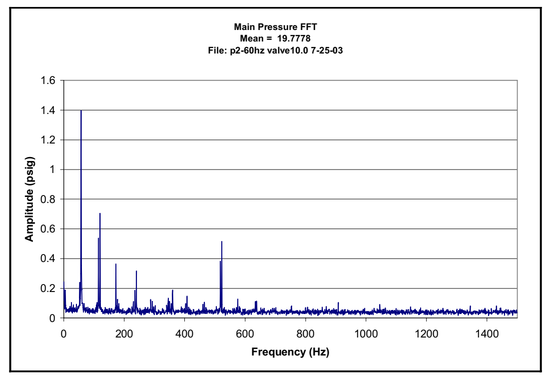
Pump #2—No Fault



Pump #2—Small Score



Pump #2—Large Score



Pump #2—Oversize Cylinder

- **Rotational harmonic frequencies vary with pump state.**

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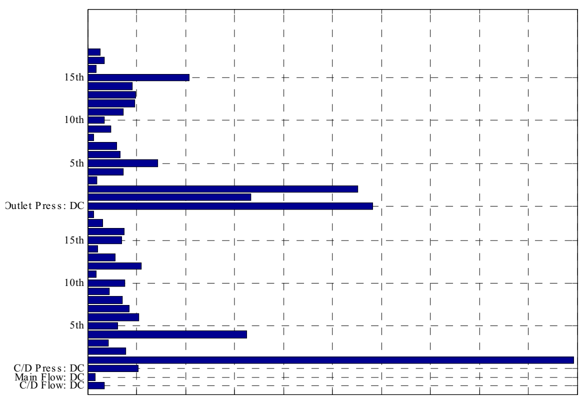
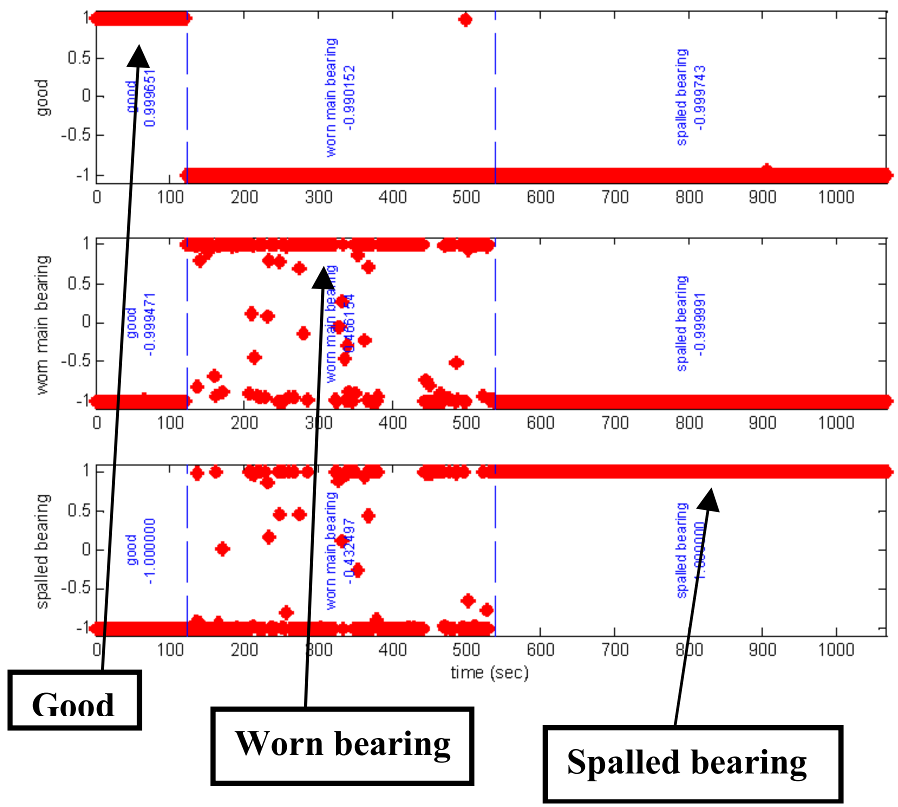
Eaton Aerospace (Vicker's) PV3-075-15





Training weights show
important features

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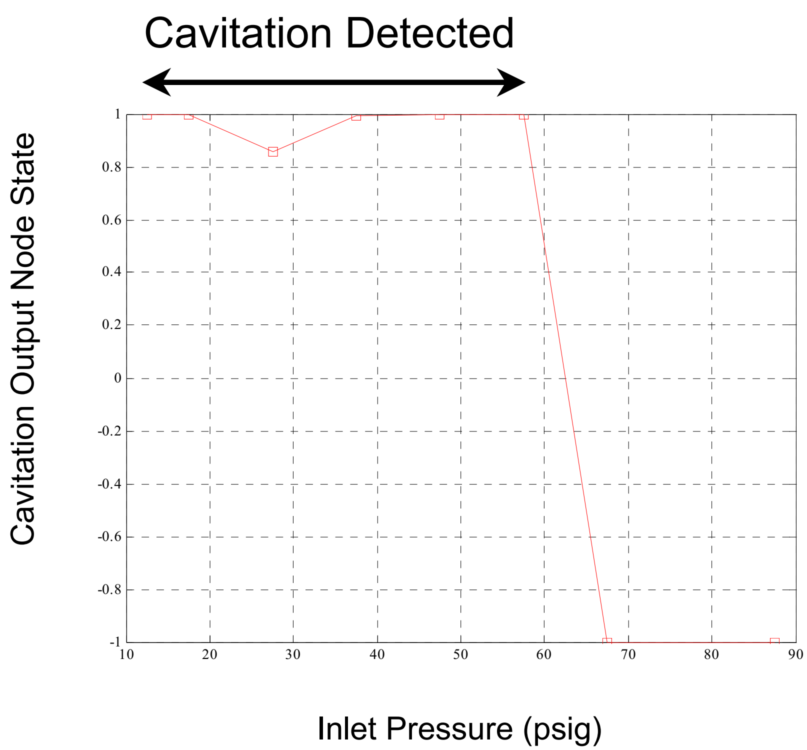
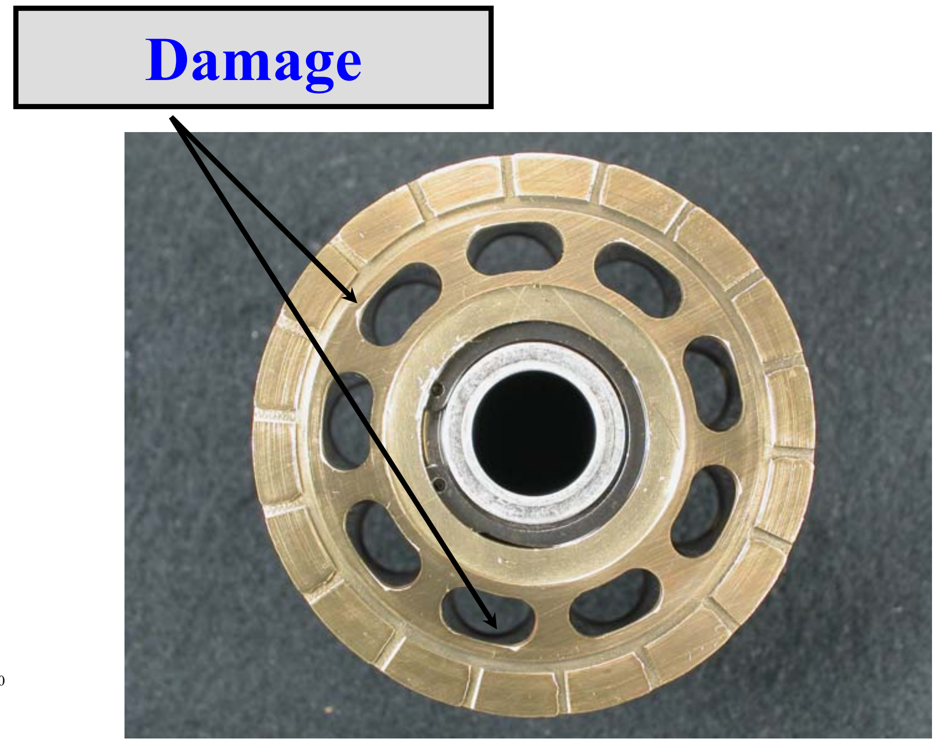
Eaton PV3-075-15 Pump Cavitation Detection





PV3-075-15 Cylinder Block Face

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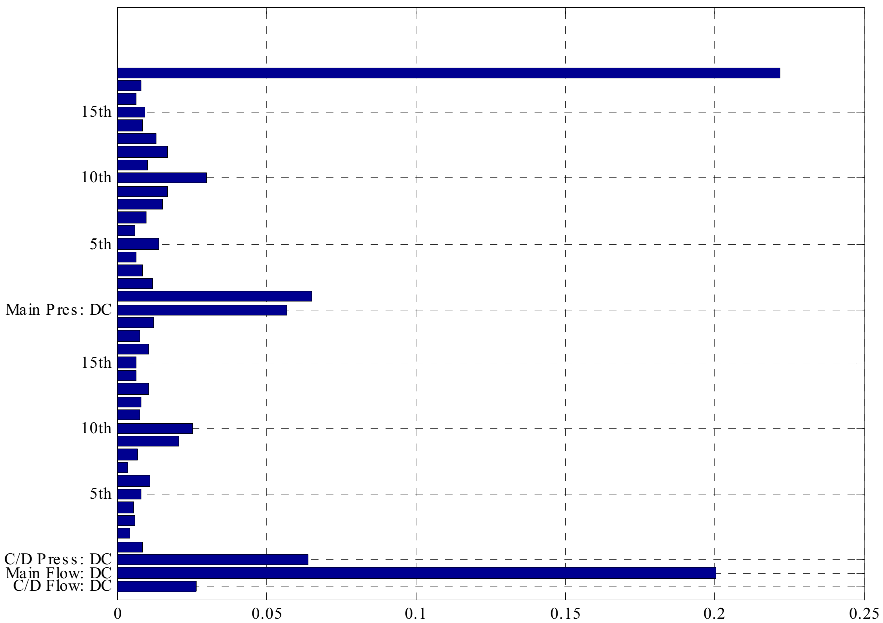
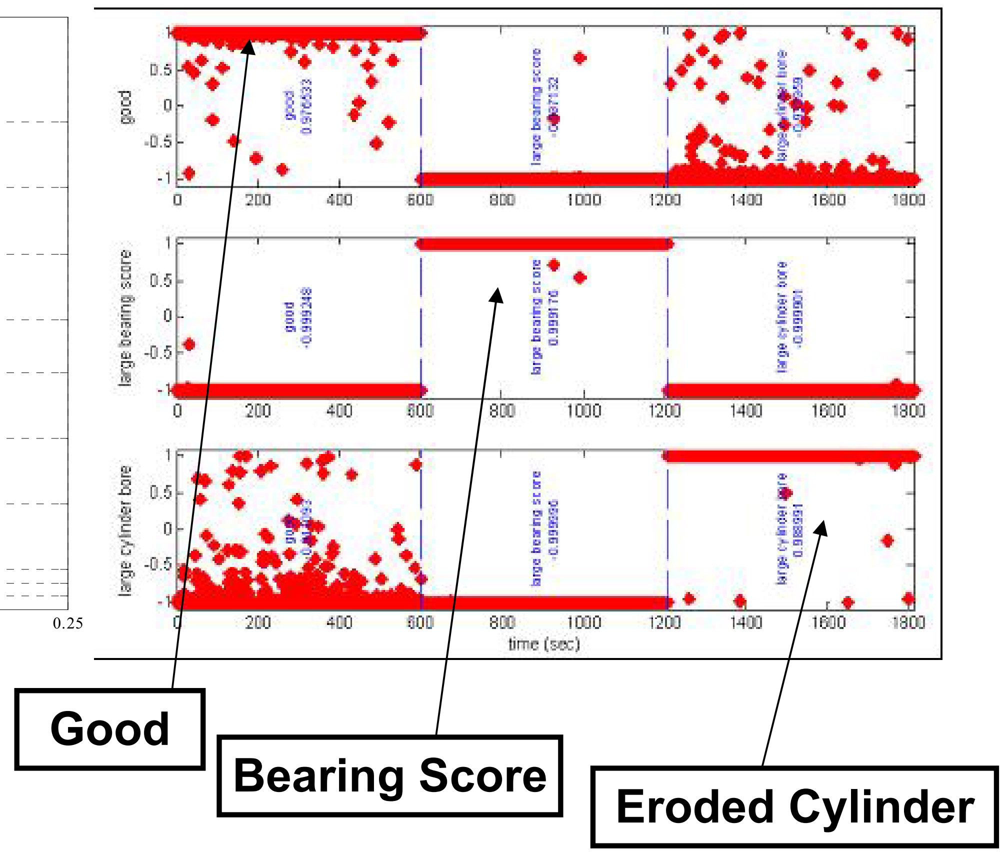
RESEARCH & DEVELOPMENT

PVP16 Industrial Pump Results





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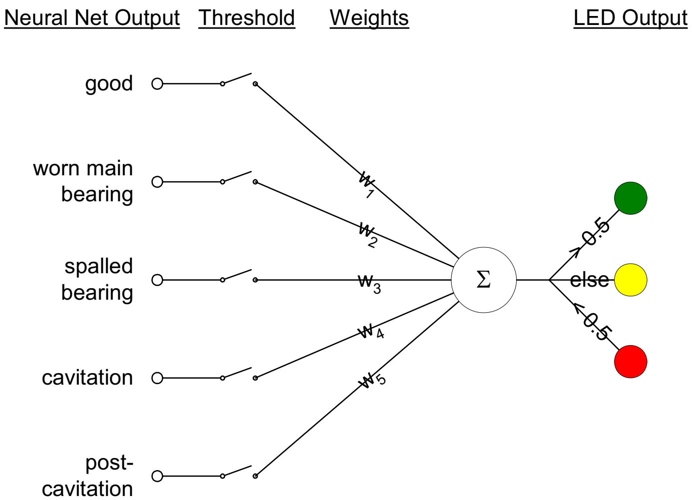
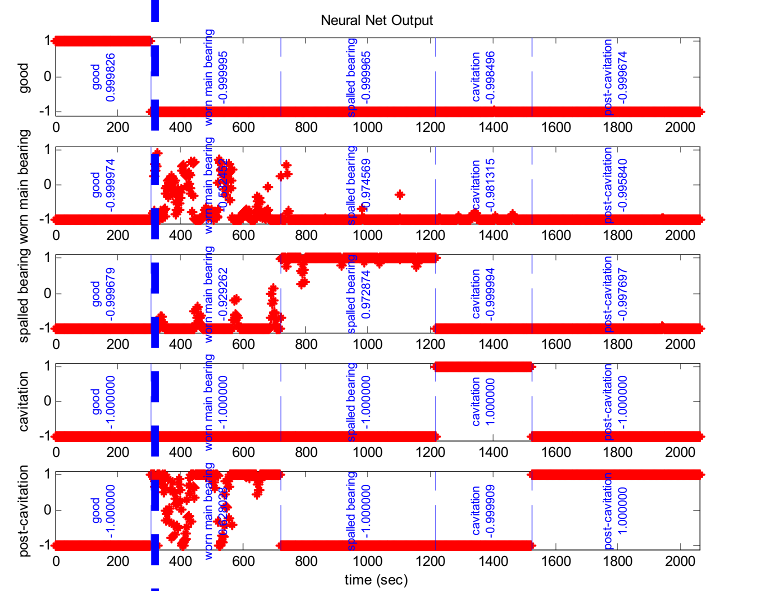
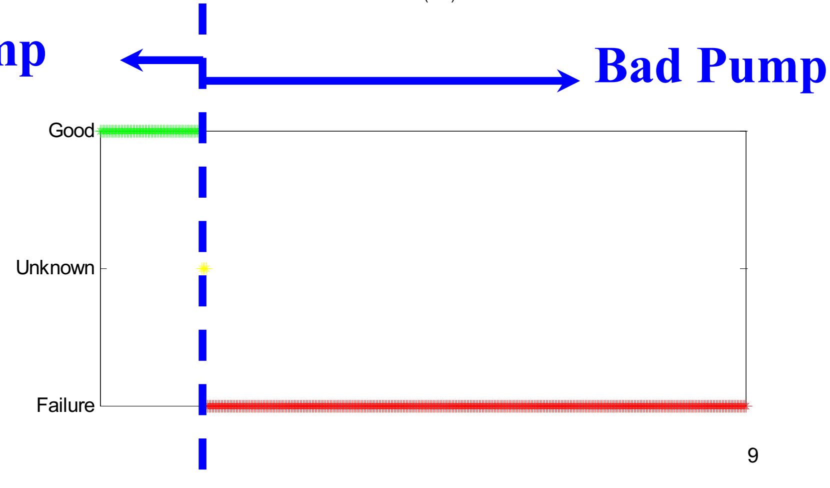
Creating a good/bad pump classifier



$$s = \sum_{k=1}^{n} w_k \forall o_k > t$$





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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***

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

New PV3-075-20 Pump

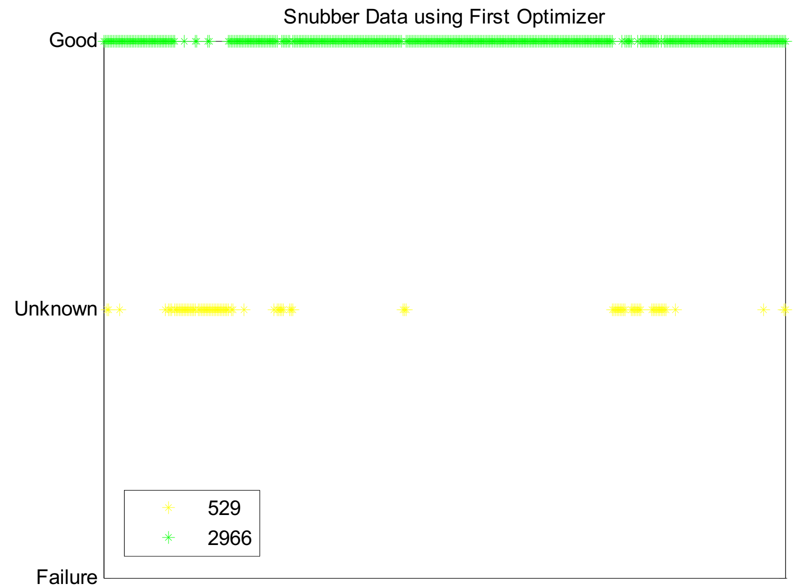
Output Node	Value
Good	+0.73
Worn Bearing	-0.99
Spalled Bearing	-0.83
Cavitation	-0.95
Post-Cavitation	-0.12

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.

Phase II SBIR Follow-on Work

New (92 % Certainty)



Rebuilt (85 % Certainty)

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

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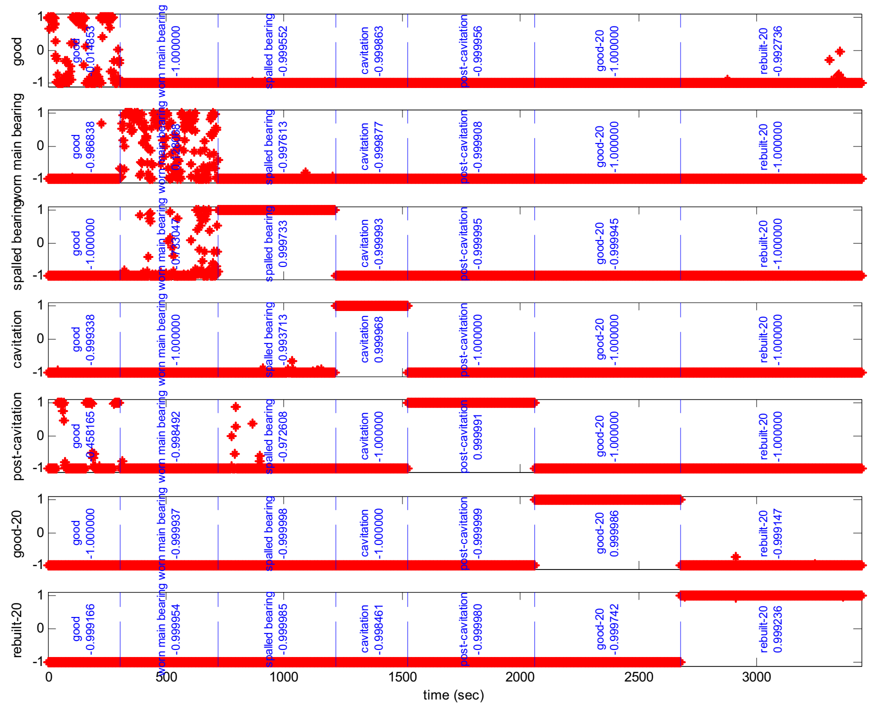
Phase II SBIR Follow-on Work



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.

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

RESEARCH & DEVELOPMENT

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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

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

Aging Aircraft Systems Squadron

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

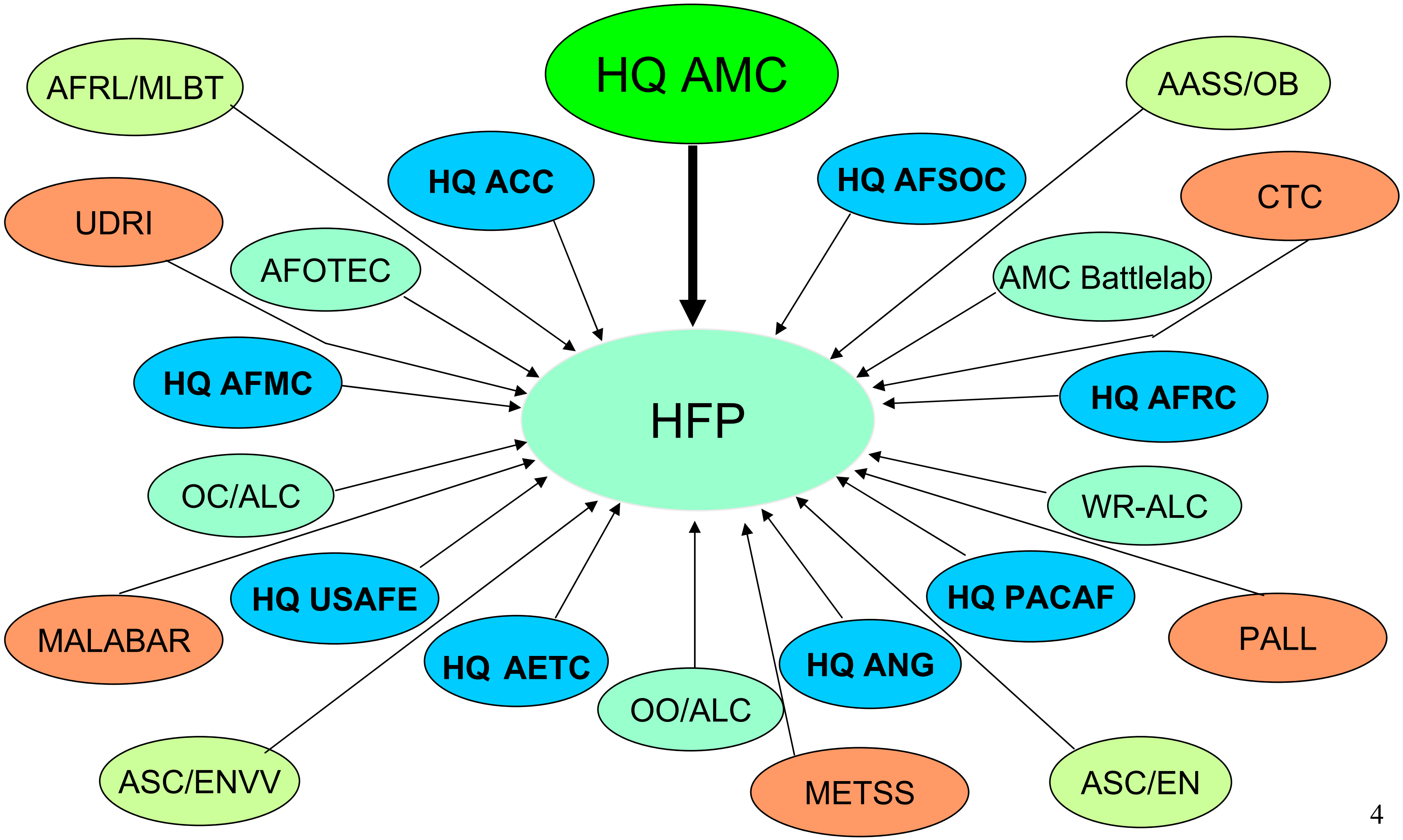
Our job is to develop, acquire, and field cross-enterprise materiel solutions that enhance fleet availability and mission capability. We deliver systems/products that provide the AF means to reduce total ownership costs.

Our Customers

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

HFP Team

Dominant Air Power: Design For Tomorrow…Deliver Today



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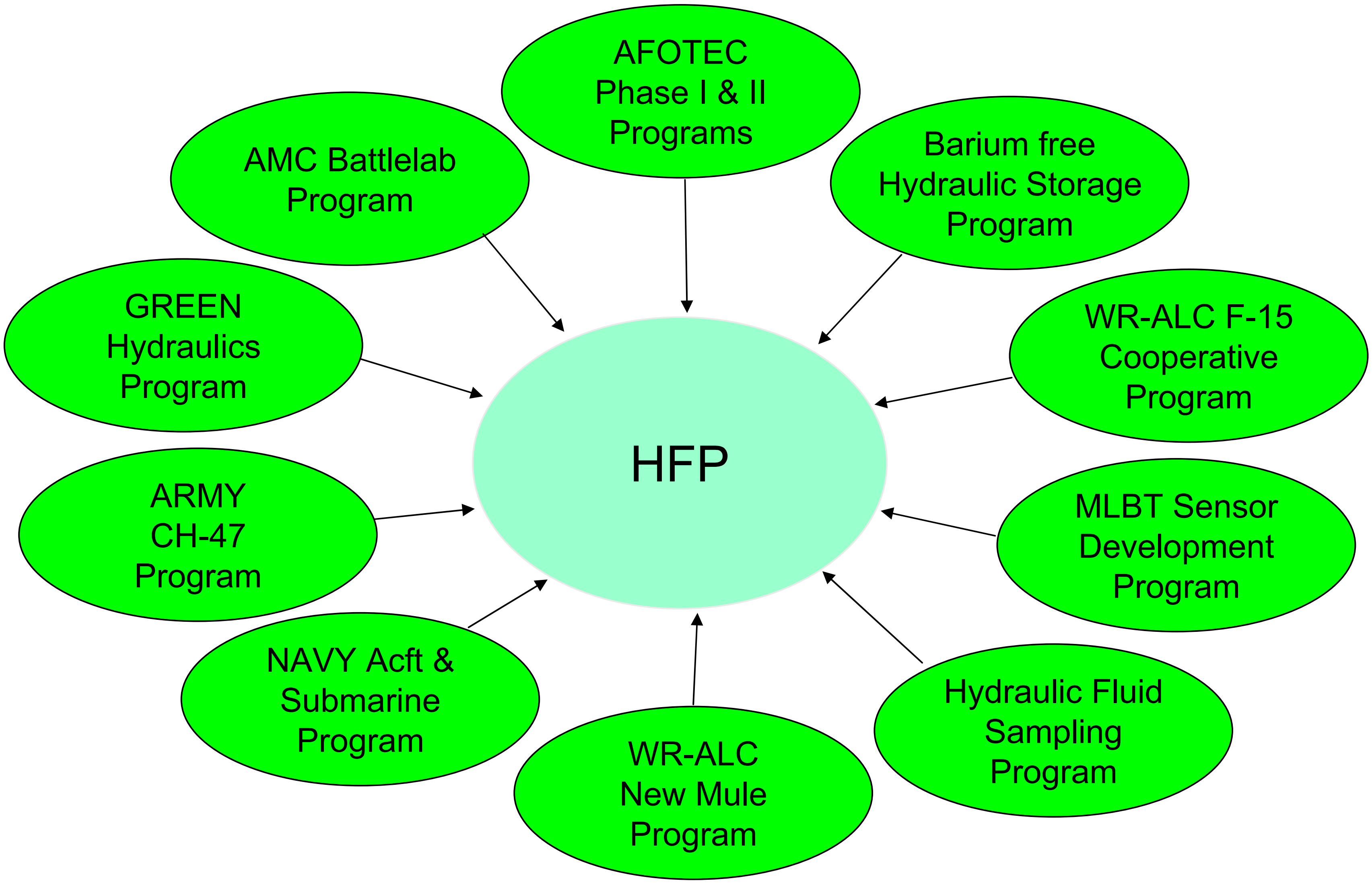
HFP Support

Dominant Air Power: Design For Tomorrow…Deliver Today



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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?

- 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

HFP Return on Investment

- **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**

Navy HFP

Dominant Air Power: Design For Tomorrow…Deliver Today

- **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

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

Dominant Air Power: Design For Tomorrow…Deliver Today

- **Phase I (Apr 00 – Jun 03)**
  - AFOTEC, 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

USAF Phase I

Dominant Air Power: Design For Tomorrow…Deliver Today

- **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

Dominant Air Power: Design For Tomorrow…Deliver Today

- 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)

Dominant Air Power: Design For Tomorrow…Deliver Today

- 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

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Purification Equipment

Dominant Air Power: Design For Tomorrow…Deliver Today

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.

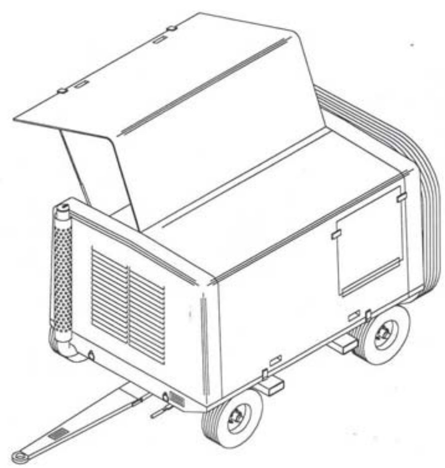
Hydraulic Fluid Purification

Dominant Air Power: Design For Tomorrow…Deliver Todav

- **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

Pall Portable Purifier

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



Malabar Portable Purifier

- **Portable and built-in configurations**

HFP Equipment (Cont'd)

- **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

P/N 885200-1

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

Hydraulic Fluid Multi-Sensor

- 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

Dominant Air Power: Design For Tomorrow…Deliver Today

- 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

Dominant Air Power: Design For Tomorrow…Deliver Today

- Develop in-line, real-time, field-level multi-sensor
- 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

Dominant Air Power: Design For Tomorrow…Deliver Today

- 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

Dominant Air Power: Design For Tomorrow…Deliver Today

- **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

Dominant Air Power: Design For Tomorrow…Deliver Today

QUESTIONS?

23

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

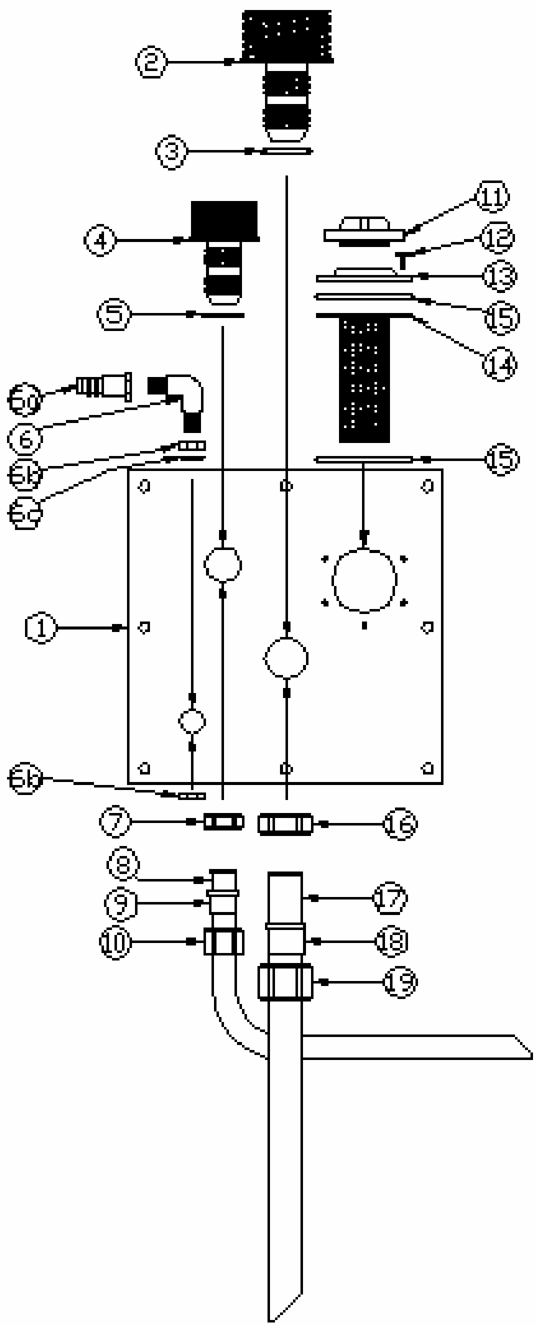
3 System Diesel Mod
Vent Dryer

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

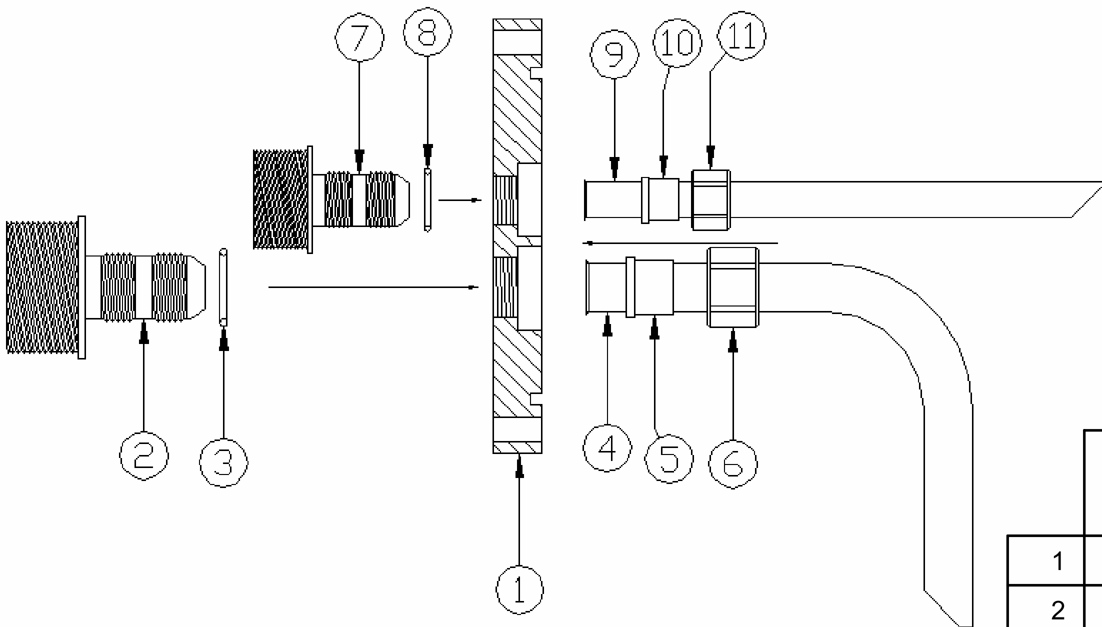
Round Tank Method

Hydraulic Reservoir End View
End Cap Removed

New Manufactured
End Cap

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

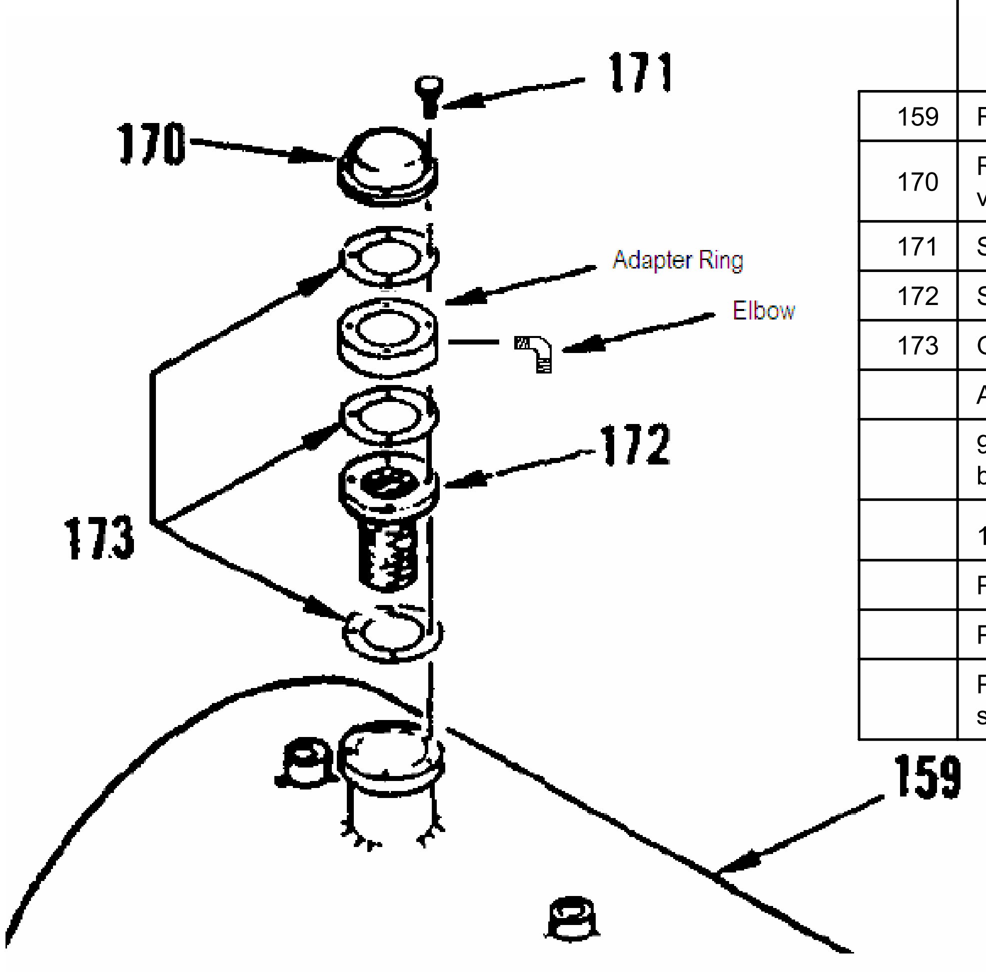
New Spacer For
Vent Dryer Fitting

Fitting For
Vent Dryer

New Spacer For
Vent Dryer Installed

Vent Dryer
Mounted On
Inside Wall
Of HTS

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

RECEIVED

JUN 0 9 2003

DISTRIBUTED

DEPARTMENT OF THE AIR FORCE
TECHNICAL ORDER

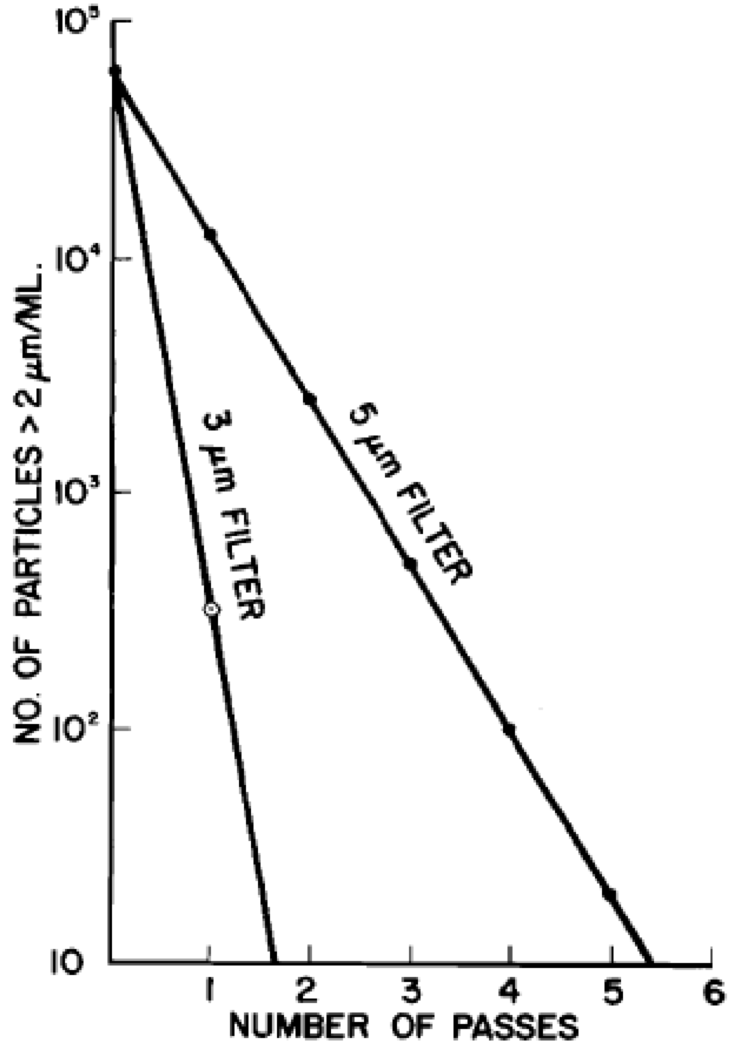
T.O.1F-16-2387
DATA CODE: 0192039
02 JUNE 2003

IMPLEMENTATION OF 600 HOUR TIME CHANGE
REQUIREMENTS FOR REPLACEMENT OF "A" AND "B"
HYDRAULIC SYSTEM FILTER ELEMENTS ON
F-16A/B/C/D AIRCRAFT

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-16 TCTO
15 Micron to 5 Micron



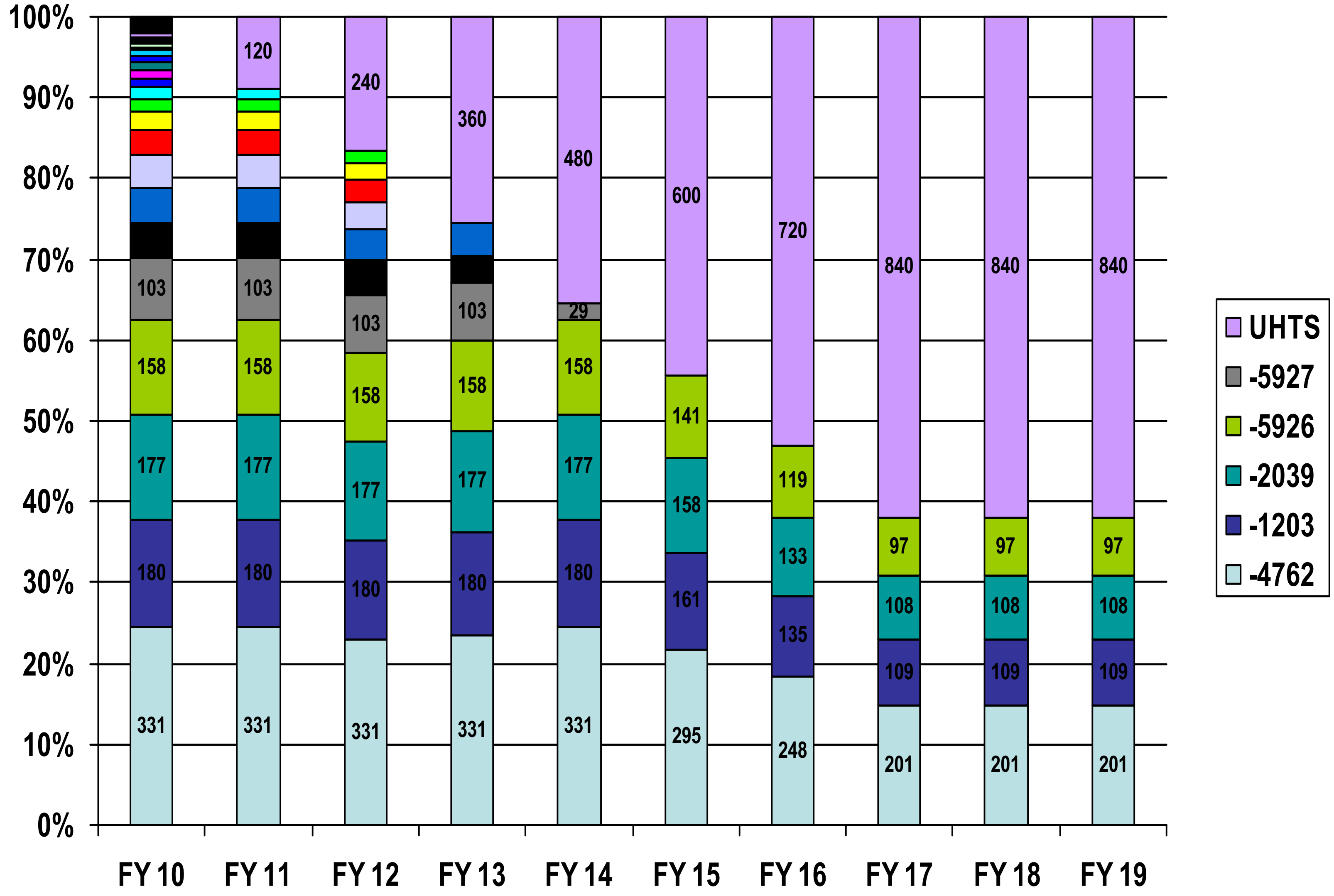
F-15

- 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
Donald.Streeter@wpafb.af.mil
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

Hydraulic Fluid Purification Who and What?

- **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.

UDRI 50 Imagination Investigation Innovation 1956-2006

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

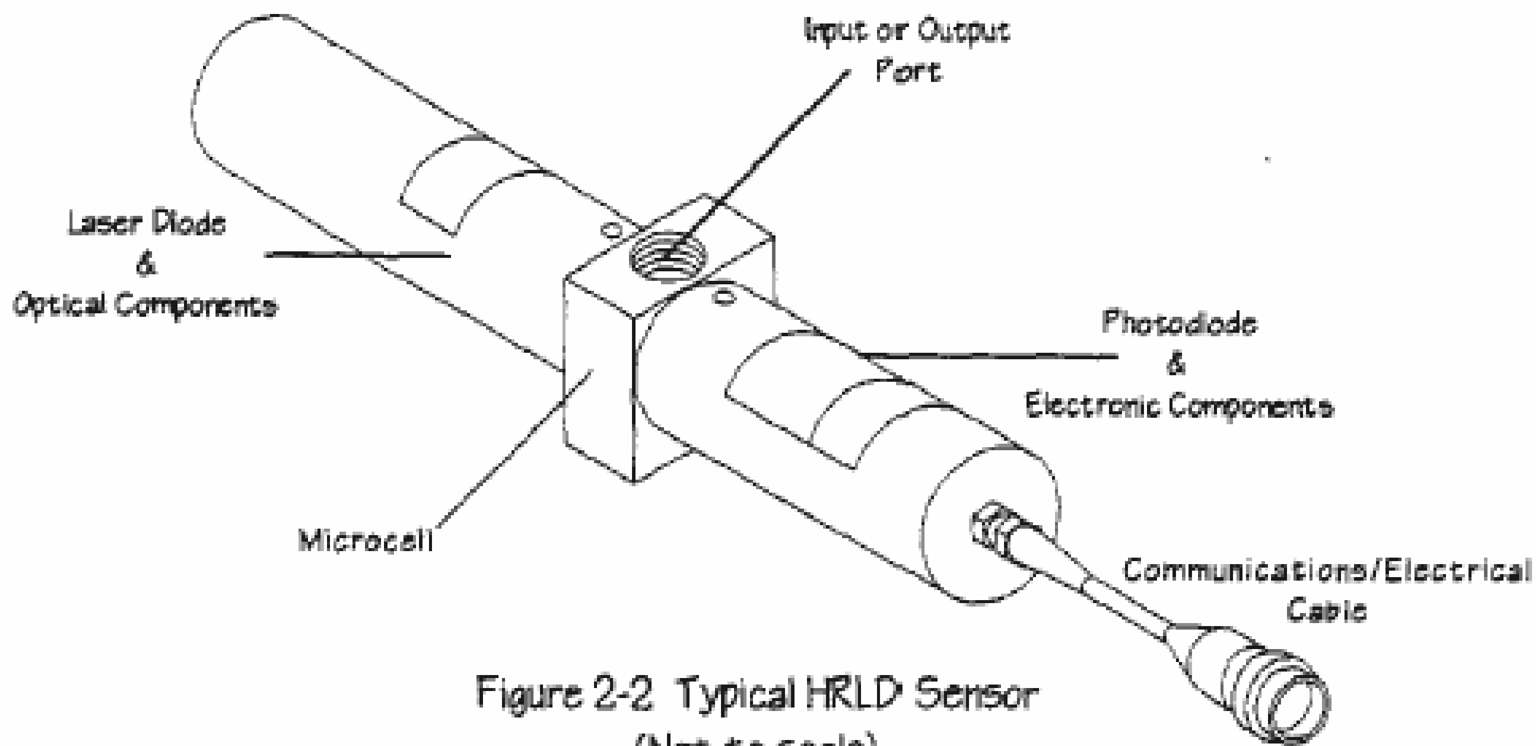


Figure 2-2 Typical HRLD Sensor
(Not to scale)

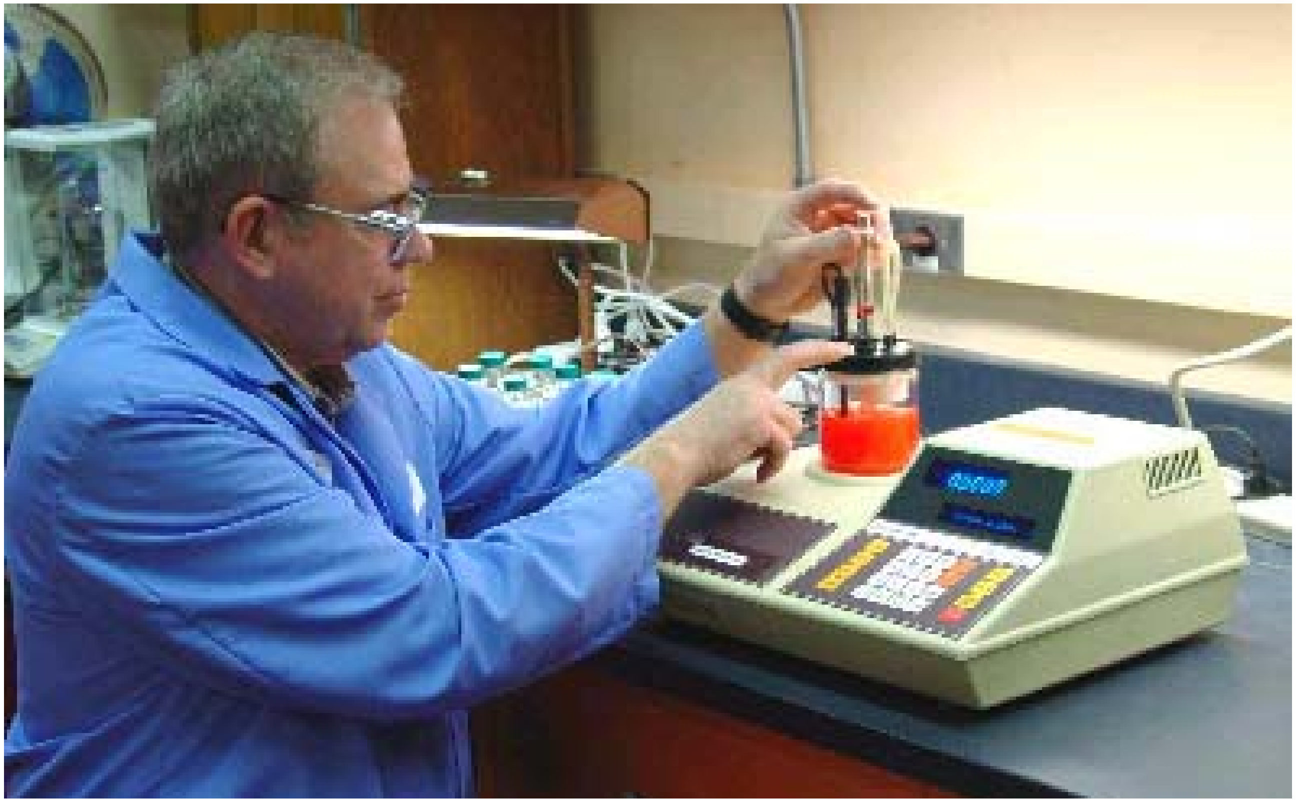
NAS 1638

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

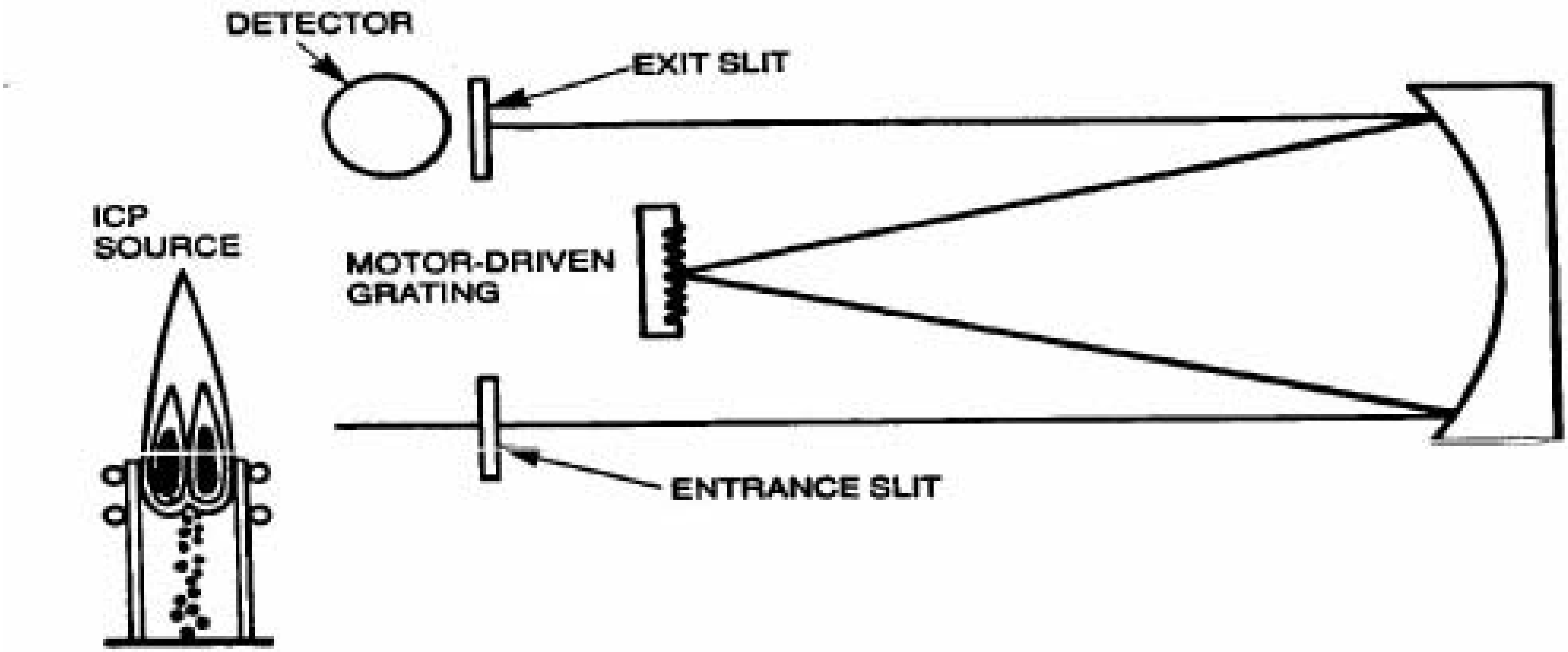
ASTM D 6304
Coulometric Karl Fisher Titration

- 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

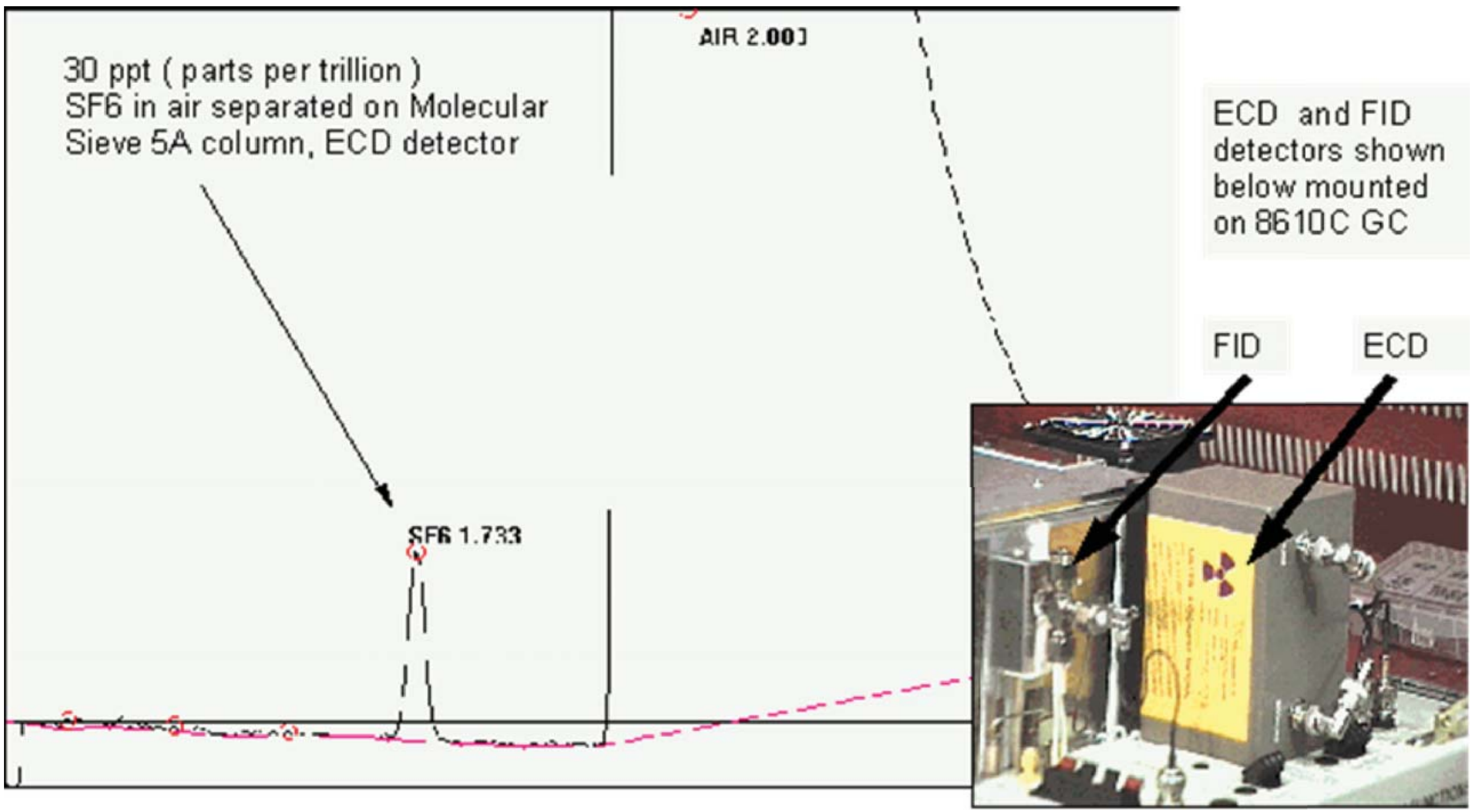


DETECTOR
EXIT SLIT
ICP
SOURCE
MOTOR-DRIVEN
GRATING
ENTRANCE SLIT

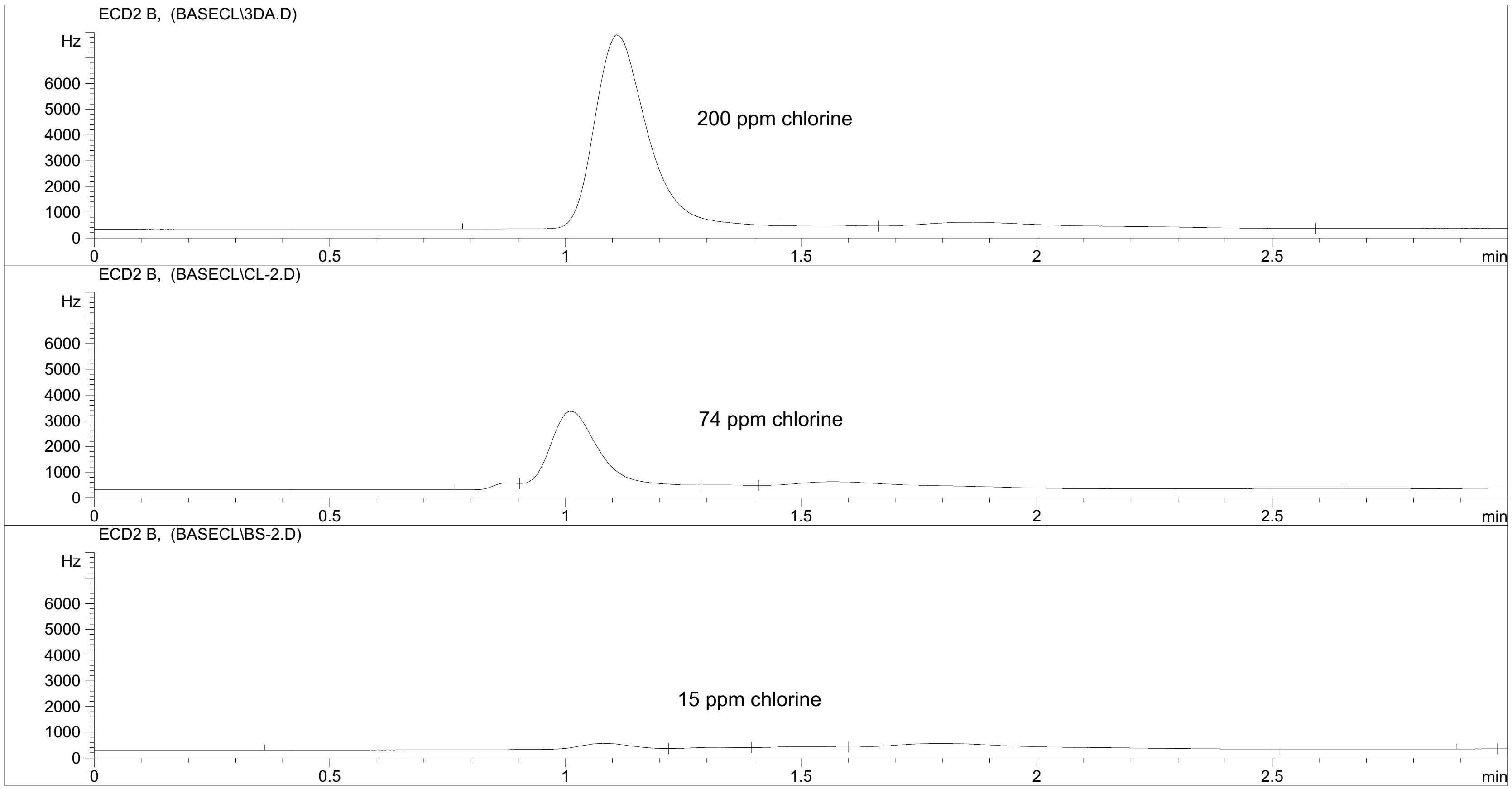
CHLORINE BY GAS CHROMATOGRAPHY

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

What is a Mule?

What is a Mule?

The Air Force Academy "Mascot" and "Flash"

What is a Mule?

- 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

?????

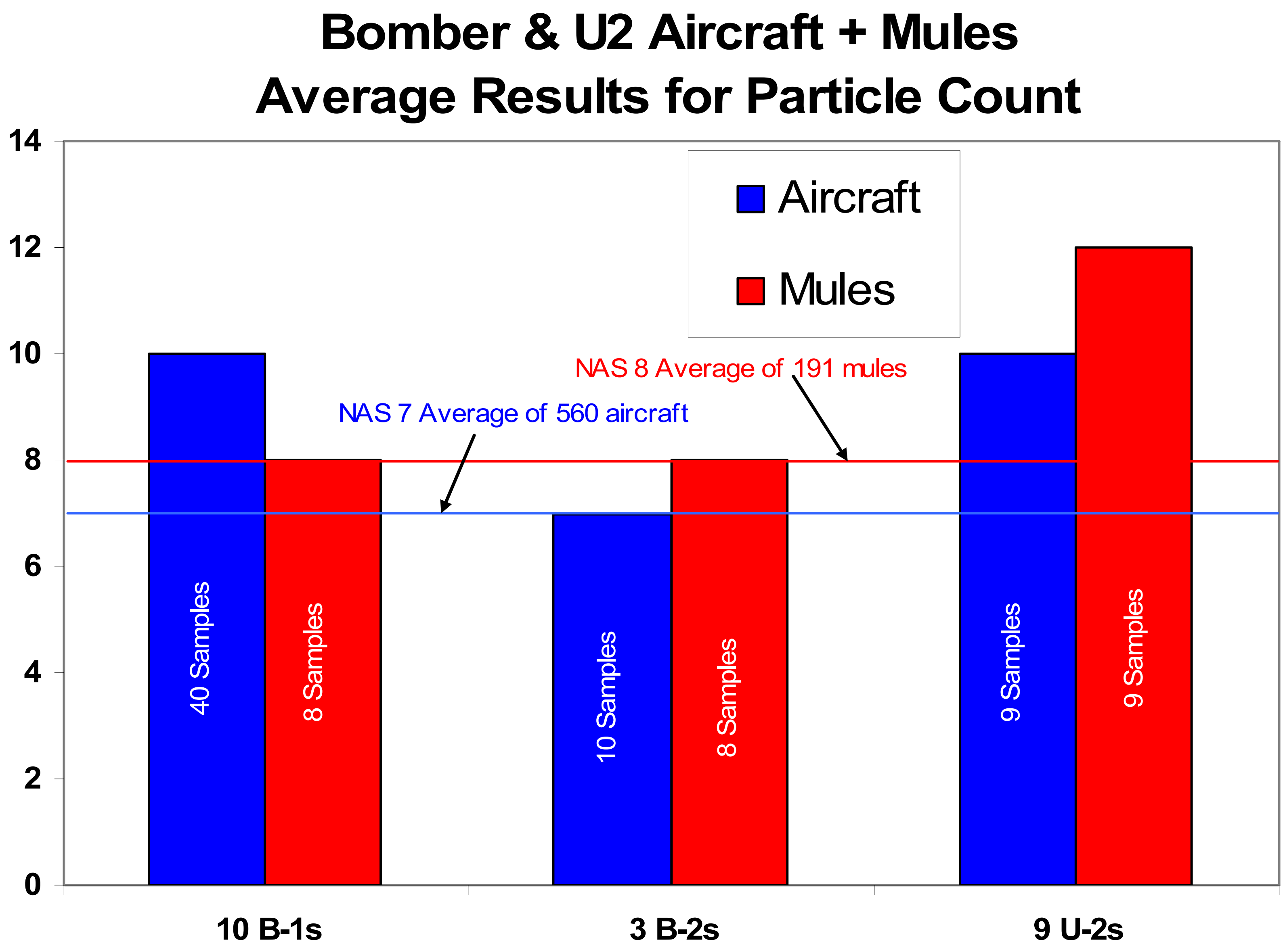
What is a Mule?

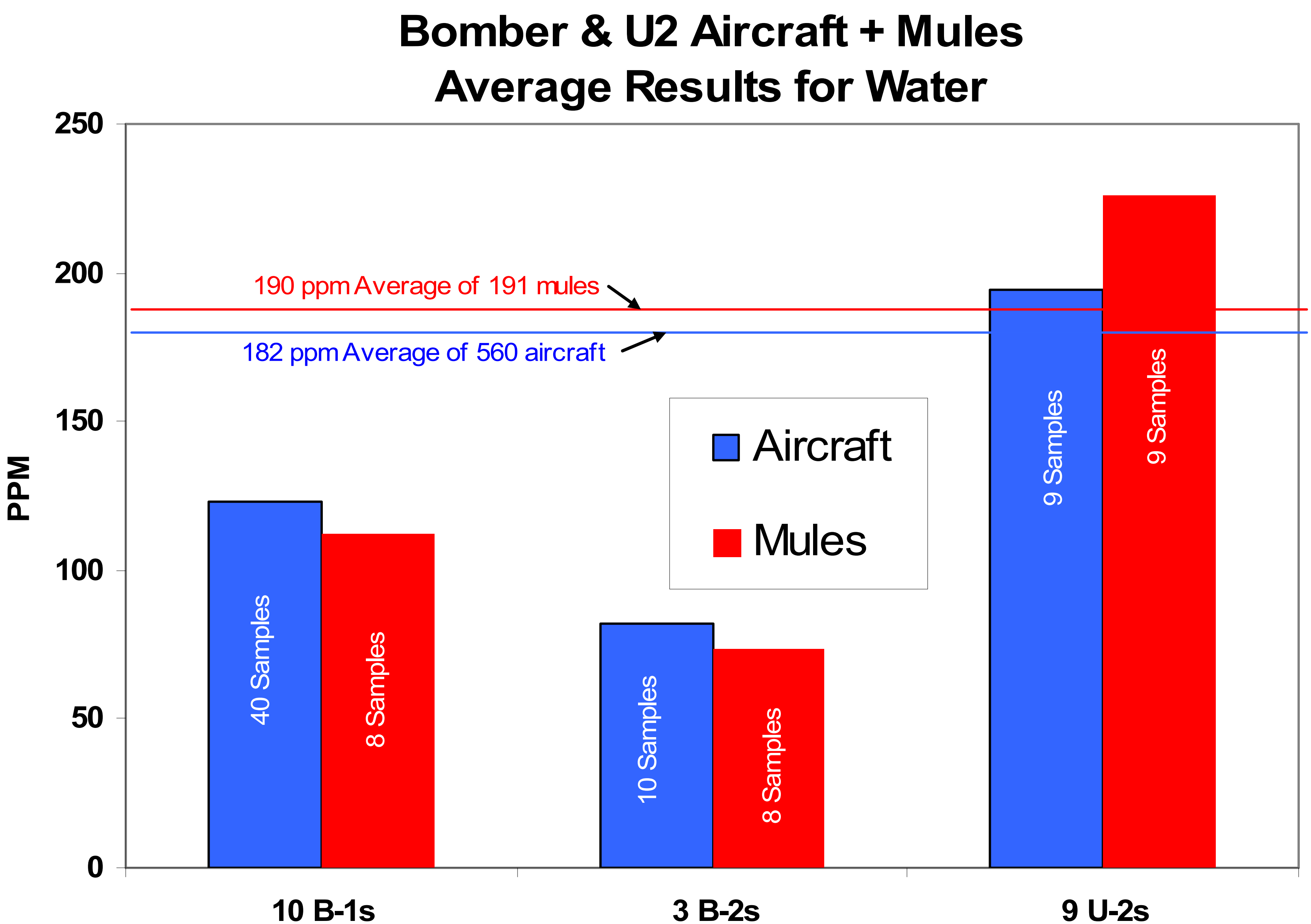
An aircraft hooked up to a mule (servicing cart), which is also hooked up to a purifier for a test.

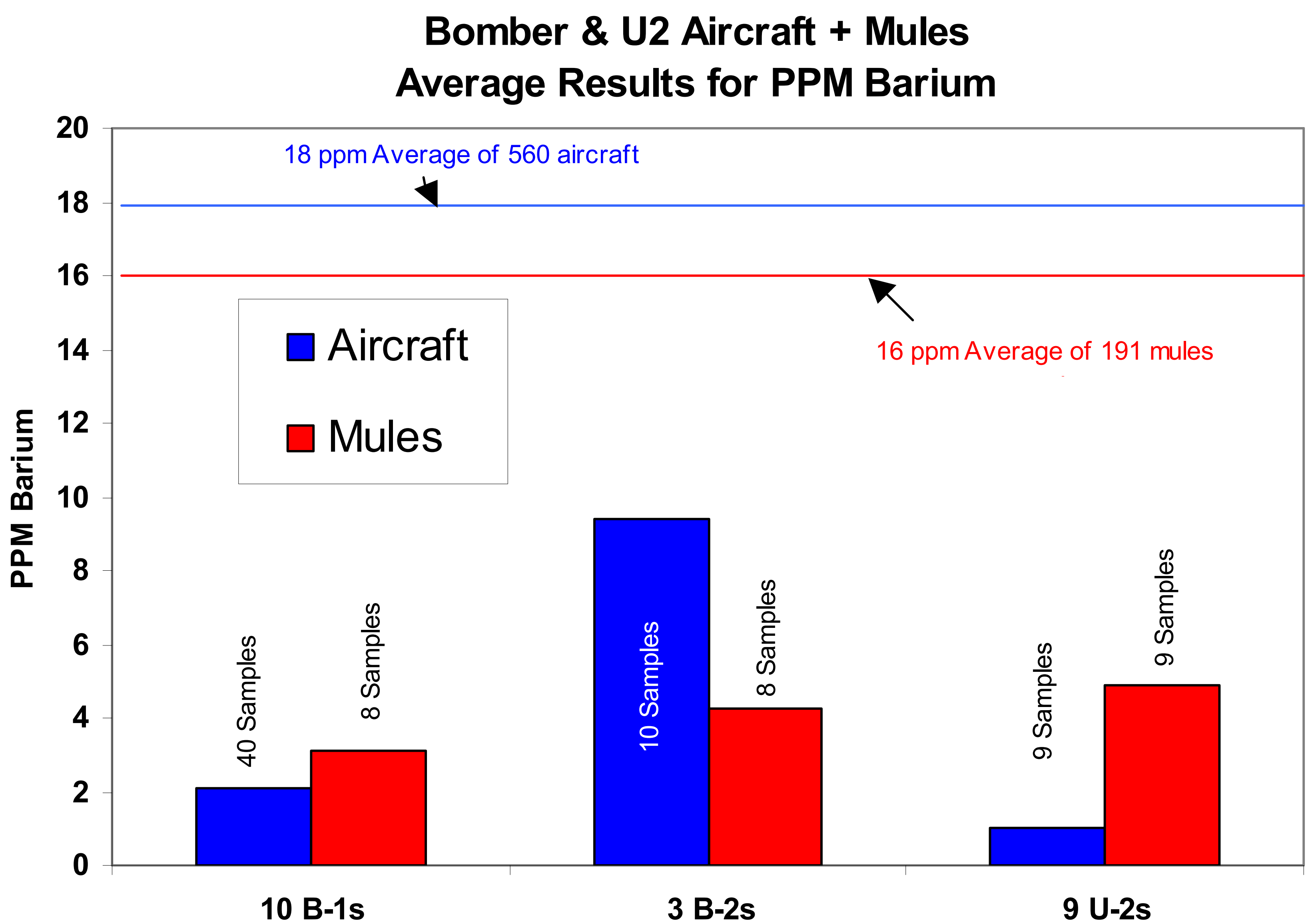
10 B1 = 40 SAMPLES

3 B-2 = 10 SAMPLES

9 U-2 (NINE SAMPLES)


Bomber & U2 Aircraft + Mules
Average Results for Particle Count
Aircraft
Mules
NAS 8 Average of 191 mules
NAS 7 Average of 560 aircraft
40 Samples
8 Samples
10 Samples
8 Samples
9 Samples
9 Samples
14
12
10
8
6
4
2
0
10 B-1s
3 B-2s
9 U-2s


Bomber & U2 Aircraft + Mules
Average Results for Water
PPM
250
200
150
100
50
0
190 ppm Average of 191 mules
182 ppm Average of 560 aircraft
Aircraft
Mules
40 Samples
8 Samples
10 Samples
8 Samples
9 Samples
9 Samples
10 B-1s
3 B-2s
9 U-2s

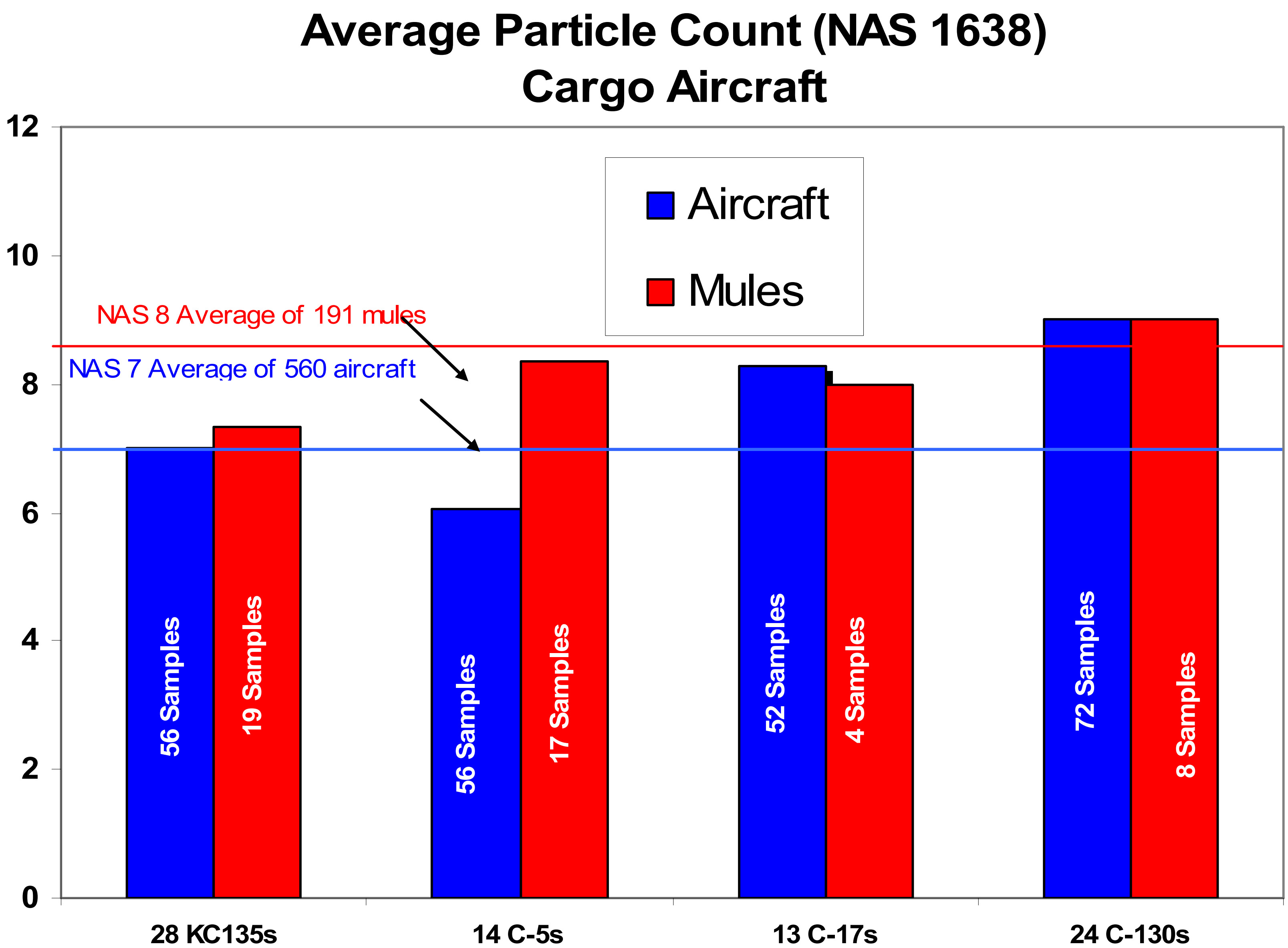

Bomber & U2 Aircraft + Mules
Average Results for PPM Barium
PPM Barium
20
18
16
14
12
10
8
6
4
2
0
18 ppm Average of 560 aircraft
16 ppm Average of 191 mules
Aircraft
Mules
40 Samples
8 Samples
10 Samples
8 Samples
9 Samples
9 Samples
10 B-1s
3 B-2s
9 U-2s

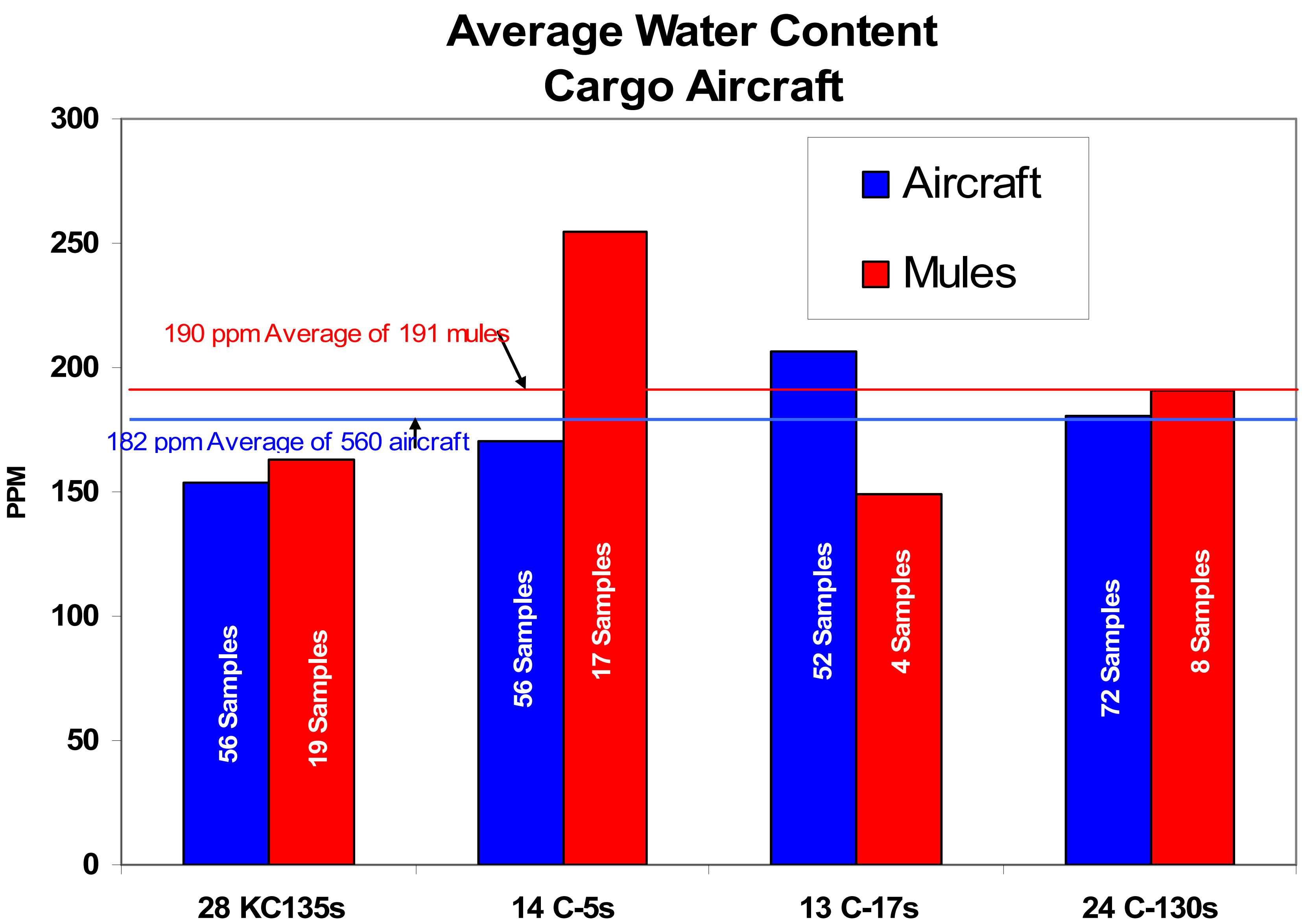
28 KC 135 (56 SAMPLES)

14 C-5 (56 SAMPLES)

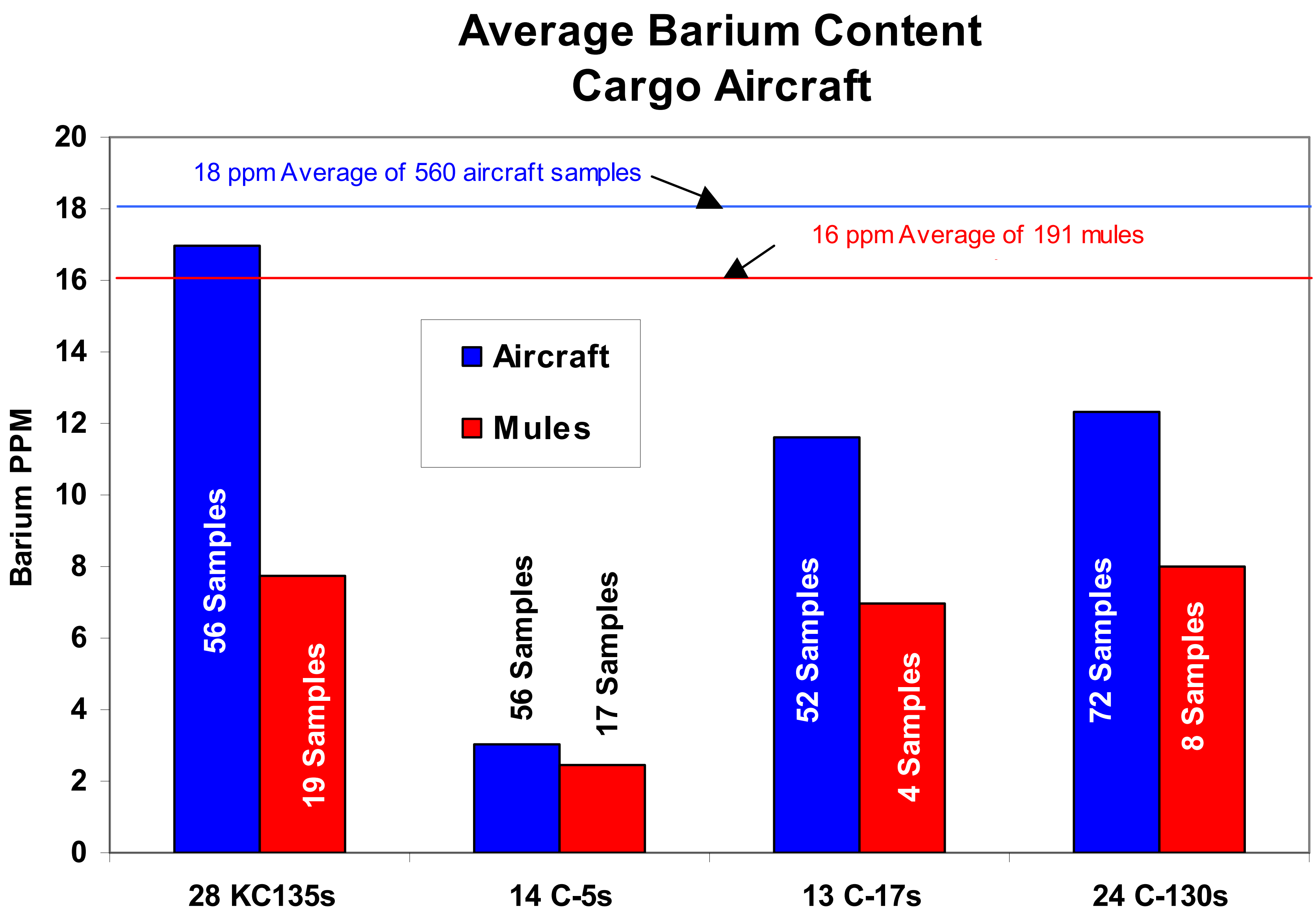
13 C-17 (52 SAMPLES)

24 C-130 (72 SAMPLES)


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



Average Water Content
Cargo Aircraft
300
250
200
150
100
50
0
PPM
Aircraft
Mules
190 ppm Average of 191 mules
182 ppm Average of 560 aircraft
56 Samples
19 Samples
56 Samples
17 Samples
52 Samples
4 Samples
72 Samples
8 Samples
28 KC135s
14 C-5s
13 C-17s
24 C-130s



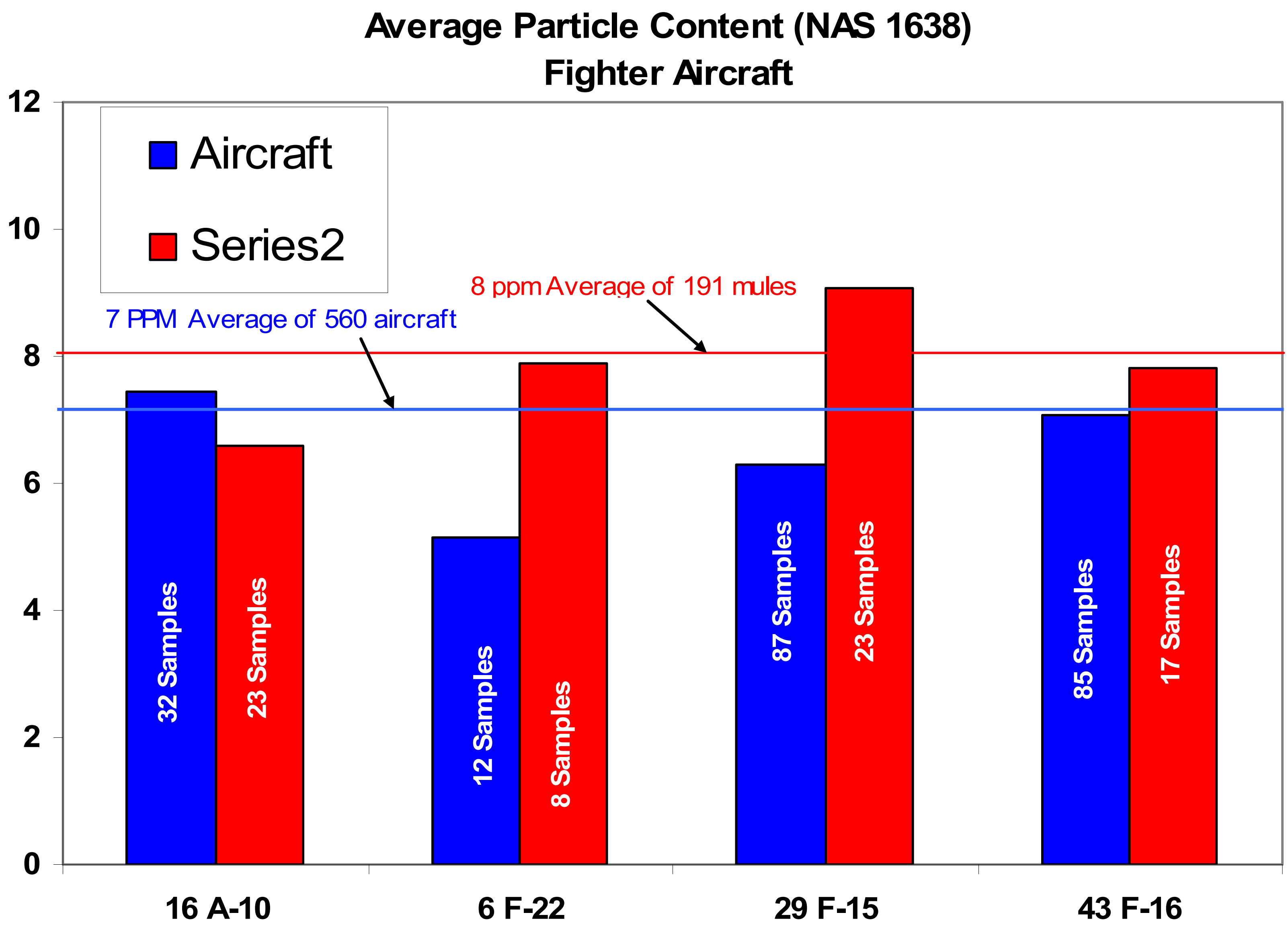
Average Barium Content
Cargo Aircraft
Barium PPM
20
18
16
14
12
10
8
6
4
2
0
18 ppm Average of 560 aircraft samples
16 ppm Average of 191 mules
Aircraft
Mules
56 Samples
19 Samples
56 Samples
17 Samples
52 Samples
4 Samples
72 Samples
8 Samples
28 KC135s
14 C-5s
13 C-17s
24 C-130s

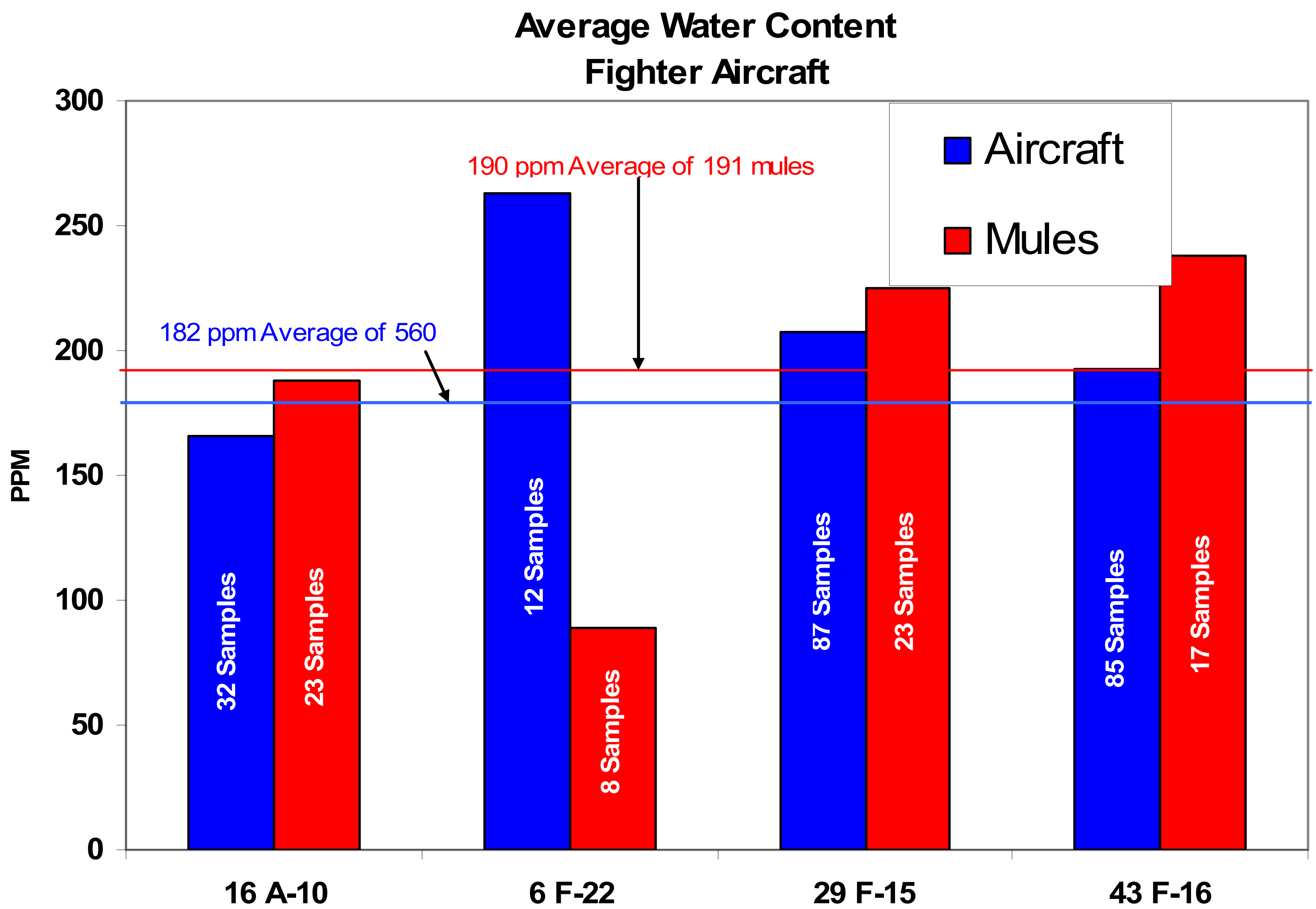
16 A-10 (32 SAMPLES)

6 F-22 (12 SAMPLES)

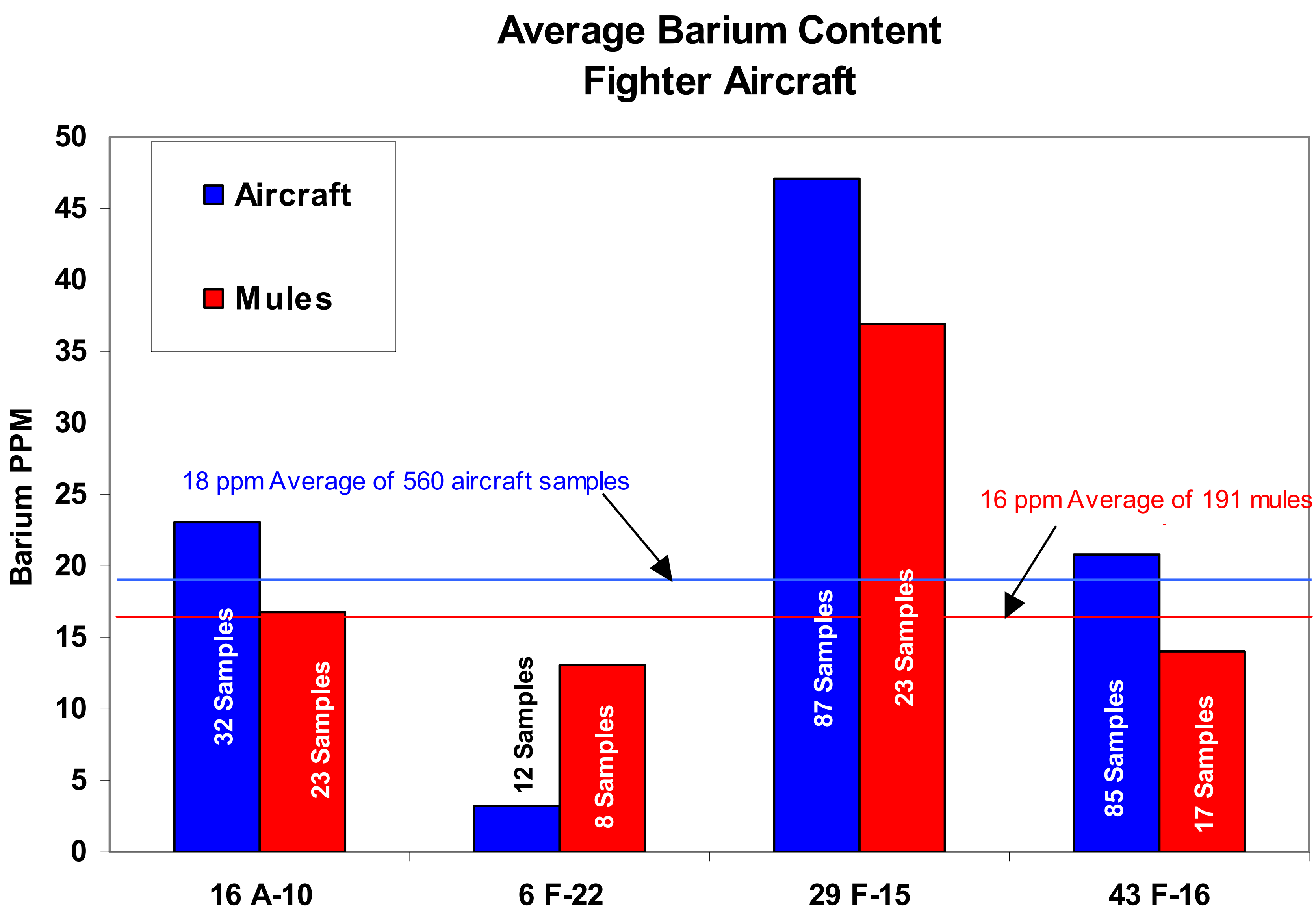
29 F-15 (87 SAMPLES)

43 F-16 (85 SAMPLES)


Average Particle Content (NAS 1638)
Fighter Aircraft
12
10
8
6
4
2
0
Aircraft
Series2
8 ppm Average of 191 mules
7 PPM Average of 560 aircraft
32 Samples
23 Samples
12 Samples
8 Samples
87 Samples
23 Samples
85 Samples
17 Samples
16 A-10
6 F-22
29 F-15
43 F-16



Average Water Content
Fighter Aircraft
300
250
200
150
100
50
0
PPM
190 ppm Average of 191 mules
182 ppm Average of 560
Aircraft
Mules
32 Samples
23 Samples
12 Samples
8 Samples
87 Samples
23 Samples
85 Samples
17 Samples
16 A-10
6 F-22
29 F-15
43 F-16

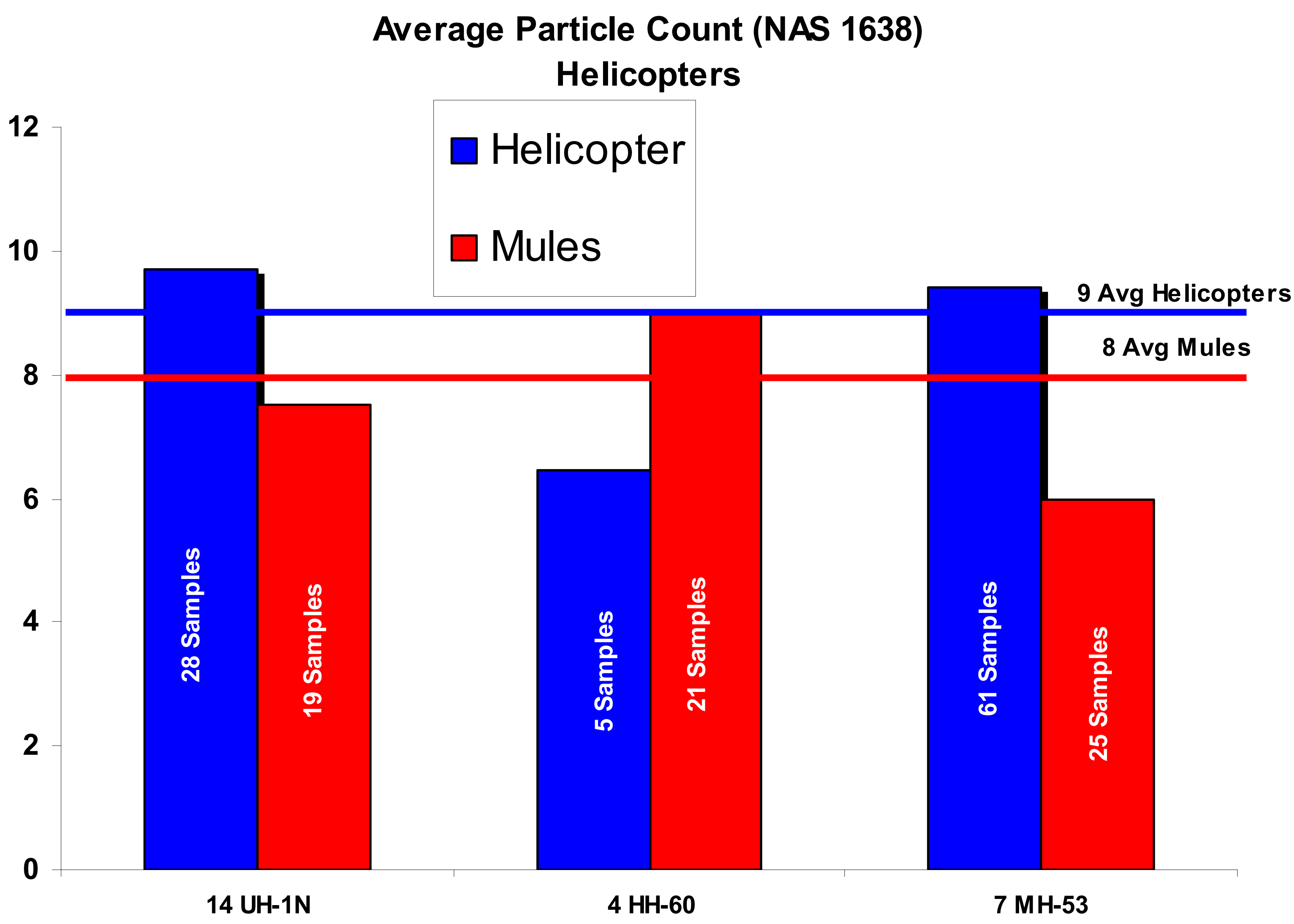


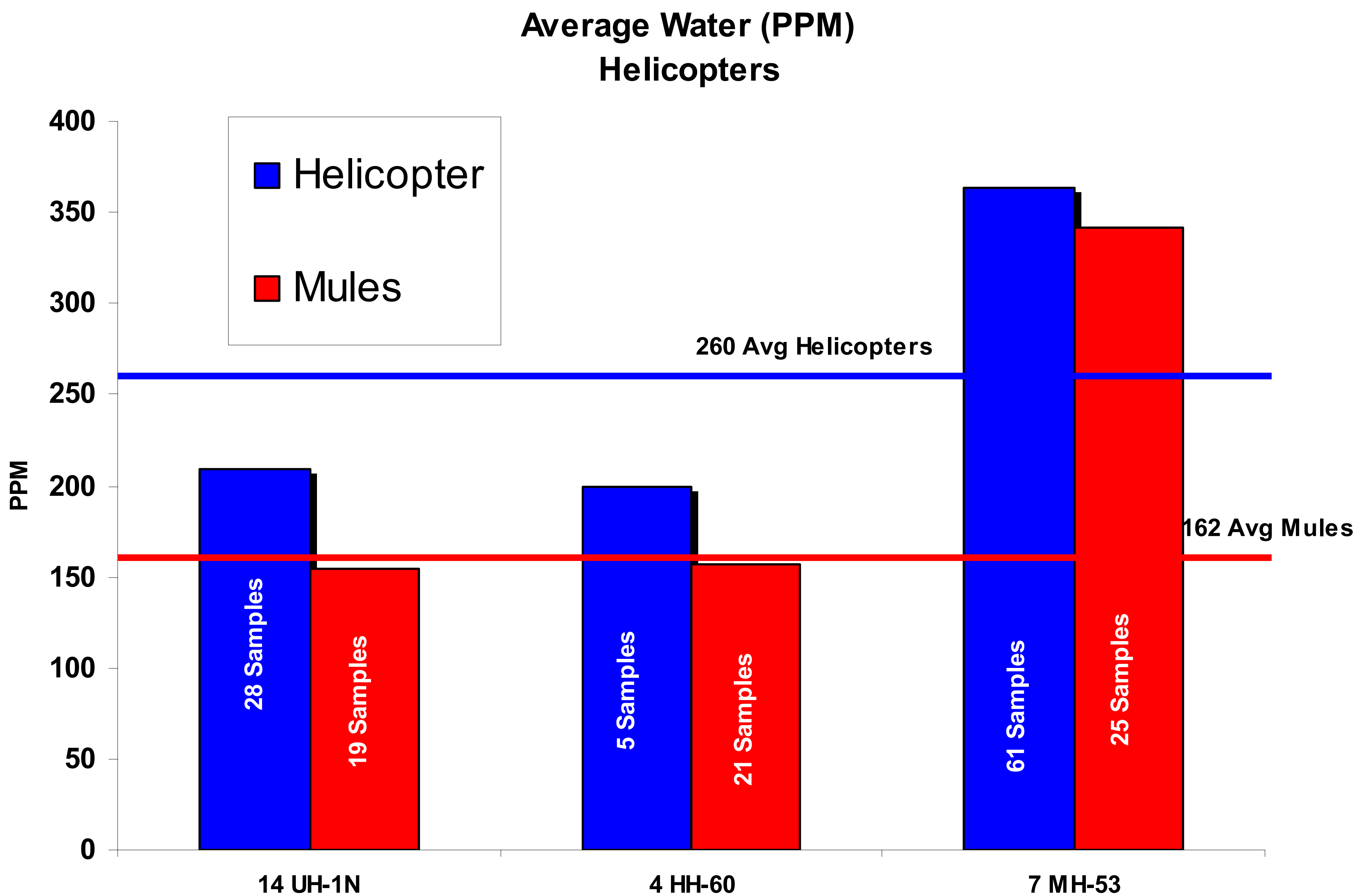
Average Barium Content
Fighter Aircraft
Barium PPM
50
45
40
35
30
25
20
15
10
5
0
Aircraft
Mules
18 ppm Average of 560 aircraft samples
16 ppm Average of 191 mules
32 Samples
23 Samples
12 Samples
8 Samples
87 Samples
23 Samples
85 Samples
17 Samples
16 A-10
6 F-22
29 F-15
43 F-16

