

HCAT PROJECT

***FUNCTIONAL ROD/SEAL TESTING AND QUALIFICATION
OF HVOF COATINGS ON NAVY ACTUATORS***



Jeff Gribble

NAS Patuxent River, MD

March 16, 2005 HCAT

Phase I Rod/Seal Test Status

- Functional Rod/Seal Testing at PAX Hydraulic Lab is Complete.
 - Pre-test and post-test rod traces were provided by Supfina.
 - Rod and seal pictures provided by NAVAIR Materials.
- HCAT JTP will validate HVOF thermal spray coatings as acceptable replacements for hard chrome plating on hydraulic/pneumatic actuators.
- Phase I test based on HCAT JTP dated 30 Sept 2003 has been modified to include:
 - High Temp at 275°F (not 300°F)
 - MIL-PRF-83282 Fluid Used (not MIL-PRF-87257)

Test Apparatus

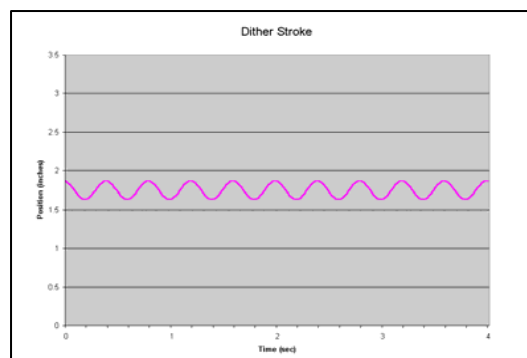
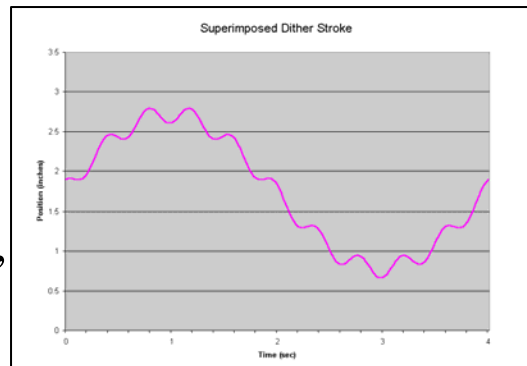
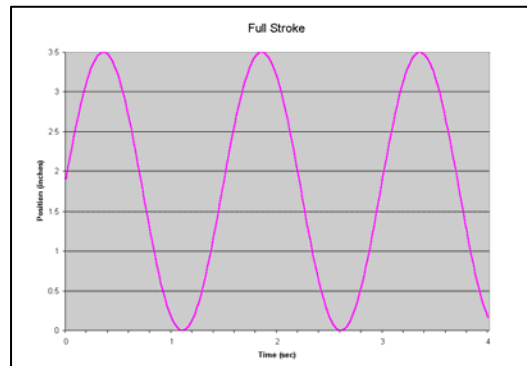
- Located at NAVAIR Patuxent River Hydraulic Lab.
- Master hydraulic piston drives four test rods. Each rod passes through two blocks (“Back End Block” and “Far End Block”).
- Apparatus is mounted inside an environmental chamber capable of maintaining a temperature between -65° and $+300^{\circ}$ F.
- The master piston passes through a sealed port on the environmental chamber.
- The hydraulic power supply is located outside the chamber for increased reliability of test hardware. Constant hydraulic pressure is applied on seals.
- Hydraulic lines to the fixture are single-ended and thus should not heat or cool the test hardware.

Test Plan

1. Evaluate four different seal configurations with four different rods. Seals tested are those in primary gland position (secondary seals simply act as scraper seals in preventing leakage). Leakage is measured between the primary and secondary gland position.
 - Each rod will be inspected and characterized before and after testing (optical microscopy and surface profilometry).
 - Hydraulic fluid leakage from each block will be measured and recorded.
2. Test originally specified 13 day test to total over 1 million cycles of full, super-imposed dither, and dither stroke cycles. Full stroke test time was extended a few days to meet the necessary cycles in JTP due to control valve replacement not operating at proper frequency response.

Stroke Profile

- Full Stroke (3.5” Stroke, 1.5 second Period, 20 Minute Duration per Hour)
- Superimposed Dither (2” Main Stroke, 0.25” Dither stroke, 4 second Period, 4 Hz Frequency, 20 Minute Duration per Hour)
- Dither (0.25” Dither stroke, 4 Hz Frequency, 20 Minute Duration per Hour)