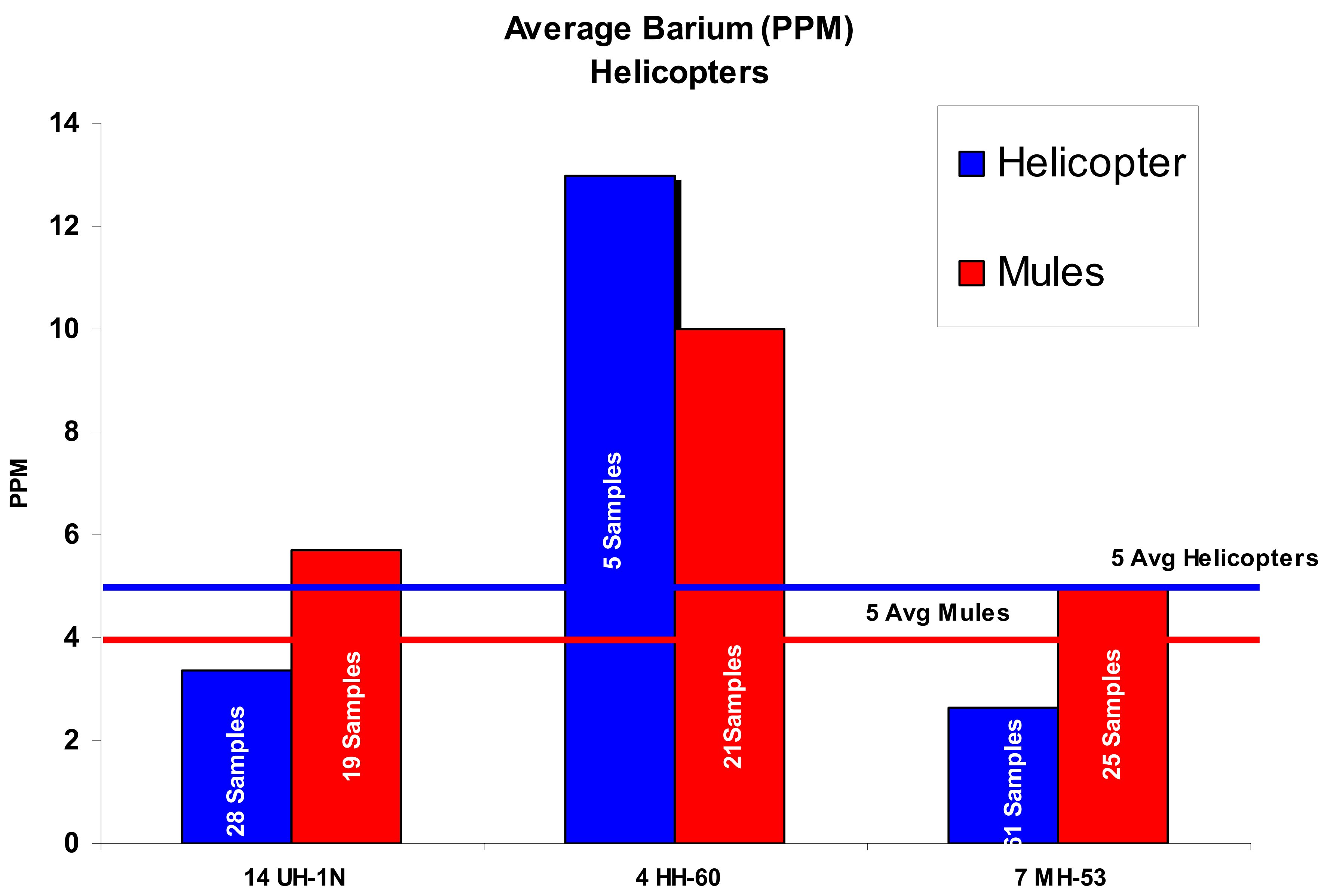
14 UH-1 (28 SAMPLES)

4 HH-60 (5 SAMPLES)

7 MH-53 (61 SAMPLES)


Average Particle Count (NAS 1638)
Helicopters
Helicopter
Mules
9 Avg Helicopters
8 Avg Mules
28 Samples
19 Samples
5 Samples
21 Samples
61 Samples
25 Samples
12
10
8
6
4
2
0
14 UH-1N
4 HH-60
7 MH-53


Average Water (PPM)
Helicopters
Helicopter
Mules
260 Avg Helicopters
162 Avg Mules
PPM
400
350
300
250
200
150
100
50
0
28 Samples
19 Samples
5 Samples
21 Samples
61 Samples
25 Samples
14 UH-1N
4 HH-60
7 MH-53


Average Barium (PPM)
Helicopters
Helicopter
Mules
PPM
14
12
10
8
6
4
2
0
5 Avg Helicopters
5 Avg Mules
28 Samples
19 Samples
5 Samples
21Samples
25 Samples
14 UH-1N
4 HH-60
7 MH-53

16 T-37 (16 SAMPLES)

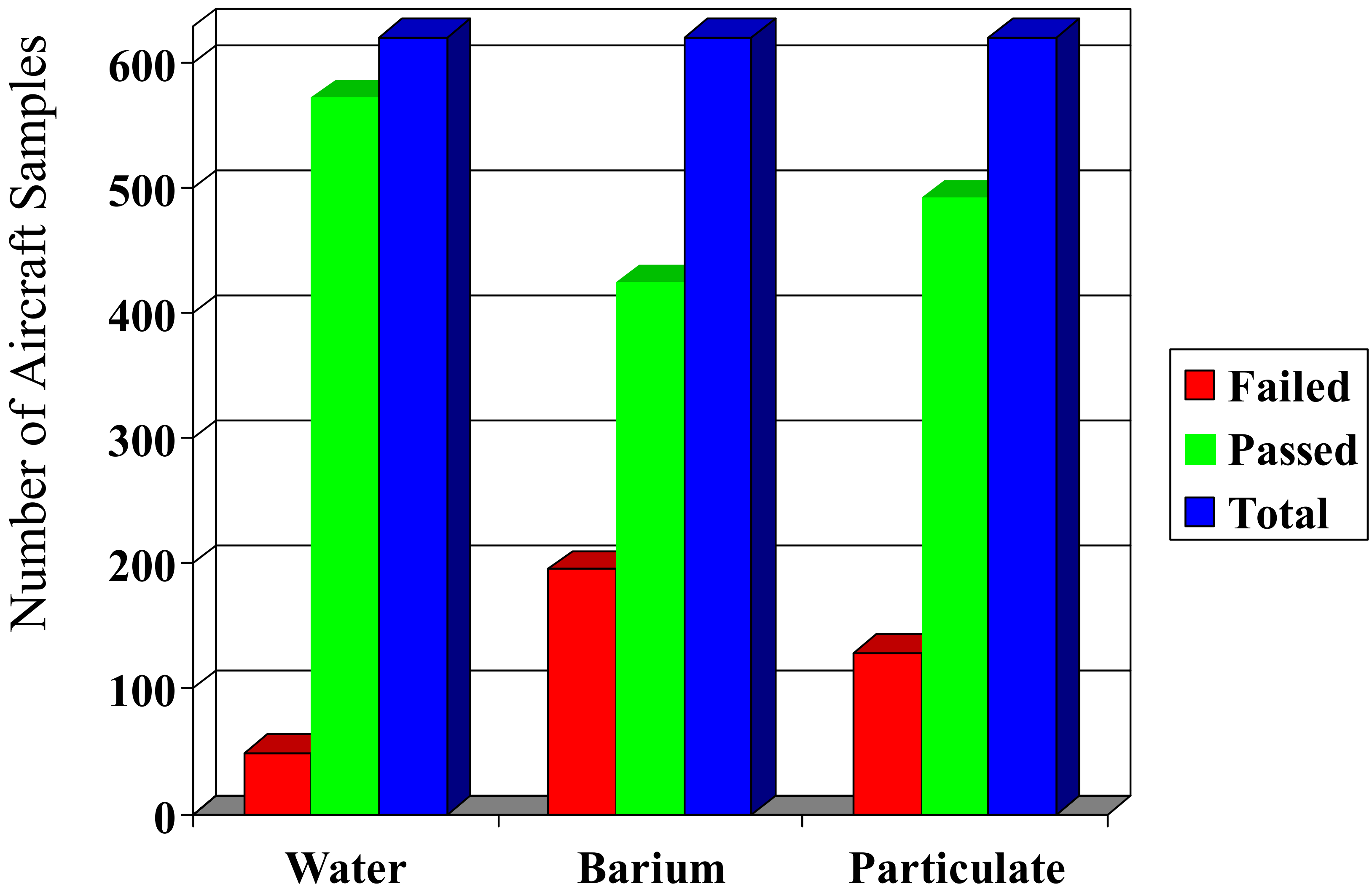
AVERAGES

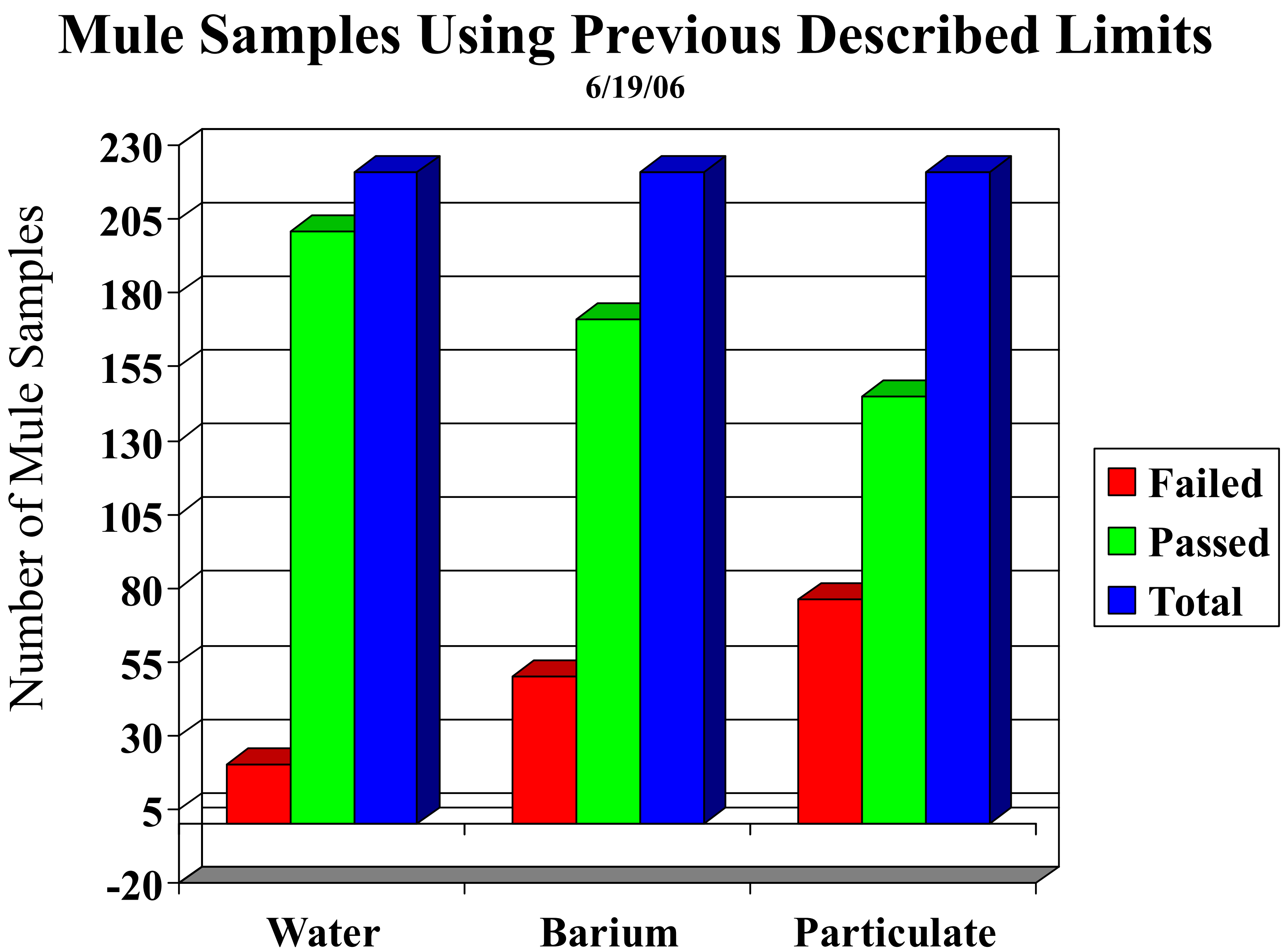
PC = 10   WATER = 199

BARIUM = 2

Aircraft Samples Using Previous Described Limits

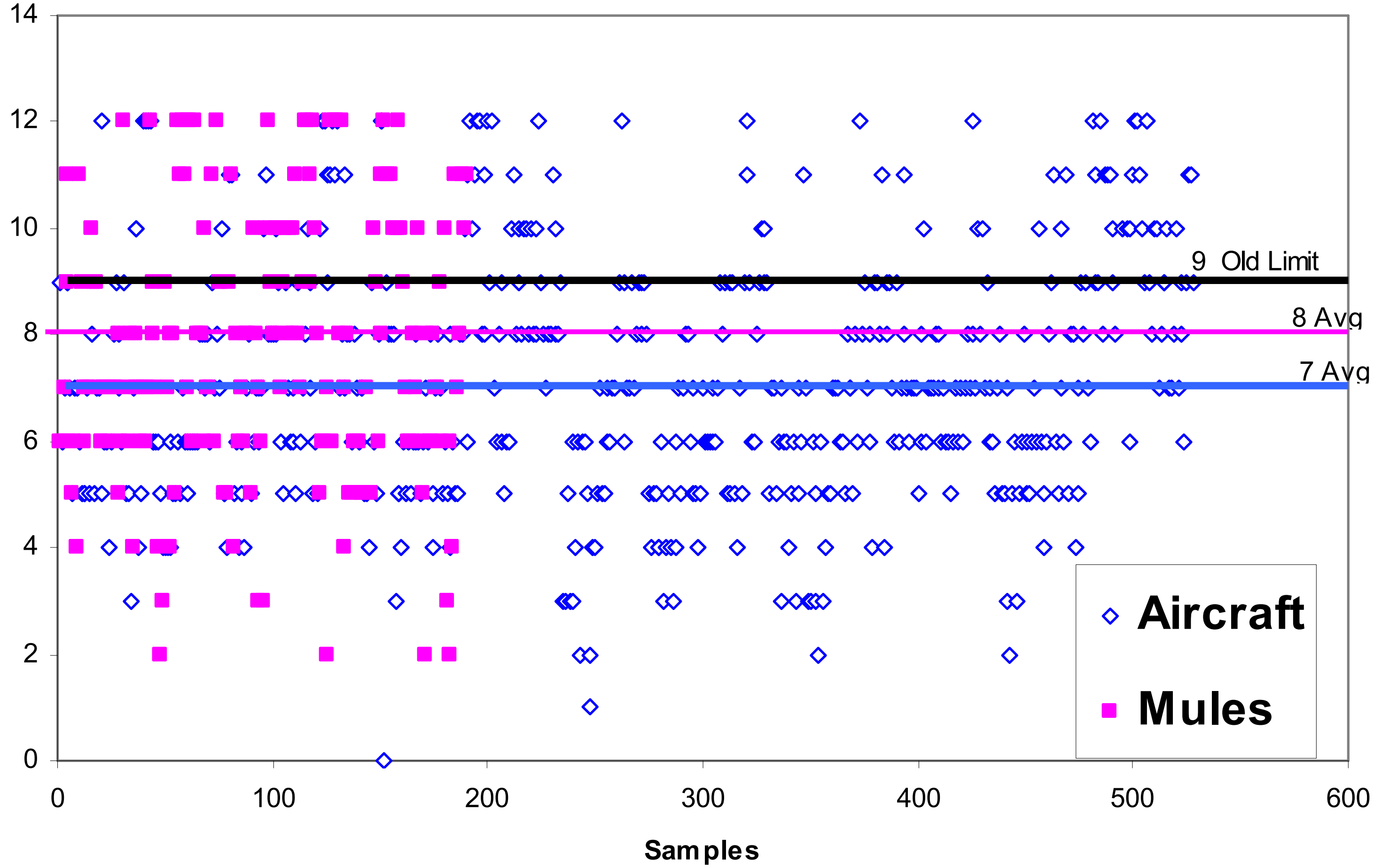
6/19/06



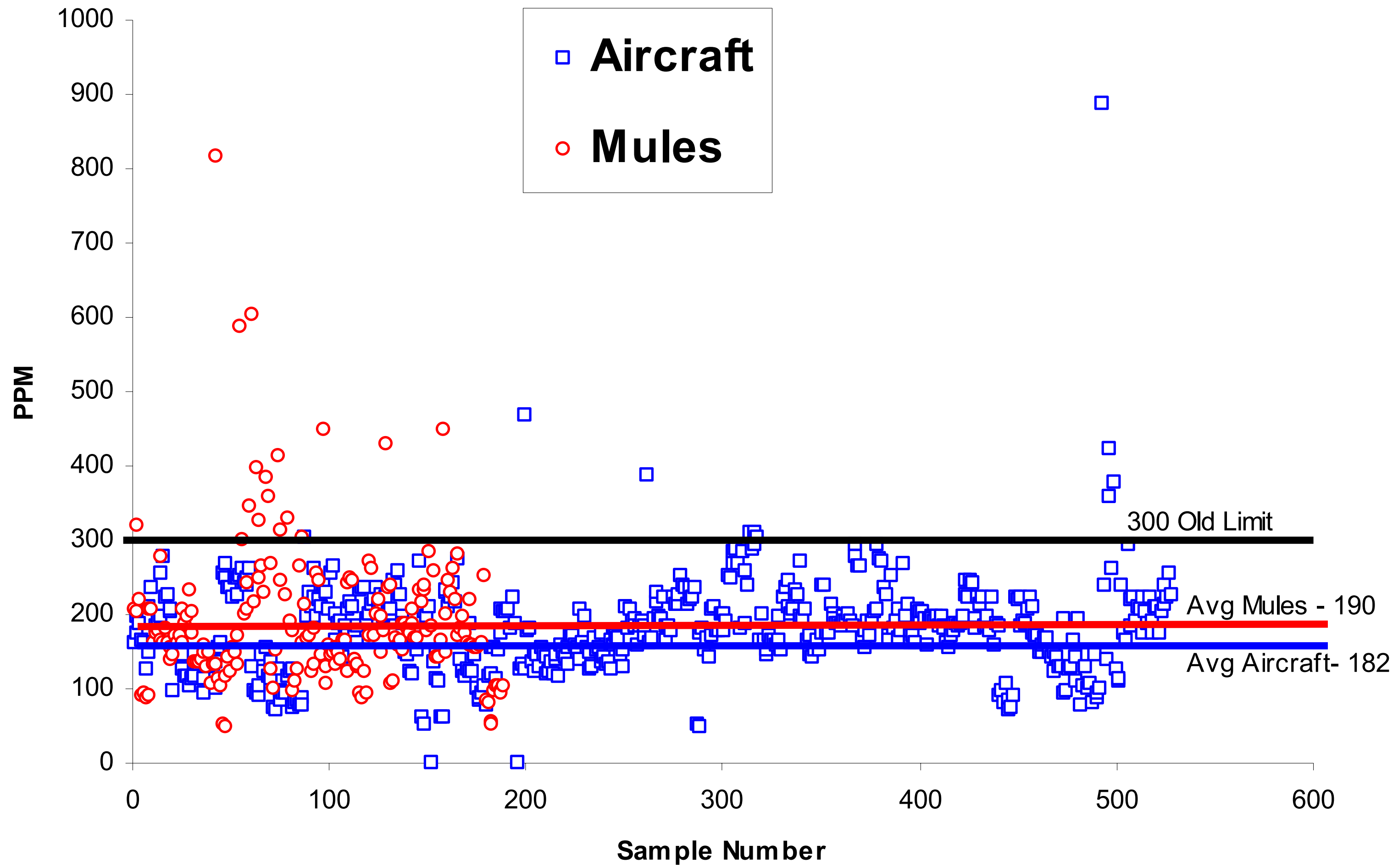


Mule Samples Using Previous Described Limits
6/19/06
Number of Mule Samples
230
205
180
155
130
105
80
55
30
5
-20
Water
Barium
Particulate
Failed
Passed
Total

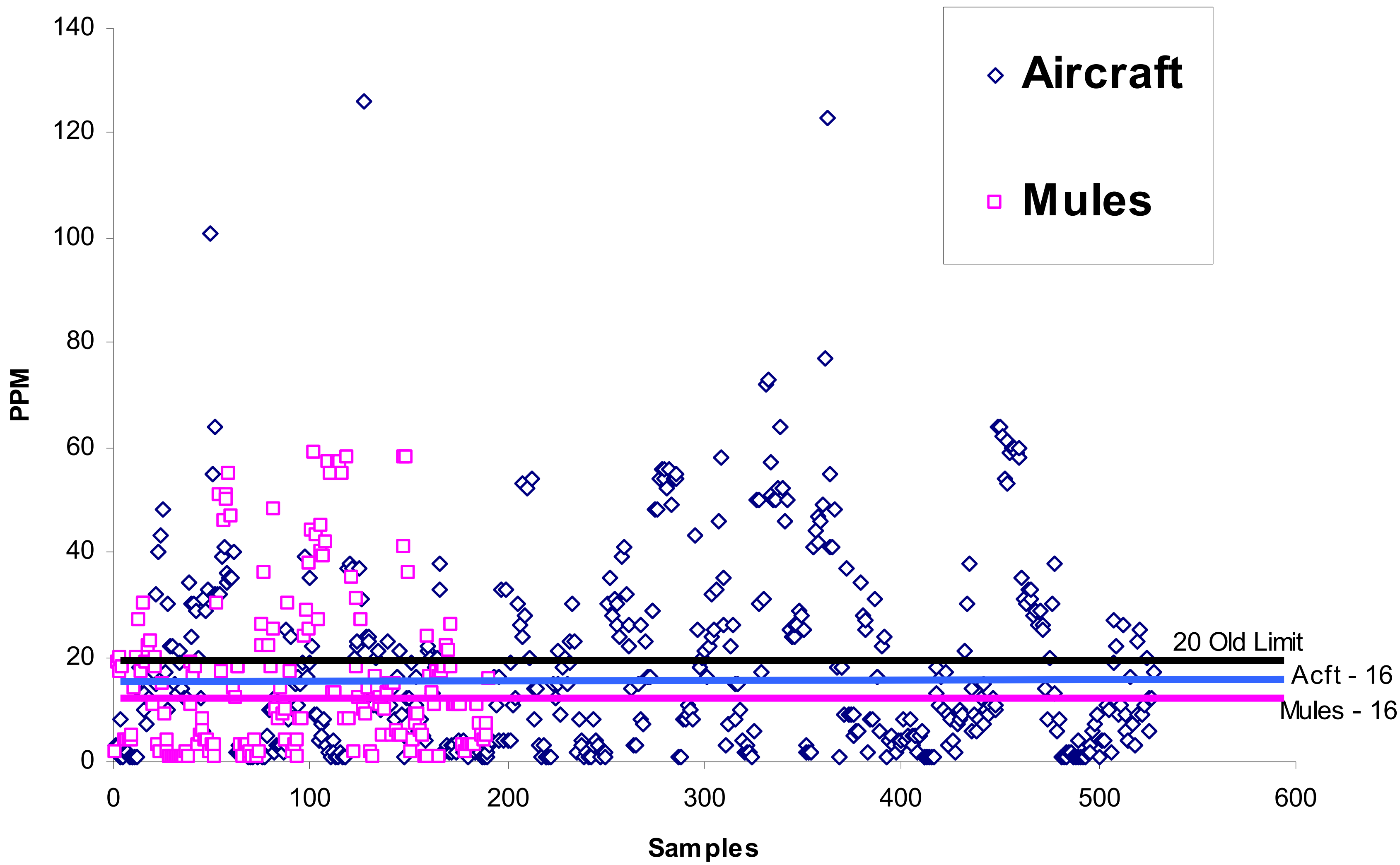
Particle Count Scatter



Water Scatter



Barium Scatter



New Vs Old

All Aircraft

	Particle Count	Water	Barium
Original Limits	9	300	20
Average	7	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

UDRI Imagination Investigation Innovation 50 1956-2006

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

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

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

Today – Demonstration Results

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

Today – Demonstration Results

- 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)

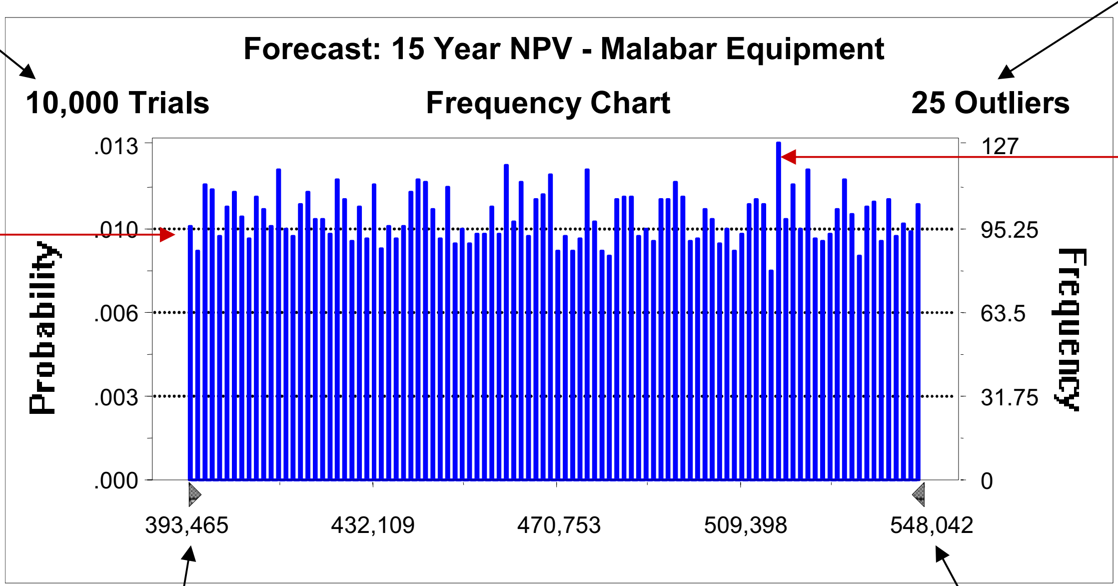
Today – Demonstration Results

Number or trials or calculations conducted

Values outside the graphic display

There is a 0.010 probability that the value $393,465 will occur

During the 10,000 trials, this value occurred 127 times.



Minimum expected value ($)

The mean (average) value of this distribution is $470,400 – this is given in the value as the mean result

Maximum expected value ($)

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

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

Today – Demonstration Results

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

Today – Demonstration Results

- 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

Today – Demonstration Results

- 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

Today – Demonstration Results

- 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

Today – Demonstration Results

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

CONOPS: 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

Video

"Sorry, no popcorn"

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 Aerospace

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

PALL Aerospace

Hydraulic System TCM

Contaminated Hydraulic Systems Reported in 2004:

Aircraft Sampling:

Particulate	23% Class 9 or Above
Water	35% 200 ppm or Above

Mule Sampling:

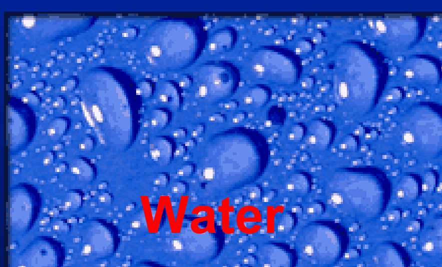
Particulate	33% Class 9 or Above
Water	34% 200 ppm or Above

Hydraulic System Contamination Reduces Service Life.

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

PALL Aerospace

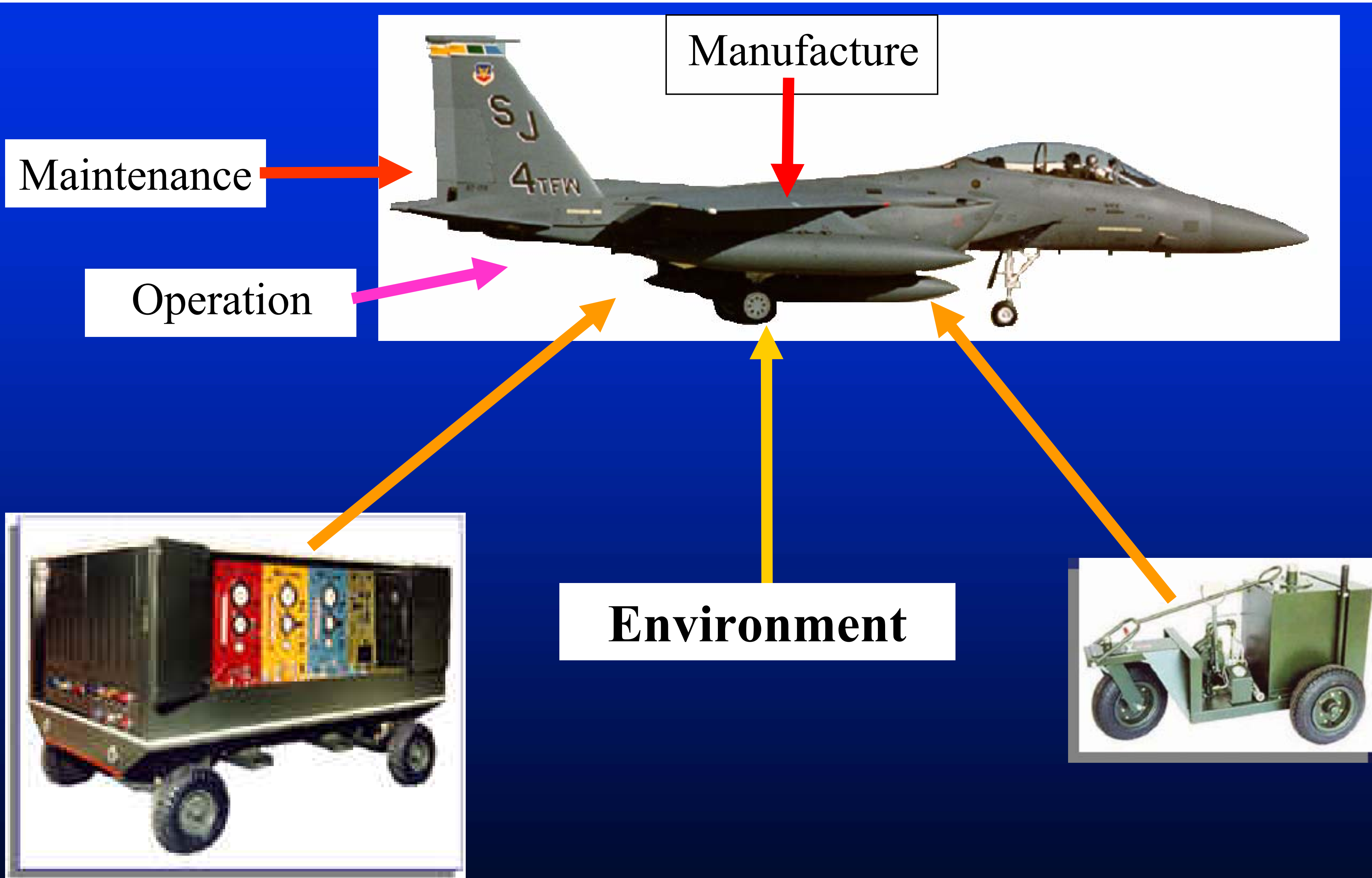
Hydraulic System TCM

Field Surveys conducted at Robins AFB, Eglin AFB and Jacksonville National Guard

Identified issues with:

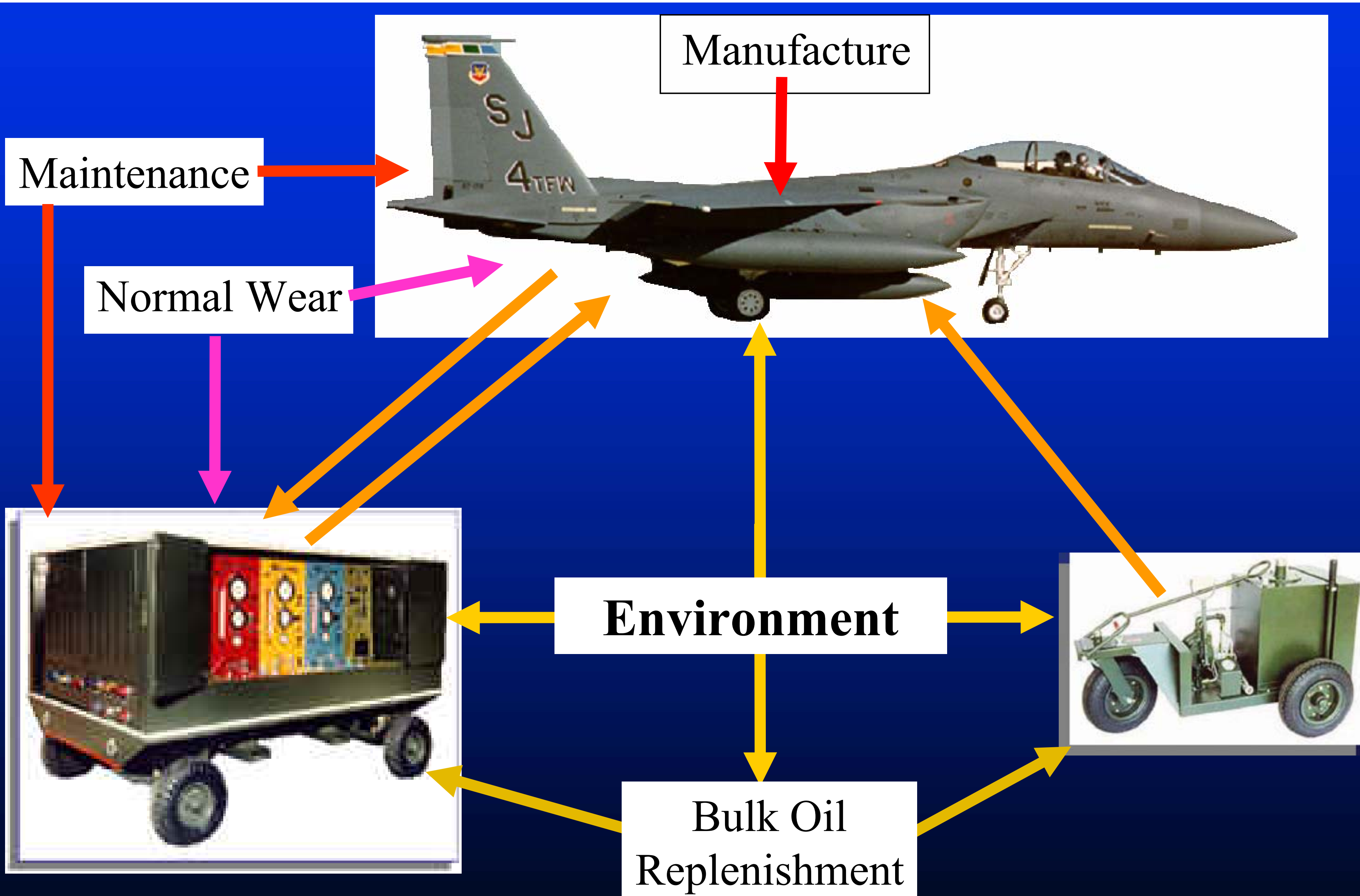
- Aircraft In-System Protection
- Portable Hydraulic Test Stands
- Portable Service Carts
- Bulk oil distribution

Sources of Aircraft System Contamination



PALL Aerospace

All Sources of System Contamination



Aircraft Hydraulic System Filter Upgrade:

Replace:	With:
15 Micron absolute	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

PALL Aerospace

Hydraulic System TCM

Existing Equipment

Existing Discharge Filter
Particulate

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

Open Reservoir Vent
Water and Particulate

Hydraulic System TCM

Existing Equipment

Open Reservoir Vent
Water and Particulate

Existing Discharge Filter
Particulate

MS28720-12
- 50 psi Bypass
- 150 psid Collapse
- 30 micron

Hydraulic System TCM

Improve Discharge Filter
Control Particulate

Adapt to MIL-F-81836

Protect Reservoir Vent
Control Water and Particulate

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

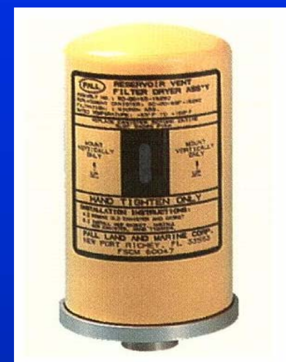
302

PALL Aerospace

Hydraulic System TCM

Upgrade Discharge Filter
Control Particulate

MS28720-12 Envelope
Non-Bypass
3 micron filter
5000 psi Collapse



Protect Reservoir Vent
Control Water and Particulate

PALL Aerospace

Hydraulic System TCM

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

305

Portable Fluid Purifier

Tested & Certified

- 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

PALL Aerospace

Hydraulic System TCM

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:

3 micron MIL-F-81836

NSN: 4330-01-047-1118

using Adapter:

NSN: 4920-01-046-8190

•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

Hydraulic System TCM

Portable Hydraulic Service Carts

•Protect vents from ambient contaminants

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

Hydraulic System TCM

PALL Aerospace

Hydraulic System TCM

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

Particulate:	NAS1638 Class 5 or Better
Water:	100 PPM or Less
Air:	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

Practice Total Contamination Control

Aircraft Systems

- 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:

– 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

MALABAR

INTERNATIONAL

FLUID PURIFICATION BRIEFING

Military Aviation

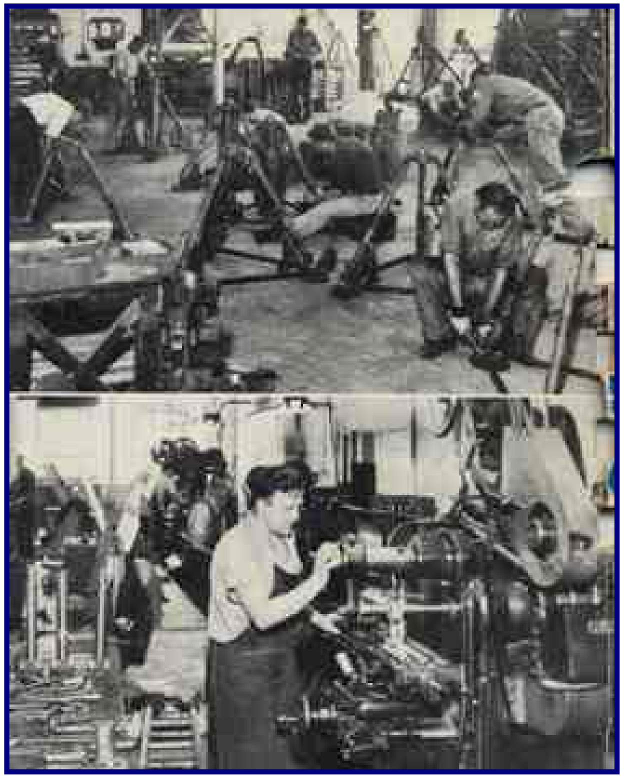
Fluid & Lubes

Workshop

20 - 22 June, 2006

Hope Hotel

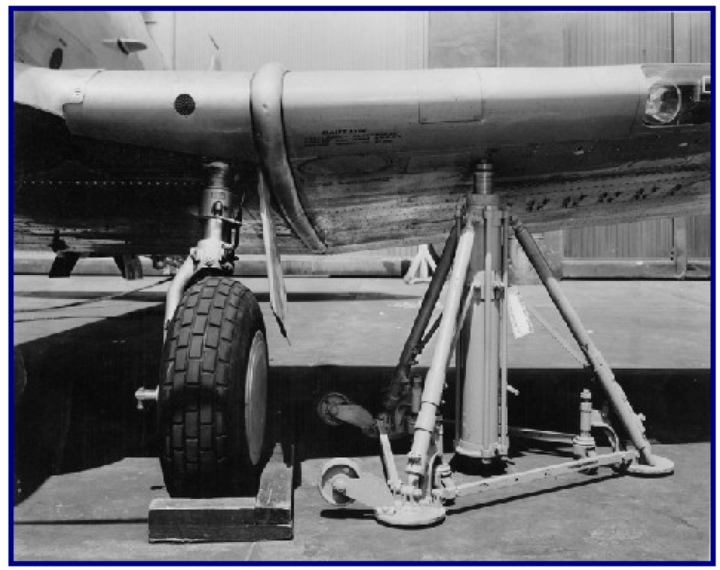
Wright-Patterson AFB



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.

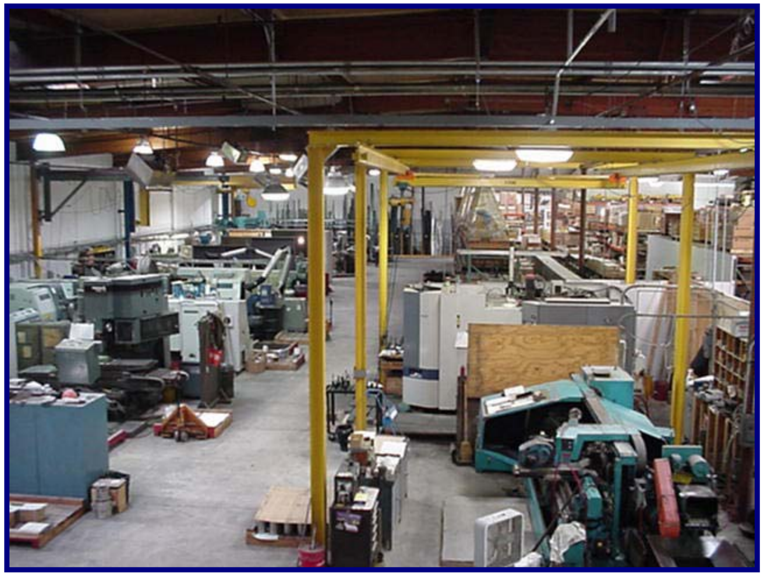


In 1968 MALABAR was acquired by E.D. Sweetland ("Gene") of the Sweetland Company a west coast distributor of hydraulic and pneumatic components.

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.



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

Welding and Fabrication Area with Full Overhead Crane Capability.

Test Facilities

225 Ton Dynamic Hydraulic
Jack Test Fixture

HTS Test Cell

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"

FLUID PURIFICATION CAPABILITY

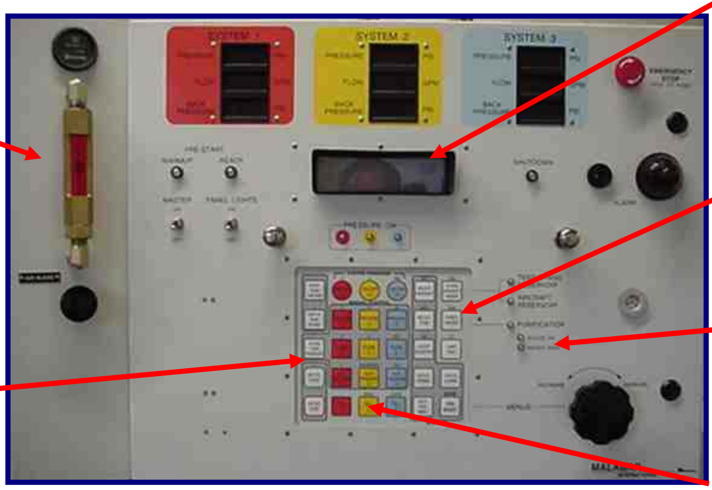
- Vacuum Distillate Process
- Fluid is sprayed under pressure into a vacuum chamber and circulated through a 2µ absolute particulate filter.
- Fluid Contaminants are removed and fluid is returned to “Original” Properties.

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

HTS Control Panel

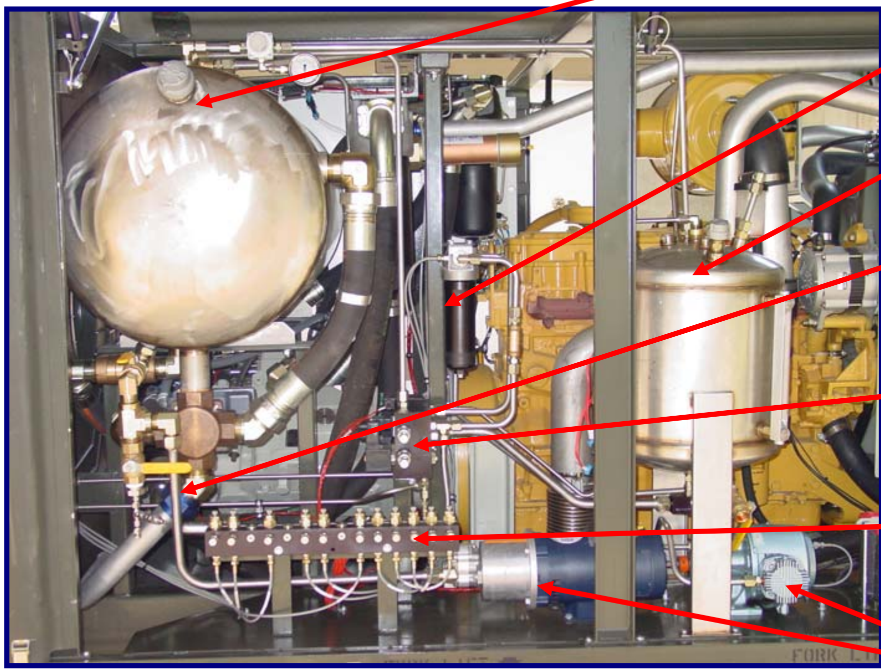
- AIR BLEED SIGHT GLASS
- OPERATOR KEYPAD



- VACUUM FLUORESCENT DISPLAY
- PURIFICATION ON/OFF
- PURIFICATION INDICATOR
- A/C FILL SWITCHES

MALABAR
INTERNATIONAL
FLUID PURIFICATION BRIEFING; 16-18 November 2004

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
INTERNATIONAL
FLUID PURIFICATION BRIEFING; 16-18 November 2004

MALABAR Model 8852
Stand-Alone Fluid Purification Unit

Current Users:

- **Lockheed Martin**
  -MIL-PRF-83282
  -MIL-PRF-87257

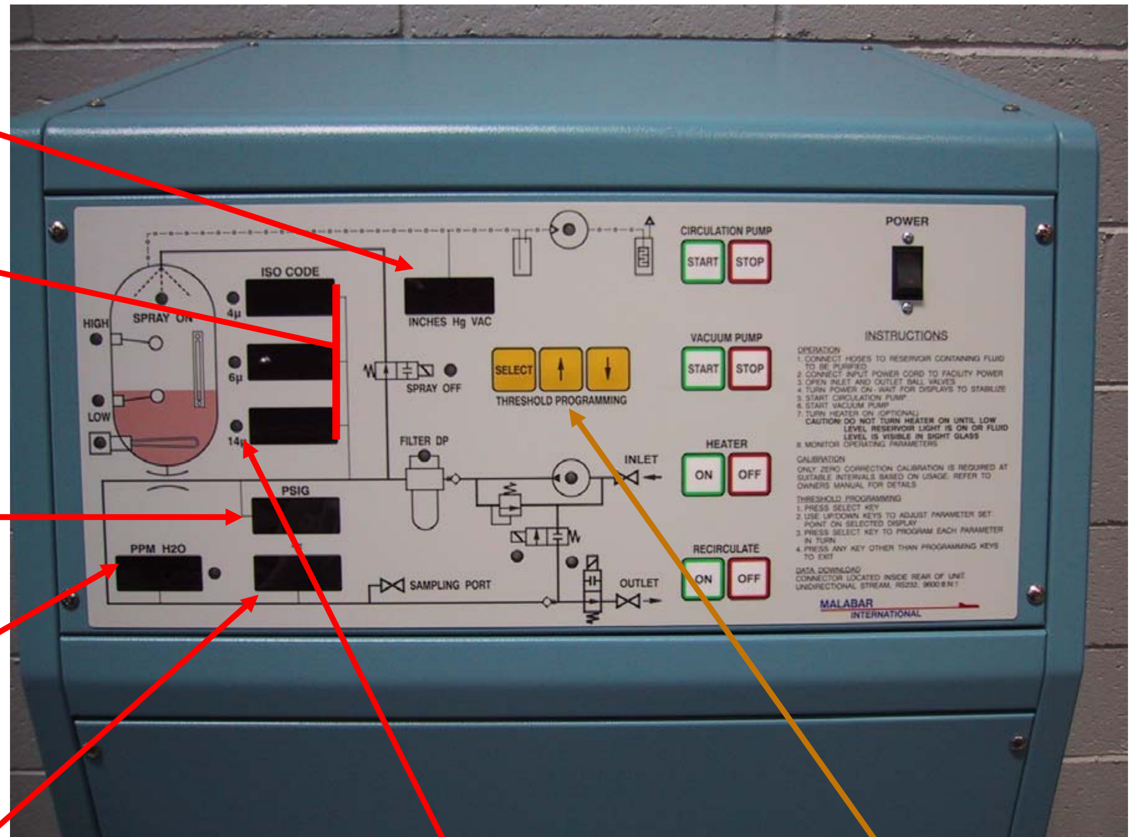
- **NASA**
  -MIL-L-23699

- **WP-AFRL**
  -2 test units

MALABAR
INTERNATIONAL
FLUID PURIFICATION BRIEFING; 16-18 November 2004

Model 8852 Control Panel

- VACUUM (in Hg)
- OPTIONAL PARTICLE COUNTER (3 digit ISO Code)
- OIL PRESSURE (PSIG)
- WATER (PPM)
- OIL TEMPERATURE (˚F)



PROGRAMMED PARAMETER LIGHTS (GREEN - GO)

- PROGRAMMING KEYS

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

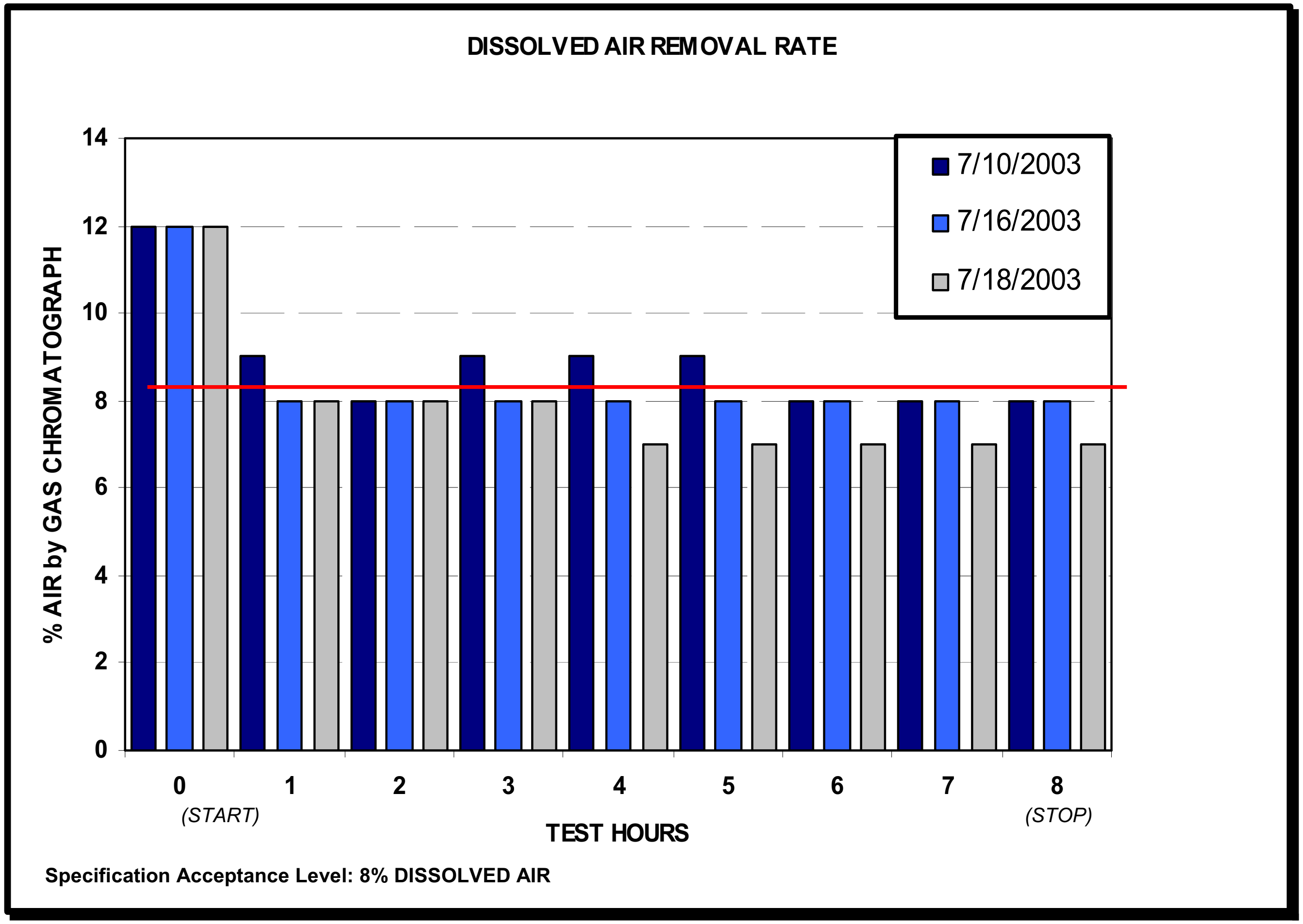
Air Force Research Laboratory Testing

- 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.

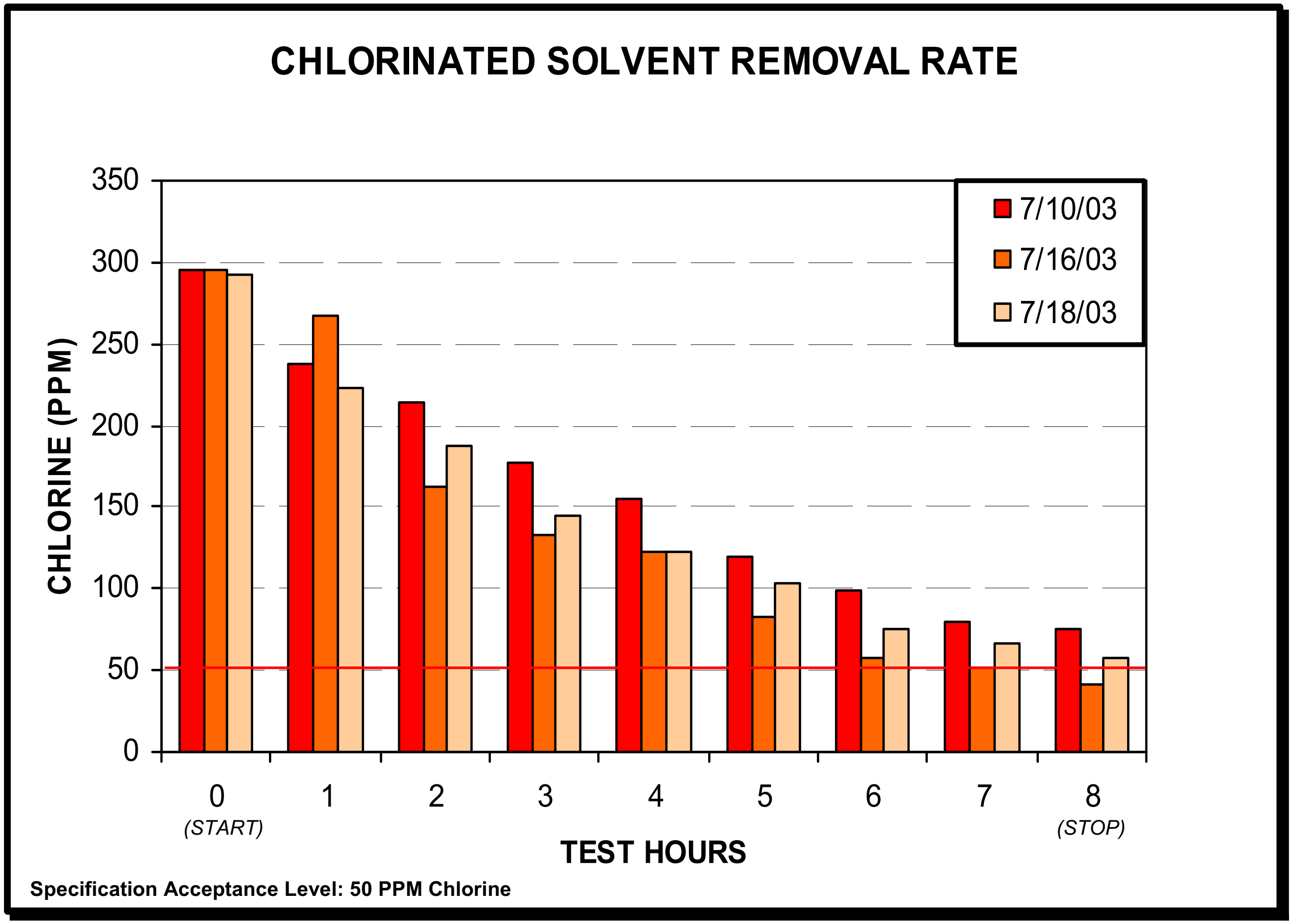
WPAFB AFRL Purification Testing – JULY 2003

MALABAR Model HTS 2/D



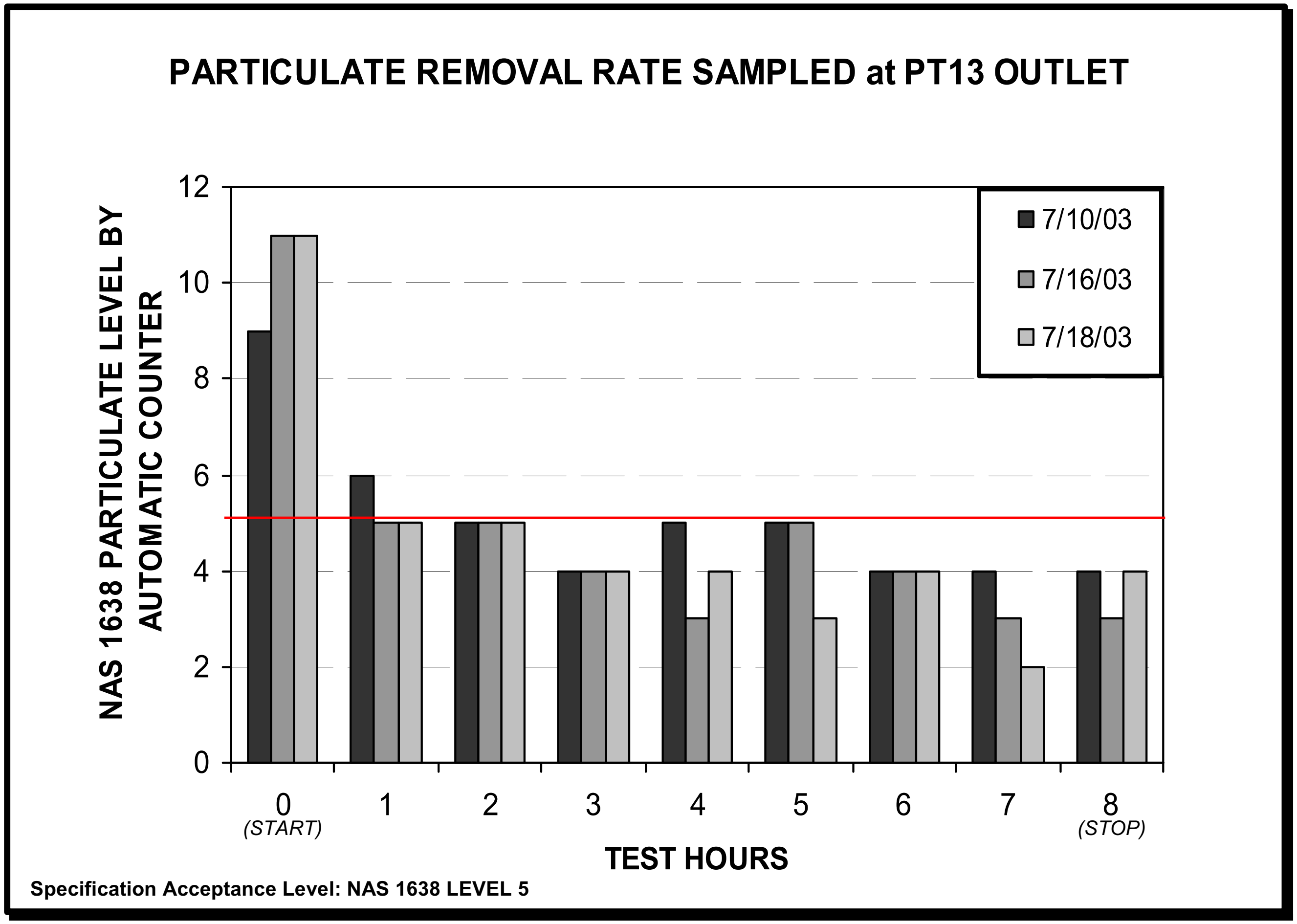
MALABAR
INTERNATIONAL
FLUID PURIFICATION BRIEFING; 16-18 November 2004

MALABAR Model HTS 2/D



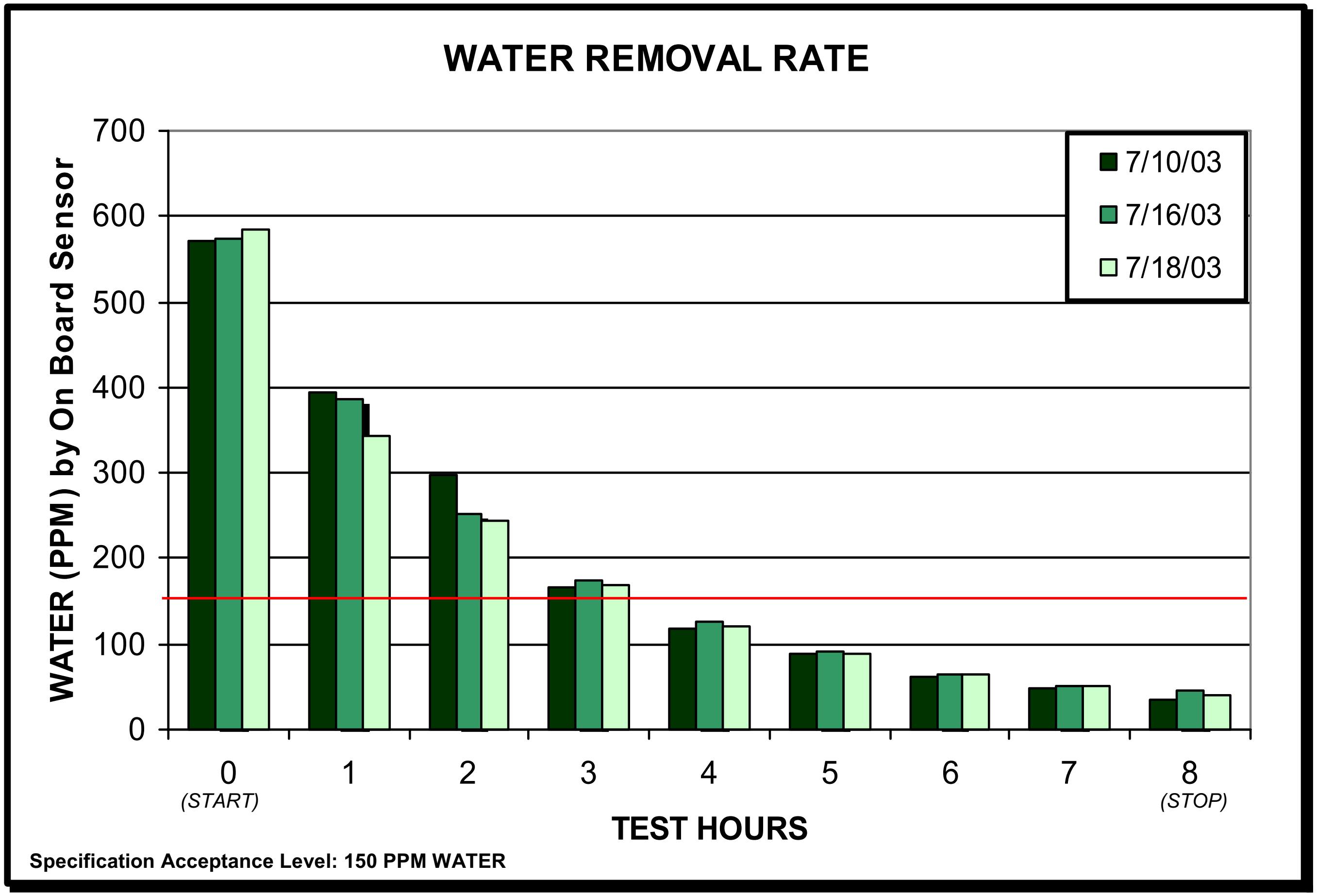
MALABAR
INTERNATIONAL
FLUID PURIFICATION BRIEFING; 16-18 November 2004

MALABAR Model HTS 2/D



MALABAR
INTERNATIONAL
FLUID PURIFICATION BRIEFING; 16-18 November 2004

MALABAR Model HTS 2/D



MALABAR
INTERNATIONAL
FLUID PURIFICATION BRIEFING; 16-18 November 2004

MALABAR TEST STAND ANALYTICAL DATA

7/10/2003

TEST	WATER (PPM)		CHLORINE ppm		% AIR	PARTICULATE NAS 1638		
HOURS	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	WATER (PPM)		CHLORINE ppm			% AIR	PARTICULATE NAS 1638		
HOURS	METER	KF	RUN 1	RUN 2	AVG	by GC	PT12	PT13	OUTLET
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
6	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	WATER (PPM)		CHLORINE ppm			% AIR	PARTICULATE NAS 1638		
HOURS	METER	KF	RUN 1	RUN2	AVG	by GC	PT12	PT13	OUTLET
0	584	455	293	293	293	12	11	11	11
1	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

U S A F

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

Hydraulic Fluid Purification Requirements

June 2006

U.S. AIR FORCE
AERONAUTICAL SYSTEMS CENTER

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

HFP IPT REQUIREMENTS

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

HFP IPT

- **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

HFP IPT

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

U.S. AIR FORCE

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**

HFP IPT

- 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

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- **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

Dominant Air Power: Design For Tomorrow…Deliver Today

- **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

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- **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

Field Requirements (Cont'd)

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- 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

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QUESTIONS?

Hydraulic Fluid Purification

927 ARW Aircraft Charts

KEVIN HIBBS
927 MXG
DSN: 273-5179

OVERVIEW

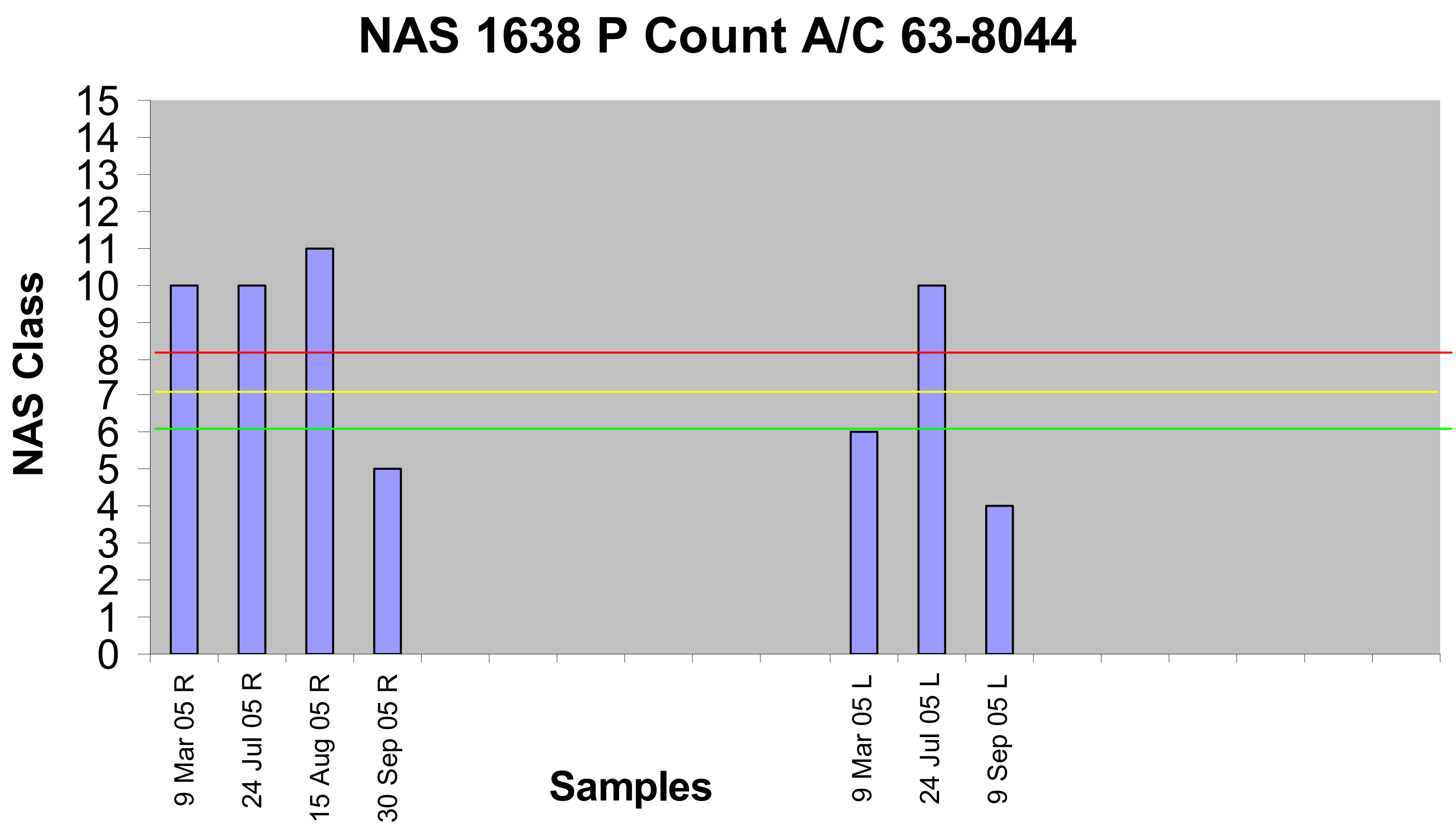
- Procedures
- Particle and water count
- Aircraft and Mule Results
- Results of initial samples indicate some samples may have been improperly taken. Or Mule contaminating our aircraft.
- Easy to contaminate sample when taken
- Shop Test Stand
- Barrel Sampling

Aircraft purification Procedures

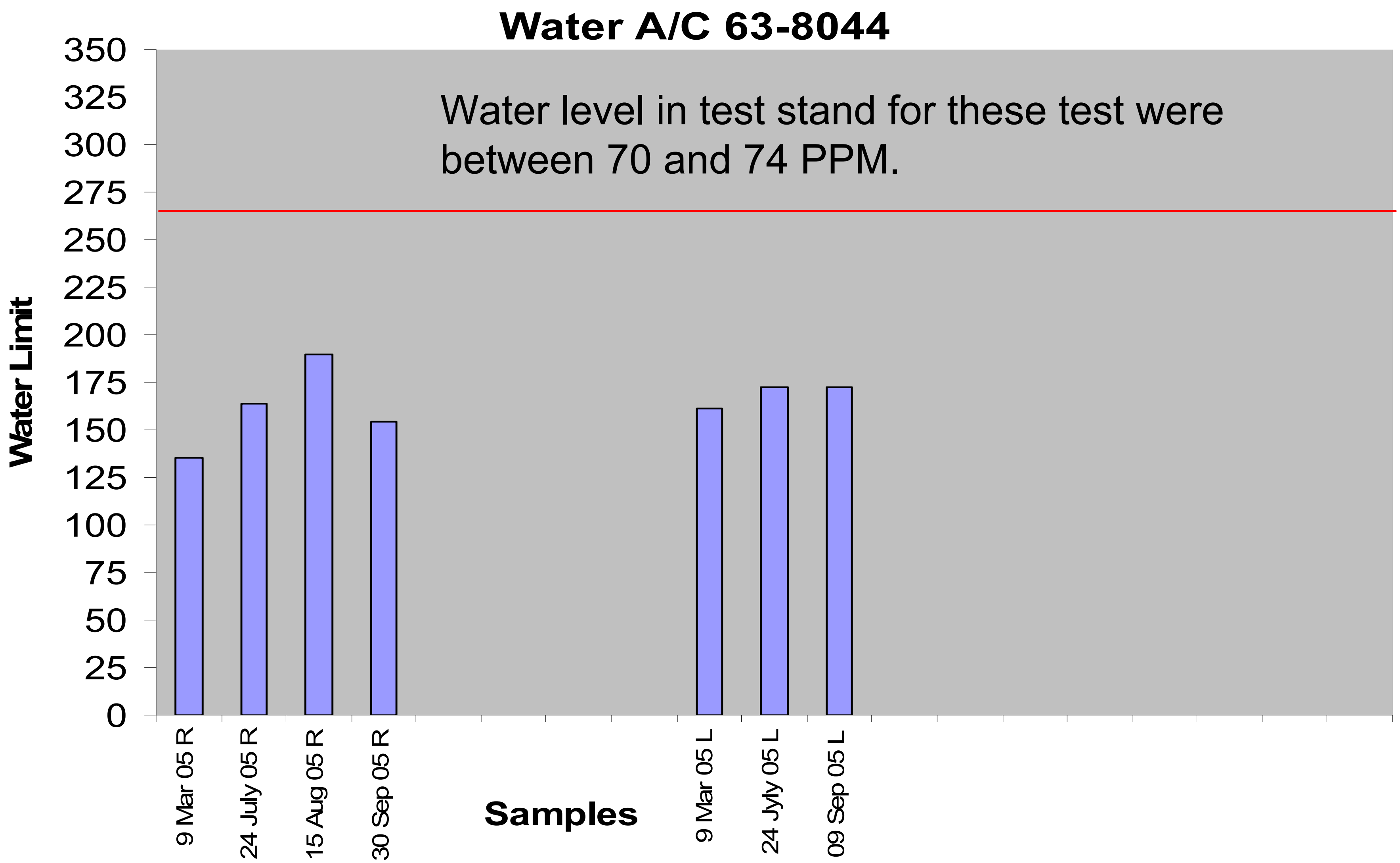
- Purifying minimum of two hours:
- Fluid level to twenty-five gallons:
- Best course of action:
- Initial purification procedures:

Tracking

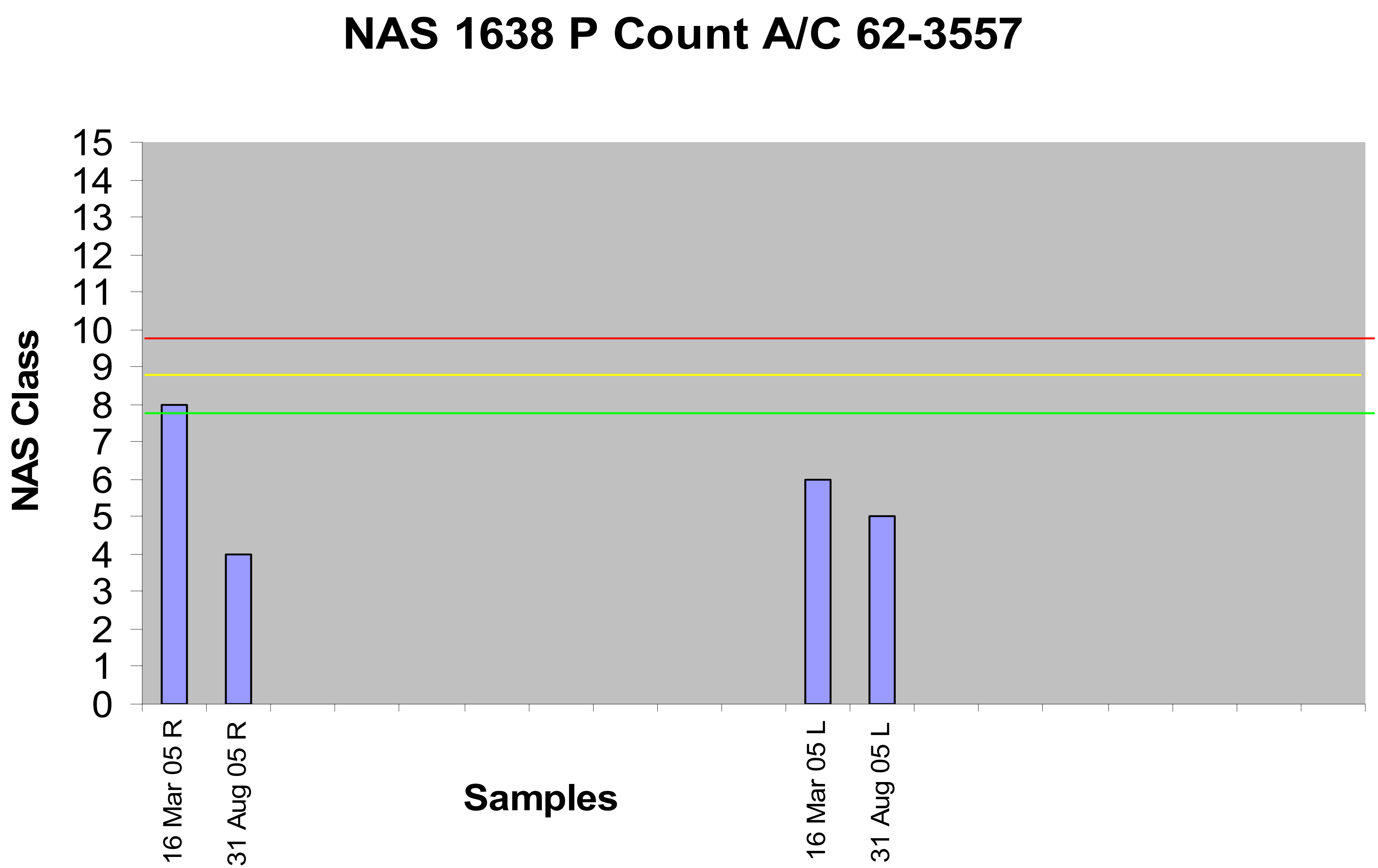
- AFTO form 22 submitted:
- Landing gear sample results
- Mule Samples
- Aircraft Samples
- Waste Drum Samples



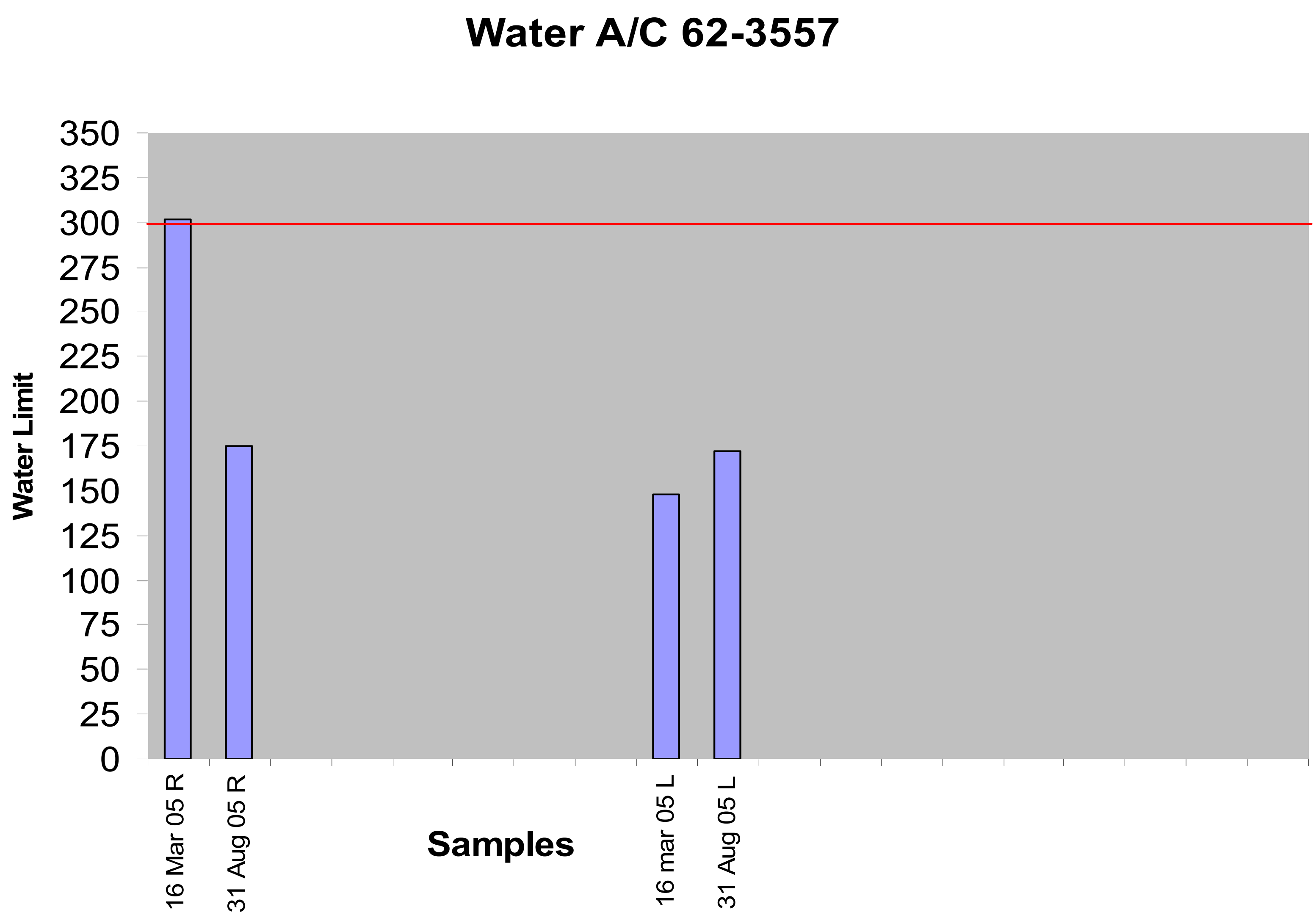
- Right System particle level high, Multi sensor would have been a great benefit.
- Second samples may have been contaminated during sampling or contaminated by the mule



- Water levels are increasing, we are trying to figure out why.
- Levels remain well within acceptable levels.

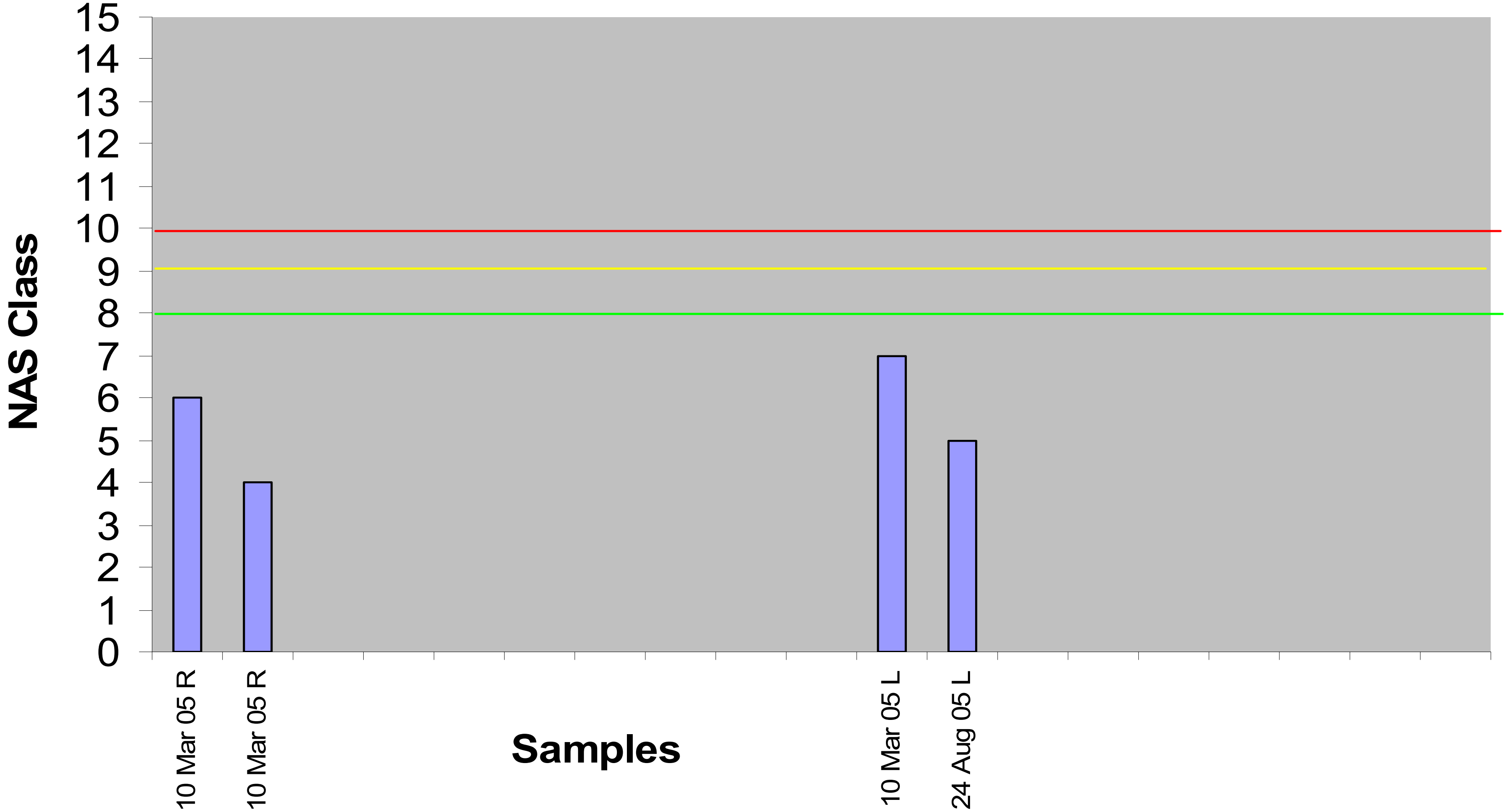


- This was one of the first aircraft we purified
- We experimented with different purification cycle times

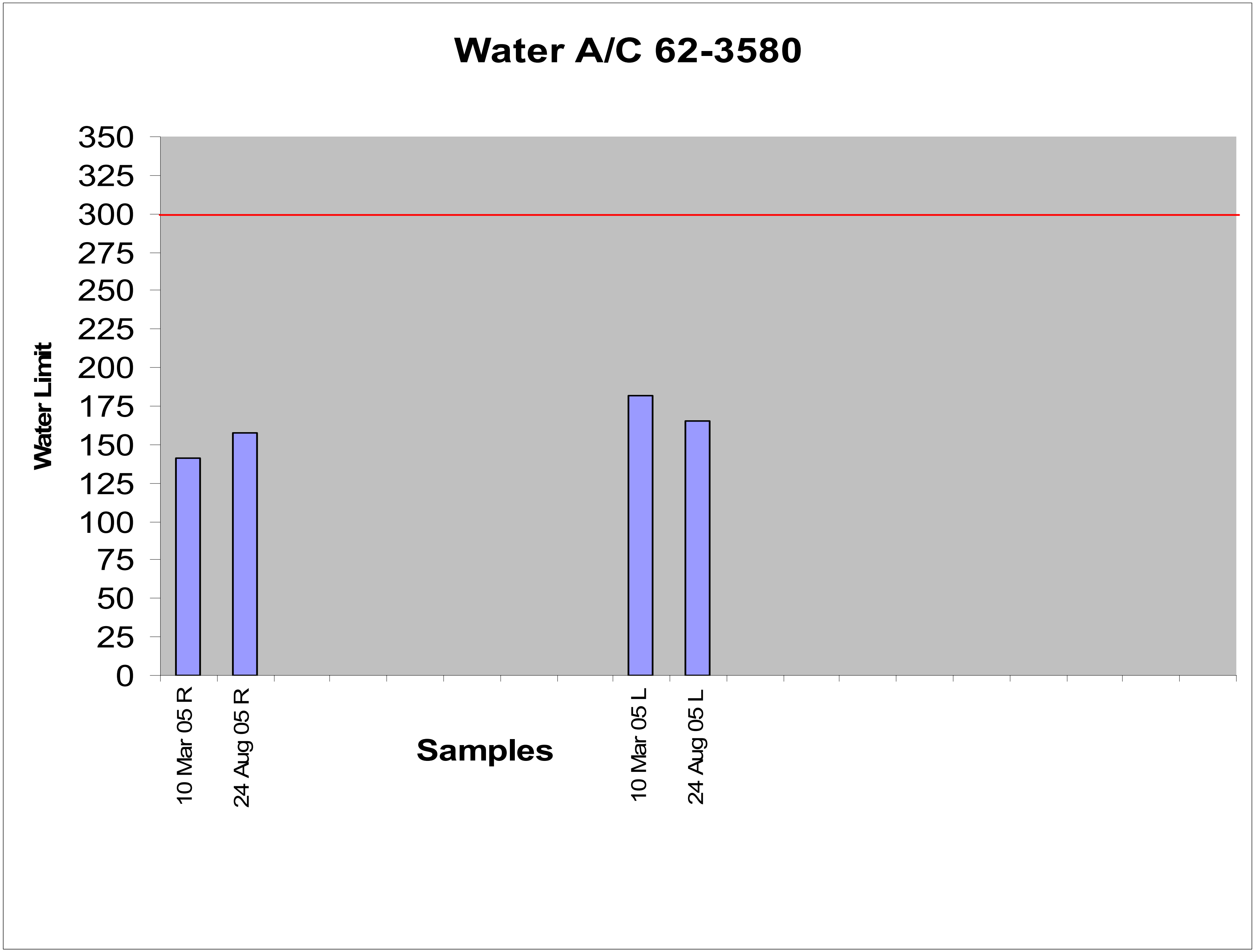


- We were above the PPM limit on the right side, did come down.
- We feel that both sides could be better.

NAS 1638 Particle Count A/C 62-3580



- This aircraft was initially clean, the results still show that purification works


Water A/C 62-3580
Water Limit
350
325
300
275
250
225
200
175
150
125
100
75
50
25
0
10 Mar 05 R
24 Aug 05 R
Samples
10 Mar 05 L
24 Aug 05 L

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

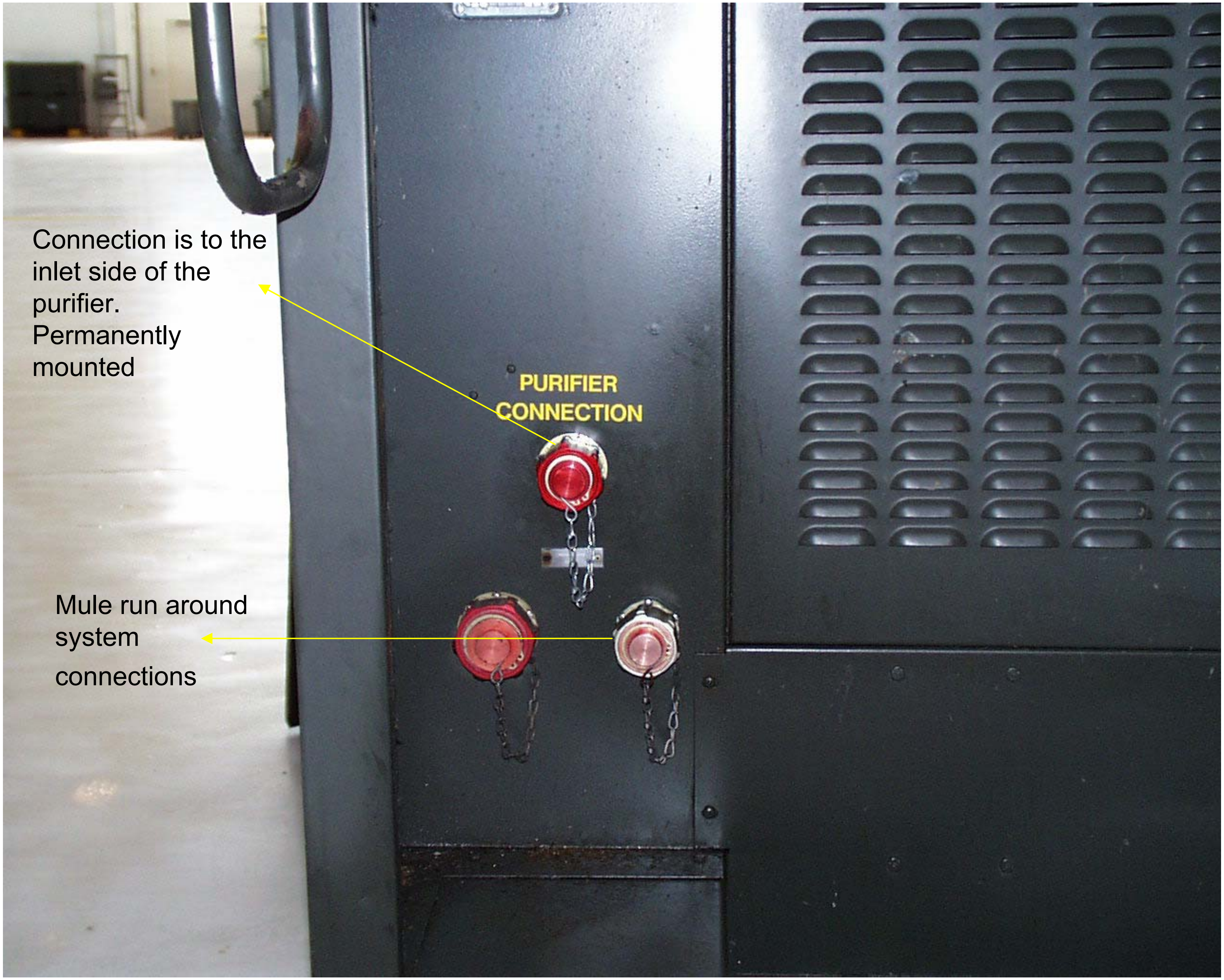
Test Stand Samples (Mule)

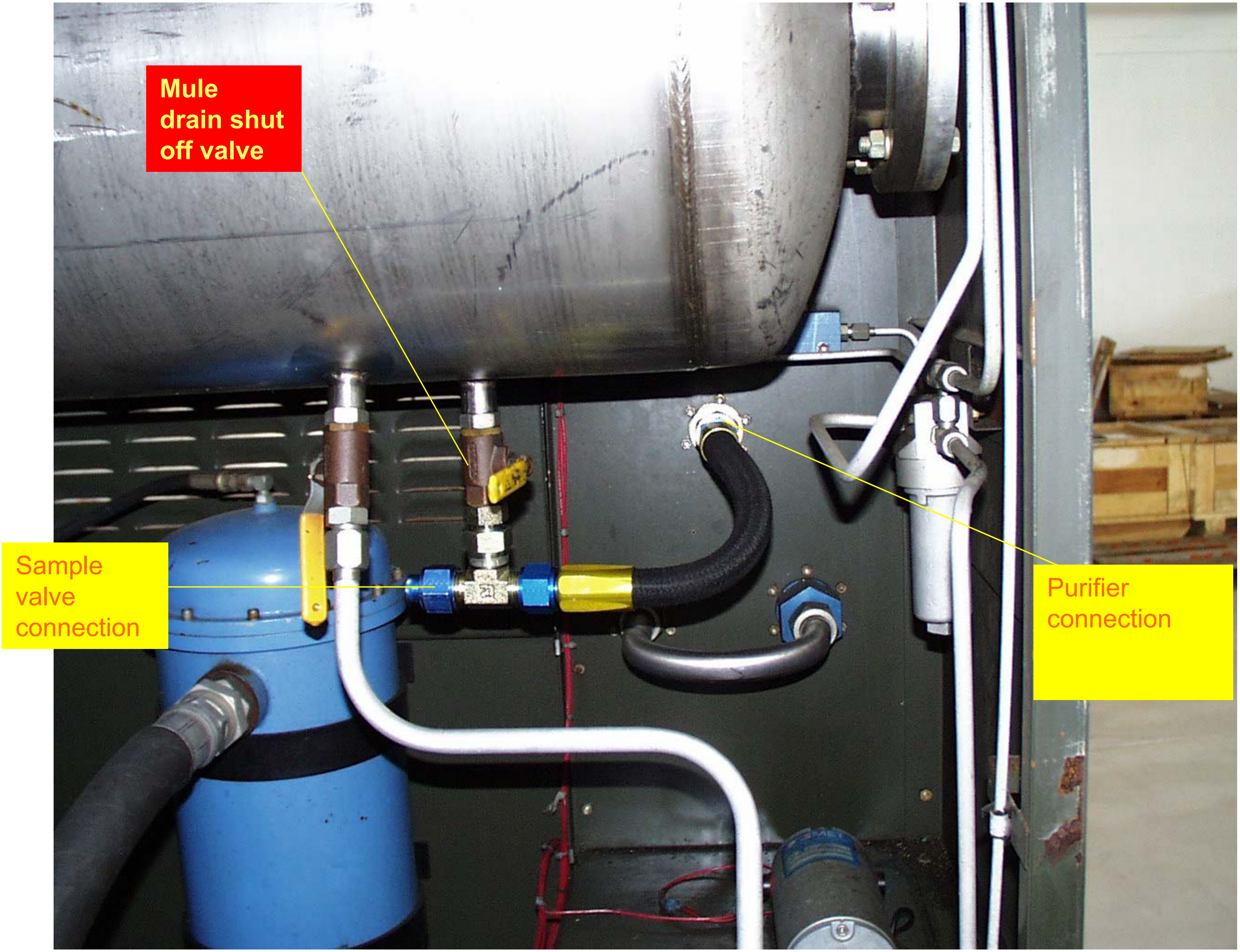
Single system units
Two Diesel, one Elect

Particle and Water count

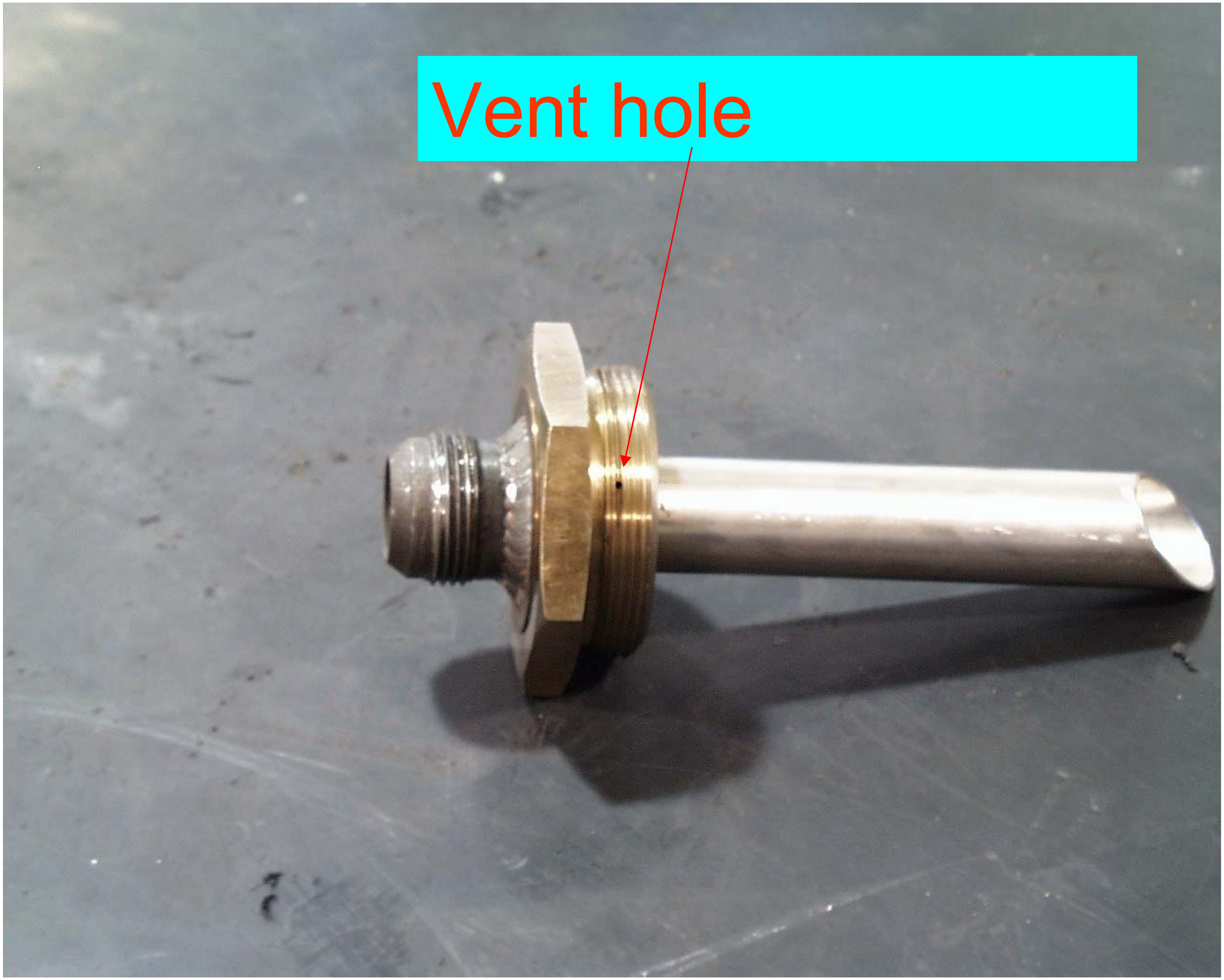
Introduction

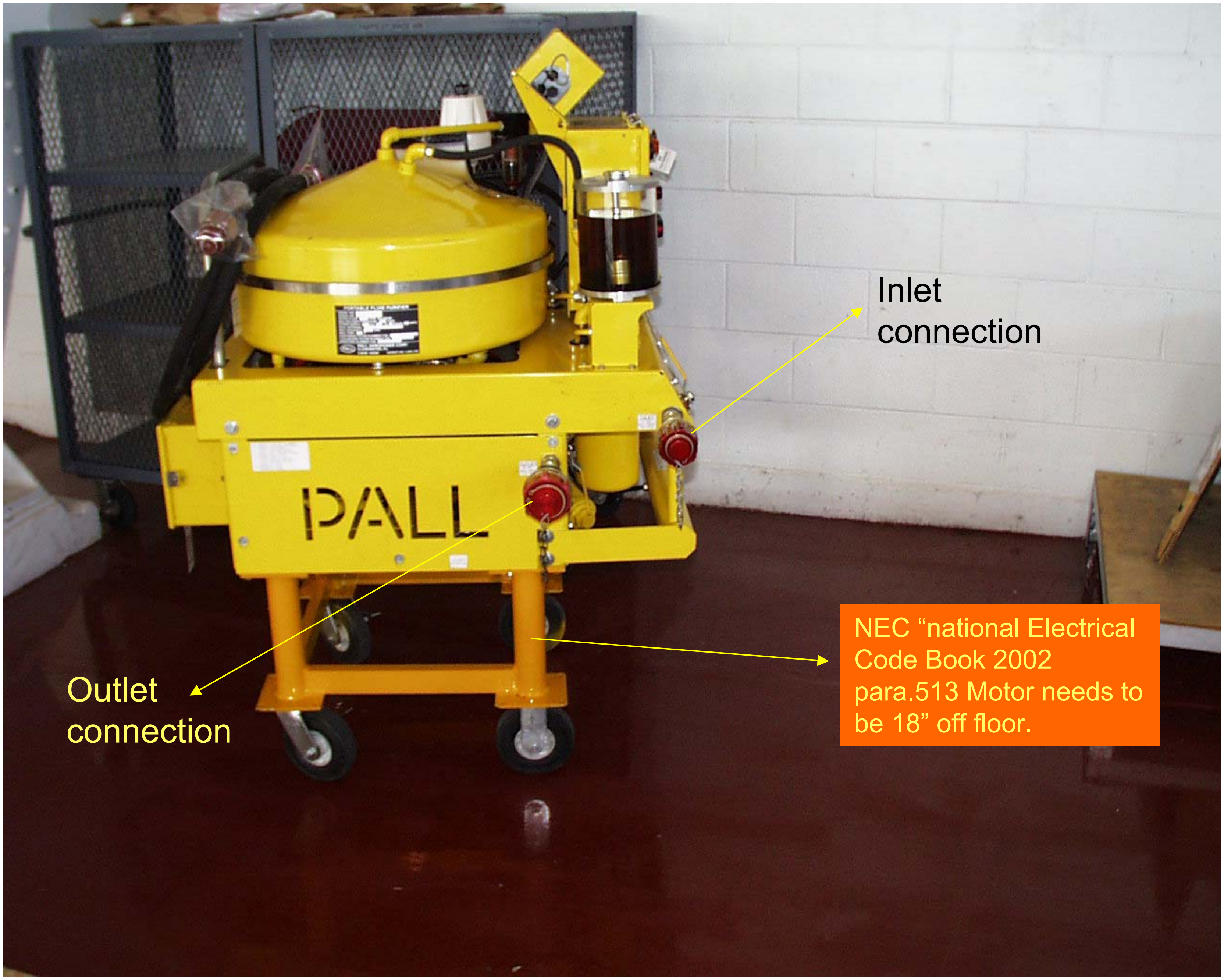
- How we modify the mules?
- How we connect to the purifier?
- How long did we purify test stands?
- Different methods?


Connection is to the inlet side of the purifier. Permanently mounted
PURIFIER CONNECTION
Mule run around system connections


Mule drain shut off valve
Sample valve connection
Purifier connection


Vent Hole


Vent hole

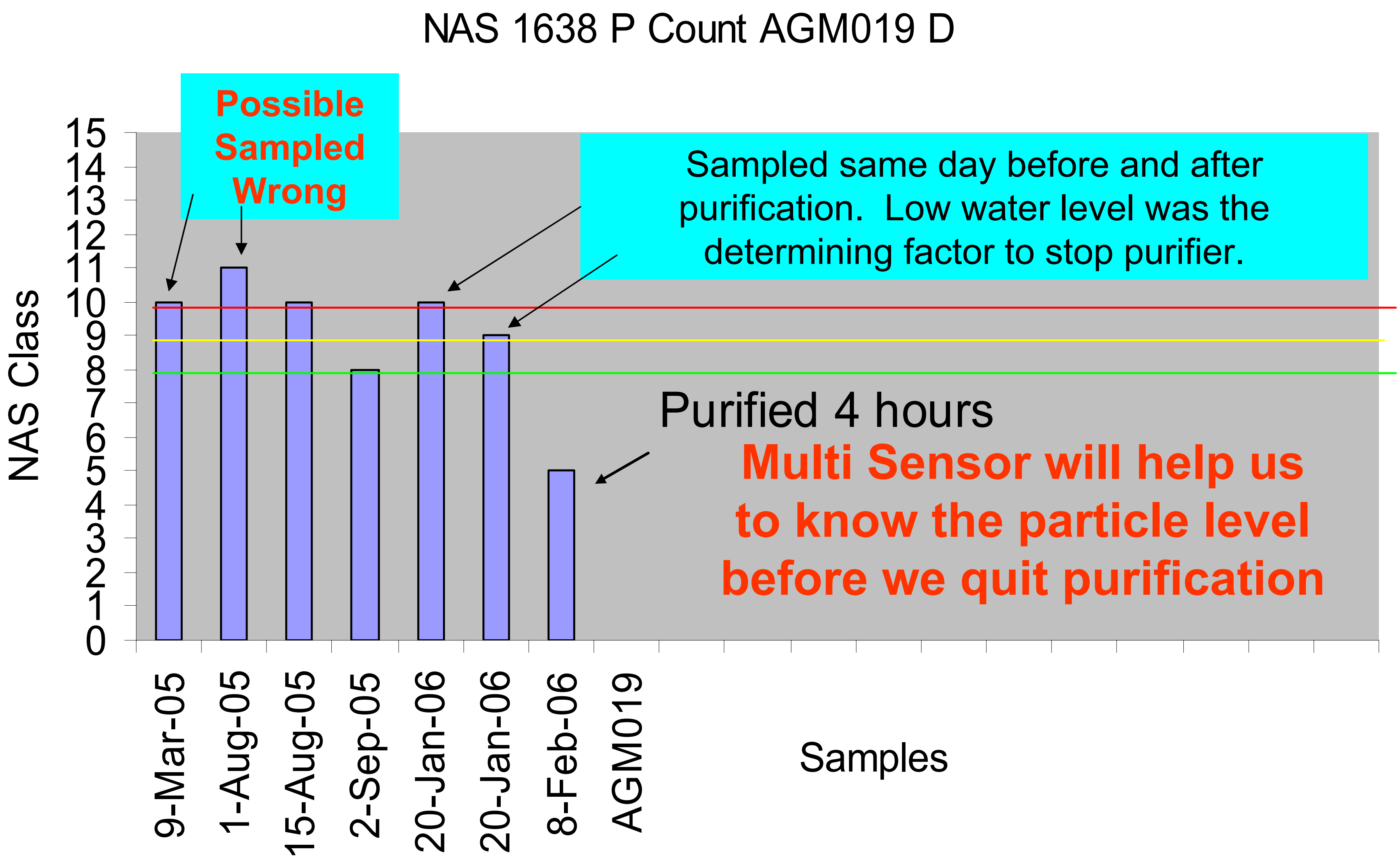

PALL
Inlet connection
NEC "national Electrical Code Book 2002 para.513 Motor needs to be 18" off floor.
Outlet connection


Inlet
connection
Outlet
connection
PALL

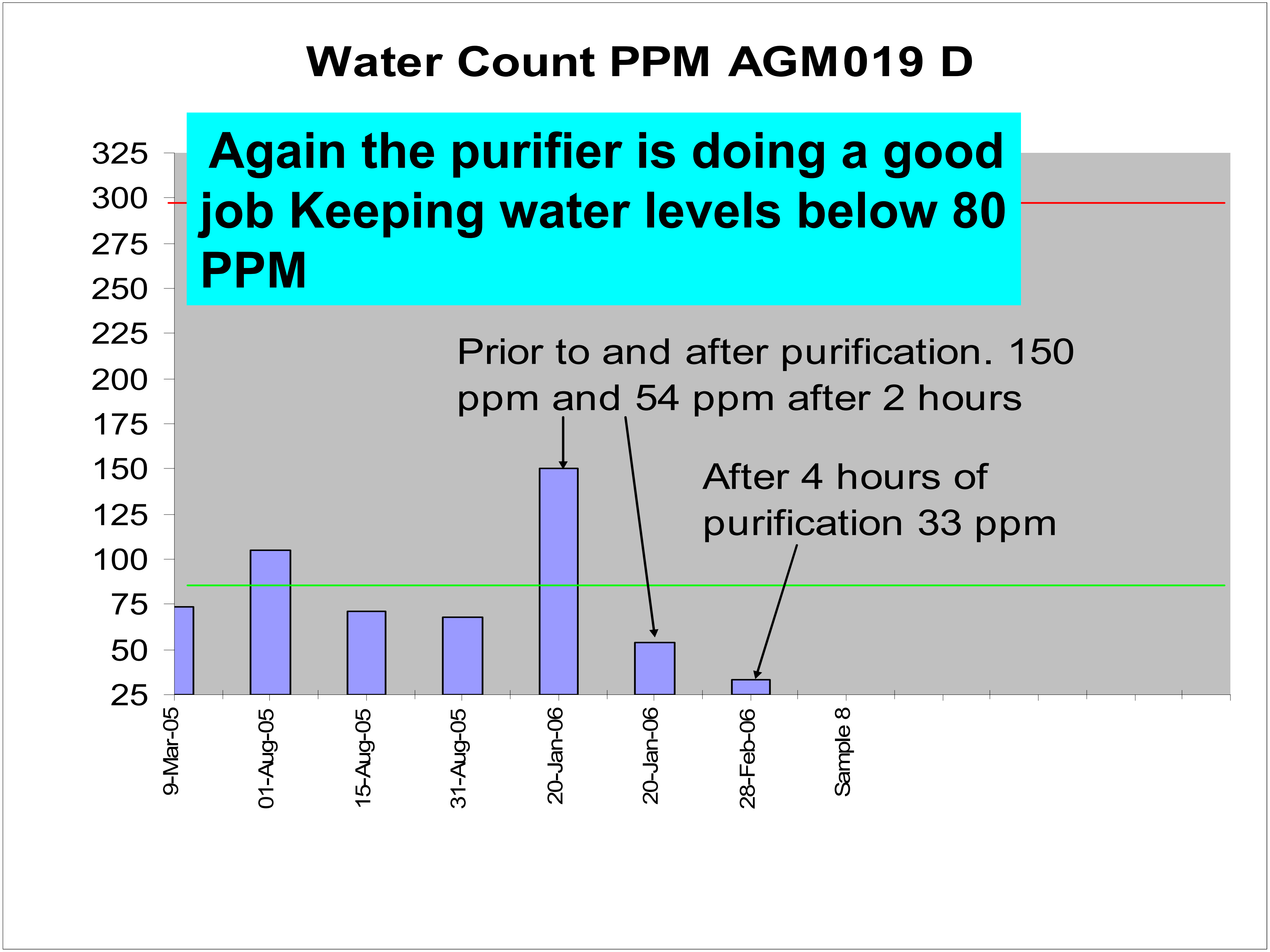

This is the inlet connection to the purifier unit from the elect mule Item goes into the reservoir fill neck.
Also connection for drum purification if ever authorized.

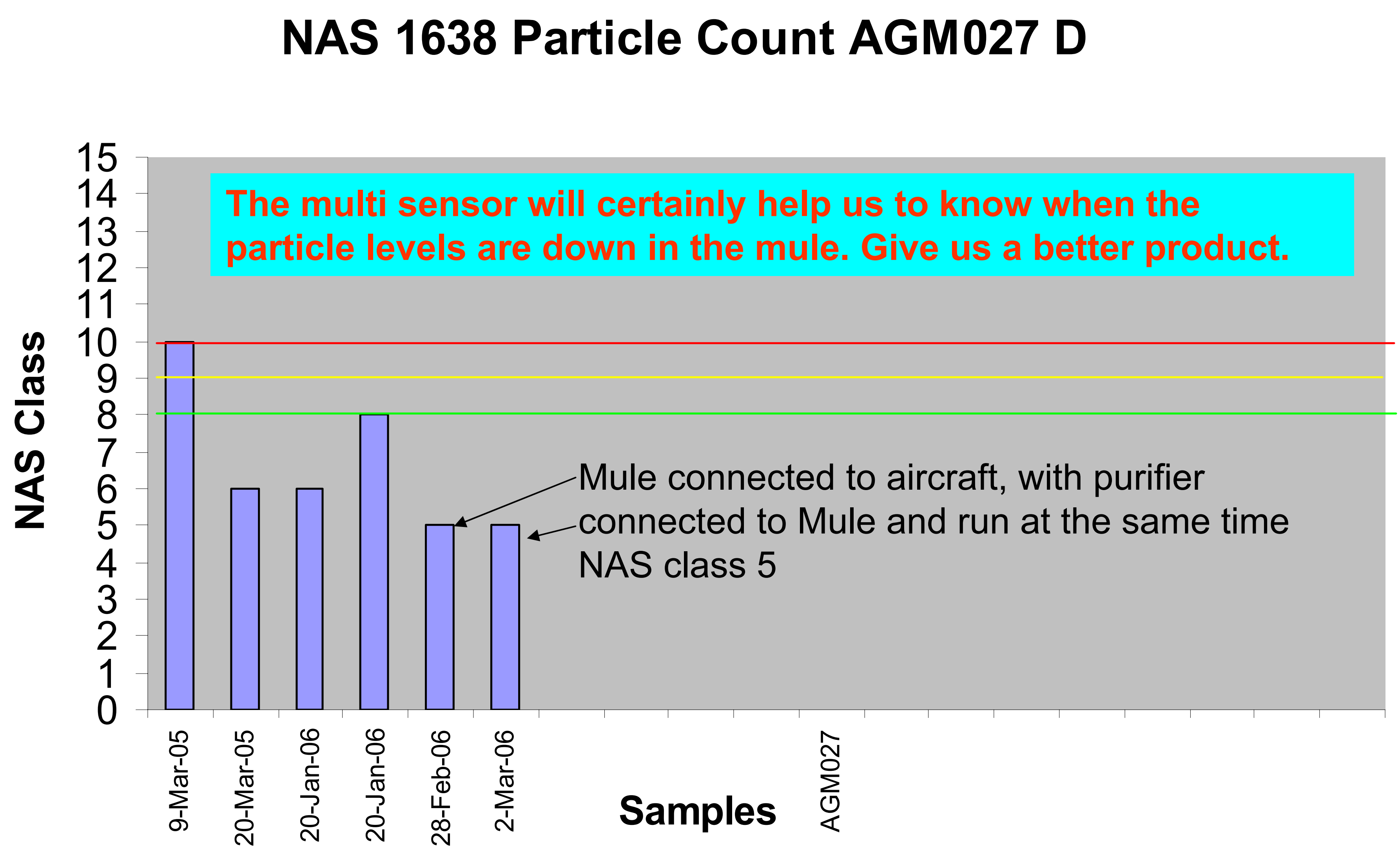
Elect Mule connections proposed

Elect Mule purification connections proposed



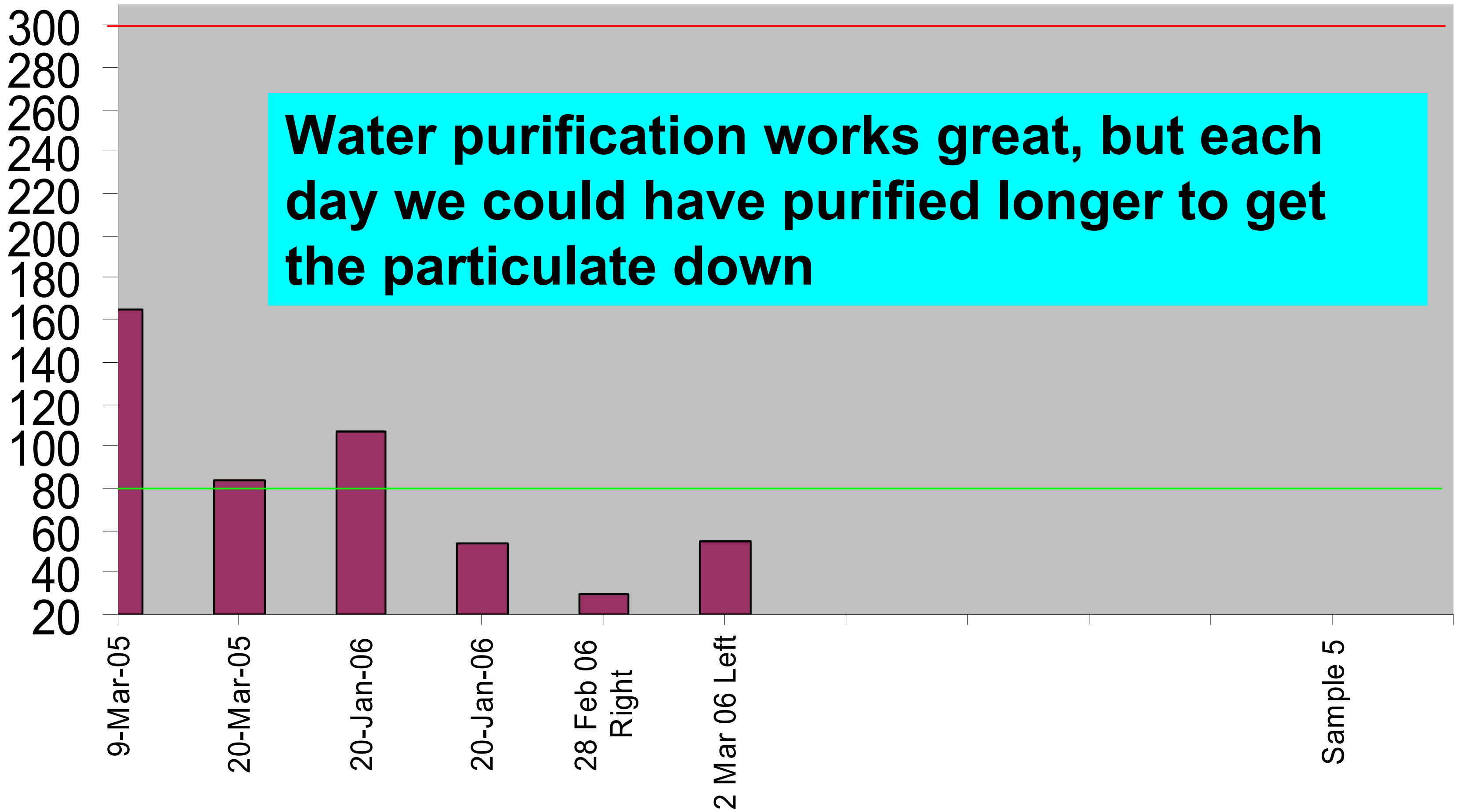
- Particle count remaining high with 2 hour purification
- Switching to using the runaround system for 15-20 minutes prior to and during the purification process.


Water Count PPM AGM019 D
Again the purifier is doing a good job Keeping water levels below 80 PPM
Prior to and after purification. 150 ppm and 54 ppm after 2 hours
After 4 hours of purification 33 ppm
325
300
275
250
225
200
175
150
125
100
75
50
25
9-Mar-05
01-Aug-05
15-Aug-05
31-Aug-05
20-Jan-06
20-Jan-06
28-Feb-06
Sample 8

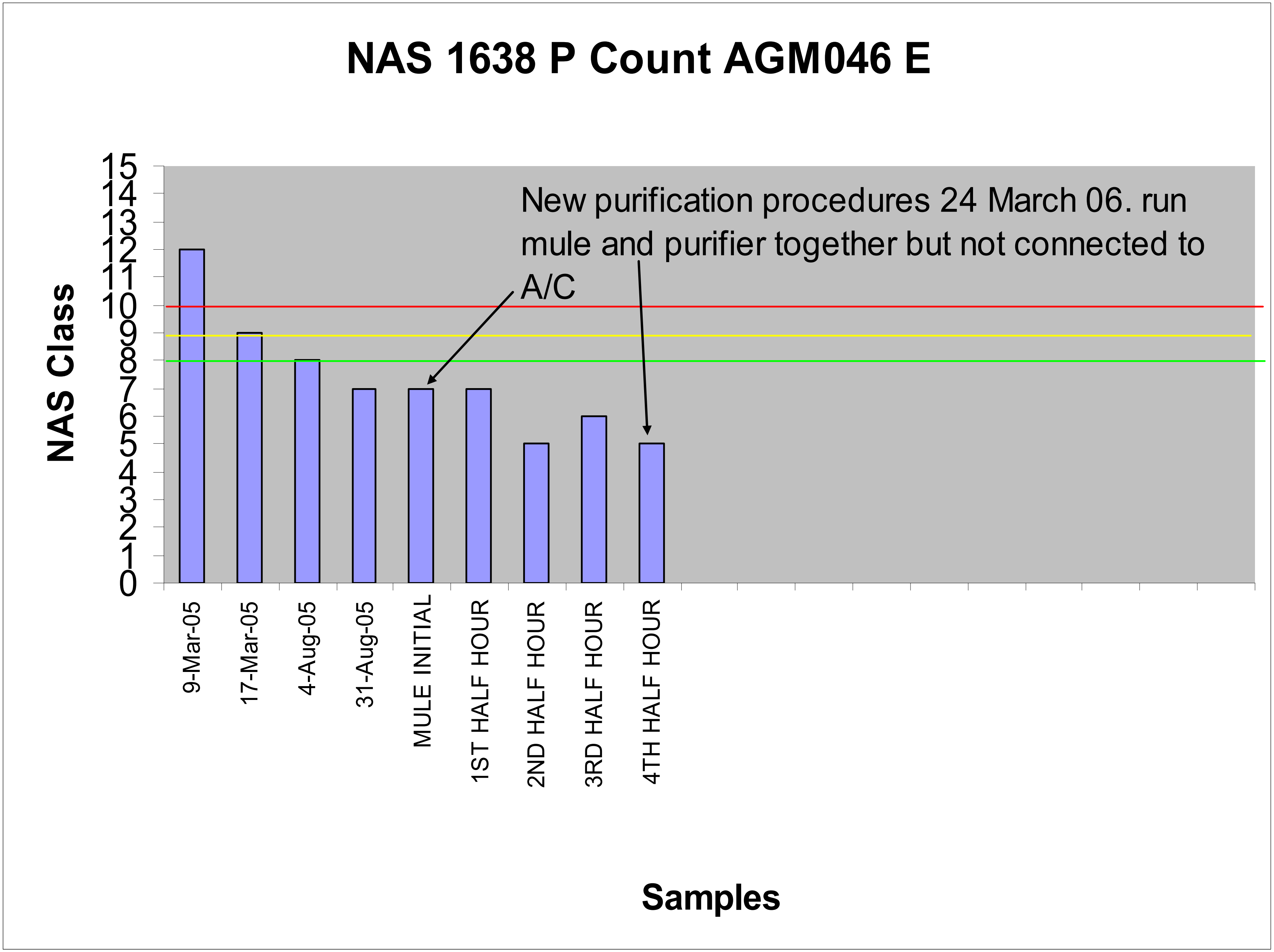


This is a diesel mule, we were having better luck on keeping it clean at two hours. The last two results were with using the runaround system with purification for the first time.

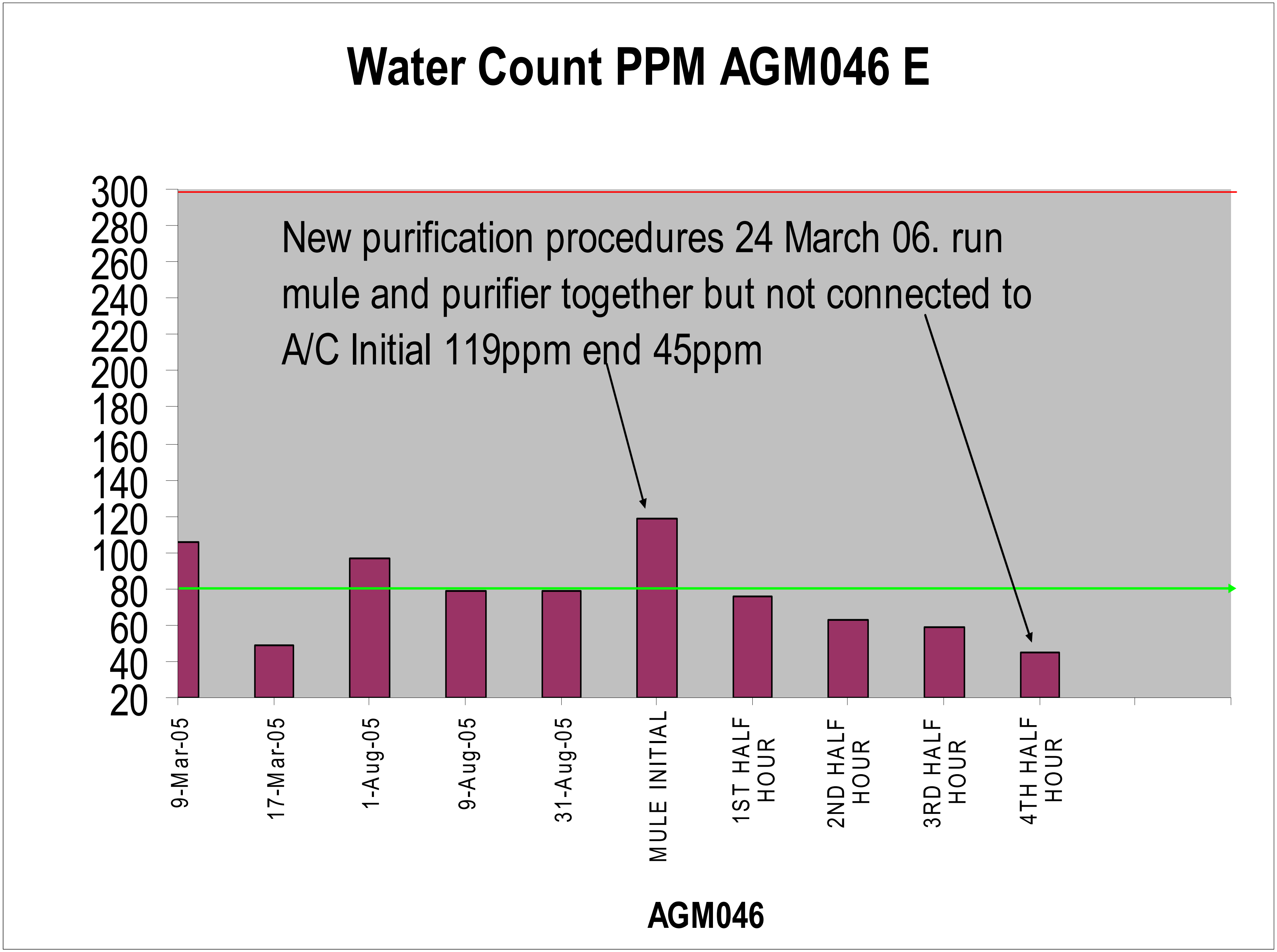
Water Count PPM AGM027 D



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



NAS 1638 P Count AGM046 E
NAS Class
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
New purification procedures 24 March 06. run mule and purifier together but not connected to A/C
9-Mar-05
17-Mar-05
4-Aug-05
31-Aug-05
MULE INITIAL
1ST HALF HOUR
2ND HALF HOUR
3RD HALF HOUR
4TH HALF HOUR
Samples


Water Count PPM AGM046 E
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
New purification procedures 24 March 06. run mule and purifier together but not connected to A/C Initial 119ppm end 45ppm
9-Mar-05
17-Mar-05
1-Aug-05
9-Aug-05
31-Aug-05
MULE INITIAL
1ST HALF HOUR
2ND HALF HOUR
3RD HALF HOUR
4TH HALF HOUR
AGM046

Mule Summary

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

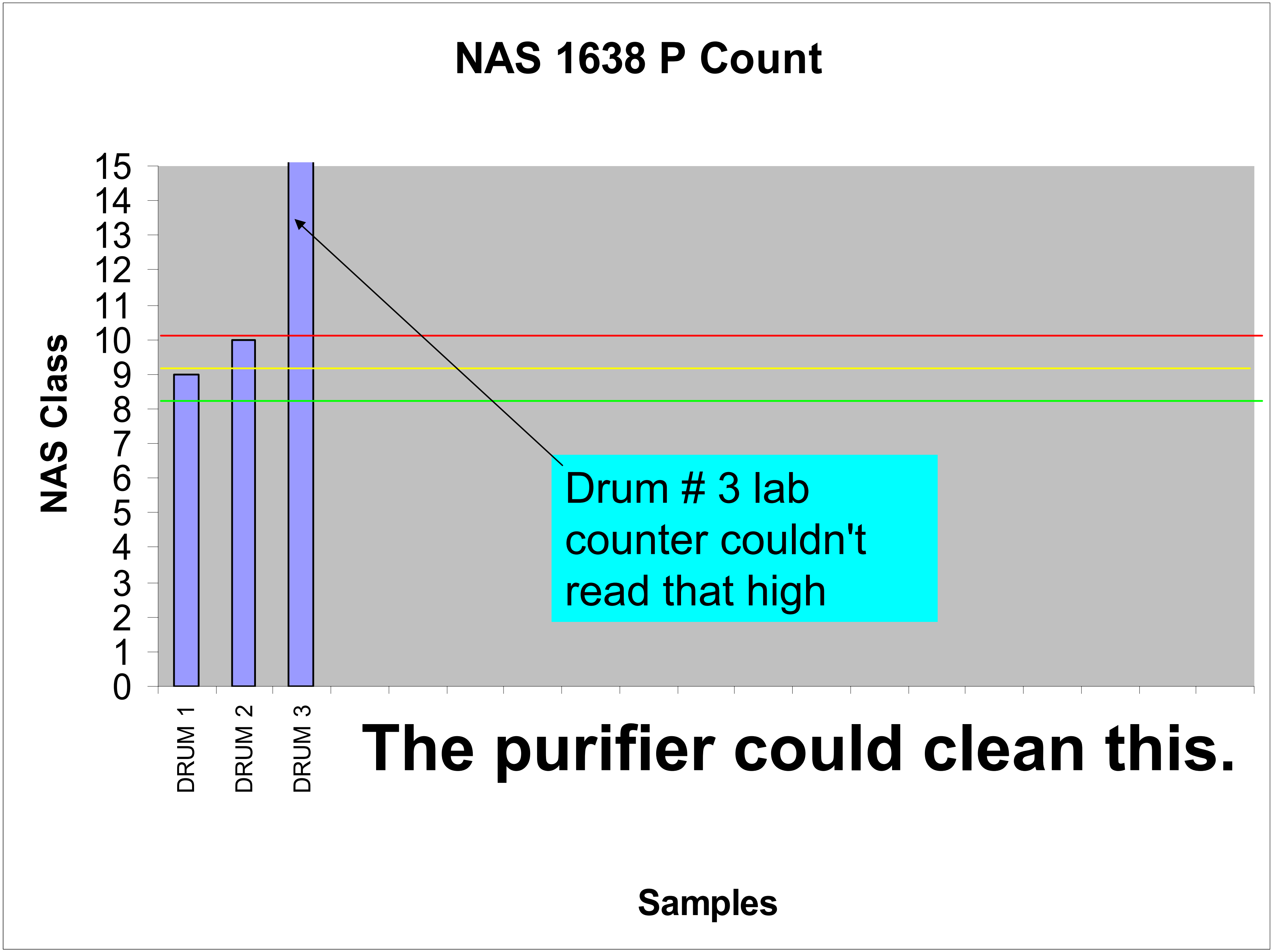
Hydraulic Shop Test Stand

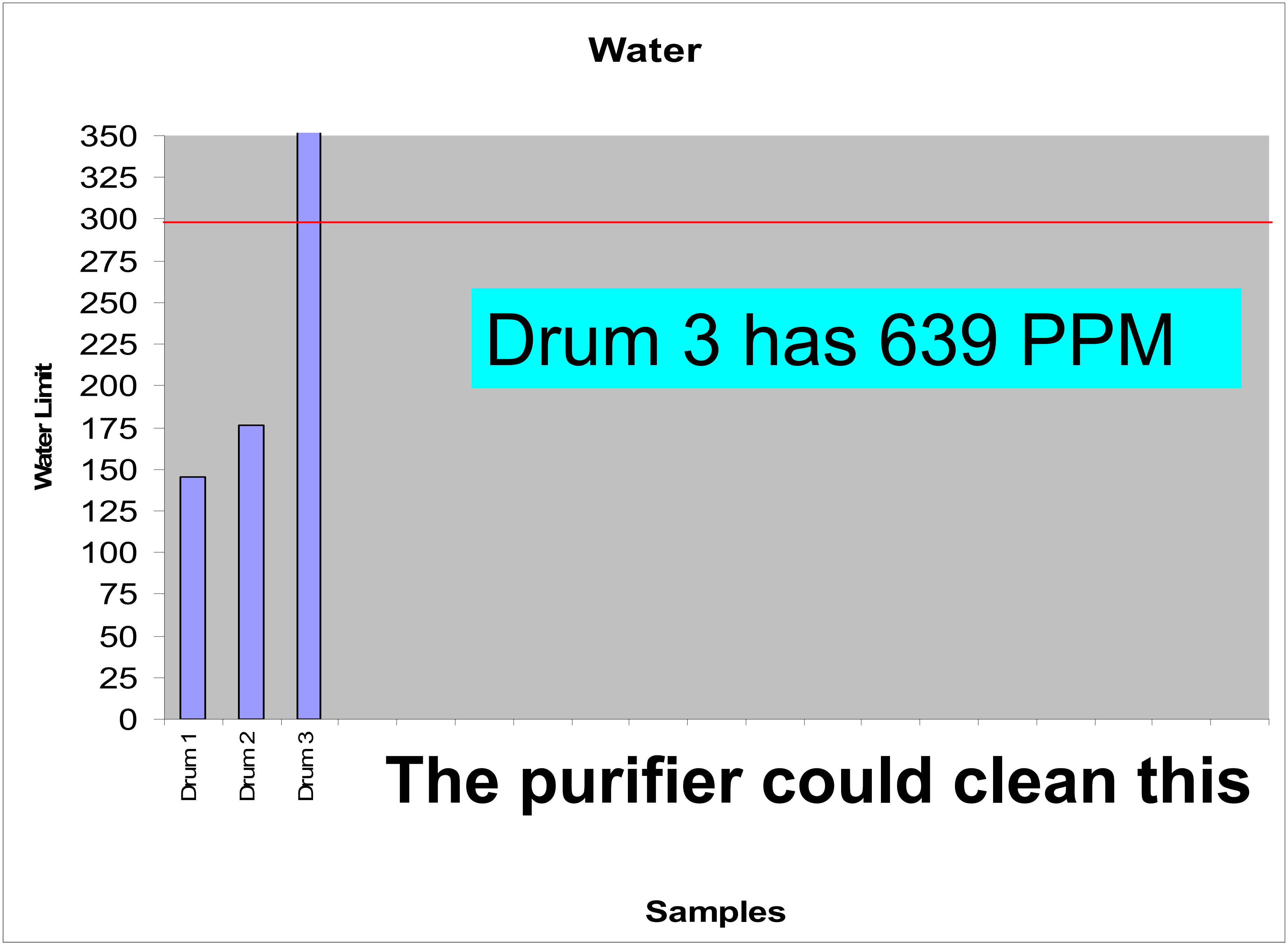
Particle and water count

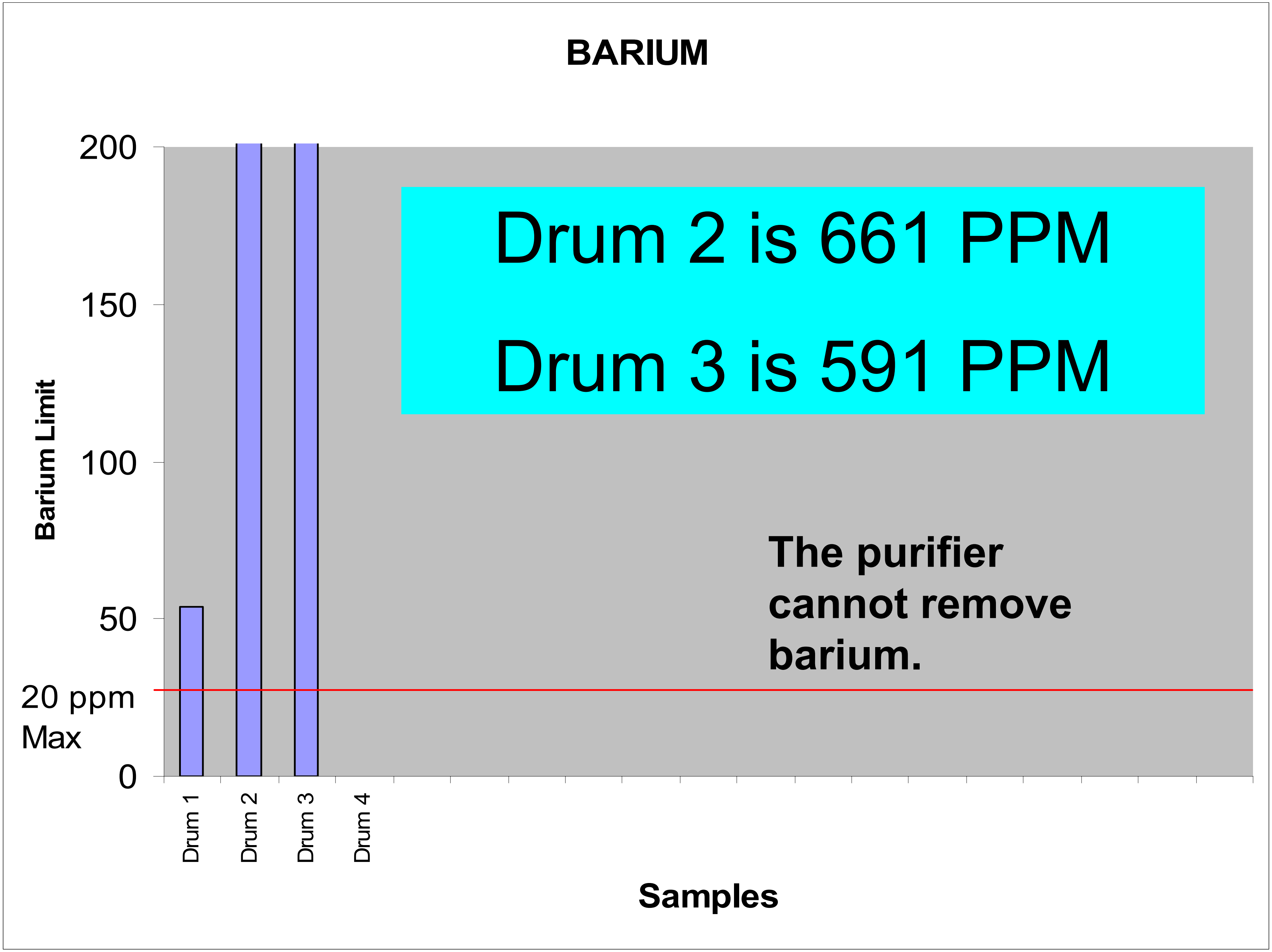
Waste Drum

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.


NAS 1638 P Count
NAS Class
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
DRUM 1
DRUM 2
DRUM 3
Drum # 3 lab counter couldn't read that high
The purifier could clean this.
Samples


Water
350
325
300
275
250
225
200
175
150
125
100
75
50
25
0
Water Limit
Drum 3 has 639 PPM
Drum 1
Drum 2
Drum 3
The purifier could clean this
Samples


BARIUM
Drum 2 is 661 PPM
Drum 3 is 591 PPM
The purifier cannot remove barium.
Barium Limit
200
150
100
50
20 ppm Max
0
Drum 1
Drum 2
Drum 3
Drum 4
Samples

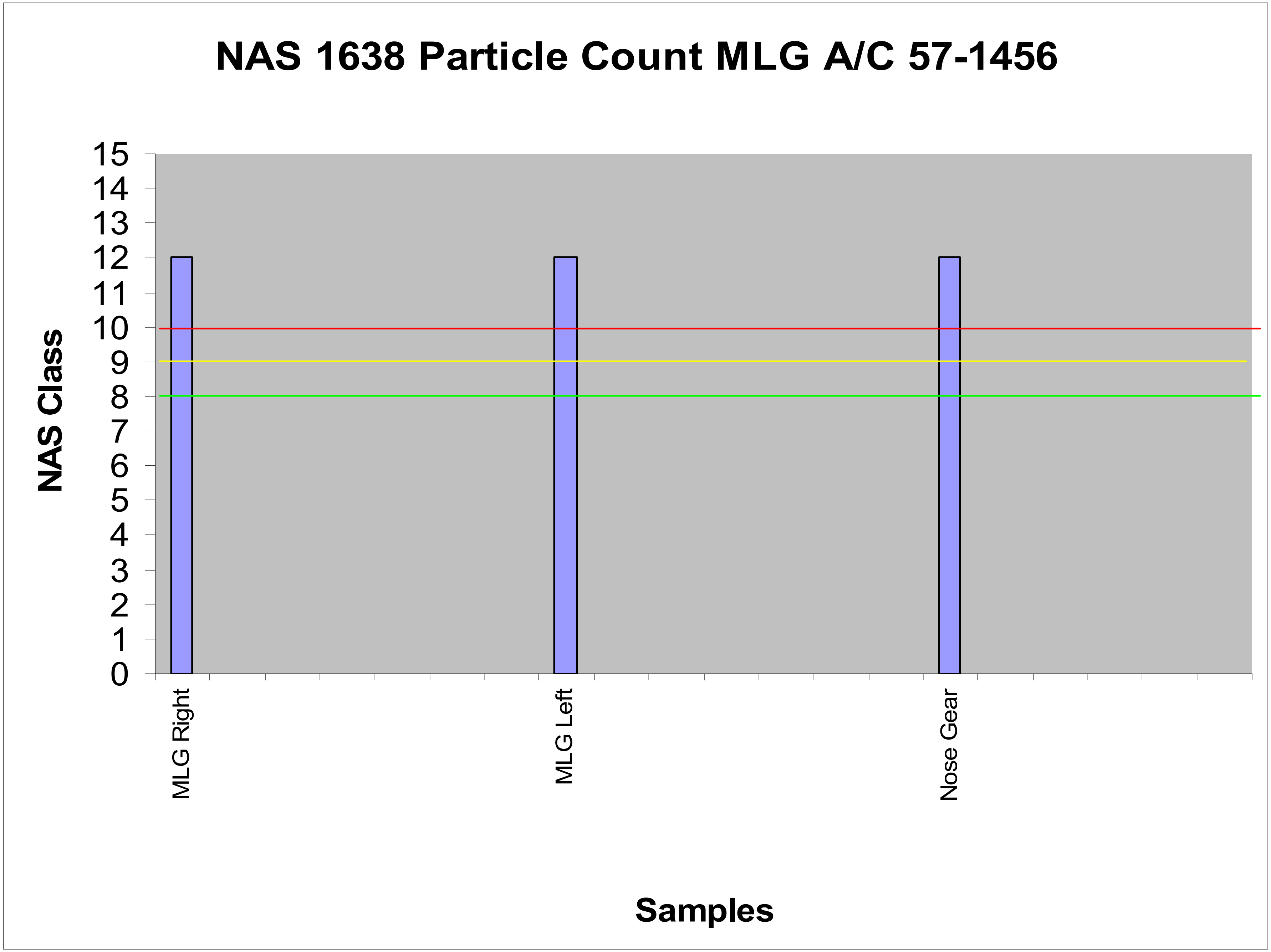
CONCLUSION

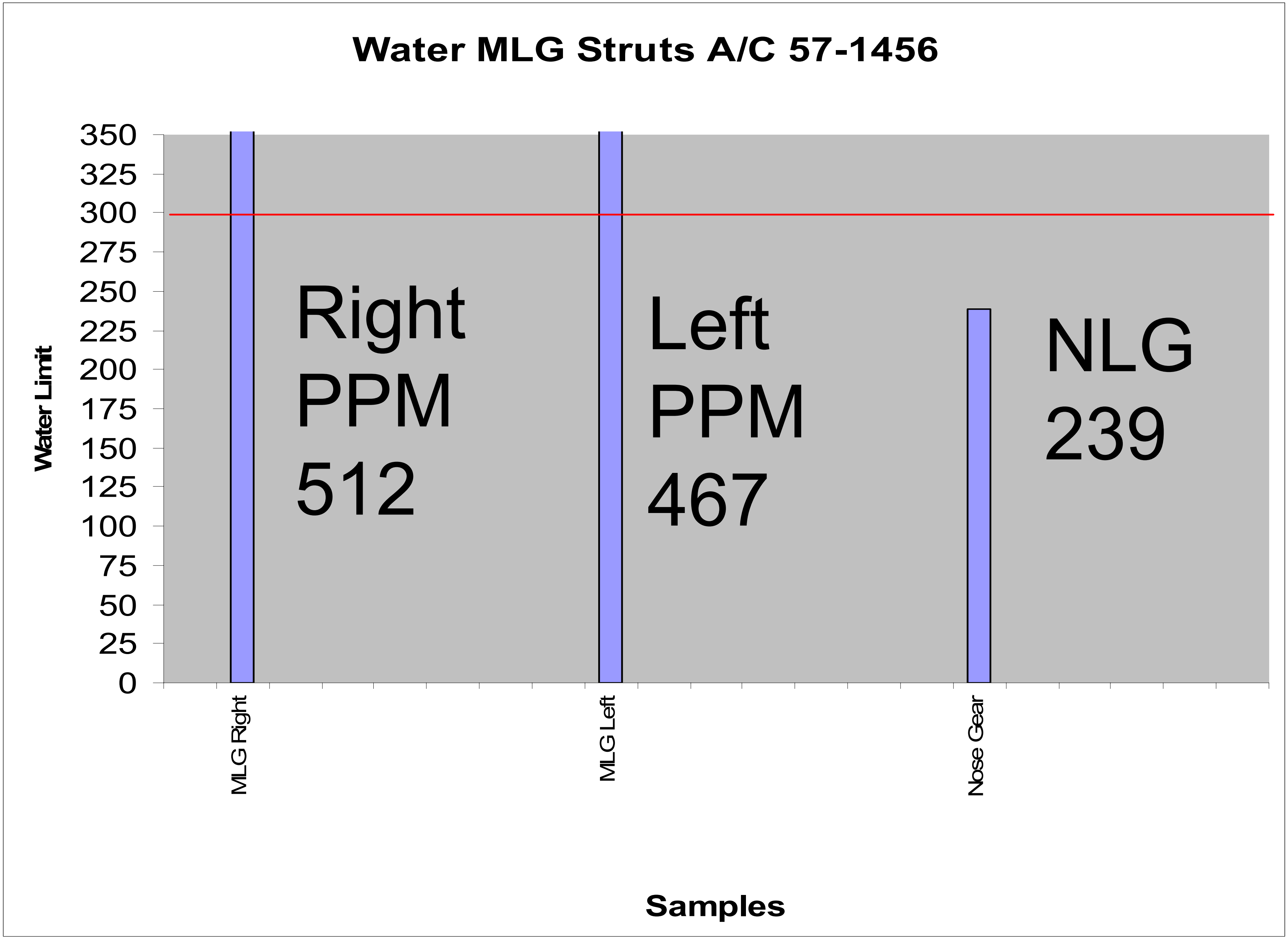
- Barium is coming from MIL-PRF-6083. located within our landing gear hydraulic struts, and components.
- If we can control the use of 46170 and 6083 we could control the drum fluids and purify them.

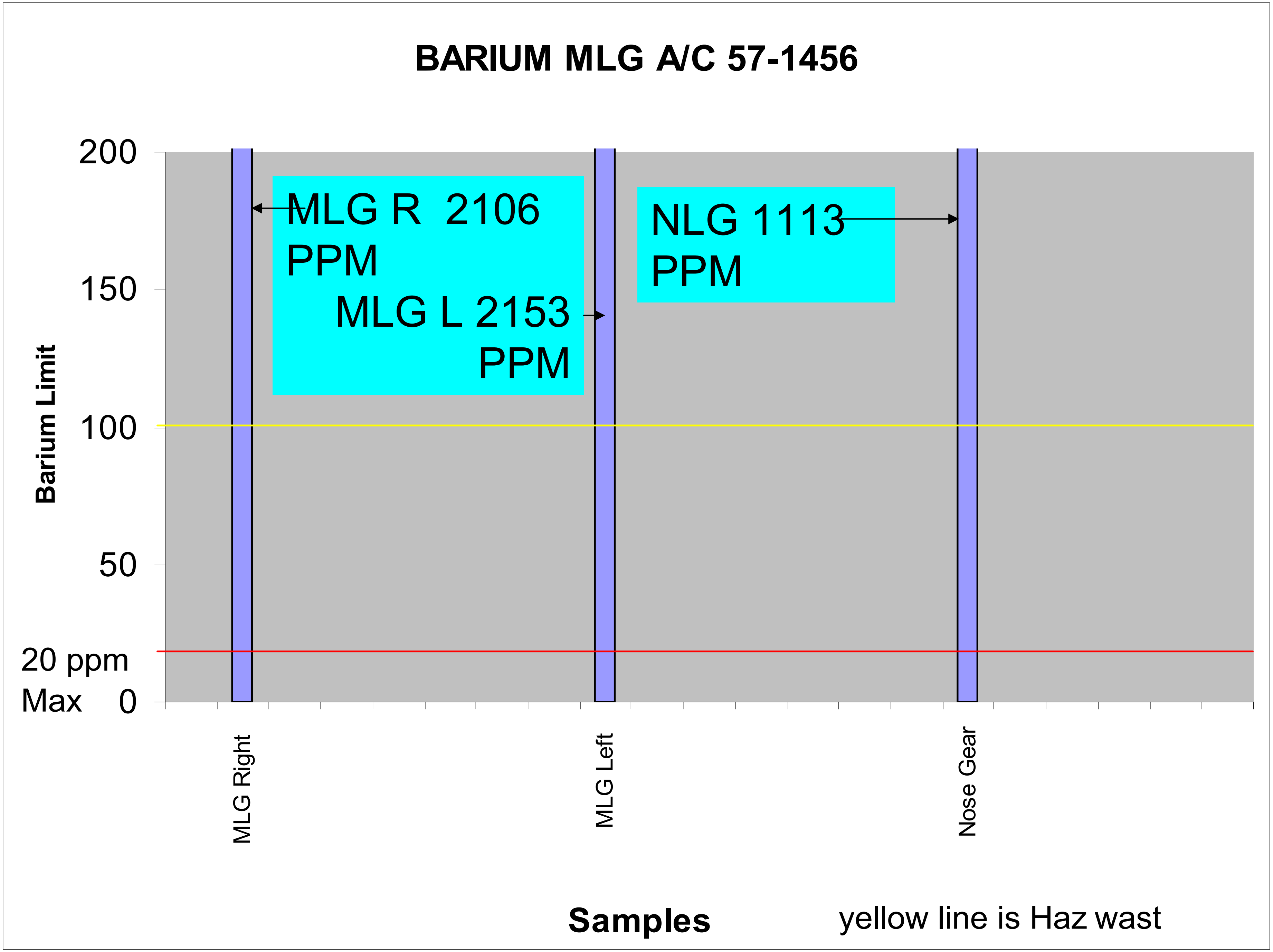
- We must drain components that are serviced with 46170 and 6083.

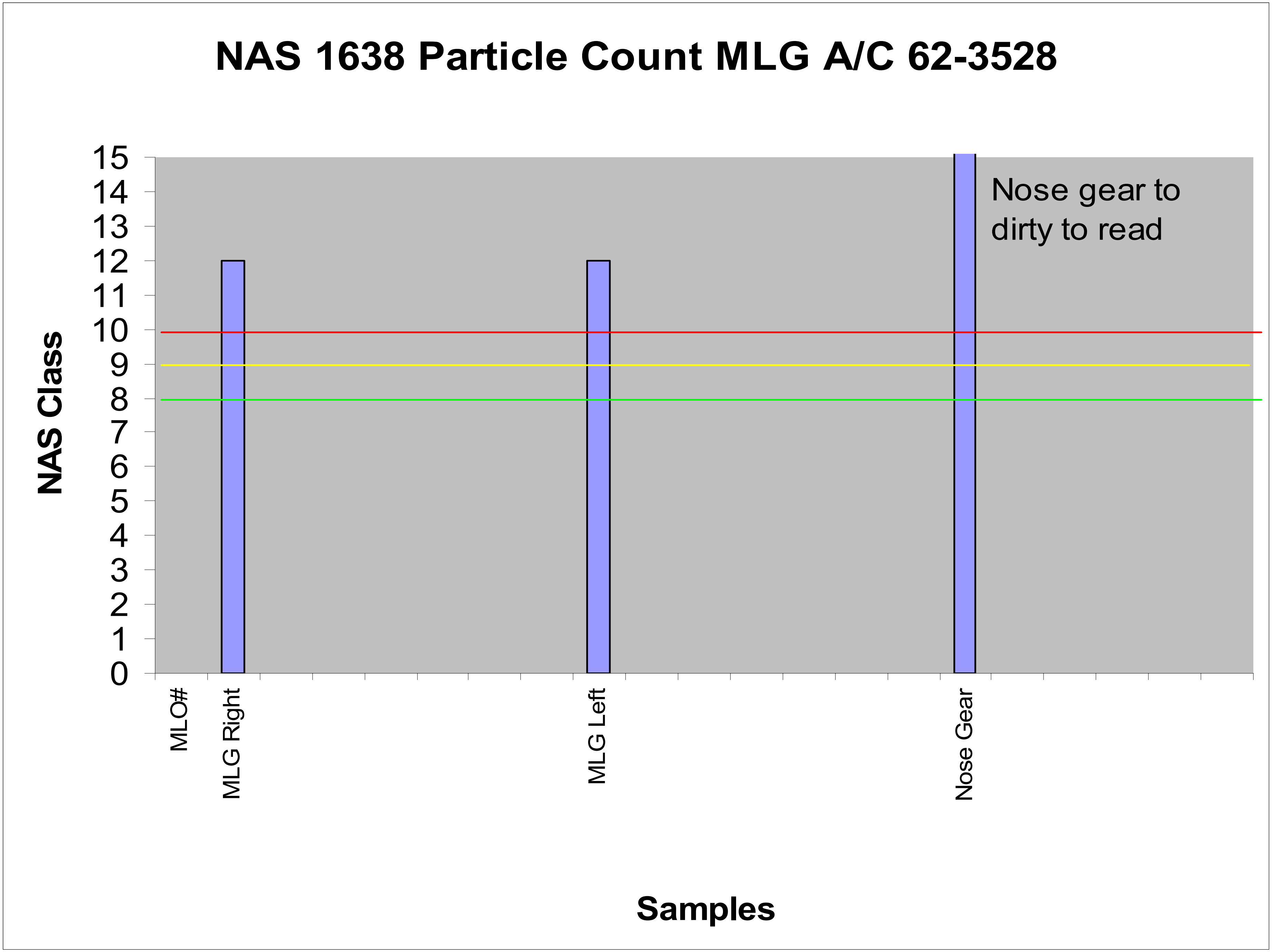
- We have to get the depots to stop using 46170 and 6083. Received two struts dated Mar 06 with 6083 fluid in them.

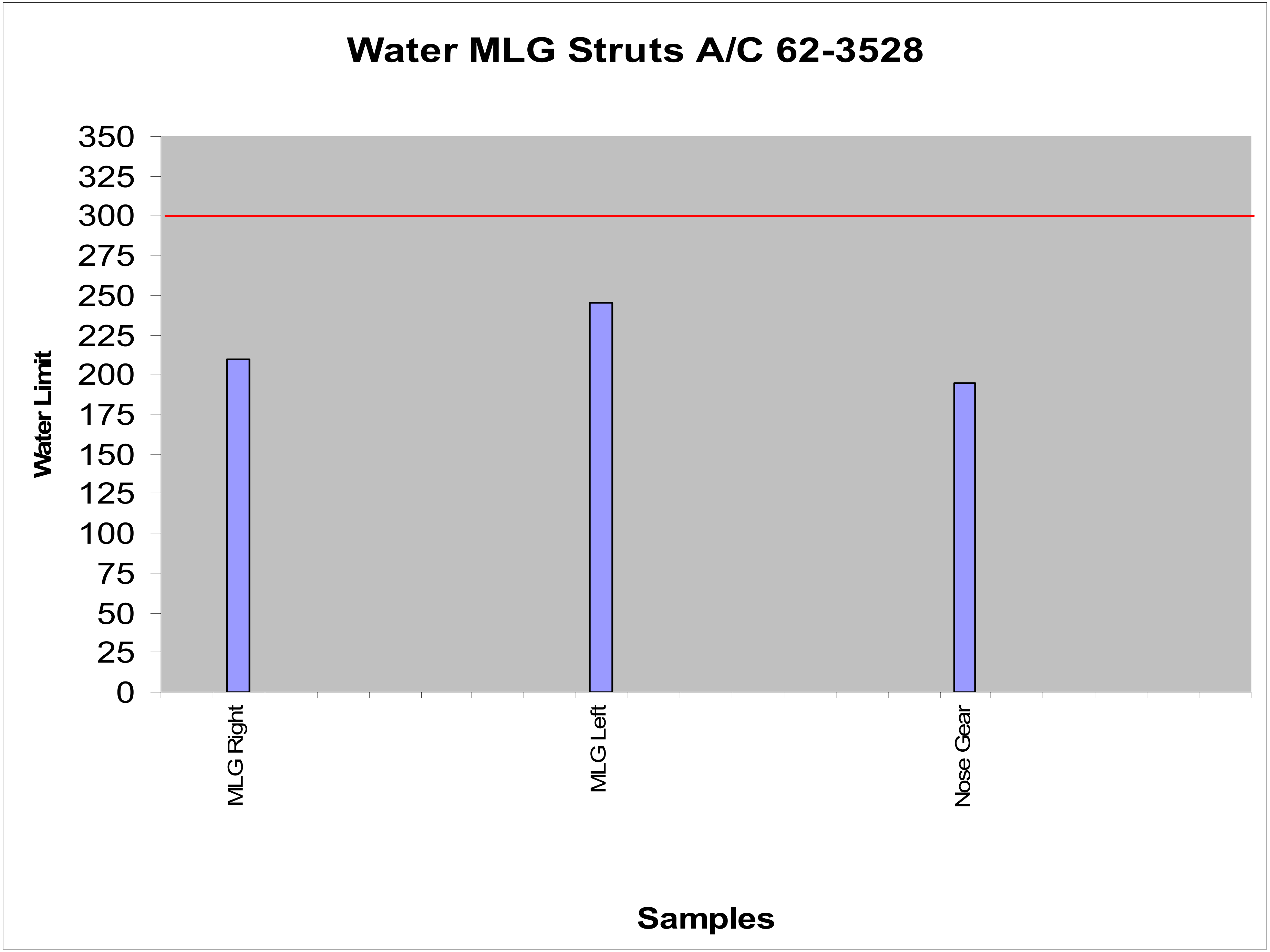
LANDING GEAR SAMPLE RESULTS.

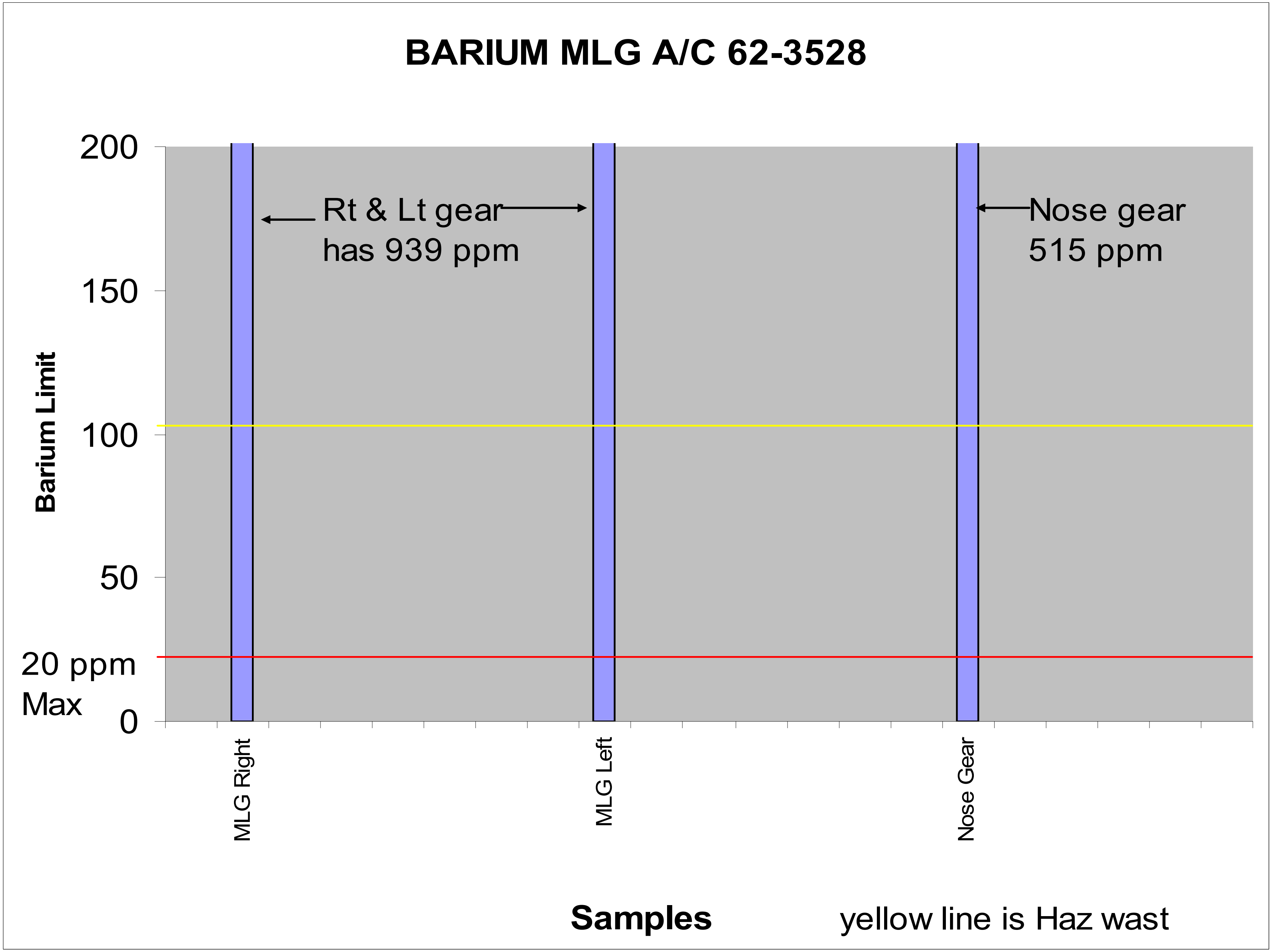

NAS 1638 Particle Count MLG A/C 57-1456
NAS Class
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
MLG Right
MLG Left
Nose Gear
Samples

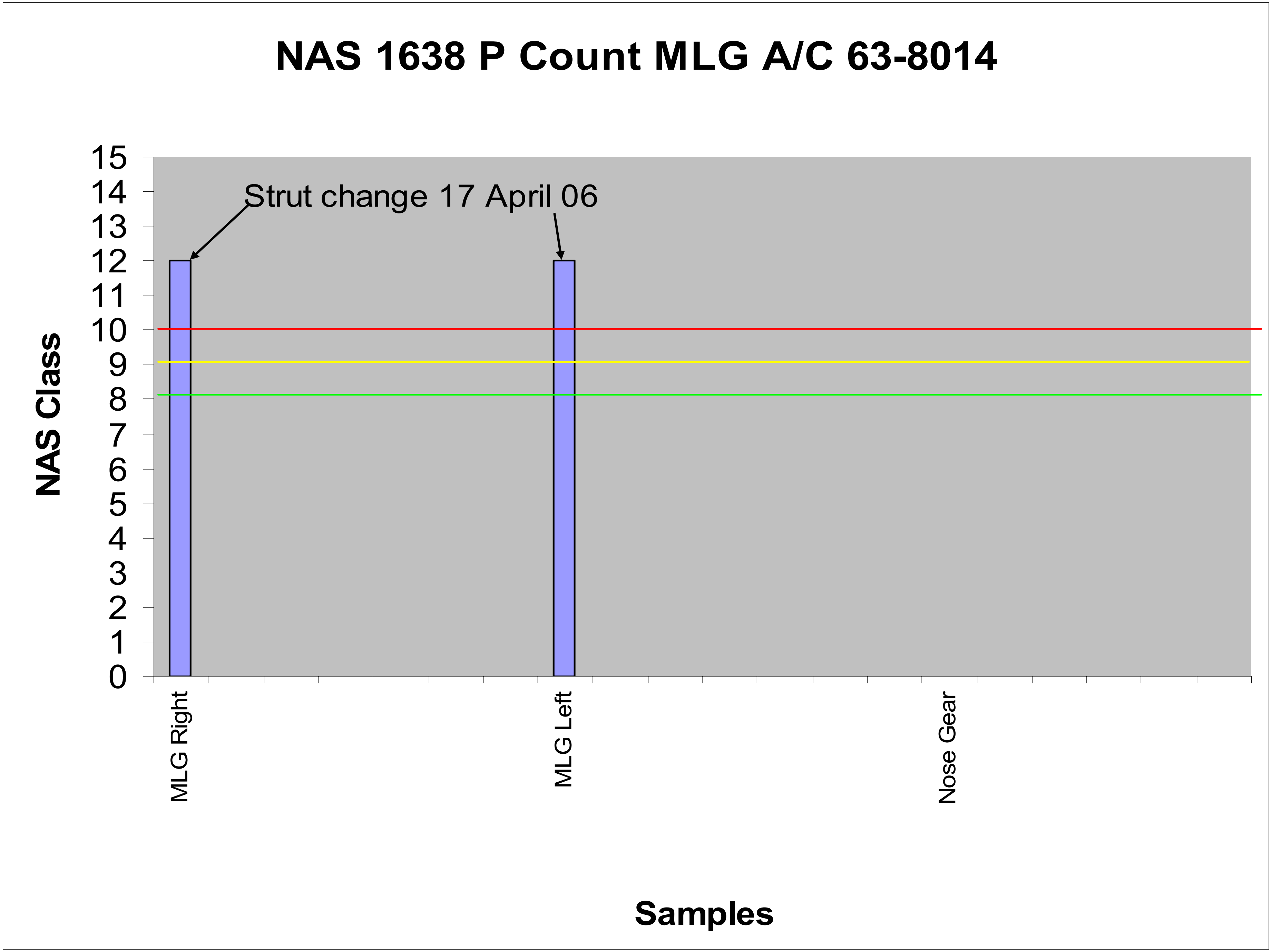

Water MLG Struts A/C 57-1456
Water Limit
350
325
300
275
250
225
200
175
150
125
100
75
50
25
0
Right PPM 512
Left PPM 467
NLG 239
MLG Right
MLG Left
Nose Gear
Samples

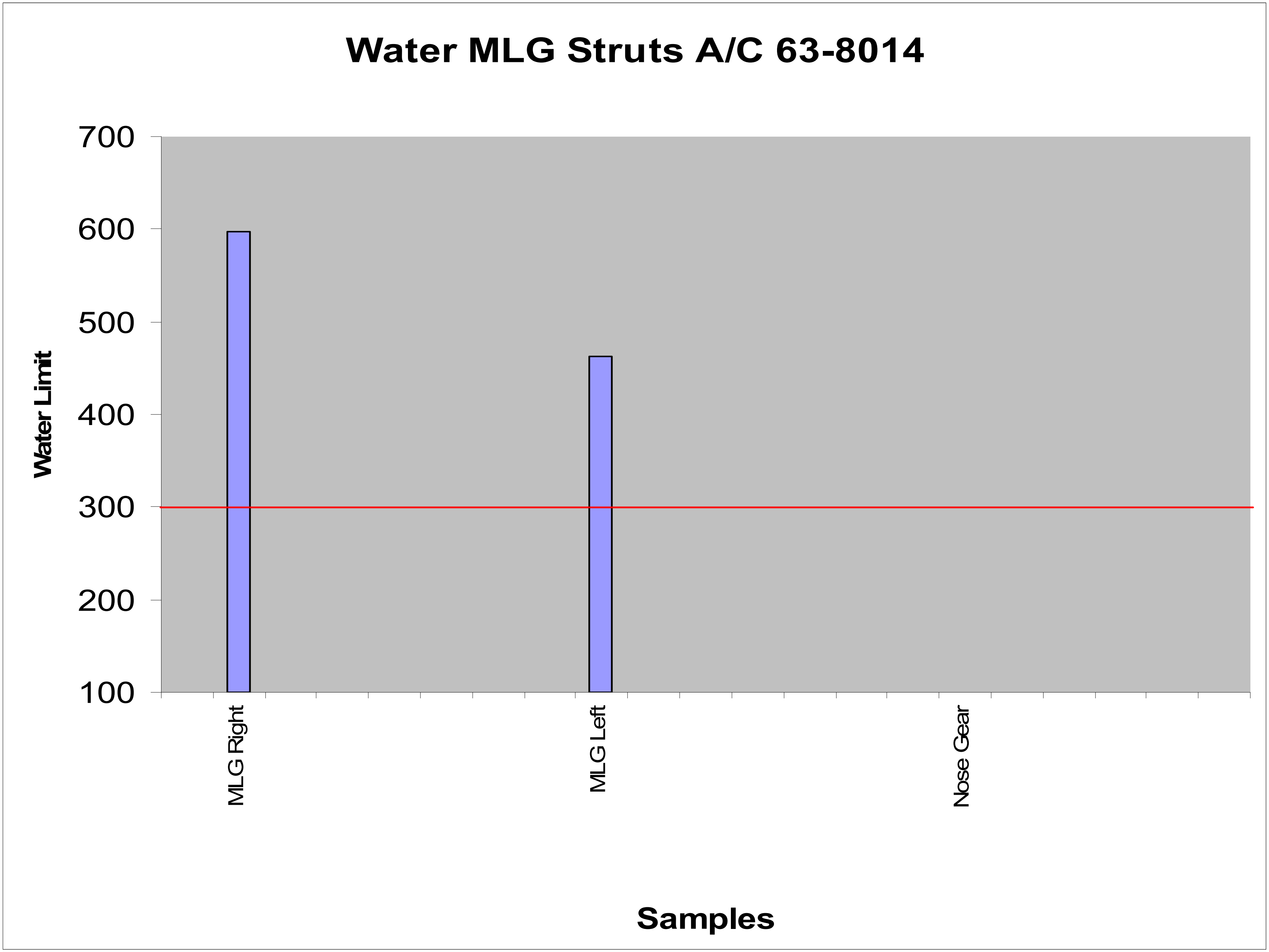

BARIUM MLG A/C 57-1456
MLG R 2106 PPM
MLG L 2153 PPM
NLG 1113 PPM
Barium Limit
200
150
100
50
20 ppm Max
0
MLG Right
MLG Left
Nose Gear
Samples
yellow line is Haz wast


NAS 1638 Particle Count MLG A/C 62-3528
NAS Class
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Nose gear to dirty to read
MLO#
MLG Right
MLG Left
Nose Gear
Samples

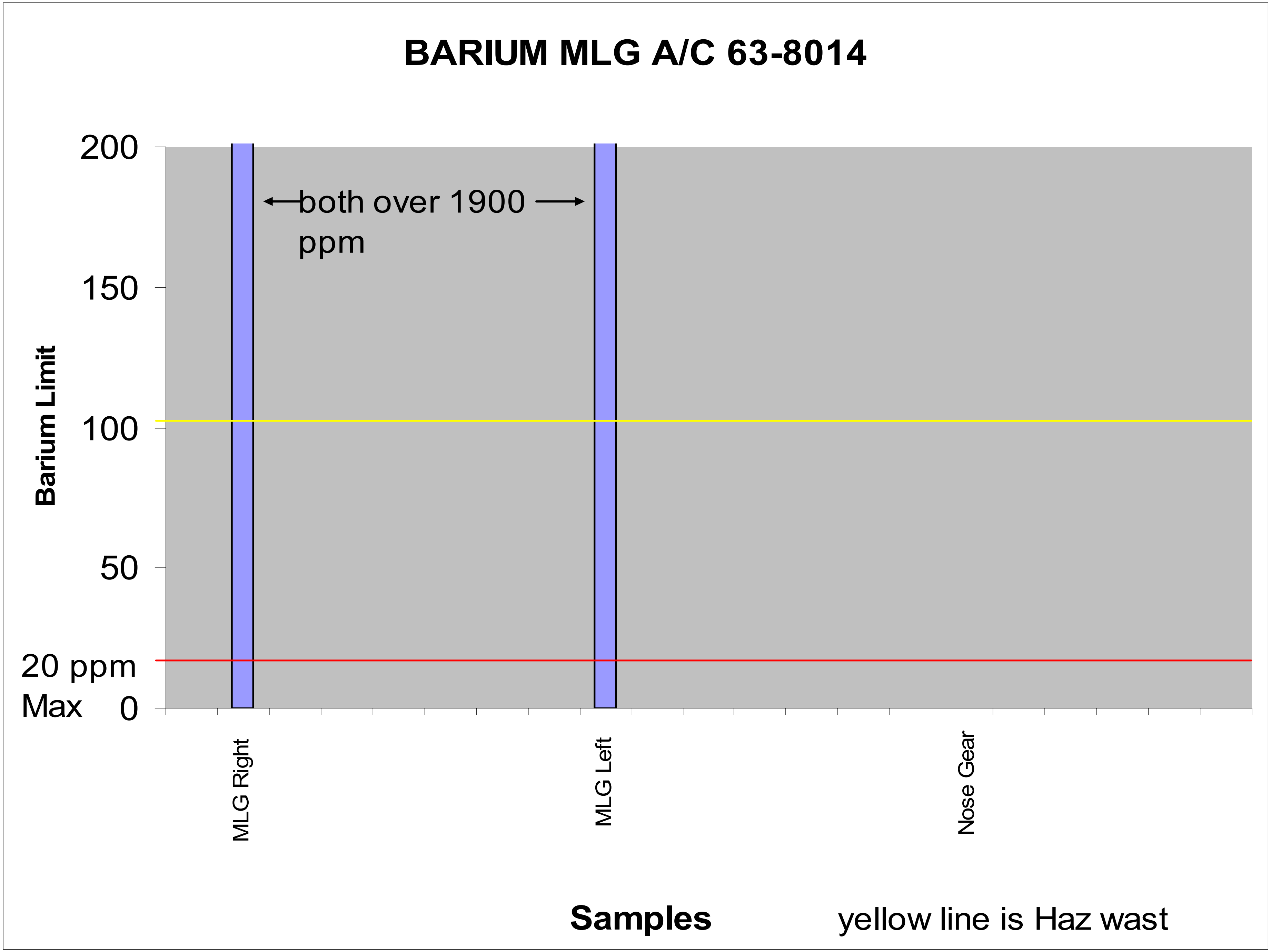

Water MLG Struts A/C 62-3528
Water Limit
350
325
300
275
250
225
200
175
150
125
100
75
50
25
0
MLG Right
MLG Left
Nose Gear
Samples


BARIUM MLG A/C 62-3528
200
150
100
50
20 ppm
Max
0
Barium Limit
Rt & Lt gear
has 939 ppm
Nose gear
515 ppm
MLG Right
MLG Left
Nose Gear
Samples
yellow line is Haz wast


NAS 1638 P Count MLG A/C 63-8014
Strut change 17 April 06
NAS Class
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
MLG Right
MLG Left
Nose Gear
Samples



Water MLG Struts A/C 63-8014
700
600
500
400
300
200
100
Water Limit
MLG Right
MLG Left
Nose Gear
Samples



BARIUM MLG A/C 63-8014
200
150
100
50
20 ppm
Max
0
both over 1900
ppm
Barium Limit
MLG Right
MLG Left
Nose Gear
Samples
yellow line is Haz wast

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.

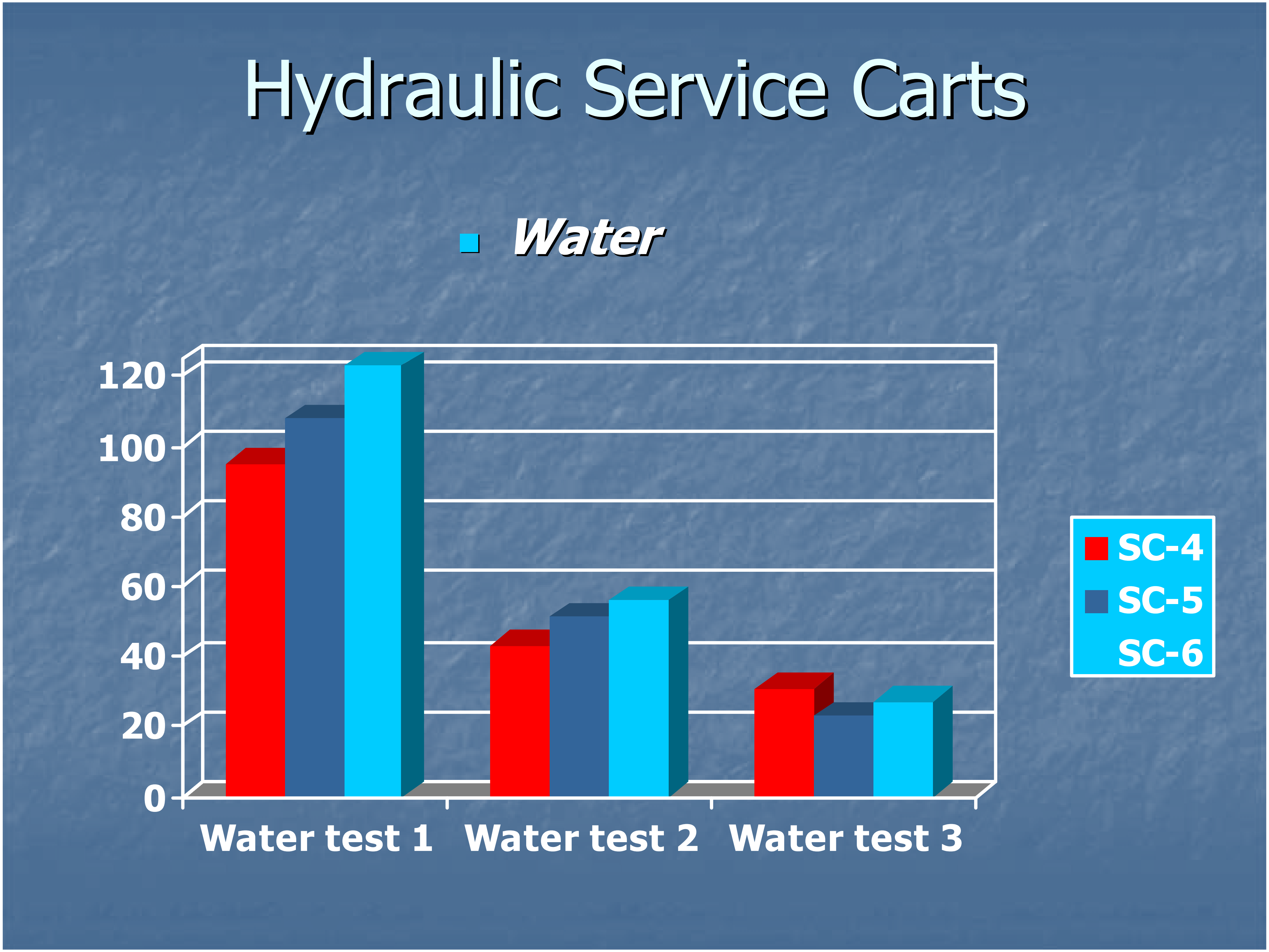
  2. We were looking at trying to hook the purifier directly to the aircraft reservoir, we have come to the conclusion that using the purifier in this manner would not give us our best results, due to we would only be cleaning approximately seven gallons of fluid out of twenty seven.

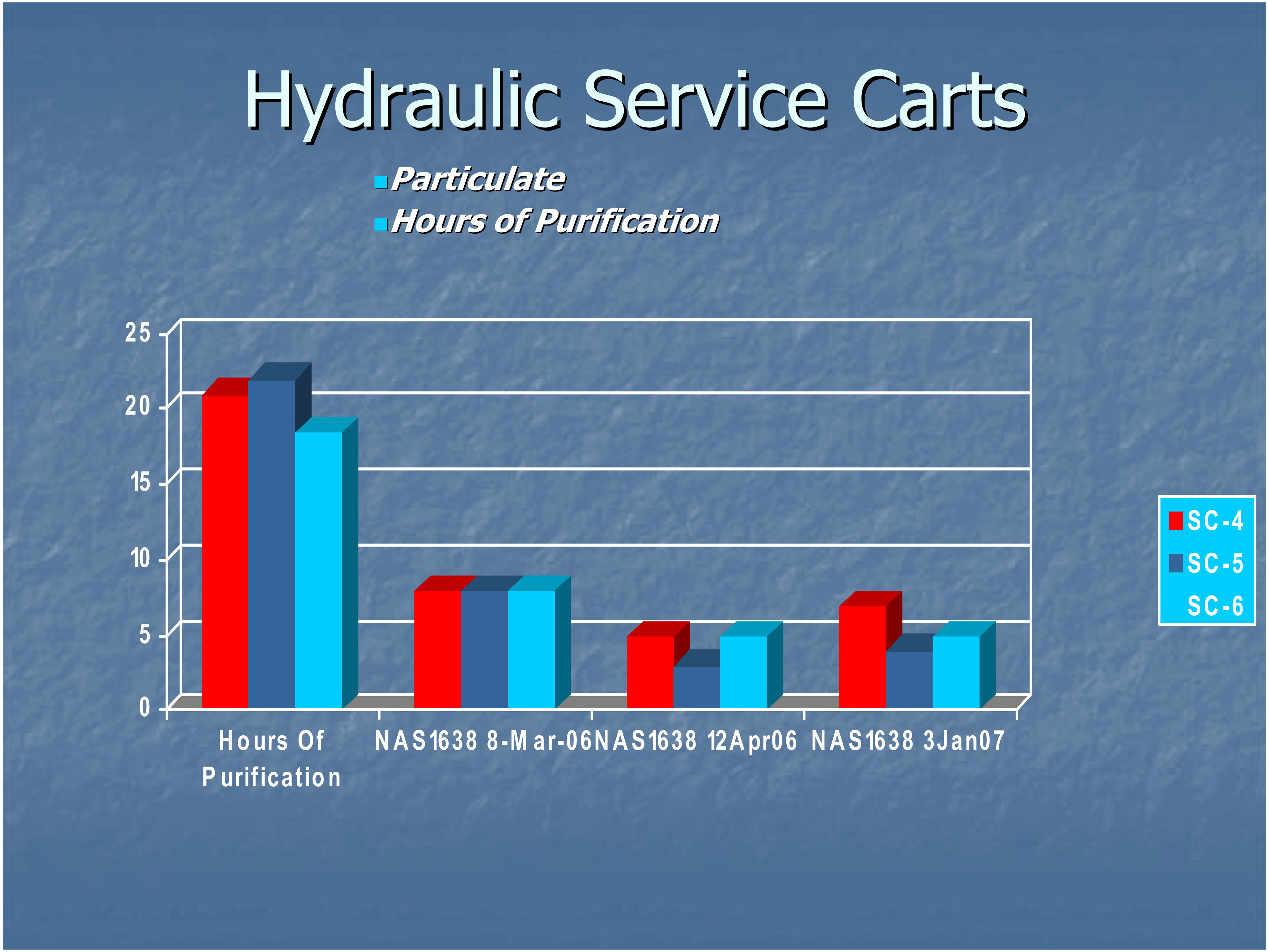
  3. We also look at the possibility of purifying our landing gear struts due to the high water and particle samples. We have determined that it is indeed needed, but is not practical due to the struts would have to be redesigned. We have no way of getting the fluid out and back into the struts.

178th Fighter Wing MXS/MXMG

Hydraulic Fluid Purification

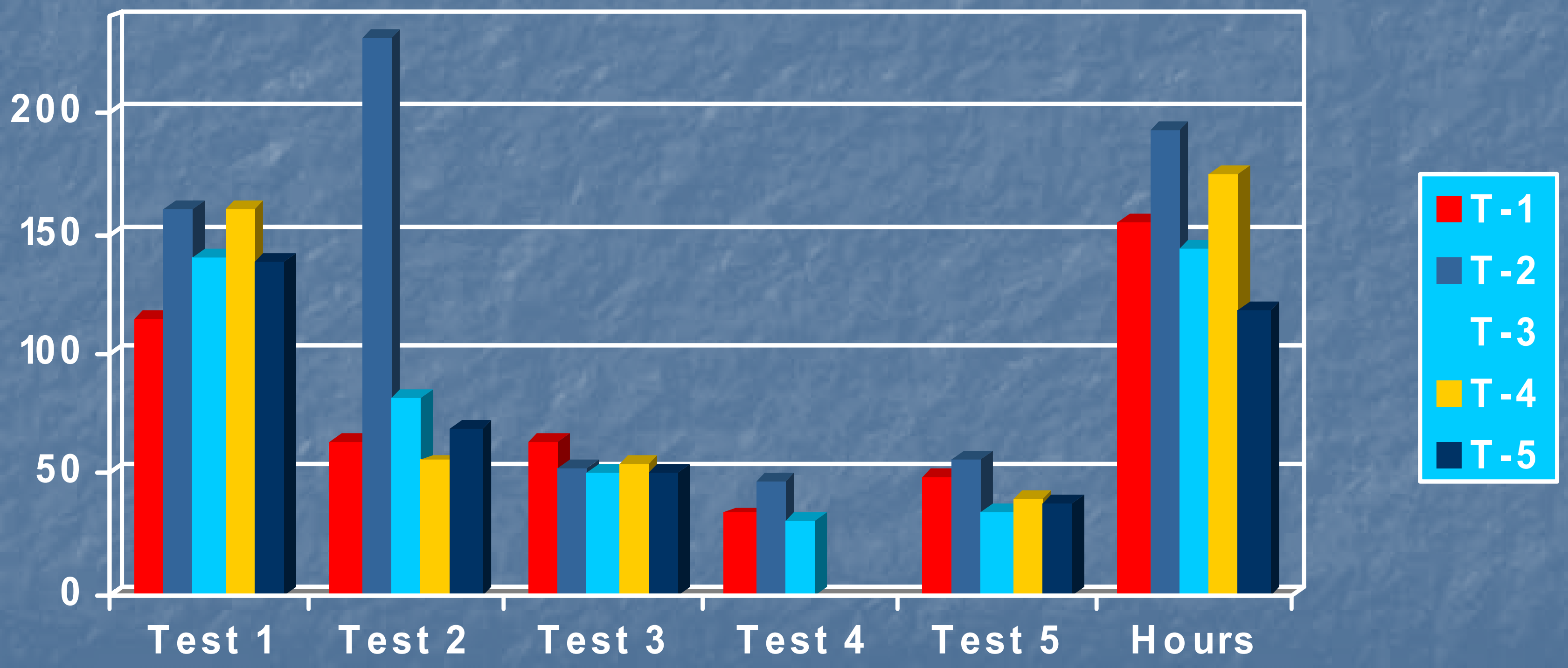
As Of December 2006


Hydraulic Service Carts
Water
120
100
80
60
40
20
0
Water test 1
Water test 2
Water test 3
SC-4
SC-5
SC-6


Hydraulic Service Carts
Particulate
Hours of Purification
25
20
15
10
5
0
Hours Of Purification
NAS1638 8-Mar-06
NAS1638 12Apr06
NAS1638 3Jan07
SC-4
SC-5
SC-6

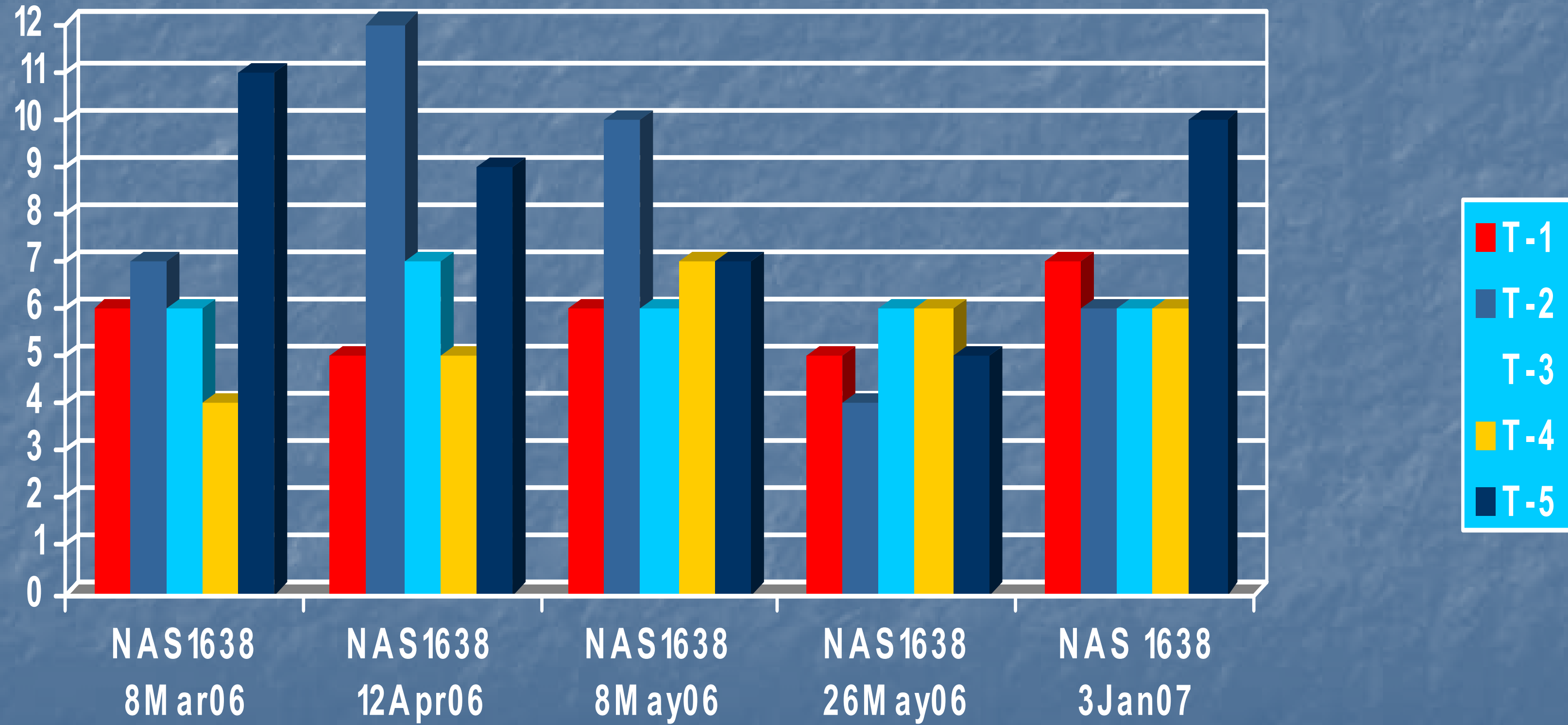
Hydraulic Mules

- ***Water***
- ***Hours of Purification***



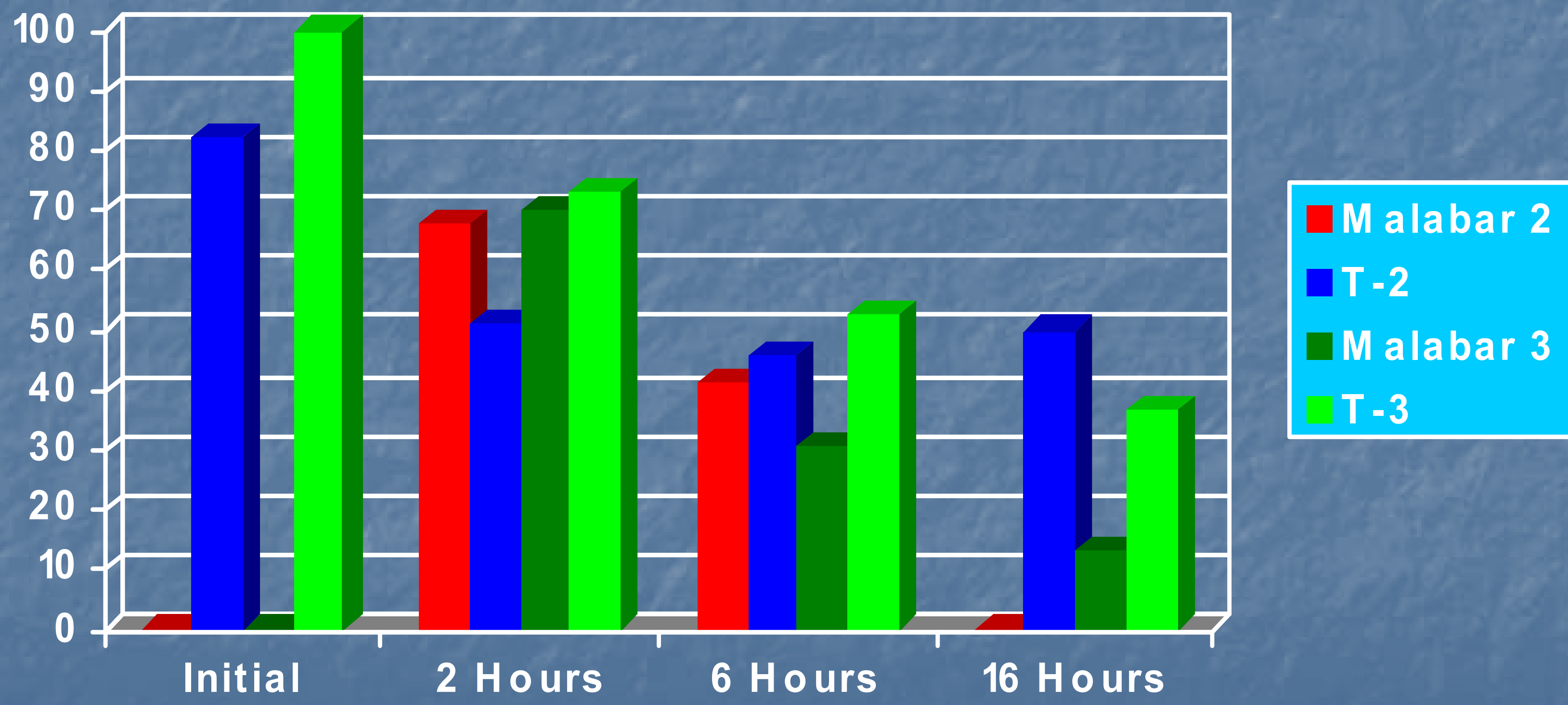
Hydraulic Mules

- ***Particulate***



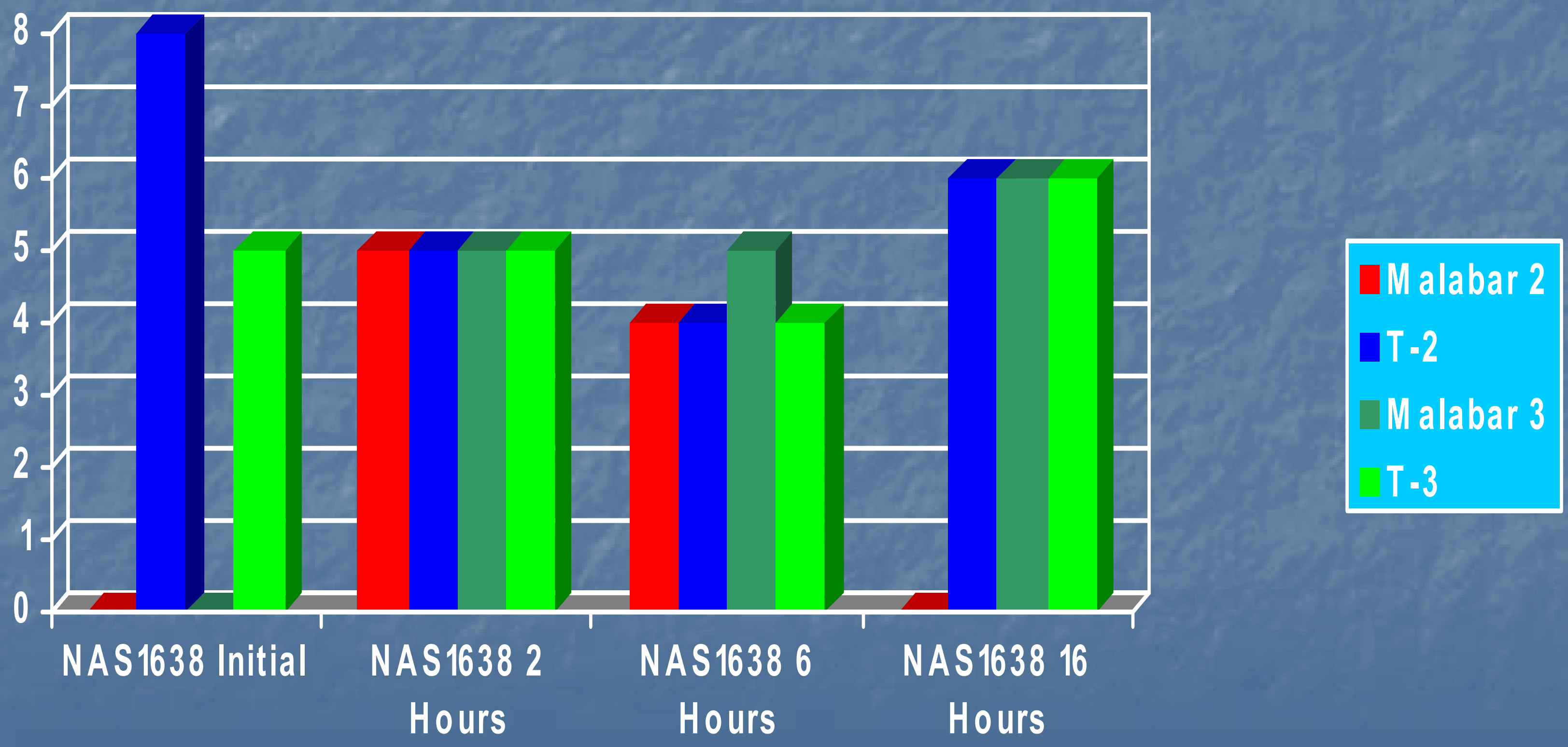
Hydraulic Mules & Malabar Samples

- ***Water***
- ***Hours of Purification***

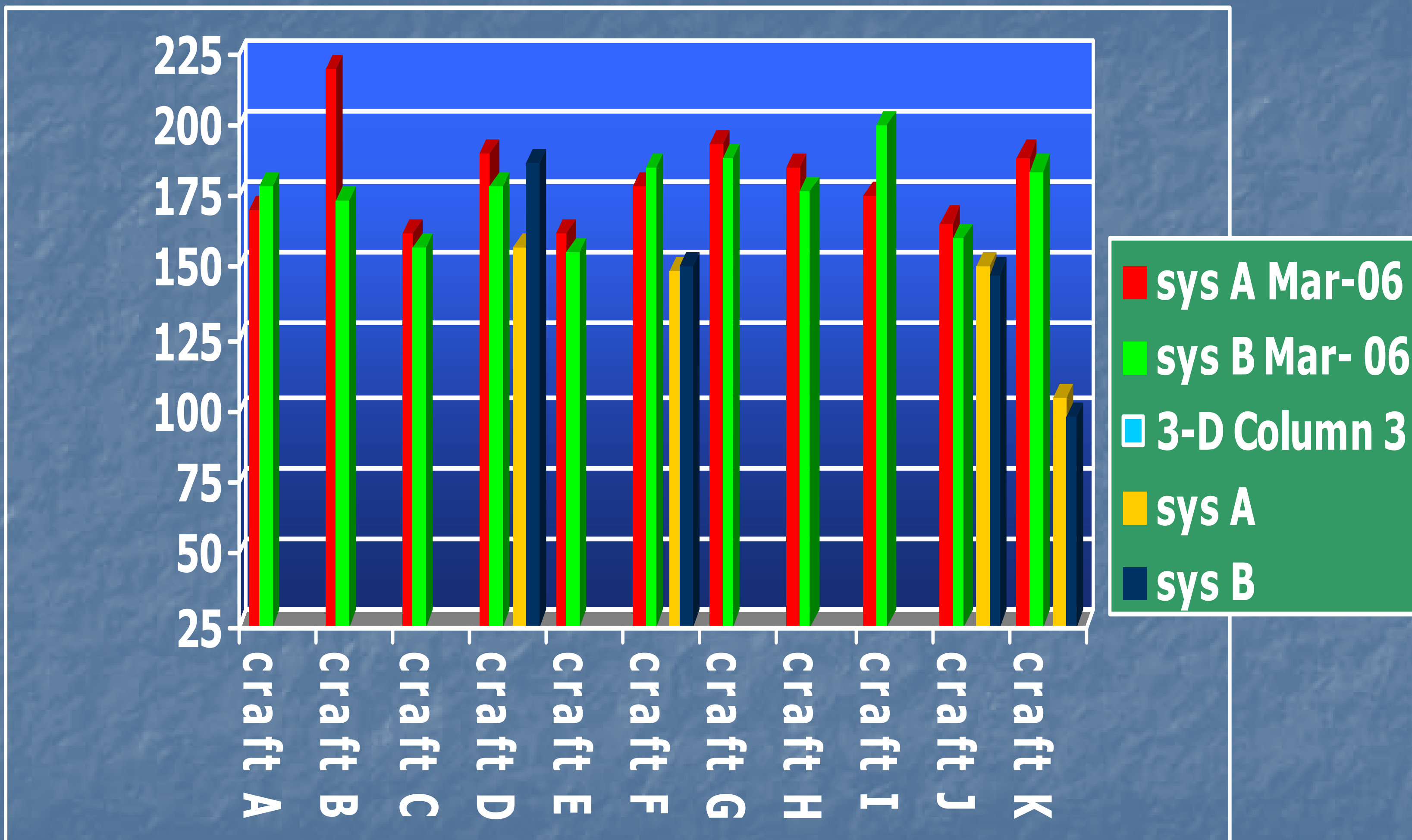


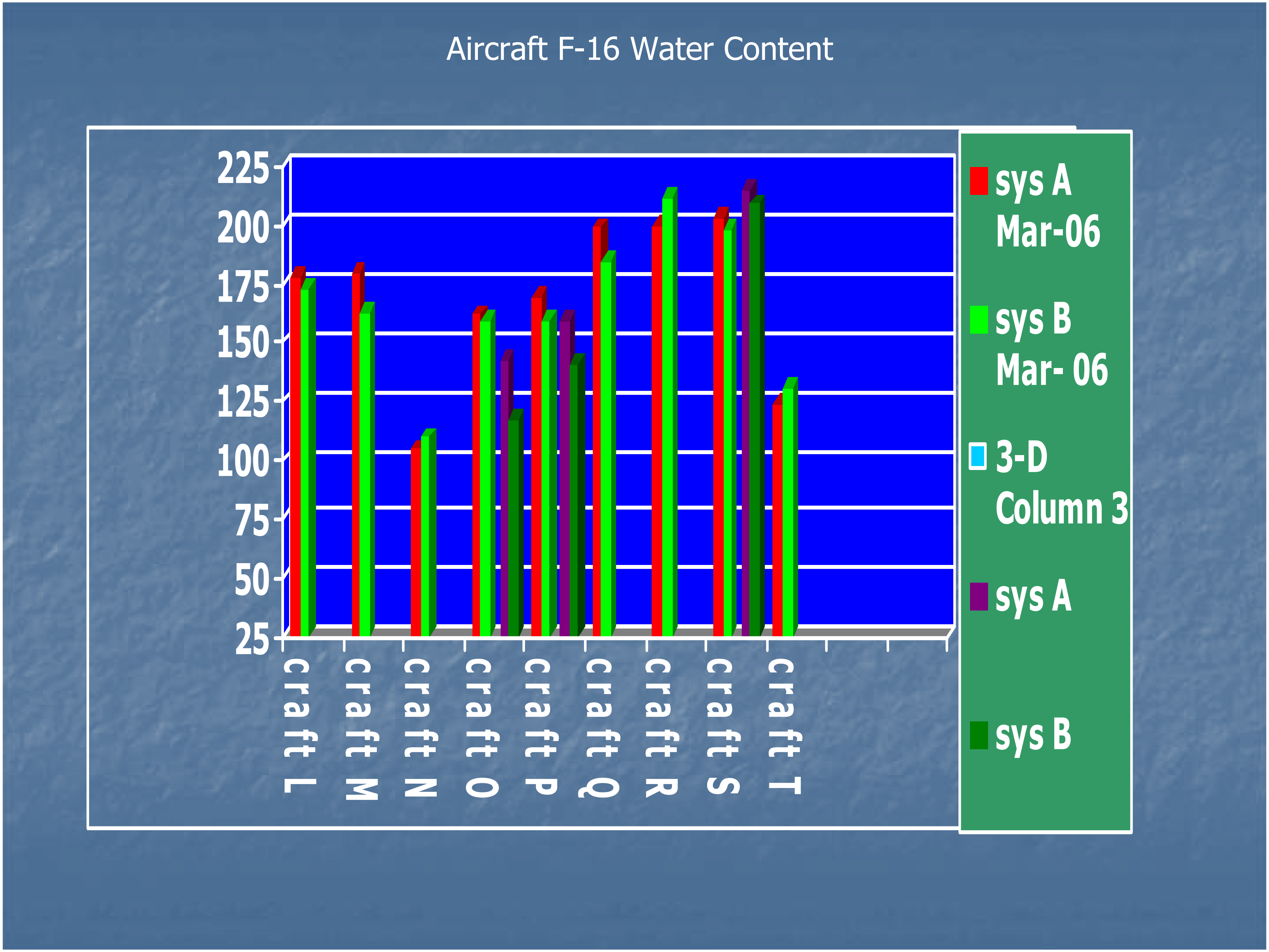
Hydraulic Mules & Malabar Samples

- ***Particulate***
- ***Hours of Purification***

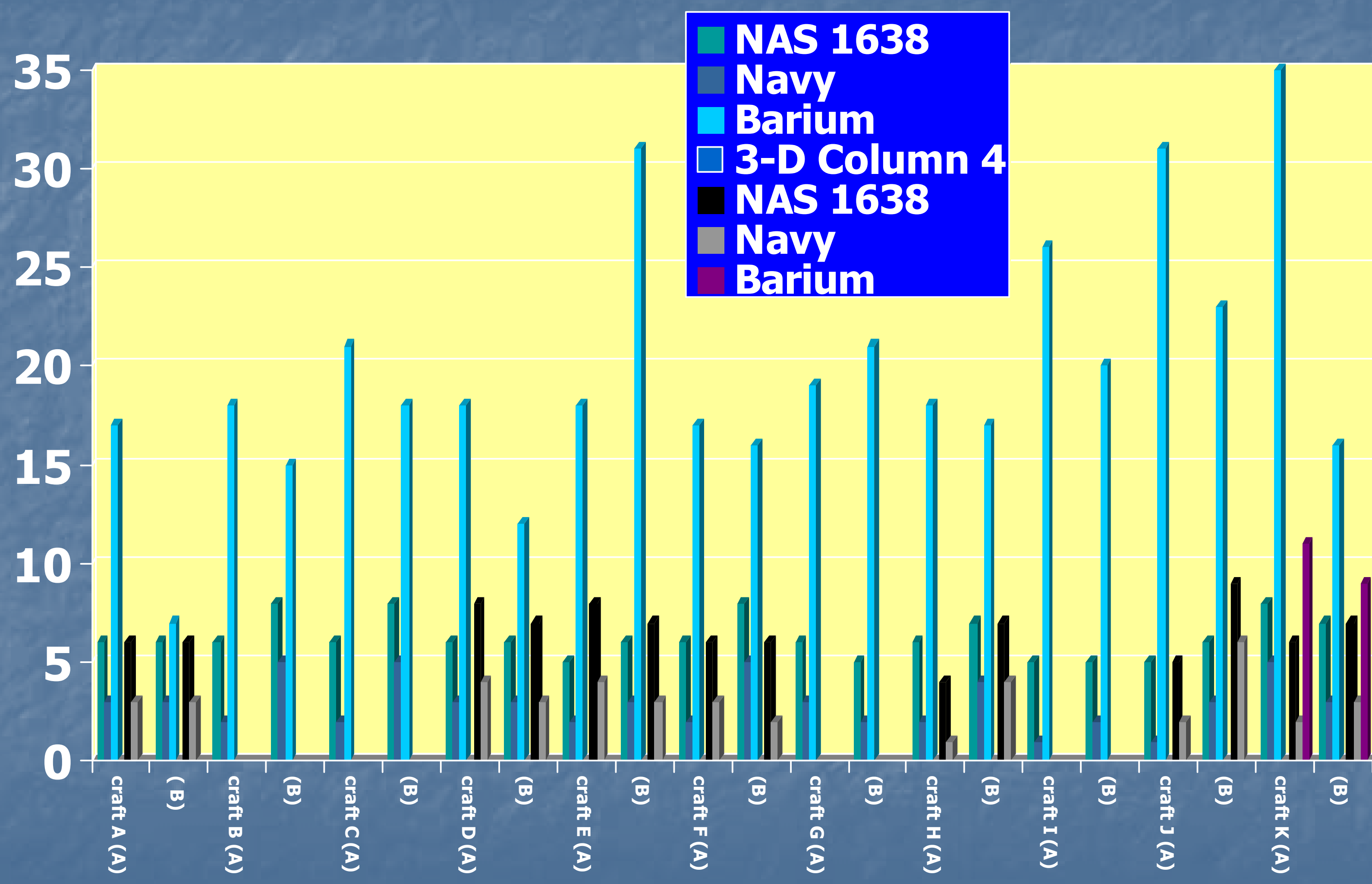


Aircraft F-16 Water Content

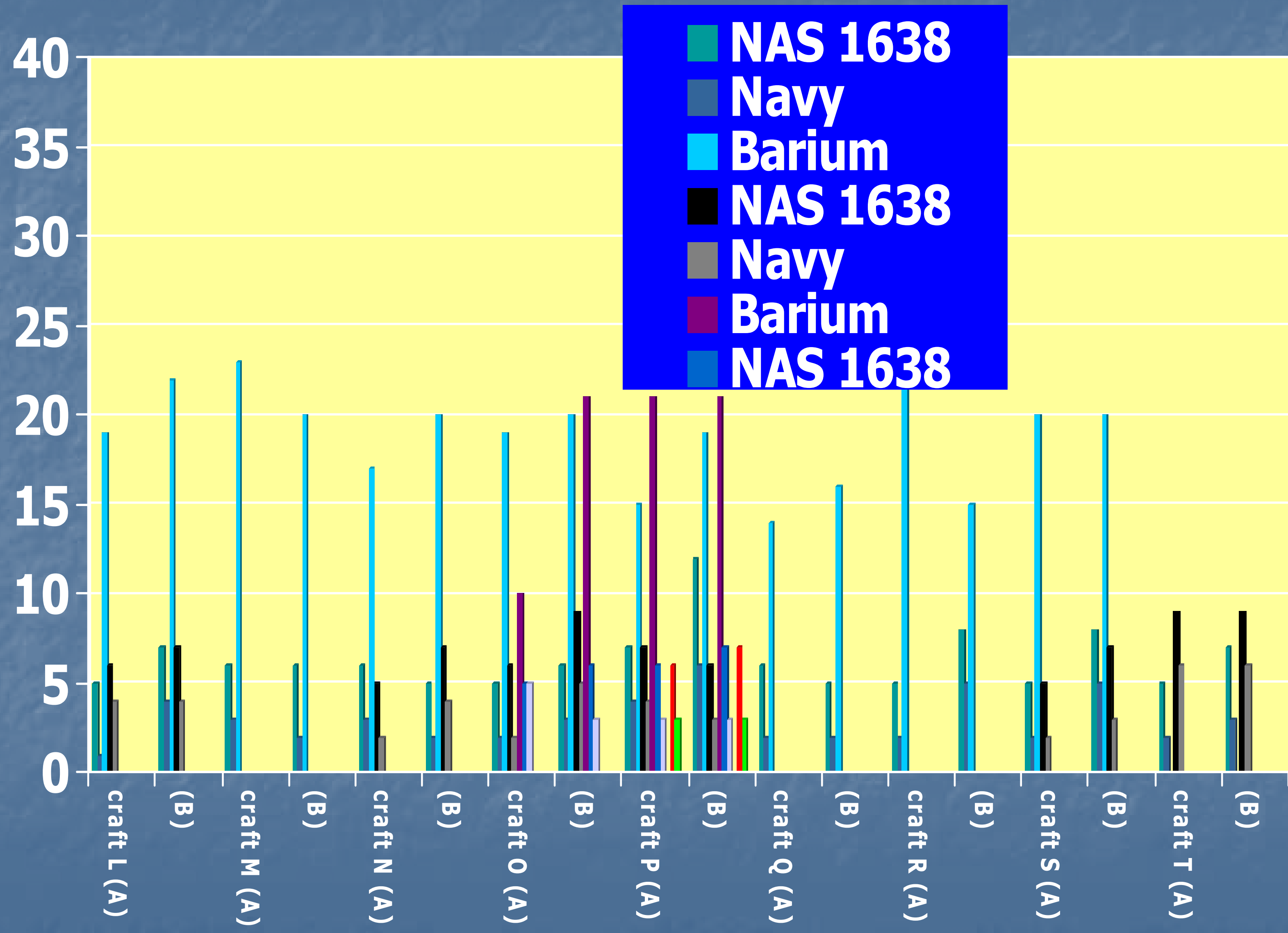



Aircraft F-16 Water Content
225
200
175
150
125
100
75
50
25
craft L
craft M
craft N
craft O
craft P
craft Q
craft R
craft S
craft T
sys A Mar-06
sys B Mar- 06
3-D Column 3
sys A
sys B

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

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	166	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

How to Use the Purifiers

"GSE Hook up"

How to Use the Purifiers

"Aircraft Hook up"

❖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.