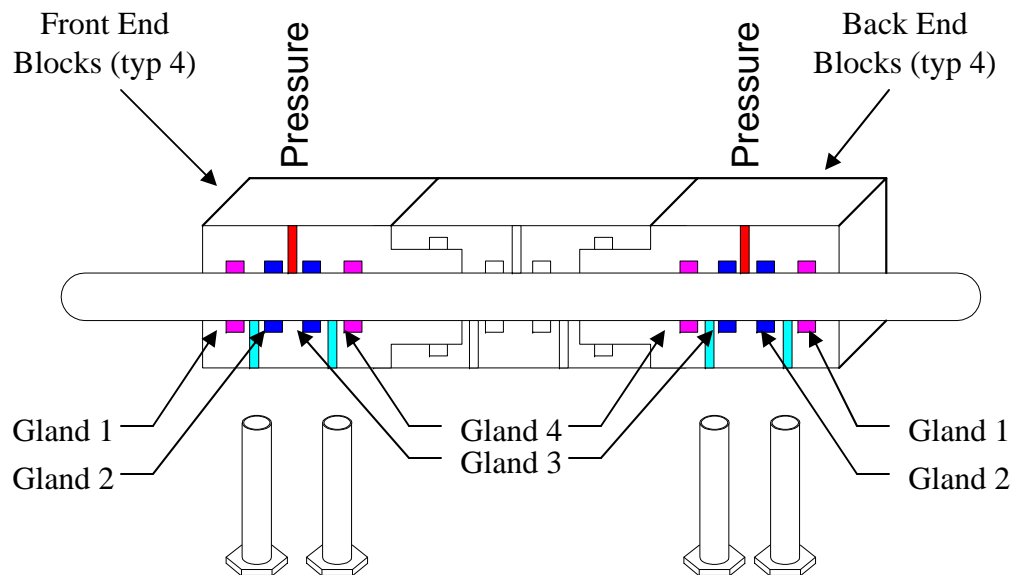
Temperature Profile

Hours	Temp (°F)
59	160
10	200
10	225
20	250
20	275
5	- 40

Note: Prior to each test day temperature shall begin at 0°F to evaluate static leakage at startup.

Test Rod and Seal Layout

- There are two seal configurations per block and two blocks per rod so that 16 rod/seal configurations are being evaluated per test.
- Primary (test seals) indicated in blue and the secondary (scraper seals) in magenta. Primary and secondary seals are similar.



SEAL CONFIGURATIONS	SUPPLIER
No. 1 MIL-P-83461 O-ring w/ PTFE Capstrip	A
No. 2 MIL-P-83461 O-ring w/ 2 backup rings	B – 1 st 27 hrs A – remainder of test
No. 3 Fluorosilicon O-ring w/ PTFE Capstrip	C
No. 4 Spring energized PTFE seal	C

Rod 1: “HVOF As-Ground”

Test Article	Supfina, Inc. Taylor-Hobson Cut Off – 0.030 In. WC/Co/Cr 86/10/4 Ground to 4 – 6 Ra 320 grit diamond As Ground
Pre-Test	Ra = 6.46 microinch
Post-Test	Location 1: Ra = 4.32 microinch Location 2: Ra = 2.95 microinch

Rod 2: “HVOF 20-22 Ground w/ SF”

Test Article	Supfina, Inc. Taylor-Hobson Cut Off – 0.030 In. WC/Co/Cr 86/10/4 Ground to 20 – 22 Ra 120 grit diamond Superfinished at NADEP JAX to 2 Ra
Pre-Test	Ra = 2.31 microinch
Post-Test	Location 1: Ra = 2.21 microinch Location 2: Ra = 2.21 microinch

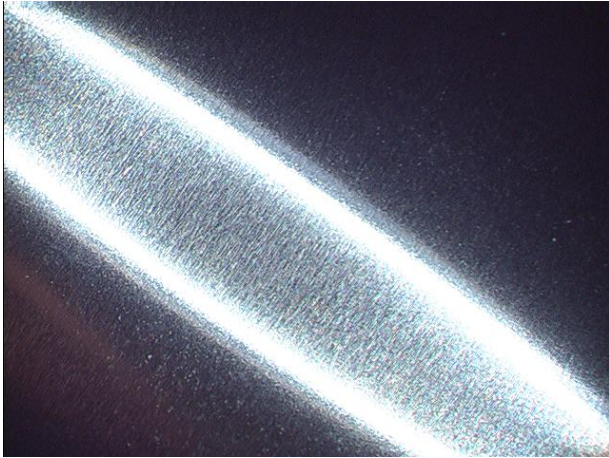
Rod 3: “HVOF 8-10 Ground w/ SF”

Test Article	Supfina, Inc. Taylor-Hobson Cut Off – 0.030 In. WC/Co/Cr 86/10/4 Ground to 8 – 10 Ra 220 grit diamond Superfinished at NADEP JAX to 2 Ra
Pre-Test	Ra = 1.49 microinch
Post-Test	Location 1: Ra = 1.28 microinch Location 2: Ra = 1.68 microinch

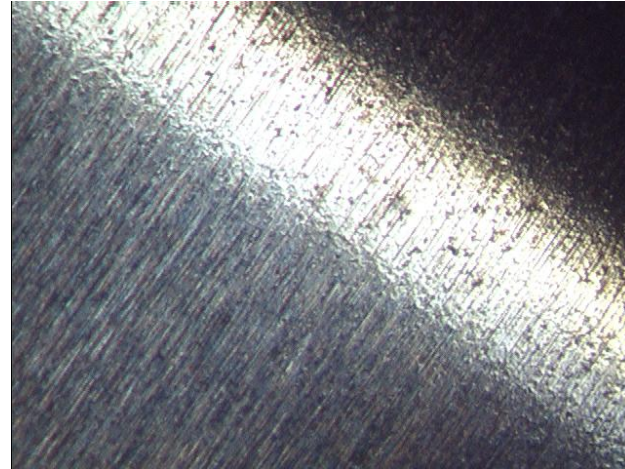
Rod 4: “Chrome”