Leads to pressure fluctuations in aircraft actuators

Leads to false reservoir level indication when the system is pressurized

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)

DOCERE

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

Ghislain Boivin, Lead Engineer- Integrated Health Monitoring:
Boivin.JG@Forces.gc.ca, 819-994-6538

Pierre Poitras, Senior Chemist, Tactical Aerospace Fluids:
Poitras.PR@Forces.gc.ca, 819-997-8769

In-Line Hydraulic Fluid Contamination Multi-Sensor

Phase II Enhancement Program

METSS Corporation

300 Westdale Ave

Westerville, OH 43082

Kenneth Heater

METSS CORPORATION
www.metss.com

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.

METSS CORPORATION
www.metss.com

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+ µm)
- 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

METSS Program Emphasis

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

First Generation HFMS Prototype

Multi-Sensor Prototype Technical Specifications

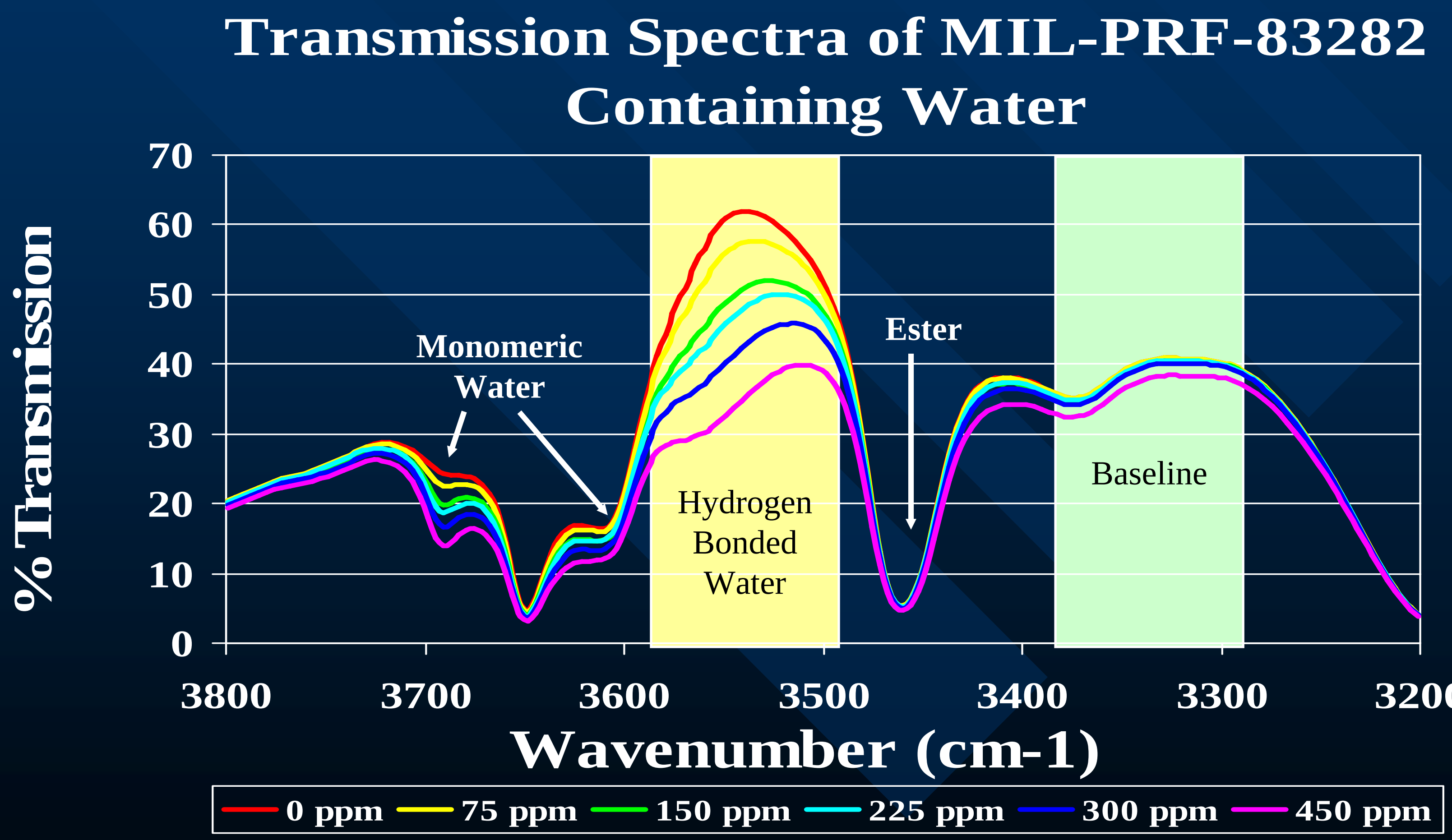
- Particle Sensor:
  - Orifice: 500 µm x 500 µm
  - Max. concentration @ 7% coincidence: 24,000 parts/ml
  - Max. pressure: 250 bar
- Water Sensor:
  - Orifice: 1270 µm
  - Max. concentration >500 ppm
  - Max. pressure: ~14 bar
- Electrical power supply:
  - 120VAC approx. 10W
- Hydraulic supply:
  - Oily liquids
  - Viscosities up to 1000 cSt
  - Temperature -20^{o}C to 100^{o}C
  - Oil compatible with Viton seals and polyamide hoses

First Generation Water Sensor Prototype

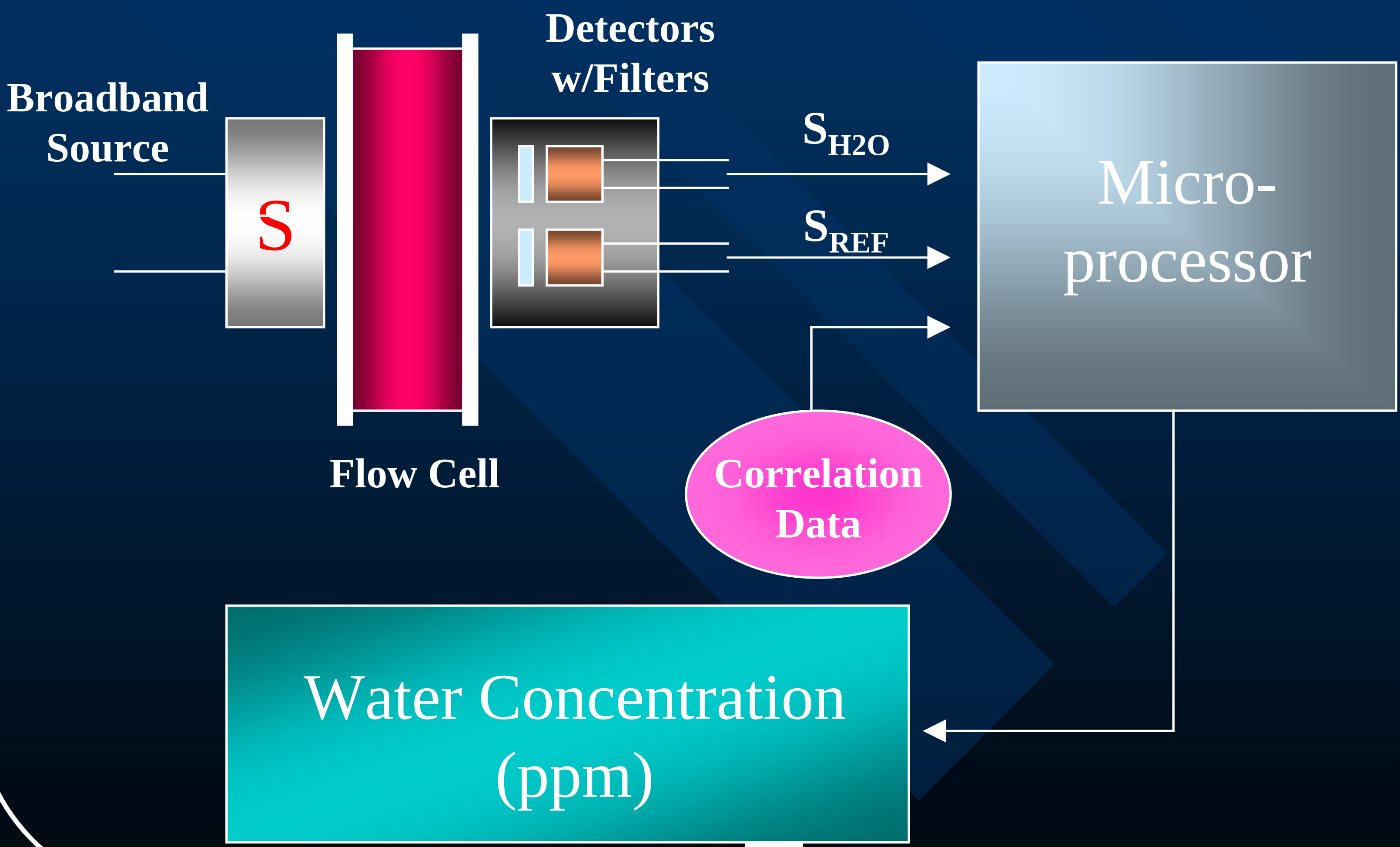
Nicolet 800 FTIR & Raman

Miniaturized Water Sensor

Basics of Operation



Water Sensor Prototype – Basic Concept



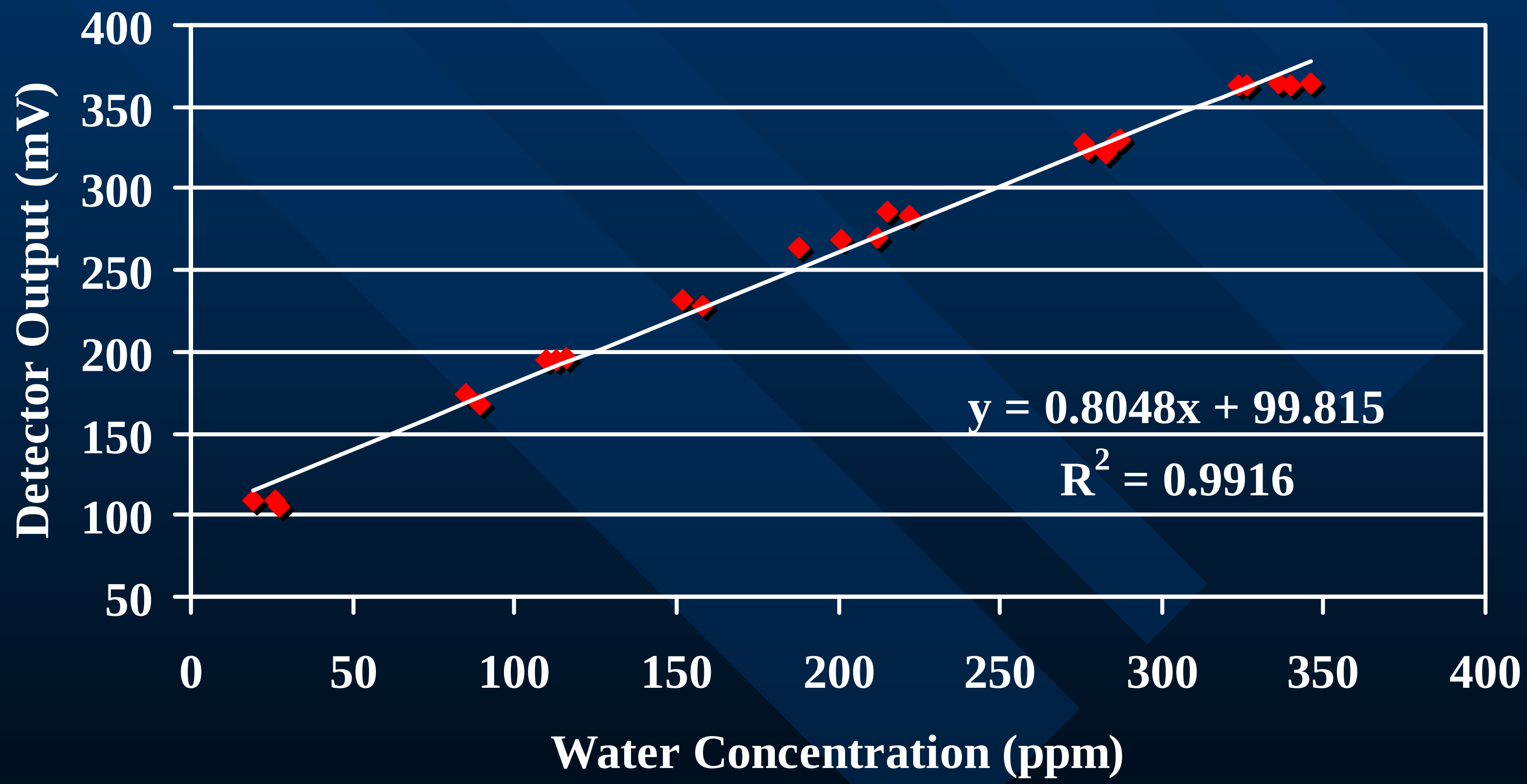
Water Sensor Performance

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

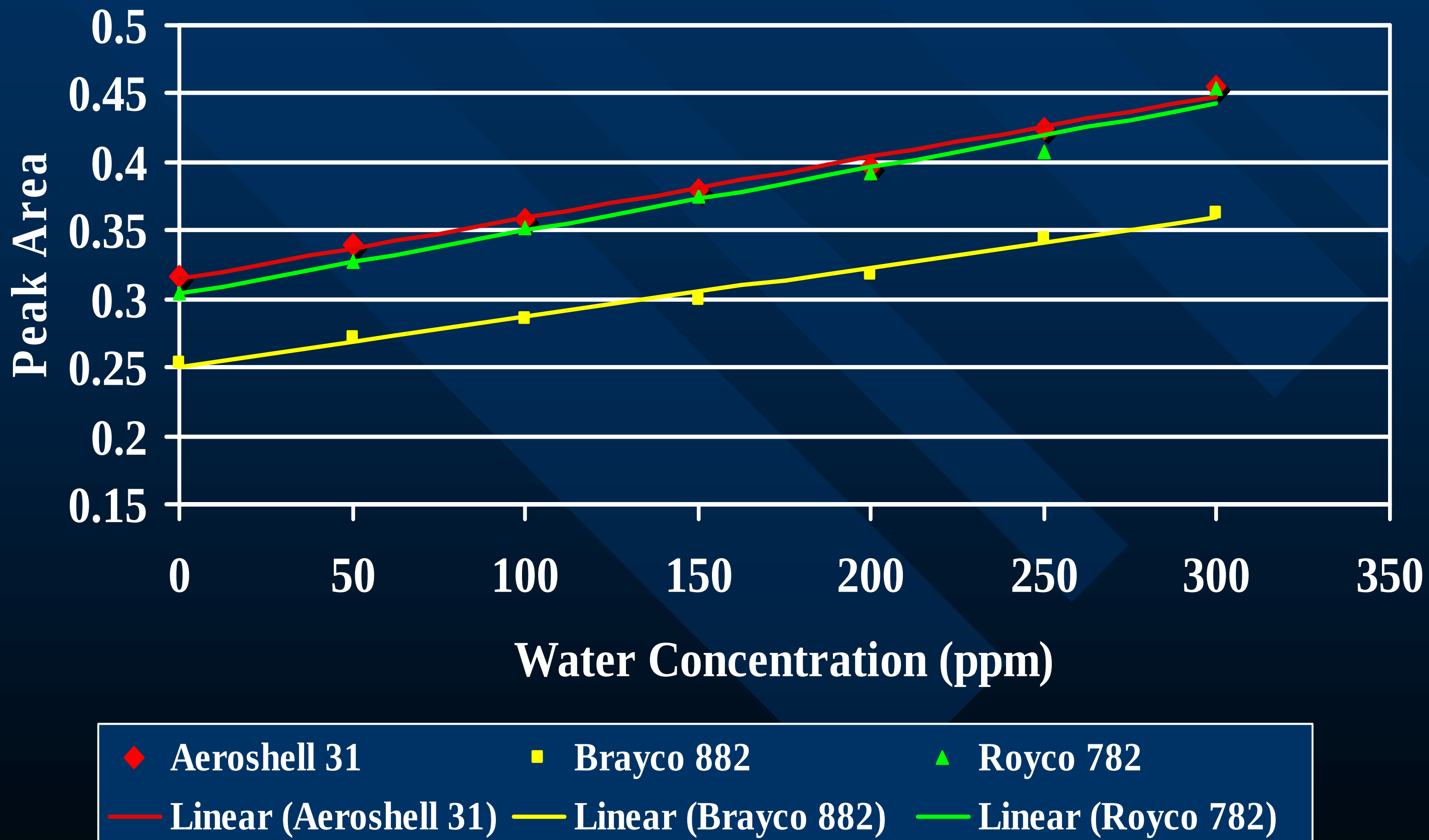
Multi-Sensor Prototype

Water Sensor Detector Response



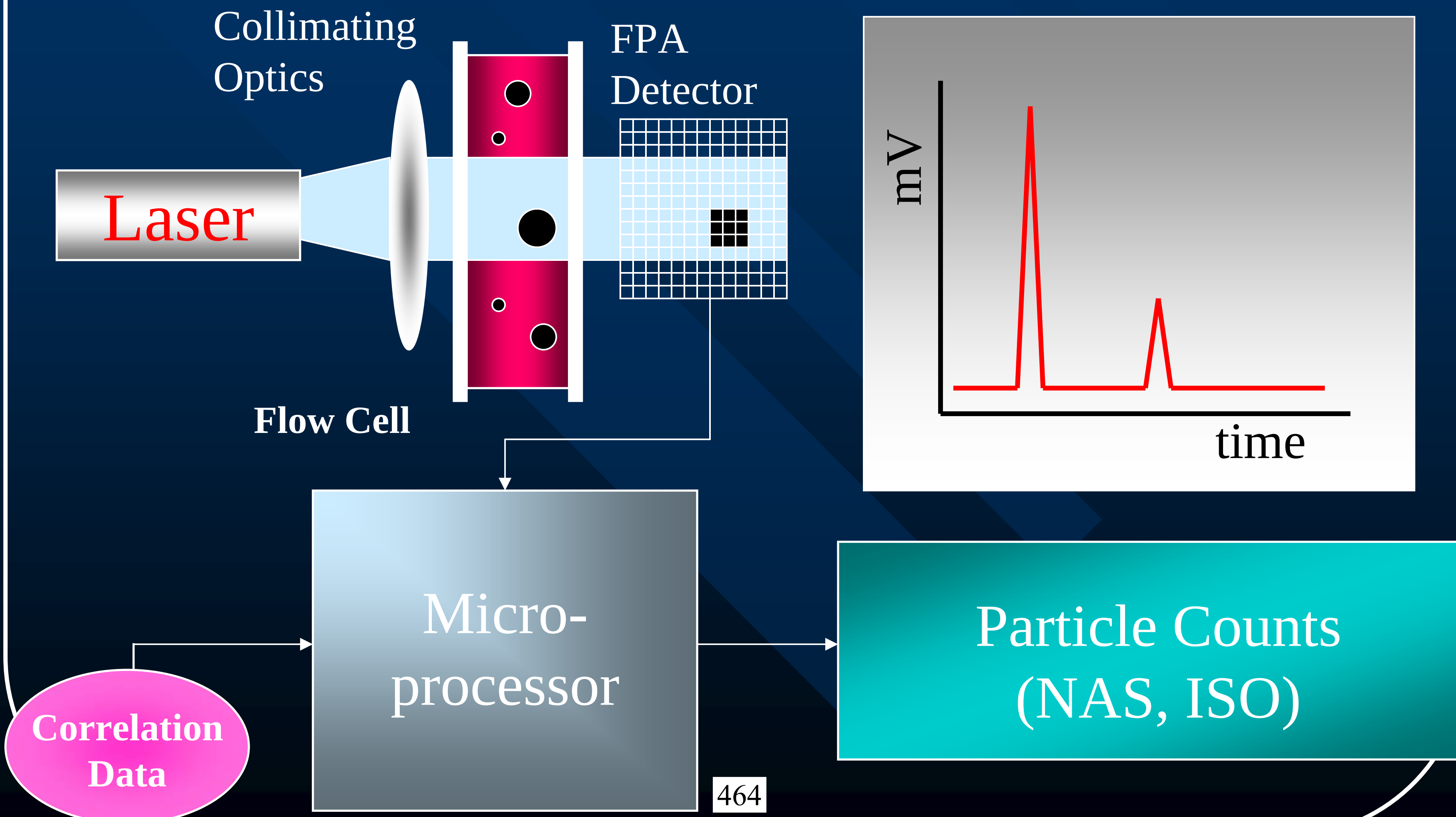
Multi-Sensor Prototype

Projected Water Sensor Response



First Generation Particle Sensor Design

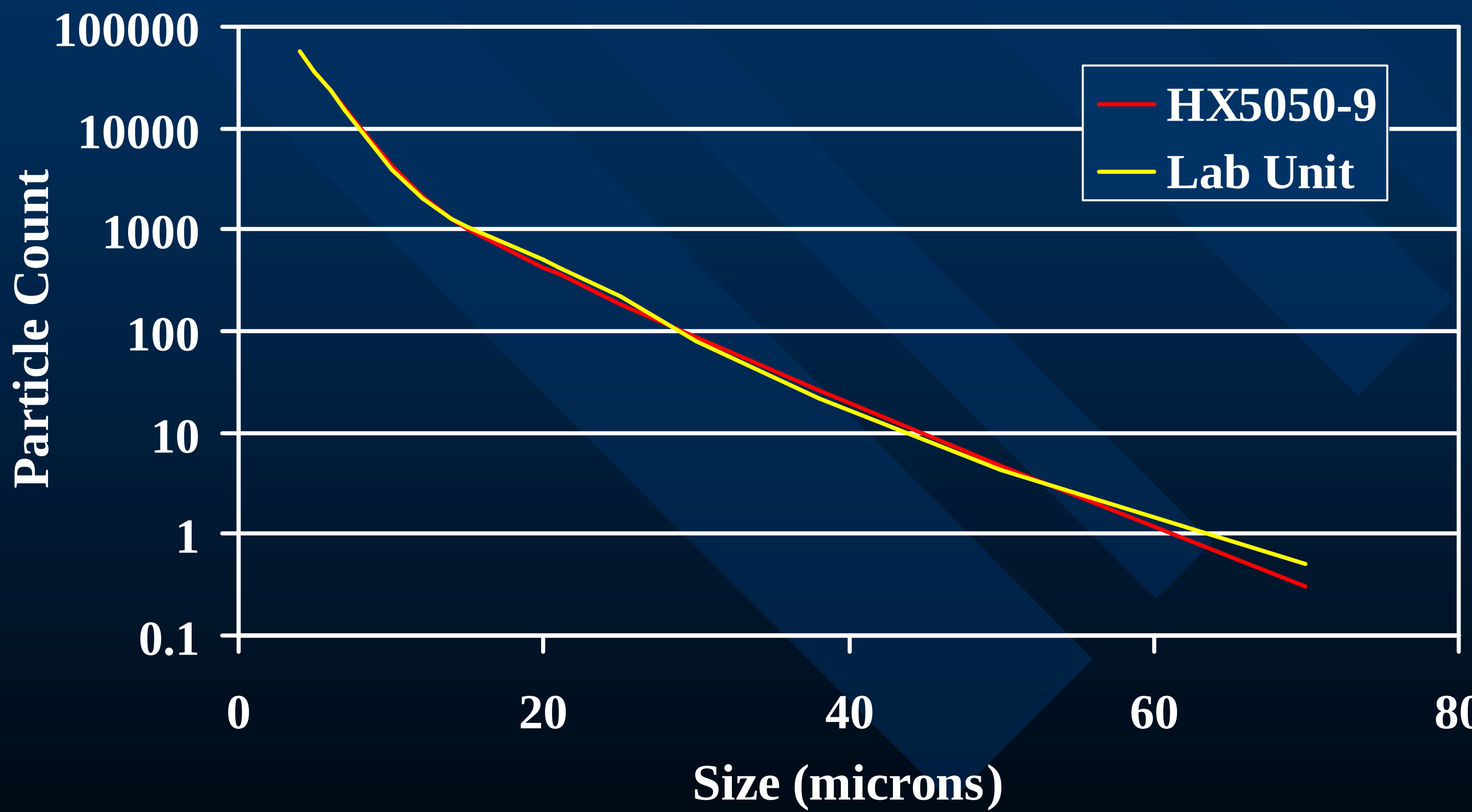
Particle Counting Basic Concept



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



METSS CORPORATION

Enhancement Objective

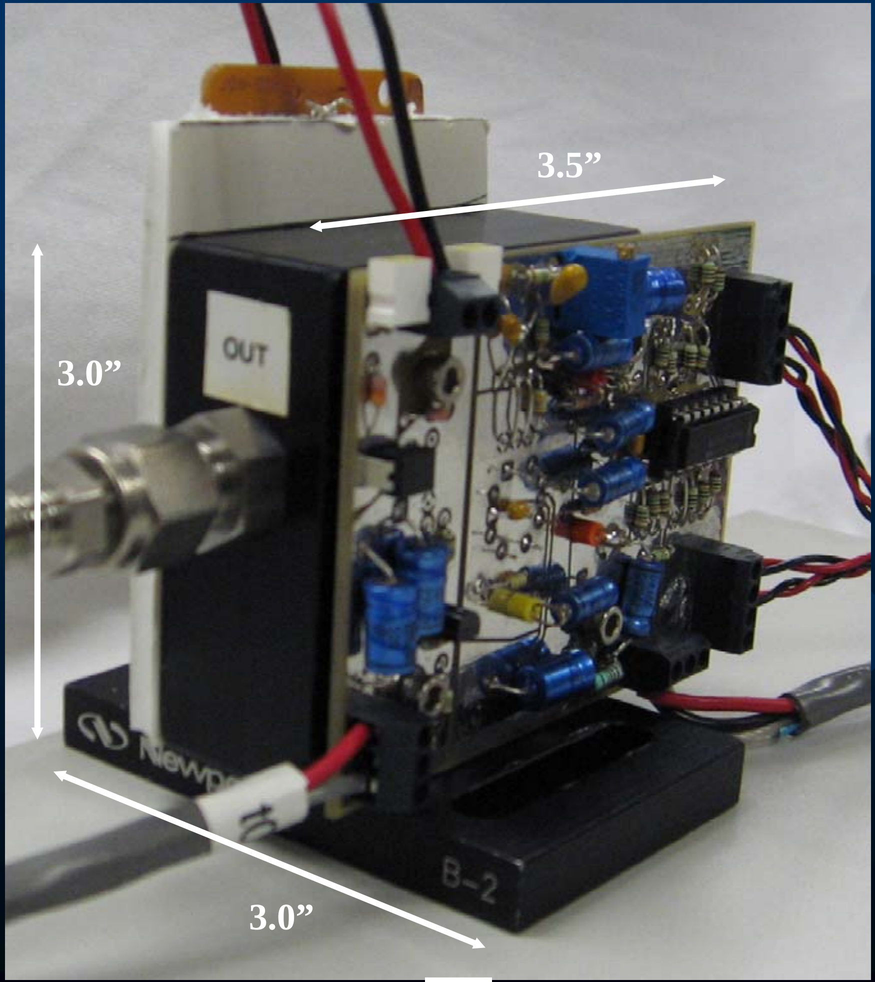
Enhancement Program Overview

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

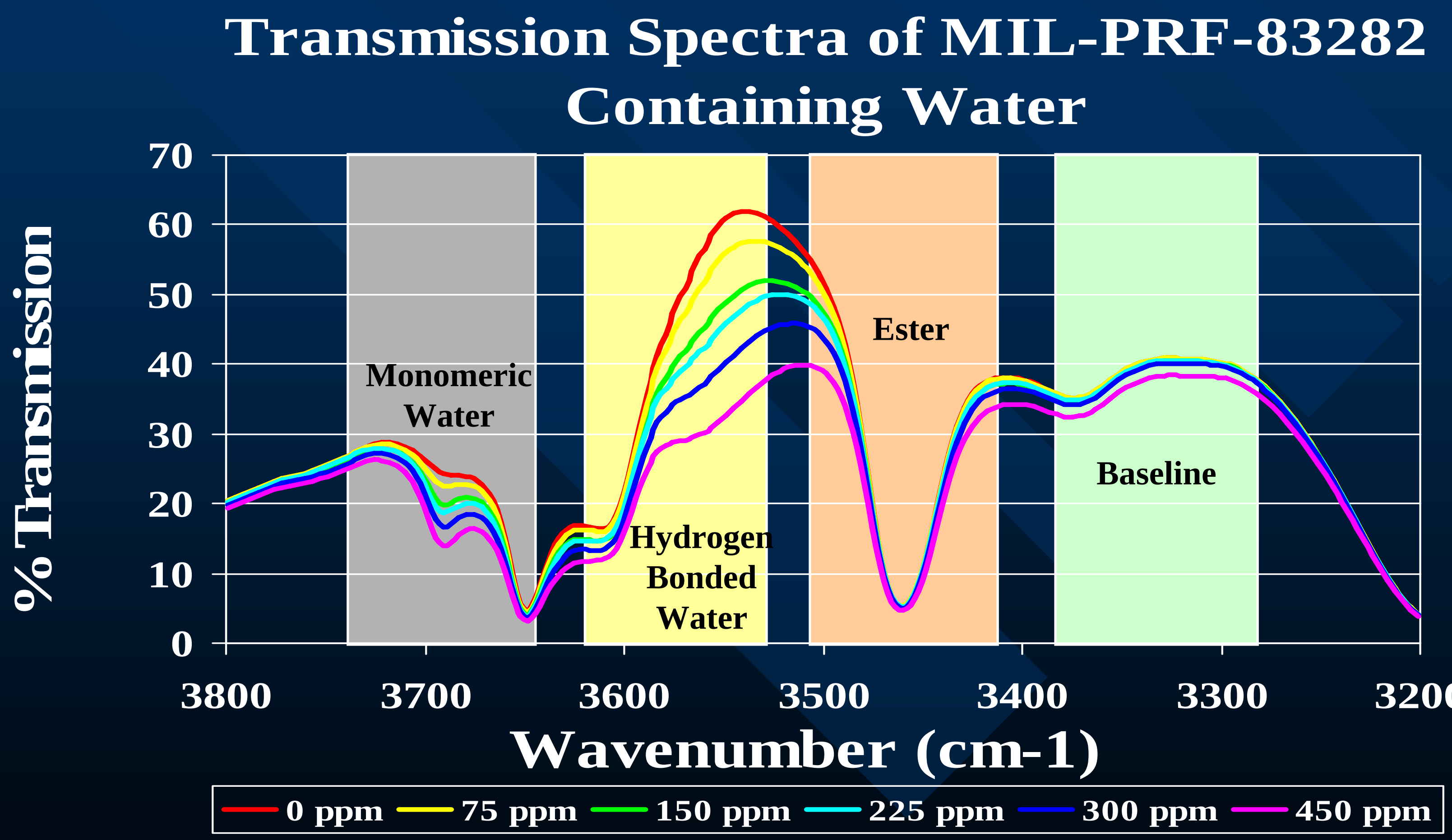
Water Sensor Development

- 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

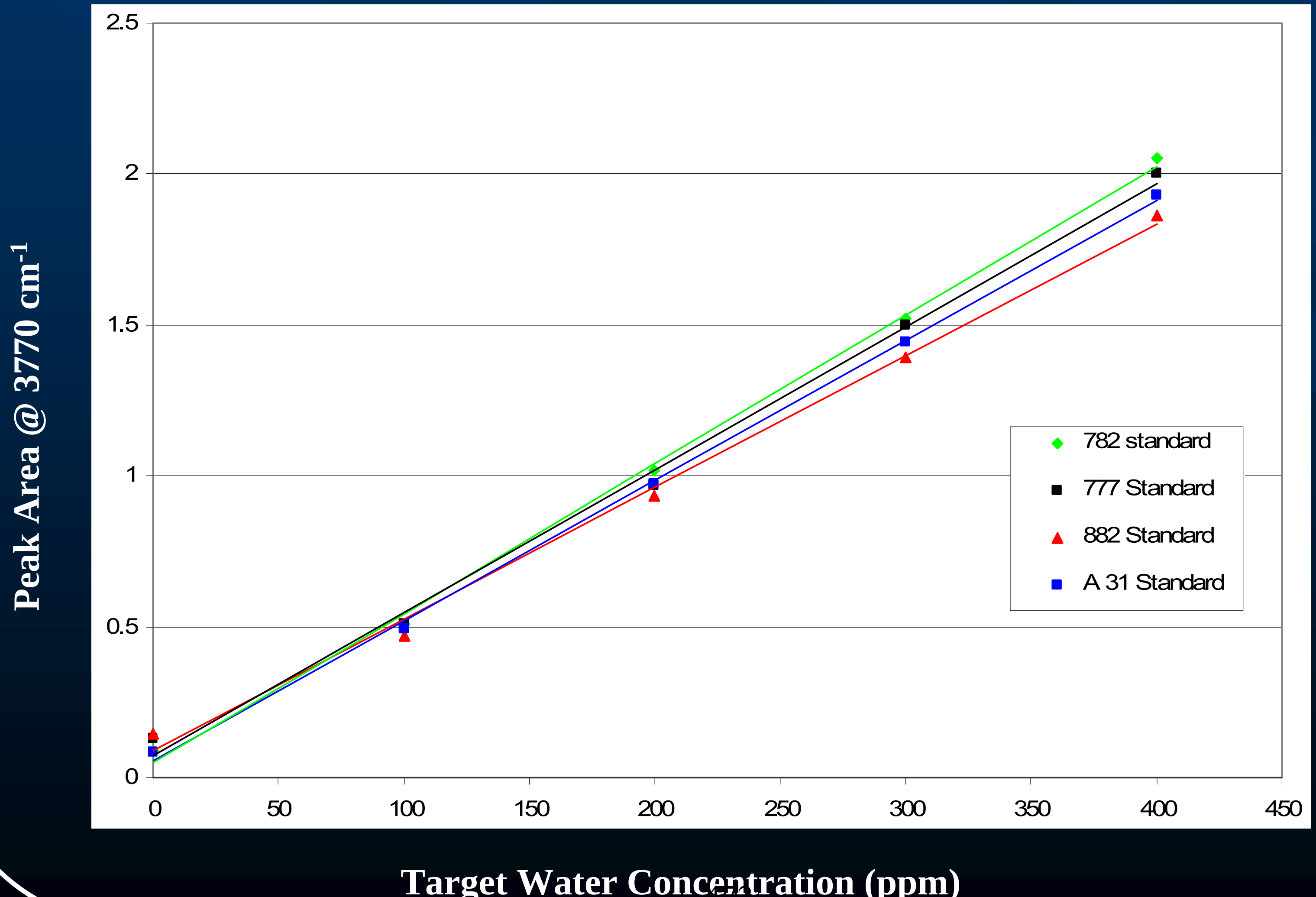
Second Generation Water Sensor



Second Generation Water Sensor - Operation



Second Generation Water Sensor - Projected Output



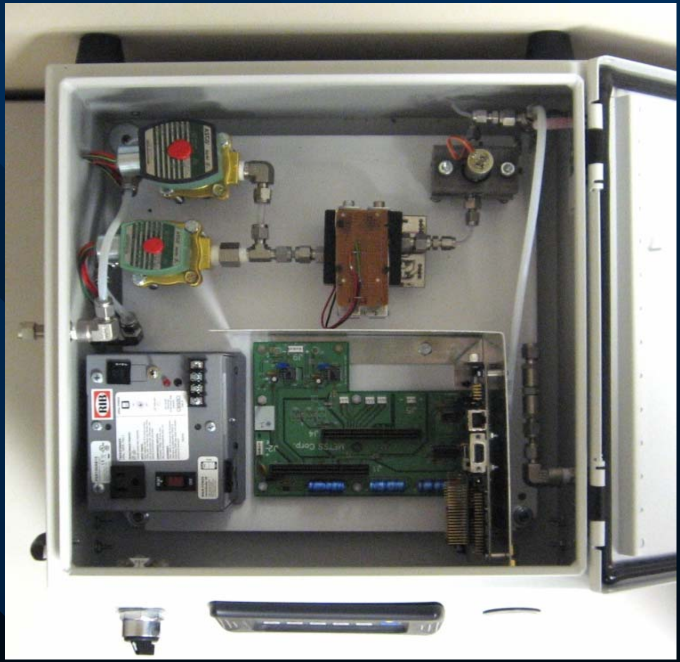
PAMAS Particle Counter

- 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

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

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 in-line 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

Portable Purifiers – Cleaning Efficiency Study

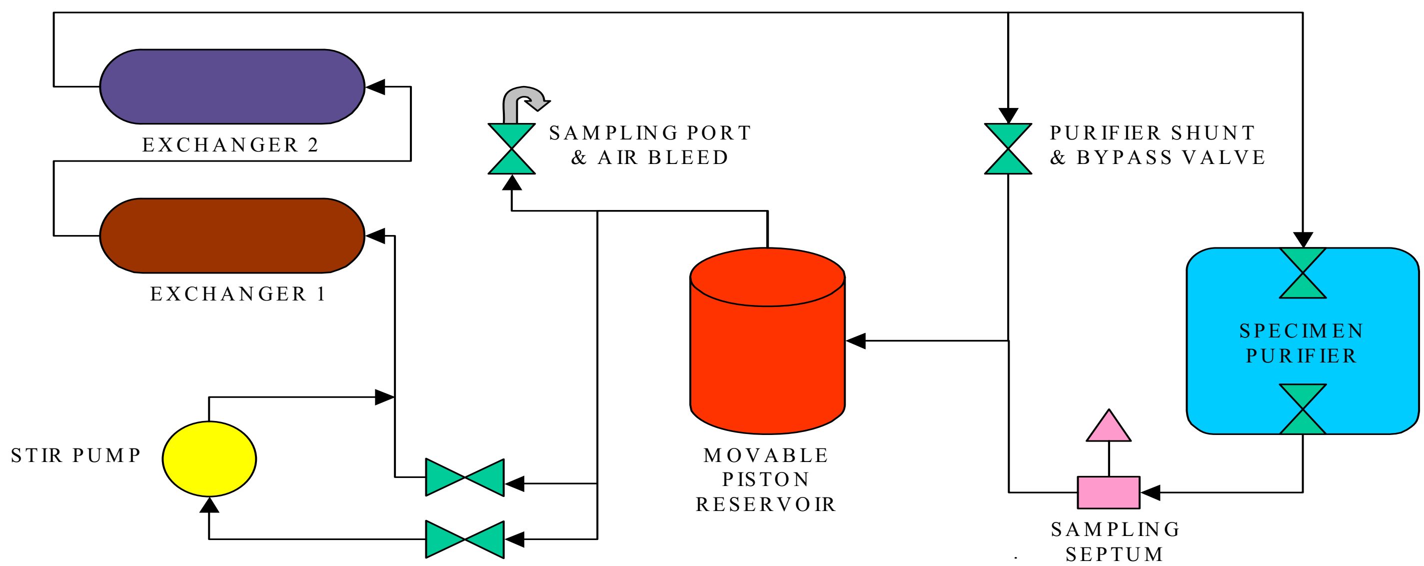
- Both the Malabar and the Pall Portable Fluid Purifiers were found by extensive hydraulic pump tests to not adversely affect hydraulic fluid quality as a result of repeated purification cycles
- Baseline cleaning effectiveness studies had not been conducted
- This study was to investigate the ability 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 ≤ 8%
- Also studied was the ability of the purifiers to remove JP-8 fuel
- The efficiency was studied for both vented and unvented systems

Portable Purifiers – Cleaning Efficiency Study

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: ~12%
- Time: 5 Hours

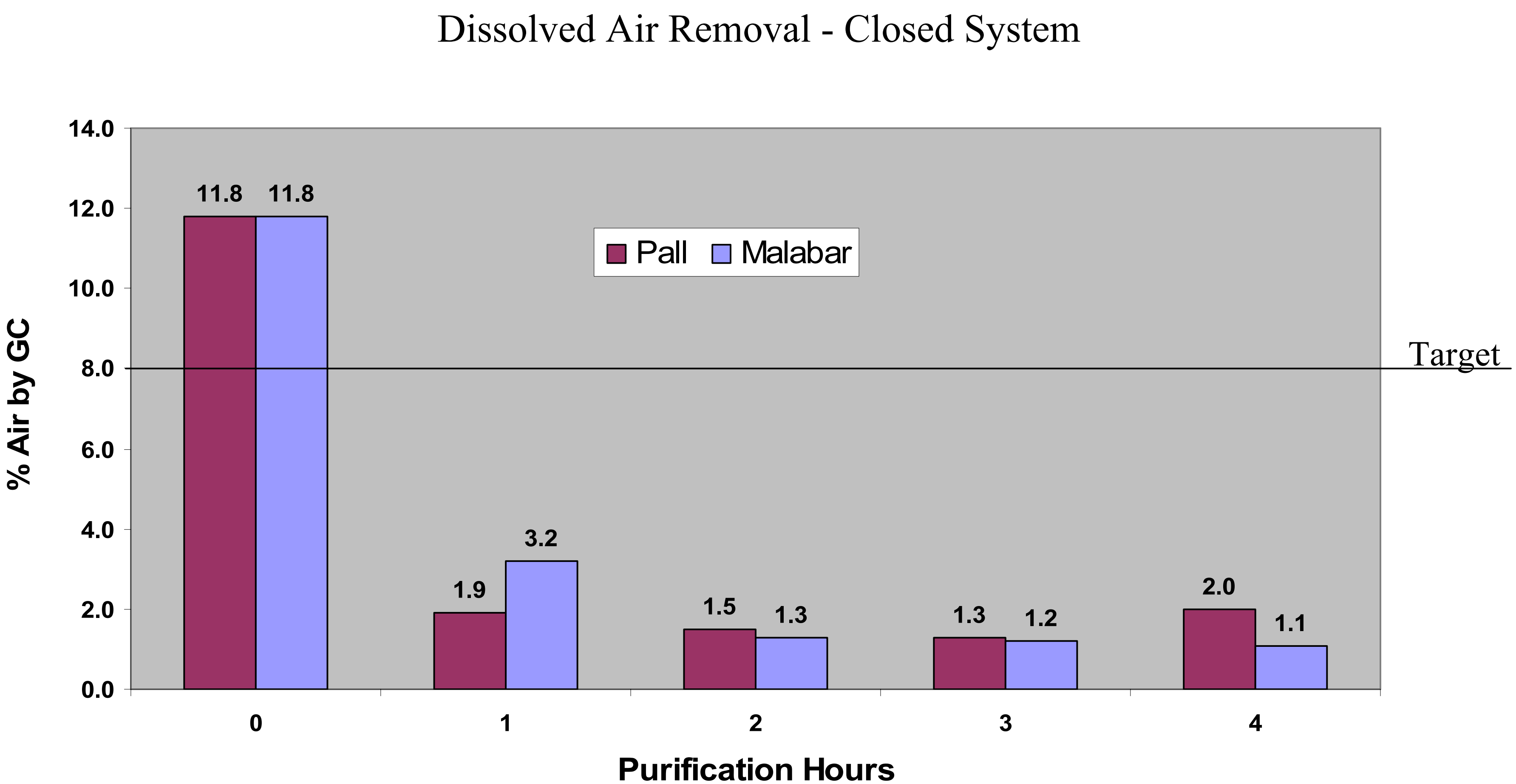
Portable Purifiers – Cleaning Efficiency Study

- Unvented (Closed) System

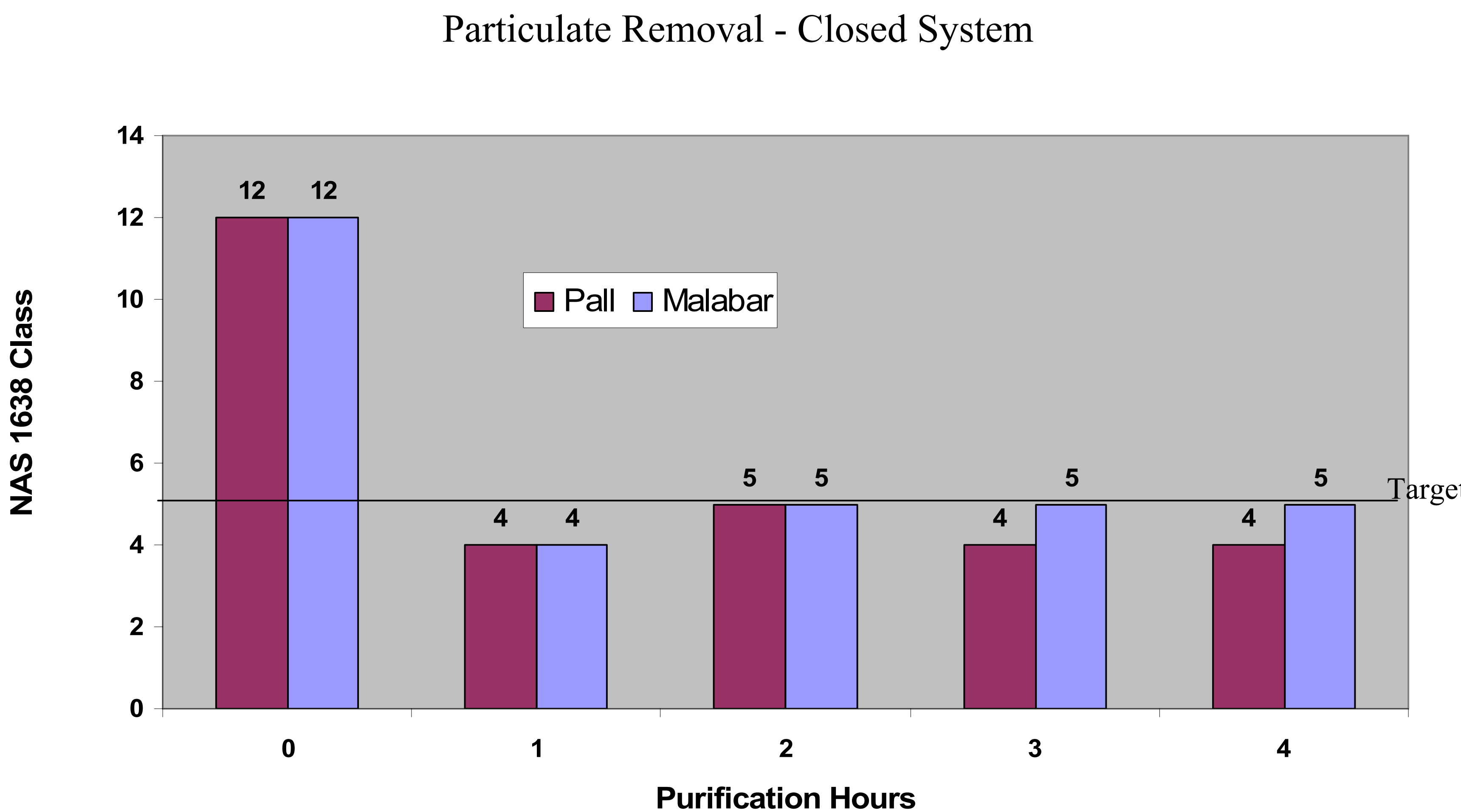
Portable Purifiers – Cleaning Efficiency Study
Pall Purifier

Portable Purifiers – Cleaning Efficiency Study
Malabar Purifier

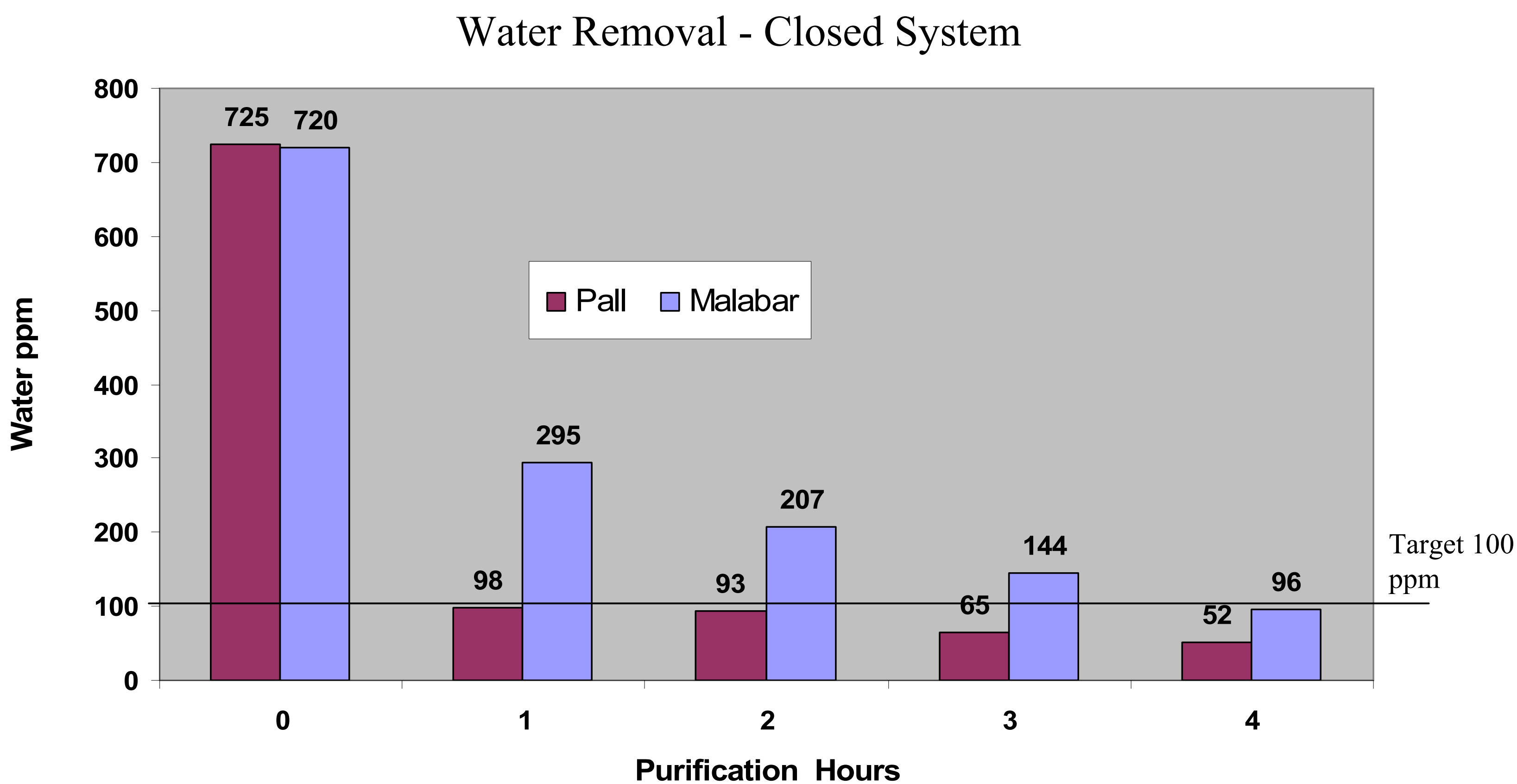
Portable Purifiers – Cleaning Efficiency Study



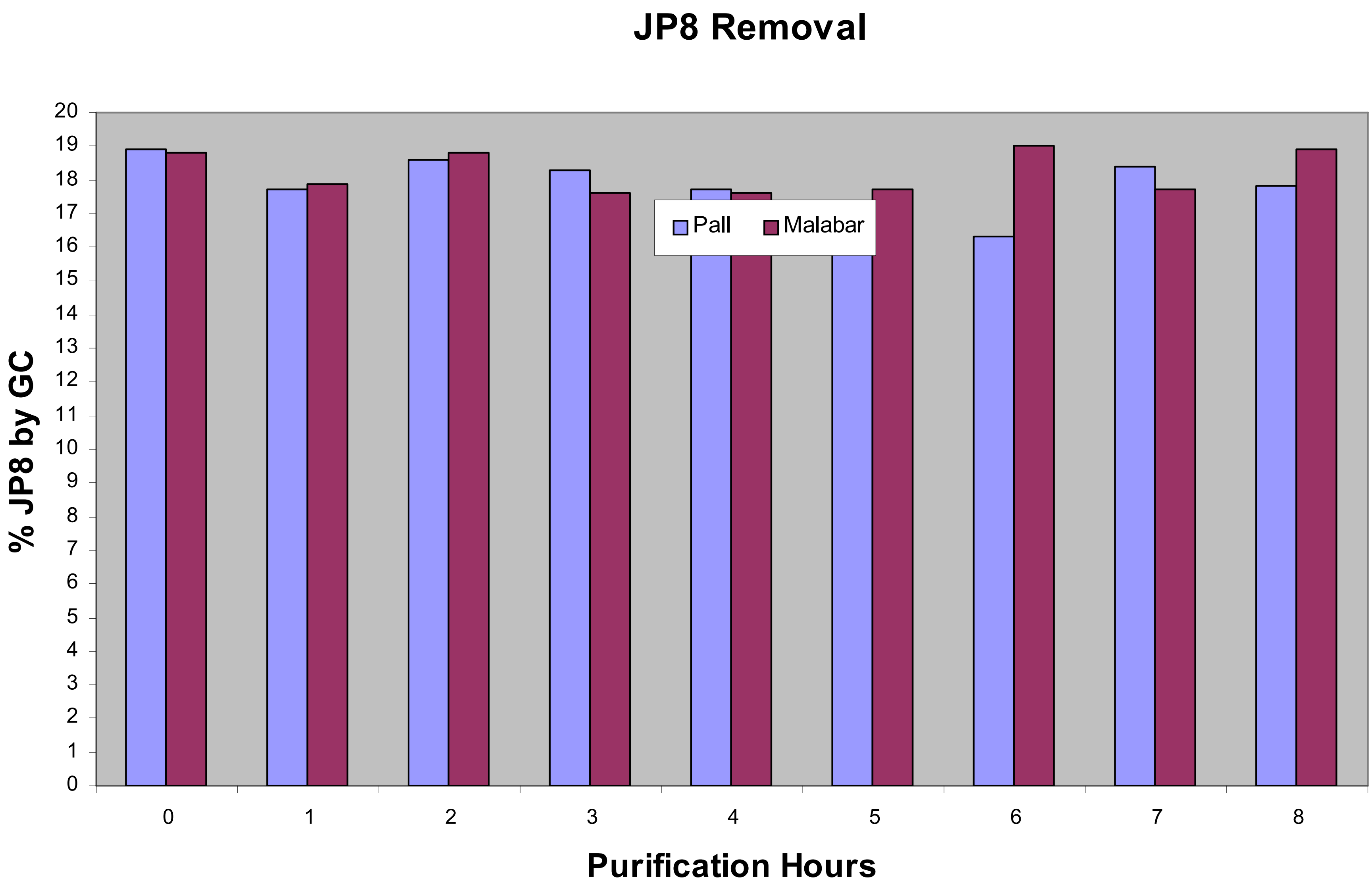
Portable Purifiers – Cleaning Efficiency Study



Portable Purifiers – Cleaning Efficiency Study



Portable Purifiers – Cleaning Efficiency Study



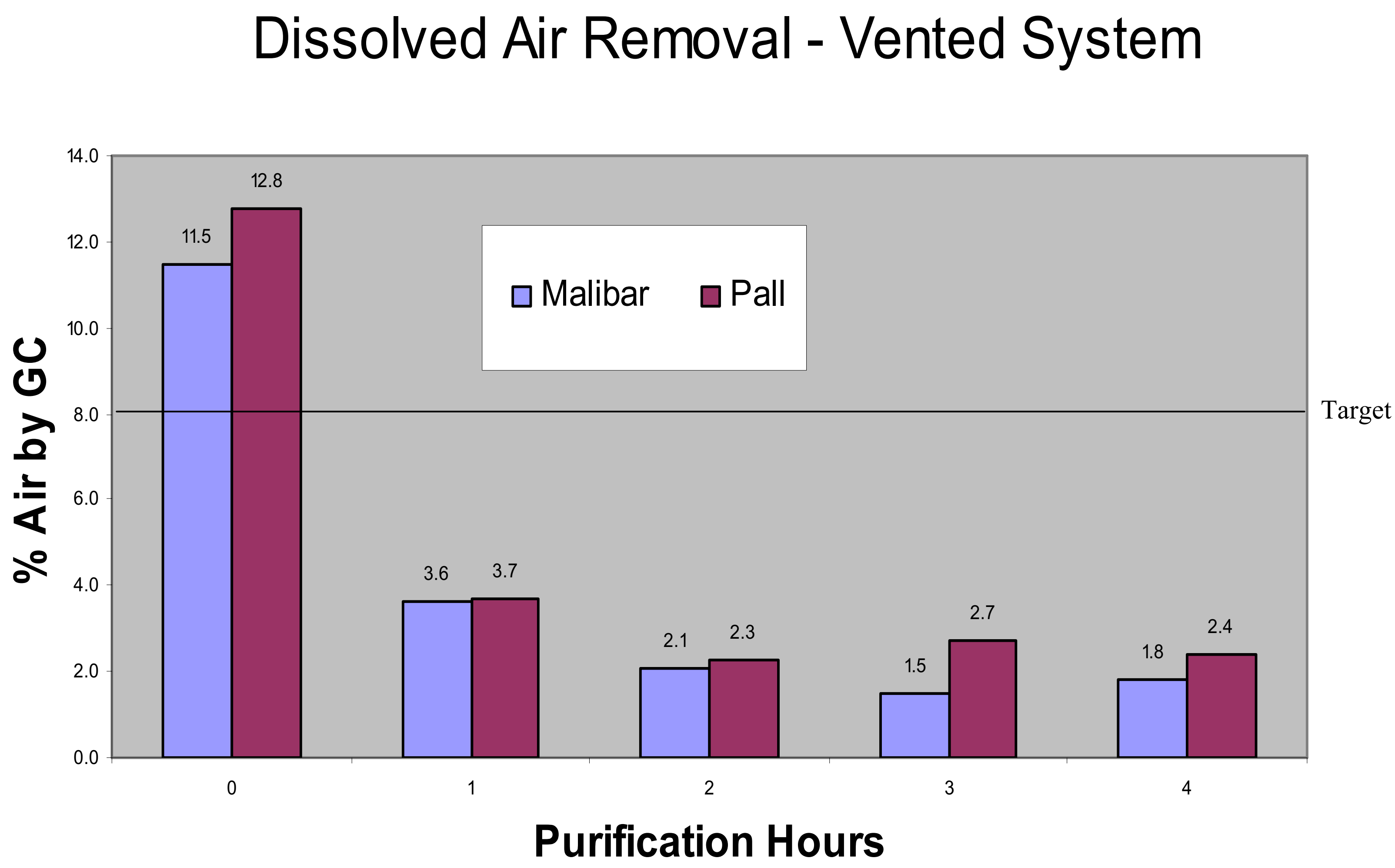
Portable Purifiers – Cleaning Efficiency Study

- Vented System

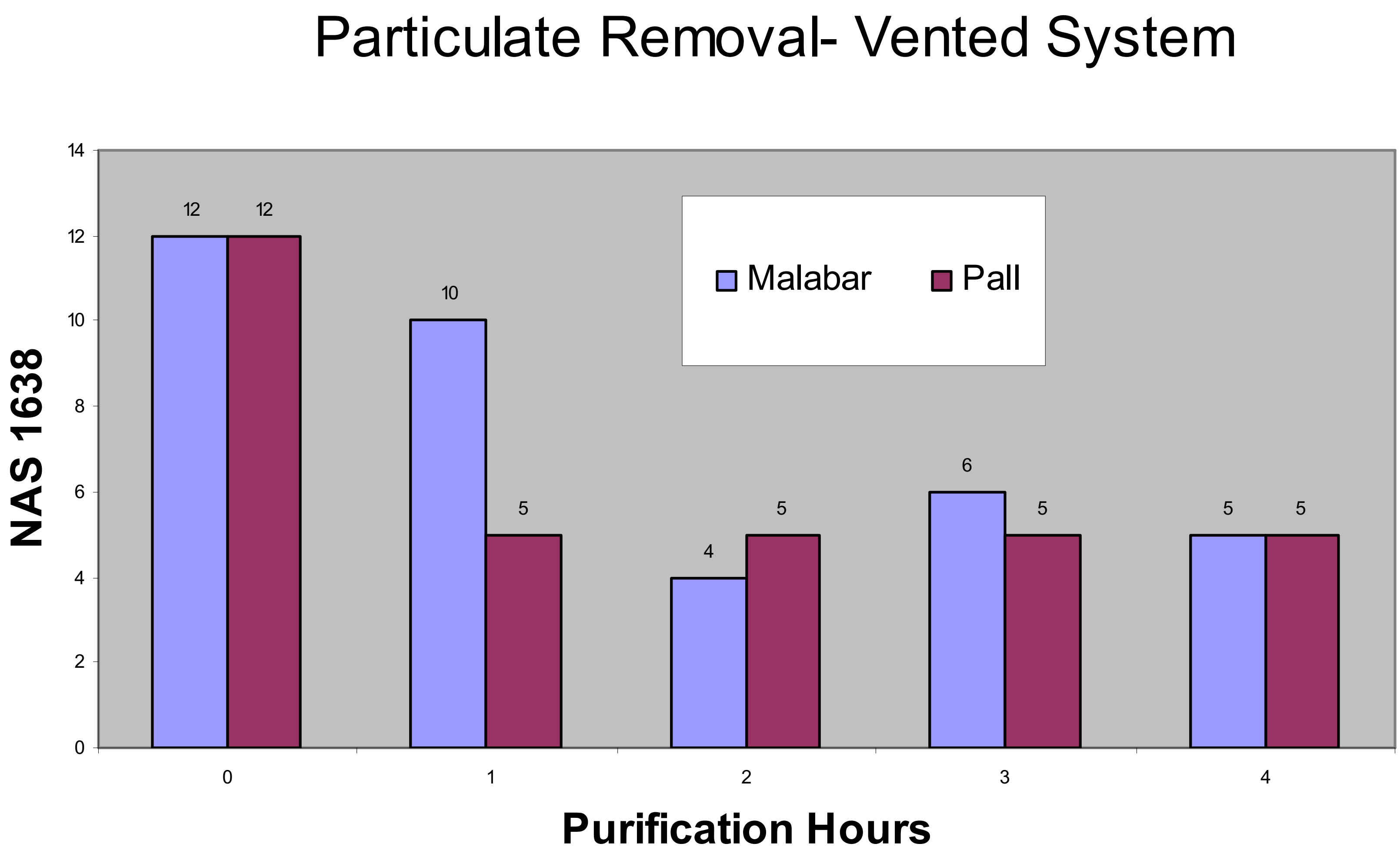
Portable Purifiers – Cleaning Efficiency Study
Pall Purifier

Portable Purifiers – Cleaning Efficiency Study
Malabar Purifier

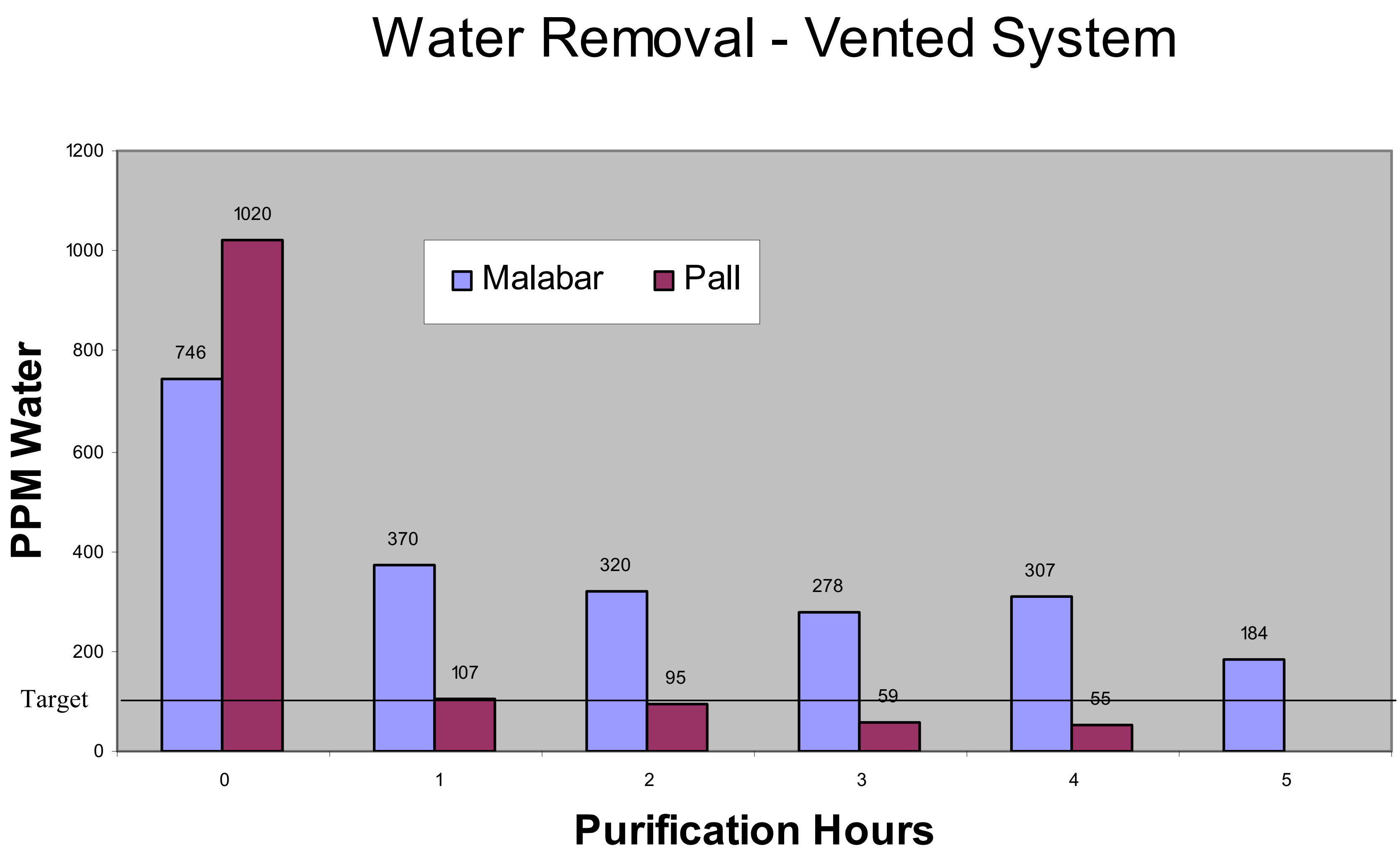
Portable Purifiers – Cleaning Efficiency Study



Portable Purifiers – Cleaning Efficiency Study



Portable Purifiers – Cleaning Efficiency Study



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 ~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 $\leq$ 100 ppm within 1 hour for both vented and unvented systems
    - The Malabar purifier required 4 hours to reduce the water content to $\leq$ 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.

Dominant Air Power: Design For Tomorrow…Deliver Today

Hydraulic Fluid Purification

Implementation

June 2006

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

Overview

Dominant Air Power: Design For Tomorrow…Deliver Today

- 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

Dominant Air Power: Design For Tomorrow…Deliver Today

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)

- 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

Pall

Malabar

Malabar Mule

HFP AUTHORIZED

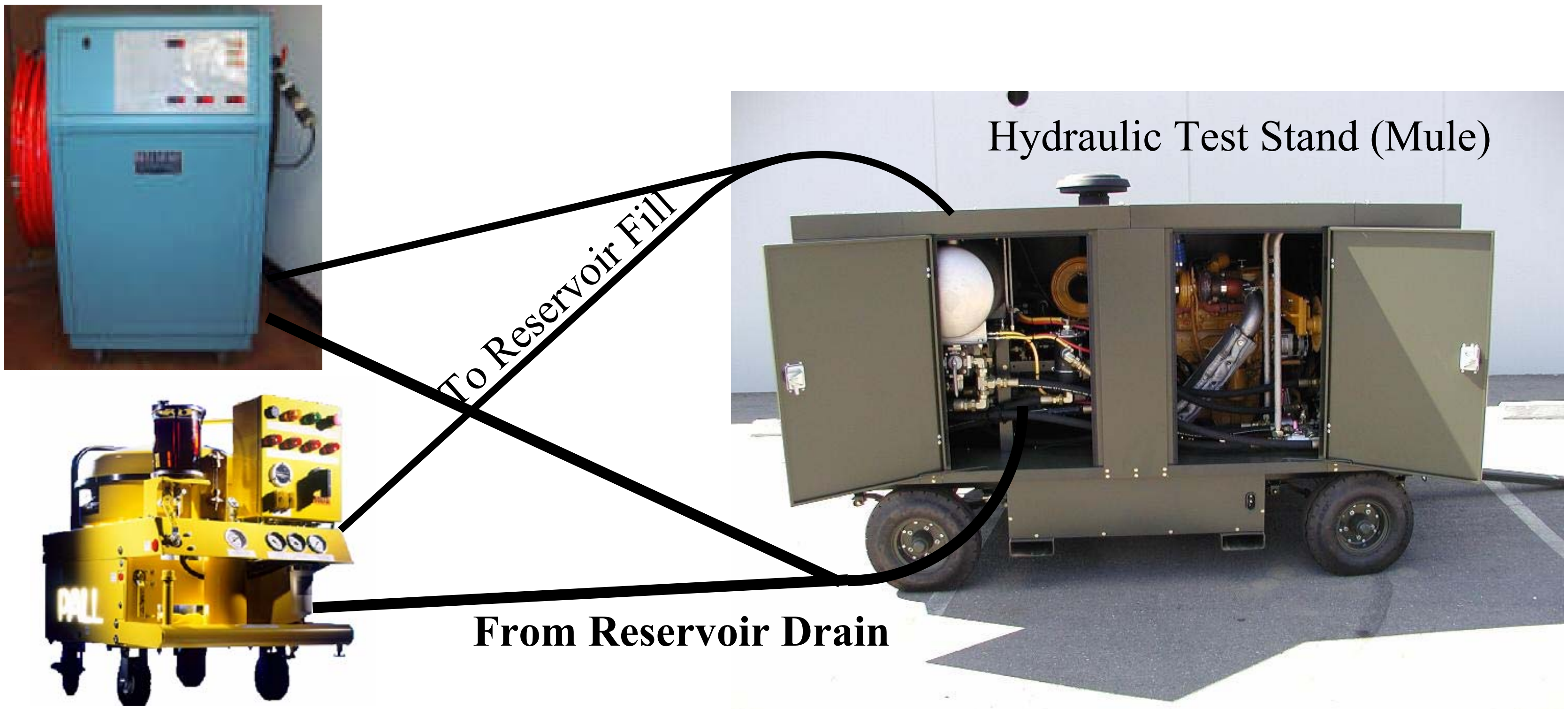
Dominant Air Power: Design For Tomorrow…Deliver Today

- **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

Dominant Air Power: Design For Tomorrow…Deliver Today

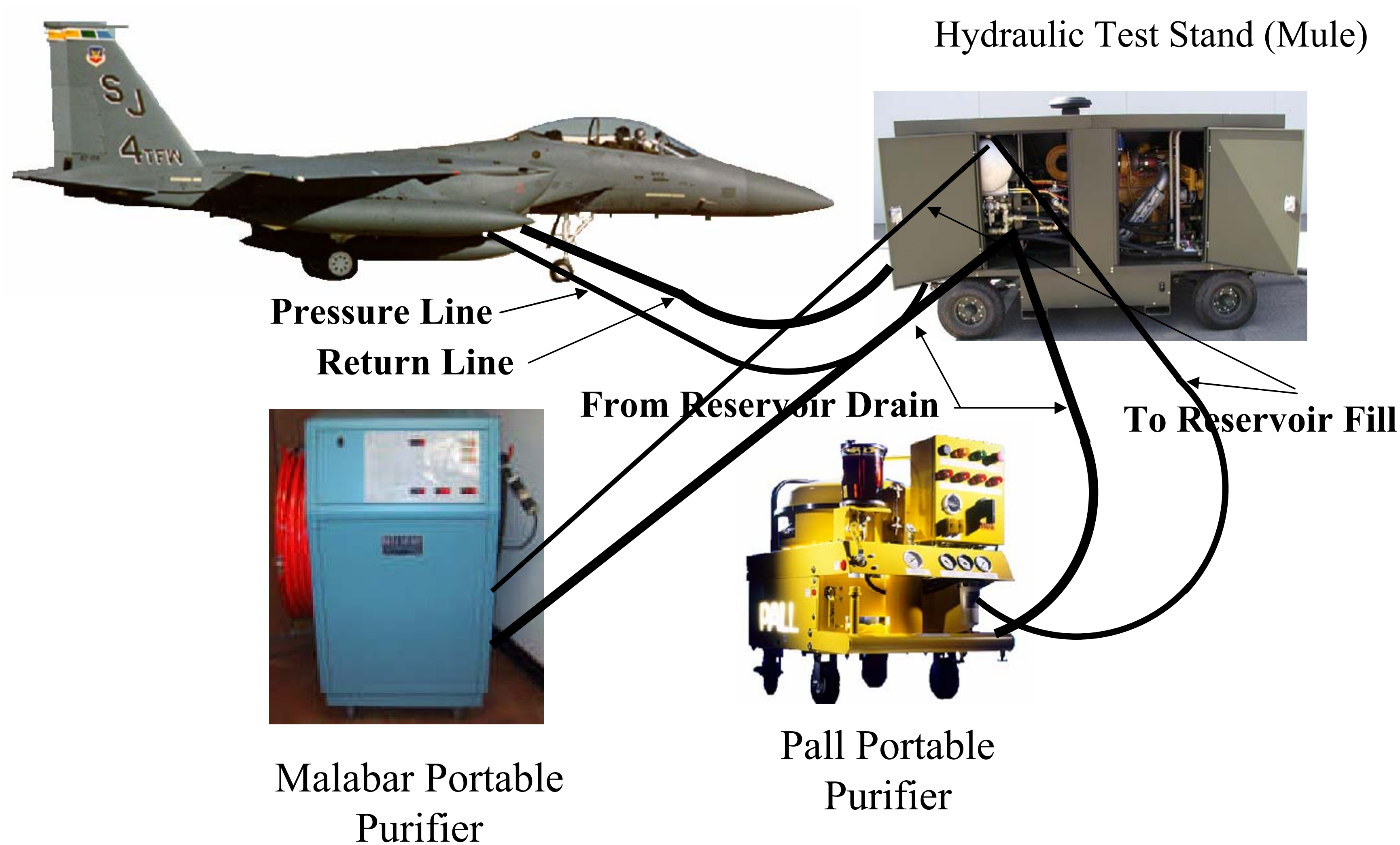
Malabar Portable Purifier



Pall Portable Purifier

Aircraft Purification Process

Dominant Air Power: Design For Tomorrow…Deliver Today



Purifier Table of Allowance

Dominant Air Power: Design For Tomorrow…Deliver Today

- 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

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- 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

- 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

ISSUES

- **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

Dominant Air Power: Design For Tomorrow…Deliver Today

- 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

QUESTIONS?

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

Enhanced Ester Objective

- 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

Property Evaluation TRL 3 → Performance Characterization TRL 3 → Element Testing TRL 3 → Sub-scale Testing TRL 4 → Full-scale Testing TRL 5 → Engine Test Full-scale TRL 6 → Engine Cert. & Flight TRL 7 & 8

Property Evaluation (TRL 3)

Viscosity
- 40C, 100C, 200C
- Viscosity @ -40ºF
- Pour Point
- P-V Coefficient
- Temp-visc coefficient
- Traction Coefficient

Physical Props
- Density
- Specific Heat
- Thermal Conductivity
- Vapor Pressure
- Evaporation Loss
- Foaming
- Refractive Index
- Color

Chemical Props
- Total Acid Number
- Electrical Conductivity
- Odor
- Toxicity
- Trace Metals

Performance Characterization (TRL 3)

Flammability
- Flash Point
- Auto-ignition temp

Oil Life
- Ox-corr stability
- Thermal Stability / corrosivity

Corrosion
- Stress Corrosion (Compressor Alloys)
- Hot Corrosion (Turbine Alloys)
- Bearing Alloys

Legacy Oil Compatibility
- Mix - Aging

Element Testing (TRL 3)

Tribological Assessment
- Load Carrying
- Performance Map w/ Adhesive wear
- Oil shut off
- Surface initiated fatigue

Elastomer Compatibility
- Hardness
- Swell
- Compression Set
- Tensile and elongation

Initial Round-robin planned (AFRL/PRTM, USN, P&W)

Sub-scale Testing (TRL 4)

Tribological Assessment
- Rolling contact fatigue (surface & subsurface)
- Spall propagation
- Cage Land Testing

Deposition Resistance
- Vapor Phase coker
- Vapor / Liquid phase (HTDT)
- Liquid Phase (HLPS)
- Formulator proprietary tests vs baseline oils
- Carbon particulate at elevated pressure
- Existing deposit washing

Full-scale Testing (TRL 5)

Tribological Assessment
- Ryder Gear Test

Deposition Resistance
- USN Bearing deposition test
- Mini-simulator

Engine Test Full-scale (TRL 6)

T63 Engine
- 250 Hours w/ hot shutdowns
- Standard TJR defines oil sampling and test regimen

Engine Cert. & Flight (TRL 7 & 8)

Controlled Service Use
- AMT
- Commercial Use
- Engine Inspections
- Filter Inspections

Color Code
- Oil Companies
- AFRL/PRTM
- AFRL/MLBT
- USN
- OEMs
- Wedeven Assoc.
- TBD

- Four candidate oils currently undergoing TRL 3 evaluation
- AFRL/PRTM has received one 55 gal drum of one candidate

3

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
Perfluoroelastomer	AMS 7275	Kalrez™	TBD[2]	TBD
Fluorosilicone	AMS 3383		TBD	121 +/- 2 C
Nitrile	AMS-R-25732		TBD	135 +/- 2 C

[1]Revised temperature from 200°C to 175°C since last SAE E-34 presentation

[2]Dupont-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

Next Steps for Oil/Elastomer Testing

- Elastomer Round Robin began Mar 06
  - Phase I : 70 hrs, 175^o 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.

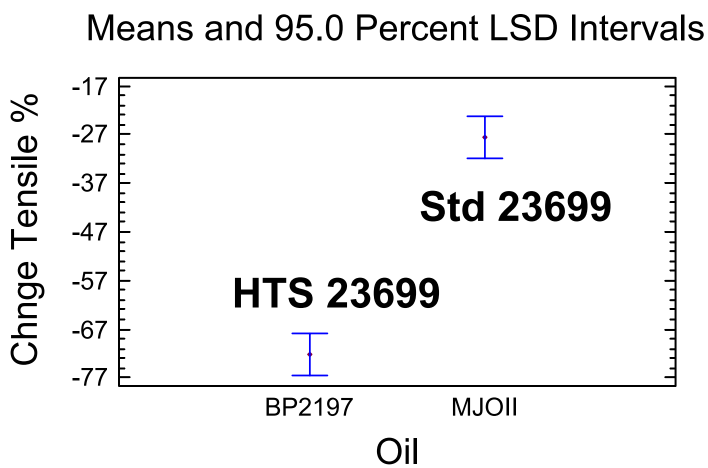
- Selection of reference Viton-A and GLT materials
  - Material should be available to anyone
- Database generated will be used to establish limits in the Draft Oil Requirements and eventual Specification

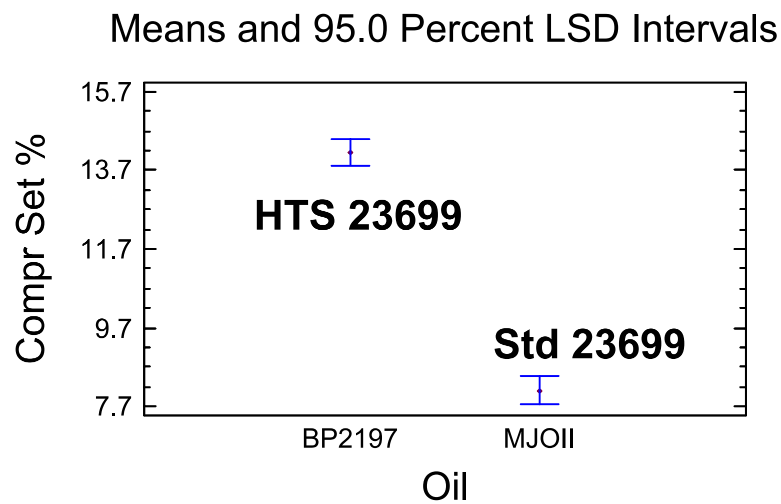
Preliminary ANOVA Results

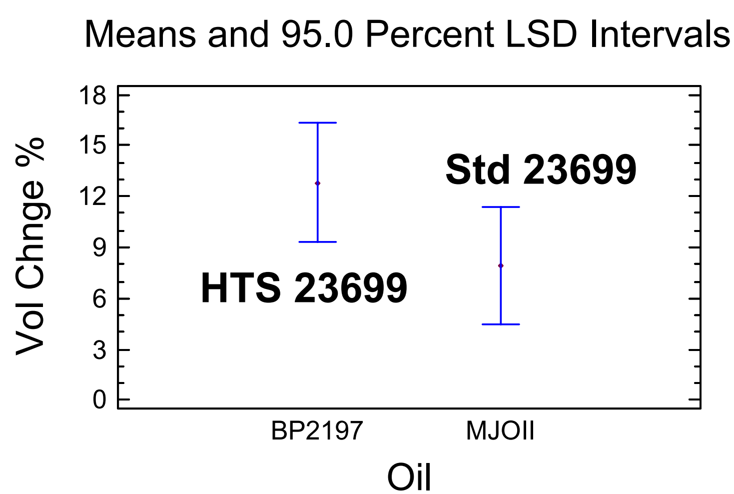
UDRI Results

Std vs HTS Oil

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







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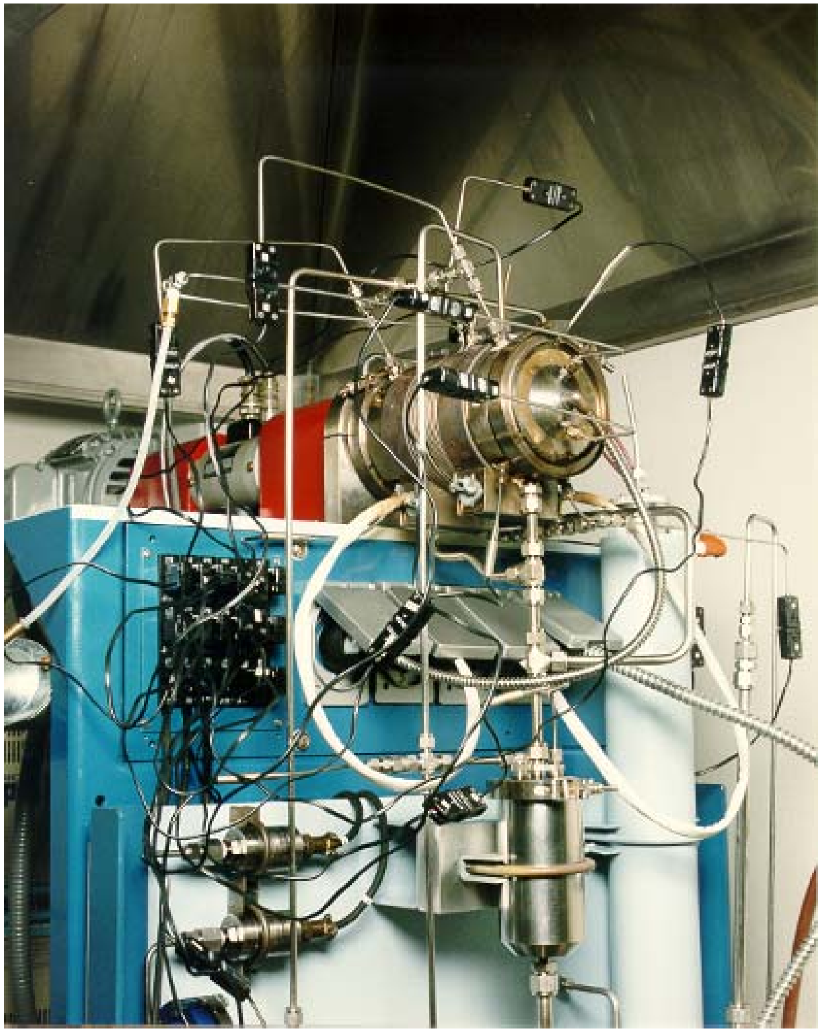
Oil Deposition -
Mini-Simulator Rig



Test Conditions

Oil Flow rate: 400 ml/min
Oil capacity: 2000 ml

Test Temps (°F):

Sump	Bearing	Hot Spot
428	527	572

Test Duration: 100hrs

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

Switch to stainless steel test heads - Apr 06

BP 2197 – May 06

Load Capacity

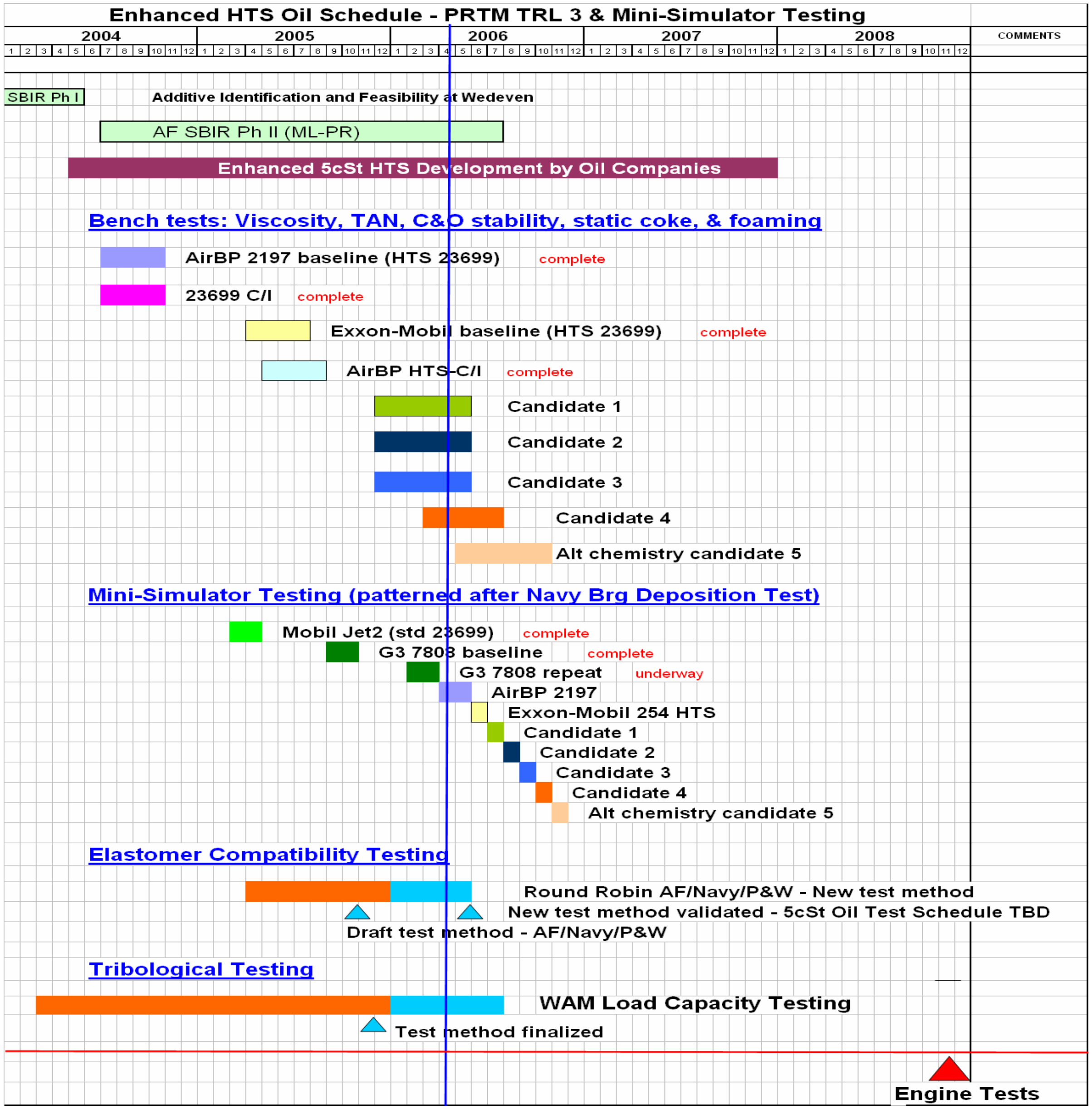
Tribology/Load Capacity:

- 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

9

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)			**WEDEVEN ASSOCIATES**				
DENSITY (ASTM D891B)	**REPORT**	**0.9957**	**N/A**	**0.9957**	**?**	**N/A**	**N/A**
VAPOR PRESSURE (ASTM D2879)	**5 Pts From 150 to 300 C mm Hg**			**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**
	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**
ELECTRICAL CONDUCTIVITY (ASTM D2624)	**pS/m, Report**			**N/A**	**N/A**	**N/A**	**N/A**
	22C	**1400**	**1170**	**N/A**	**N/A**	**N/A**	**N/A**
	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**
Al	**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 COMPANY	USAF/PRTM	USAF/MLBT	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**

<u>Sample Temperatures</u>

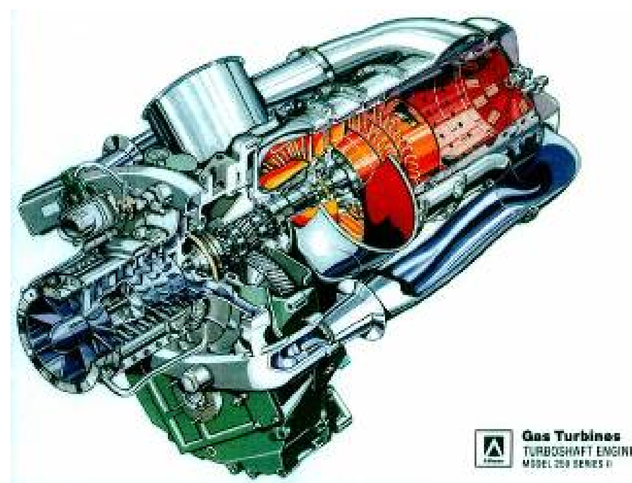
•Oil in 300°F

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

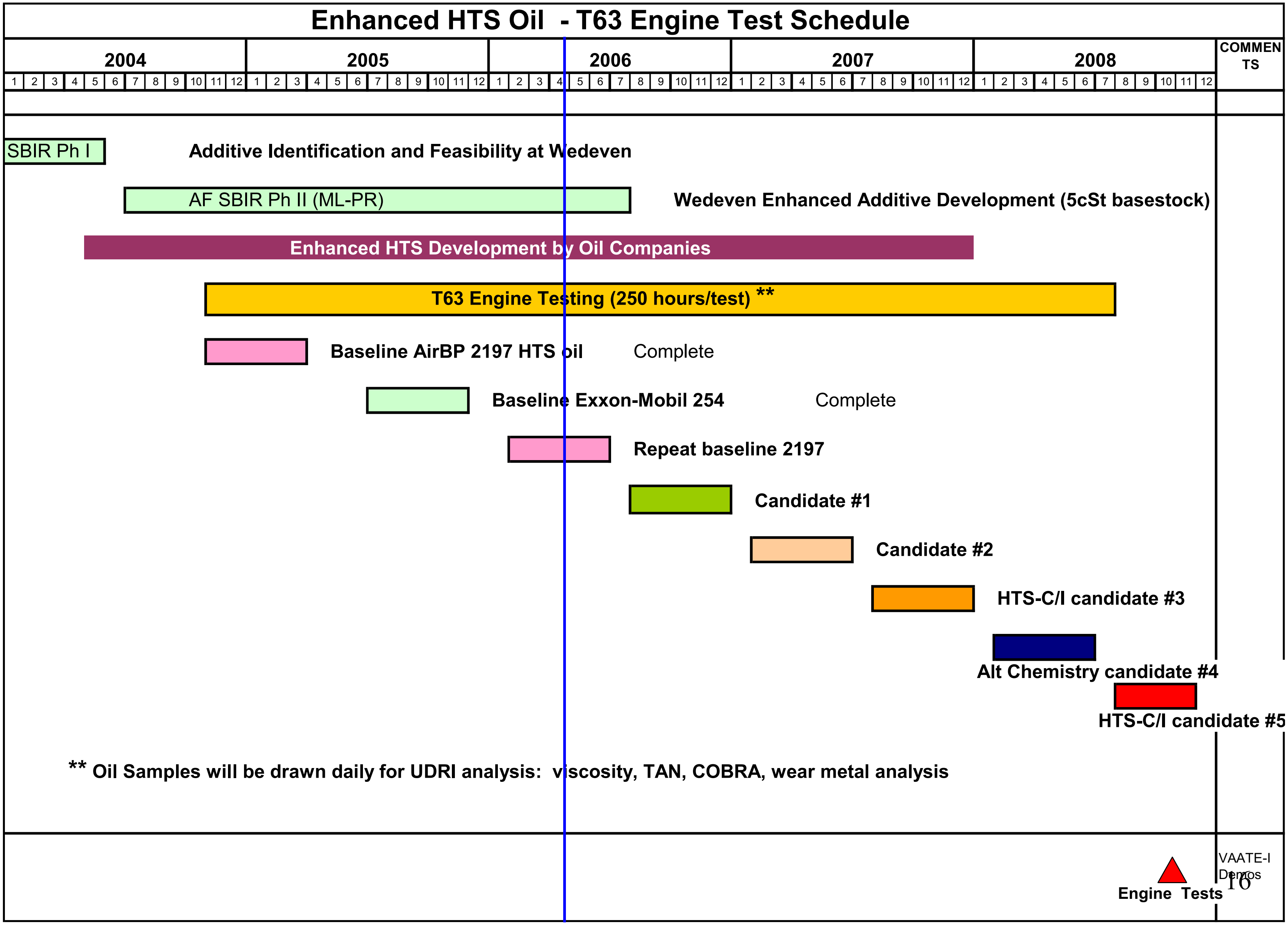
•Soak back - No 6 & 7 brg 670°F, No 8 560°F

<u>Status</u>

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



T63 Test Schedule



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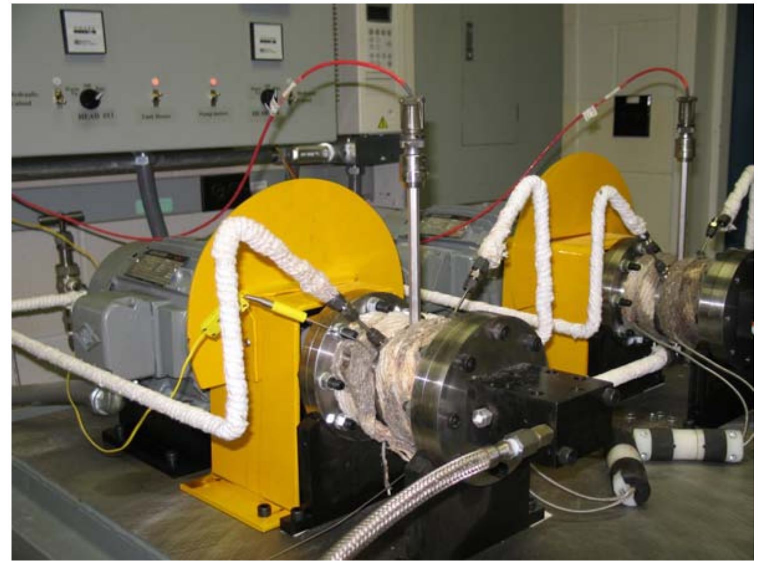
40 mm Bearing Testing - Beyond Target Requirements

- **Prior research by Nixon et. al., and Trivedi et. al., indicate lubricant anti-wear 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**

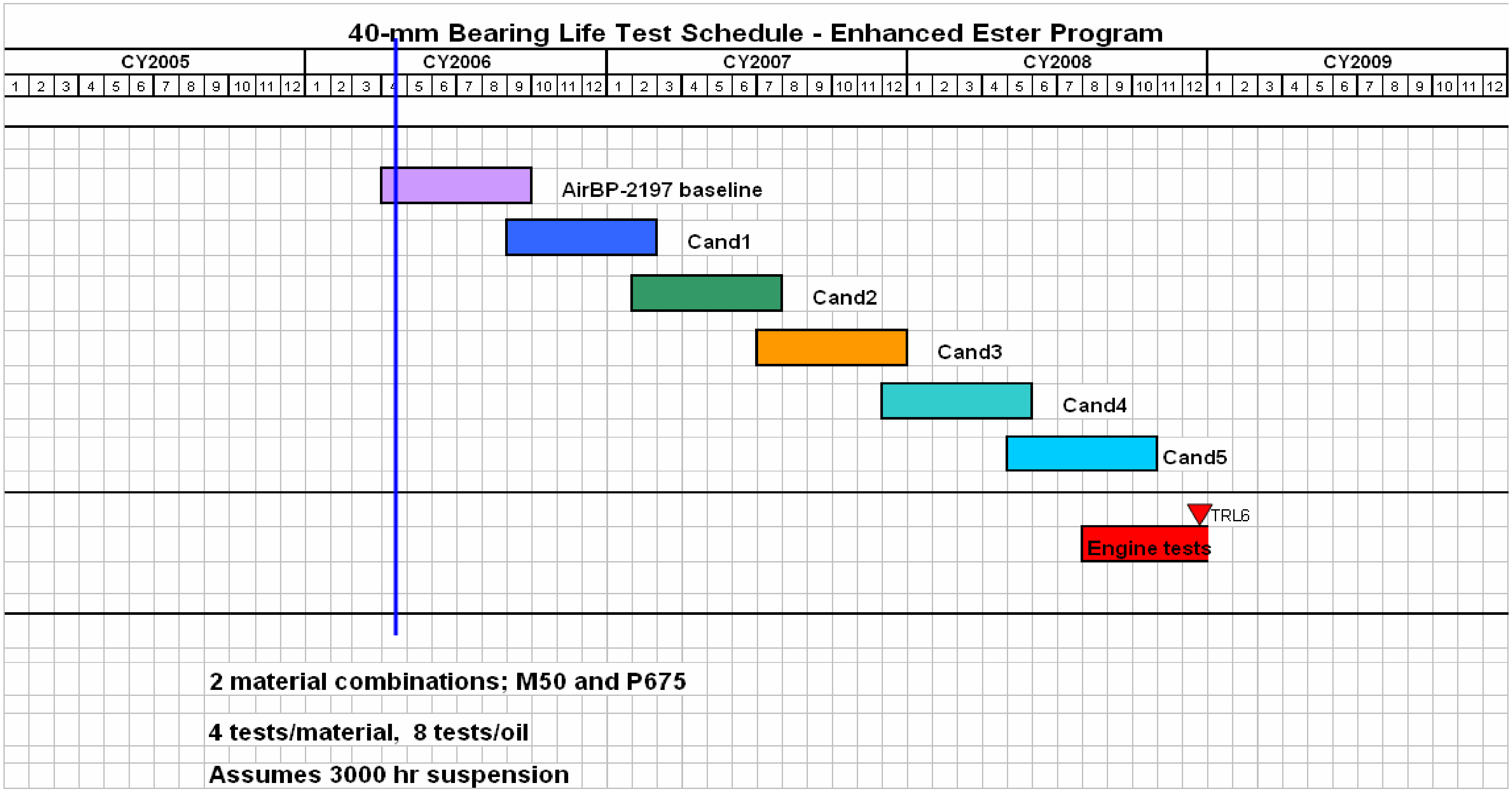


Bearing test heads with insulated head and oil supply lines for high temp operation

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

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

40 mm Bearing Test Schedule



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Overall Program 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*

"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*

AHTL Development

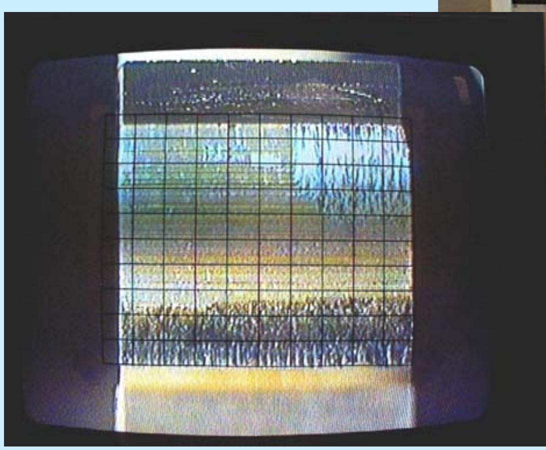
- **Properties:**
  - *Higher viscosity, 9 cSt versus 5 cSt measured at 100 deg C*
    - *suitable for use in normal gearbox operating ranges*
  - *Good to –32 deg C (13,000 cSt)*
    - *Coincides with Army limit*
    - *Tradeoff from –40 deg C (5 cSt), -60 deg C (3 cSt)*
    - *But, additional benefits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

U. S. Navy Ryder Gear Test

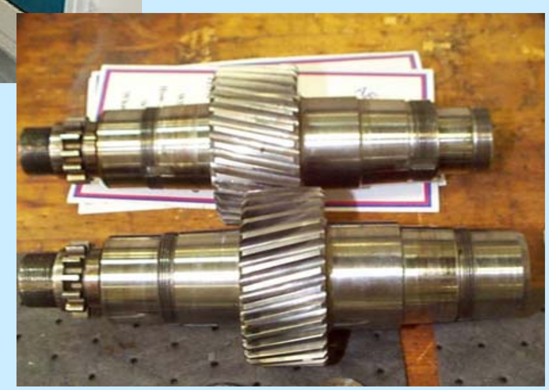
Control Console

Test Spur Gears

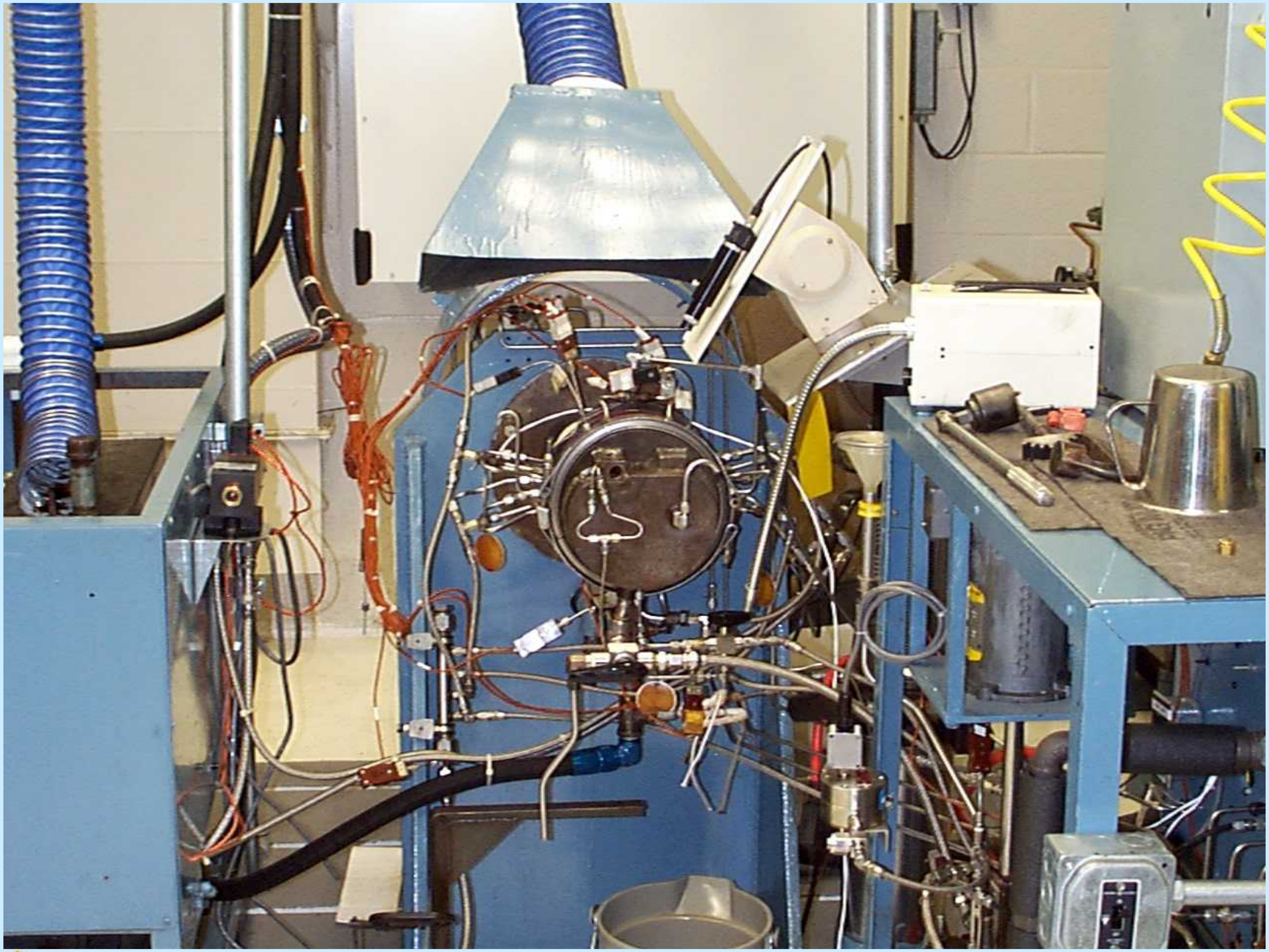
Scuffing Measurement



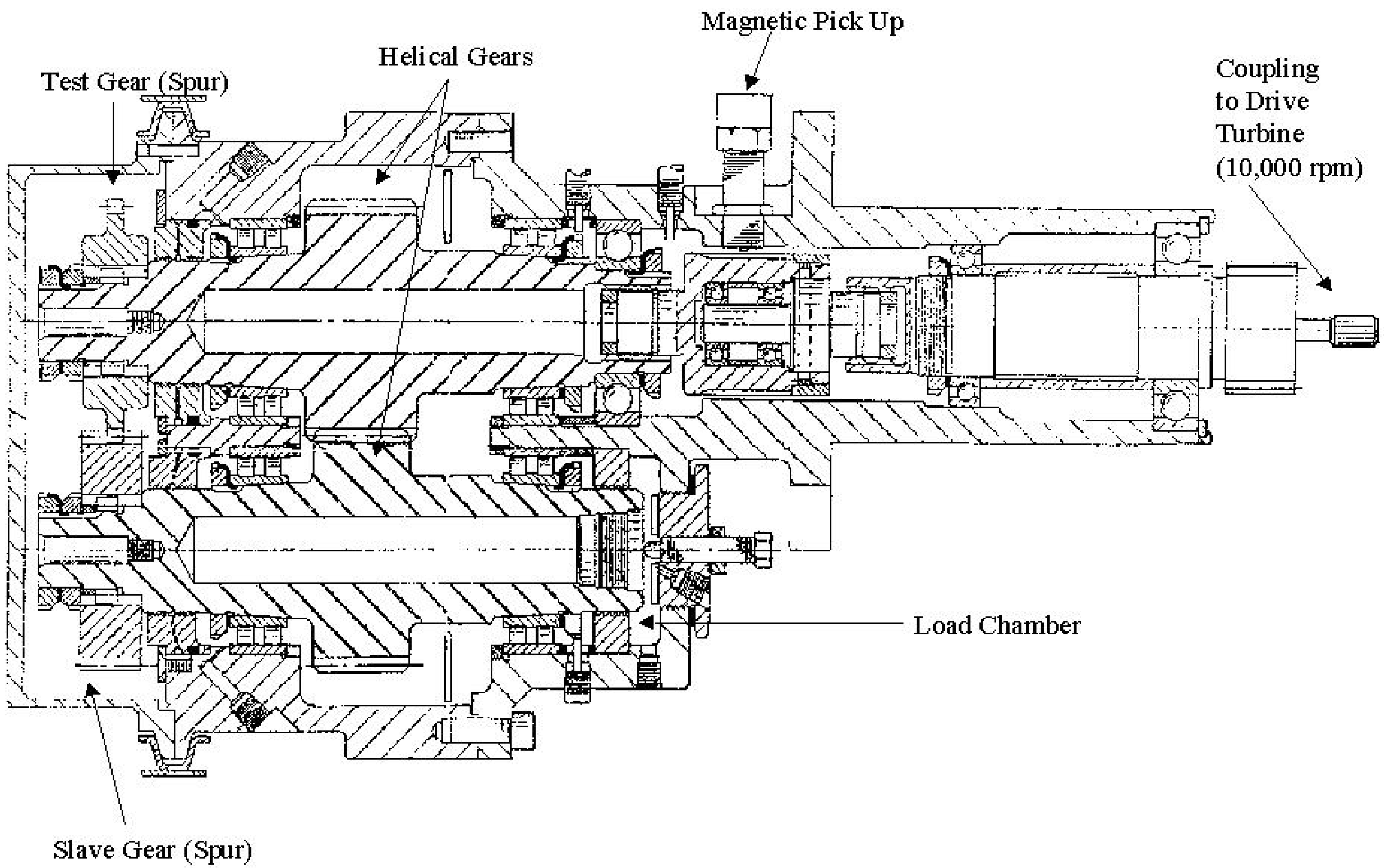
Helical Loading Gears



U. S. Navy Ryder Gear Test

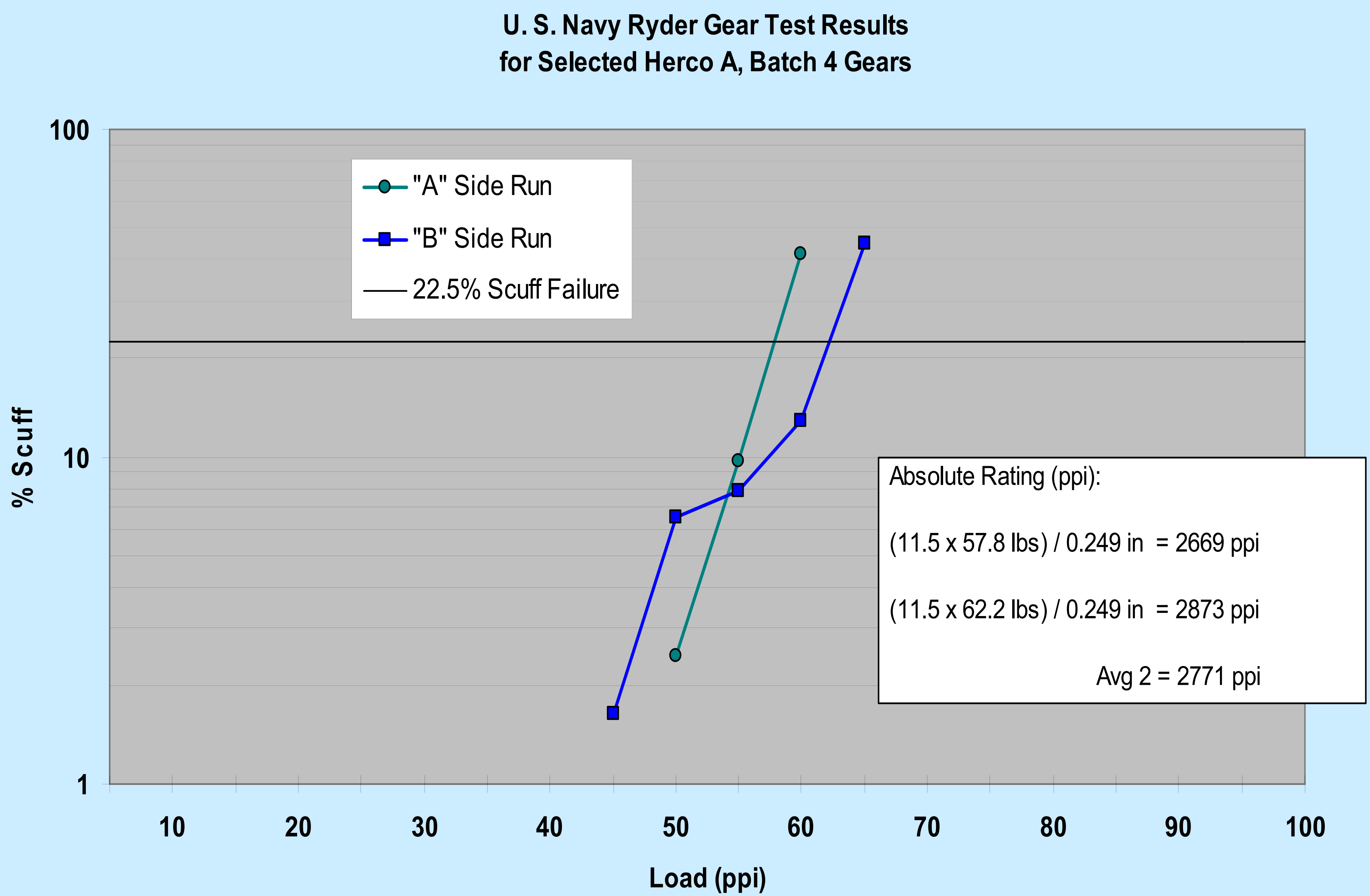


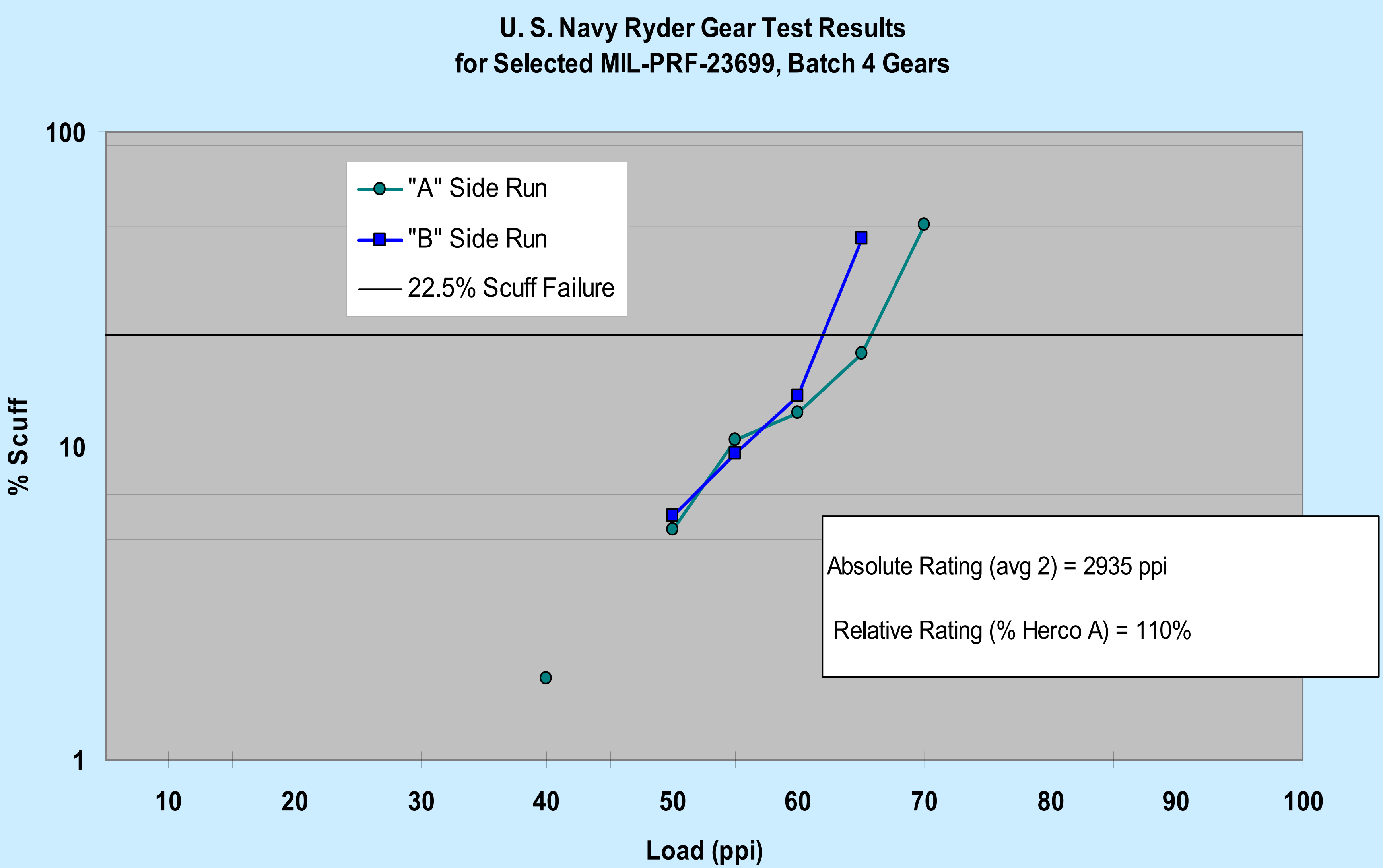
U. S. Navy Ryder Gear Test



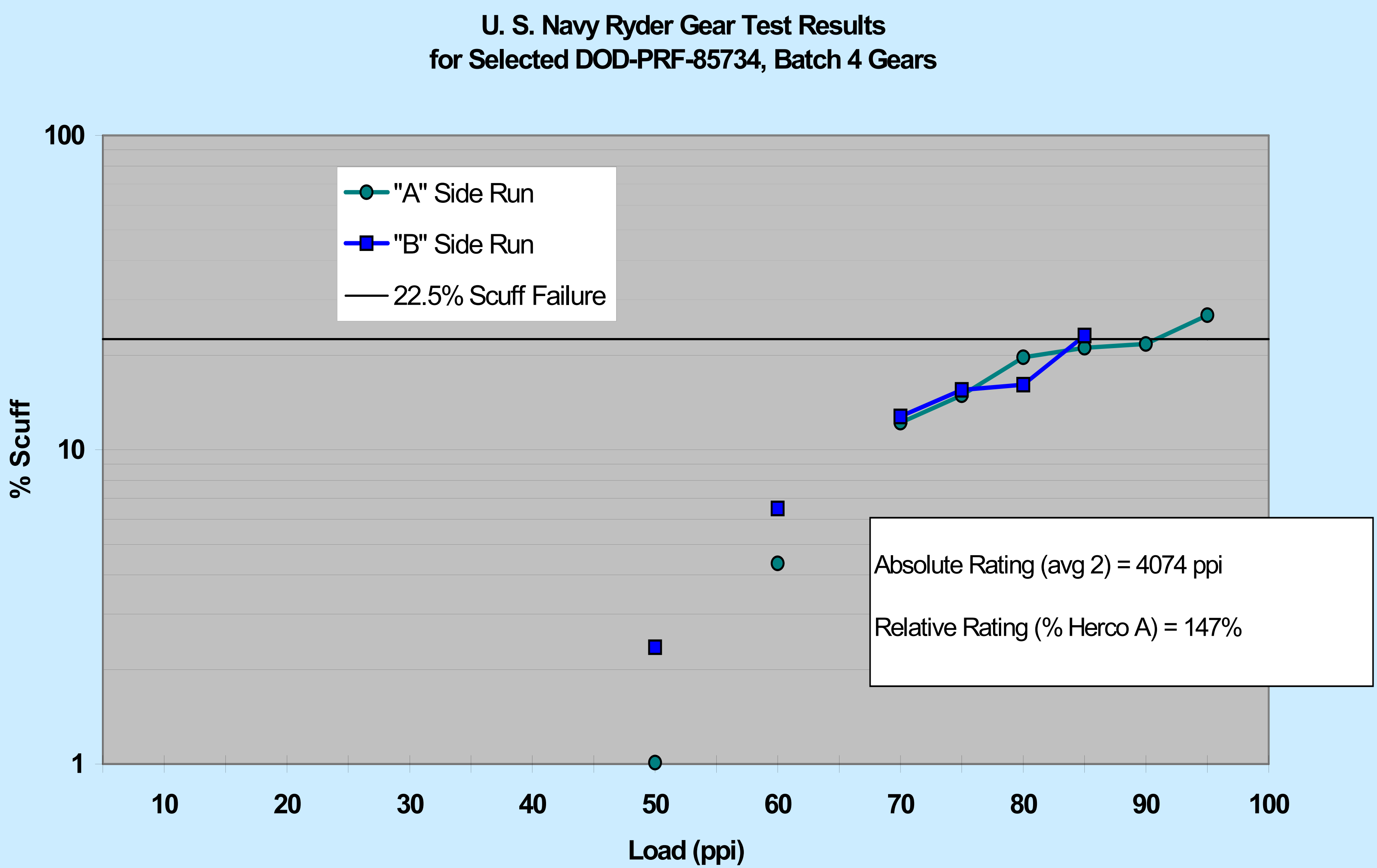
Ryder Gear Test (Top View)

UNCLASSIFIED – DISTRIBUTION UNLIMITED

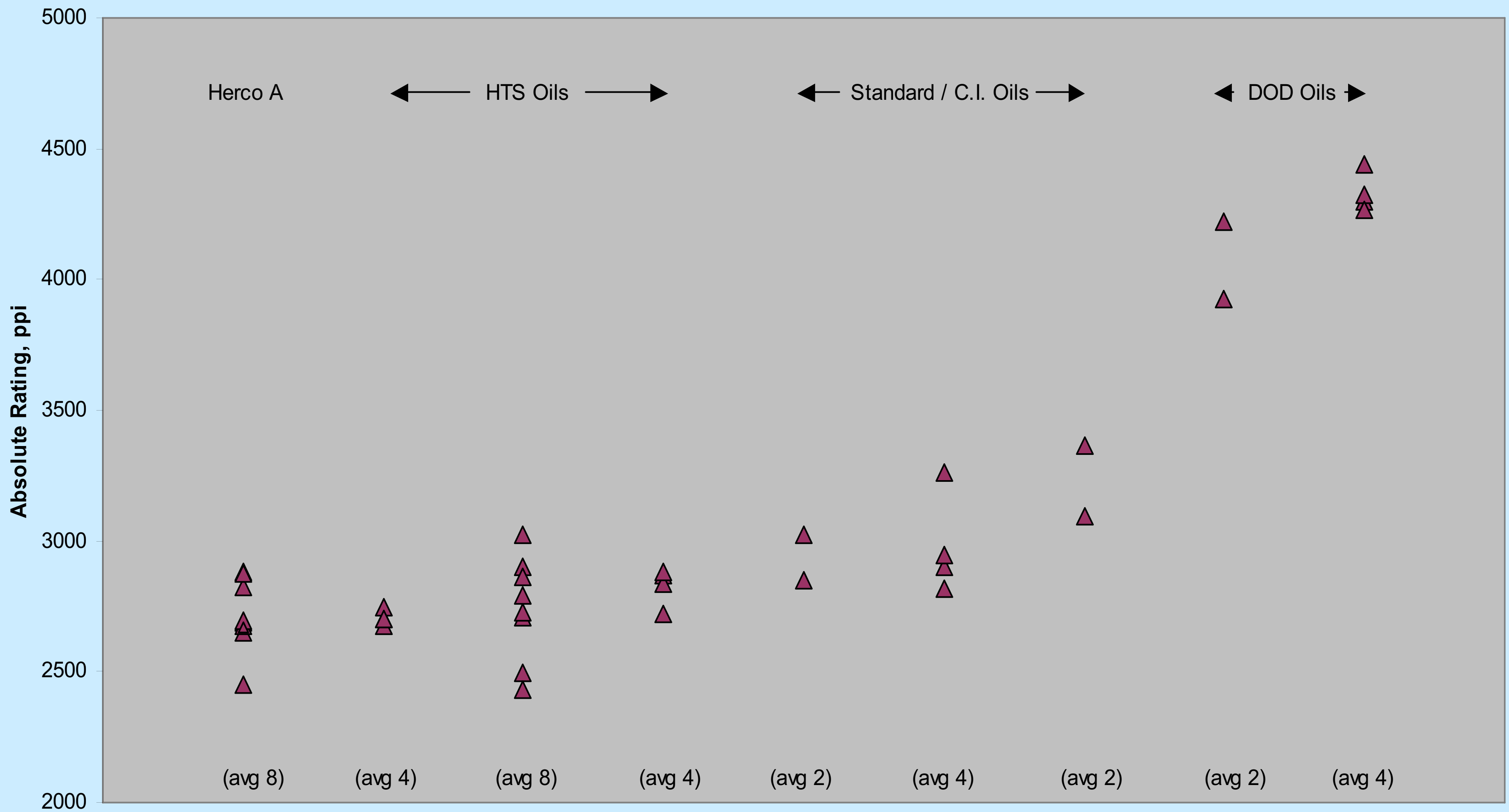

U. S. Navy Ryder Gear Test Results
for Selected Herco A, Batch 4 Gears
"A" Side Run
"B" Side Run
22.5% Scuff Failure
% Scuff
100
10
1
10
20
30
40
50
60
70
80
90
100
Load (ppi)
Absolute Rating (ppi):
(11.5 x 57.8 lbs) / 0.249 in = 2669 ppi
(11.5 x 62.2 lbs) / 0.249 in = 2873 ppi
Avg 2 = 2771 ppi

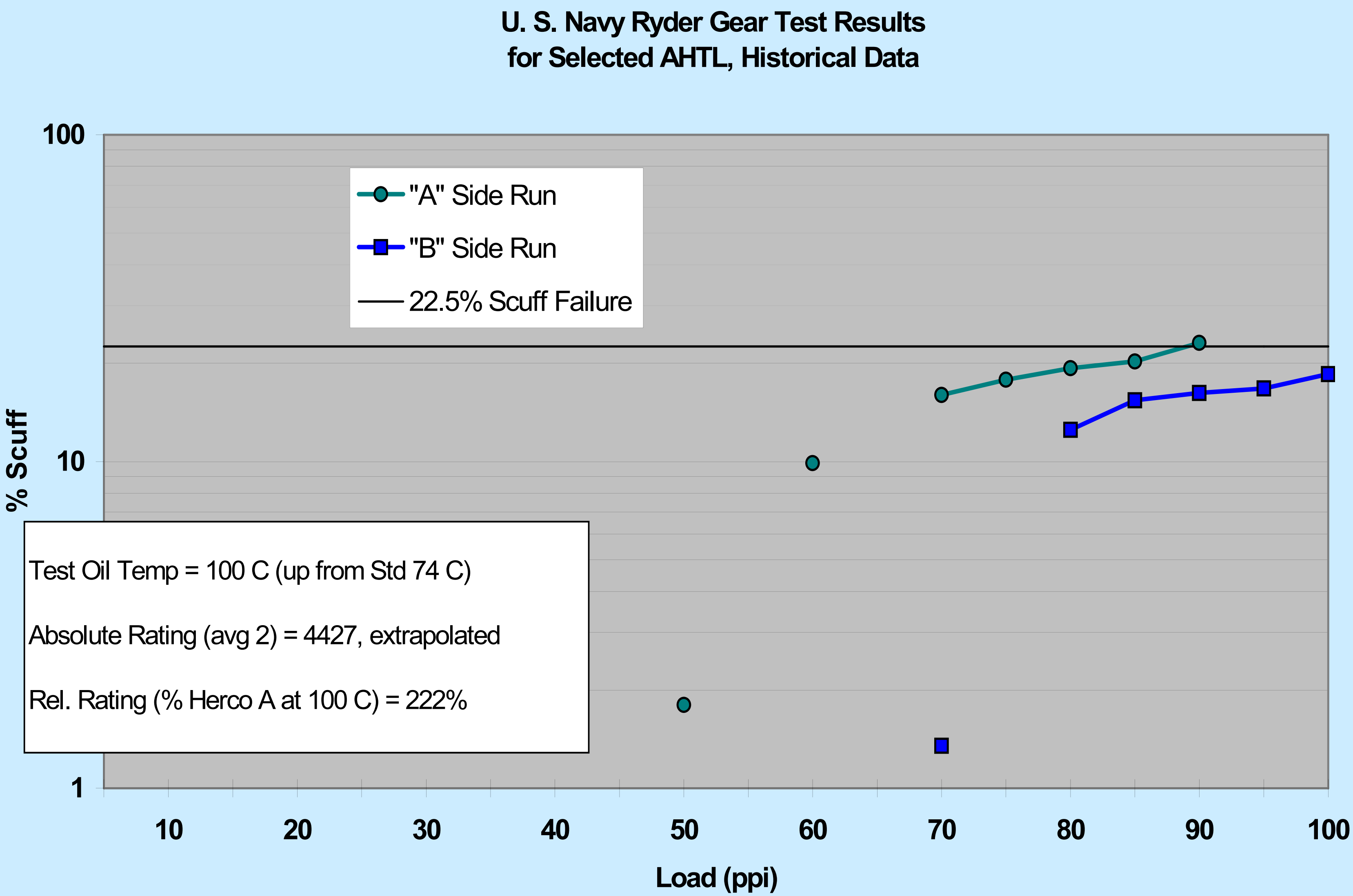


U. S. Navy Ryder Gear Test Results
for Selected MIL-PRF-23699, Batch 4 Gears
"A" Side Run
"B" Side Run
22.5% Scuff Failure
Absolute Rating (avg 2) = 2935 ppi
Relative Rating (% Herco A) = 110%
% Scuff
100
10
1
10
20
30
40
50
60
70
80
90
100
Load (ppi)


U. S. Navy Ryder Gear Test Results
for Selected DOD-PRF-85734, Batch 4 Gears
100
10
1
% Scuff
"A" Side Run
"B" Side Run
22.5% Scuff Failure
Absolute Rating (avg 2) = 4074 ppi
Relative Rating (% Herco A) = 147%
10
20
30
40
50
60
70
80
90
100
Load (ppi)

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




U. S. Navy Ryder Gear Test Results
for Selected AHTL, Historical Data
"A" Side Run
"B" Side Run
22.5% Scuff Failure
% Scuff
100
10
1
10
20
30
40
50
60
70
80
90
100
Load (ppi)
Test Oil Temp = 100 C (up from Std 74 C)
Absolute Rating (avg 2) = 4427, extrapolated
Rel. Rating (% Herco A at 100 C) = 222%

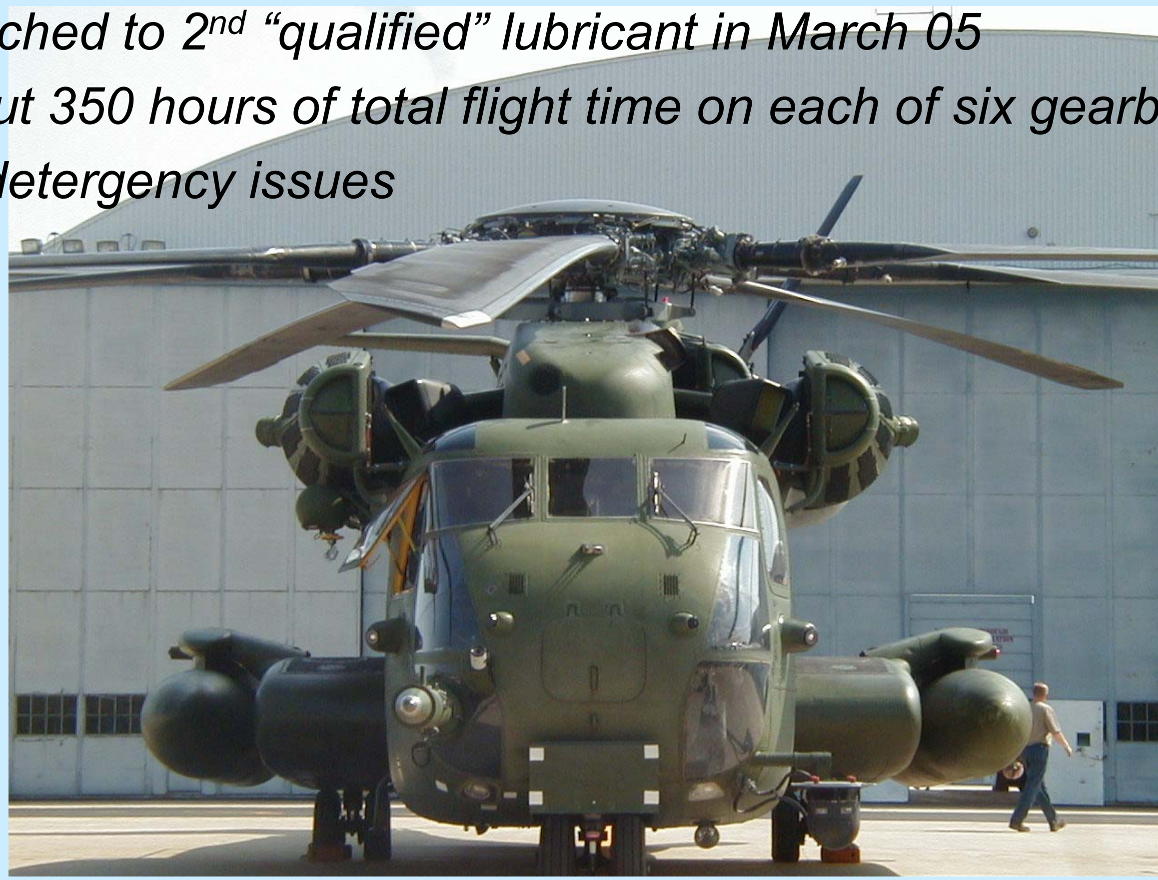
Additional AHTL Testing

- **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*



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?*

"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.*

USAF FLUIDS WORKSHOP 2006

The Need For A Synergist Approach

For The Development Of Advanced Aerospace Lubricants

Curtis Genay

Lubricants Technologist

Pratt & Whitney

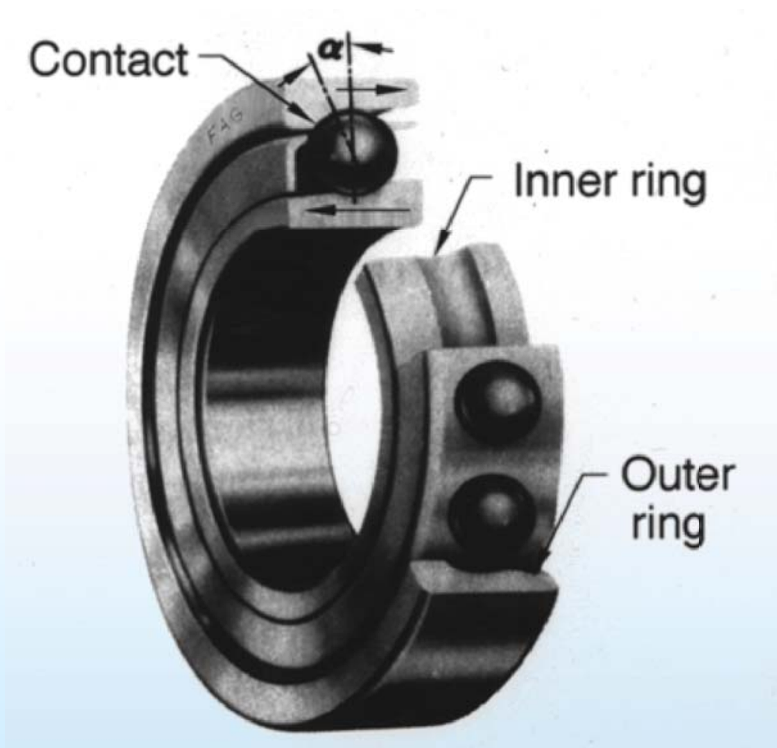
Mechanical System Design Issues

→ Bearing Materials Development

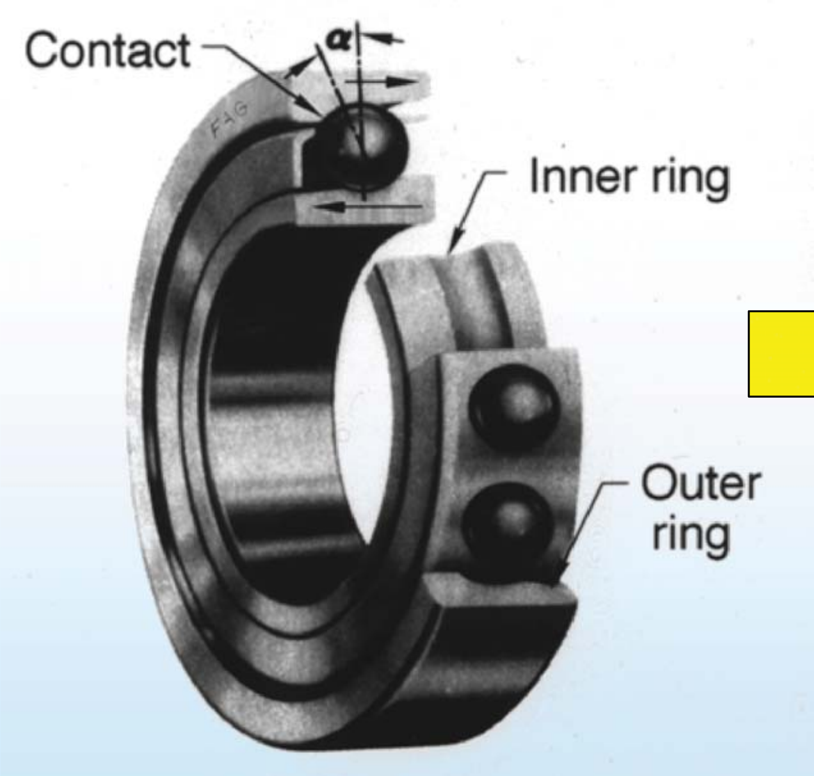
→ Future Lubricant Requirements

= Need For Synergistic Approach

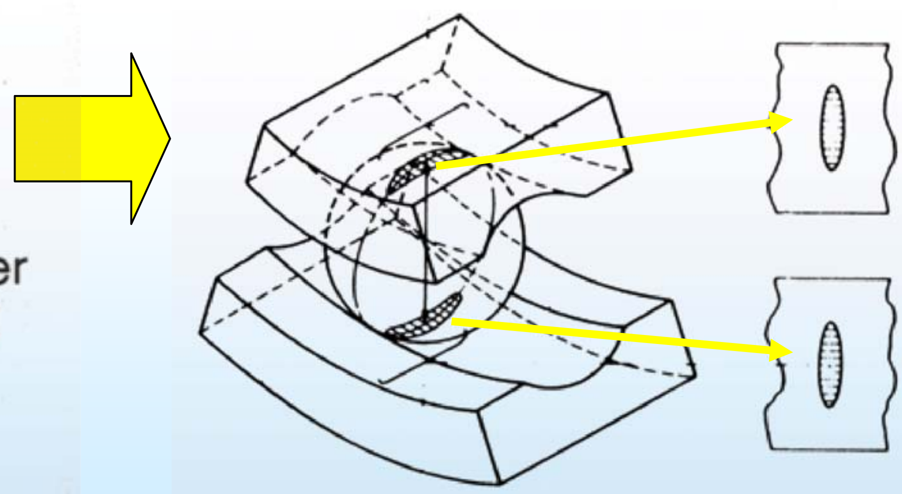
A Bearing Is Not a Component → It Is a System !



Bearing Contact Ellipse Is Where All the Action Occurs

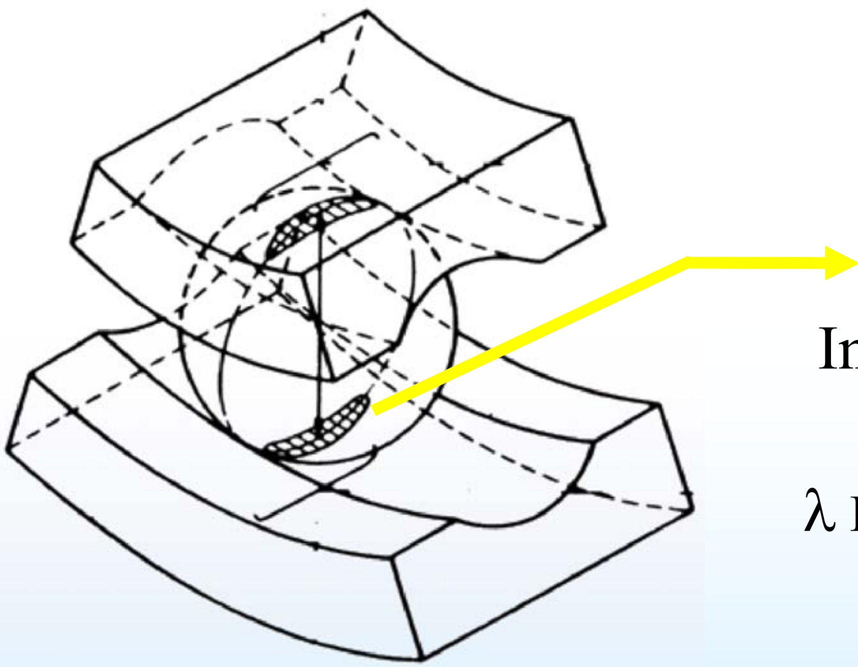


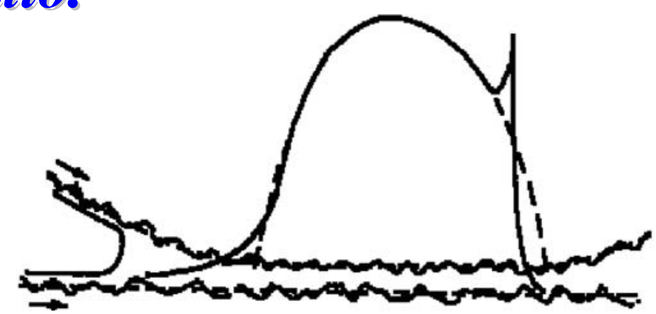
Load at the Ball / Race Contact
Is an Elliptical Pressure Area



4

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





Interacting Surfaces & Lubricant:

$$\lambda \text{ Ratio} = \frac{\text{Thickness of Lubricant Film}}{\text{Thickness of Surface Asperity}}$$

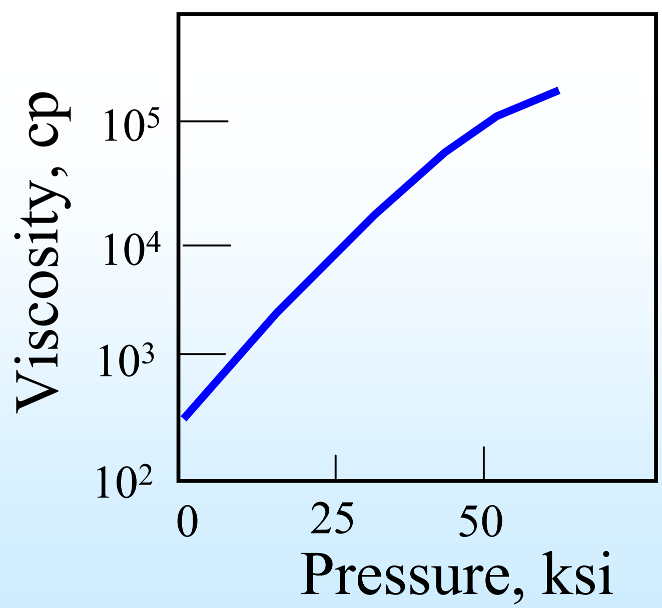
λ Ratio > 1 Full EHD Lubrication

λ Ratio < 1 Boundary Lubrication

Lubricating Characteristics

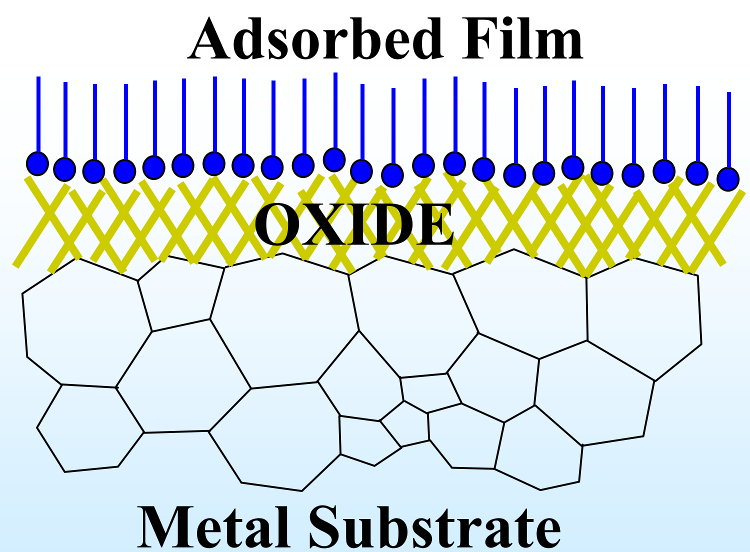
Pressure - Viscosity:

The Secret to Load Bearing Capability

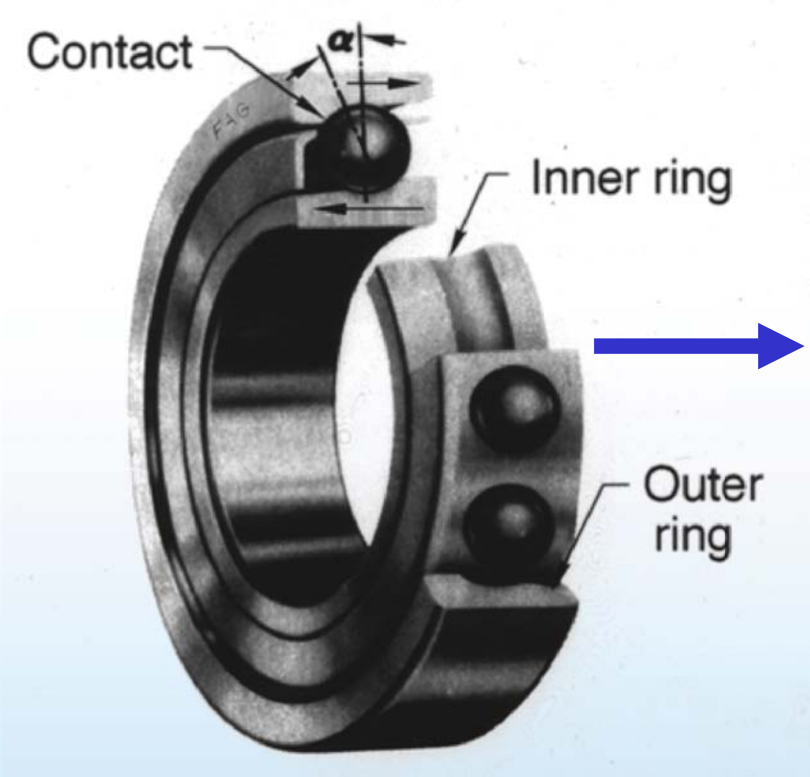


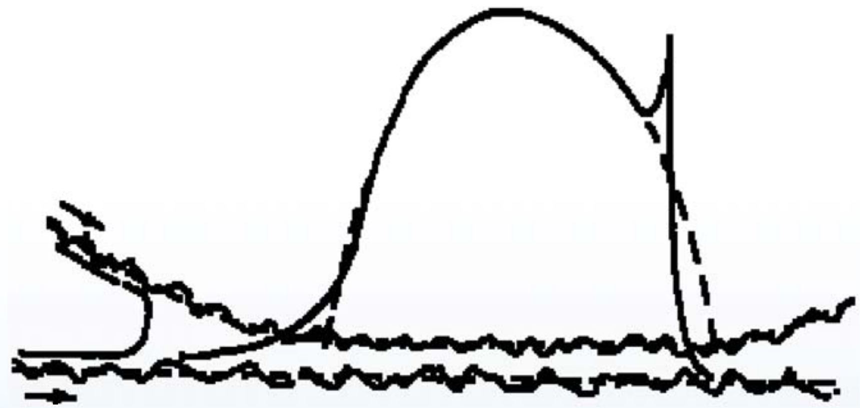
Anti-wear Additive:

The Secret to Boundary Lubrication



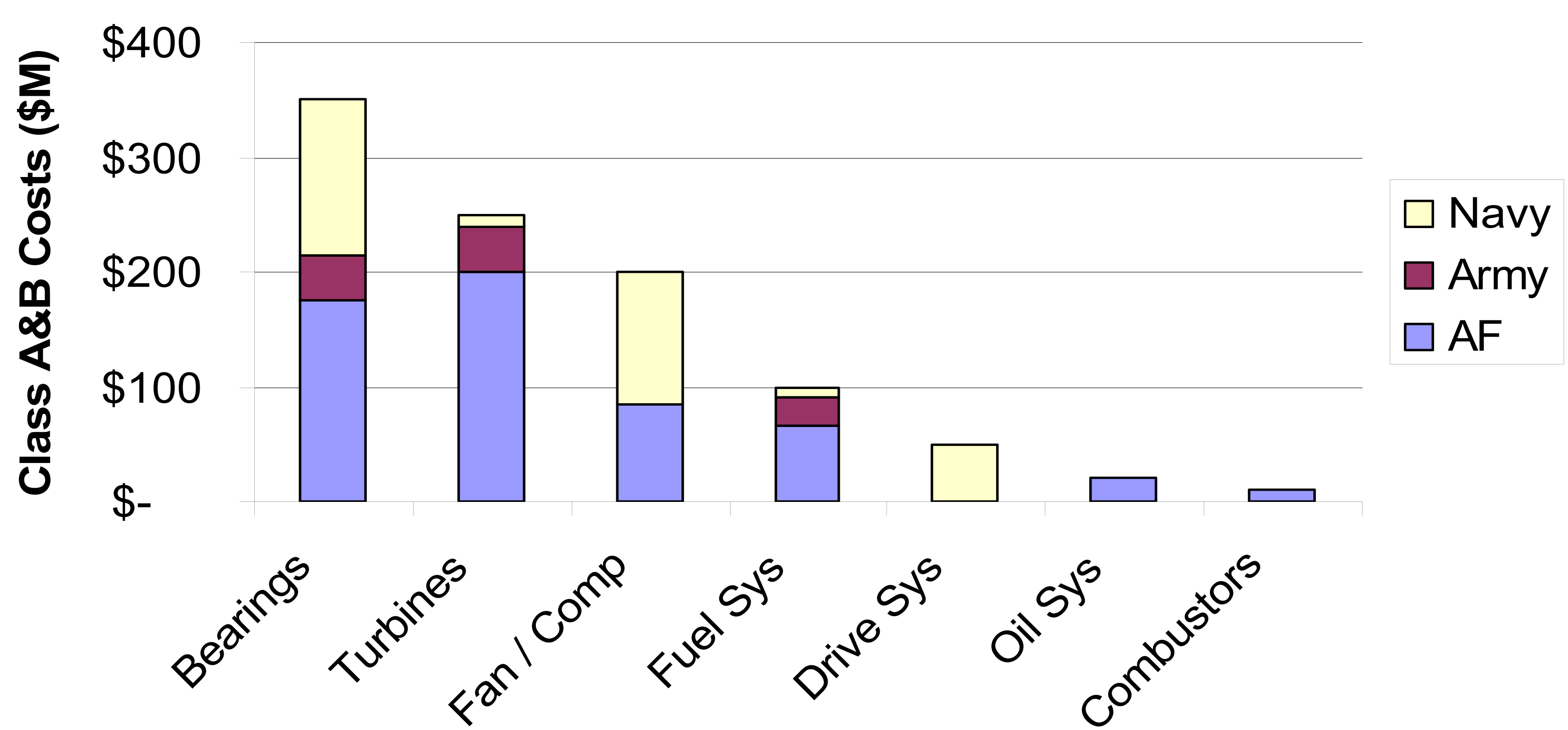
So, A Bearing Is Not A Component → It Is A System.





And Thus, There Is Much to Consider...

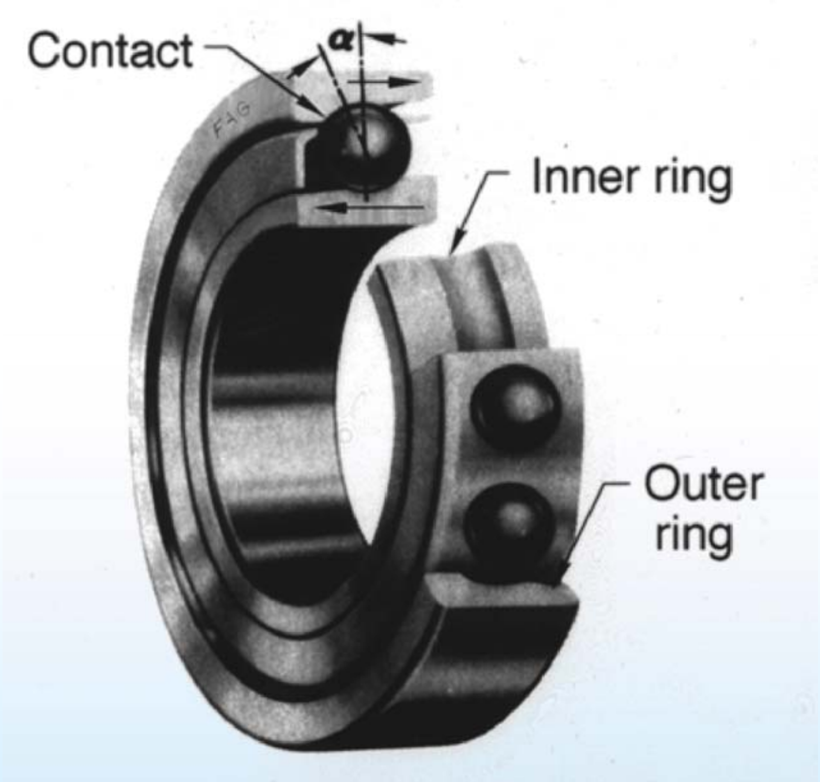
Bearings Are #1 DoD Safety Issue



The Bearing / Lubricant System

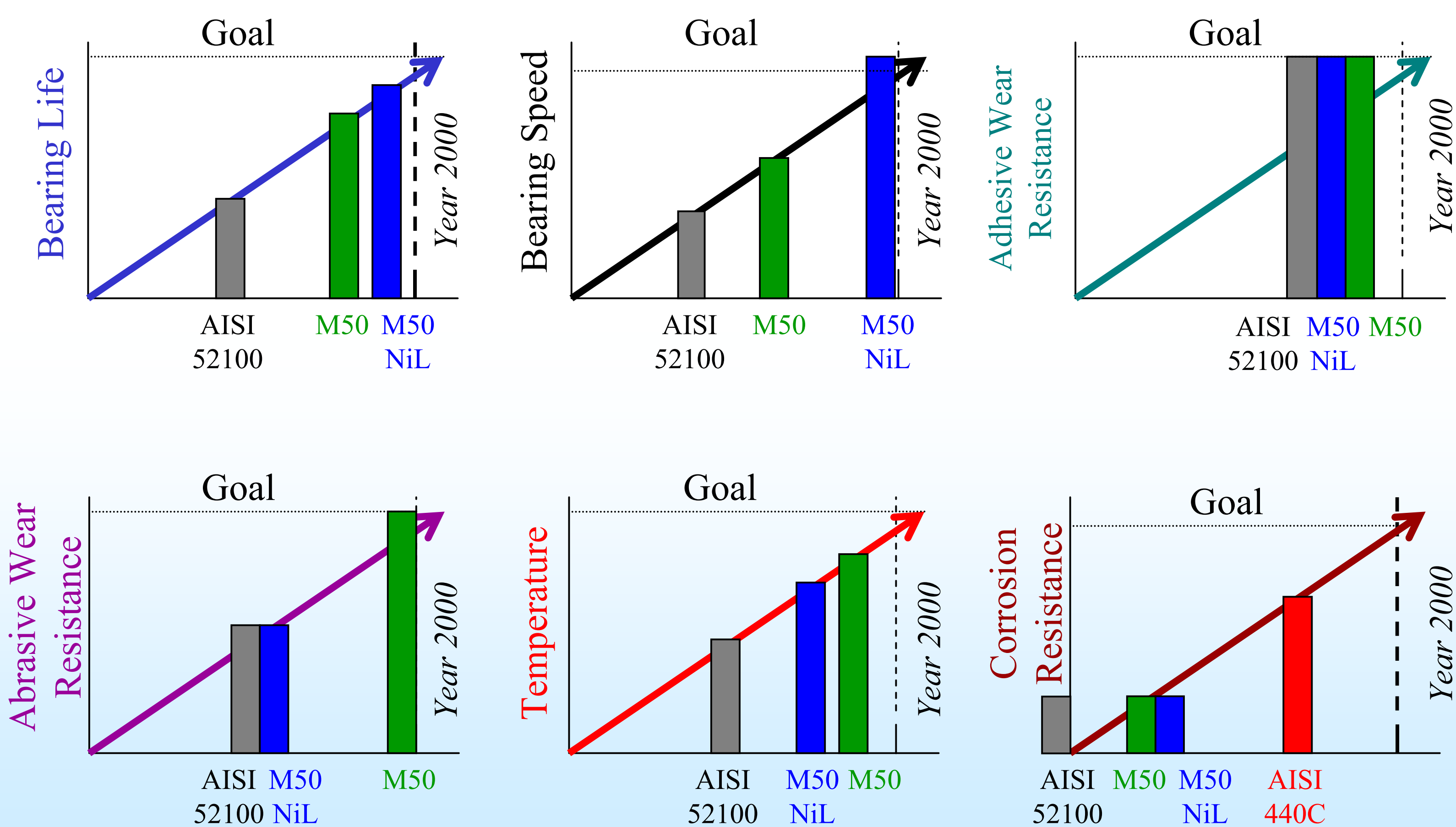
Bearing Material Needs:

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



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

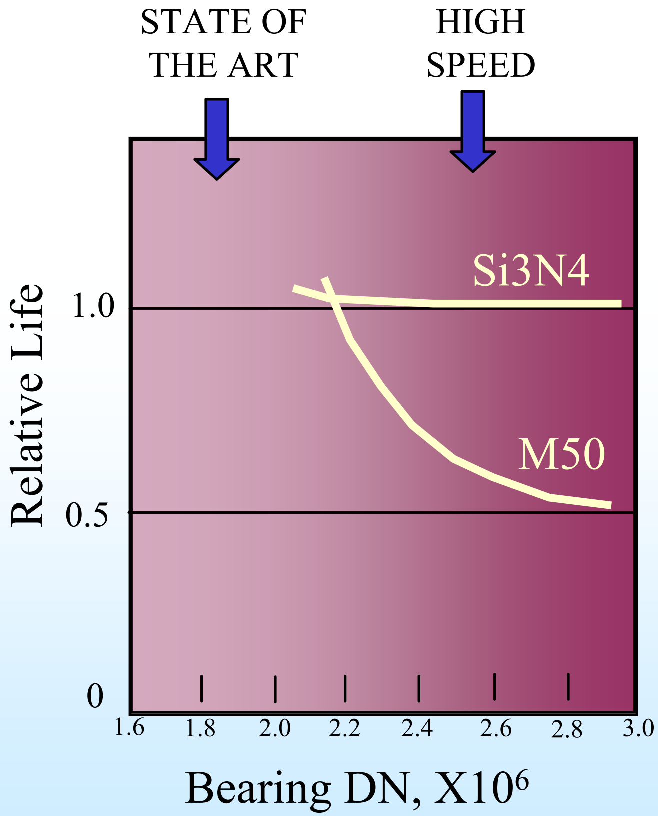
Bearing Material Requirements Into the Next Millennium



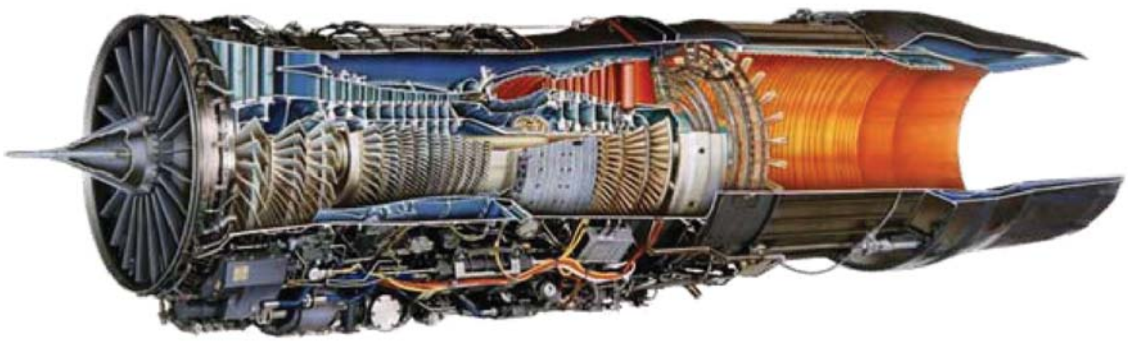
Si_3N_4 Hybrid Bearings Enable High Speeds

Pyrowear 675 / Si_3N_4 Full Scale Bearing Successfully Ran at 675°F (357°C)

Si_3N_4 Lowers Ball Centrifugal Loads & Frictional Heating



Gas Turbine Challenges For Ester Based Lubricants



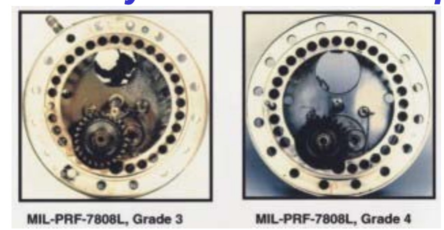
Advanced Aircraft Engine Designs Require Improved Performance And "Life" (Higher – Hotter – Faster):

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

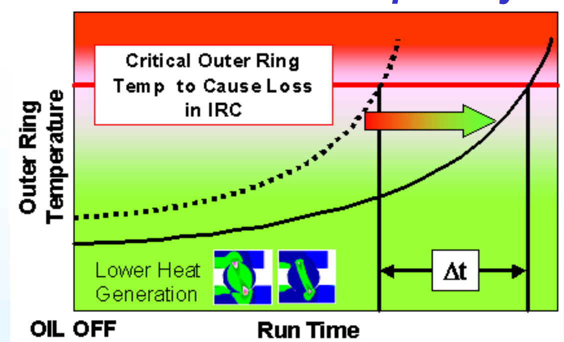
Consequence: Increased Thermal and Tribological Demands on the Engine Lubrication System → Challenges For Formulators

Enhanced Oils Needed to Meet Demanding Requirements

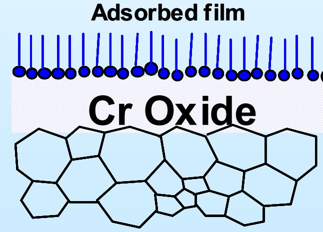
Higher Thermal Stability → **Increased System Thermal Capacity**



Better Boundary Film Formation → **Increased Oil Out Capability**



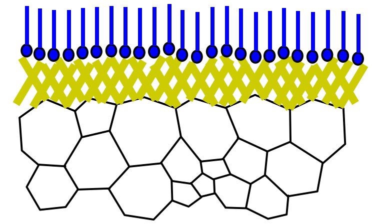
Surface Reactant with Stainless Steel → **Enable all Stainless Bearing**



Mitigate Adhesive Wear

13

Boundary Lubrication - Basic Principles



Adhesive Wear Defended by Boundary Lubrication

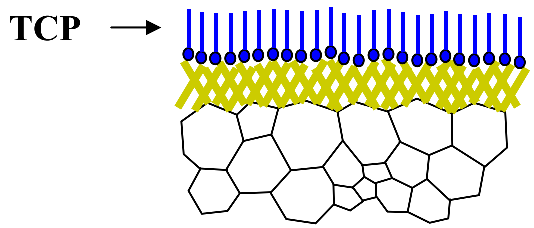
- Occurs During: Start-up, Shut-down & High G Maneuvers
- Molecular Boundary Layers Form Last Line of Defense
- Influenced by Materials, Surface Treatments & Roughness

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

Boundary Lubrication - Tricresyl Phosphate (TCP)

TCP In All Currently Approved Aircraft Lubricant Formulations

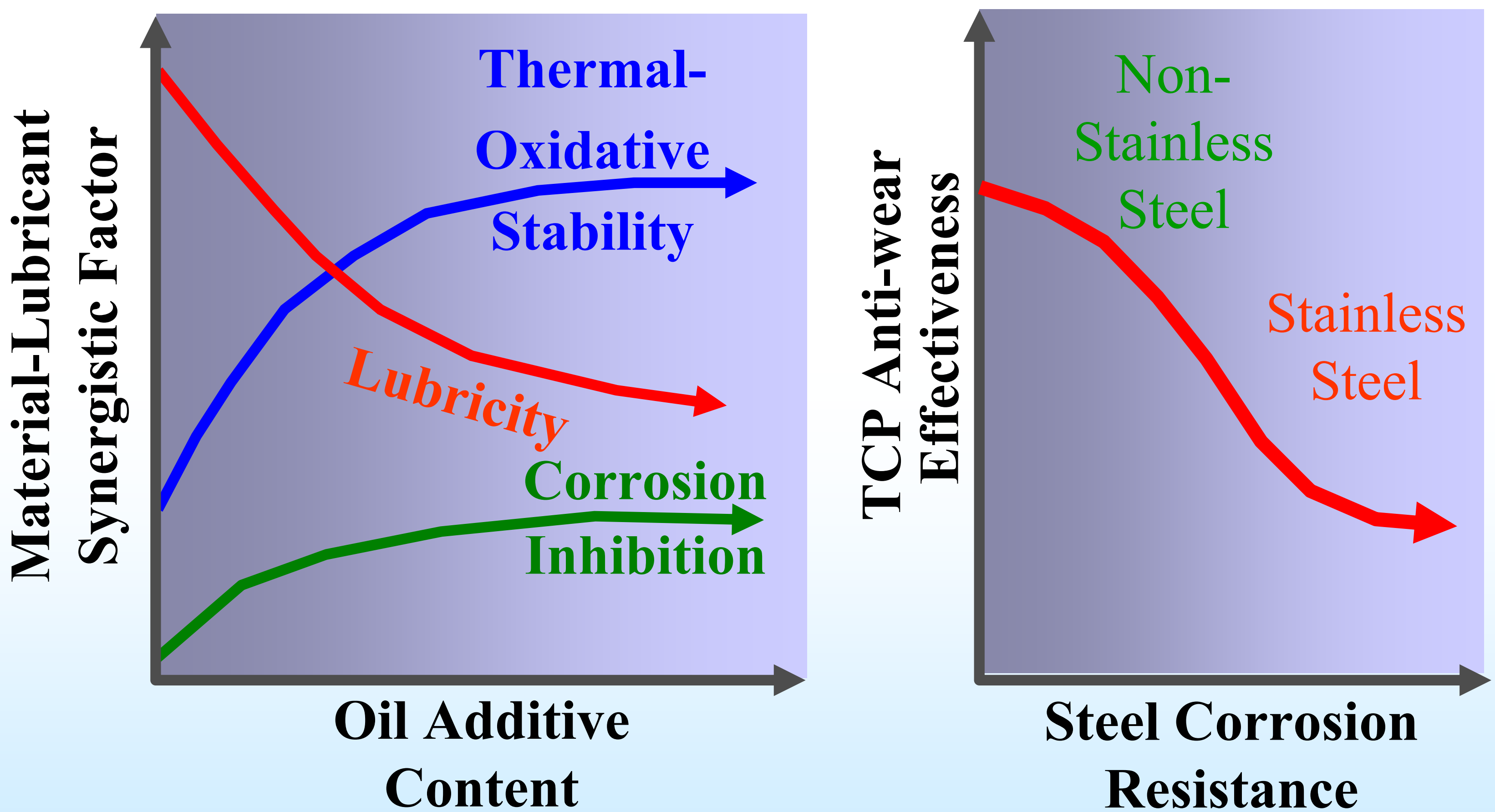


Properties/Characteristics:

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

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

Material-Lubricant Synergistic Factors



Critical Properties Of The Lubricant

Viscosity & Density	- Heat Generation - Lubrication System Pressure - Component Size & System Weight - Pump-ability
Vapor Pressure	- Compartment Pressure & Operability - Fluid Losses - Pump Performance
Foaming Characteristics	- Engine Pump Operability (Cavitation) - Tank Size - Component Speeds - Lubricant Cooling Capacity

Critical Properties Of The Lubricant

Specific Heat & Thermal Conductivity	- Heat Exchanger Size
Auto-Ignition Temperature	- Bearing Compartment Operating Temperature - System Weight
Elastomer / Material Compatibility	- System Integrity

Material-Lubricant Synergistic Factors

Enabling Technology Required For Improved Bearings:

Boundary Lubrication of Corrosion Resistant Bearing Steals

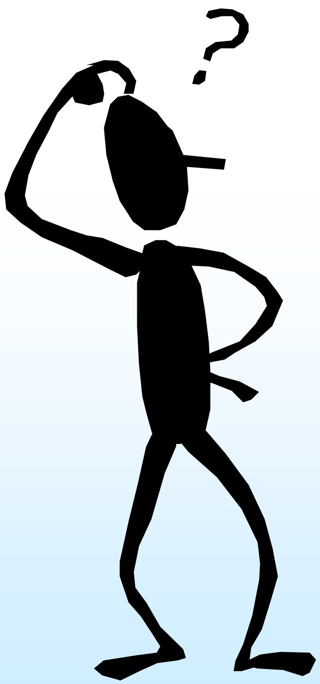
Potential Approaches:

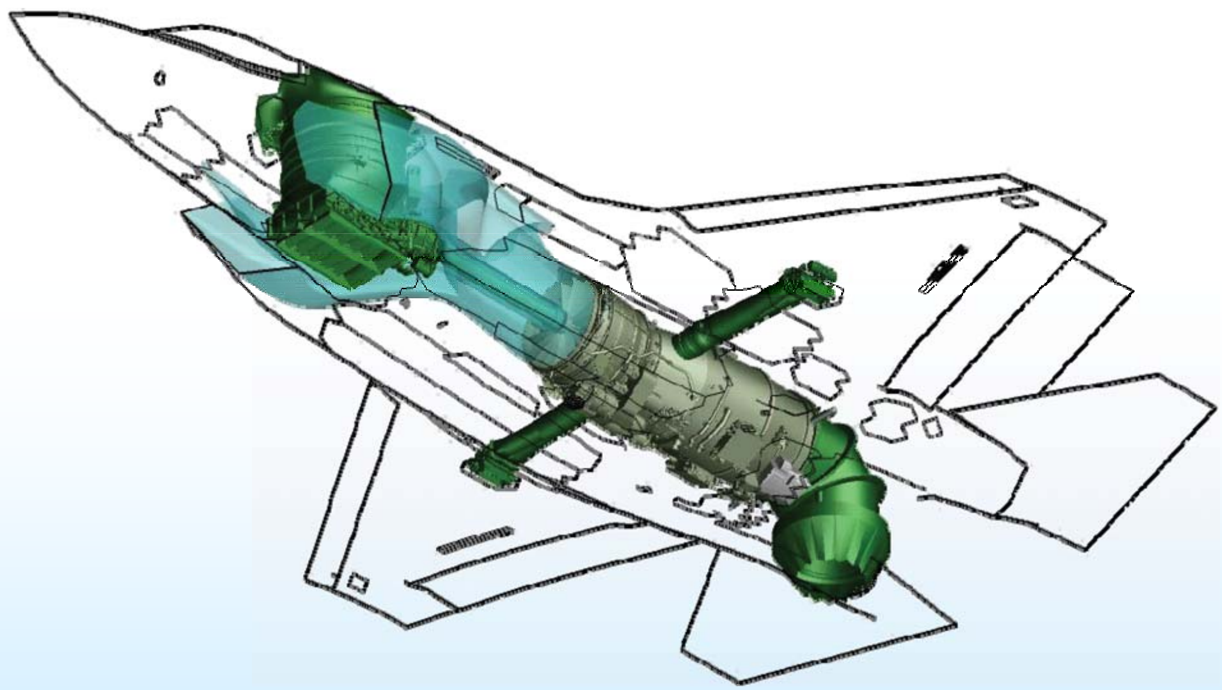
- **Use Si_3N_4 Rolling Elements - Hybrid Bearings**
- **More Chemically Reactive Anti-Wear Additives**
- **Bearing Surface Treatments To Increase Reactivity To TCP**

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

Material / Lubricant Synergism

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

Small Business Innovative Research Program (SBIR)

- 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

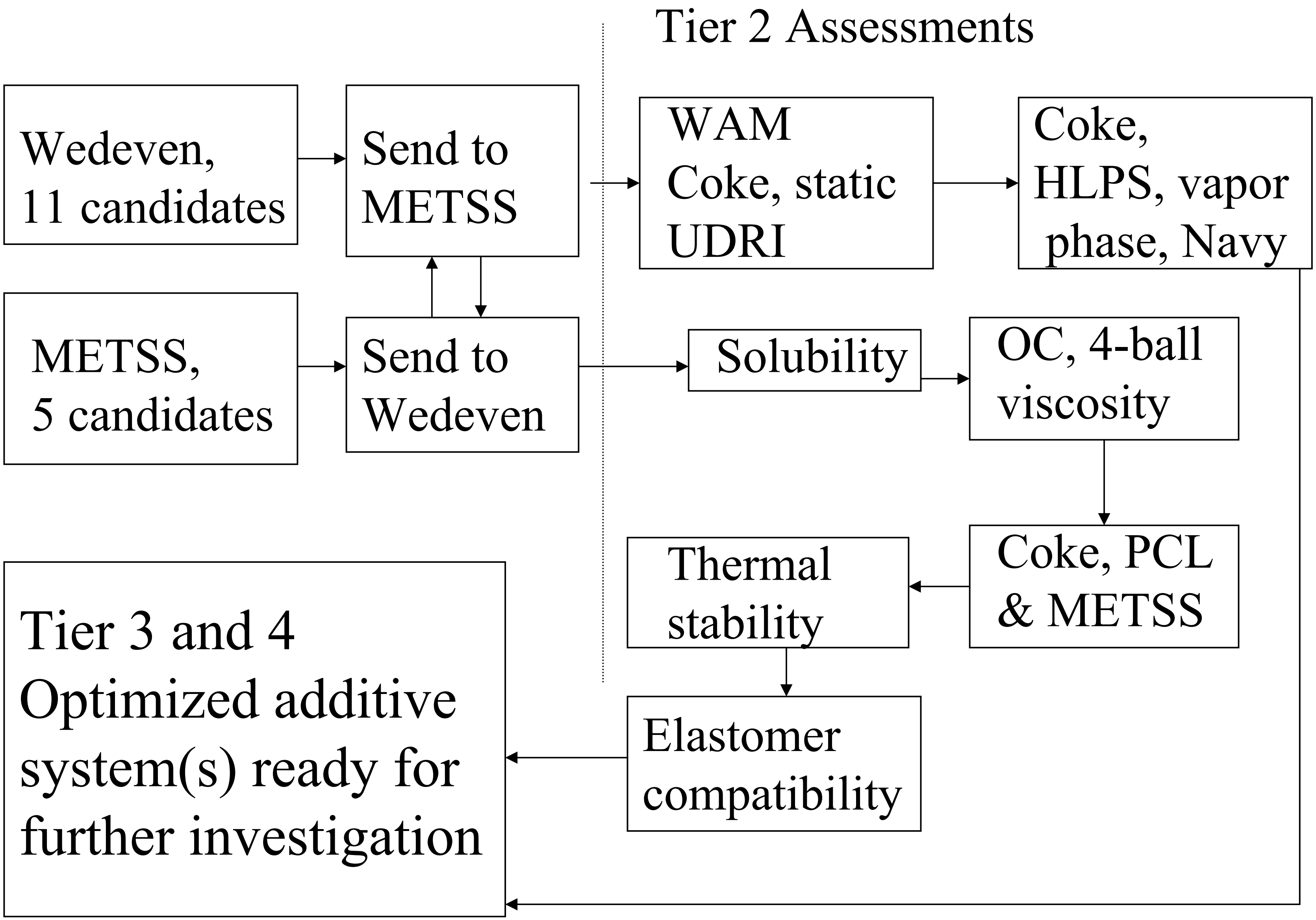
Gas Turbine Engine Oil Additives for Advanced Bearing Steel

- 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



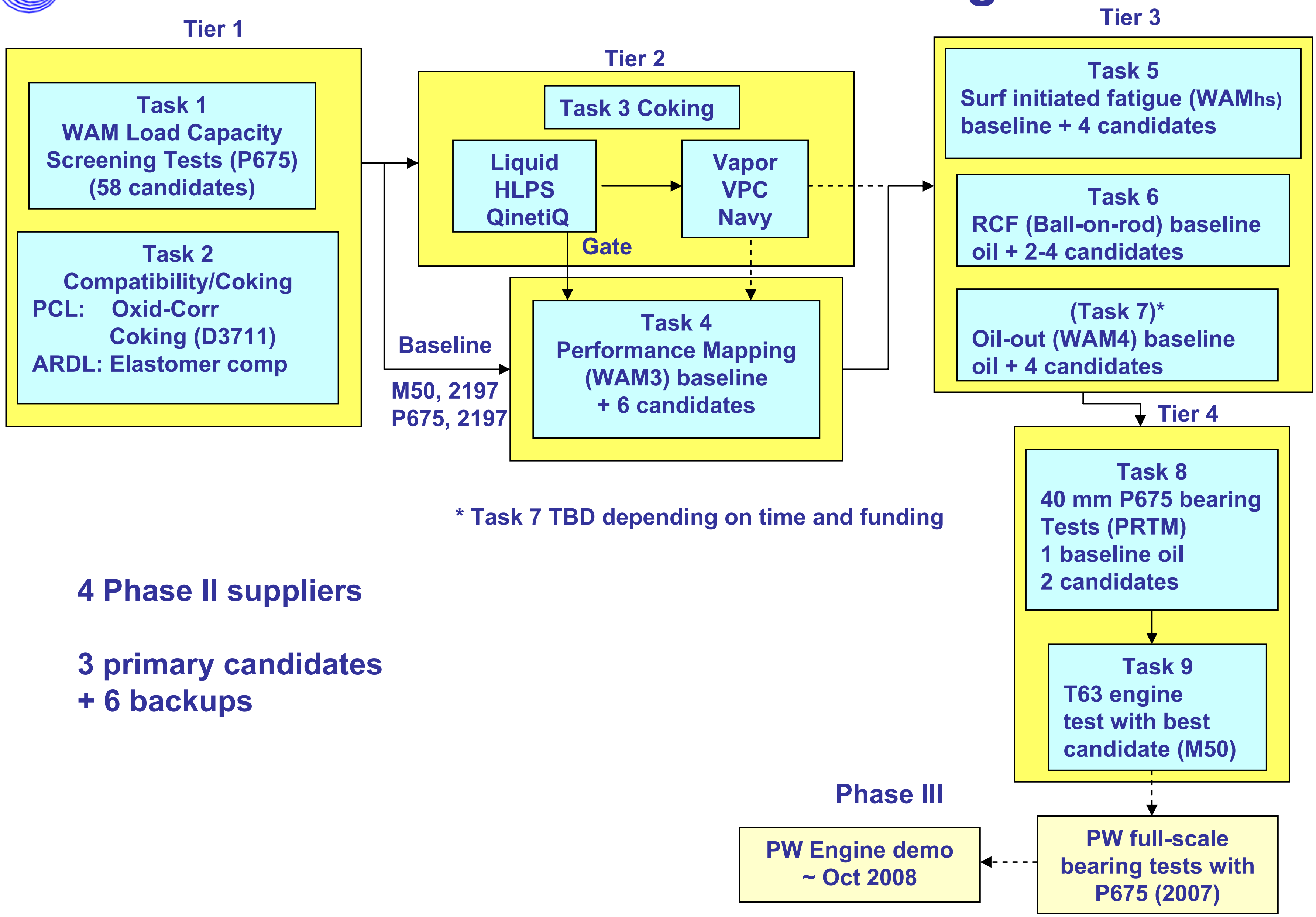
Gas Turbine Engine Oil Additives for Advanced Bearing Steel

- 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

SBIR Additive Phase II Testing Plan



4 Phase II suppliers

3 primary candidates
+ 6 backups

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

METSS

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.

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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

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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

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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 iron-phosphorus surface film

METSS

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.*

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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 AF- seek 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.

METSS

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.

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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

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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

METSS

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.

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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

METSS

Testing and Evaluation - Tier 1

- Physical and Chemical Properties
- Mixture Compatibility
- Low Temperature Stability and Viscosity @ $-40^{o}C$
- 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.

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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^{o}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^{o}C
  - FKM aged 72 hours @ 175^{o}C
  - FVMQ aged 72 hours @ 150^{o}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^{o}C with 50 ml/min flow
- Thermal Stability & Corrosivity (FTM 3411)
  - 96 Hours @ 274^{o}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*

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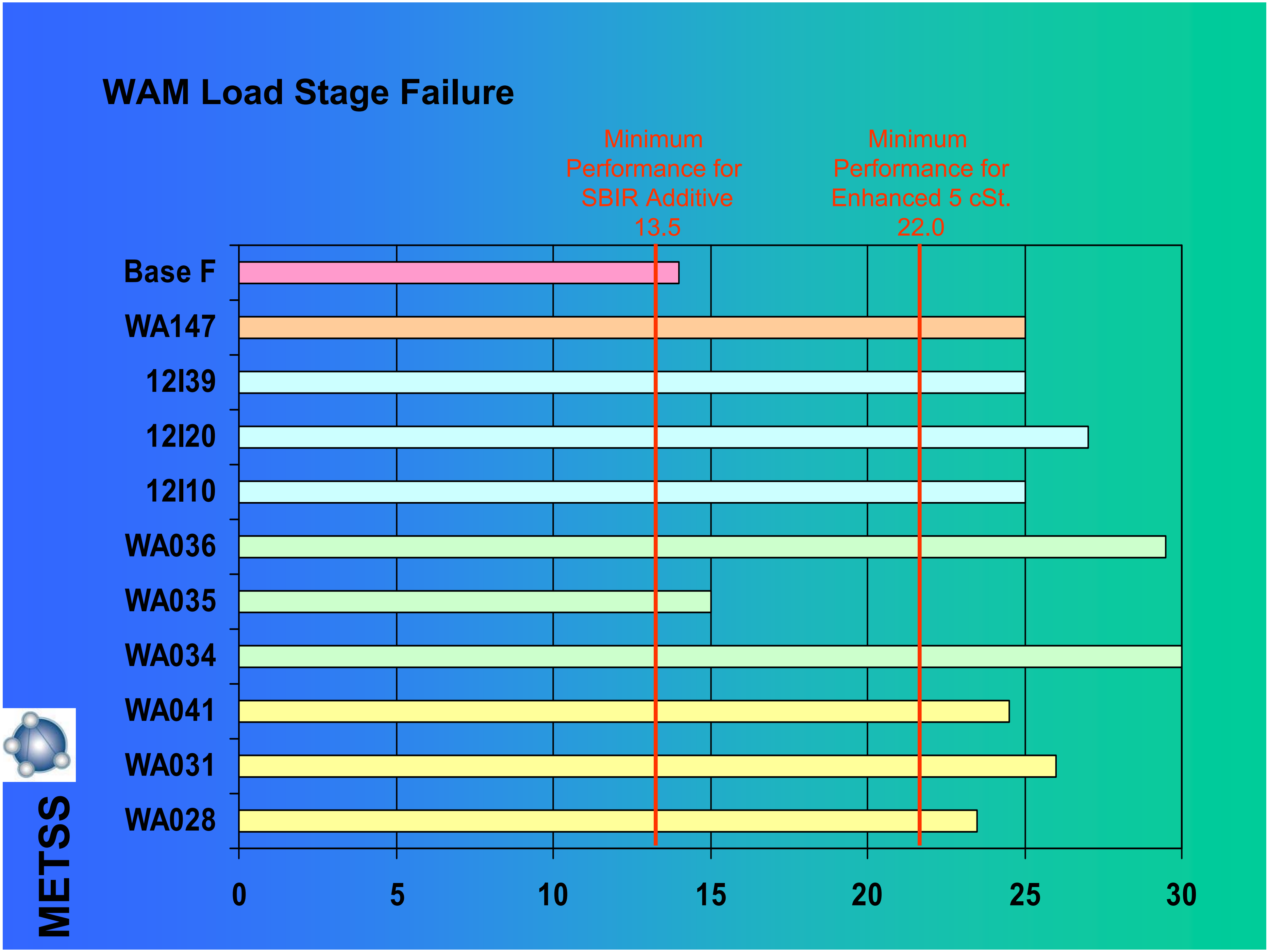
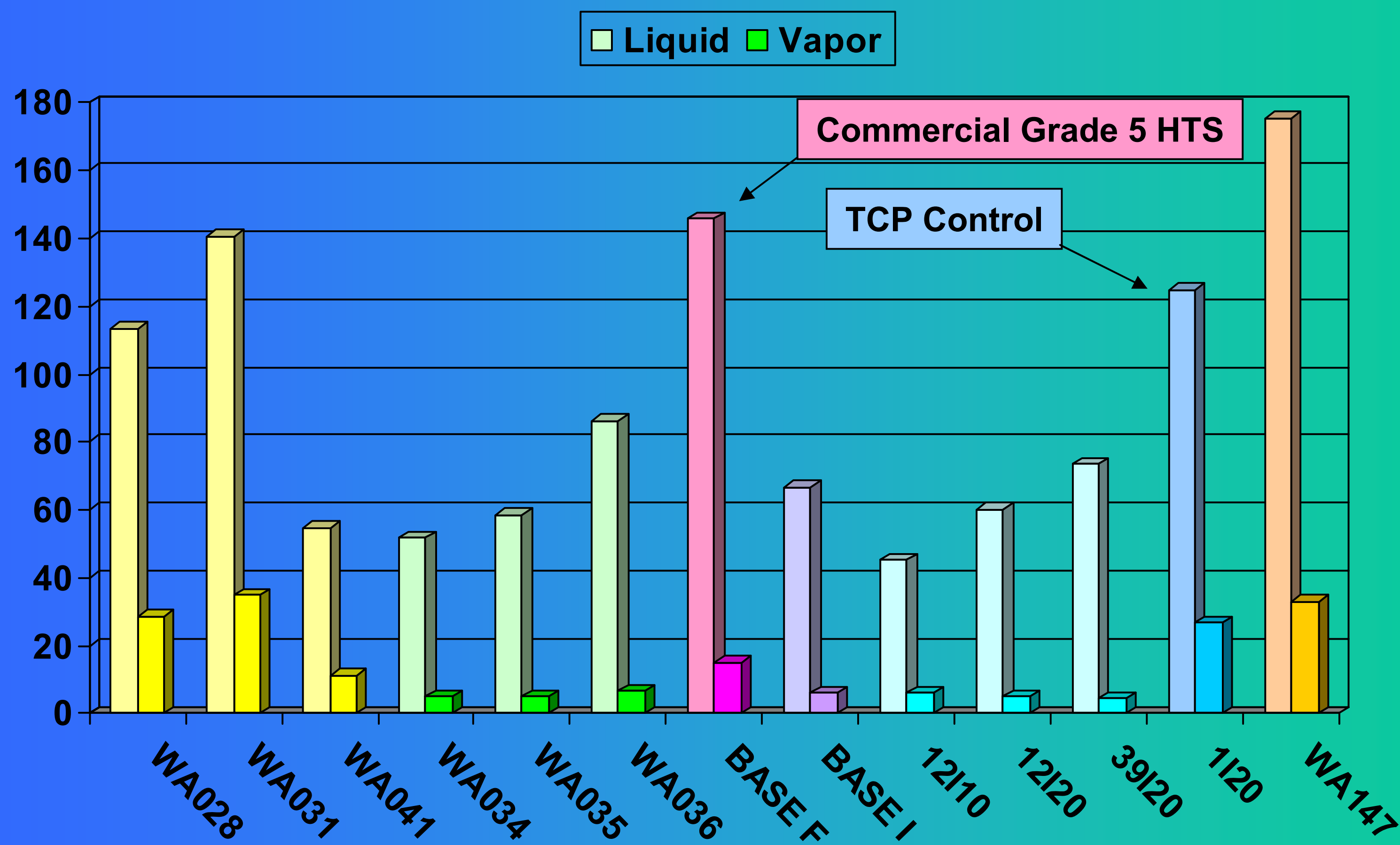

WAM Load Stage Failure
Minimum Performance for SBIR Additive 13.5
Minimum Performance for Enhanced 5 cSt. 22.0
Base F
WA147
12I39
12I20
12I10
WA036
WA035
WA034
WA041
WA031
WA028
0
5
10
15
20
25
30
METSS

D3711 Coking Tendency - Gross Deposit, mg



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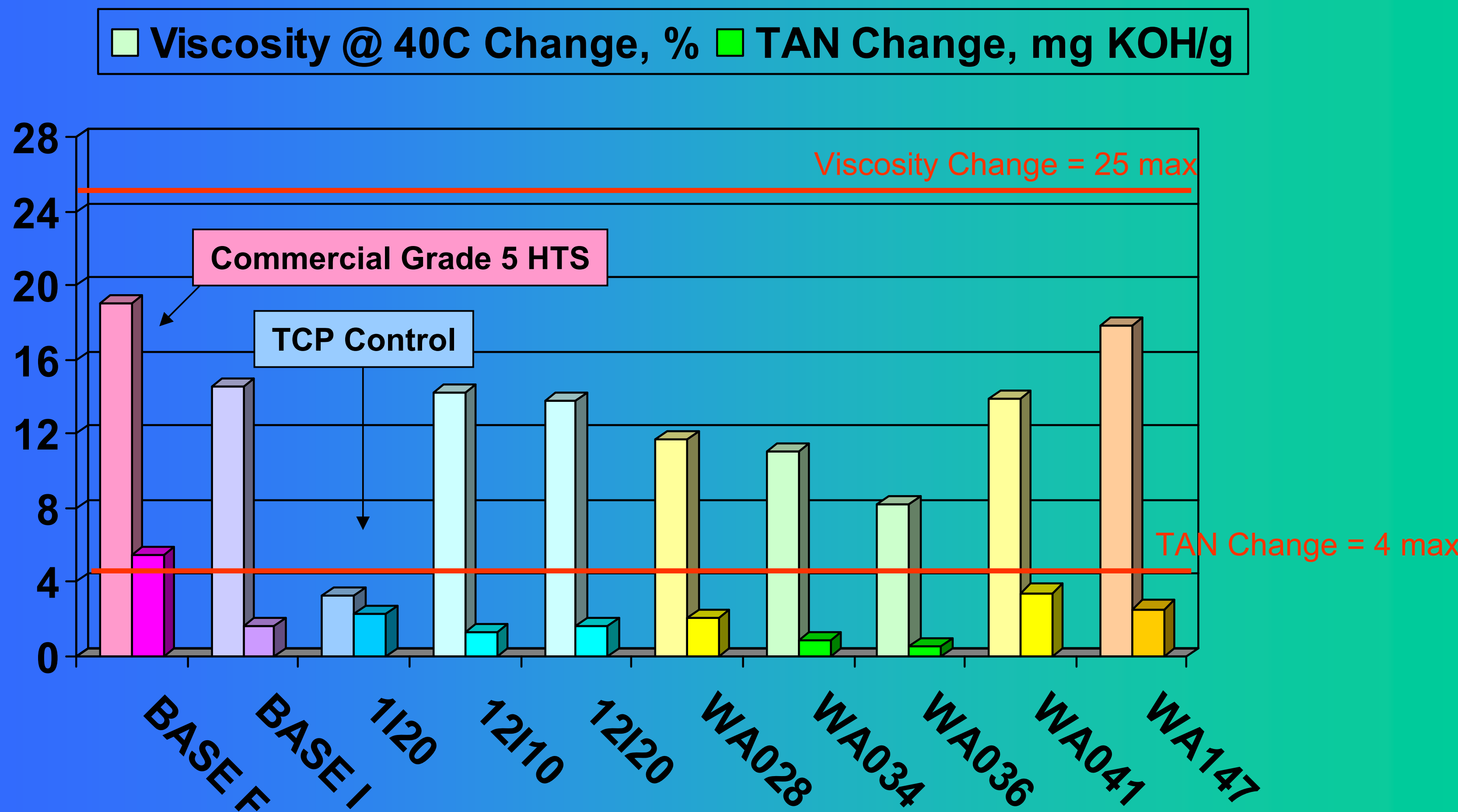
Corrosion-Oxidation Stability Test Results



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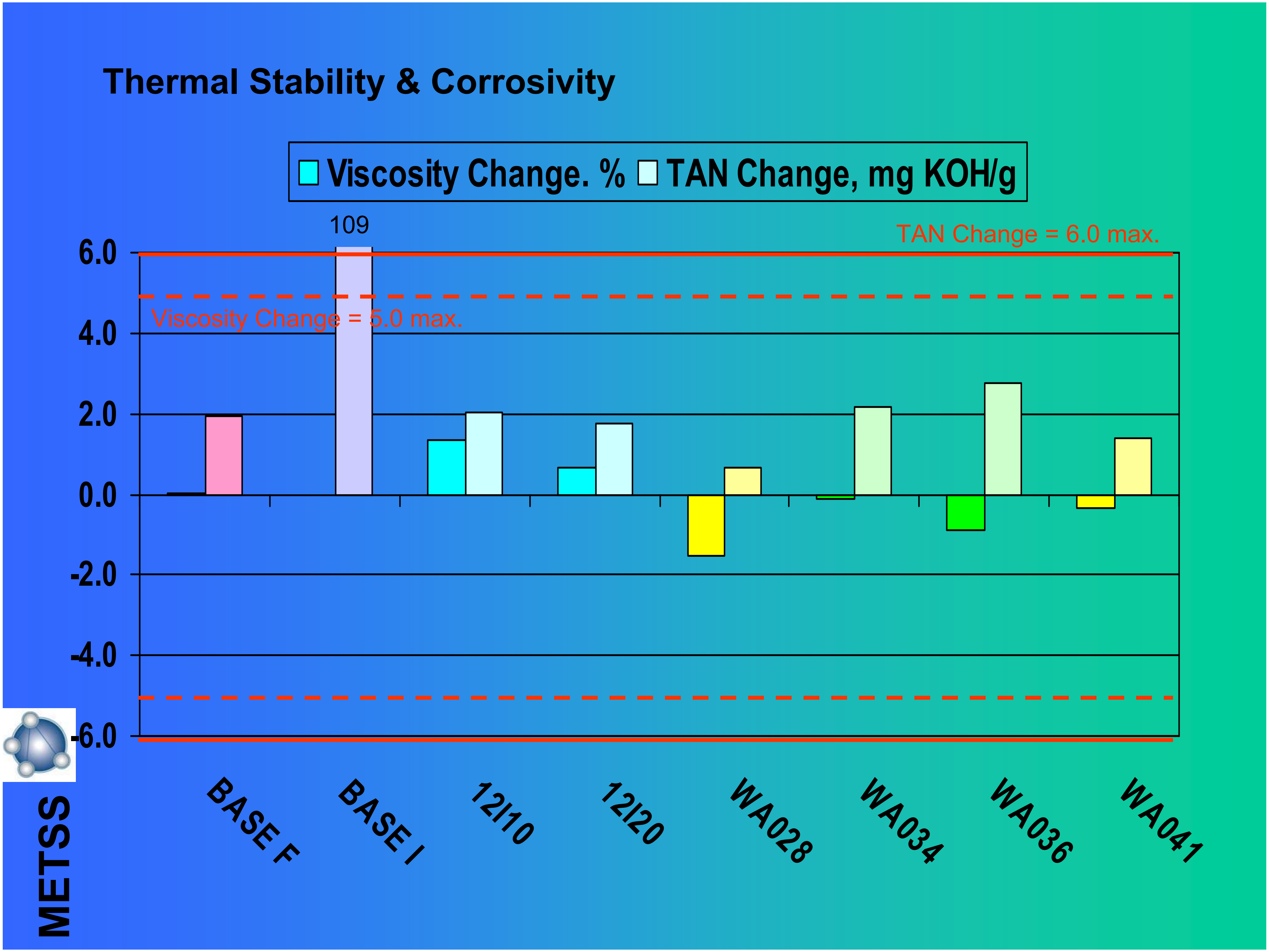
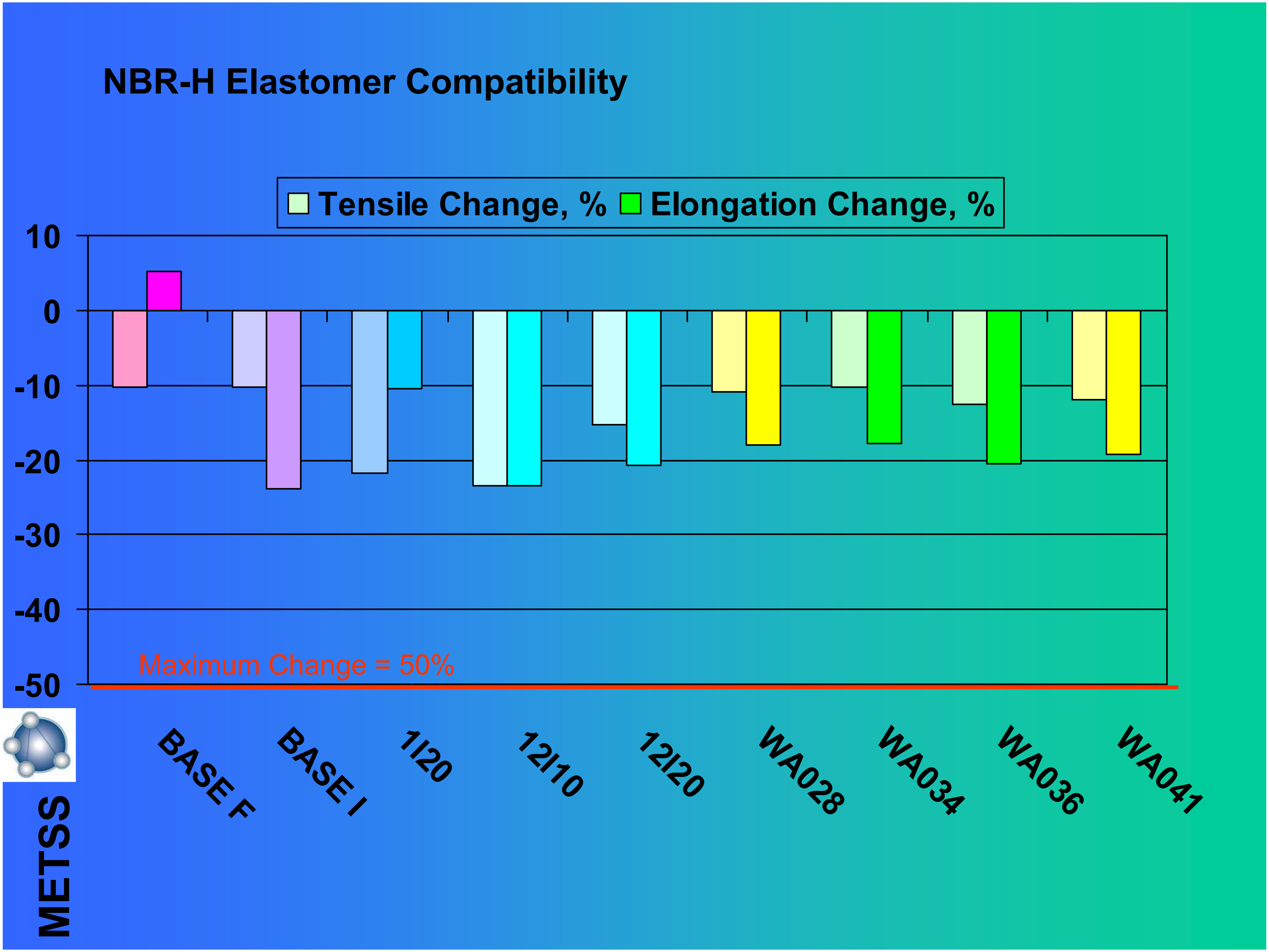
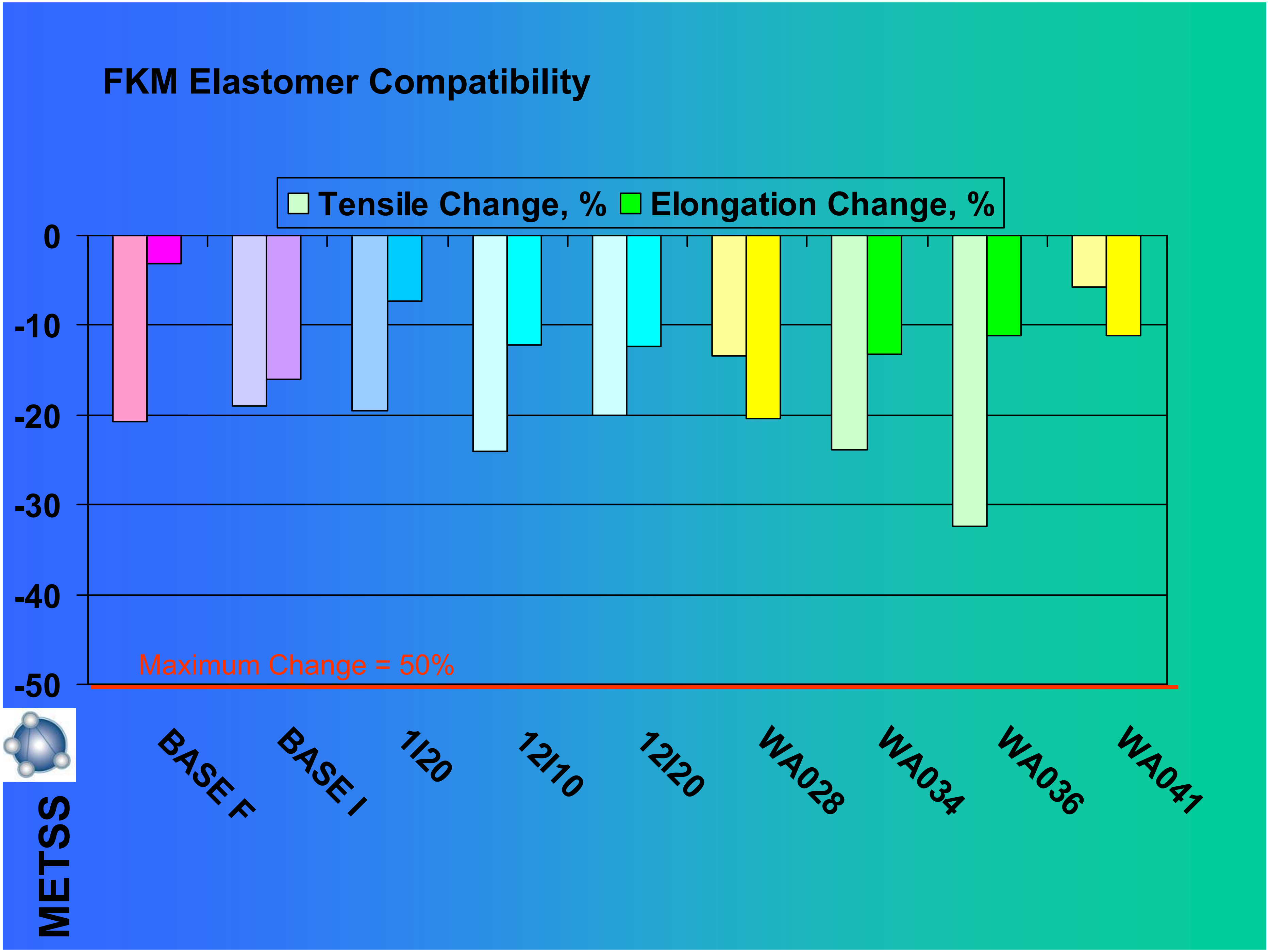
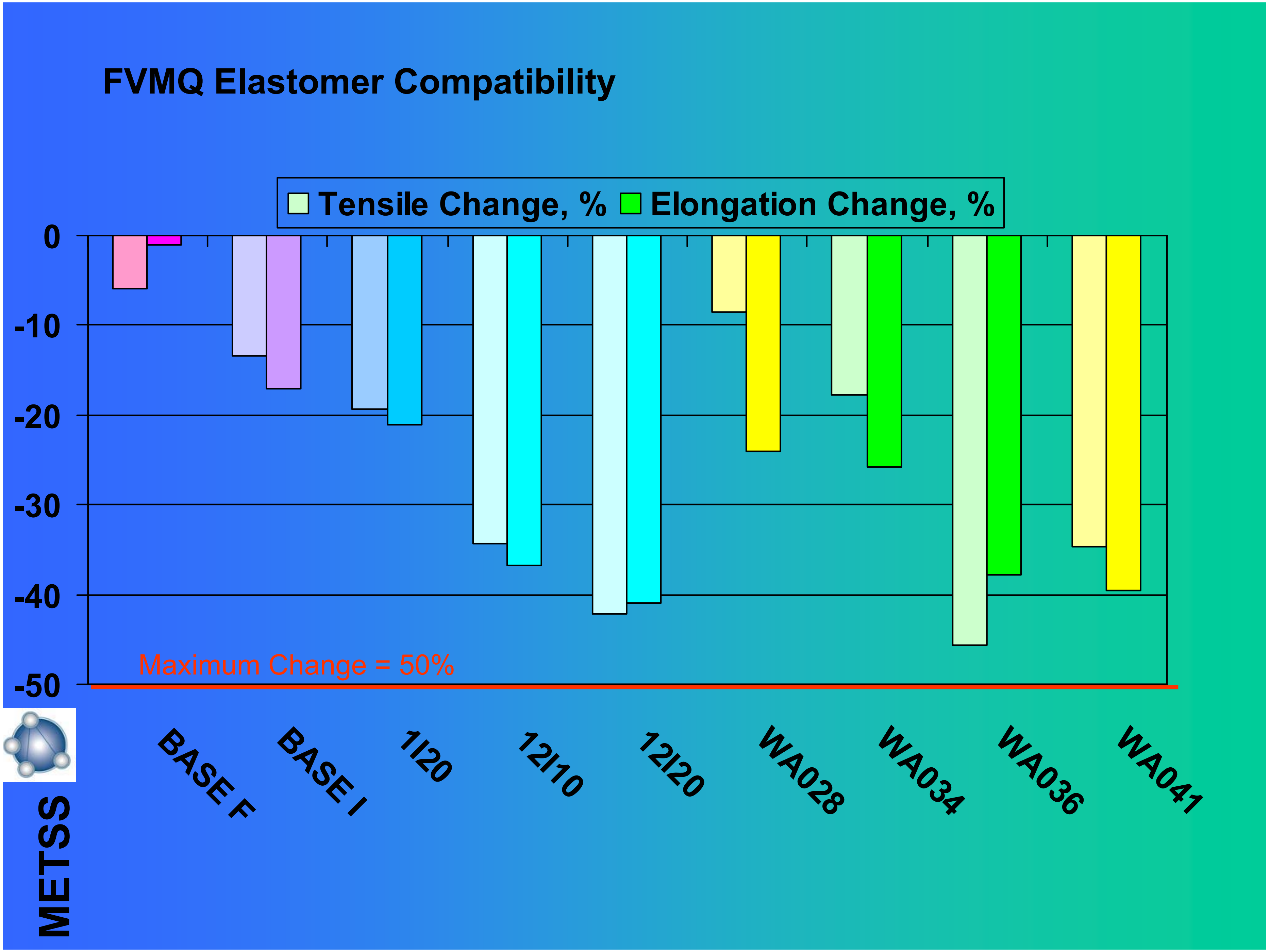

Thermal Stability & Corrosivity
Viscosity Change. %
TAN Change, mg KOH/g
109
TAN Change = 6.0 max.
Viscosity Change = 5.0 max.
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
BASE F
BASE I
12I10
12I20
WA028
WA034
WA036
WA041
METSS



NBR-H Elastomer Compatibility
Tensile Change, %
Elongation Change, %
10
0
-10
-20
-30
-40
-50
Maximum Change = 50%
BASE F
BASE I
1I20
12I10
12I20
WA028
WA034
WA036
WA041
METSS



FKM Elastomer Compatibility
Tensile Change, %
Elongation Change, %
0
-10
-20
-30
-40
-50
Maximum Change = 50%
BASE F
BASE I
1I20
12I10
12I20
WA028
WA034
WA036
WA041
METSS



FVMQ Elastomer Compatibility
Tensile Change, %
Elongation Change, %
0
-10
-20
-30
-40
-50
Maximum Change = 50%
BASE F
BASE I
1I20
12I10
12I20
WA028
WA034
WA036
WA041
METSS

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 .
- These synthetic lubricant formulations use commercially available products.
  - Air BP; ExxonMobil; Lubrizol; METSS

METSS

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.

METSS

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

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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

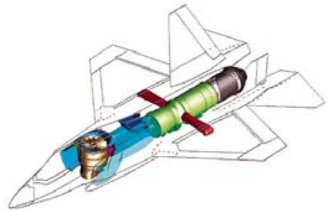
21 June 2006

SBIR Phase II Additives for Corrosion-Resistant Steels

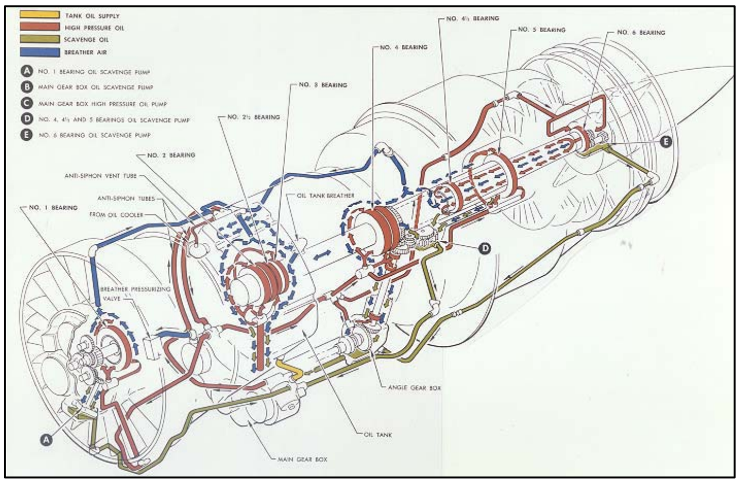
Outline

- 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)



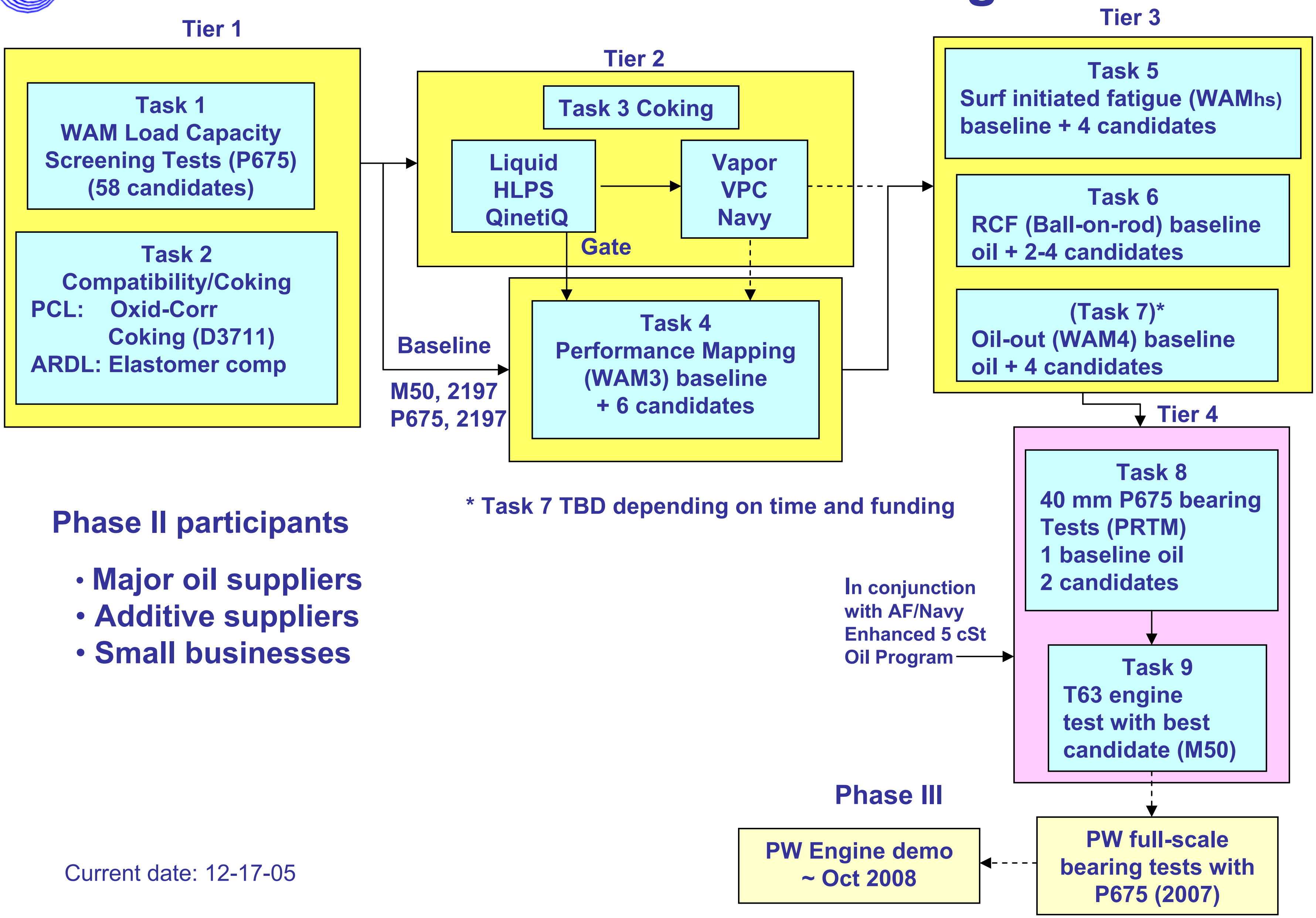
Coking		
Liquid	**Vapor**	**Mixed**
HLPS QinetiQ	VPC Navy	D3711 Phoenix

Compatibility		
Oxid-Corr	**Elastomer**	**Thermal stability**
O-C Phoenix	D471 ARDL	Phoenix

Tribology			
Scuffing	**Wear**	**Surface Fatigue**	
WAM8/9 WA, Inc.	WAM8 WA, Inc.	WAMhs WA, Inc.	RCF UES

3

SBIR Additive Phase II Testing Plan



Phase II participants

- Major oil suppliers
- Additive suppliers
- Small businesses

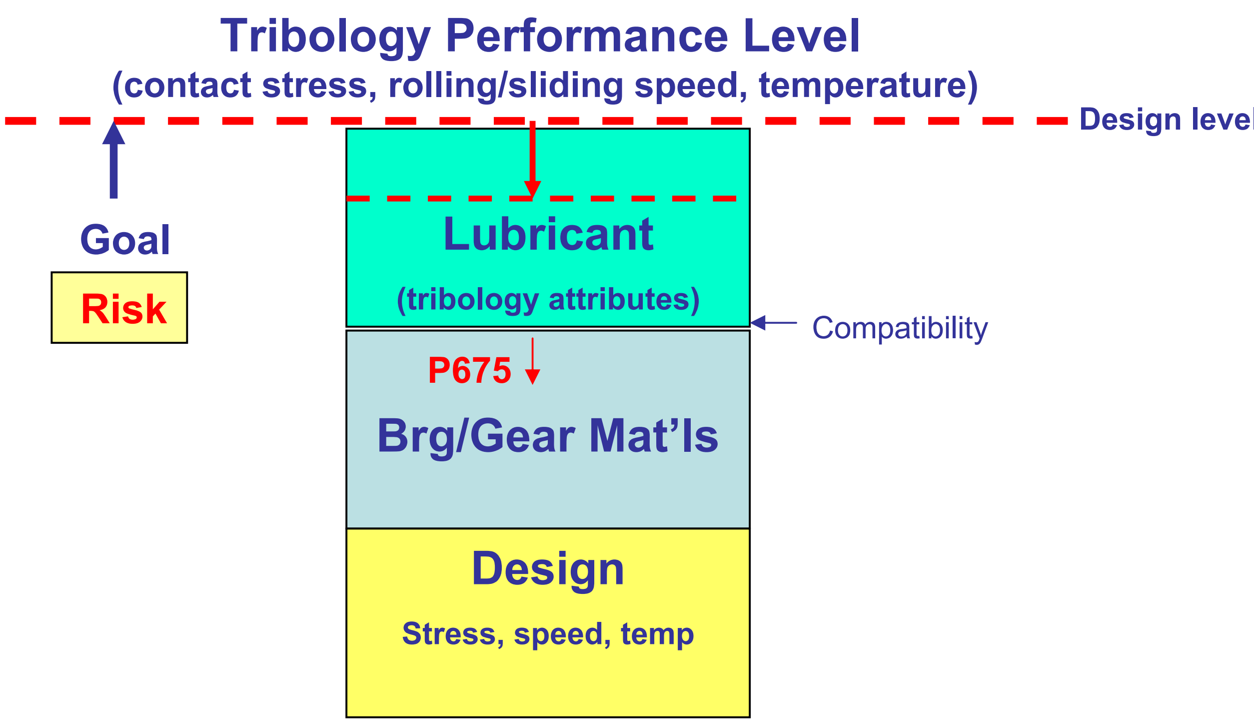
Current date: 12-17-05

Tribology Strategy

- Wear
- Scuffing
- Surf fatigue

9310, Pyrowear 53, P675 (low temp temper)

M50, M50NiL Pyrowear 675



5

Tribology Strategy

9310, Pyrowear 53, P675 (low temp temper)

- Wear
- Scuffing
- Surf fatigue

M50, M50NiL Pyrowear 675

Tribology Performance Level

(contact stress, rolling/sliding speed, temperature)

Design level

Goal

Risk

Lubricant
(HTS/CI oils)

P675
Brg/Gear Mat'ls

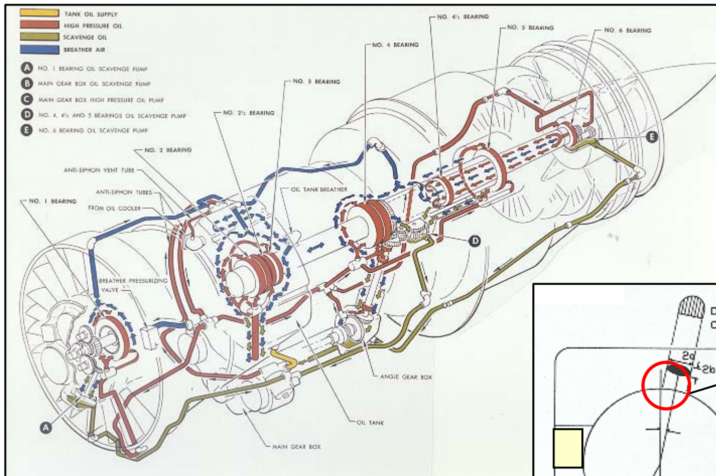
Design
Stress, speed, temp

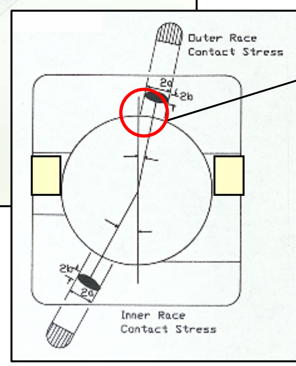
HTS/CI oils, stainless steels

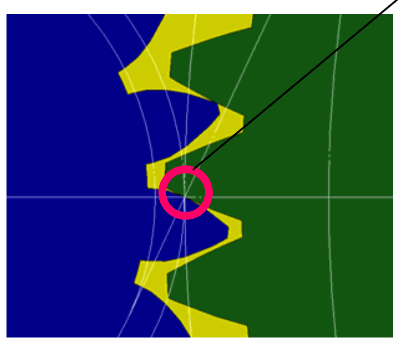
Need systems approach

6

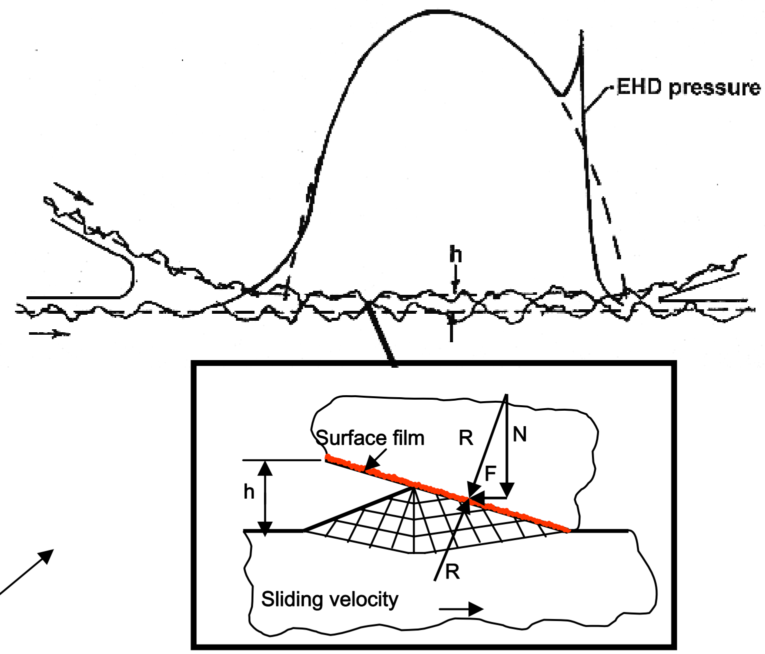
Baseline Tribology Testing – Approach







Stress & power transmitted

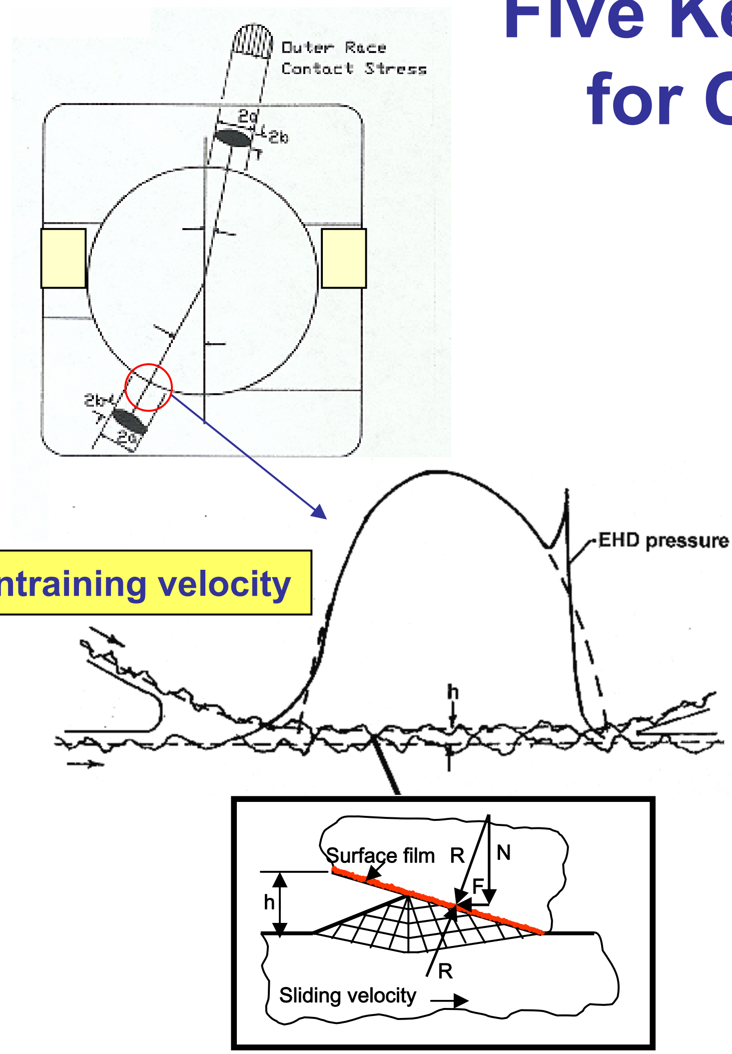


- **Wear**
- **Scuffing (historical, mature)**
- **Fatigue**

Load & power limit

Life & durability 7

Five Key Tribology Parameters for Oil/Material Evaluation



Entraining velocity

Sliding velocity

Lubr mechanisms
- Hydrodynamic & EHD
- Micro-EHD
- Boundary lubr. (surface film)

Failure mechanisms
- Wear (polishing, corrosive adhesive, abrasive)
- Scuffing (micro, macro)
- Fatigue (micro-pitting, pitting)

→ **Link to service conditions**

Degree of asperity penetration (h/σ)

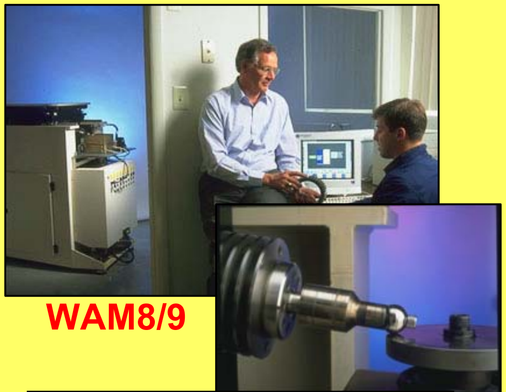
Contact temp ($T_c = T_{bulk} + T_{flash}$)

Contact Stress (asperity stress)

8

Tribology Testing

Suite of three types of machines cover current test methods



WAM8/9

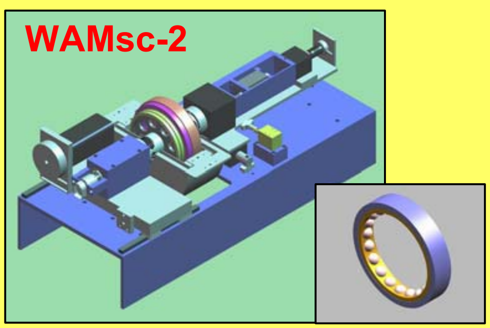
Rolling/sliding contact

- Scuffing, adhesive wear
- Performance mapping

WAM_{hs}

High Stress rolling/sliding

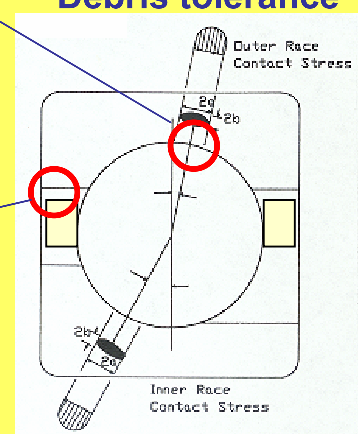
- Surface fatigue
- Debris tolerance



WAMsc-2

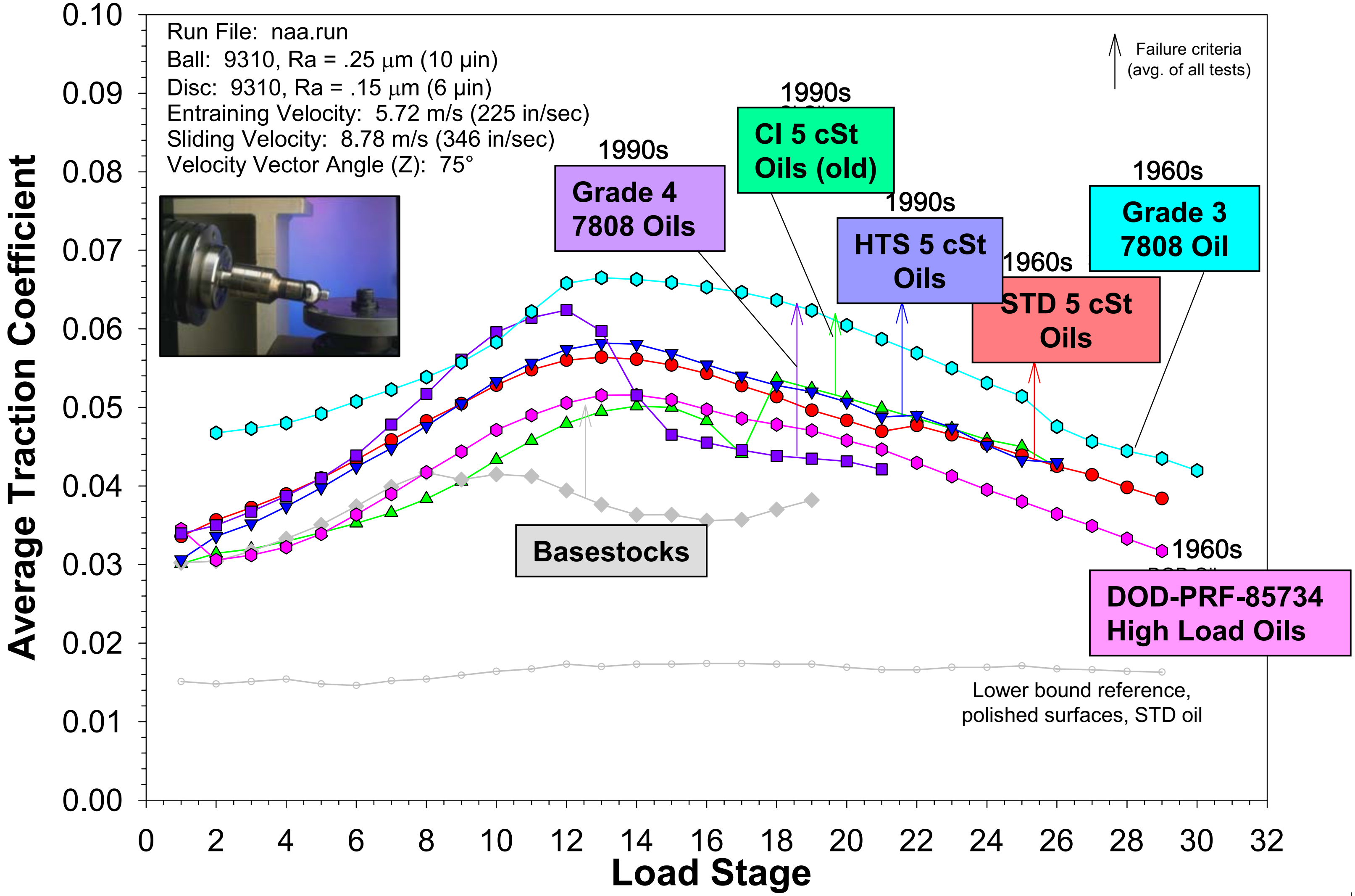
Cage-land sliding contact

- Abrasive wear
- Oil-out



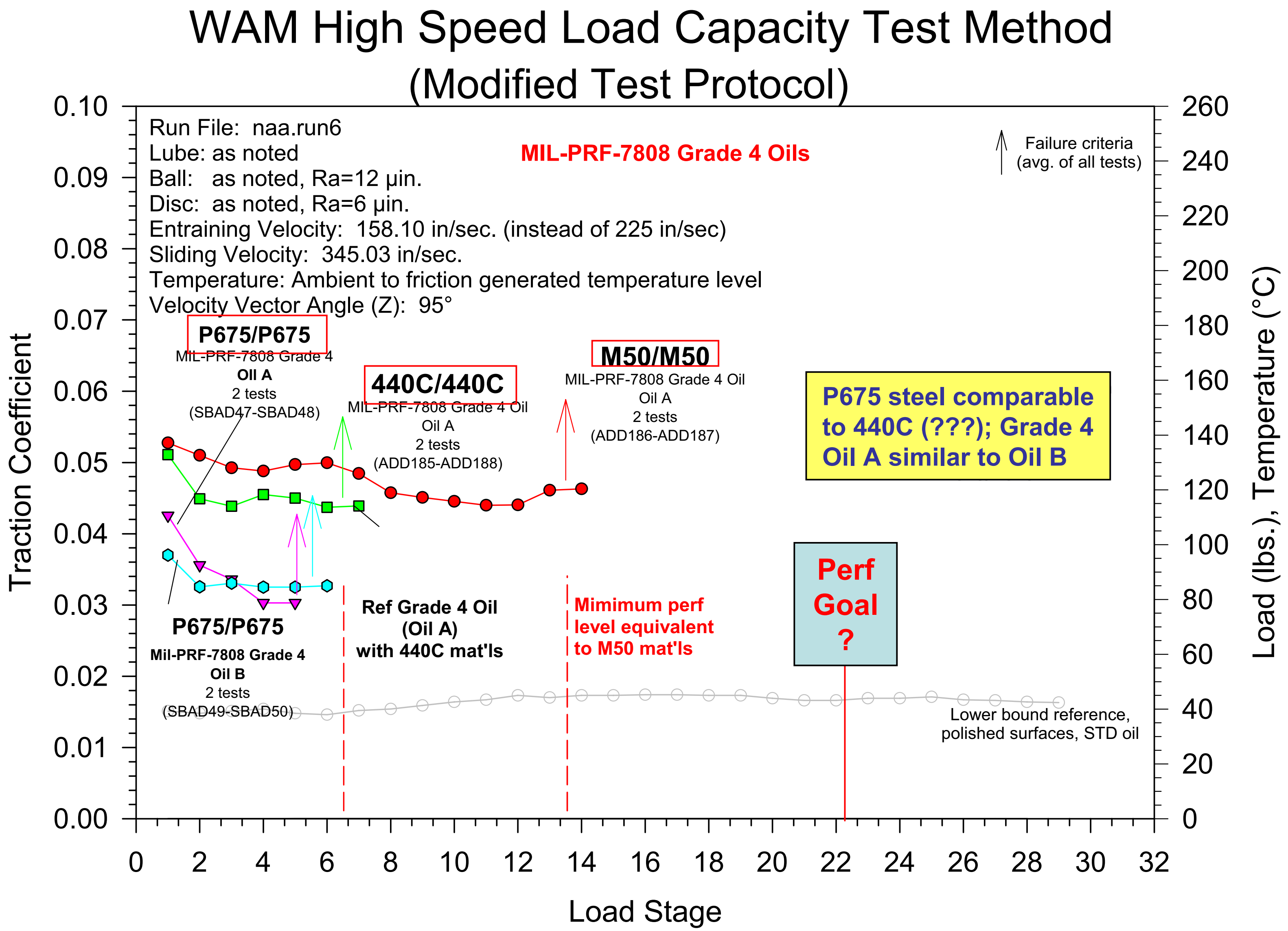
Master Chart for Oil Scuffing Performance

Historical trends in oil lubricating performance



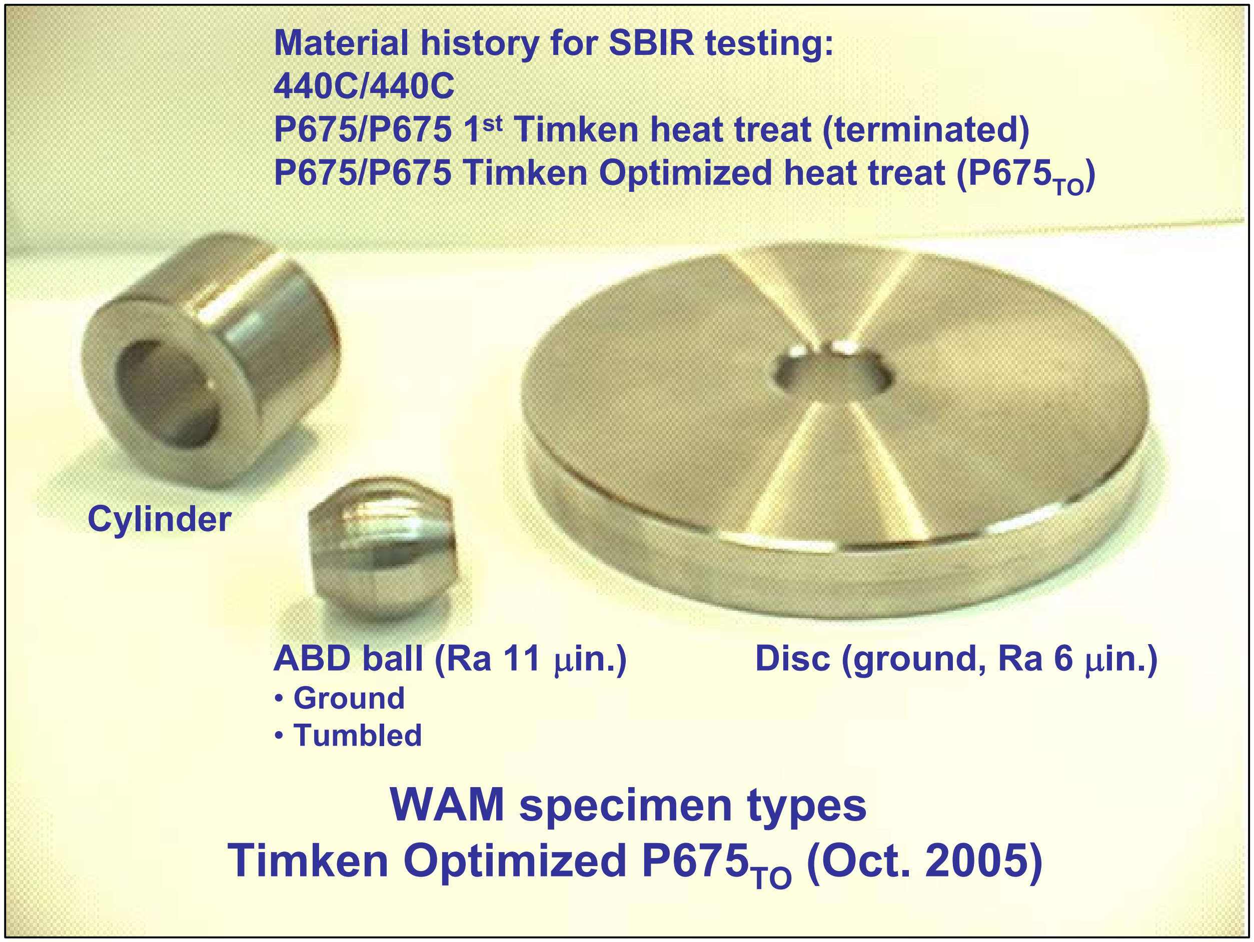
Qualified product types and basestocks

Baseline Testing – Minimum Performance



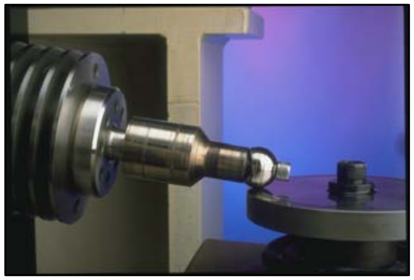
W/Testing/SBIR-Add/Project/WAMLCC/AVG/RM284A M50 & 440C.jnb

WAM Screening Tests with Timken Optimized P675



Supplier A Formulations and Down-Selections

WAM load capacity screening tests



WA111 (4 cSt)
WA112 (4 cSt)
WA113 (4 cSt)
WA114 (4 cSt)
WA115 (4 cSt)
WA010
WA011
WA012
WA013
WA014
WA024 (4 cSt)
WA025 (4 cSt)
WA034
WA035 (CI)
WA036 (CI)

(15)

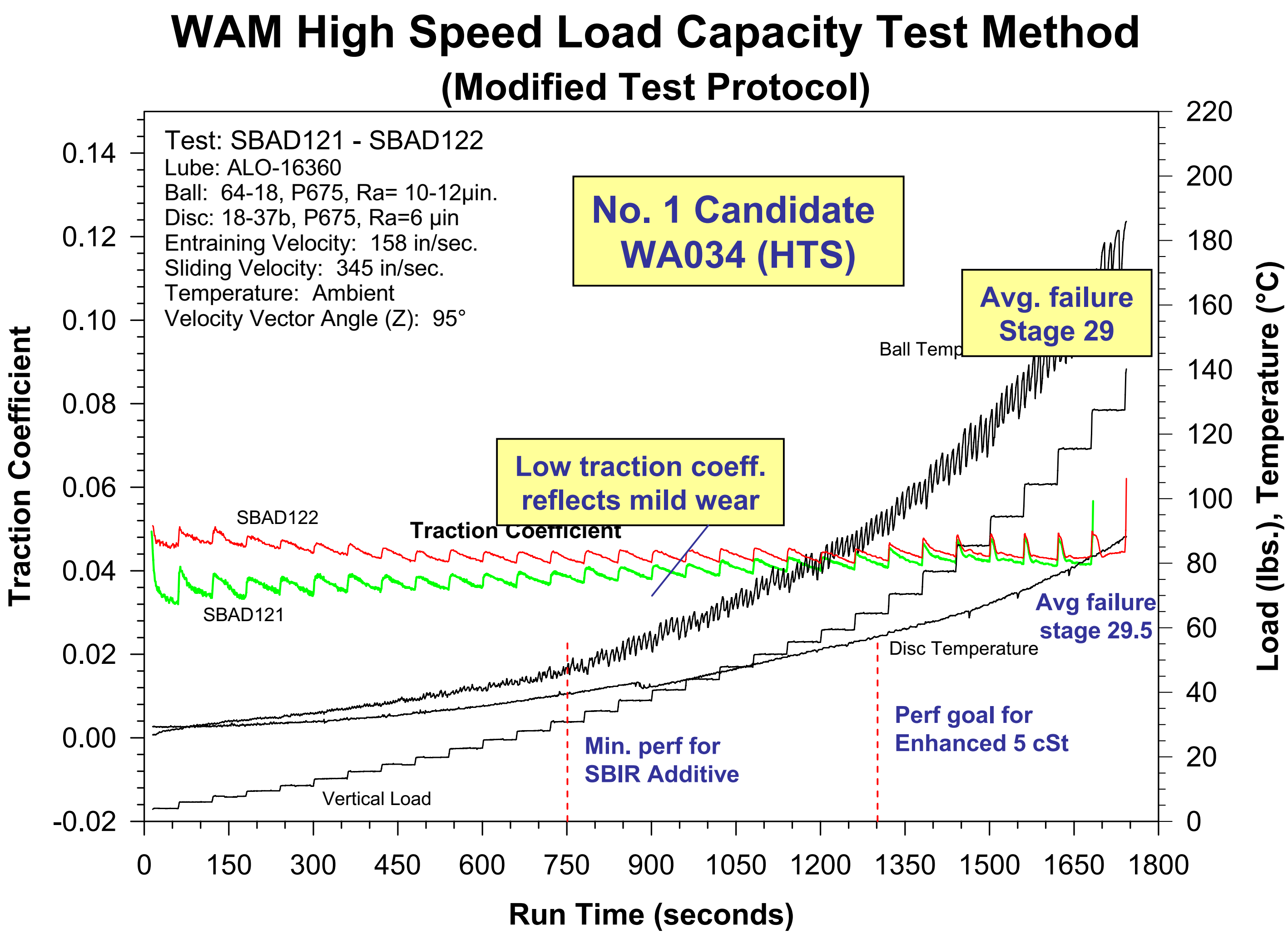
→

#1 WA034
#2 WA036 (CI)
#3 WA035 (CI)

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

WAM Screening Tests with Timken Optimized P675

Supplier A Priority Candidates



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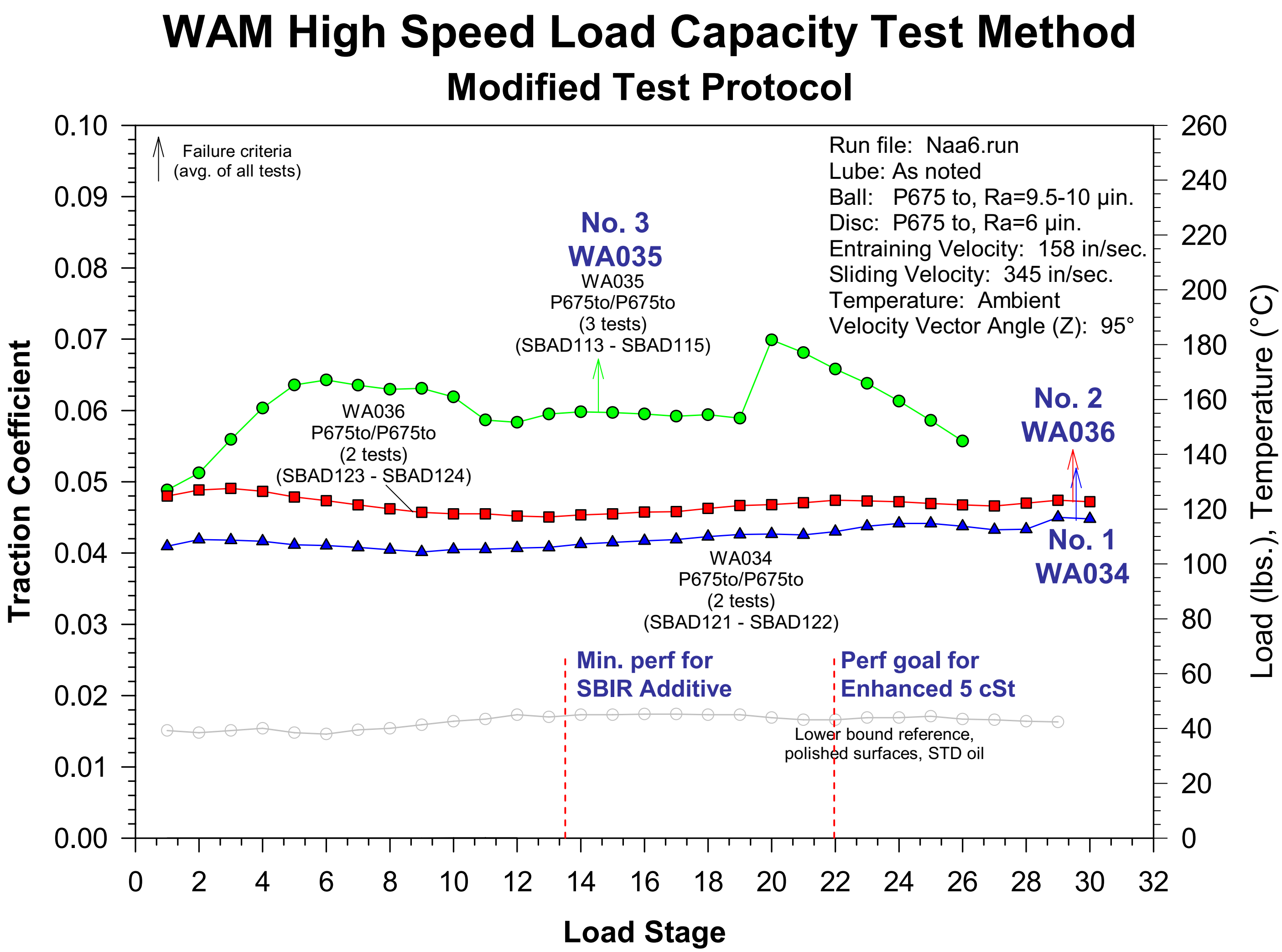
WAM Screening Tests with Timken Optimized P675

Supplier A Priority Candidates



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

Supplier B Formulations and Down-Selections

WAM load capacity screening tests

WA001 (4 cSt)	WA028	WA048
WA002 (4 cSt)	WA029	WA049
WA003 (4 cSt)	WA030	WA050
WA004 (4 cSt)	WA031	WA051
WA005 (4 cSt)	WA032	WA052
WA006 (4 cSt)	WA033	WA0
WA007 (4 cSt)		
WA008 (4 cSt)		
WA009 (4 cSt)	WA037 (CI)	
WA017 (4 cSt)	WA038 (CI)	
WA018 (4 cSt)	WA040 (CI)	
WA019 (4 cSt)	WA041	
WA020 (4 cSt)	WA042 (CI)	
WA021 (4 cSt)	WA043 (CI)	
WA022 (4 cSt)	WA044	
WA023 (4 cSt)	WA045 (CI)	
WA026 (4 cSt)	WA046 (CI)	
WA027 (4 cSt)	WA047	

(40)

Tested by WA, Inc. outside of SBIR

→

#1 WA041
#2 WA028
#3 WA031
WA051 is backup for WA041

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

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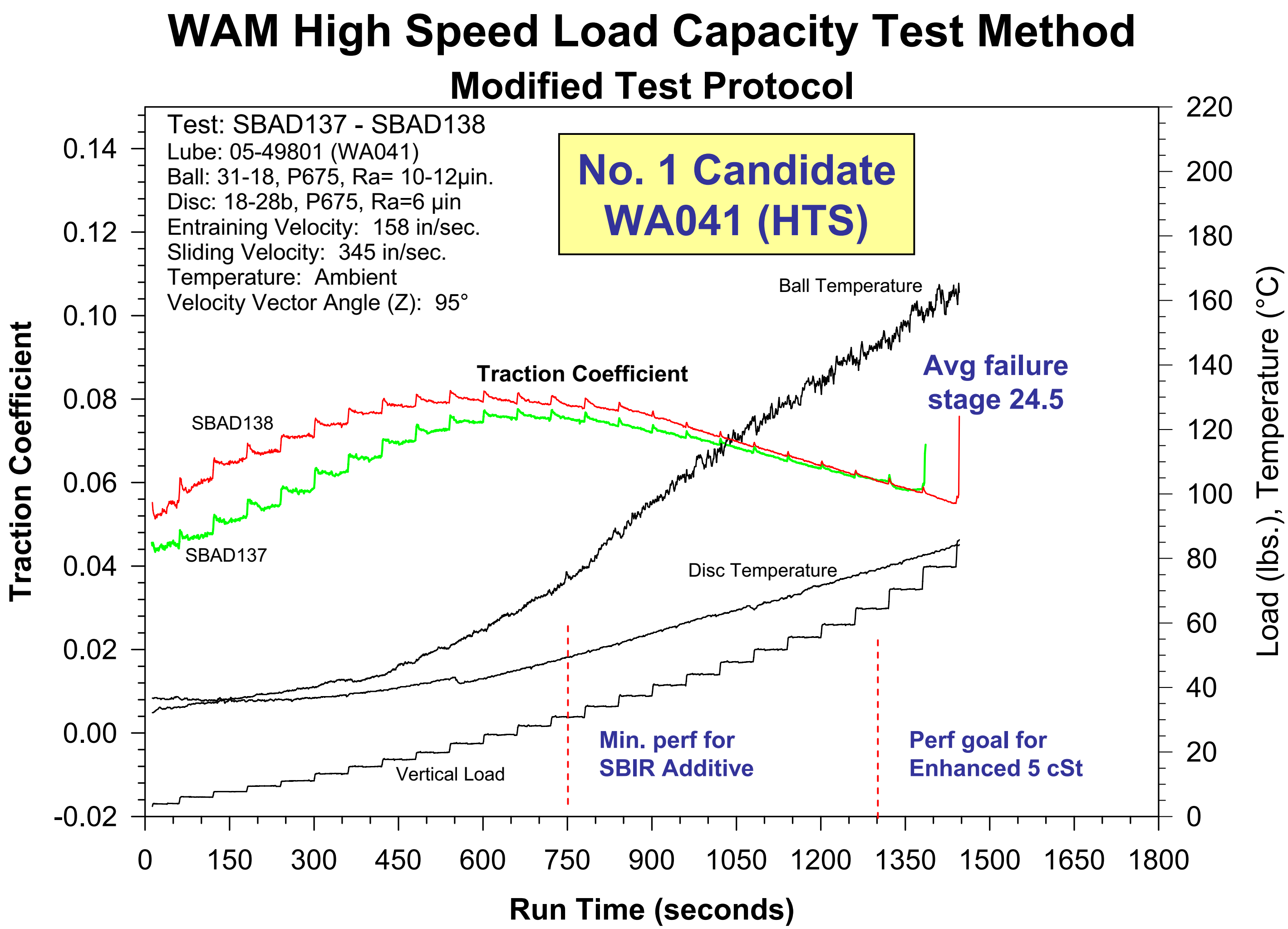
WAM Screening Tests with Timken Optimized P675

Supplier B Priority Candidates



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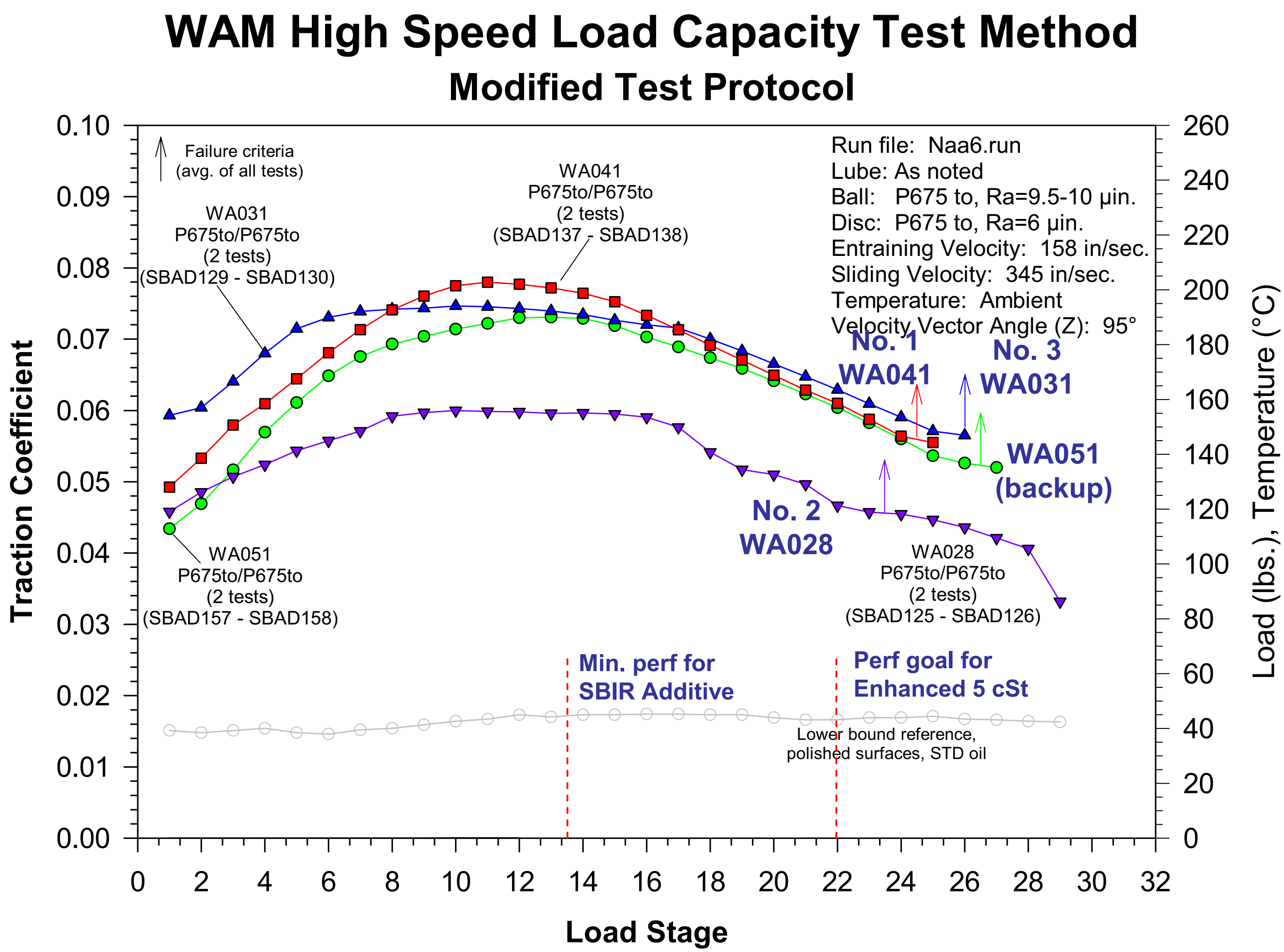
w/testing/sbir-ADD/Projest/LCCjnb

WAM Screening Tests with Timken Optimized P675

Supplier B Priority Candidates



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

Supplier C Formulations and Down-Selections

WAM load capacity screening tests

WA101 (4 cSt)
WA102 (4 cSt)
WA103 (4 cSt)
WA104 (4 cSt)
WA105 (4 cSt)
WA106 (4 cSt)
WA122 (4 cSt)
WA123 (4 cSt)
WA124 (4 cSt)
WA125 (4 cSt)
WA126 (4 cSt)
WA127 (4 cSt)
WA128 (4 cSt)
WA129 (4 cSt)
WA131 (4 cSt)
WA132 (4 cSt)
WA133 (4 cSt)
WA134 (4 cSt)
WA135 (4 cSt)

WA136 (4 cSt) (WA141)
WA137 (4 cSt) (WA142)
WA138 (4 cSt)
WA139 (4 cSt) (WA143)
WA140 (4 cSt)

Oils WA136, WA137 & WA139 evaluated for:
Oxid-corr, elastomer compat and coking (D3711)
Results: problems with WA137 & WA139

Chemistry of WA136, WA137 & WA139 put in Nyco 5 cSt ref base oil

WA144
WA145
WA146

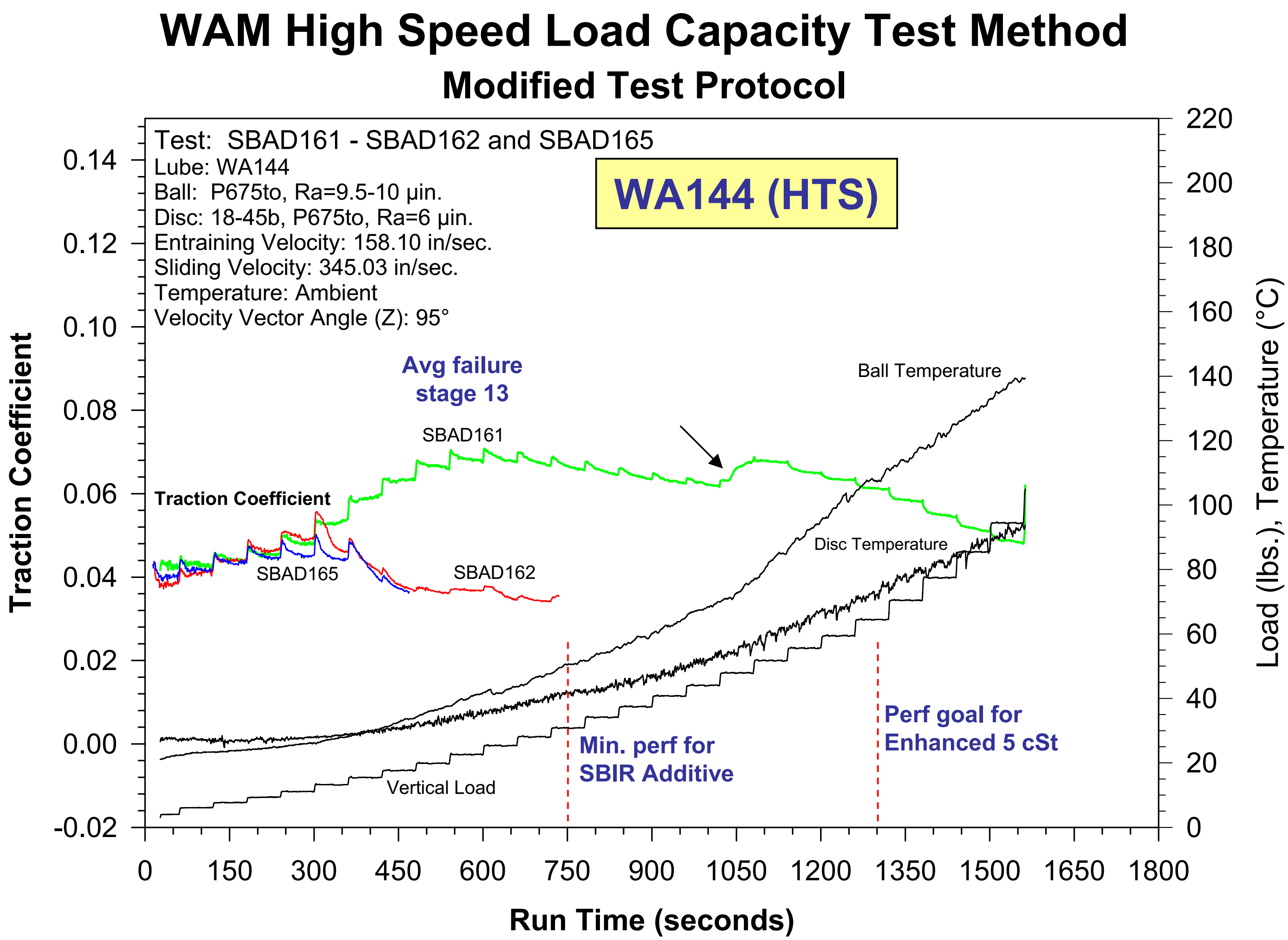
(28)

No down-selected formulations, except for WA144, which was boosted by WA, Inc. to pass scuffing test
New WA/Supplier C formulation is WA147

Total formulations evaluated: 84 (not including METSS)

WAM Screening Tests with Timken Optimized P675

Supplier C Candidate



wamlcc/sbir-add/modifiedtestprotocol/DOD.jnb

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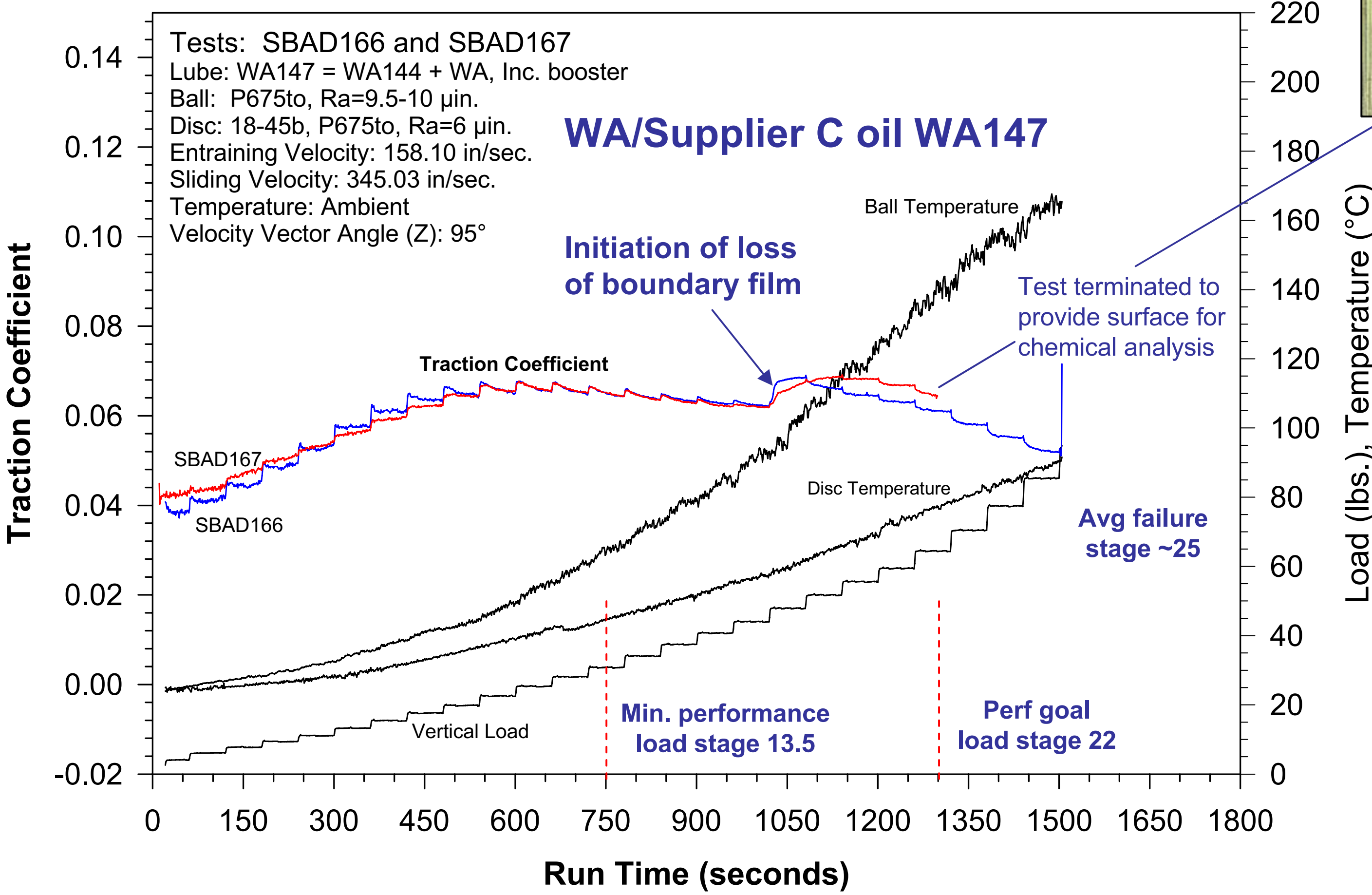
WAM Screening Tests with Timken Optimized P675

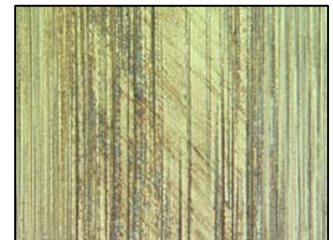
WA, Inc./Supplier C Candidate

WAM High Speed Load Capacity Test Method

Modified Test Protocol



Disc track; test SBAD167



100x

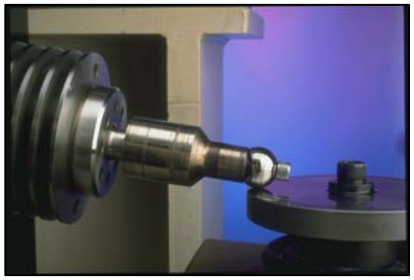
WA147 also passes coking & compatibility tests

21

wamlcc/sbir-add/modifiedtestprotocol/DOD.jnb

METSS Formulations and Down-Selections

WAM load capacity screening tests



?
12E20
12I20
39I20
12I10

→

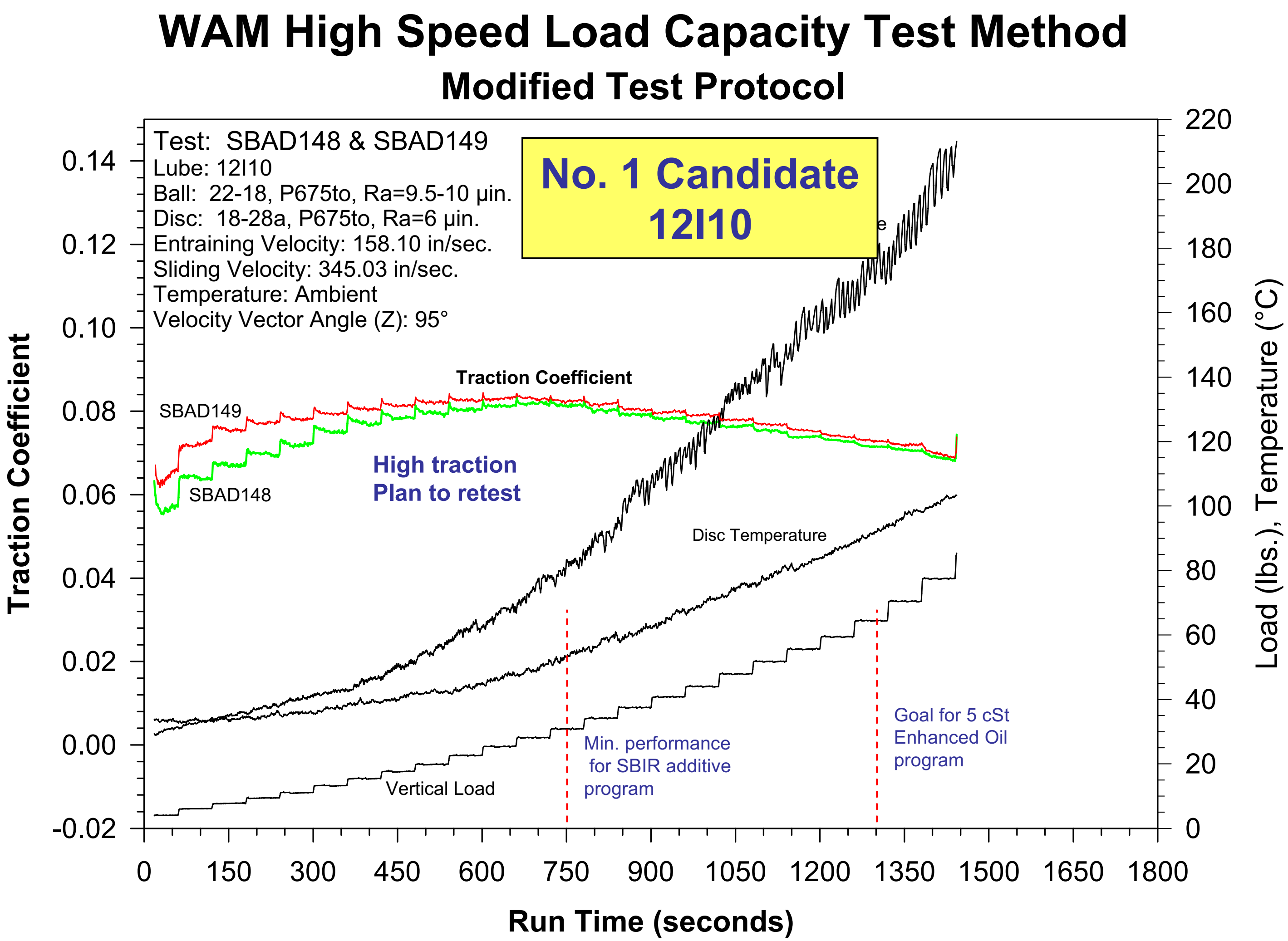
#1 12I10
12I20
39I20

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

22

WAM Screening Tests with Timken Optimized P675

METSS Candidates



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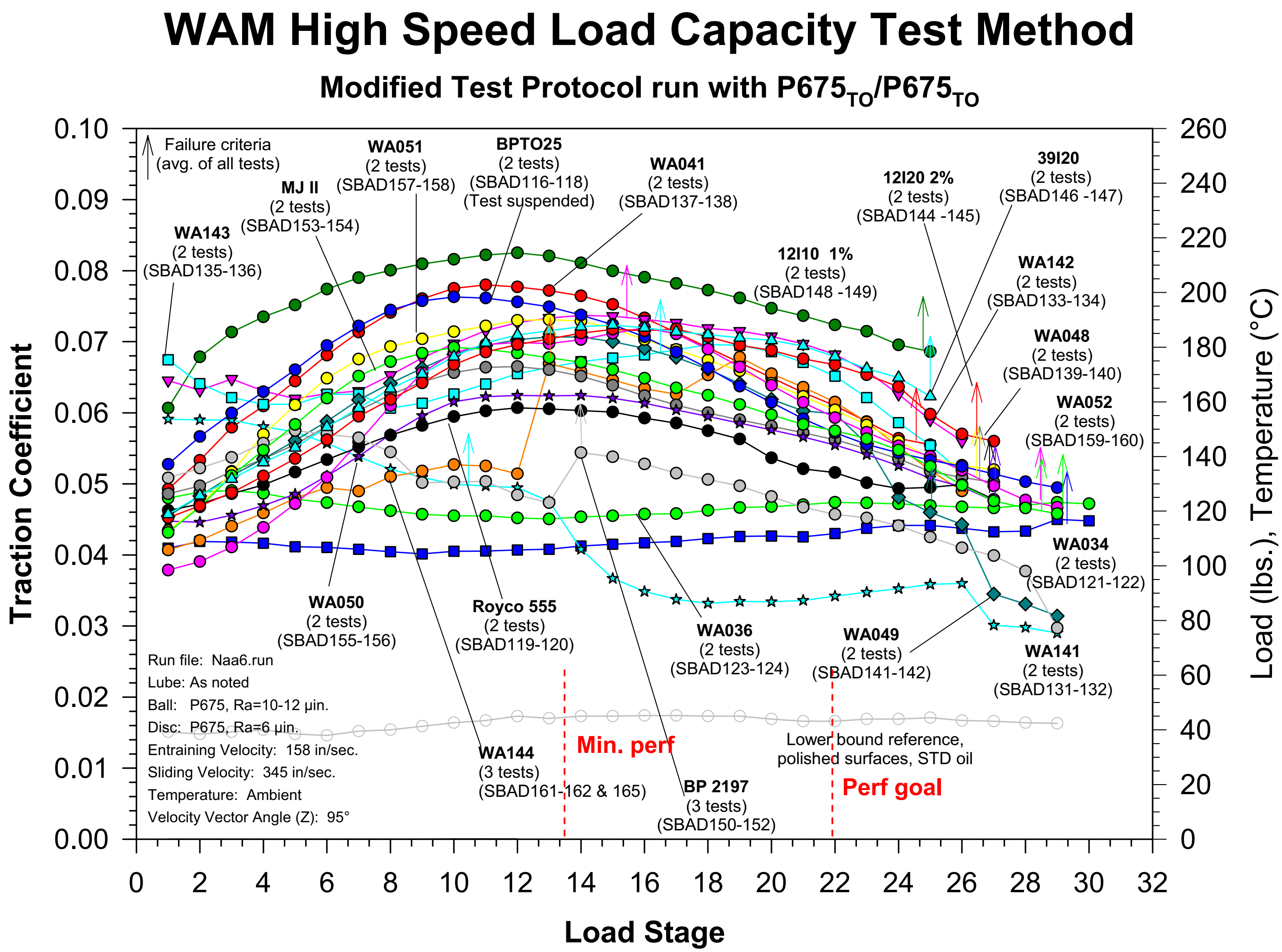
wamlcc/sbir-add/modifiedtestprotocol/DOD.jnb

WAM Screening Tests with Timken Optimized P675

Monster Graph – All oils tested with $P675_{TO}$



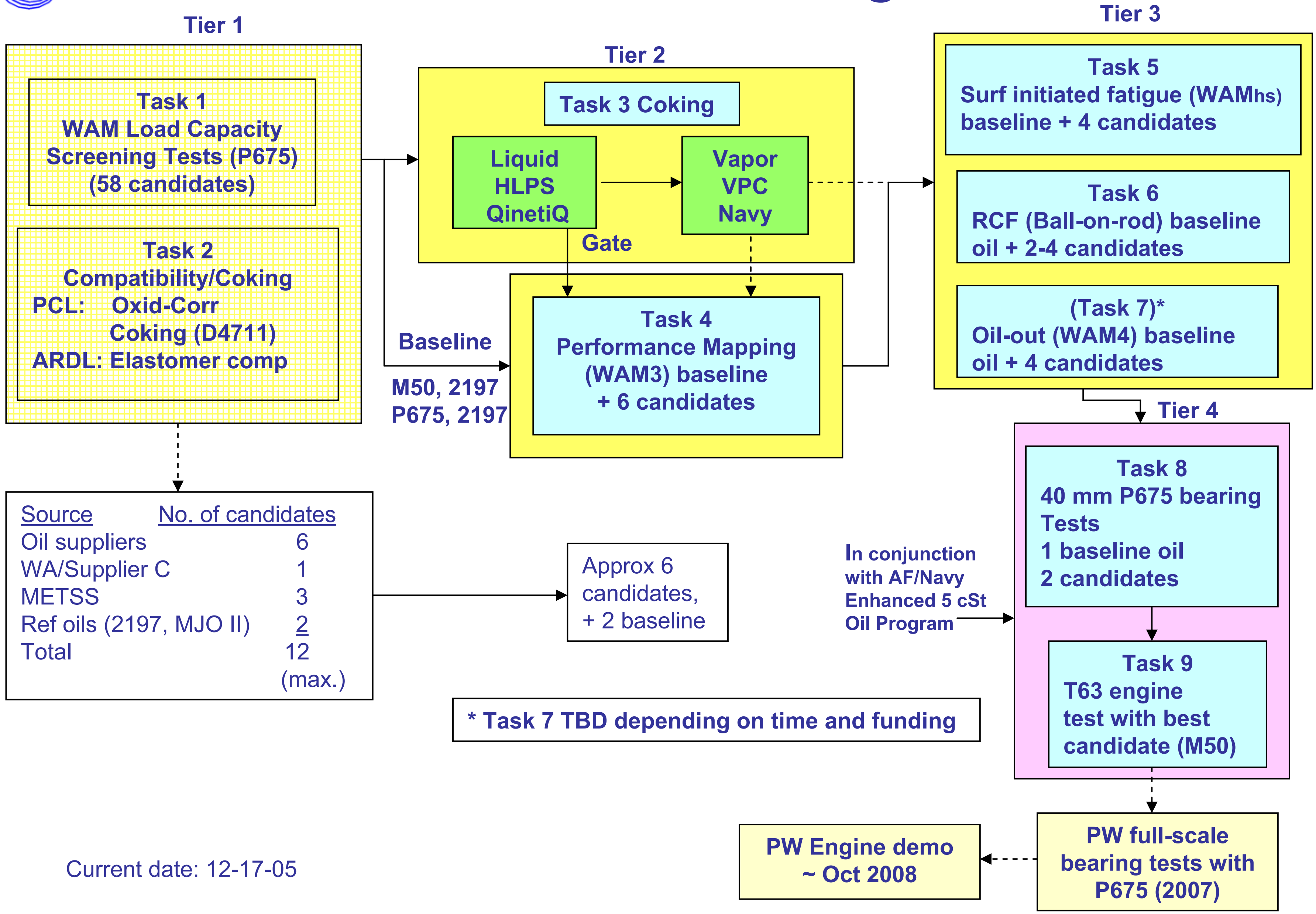
8 candidates pass performance goal

Traction variation implies significant chemical effect on wear (& surface fatigue)

24

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

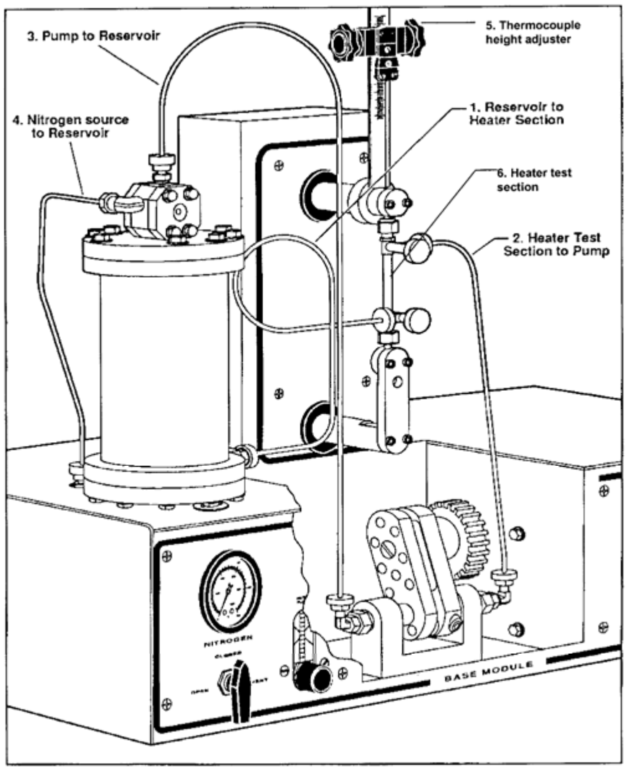
SBIR Additive Phase II Going Forward Plan



Coking Tests at QinetiQ

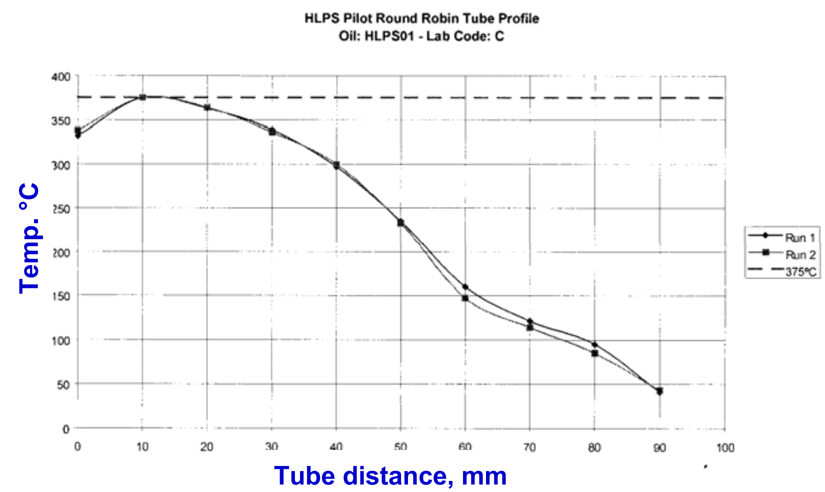
HLPS – liquid phase

Annex D **Schematic of HLPS Apparatus**
(Reproduced with permission of Alcor)

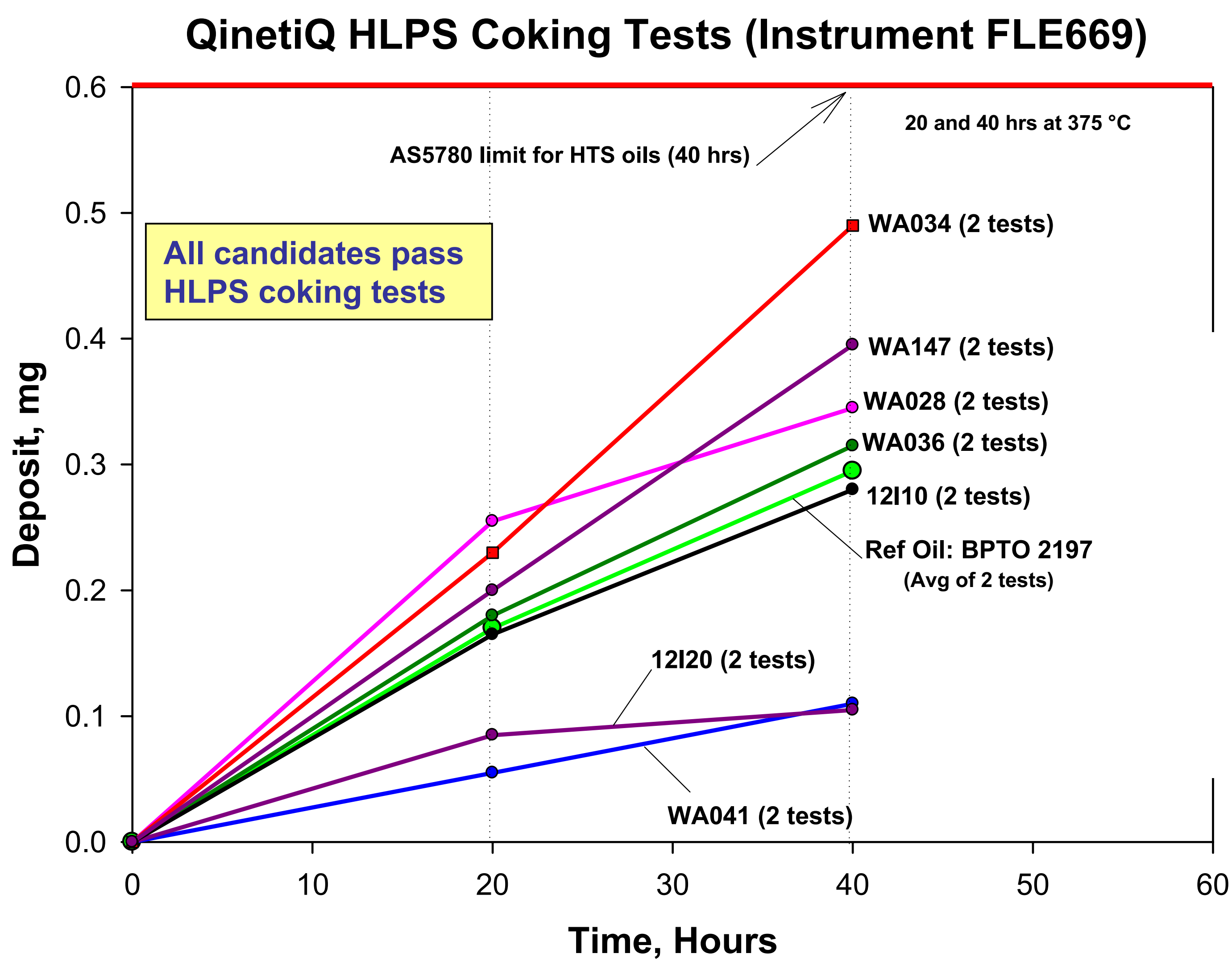


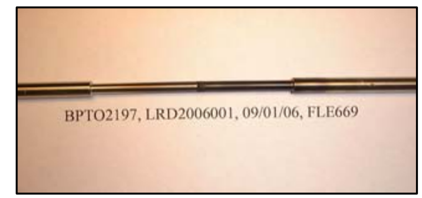
Note: This method requires air to be used in place of nitrogen.

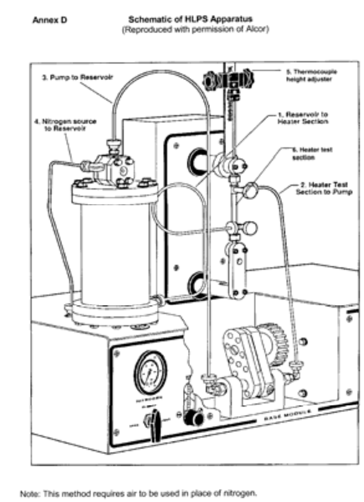
HLPS 320 Instrument



Coking Tests at QinetiQ





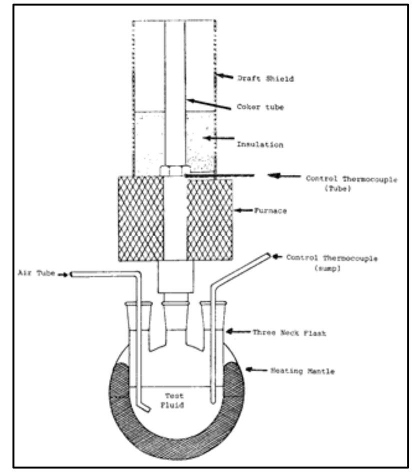


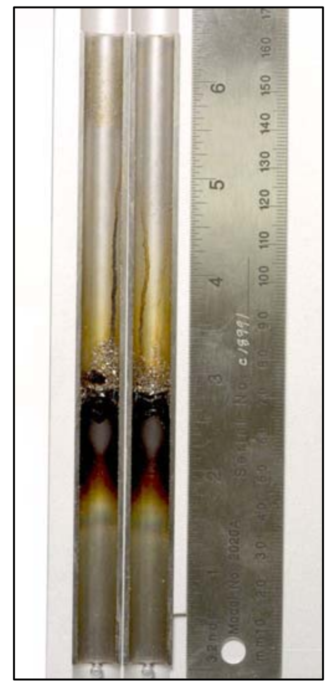
Current date: 6-12-06

Coking Tests at U.S. Navy

Vapor Phase Coking

343 °C nominal tube temperature data





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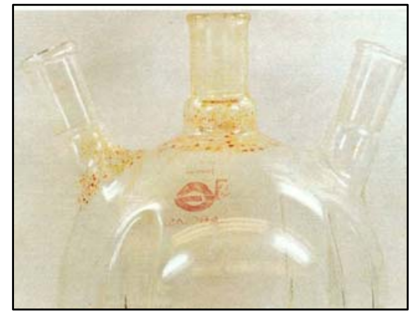
U.S. Navy Vapor Phase Coking Tests

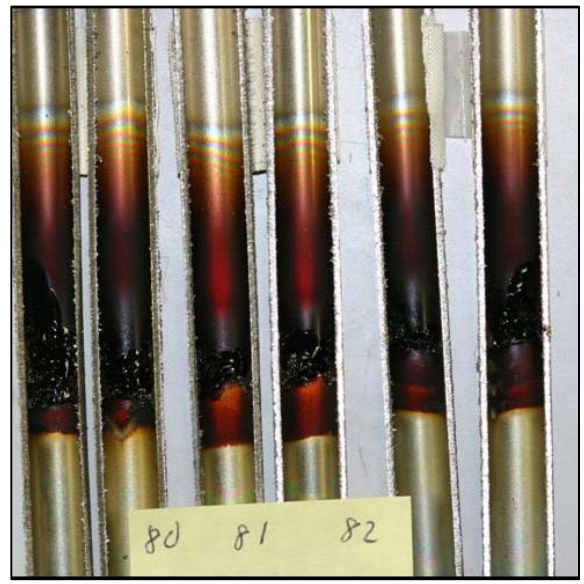
Wedeven SBIR Additive Project
Air Force Contract No. FA8650-04-C-05034
May 22, 2006

343 °C nominal tube temperature data



Test Oil	Avg. deposit (3 tests), mg
Air BP 2197 (ref HTS)	212
23699 “Dirty Oil” (DLA04-1075)	332
12I10	305
12I20	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

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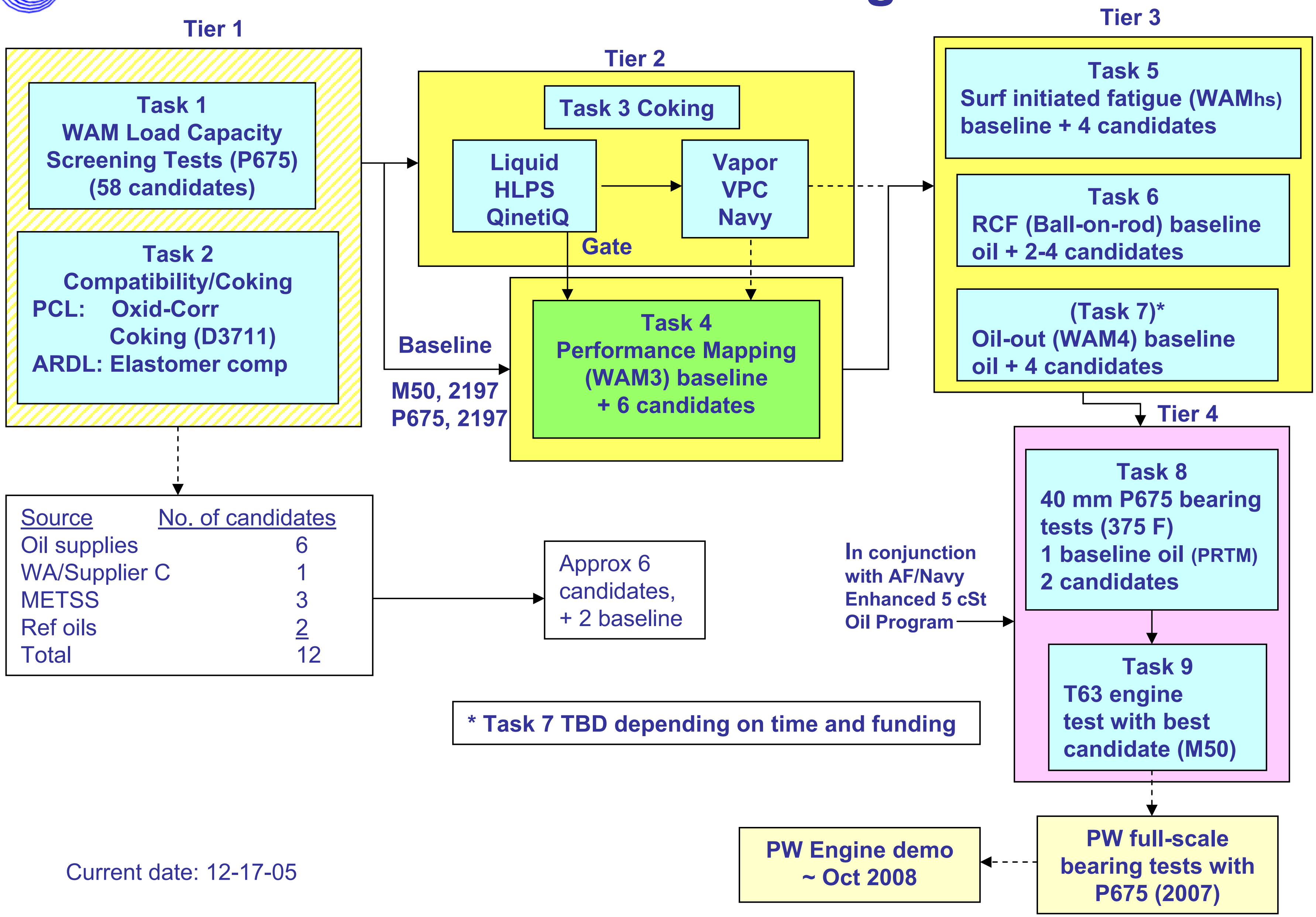
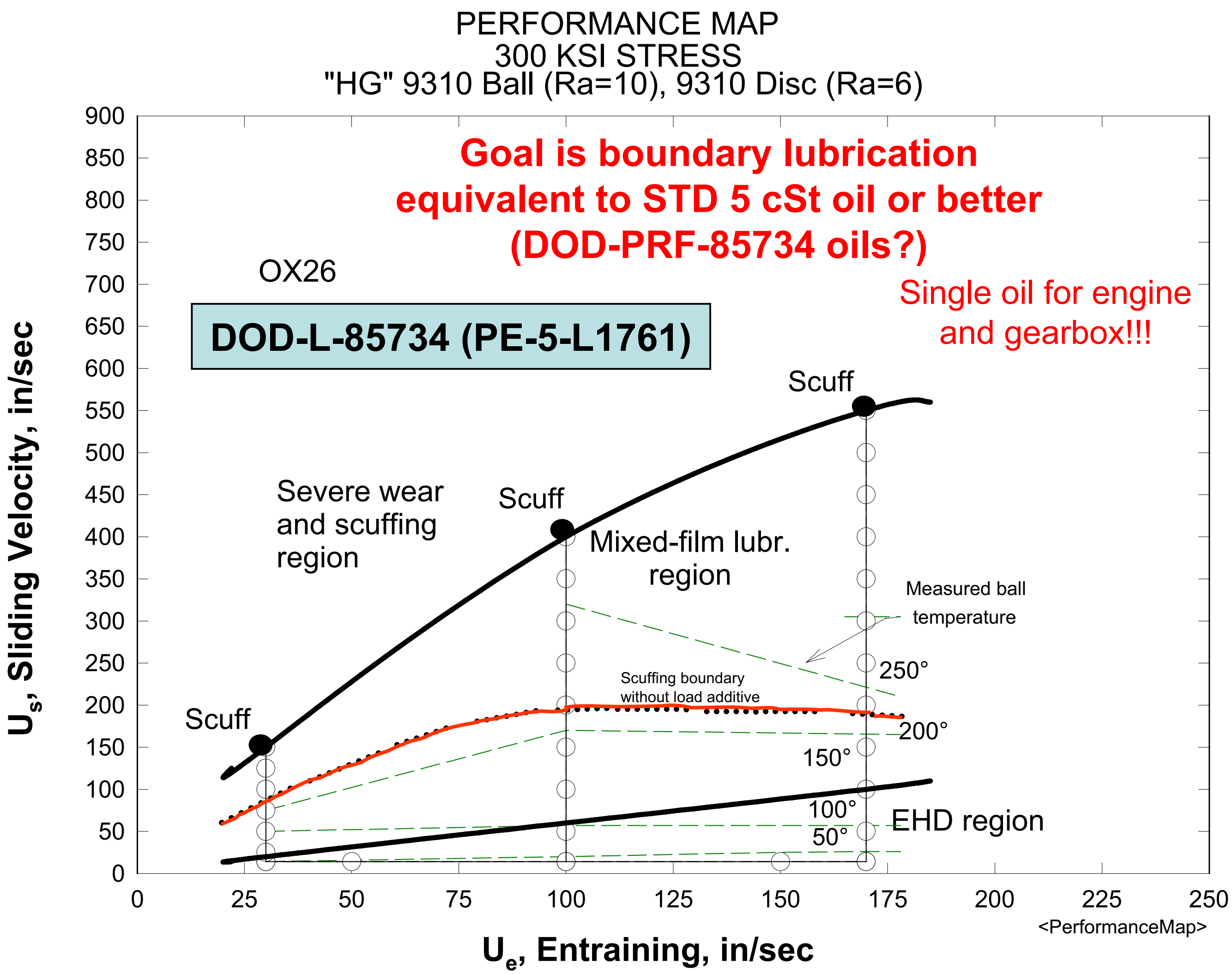
SBIR Additive Phase II Going Forward Plan

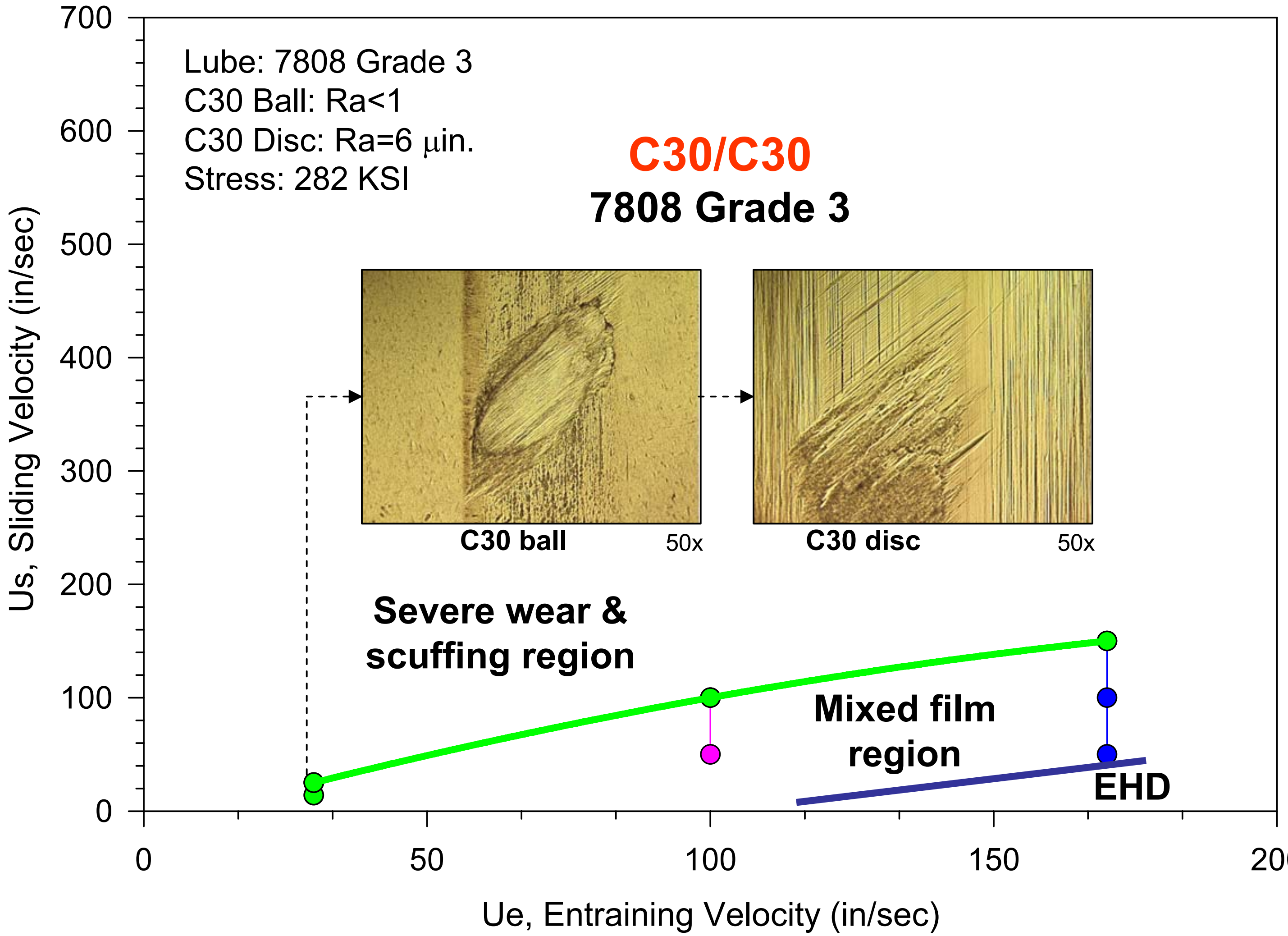


Current date: 12-17-05

Performance Mapping



Impact of Corrosion Resistant Materials on Boundary Lubrication



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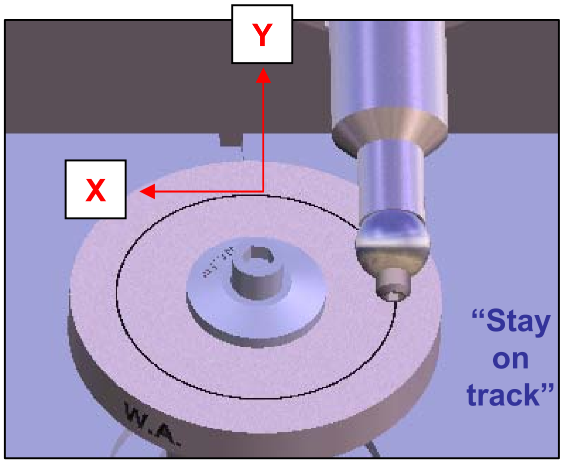
WAM3 Upgraded for Automated Performance Mapping

- 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

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



WA, Inc. designed & fabricated WAM System Control Board

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

Simplified and robust electronics

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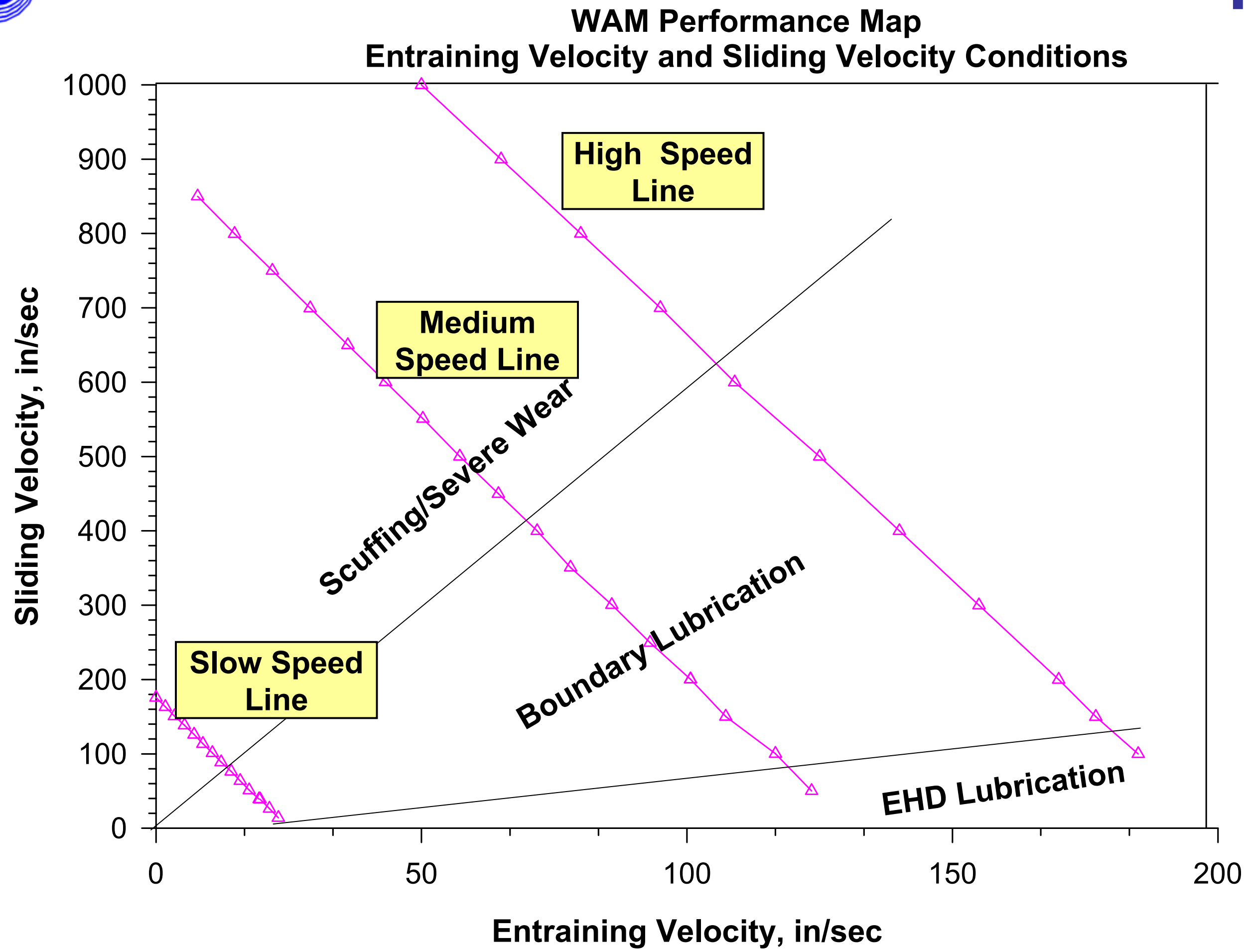
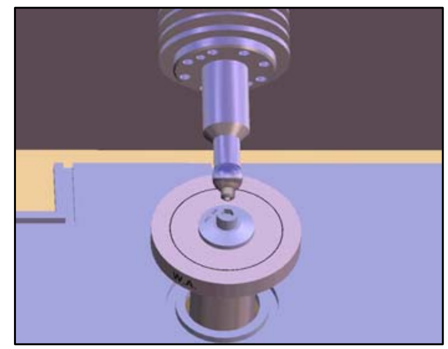
Automated Performance Mapping





Slow Speed	Ue =	23 -> 0 in/sec
(140 minutes poss.)	Us =	14 -> 176 insec
	Skew =	33.7-> 90 -> 0

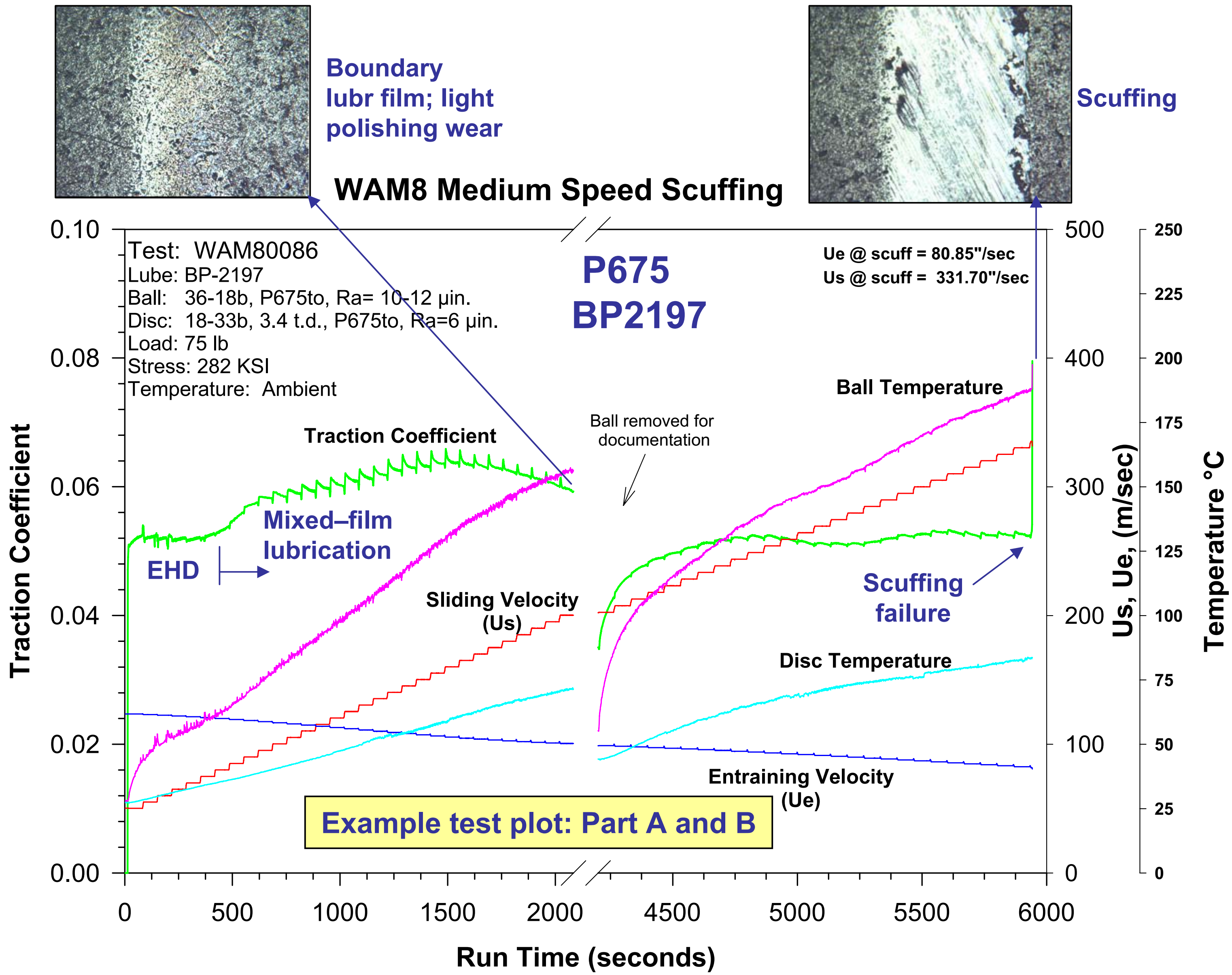
High Speed	Ue =	185.33 -> 19.86 in/sec
(130 minutes poss.)	Us =	100.36 -> 1200 in/sec
	Skew =	30.3 -> 90 -> 3.8

1 Map = 3 test lines

Medium Speed	Ue =	123.5->7.84
(170 minutes poss.)	Us =	50.24 -> 850 in/sec
	Skew =	23 -> 90 -> 0

Three testing lines cover lubrication & failure regimens

Automated Performance Mapping



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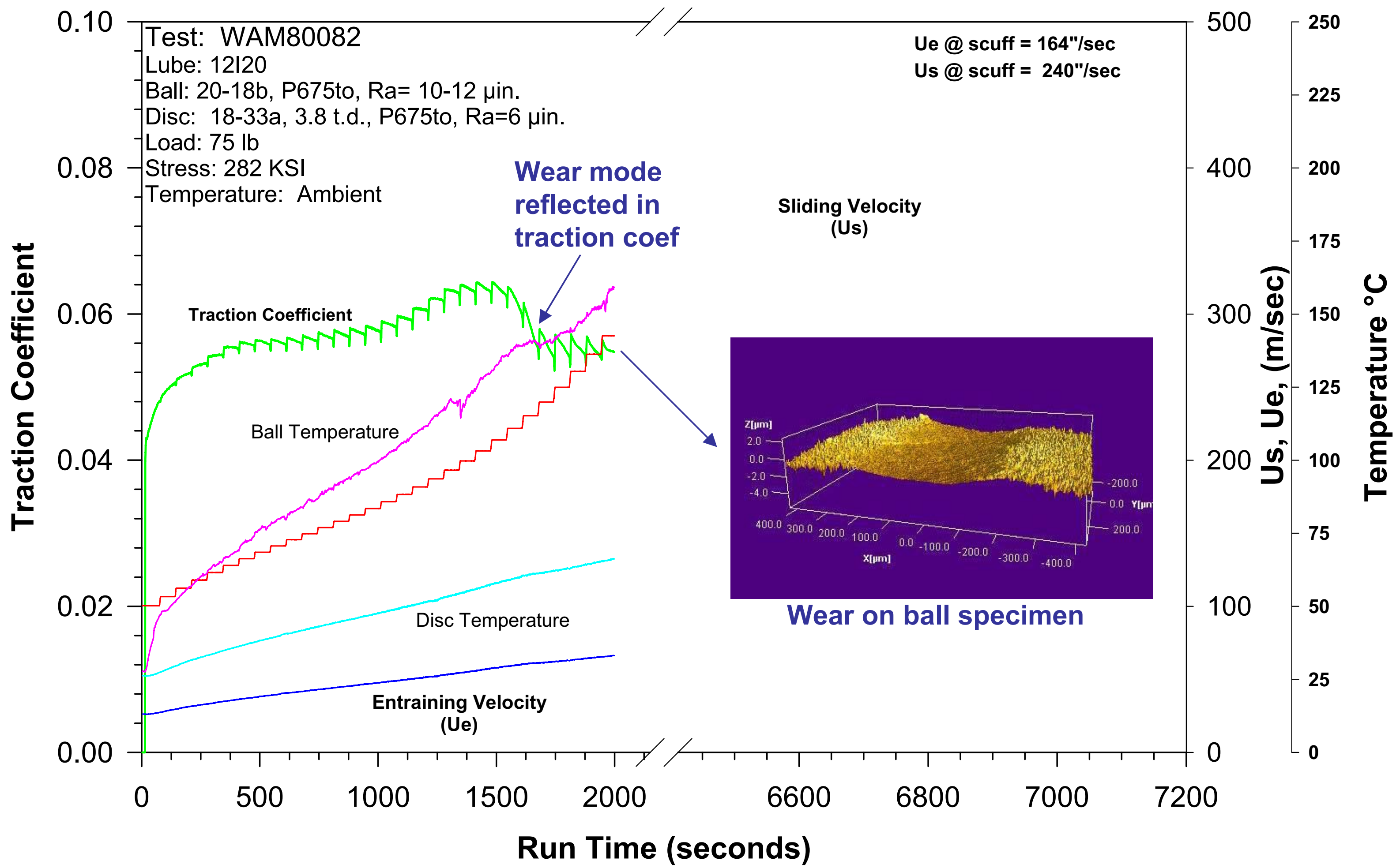
Automated Performance Mapping

WAM8 High Speed Scuffing



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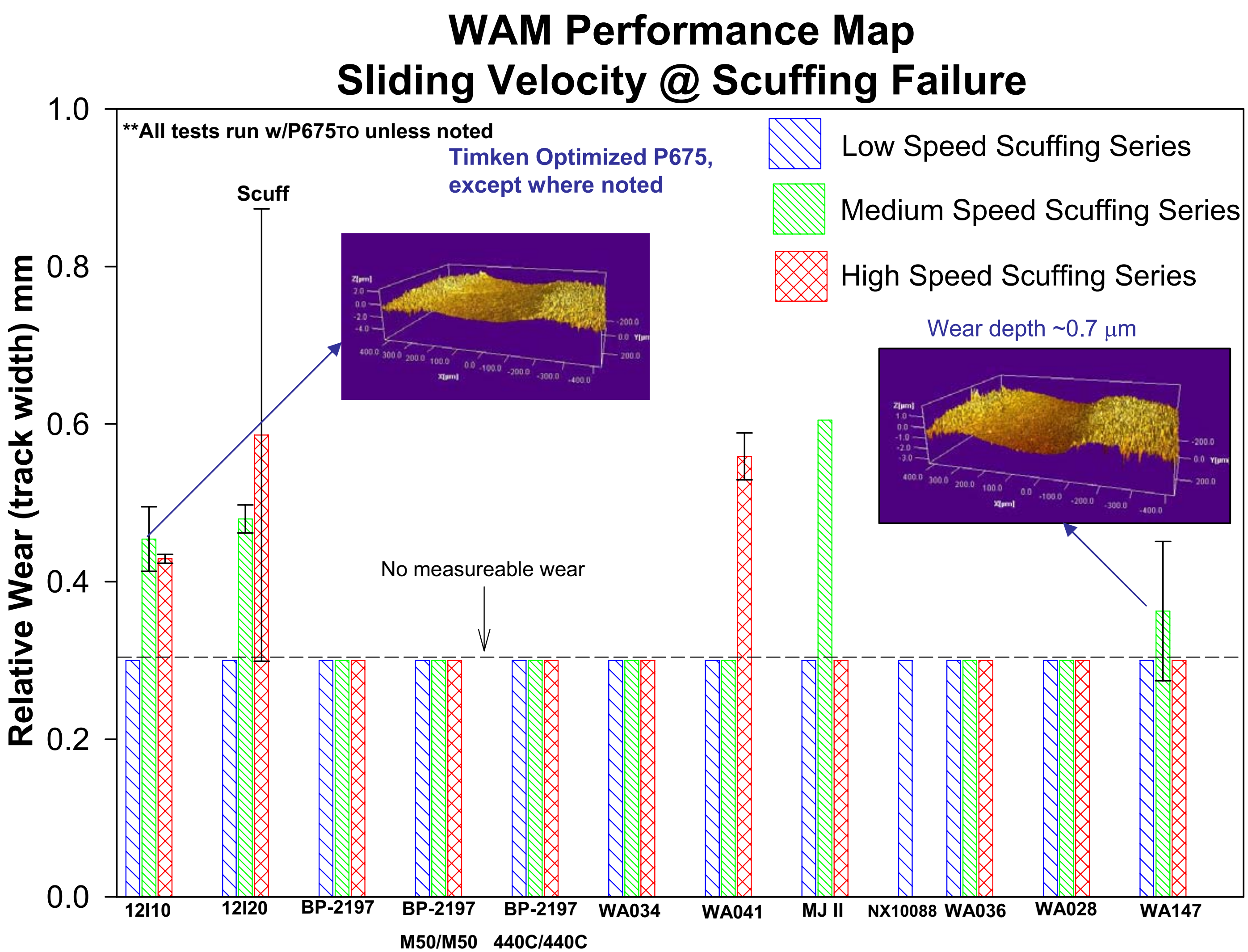
Automated Performance Mapping

First part of test evaluates wear performance



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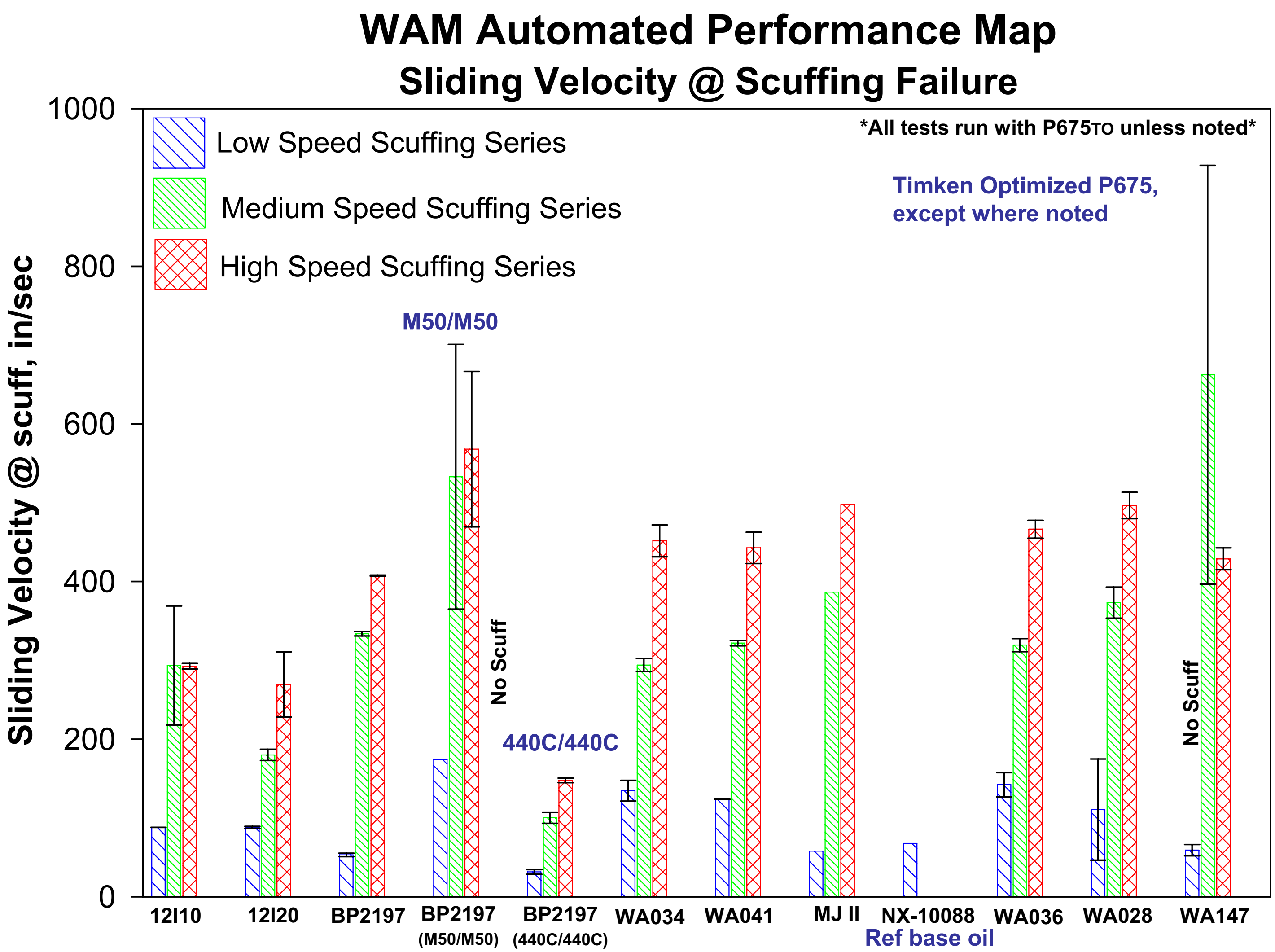
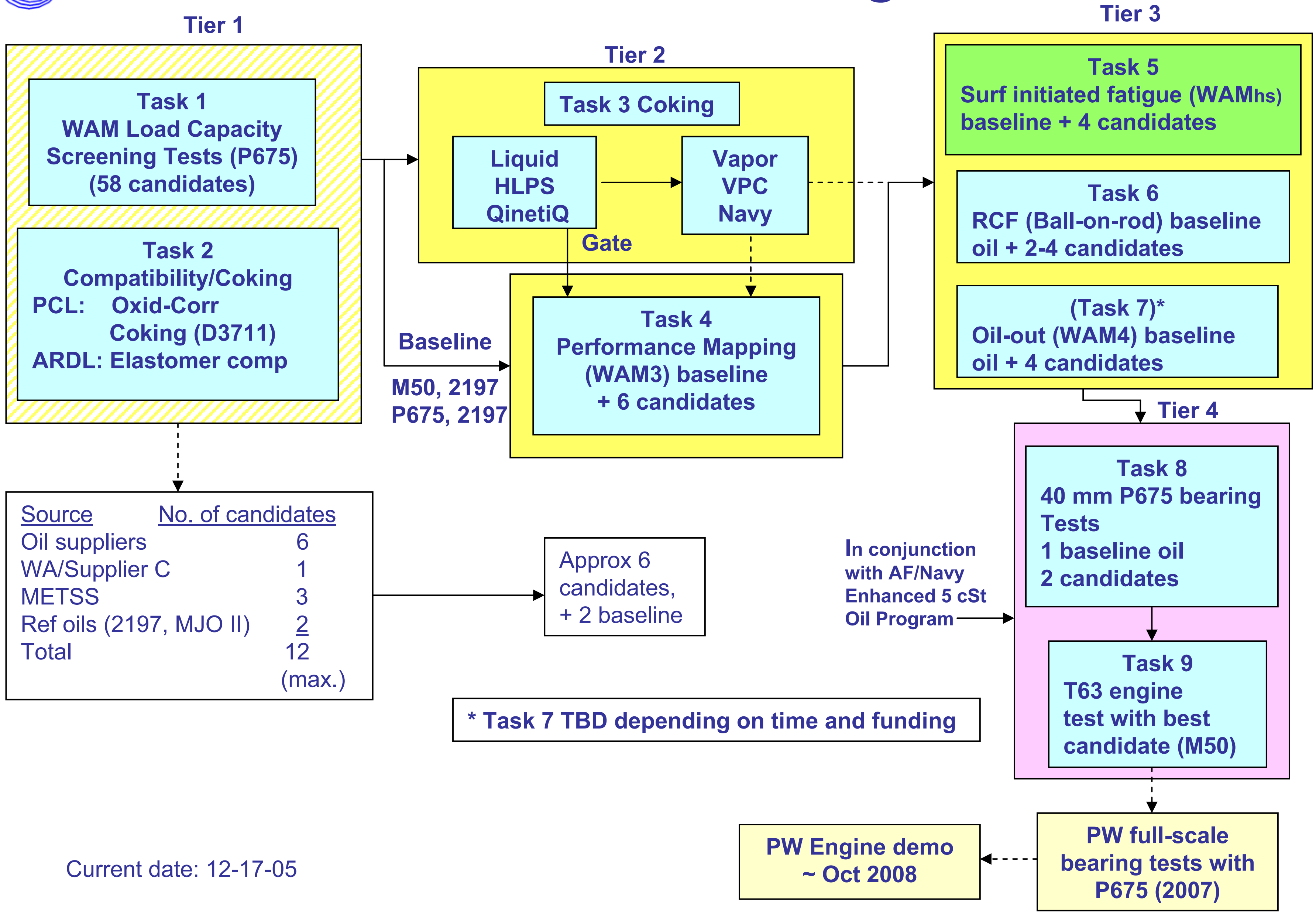
Automated Performance Mapping

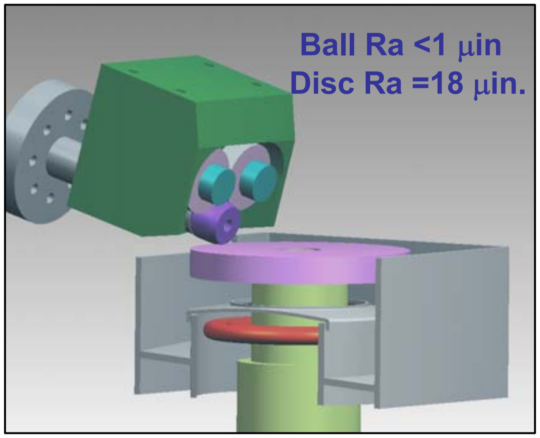
Second part of test evaluates scuffing performance

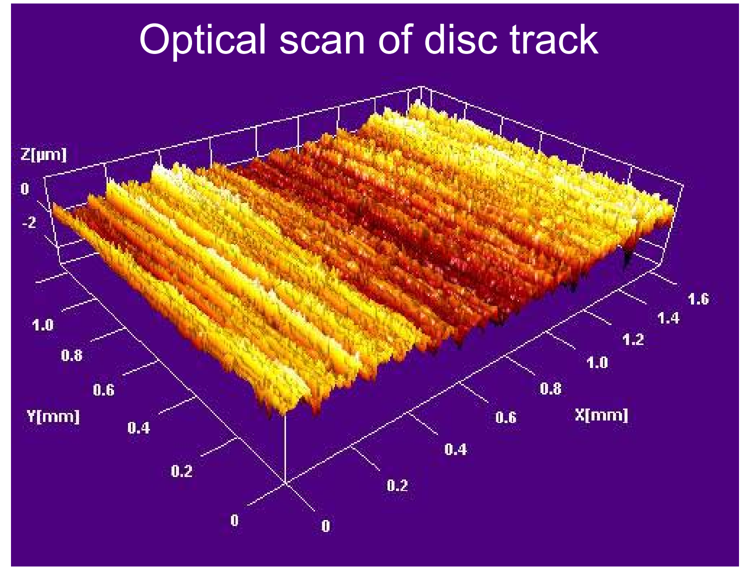


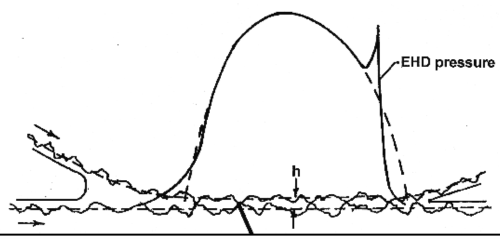
SBIR Additive Phase II Going Forward Plan

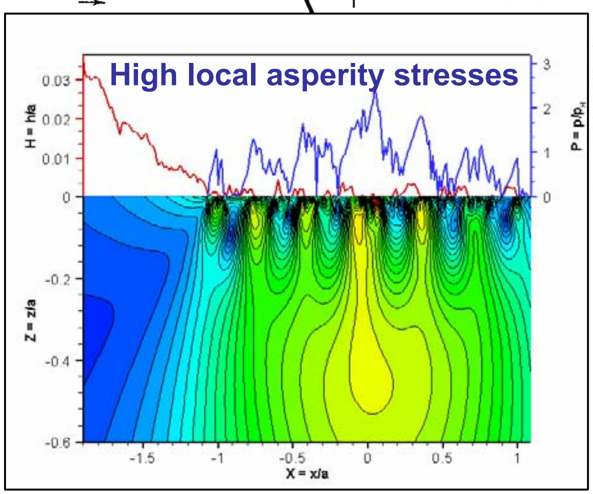


WAM$_{hs}$ Test – Surface Initiated Fatigue









Ball Ra < 1 μin

Disc Ra = 18 μin

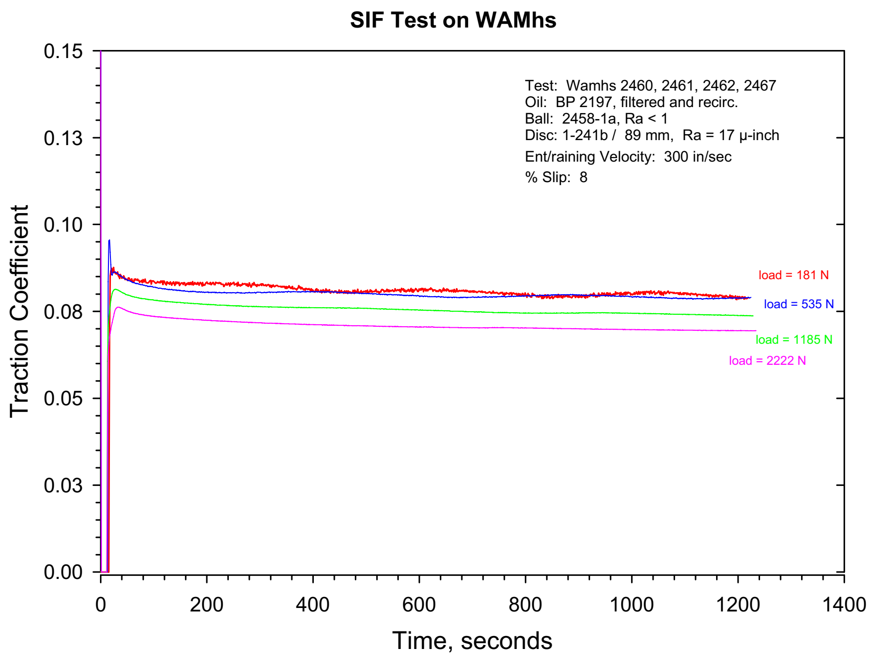
WAM$_{hs}$ Test Conditions

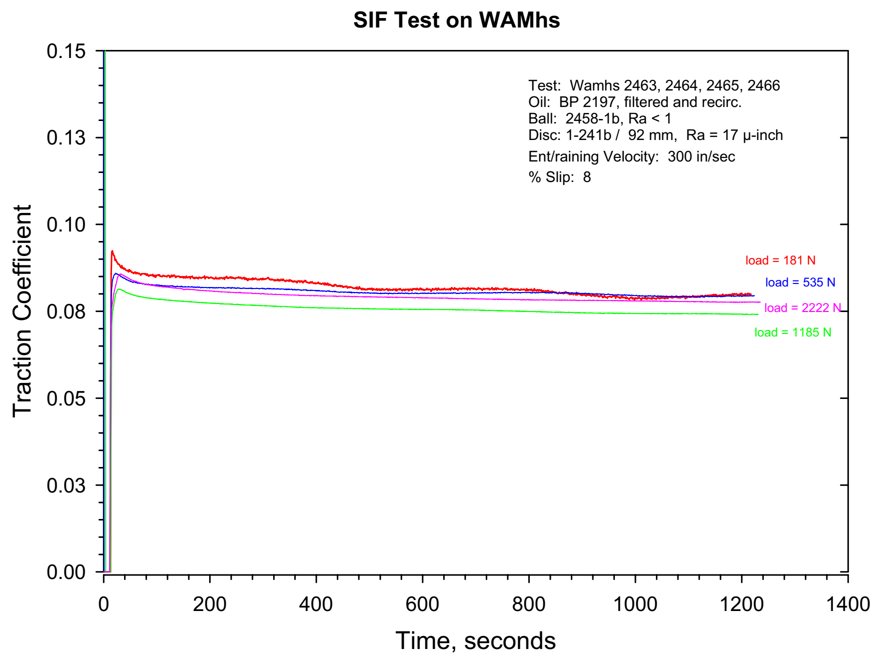
Ue = 300 in/sec
Us = variable (2% - 8% slip)
Z = 4.5° (skew)
Time = 1200 sec
Hertz stress = 230, 330, 430 and 530 ksi
Temperature = 100 °C

Status: Two primary candidates completed, plus baseline

Progressive Loading SIF- M50 Traction Behavior

Test temperature: 100° C
Test oil: BP2197



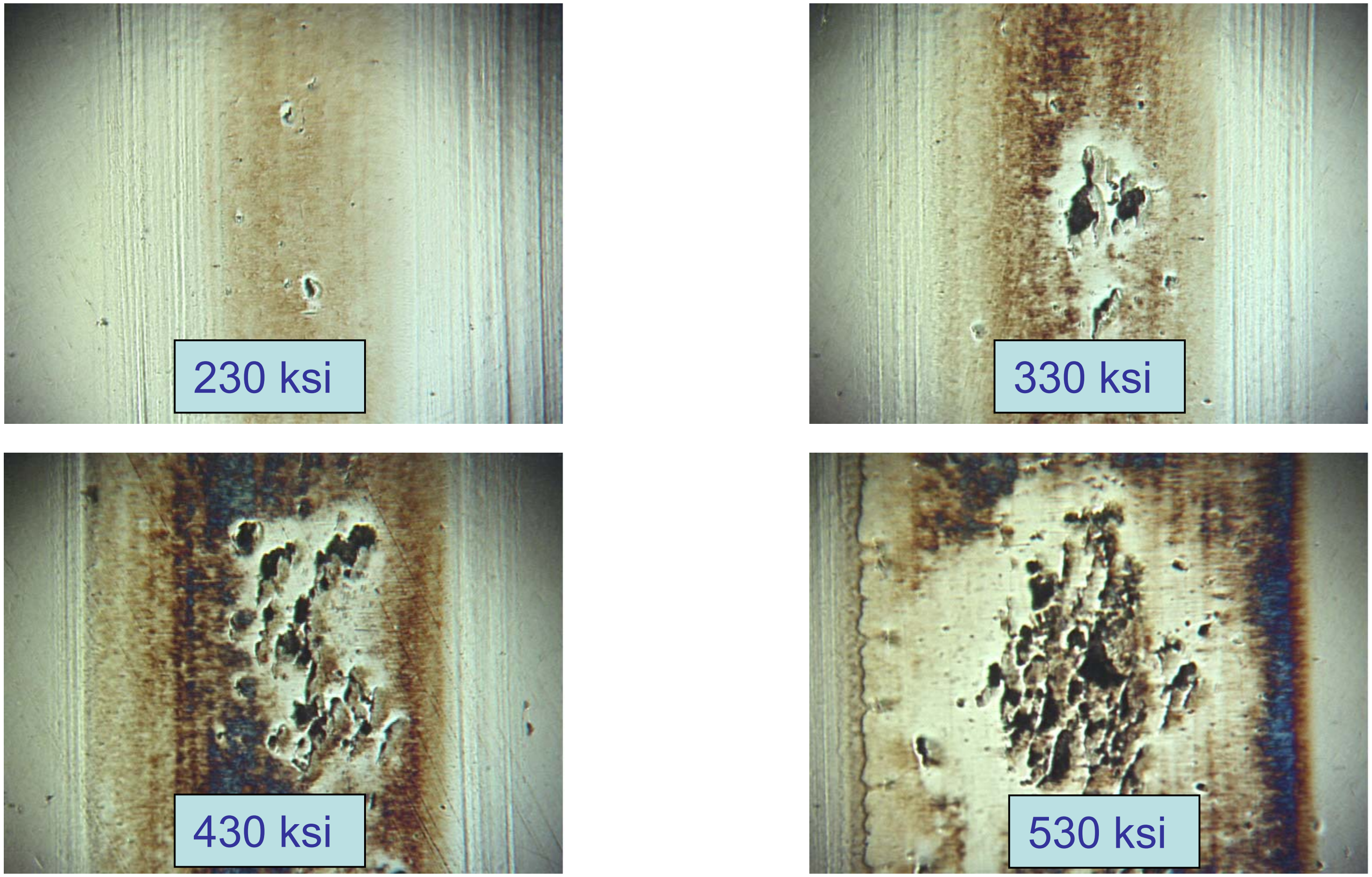


41

Progressive Loading SIF- M50

Test temperature: 100° C
Test oil: BP2197

Ball 2458-1a



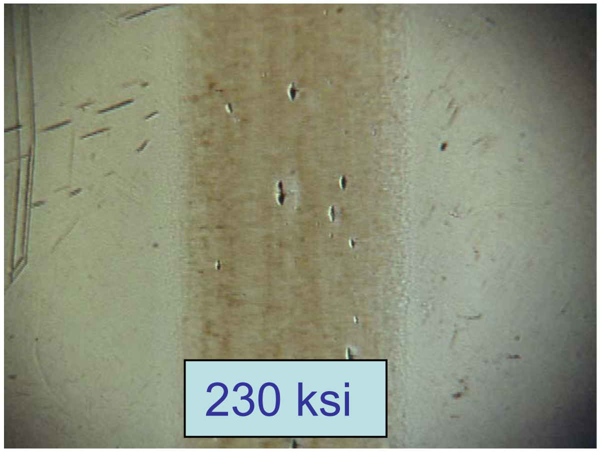
Fatigue initiates at 330 ksi. Small “spots” at 230 ksi are most likely pre-existing finishing marks in M50 ball.

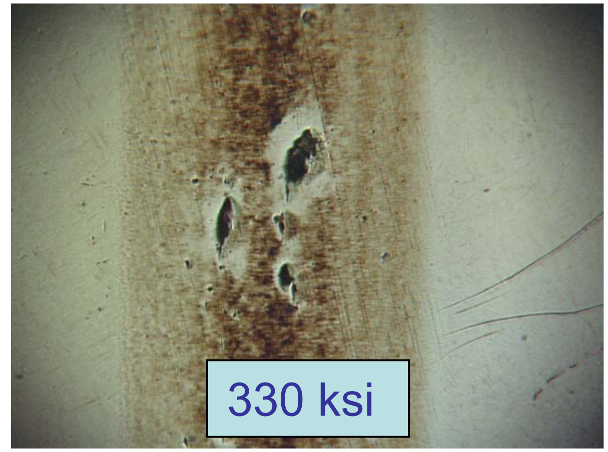
Progressive Loading SIF- M50

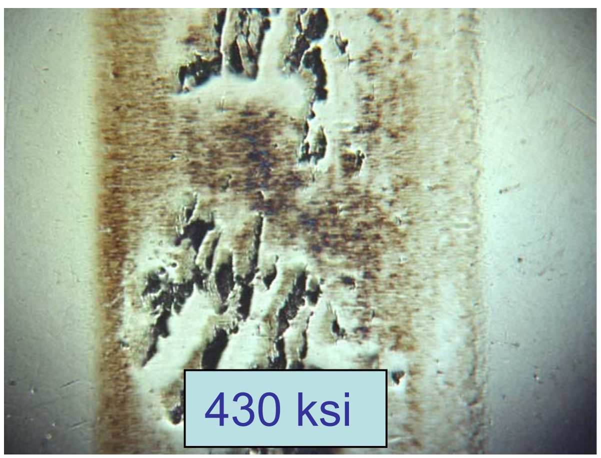
Ball 2458-1b

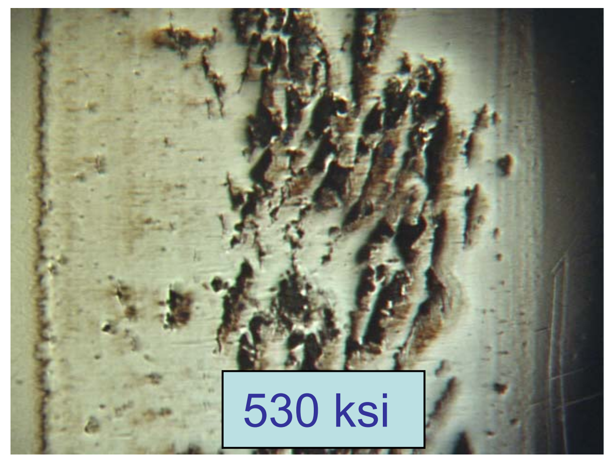
Test temperature: 100° C
Test oil: BP2197

*repeat







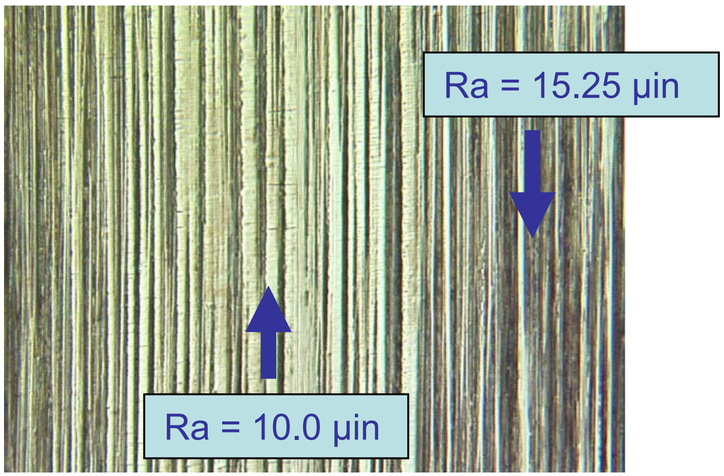


Fatigue initiates at 330 ksi. Small “spots” at 230 ksi are most likely pre-existing finishing marks in M50 ball.

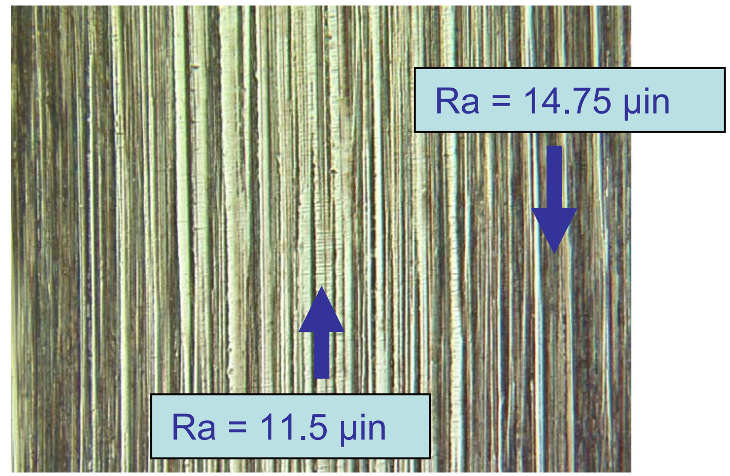
Progressive Loading SIF- M50

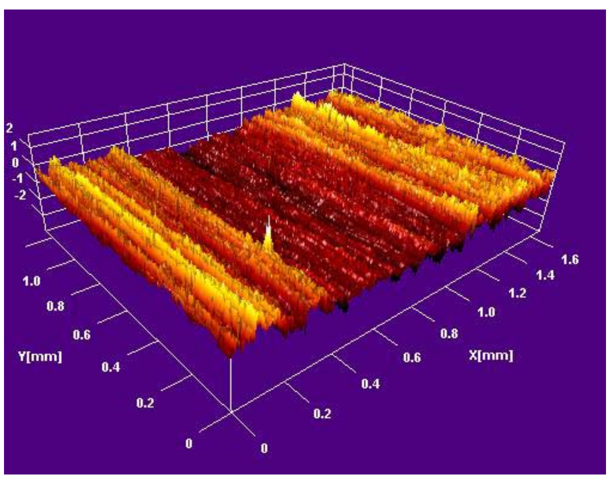
Test temperature: 100° C
Test oil: BP2197

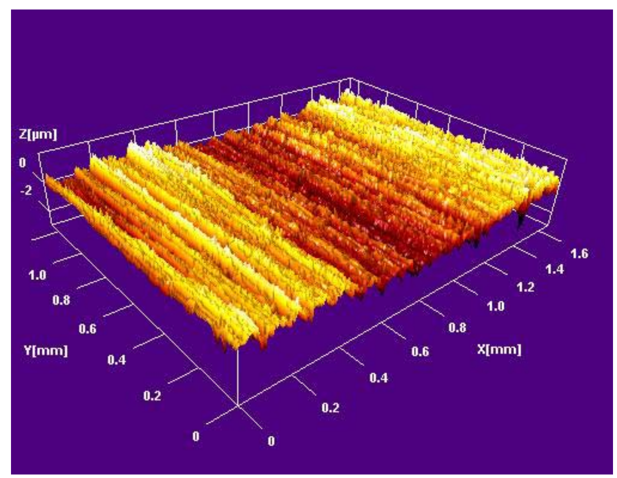
Disc 1-241b / 89mm



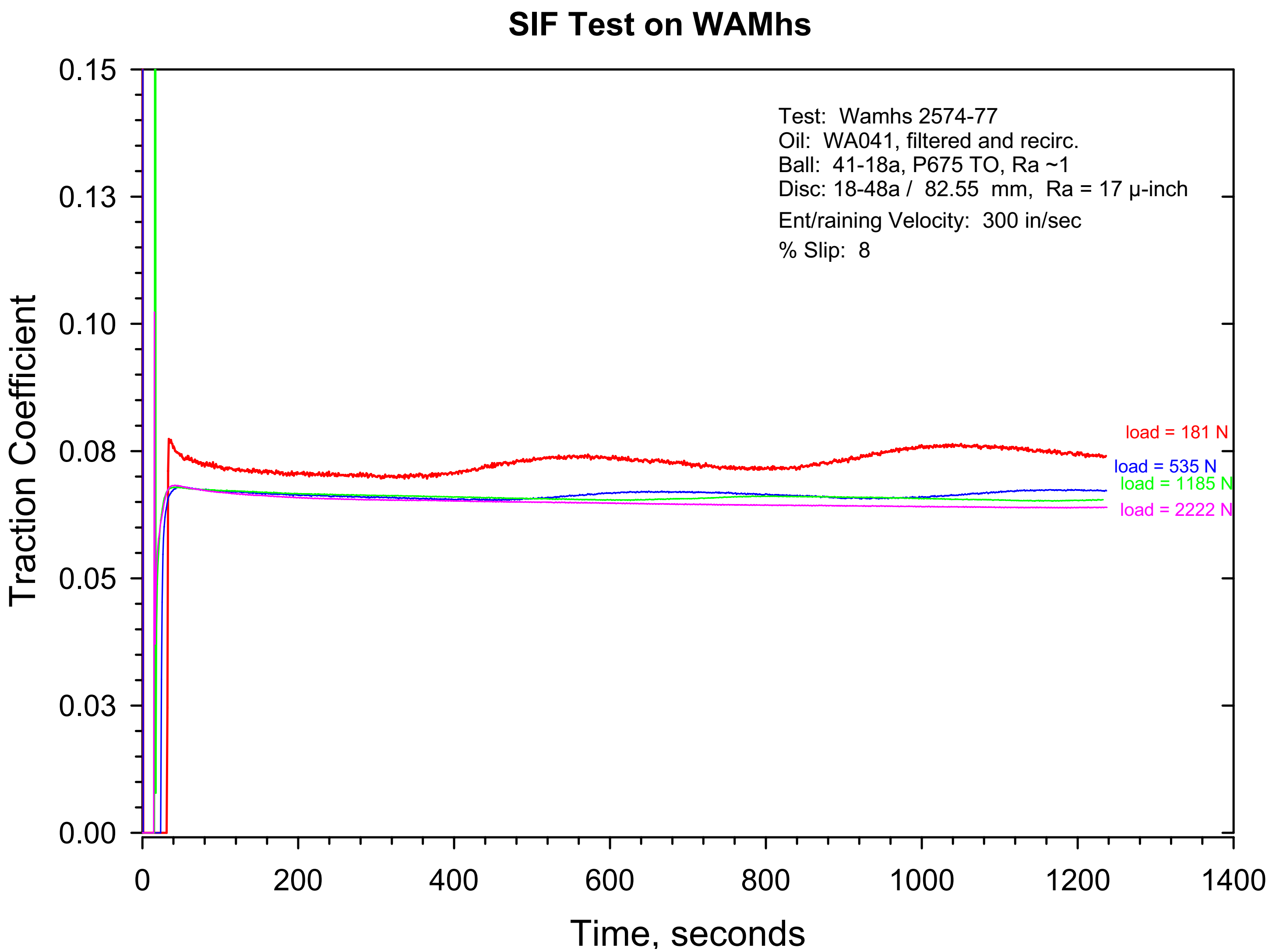
Disc 1-241b / 92mm







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

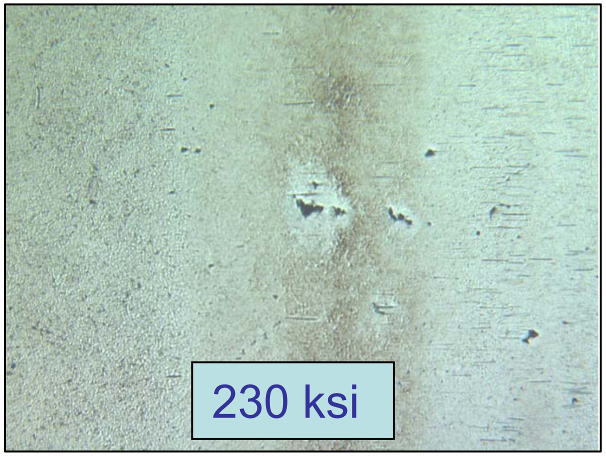


45

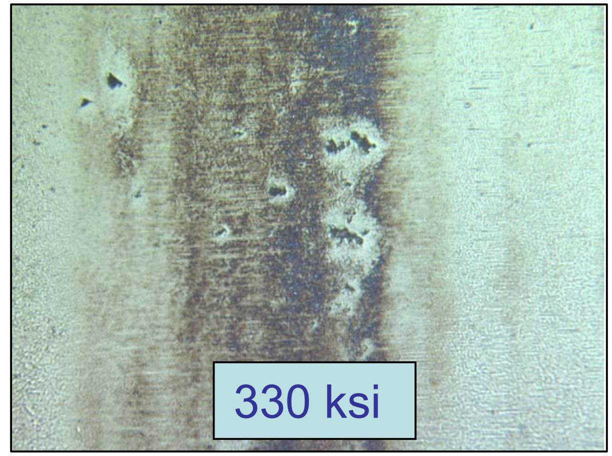
Progressive Loading SIF- P675TO
Oil: WA041 (100 C)

Ball 41-18a

Prominent chemical surface film



100X



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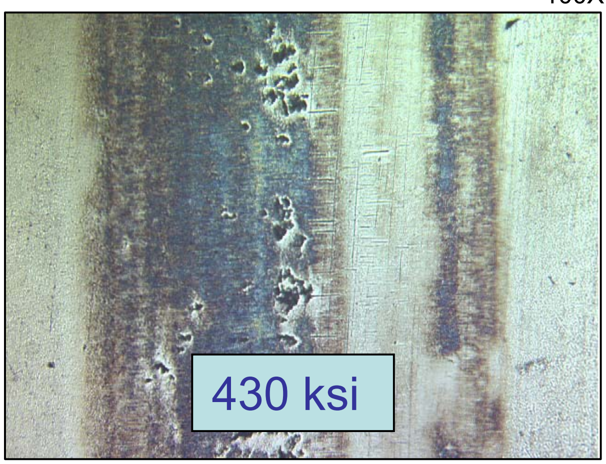
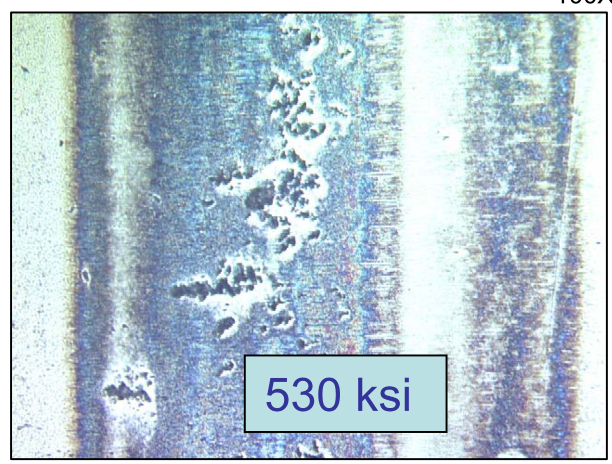


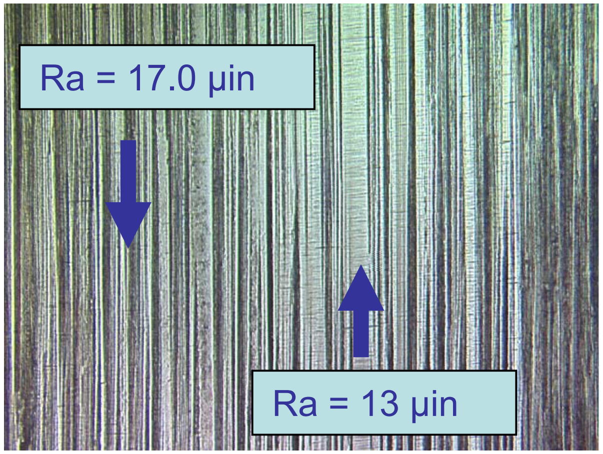
50X

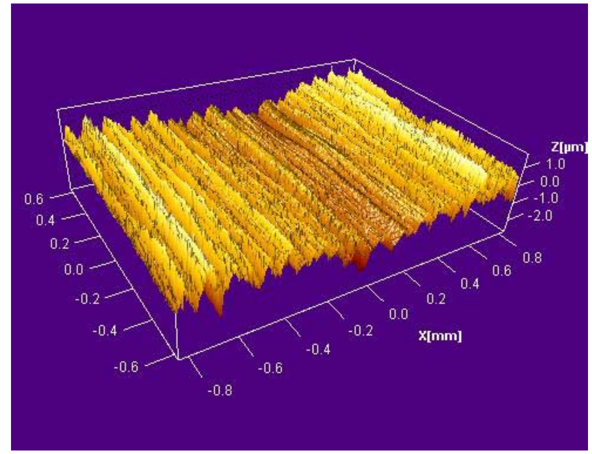


50X

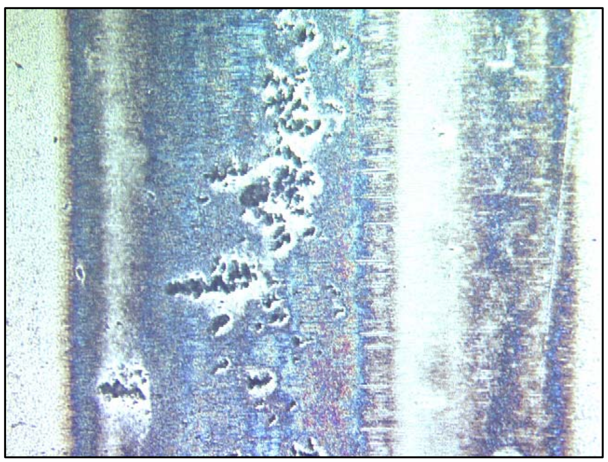
46

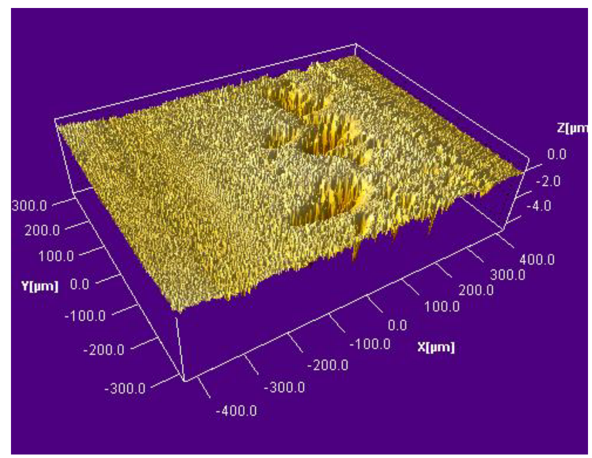
Progressive Loading SIF- P675TO
Oil: WA041 (100 C)





SIF: No red flags



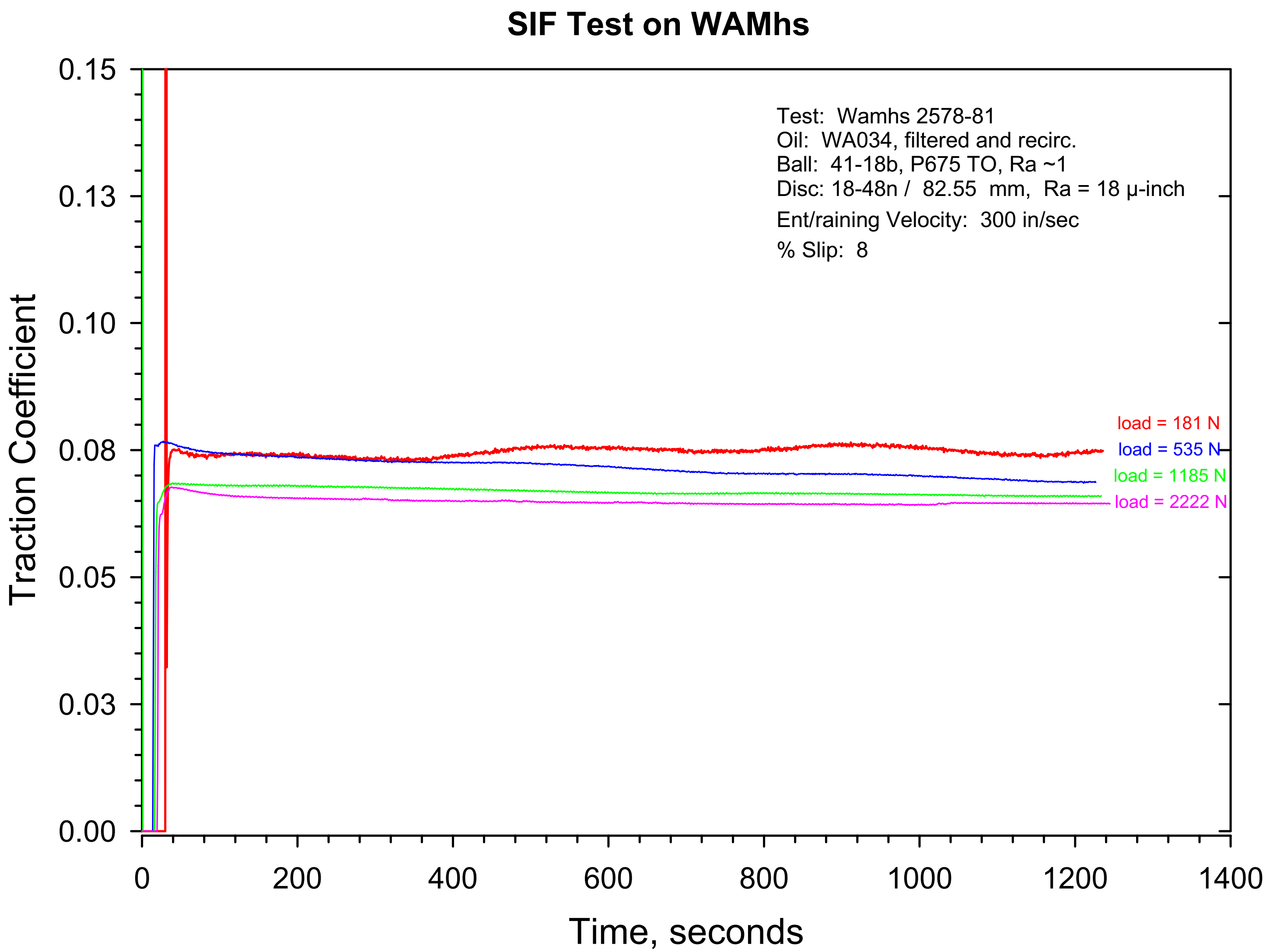


Ball and disc specimens after final stage of SIF test (530 ksi) with P675 specimens and WA041 oil. Typical depth of surface damage on ball is ~ 4 micron.
Disc shows polishing wear and a reduction in Ra from 17 µ-inch to 13 µ-inch.

47

Progressive Loading SIF- P675

Oil: WA034 (100 C)

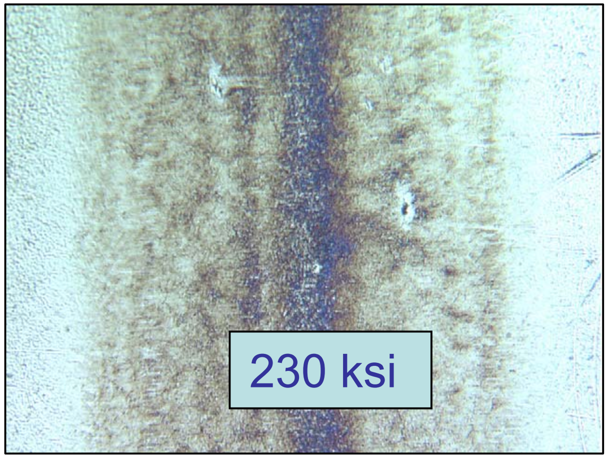


48

Progressive Loading SIF- P675TO
Oil: WA034 (100 C)

Ball 41-18b

Prominent chemical surface film



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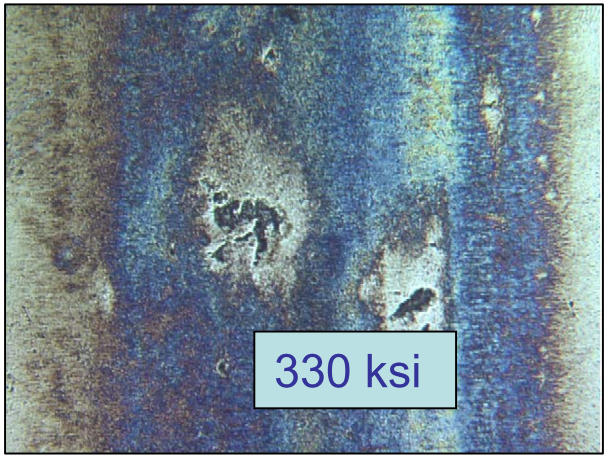
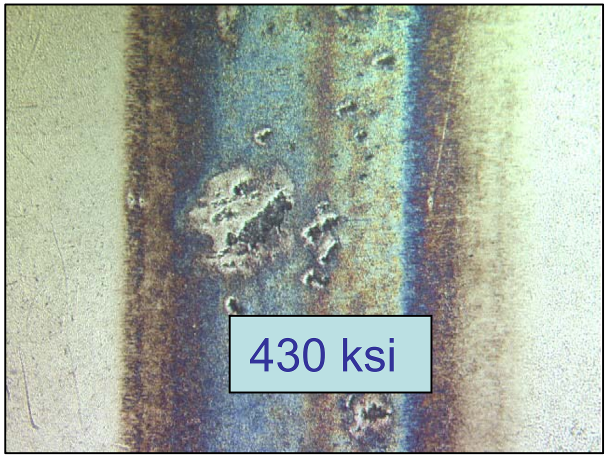
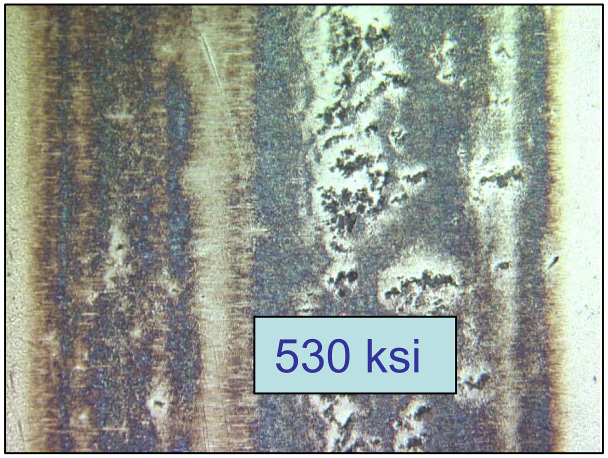


100X

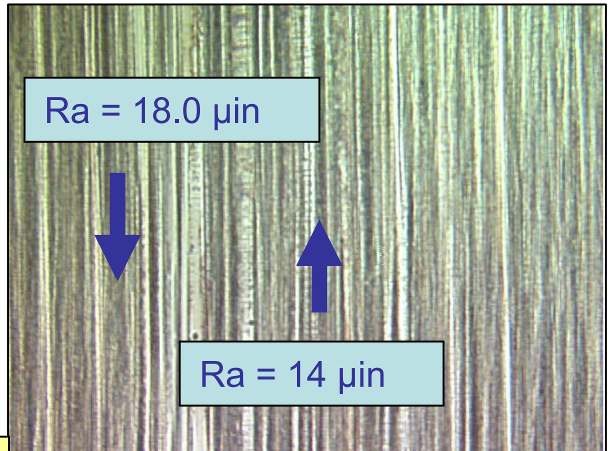


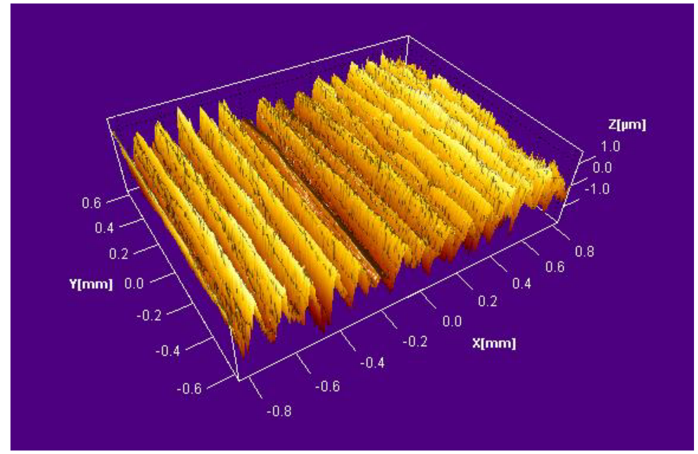
50X



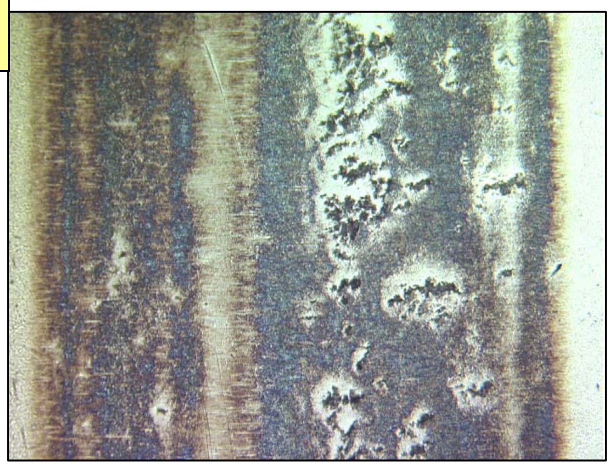
50X

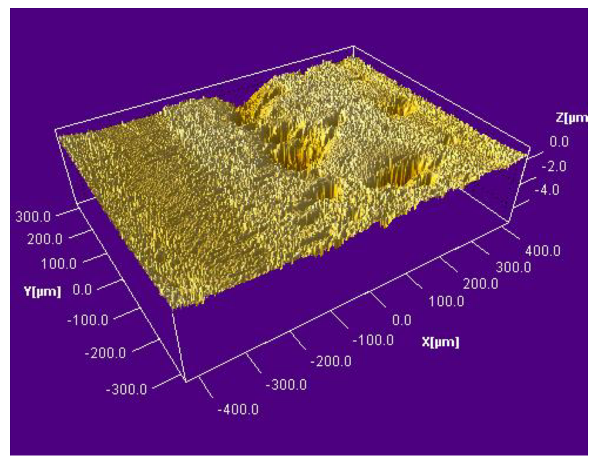
Oil: WA034 (100 C)





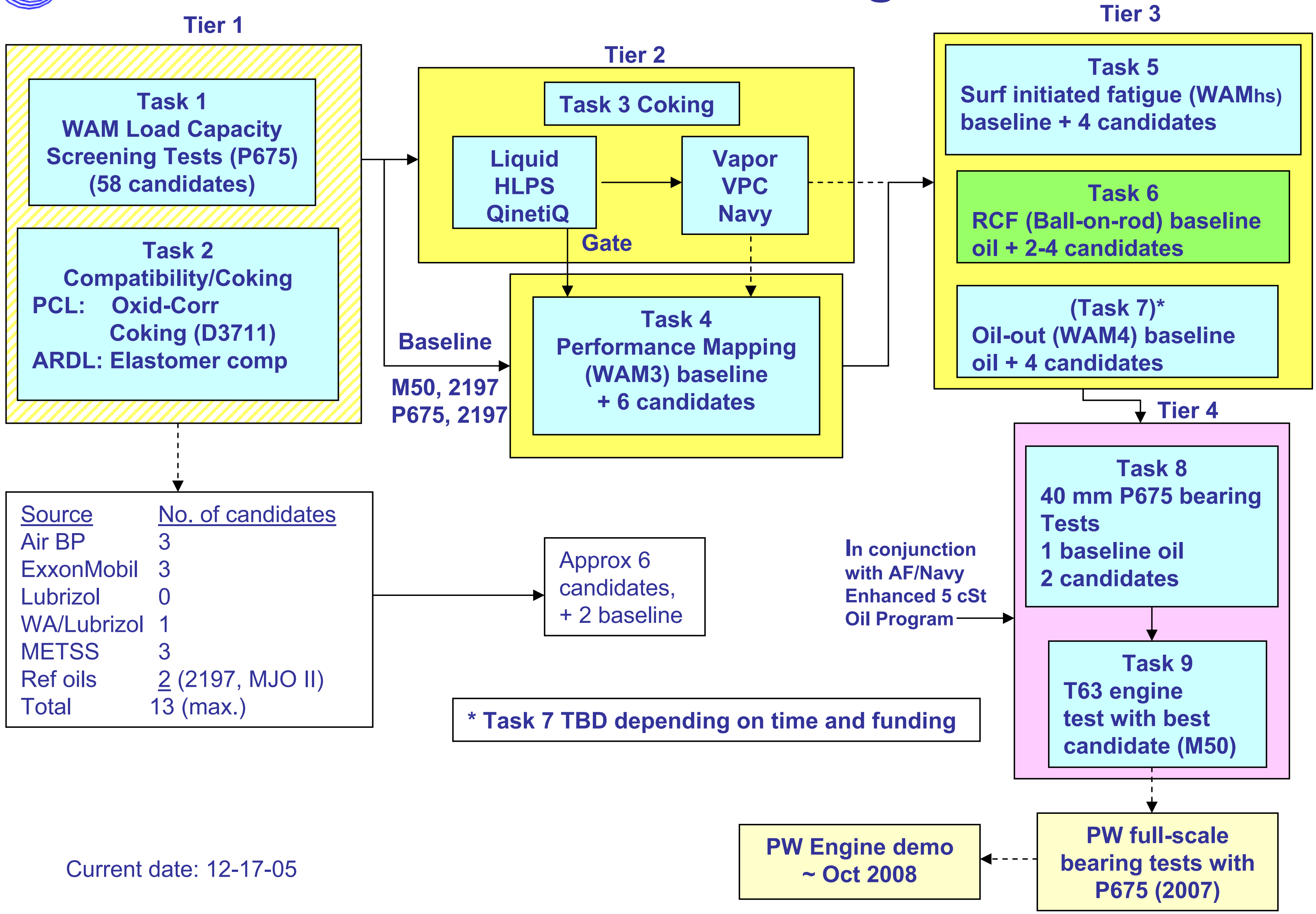
SIF: No red flags



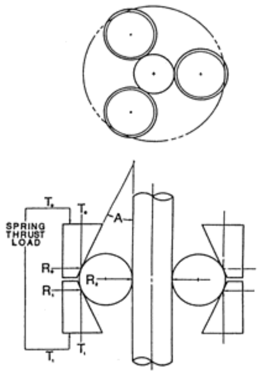


Ball and disc specimens after final stage of SIF test (530 ksi) with P675 specimens and WA034 oil. Typical depth of surface damage on ball is ~ 4 micron.
Disc shows polishing wear and a reduction in Ra from 18 µ-inch to 14 µ-inch.

SBIR Additive Phase II Going Forward Plan

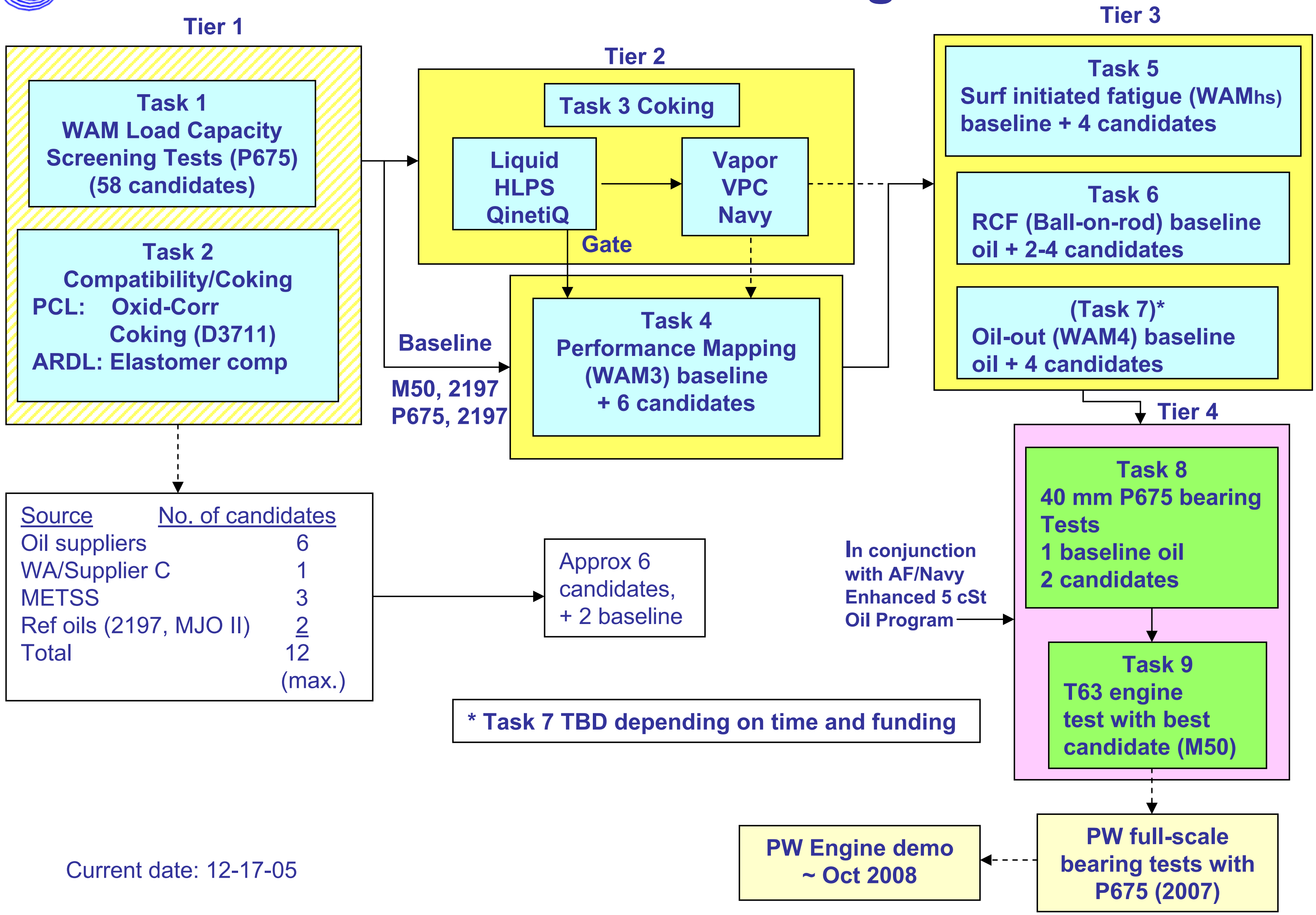


RCF Tests by UES



- PO with UES
- Ball mat'l: Si_3N_4 (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

SBIR Additive Phase II Going Forward Plan



Advanced Additives for Corrosion Resistant Steels

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

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^{o}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

Successful Grease Composition

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

Advantages to This Formulation

- 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

MIL-PRF-32014 R&D

- 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

F-112 Advanced Cruise Missile Engine

- Final validation
  - Engine test
  - > $1M
  - Overhaul extended to 60 mo., bearings reused most often
- Williams Engine Co., “We can’t fail this grease!” Using in other #1 engine bearings.

MIL-PRF-32014 Attributes

- 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 ball wear, mm max	0.65	0.41
Falex spindle 204 bearing, hrs max	500	pass
High speed 203 bearing, hrs max	25	pass
High speed 203 bearing, hrs max After 6 months storage in humidity chamber	25	pass

High humidity oven for 6 mo. storage test

High-speed 203
bearing test
4 hr at room temp,
21 hr at 115^{o}C,
1769 N load,
As received grease
and after 6 mo.
storage at 71^{o}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

Property	MIL-PRF-81322	MIL-PRF-32014
		(Rheolube 374A)
Base Oil Type	PAO	PAO
Kinematic Viscosity 100ºC, cSt.	5.4	16.6
Kinematic Viscosity 40ºC, cSt.	31.5	121
Pour Point, ºC	-62	-48
Thickener Type	Clay	Lithium Simplex
Color	Red	Tan
Penetration, 60X, 1/10 mm	305	267
Dropping Point, ºC	>260	273
Oil Separation, 24 hrs, 100ºC, % loss	0.45	3.3
Evaporation, 24 hrs, 100ºC, % loss	0.2	0.29
4 Ball Wear, 60 min, 1200 RPM, 40 kg, mm	0.56	0.44

Comparative Testing - SRV

- 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

Default Report Mask

File

SRV® 4 TEST SYSTEM

HW Config	Oscillation	Printout Date	8/23/2005 12:17:02 PM
Test No	m00142	Measurement Date	8/23/2005 11:17:39 AM
Operator	DB	Test Mode	ASTM D5706(StepLoad).opr
Upper Specimen	Ball 10mm 52100	Type of Test	TR #KA050725
Interfacial Media	MIL-PRF-32014	Note	Lot TJ050321
Lower Specimen	Disk 52100		

Comment

Friction coeff
Load
Resistance average
Temp. Block

Results:

f min	f max	f 15	f 30	f 90	f 120	Wk [mm]	Wear [man]
0.072	0.526	0.103	0.090	0.000	0.000		

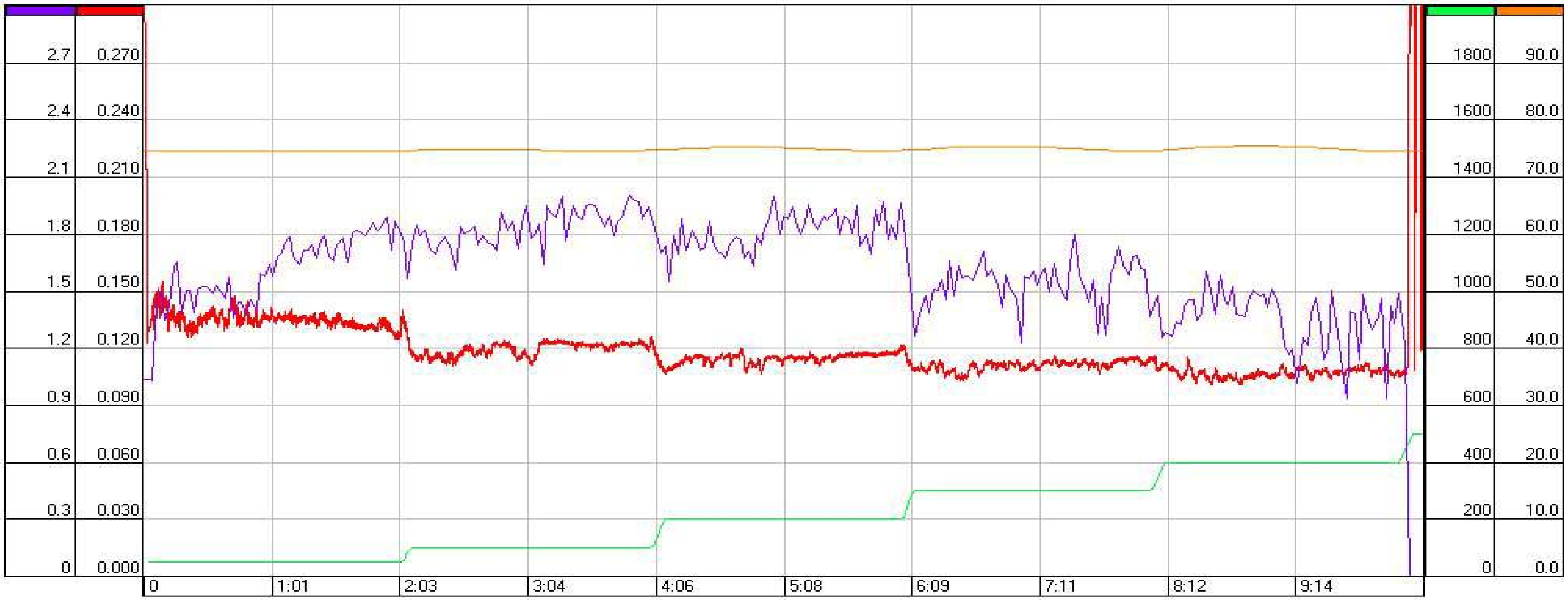
NYE Synthetic Lubricants, Fairhaven, MA

Default Report Mask

File

SRV® 4 TEST SYSTEM			
HW Config	Oscillation	Printout Date	8/23/2005 12:13:59 PM
Test No	m00141	Measurement Date	8/23/2005 10:45:44 AM
Operator	DB	Test Mode	ASTM D5706(StepLoad).opr
Upper Specimen	Ball 10mm 52100	Type of Test	TR #KA050725
Interfacial Media	MIL-PRF-81322	Note	Lot 05-02948
Lower Specimen	Disk 52100		

Comment



Friction coeff
Load
Resistance average
Temp. Block

Results:

f min	f max	f 15	f 30	f 90	f 120	Wk [mm]	Wear [man]
0.101	0.480	0.000	0.000	0.000	0.000		

NYE Synthetic Lubricants, Fairhaven, MA

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

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

Amoco 32014 MIL-PRF-81322 Brayco 807RP

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

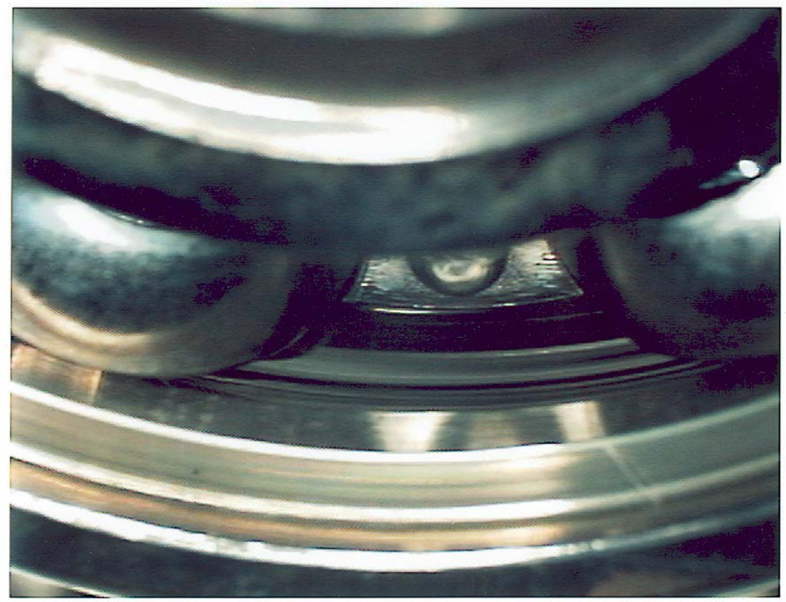
Comparative - Water Washout

	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 Lot# B87890	1.8 / 1.5 (1.7 average)	No corrosion	1.3 / 2.3 (1.8 average)	Corrosion in raceway
MIL-PRF-32014 Lot# TJ050321	2.3 / 2.7 (2.5 average)	No corrosion	1.2 / 0.8 (1.0 average)	No corrosion

Comparative - Water Washout

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 Compatibility Study

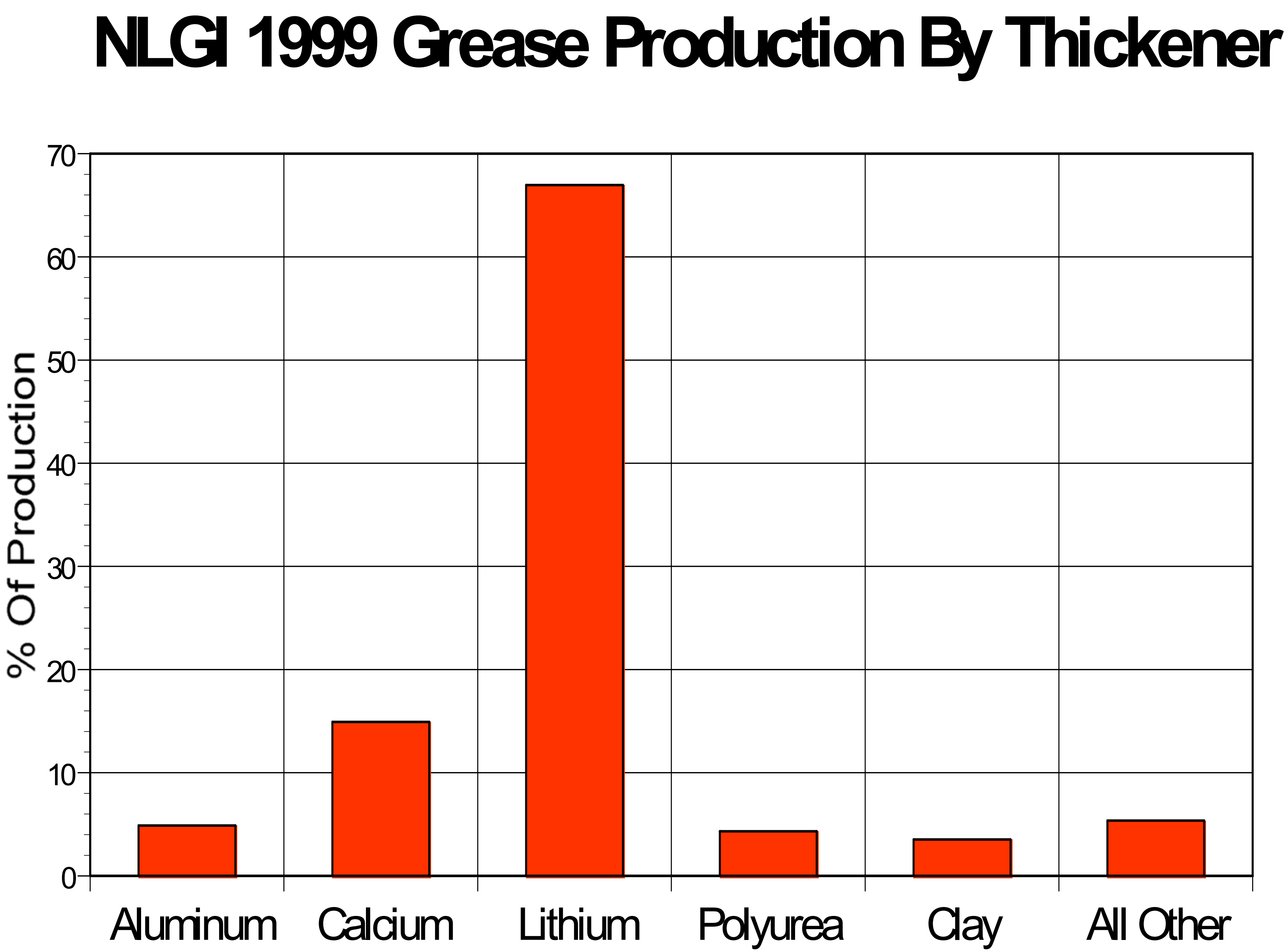
- Grease A = MIL-PRF-81322
- Grease B = MIL-PRF-32014
- Grease C = Brayco 807 RP
- 50/50 Mix of A and B
- 50/50 mix of B and C
- 50/50 Mix of A and C

Grease Compatibility Study

- 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
% Of Production
70
60
50
40
30
20
10
0
Aluminum
Calcium
Lithium
Polyurea
Clay
All Other

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

C-5 Landing Gear Corrosion

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

C-5 Landing Gear Corrosion

C-5 Landing Gear Struts ready for final assembly

C-5 Landing Gear Corrosion

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

C-5 Landing Gear Corrosion

MLG Bogie PN 4G12011

$206,359.63

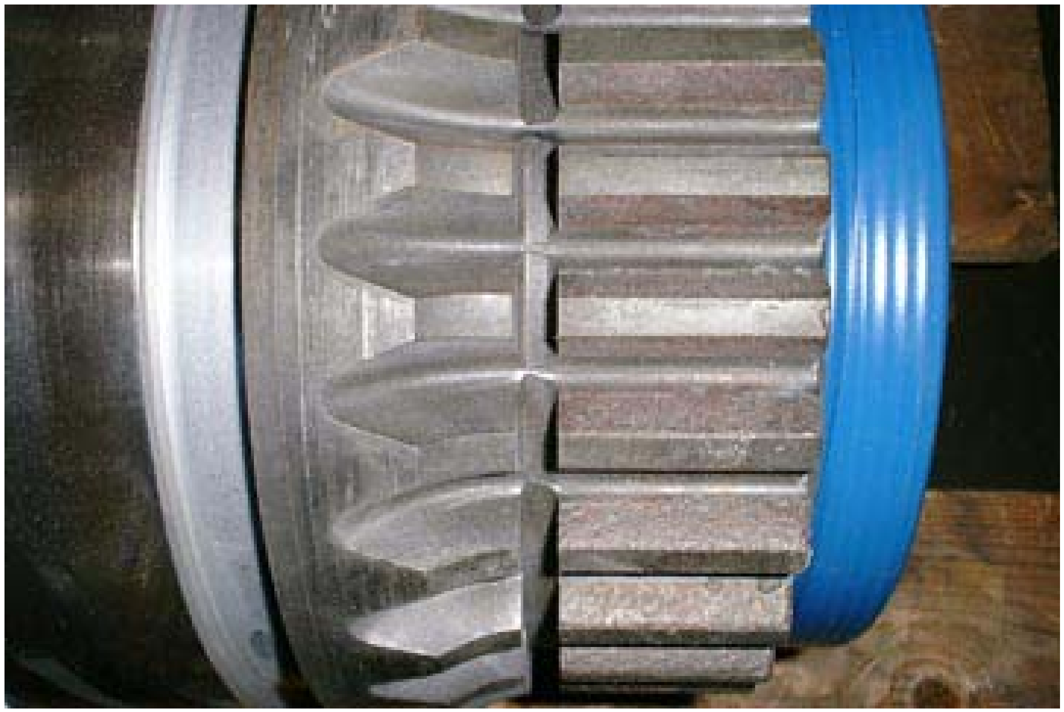
C-5 Landing Gear Corrosion

Brake Collar PN 4G12031

C-5 Landing Gear Corrosion

Gudgeon Bearing PN 4G13406

C-5 Landing Gear Corrosion



Splined Tube PN 4G13413

$13,574.78

C-5 Landing Gear Corrosion

Forward Axle PN 4G12030

C-5 Landing Gear Corrosion

Roll Pin PN 9510447

$11,582.40

C-5 Landing Gear Corrosion

Ball Screw Nut Bearing Balls PN BB562-1

C-5 Landing Gear Corrosion

Crosshead Area C from partially disassembled gear

C-5 Landing Gear Corrosion

Wheel Bearing Rollers

C-5 Landing Gear Corrosion

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

NAVAIR

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

NAVAL AVIATION TECHNOLOGIES

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)

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E2/C2 Potential Savings

Component P/N	Component Cost	Usage per year	Matl cost per 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**

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

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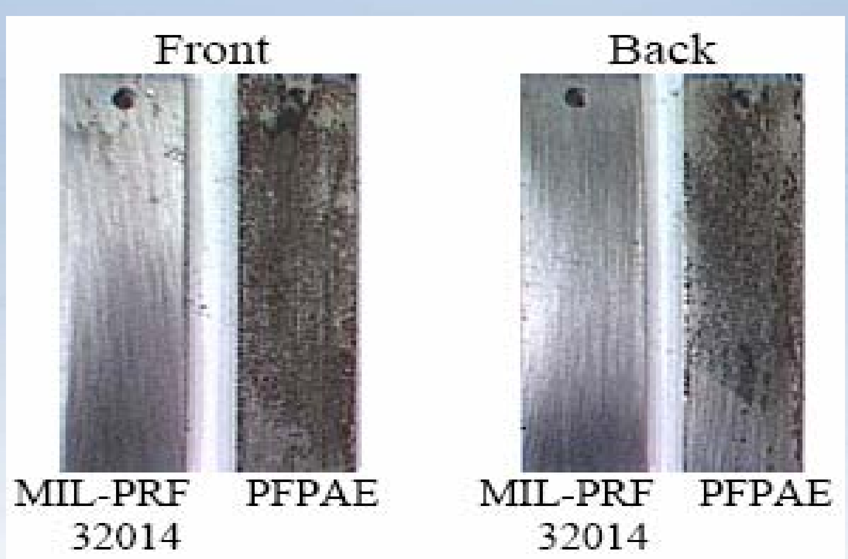
Improved Grease Composition

- 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

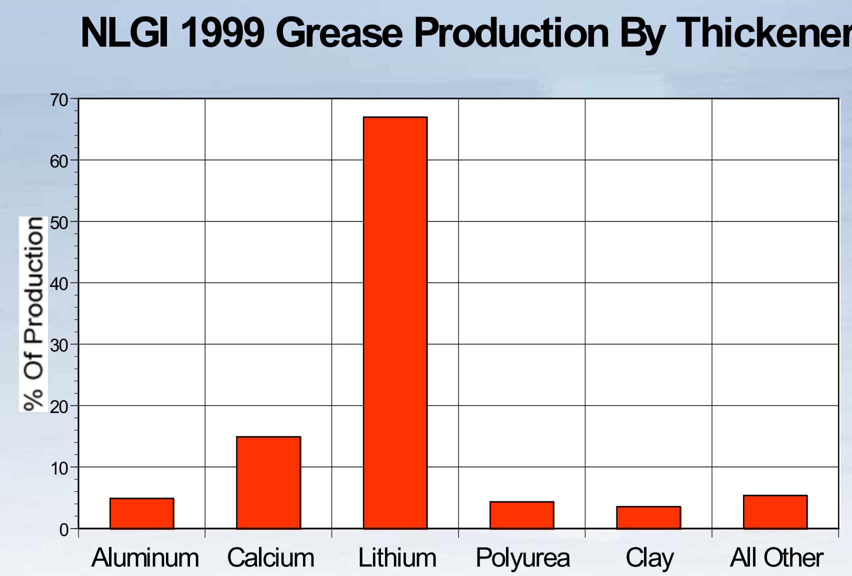


Grease Comparison

	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)

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^{o}C)
- High speed (30K rpm)
- Corrosion resistant
- Available (2 vendors)
- Non-proprietary
- Compatible



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


L Inbd
Gudgeon
Spacer
R Inbd
Gudgeon
Spacer


R Rotation
Collar

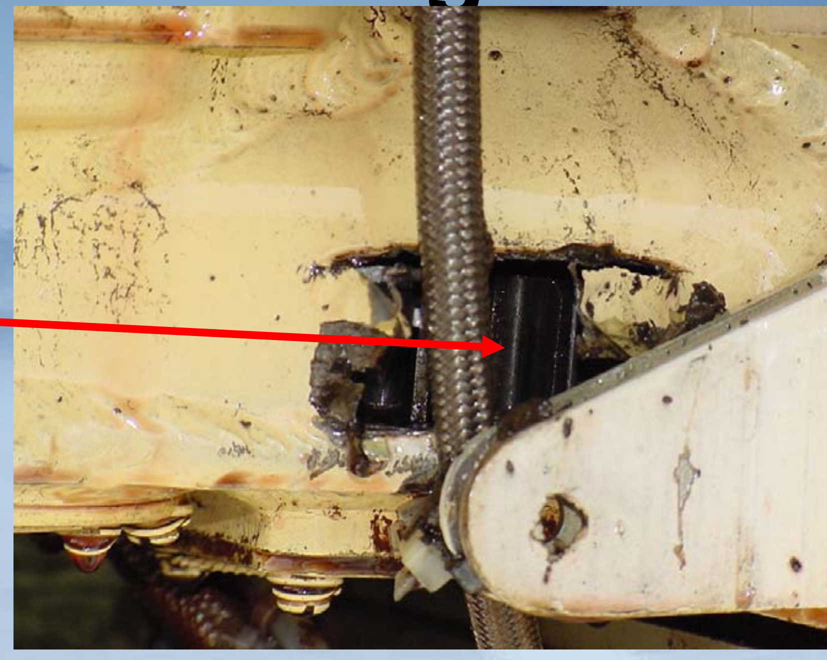

L Rotation
Collar

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

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.

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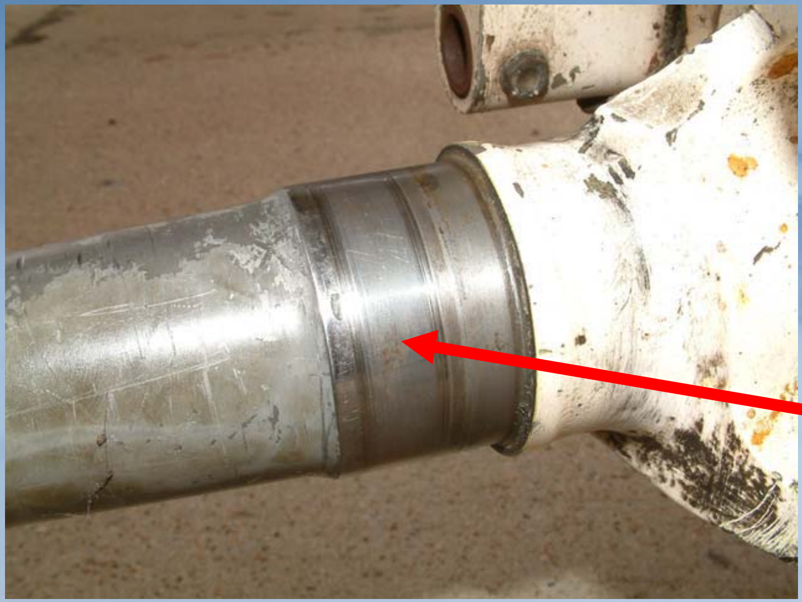
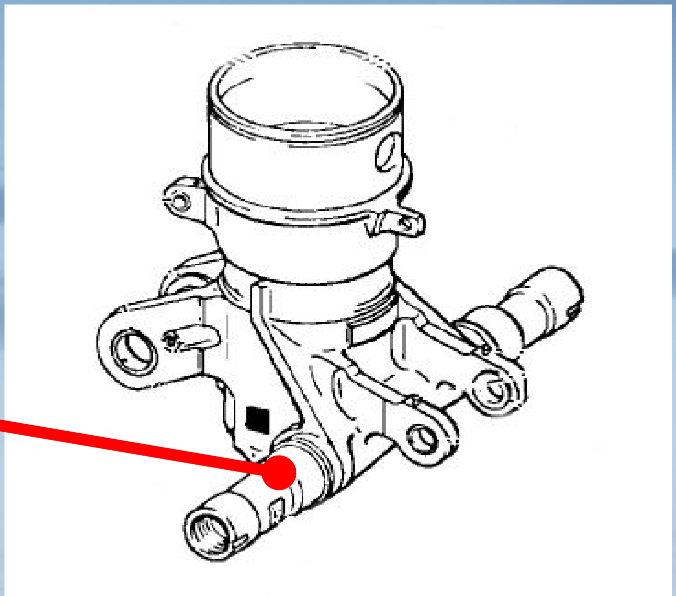
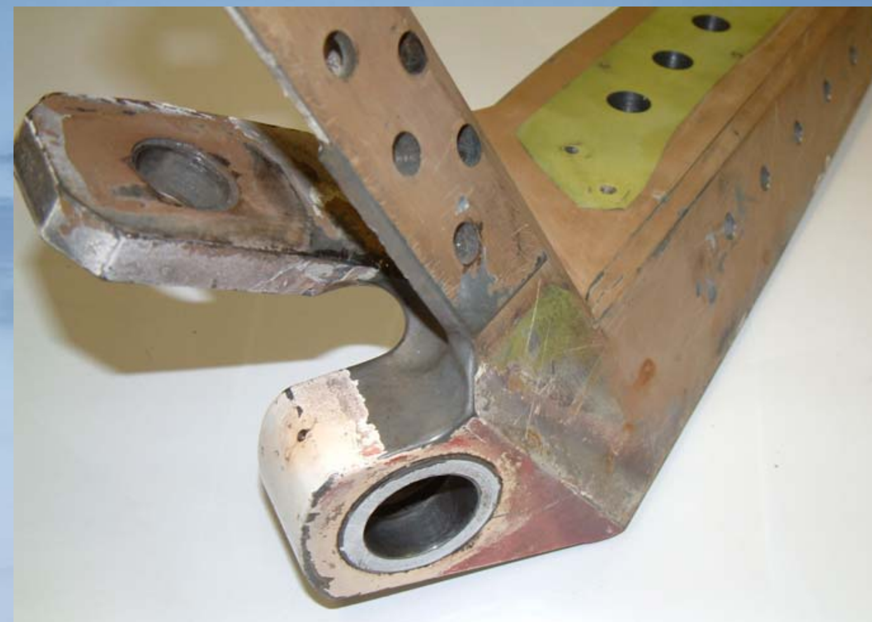
E2/C2 Caster Barrel





- 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.

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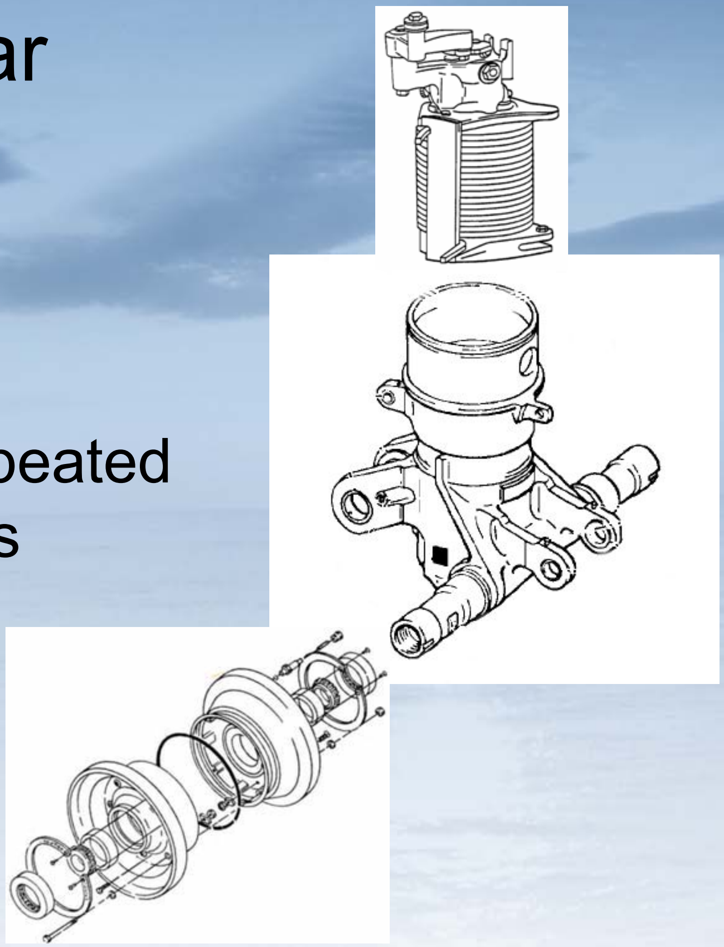
Stage 1: Field Testing

- 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



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Spray Wash Test

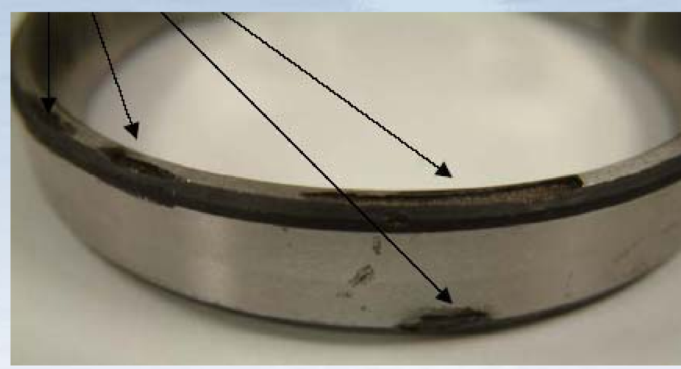

MIL- PRF- 81322
ST SAMPLE
MIL- PRF- 32014
TEST SAMPLE
81322
32014


-PRF-81322
MIL-PRF 32014
RF-81322
MIL-PRF 32014

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 


602
602
NAVY
USS HARRY S. TRUMAN
E-2C
165508
VAW-126

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)

Cold Soak Torque Test Results

Component	Lubricant	Torque at 70ºF (in-lbs)	Break-Out Torque at -40ºF	Running Torque at -40ºF
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

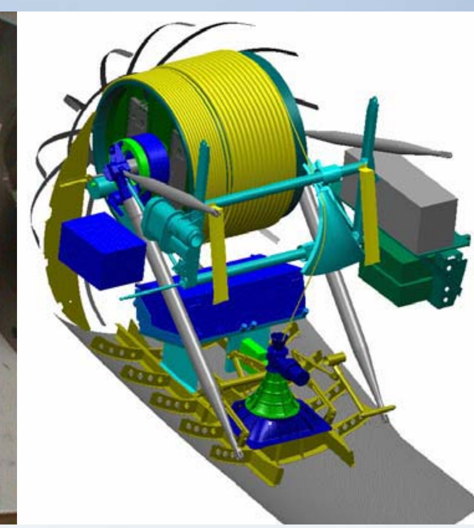
Stage 2: Operational Flight Testing

- **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

Additional Fleet Applications

E-2D Advanced Hawkeye

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

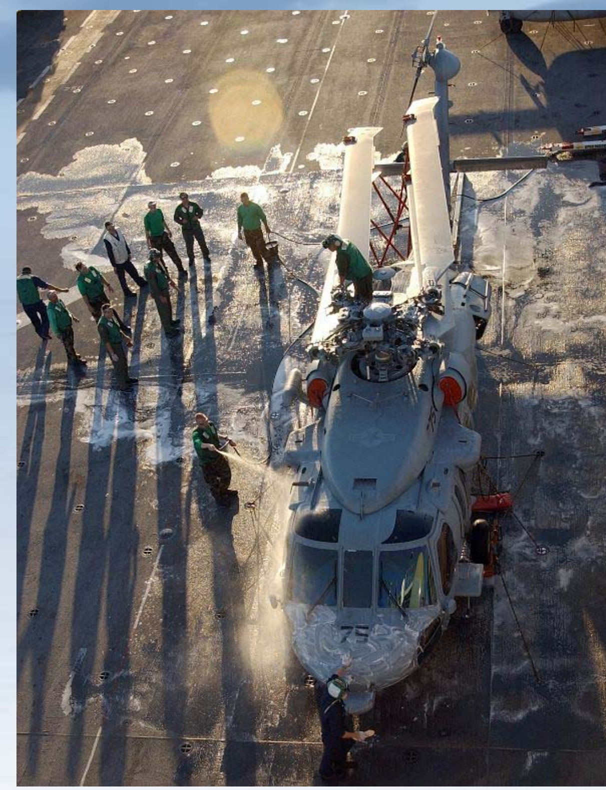


Additional Fleet Applications

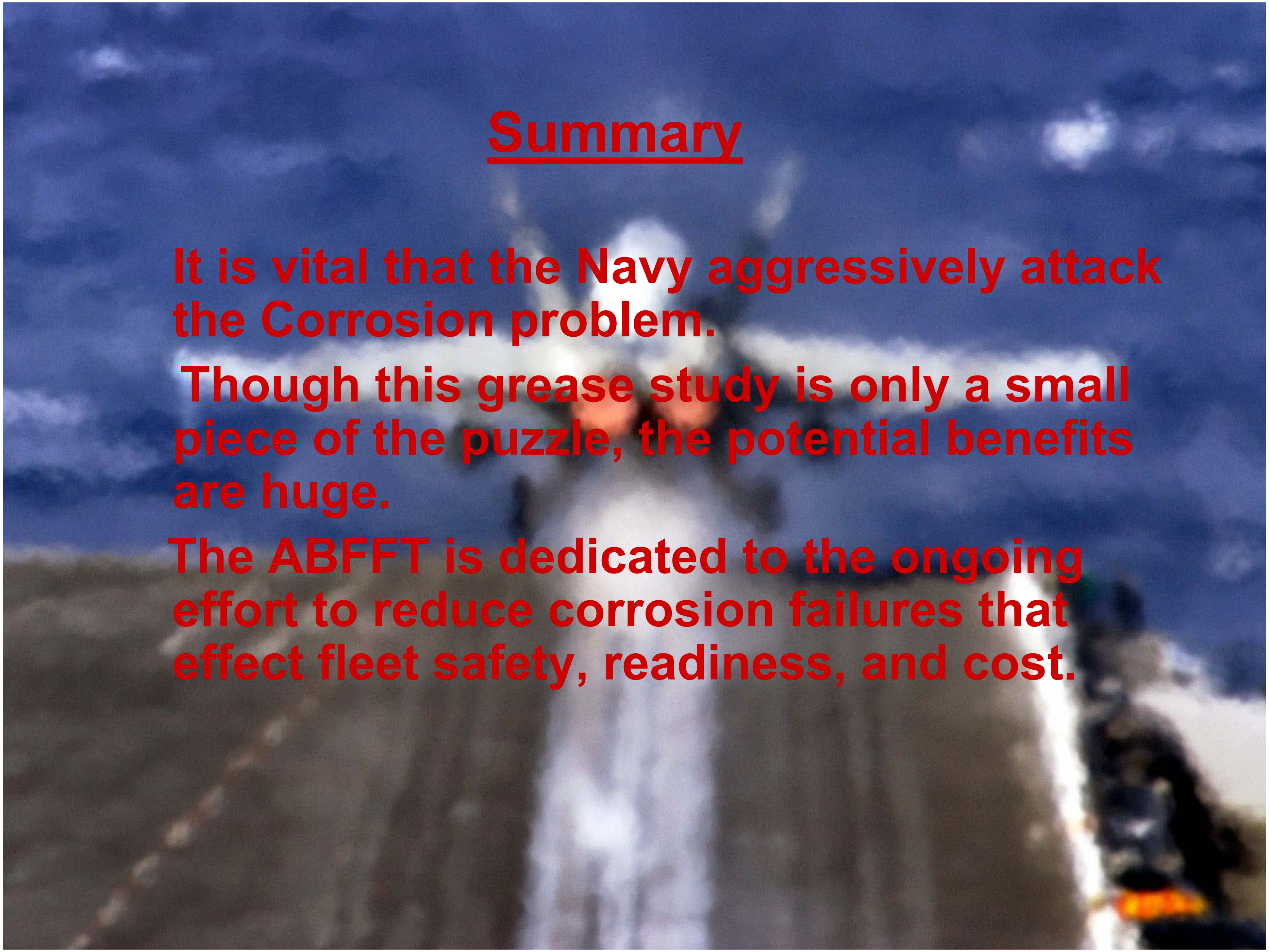
- T-34/44 Catastrophic Wheel Bearing failures due to corrosion
  - Engineering Investigation identified possible grease deficiency
  - Proposed change to MIL-PRF-32014
- JSF Upper Lift Fan Bearing and Components

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



NAVAL AVIATION TECHNOLOGIES


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.


Questions ?

Screening Tests Results for Low Cost Alternative F100 Nozzle Actuator Greases

Angela Campo

Fluids and Lubricants Group

Wright-Patterson AFB

Outline

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

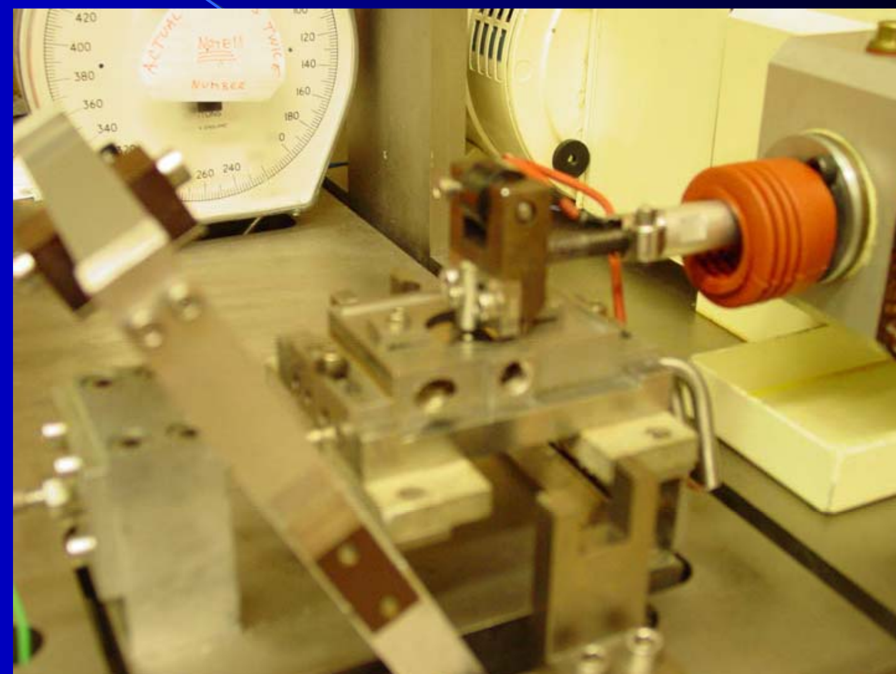
Introduction

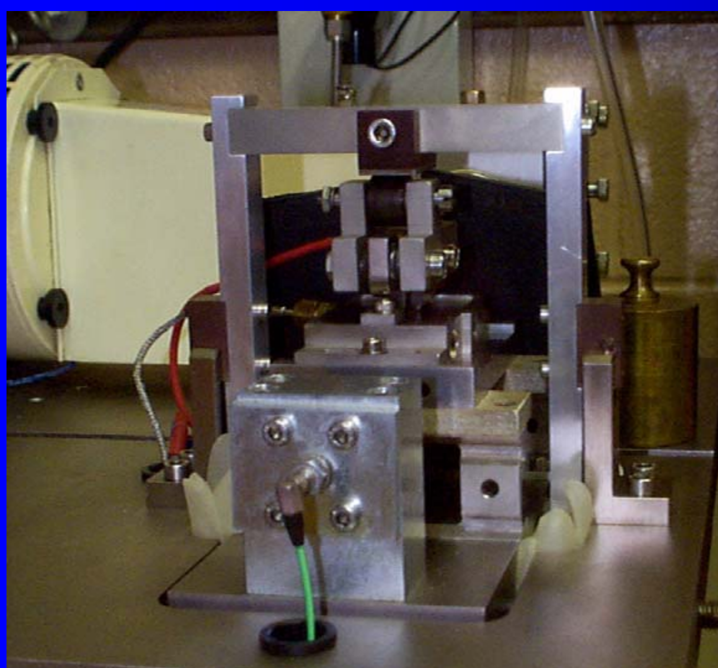
- There was a need for a grease that was 50% of the cost of the NYE Uniflor
  - Initially, cost was the main factor in choosing a new grease. But new actuator design and technology called for a better performing grease
- A test matrix was developed to narrow the grease candidates from 56 to 8 samples
  - 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
- 3% relative humidity of sample chamber
- 20N load for 5 min., then 250N for 2 hours
- 52100 steel disc and ¼ inch ball
- 1 gram of sample
- 3 Hz frequency
- 9mm Stroke

Formulation	Average Scar Area (mm^2)	Standard Deviation (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 candidate	0.72	0.02
Braycote 602EF	1.23	0.10

Comparison of Wear Scar

MIL-PRF-32014

0.15mm^2

0.71mm^2

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

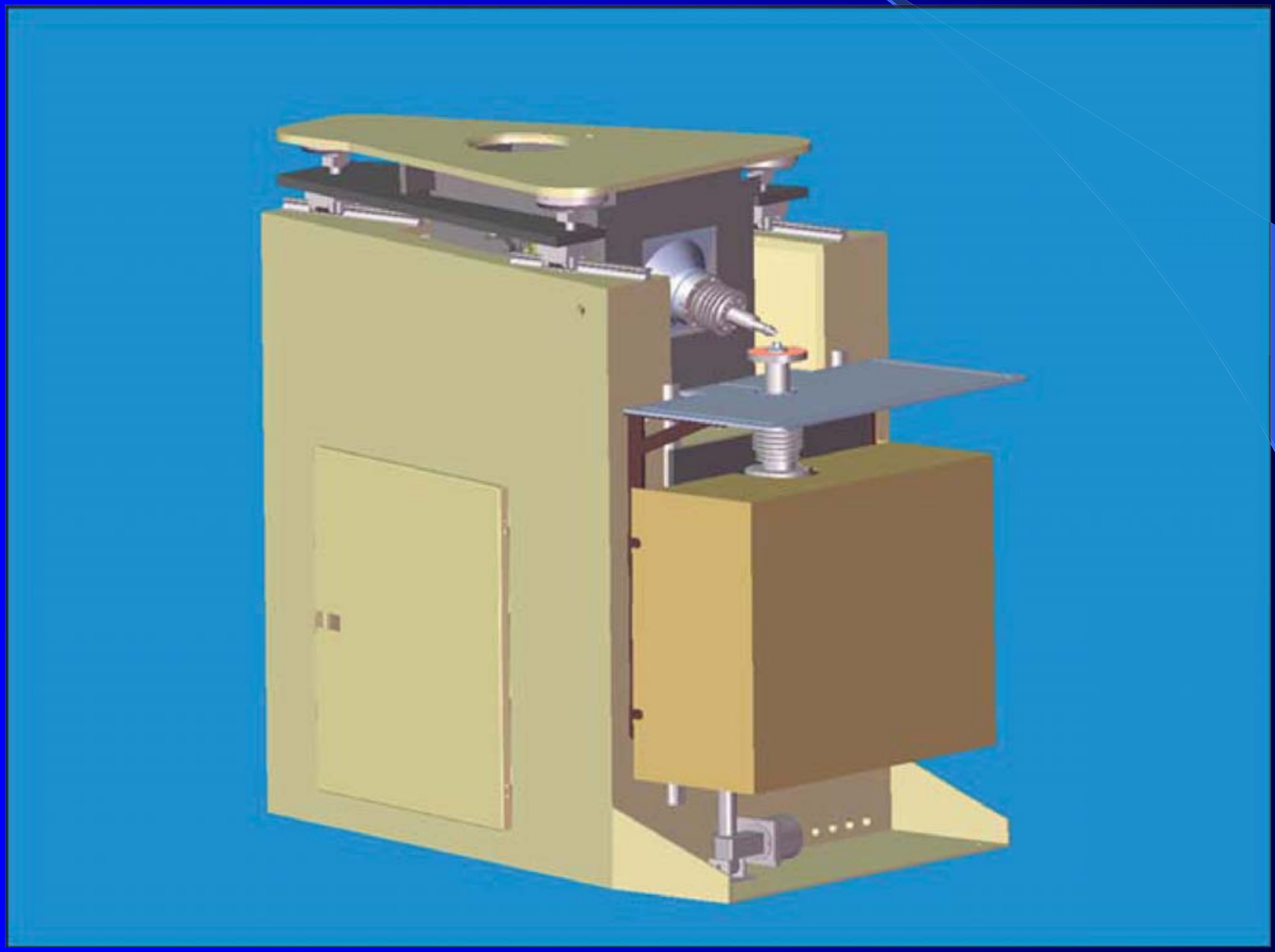
WAM Tribology

- Test consists of six cycles
- A cycle consists of an acceleration period, steady-state 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 MoS_2

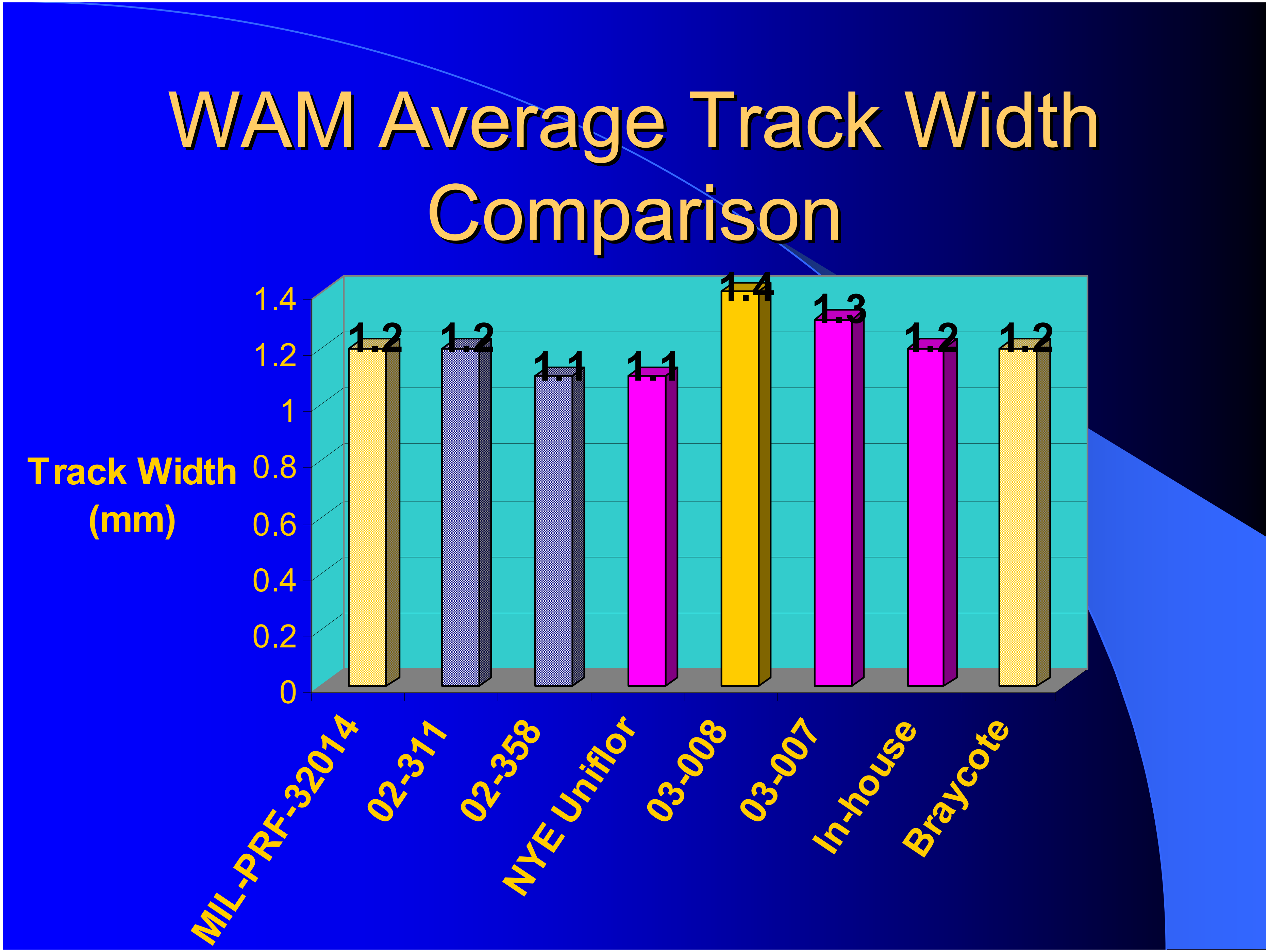
Explanation of a WAM Cycle

- 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

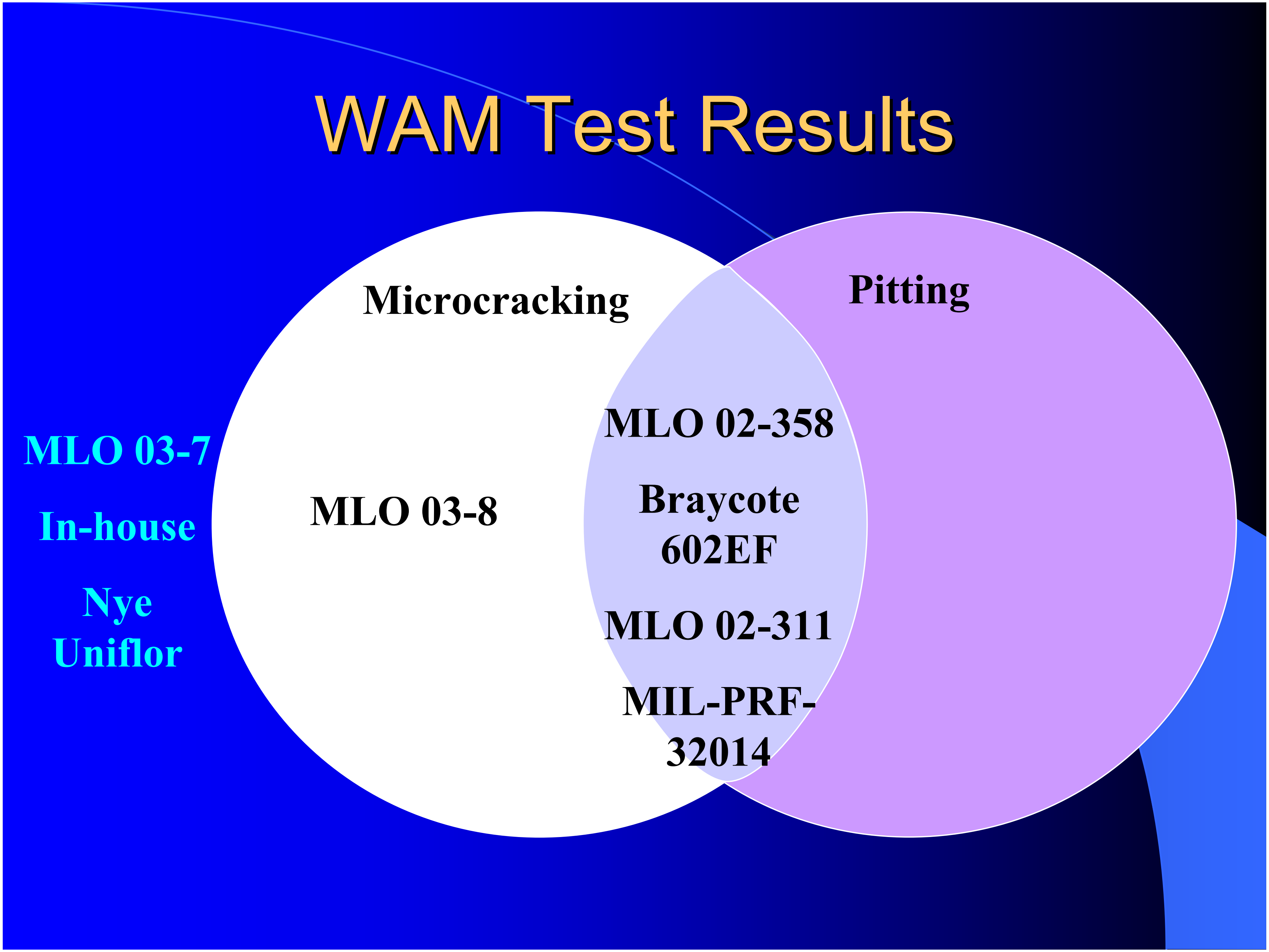
WAM Testing Machine Diagram



WAM Ball and Disc Arrangement



WAM Average Track Width Comparison
Track Width (mm)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1.2
1.2
1.1
1.1
1.4
1.3
1.2
1.2
MIL-PRF-32014
02-311
02-358
NYE Uniflor
03-008
03-007
In-house
Braycote

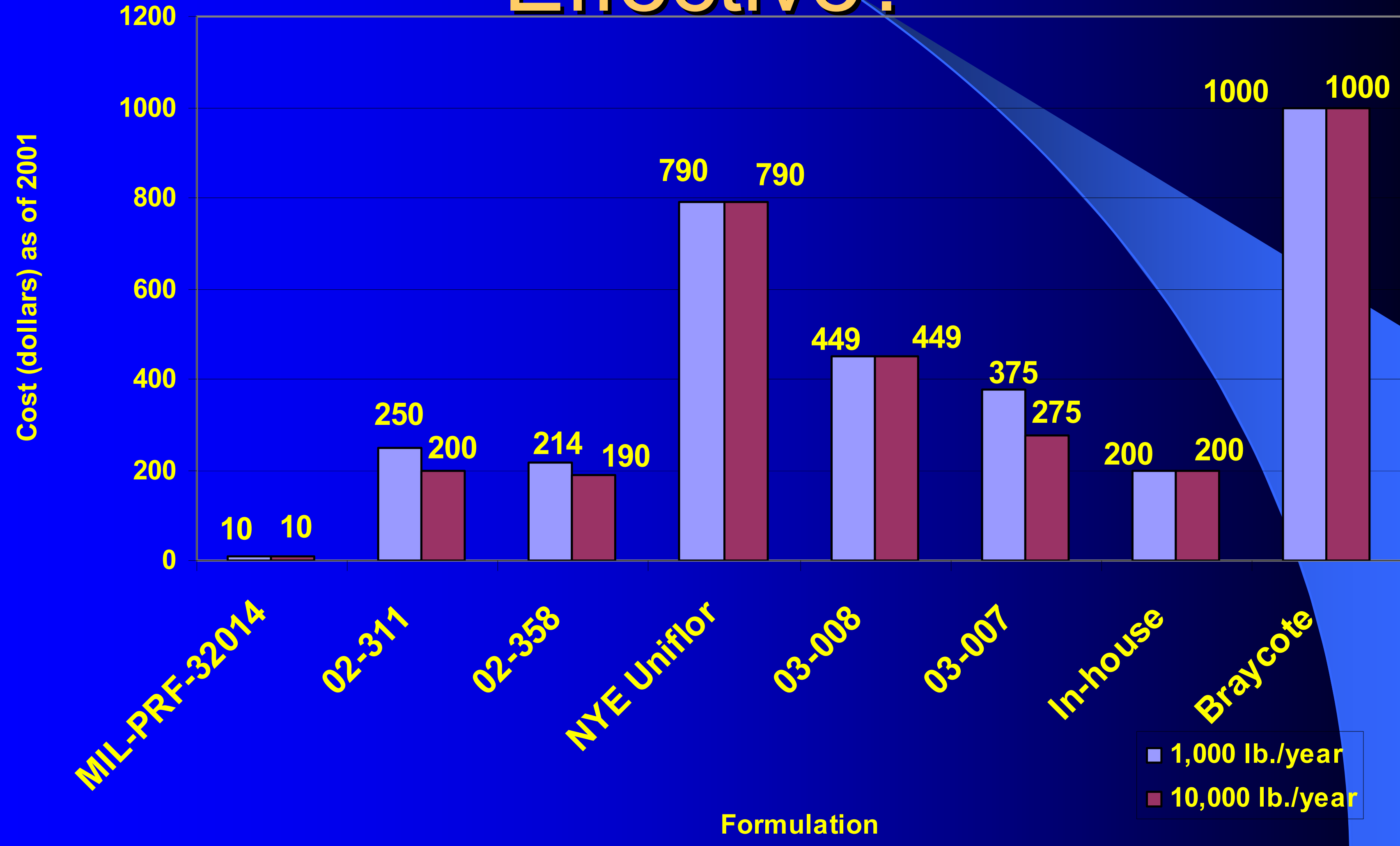

WAM Test Results
Microcracking
Pitting
MLO 03-7
In-house
Nye
Uniflor
MLO 03-8
MLO 02-358
Braycote
602EF
MLO 02-311
MIL-PRF-
32014

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	**18**
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

METSS CORPORATION

High Temperature Lubricant Phase II Status Report

METSS Corporation

300 Westdale Avenue

Westerville, OH 43082

June 22, 2006

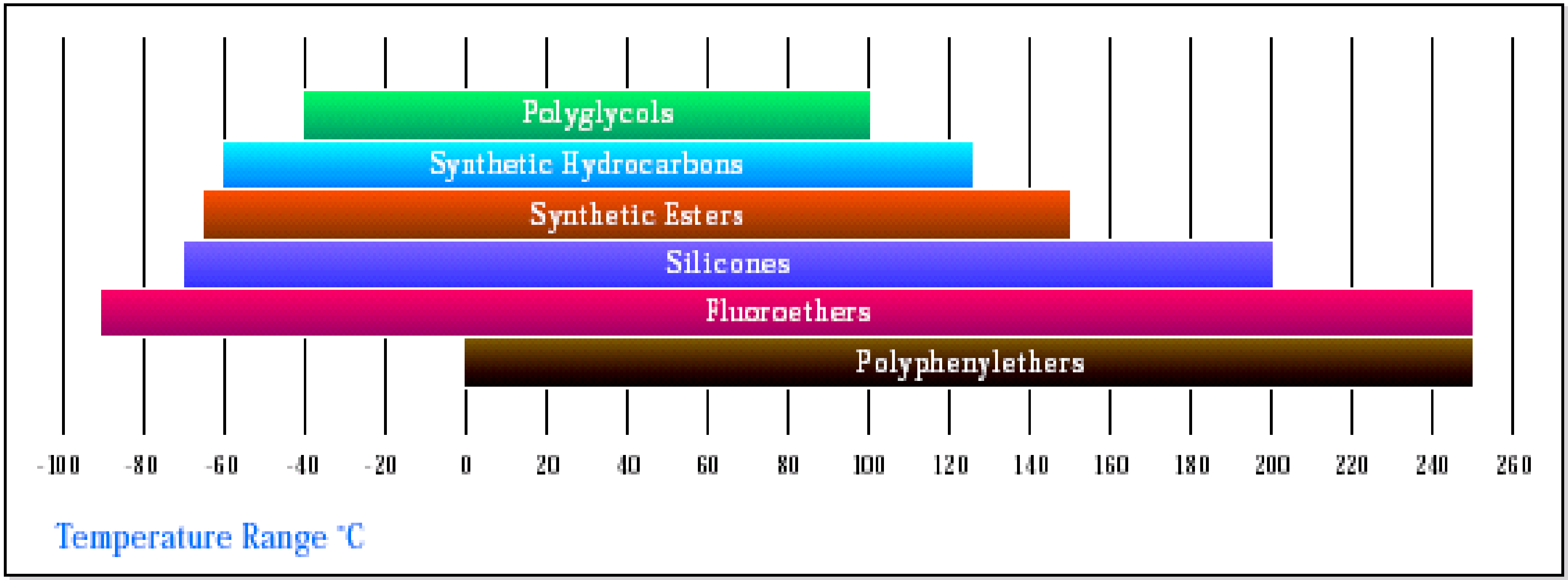
Navy Contract No. N68335-05-C-0077

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°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

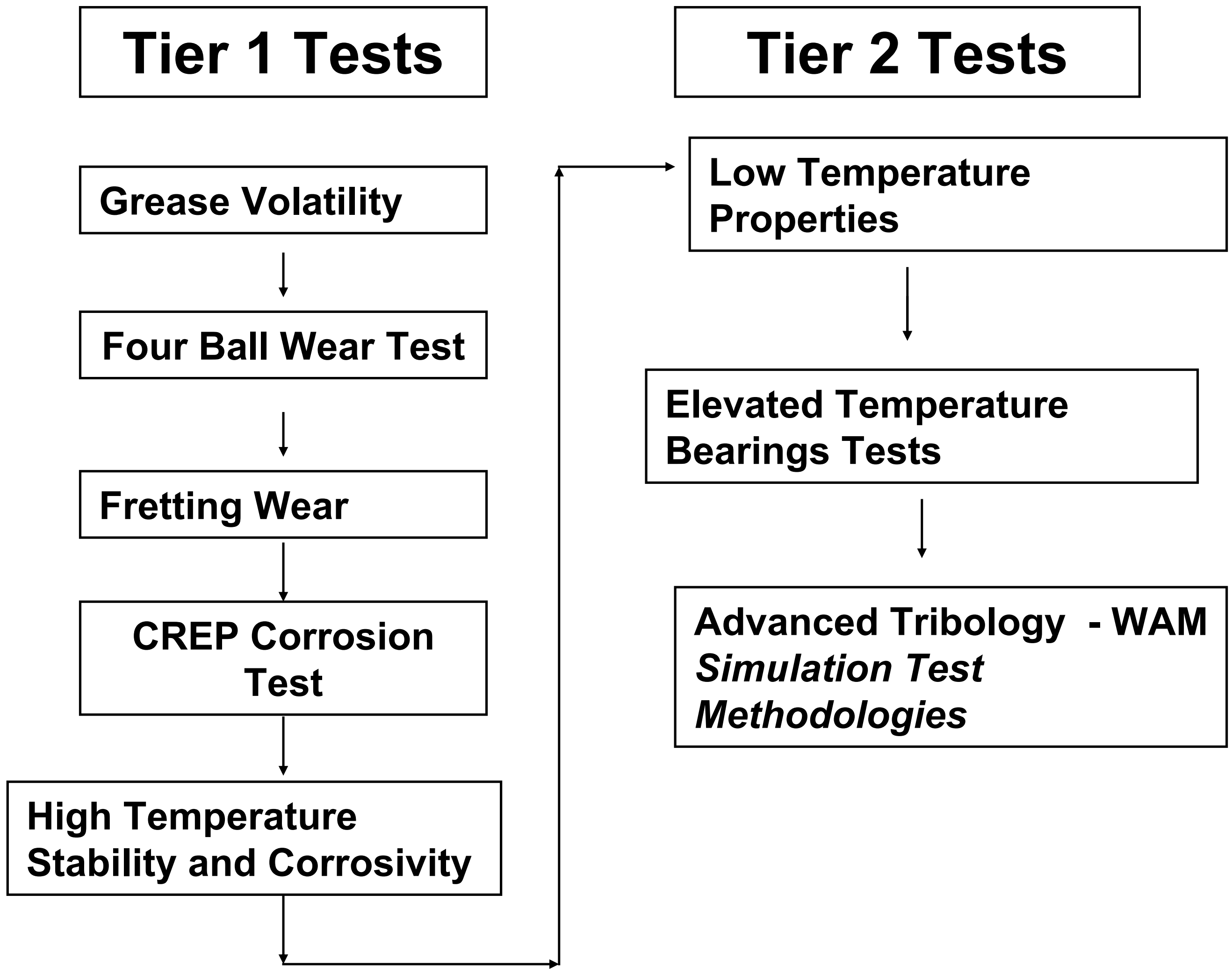
Other Materials

- **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.

Testing & 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 $< 5\%$)
  - M50/M50, 440C/440C, Si_3N_4/440C, Si_3N_4/Pyrowear 675

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

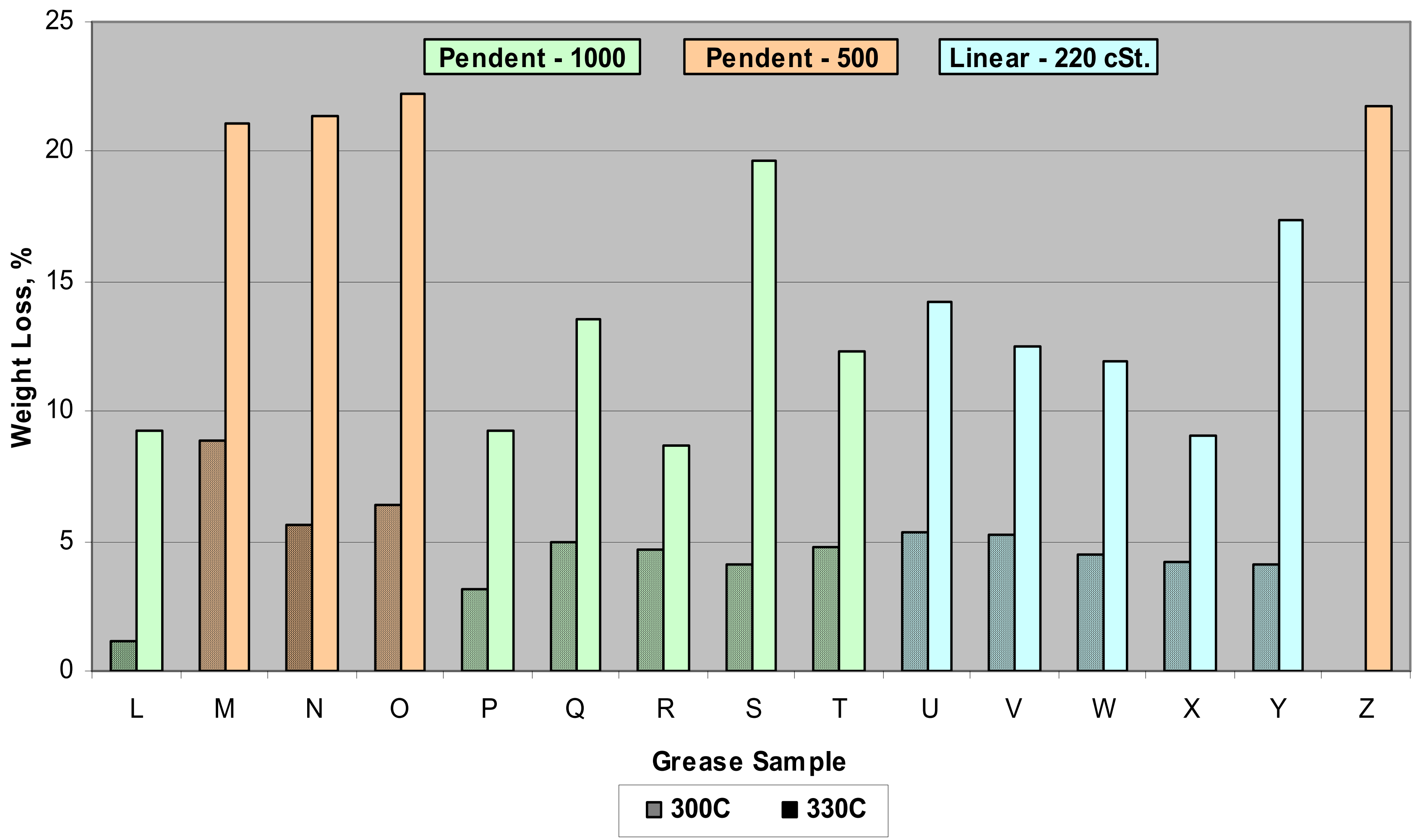
PFPAE Grease Formulation Variables

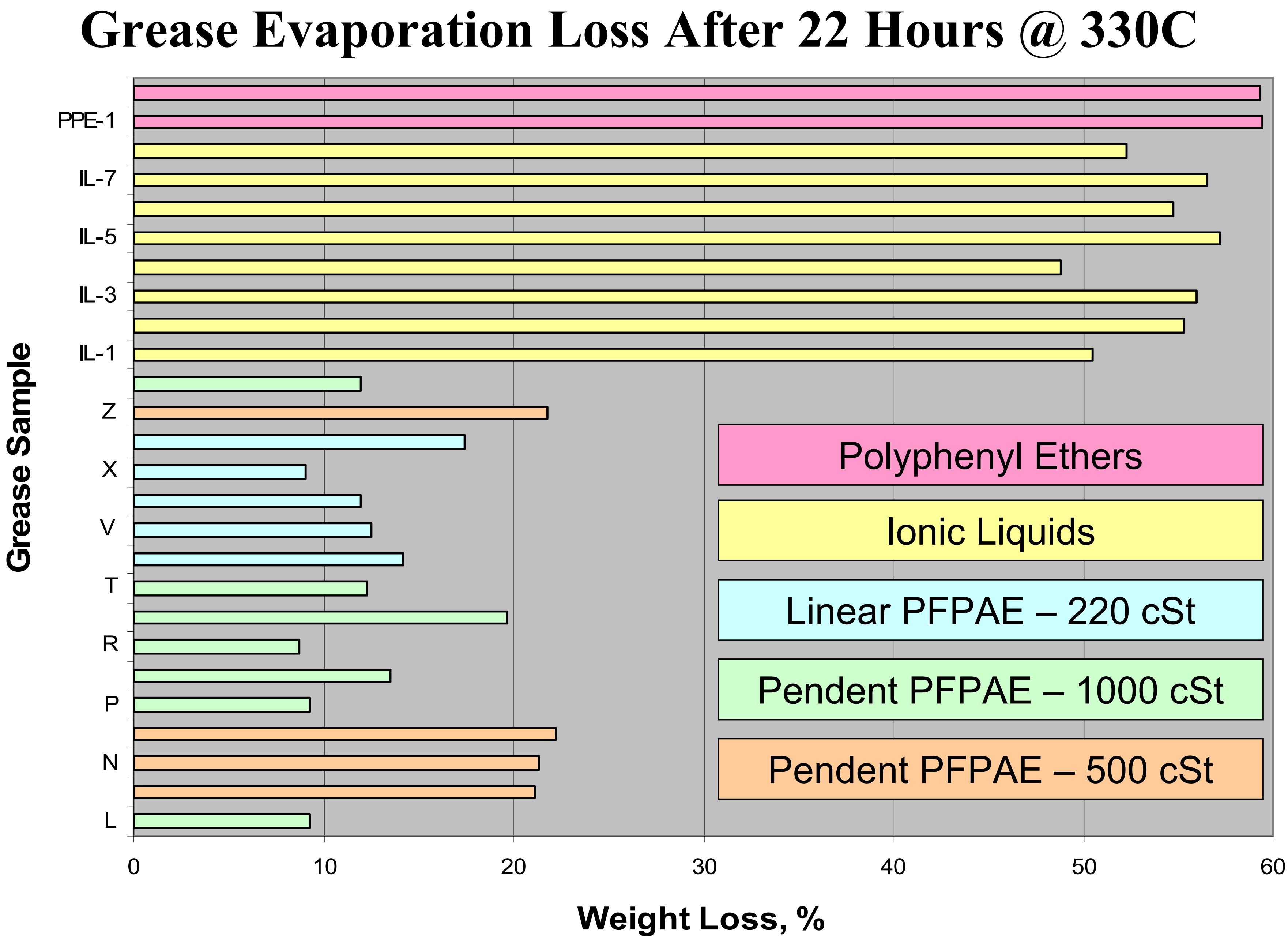
- PFPAE Fluid Types
  - Linear vs. Pendent
- Fluid Viscosity
  - 220, 500, 1000 cSt.
- Thickeners
  - PTFE, BN, Graphite/MoS_2
- Additives
  - Dispersed (Insoluble)
    - Disodium Sebacate - DSS
    - Sodium Nitrite - $NaNO_2$
    - Calcium Hydroxide $Ca(OH)_2$
  - Soluble
    - Fluorinated Benzene Sulfonic 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% $Ca(OH)_2$	---
M	Pendent PFPE	500	Graphite	5% $Ca(OH)_2$	MoS_2
N	Pendent PFPE	500	BN	---	---
O	Pendent PFPE	500	BN	5% $Ca(OH)_2$	---
P	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	---
T	Pendent PFPE	1000	Graphite	2% KBSANa	MoS_2
U	Linear PFPE	220	PTFE	---	---
V	Linear PFPE	220	BN	---	---
W	Linear PFPE	220	BN	5% $Ca(OH)_2$	---
X	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
PPE-1
IL-7
IL-5
IL-3
IL-1
Z
X
V
T
R
P
N
L
Grease Sample
0
10
20
30
40
50
60
Weight Loss, %
Polyphenyl Ethers
Ionic Liquids
Linear PFPAE – 220 cSt
Pendent PFPAE – 1000 cSt
Pendent PFPAE – 500 cSt

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^oC.
- 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.

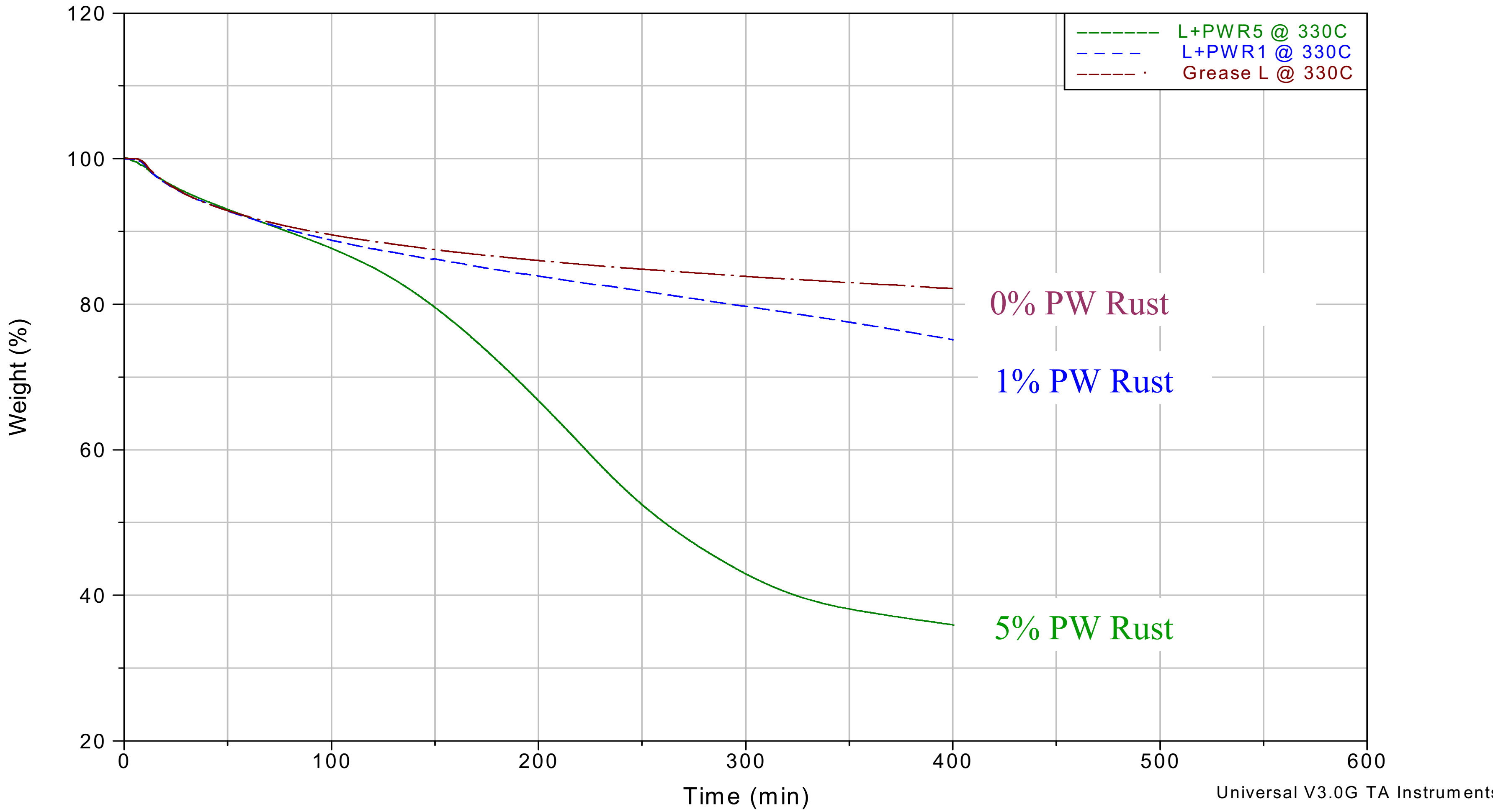
PW Pyrowear 675 Corrosion Product XRF*

XRF - PW Pyroware 675 Corrosion Product

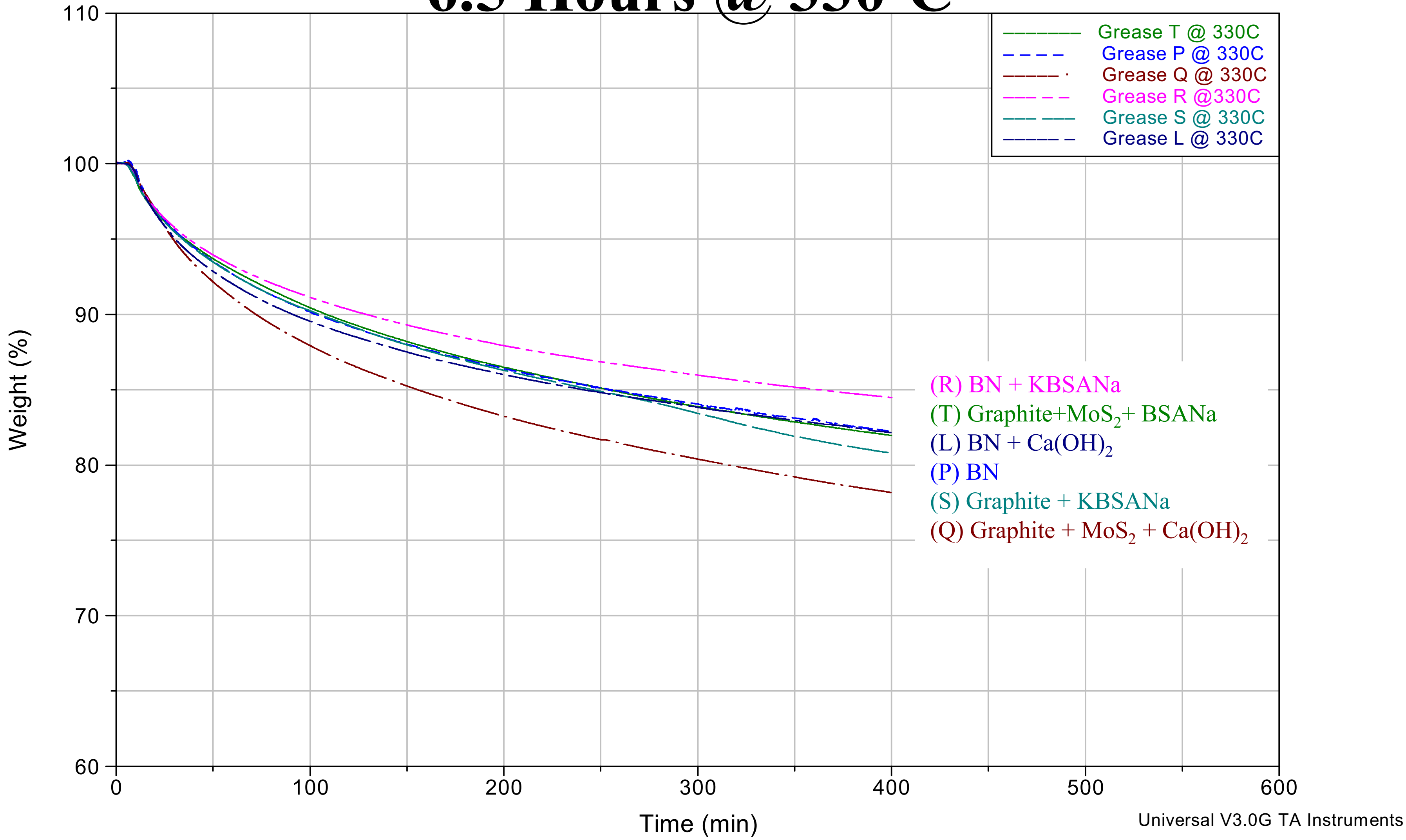
Z	wt%	Z	wt%	Z	wt%
Sum Be - F	nd	29 Cu	nd	52 Te	nd
11 Na	nd	30 Zn	0.07	53 I	0.020
12 Mg	nd	31 Ga	nd	55 Cs	0.038
13 Al	nd	32 Ge	nd	56 Ba	0.055
14 Si	0.63	33 As	nd	Sum La - Lu	0.530
15 Px	0.04	34 Se	nd	72 Hf	nd
16 Sx	0.00	35 Br	nd	73 Ta	nd
17 Cl	0.50	37 Rb	nd	74 W	nd
18 Ar	0.03	38 Sr	nd	75 Re	nd
19 K	nd	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 Tl	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
		51 Sb	nd	95 Am	nd

*Data provided courtesy of DuPont.

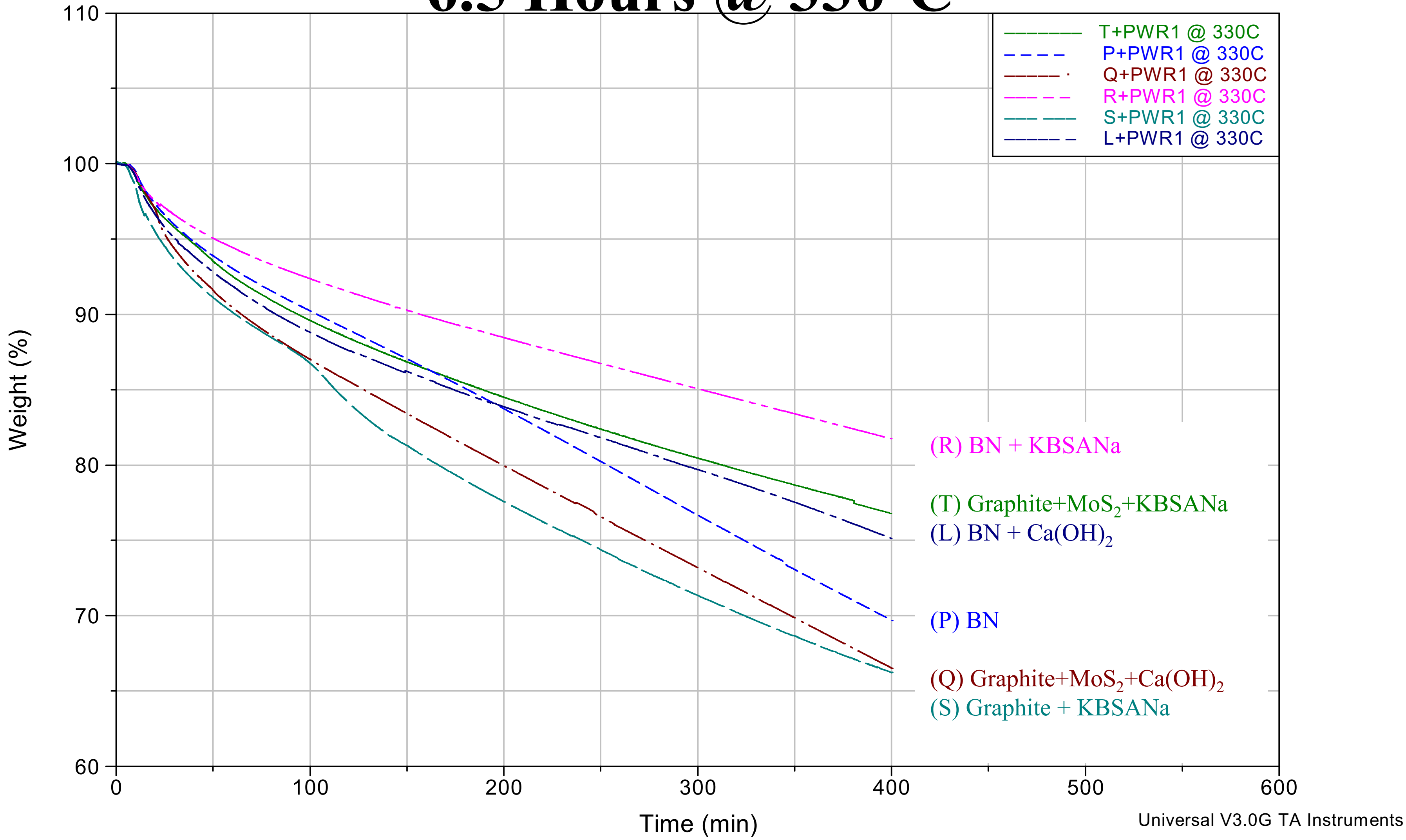
Effect of PW P675 Rust Concentration on Grease L at 330°C



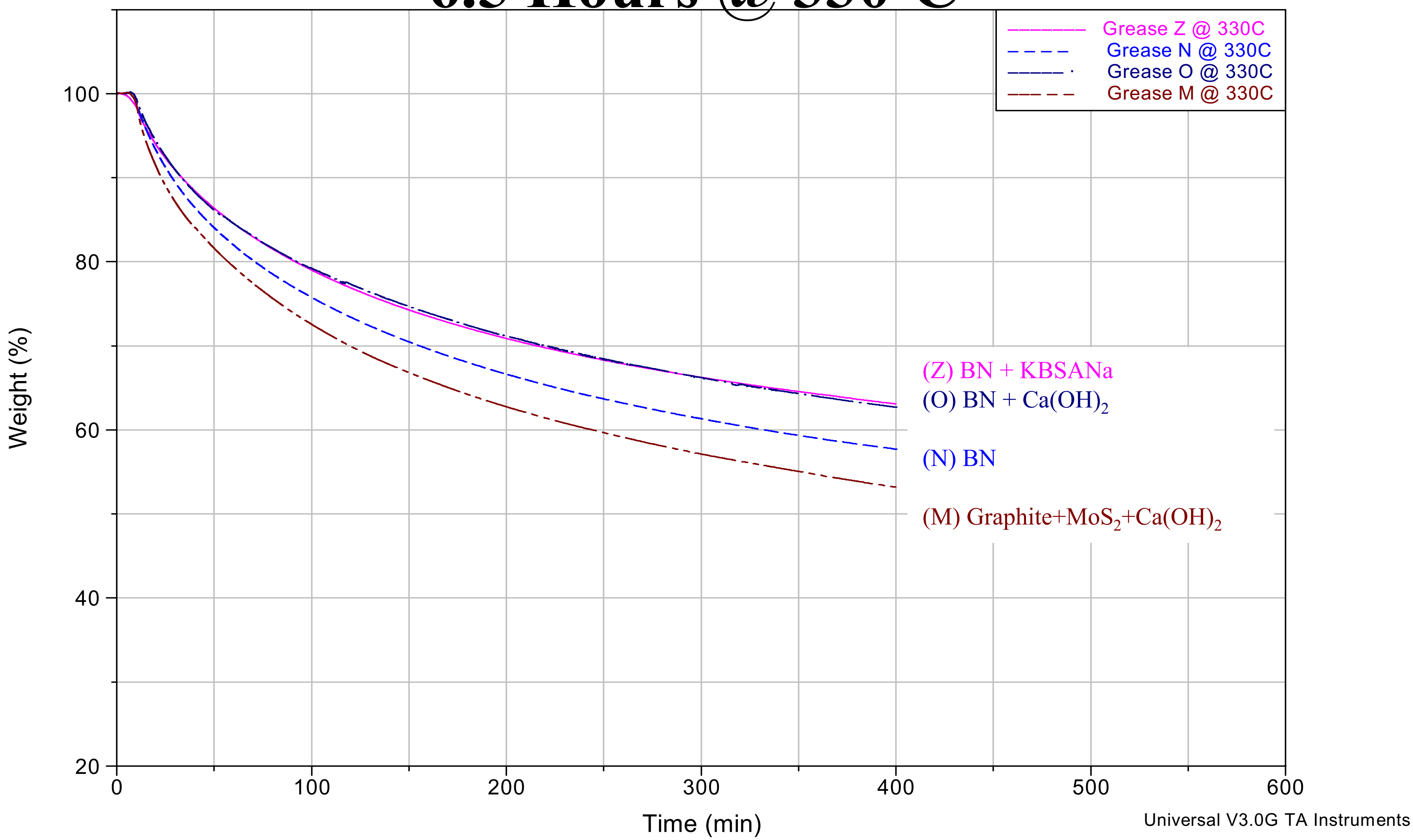
Pendent 1000-cSt. Greases *Without* P675 Rust 6.5 Hours @ 330°C



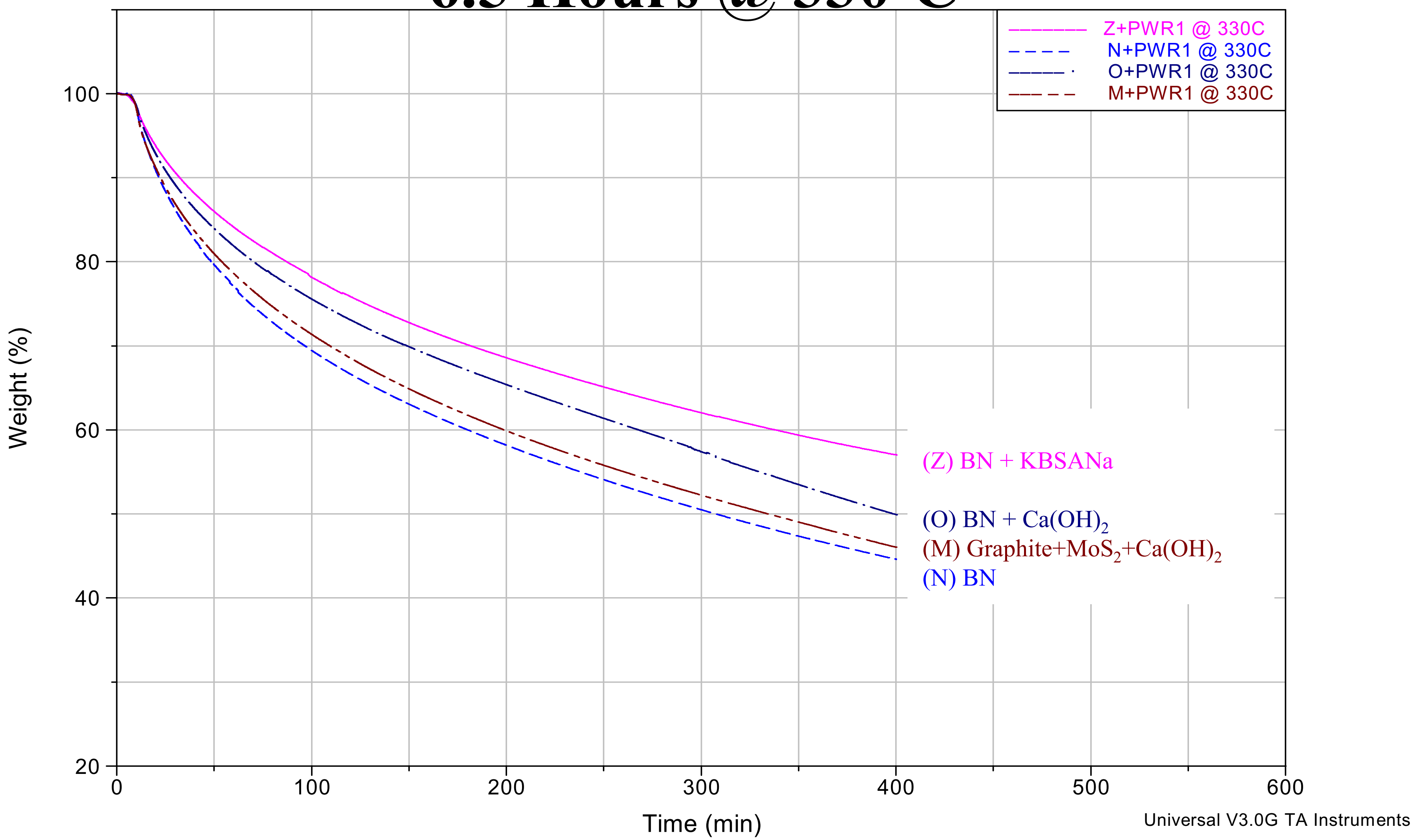
Pendent 1000-cSt. Greases *With* P675 Rust
6.5 Hours @ 330°C



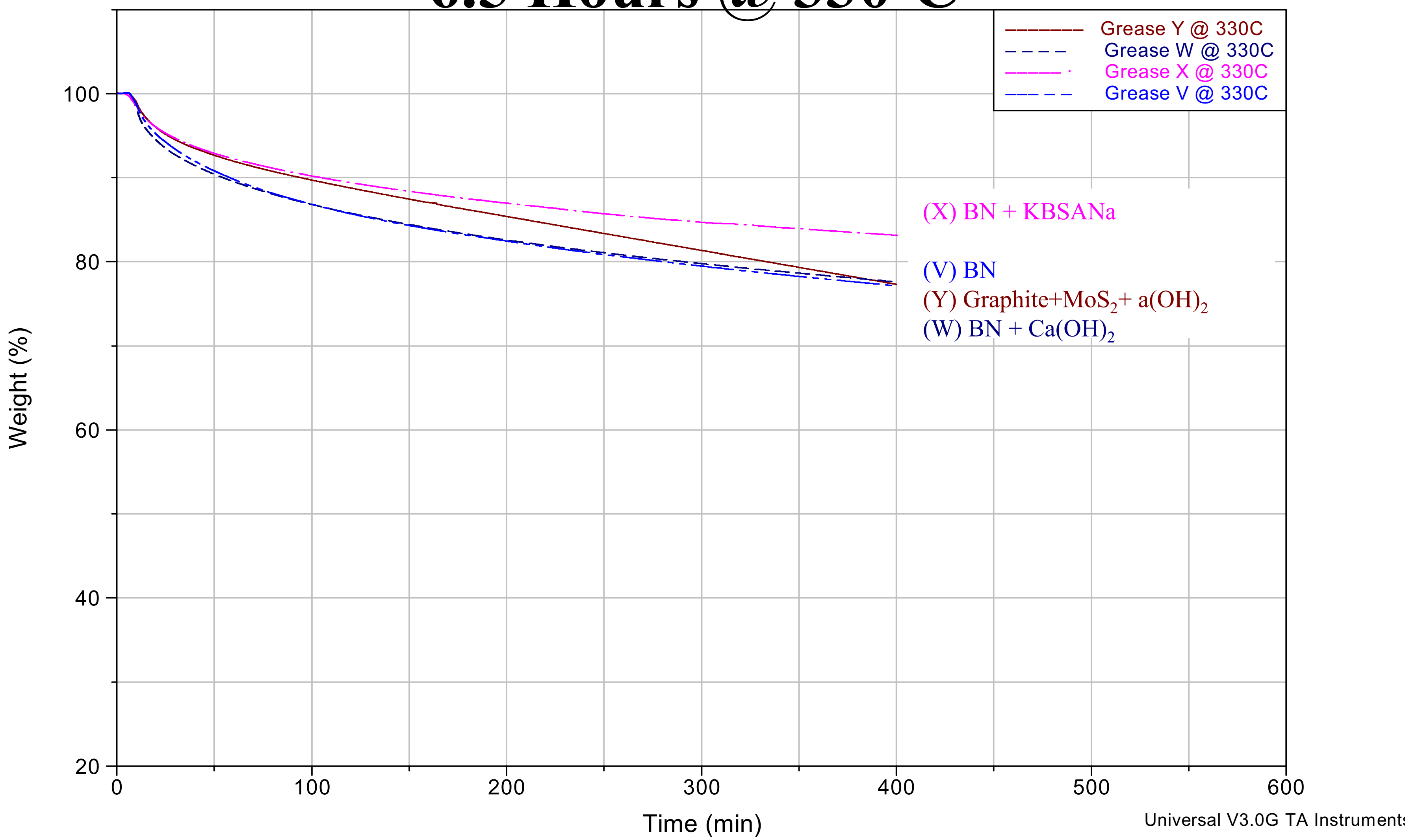
Pendent 500-cSt. Greases *Without* P675 Rust 6.5 Hours @ 330°C



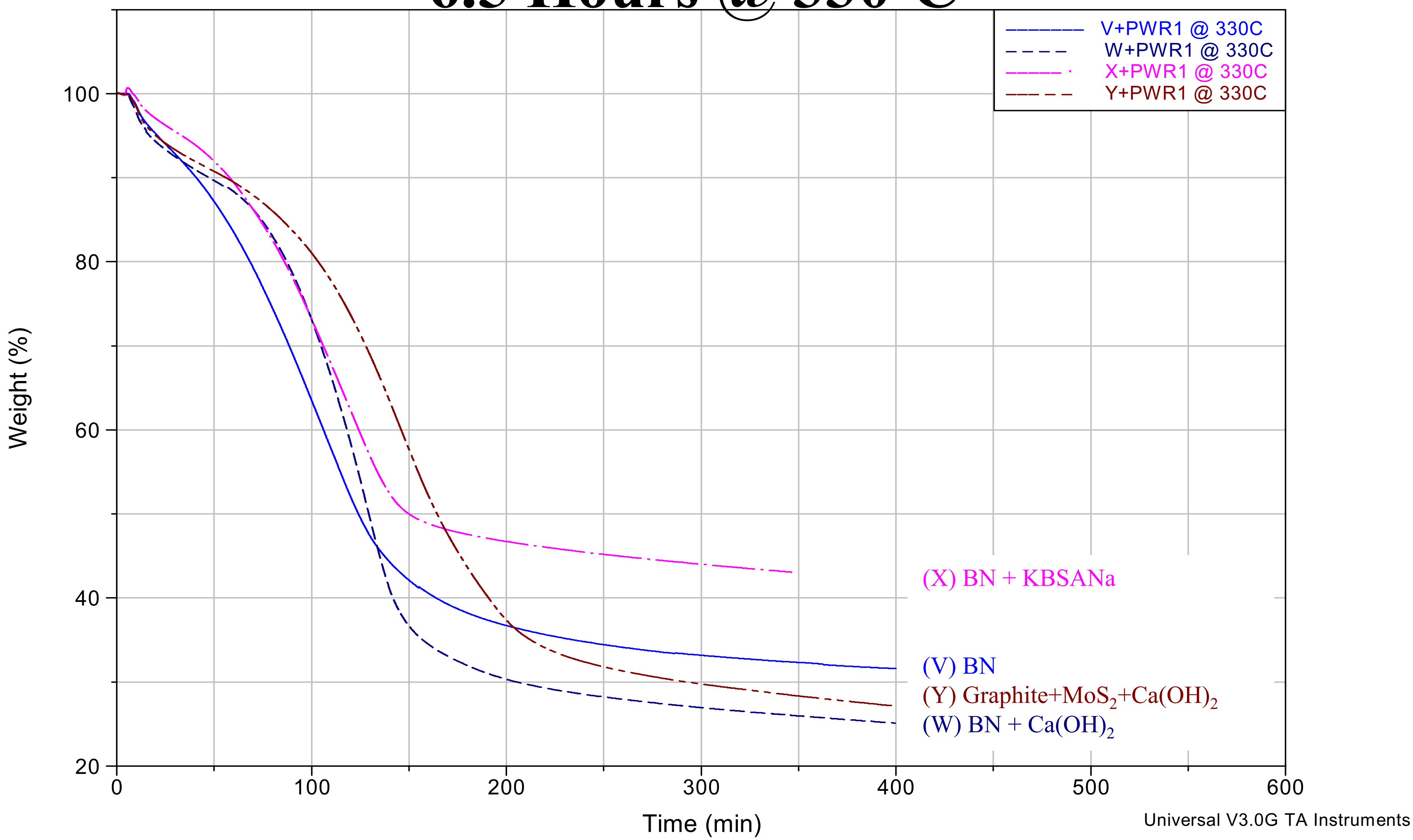
Pendent 500-cSt. Greases *With* P675 Rust
6.5 Hours @ 330^{o}C



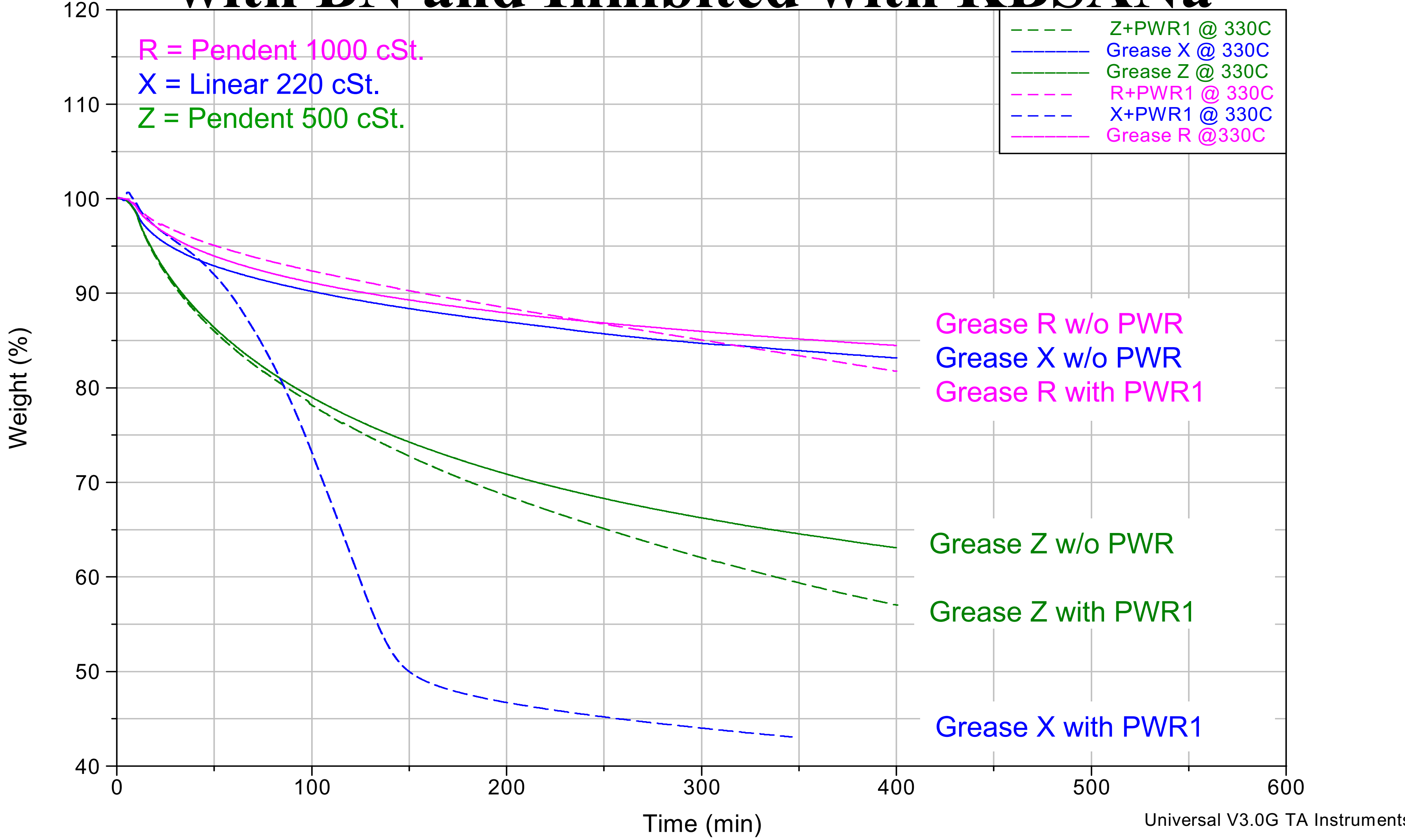
Linear 220-cSt. Greases *Without* P675 Rust 6.5 Hours @ 330^{o}C



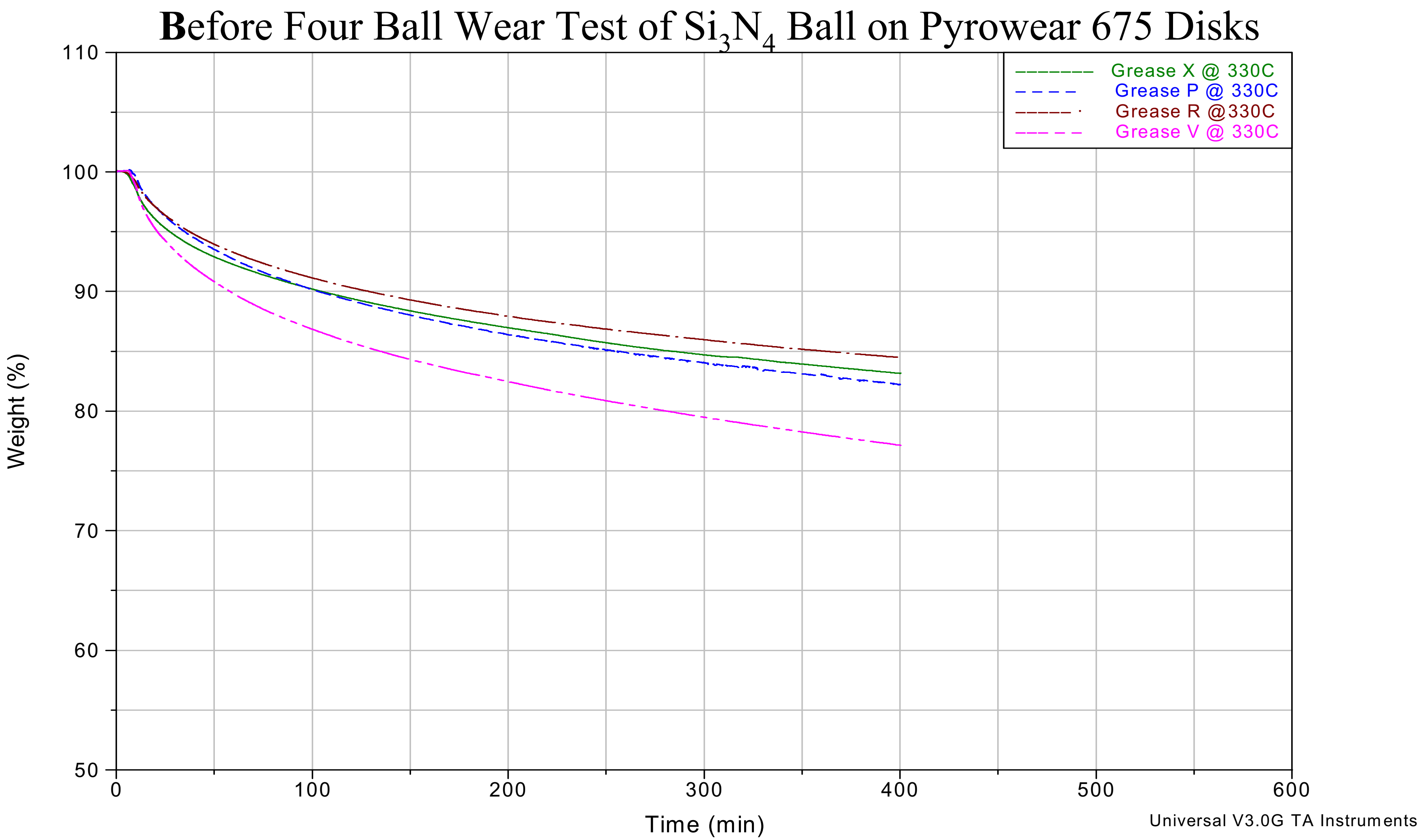
Linear 220-cSt. Greases *With* P675 Rust
6.5 Hours @ 330^{o}C



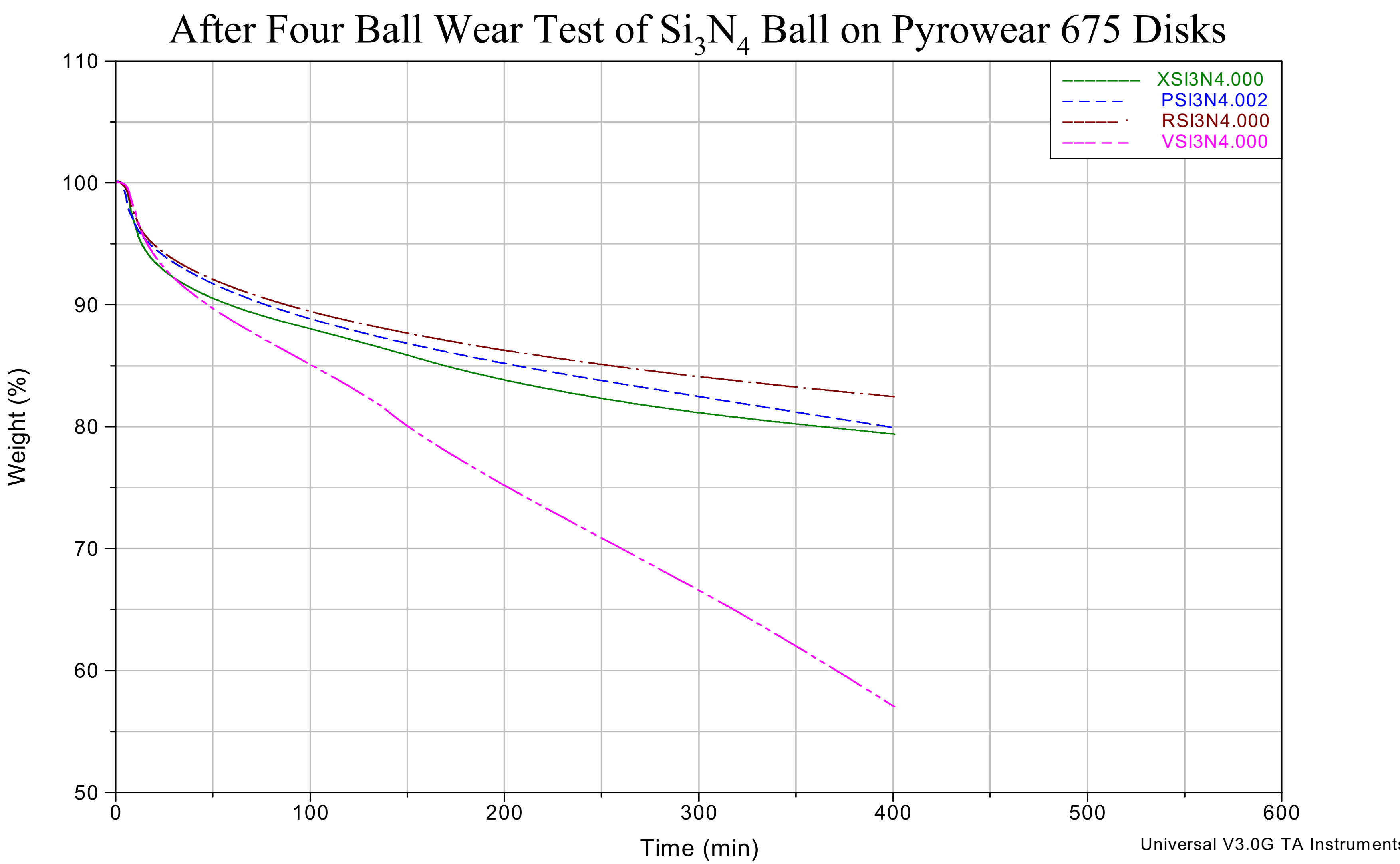
TGA Comparison of Greases Thickened with BN and Inhibited with KBSANa



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



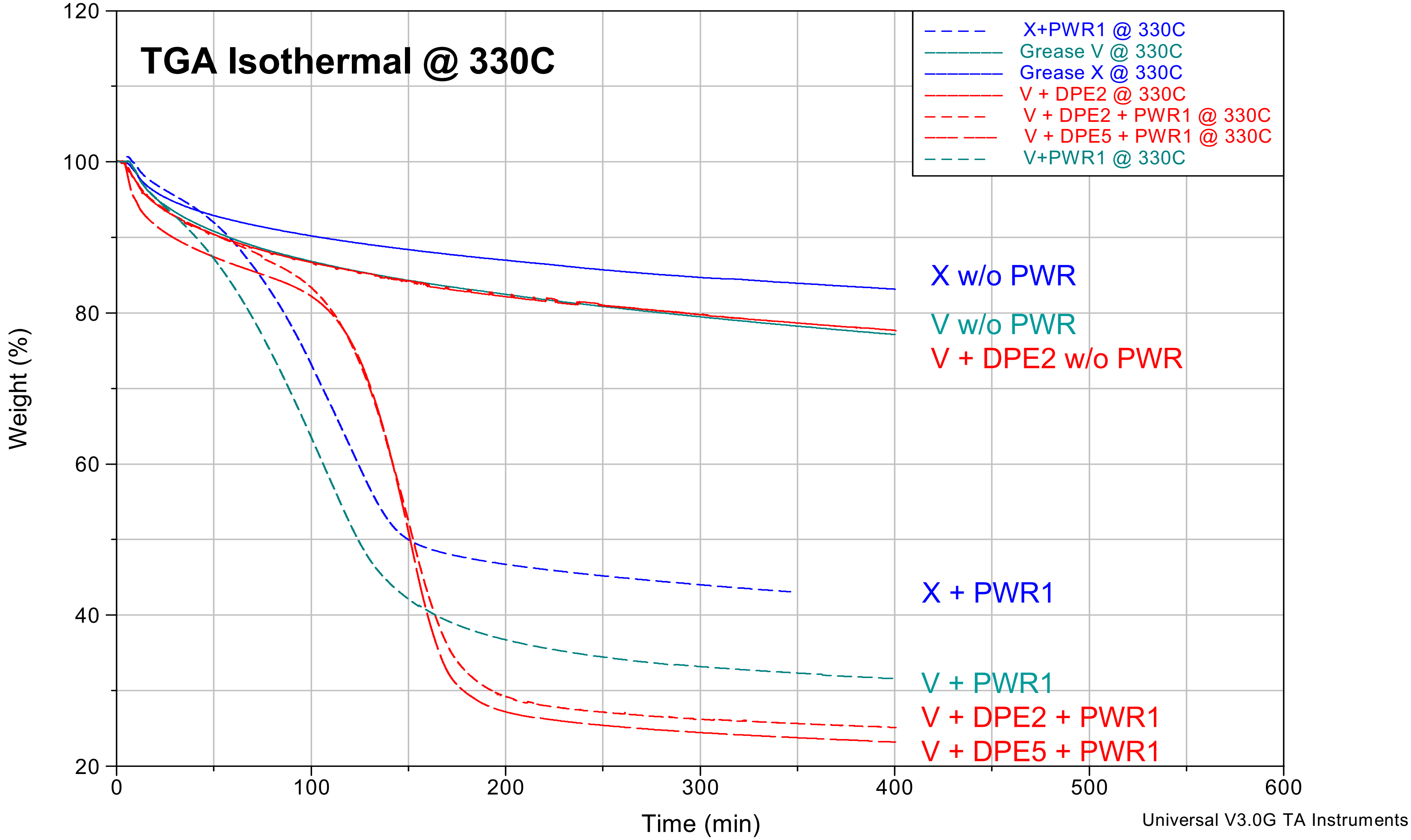
Isothermal TGAs (6.5 Hours @ 330C) of Aged Grease Samples Obtained



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

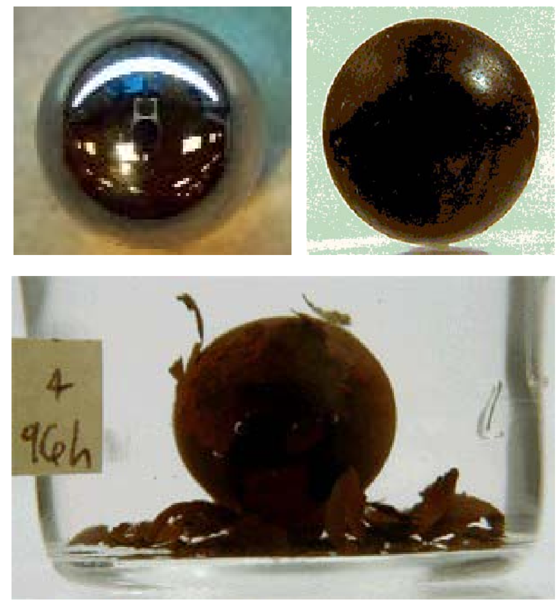
- Obtained sample of Fluorinated Diphenyl Ether (DPE) from AFRL.
- Added to Grease V (Linear 220 cSt + BN) at 2% and 5% treat levels.
- Ran TGAs on Grease V+DPE with and without PW Pyrowear Rust. Compare with data obtained for Grease X (Linear 220cSt + KBSANa).
- Ran TGAs on DPE alone.

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



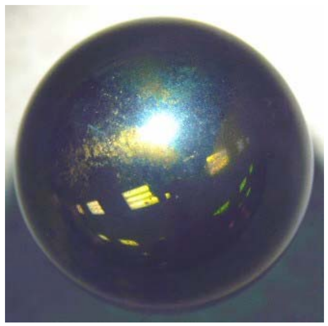
Thermal Stability & Corrosivity Test

- Modified DuPont procedure for Fluids
- Immerse metal Test Specimens in Grease
- 96 Hours @ 330^{o}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.

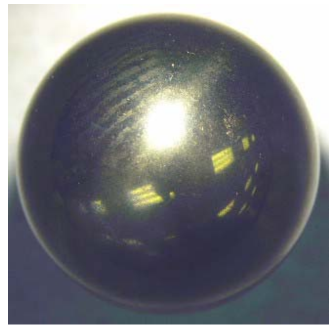


Thermal Stability & Corrosivity Test Results

Grease R



M50 = 2



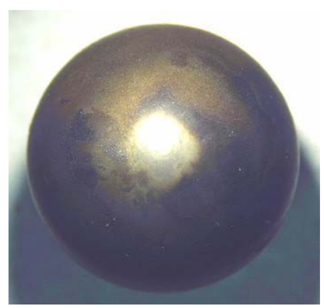
440C =2

Si_3N_4 = 1

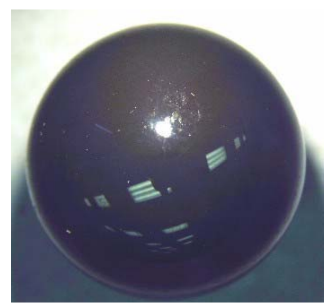
P675 = 2

Grease S

M50 = 6



440C = 5



Si_3N_4 = 1

P675 = 5

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

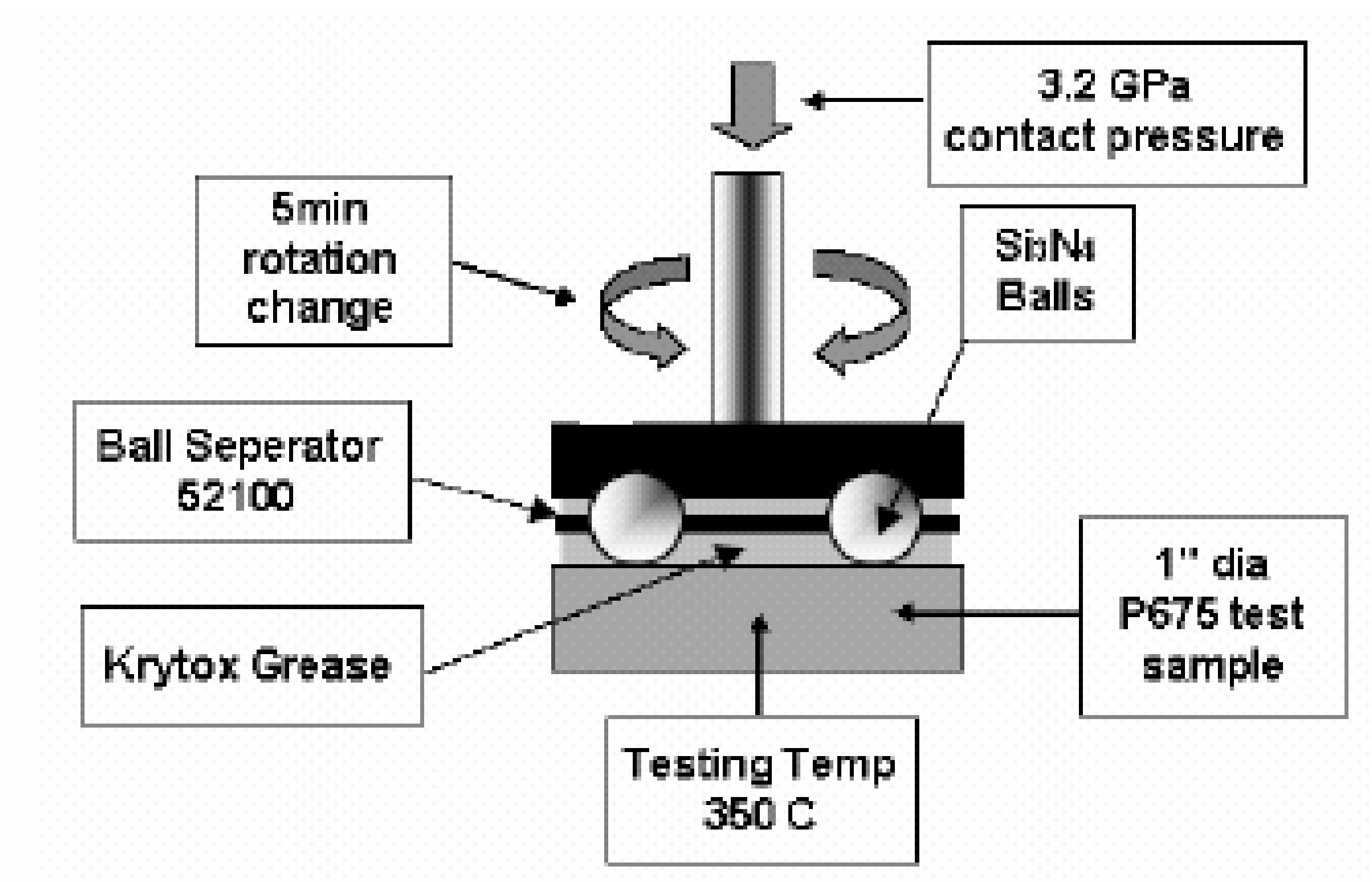
To Do List for
HT Lube Phase II Program

- **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?

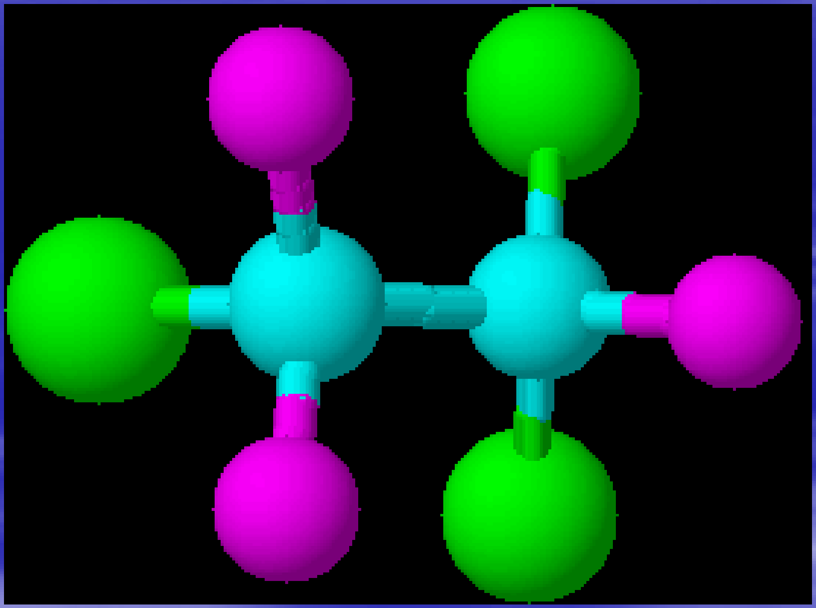
- Ozone (O_3) absorbs ultraviolet light in the atmosphere and breaks down into O_2
- O_2 can then react with O and form O_3 again.
- CFC's interfere the ozone cycle by reacting with O_3 which forms products that in turn destroy more ozone molecules.
- As the concentration of CFC's increase in the atmosphere, 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 eco-friendly 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

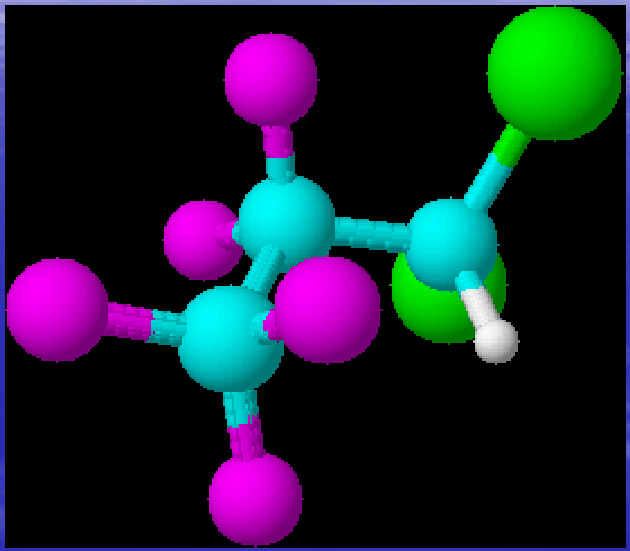


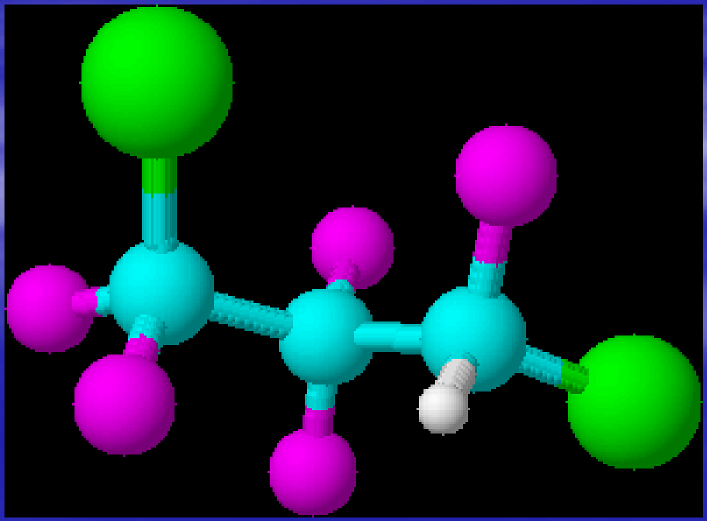
Could HCFC's replace Freon 113?

- 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 solution only.

AK 225

- AK 225 is a mixture of two HCFC solvents. It performed very well in cleaning tests[1]
- 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



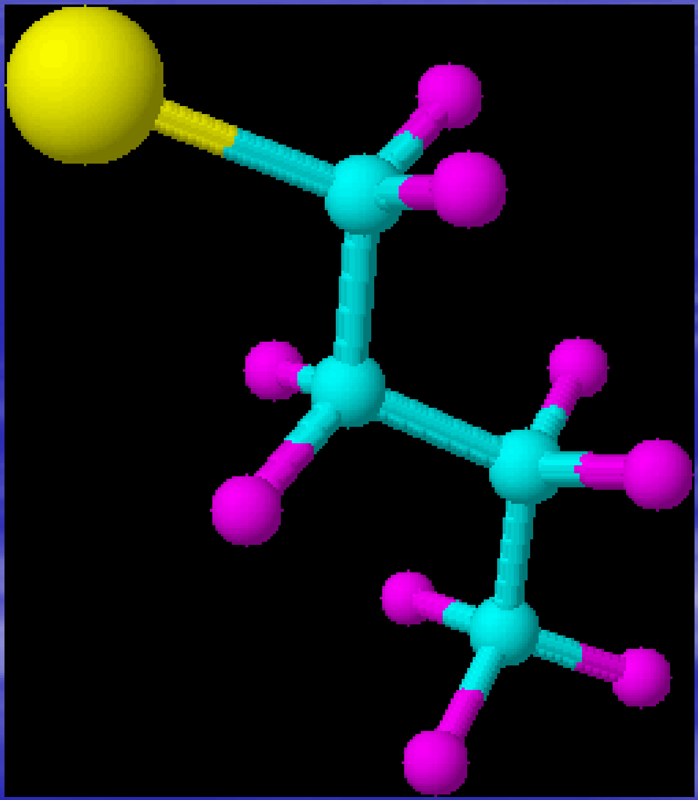


Candidate to replace Freon 113

- Perfluorobutyl Iodide, PFBI
- Performed very well in cleaning tests[1]
- Initial toxicity studies[2] 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

PFBI

- Boiling point = 54°C
- Does not contain chlorine
- Does not react with ozone
- Currently is priced similar to AK 225_3
- 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

1. AFRL-ML-WP-TR-2003-4040 “The Wipe Solvent Program” Marcie Roberts (UDRI), Lois Gschwender, Ed Snyder
2. International Journal of Toxicology 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

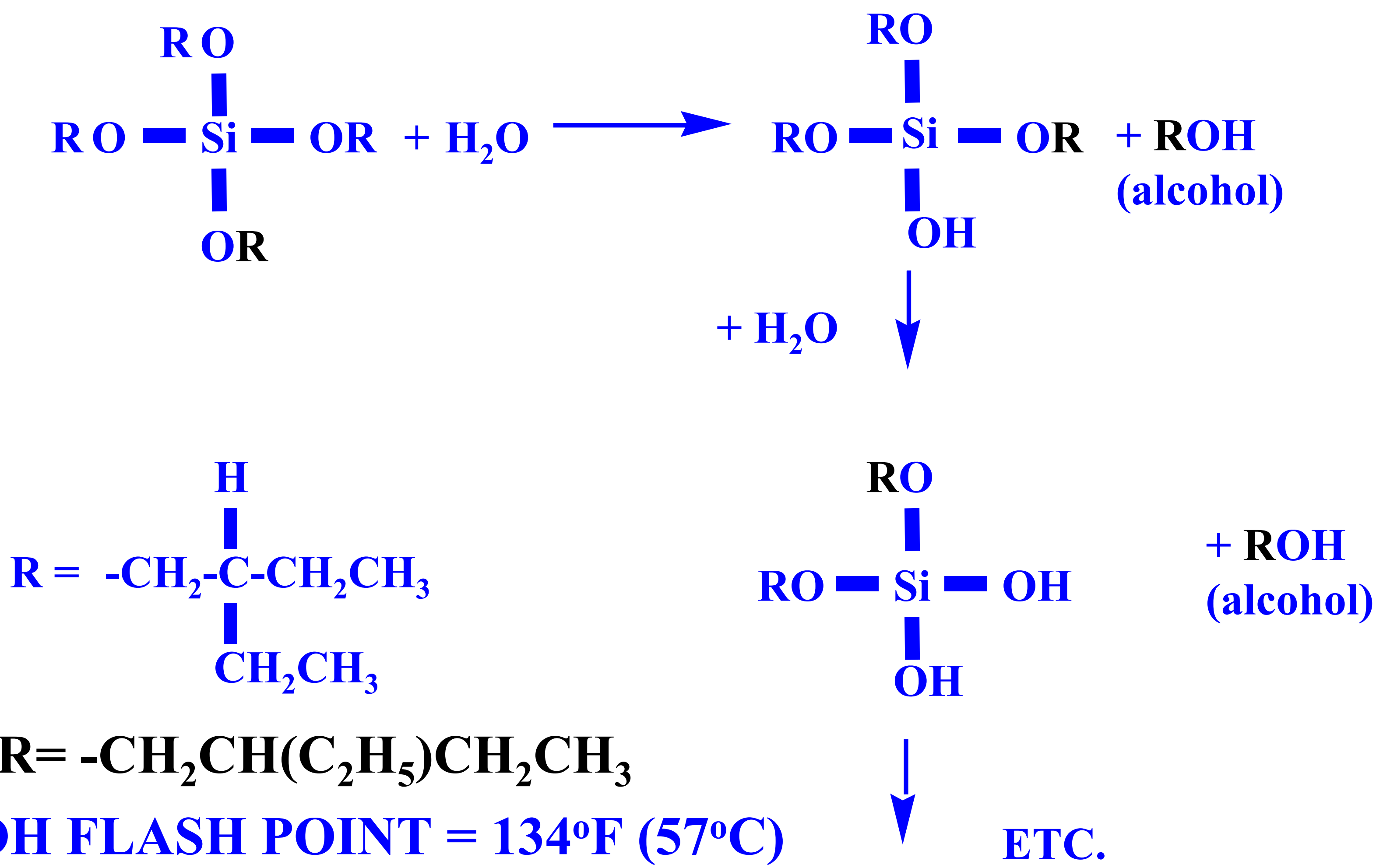
Outline

- 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



R= $-CH_2CH(C_2H_5)CH_2CH_3$

ROH FLASH POINT = 134°F (57°C)

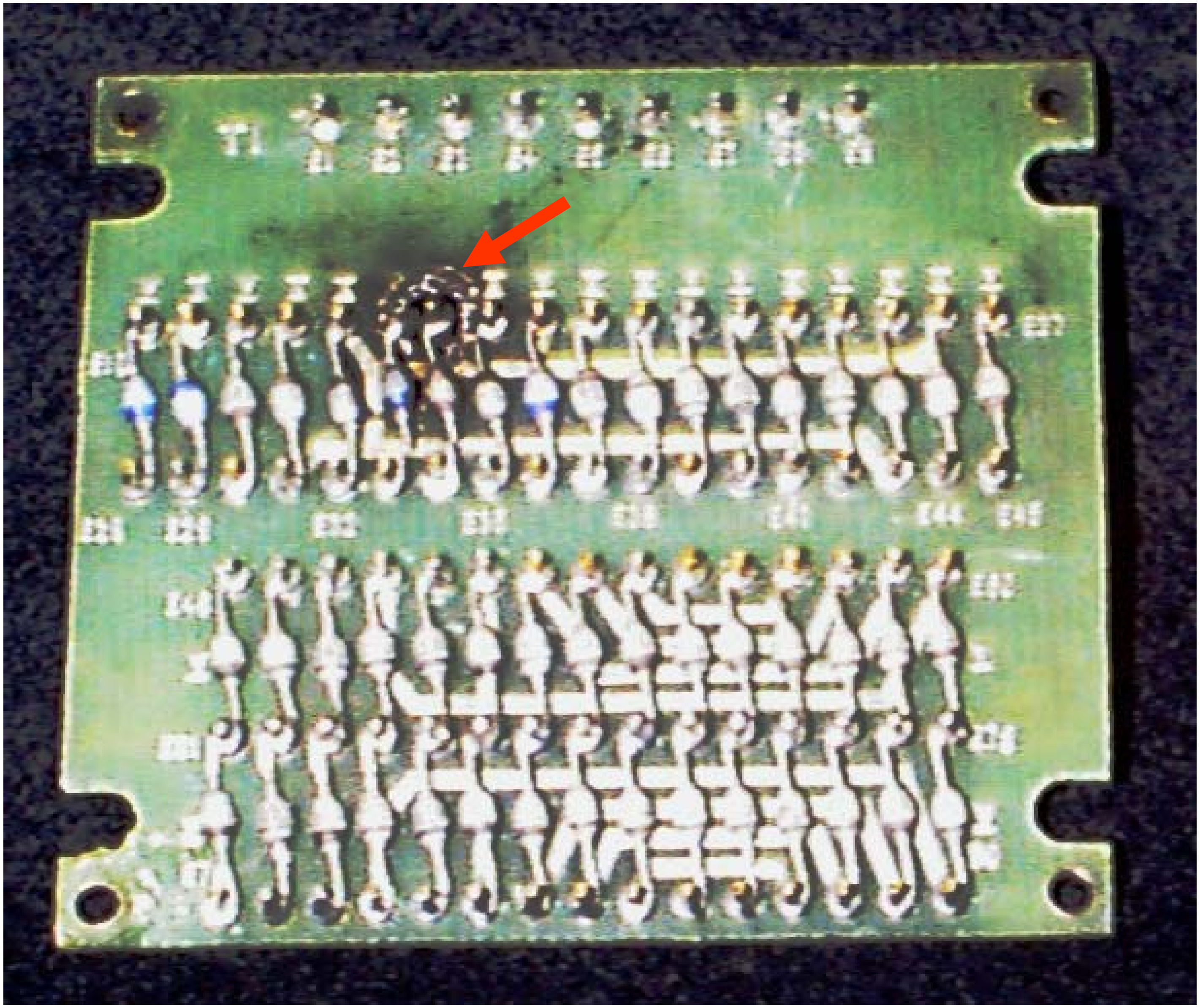
Solution - PAO Coolant

- 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*
Density

*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

<u>Polyalphaolefin</u>

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

SR-71 PAO Formulation Evaluation - Good Bench Test Results

- 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 ☑

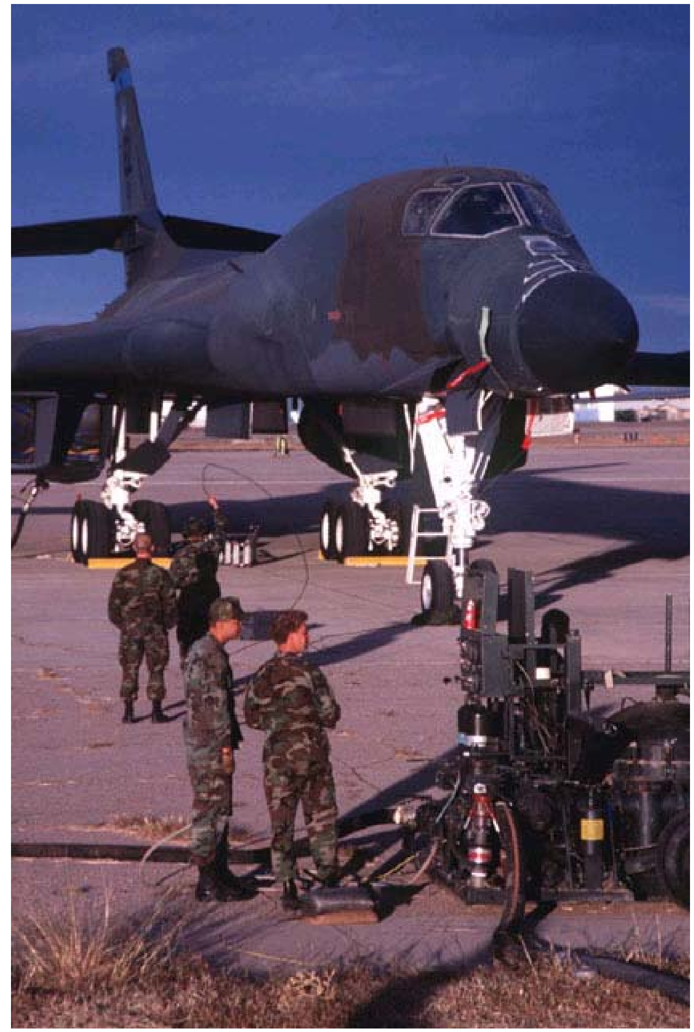
Full system conversion approved for SR71

ASD/RWNA Programs (Hughes)

- 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

F-18

Navy Coolant Issues

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

F-14

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

Key MIL-PRF-87252 Features

- 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

A Major Systems Application Opportunity

- <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
  - EF111*
  - EC-130
  - F-15
  - F-16 (block 60 foreign sales)
  - F-22 (base-lined)
  - JSF (base-lined)
- Navy
  - F-14
  - F/A-18**
  - S-3
  - P-3
  - E/A6B
  - 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

PAO Coolant Transition Issues

- *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^{o}C/100 hours to meet the specification
- All products on Qualified Product List were tested at elevated temperatures
- Specification changed to require 200^{o}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

New Interest-High Pressure Switches

- 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	200 - 1000 kV
• Current	20 - 250 kA
• Rise-time	< 50 ns
• Charge transfer	~ 0.5 Coulombs/pulse
• Jitter	<< 50 ns
• Pulse repetition rate	50 - 100 pps
• Pulse width	50 - 500 ns
• Switch lifetime	$10^7 – 10^8$ pulses

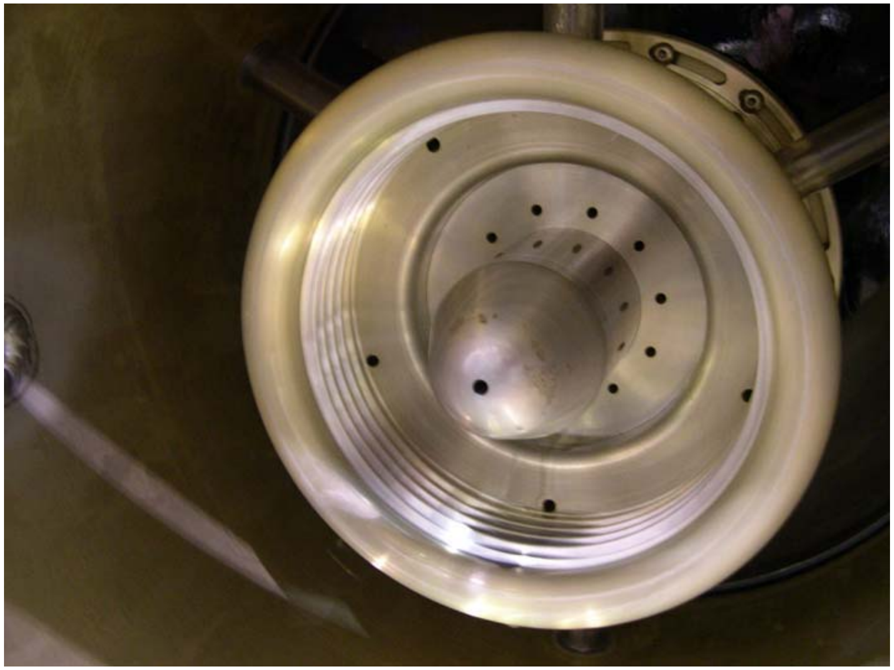
High Pressure Switching Technology

- 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
  - H_2 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 spin-offs - 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