Test Article	Supfina, Inc. Taylor-Hobson Cut Off – 0.030 In. Chrome plated at NADEP JAX Ground to 12 – 15 Ra 60 grit Al2O3 As Ground
Pre-Test	Ra = 12.27 microinch
Post-Test	Location 1: Ra = 2.80 microinch Location 2: Ra = 4.82 microinch

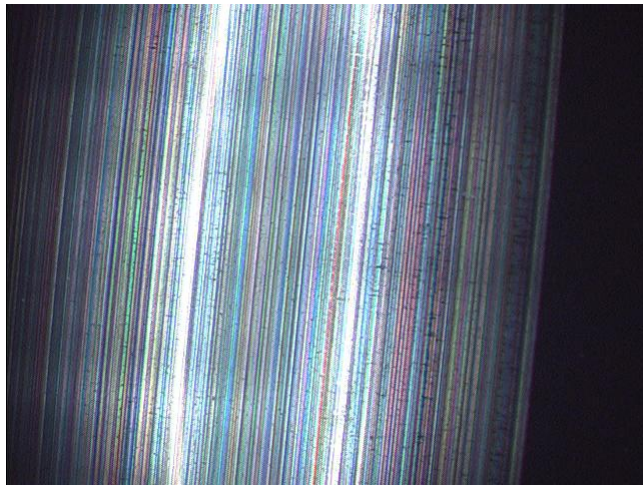
Rod #1 HVOF 4-6 Ra As-Ground



Pre-Test (20x)

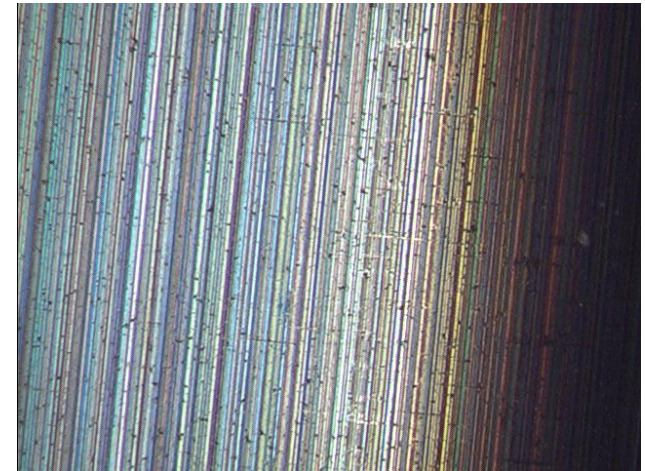


Pre-Test (100x)



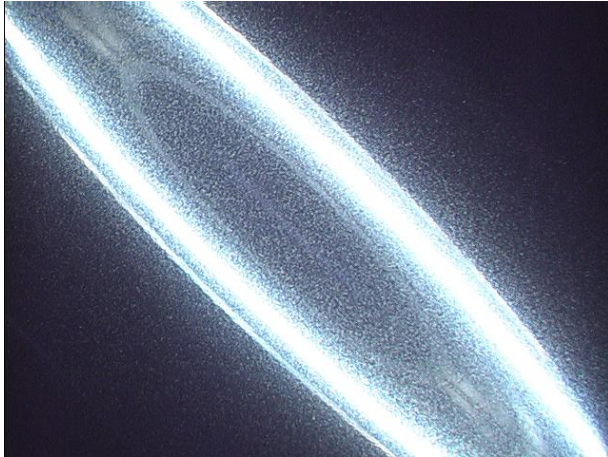
Post-Test (20x)

Post-test linear
scratches
observed.

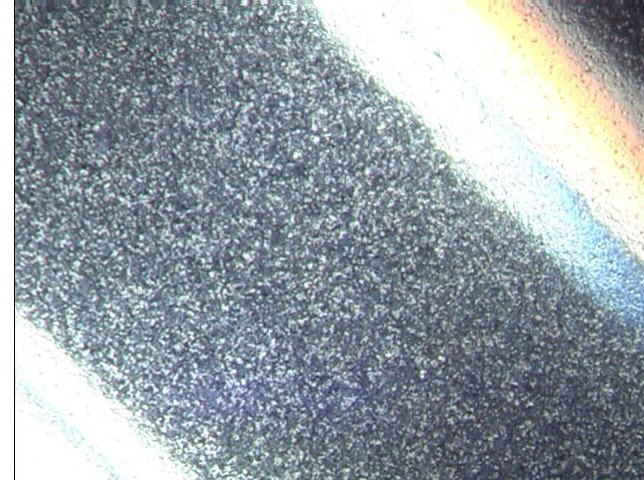


Post-Test (100x)

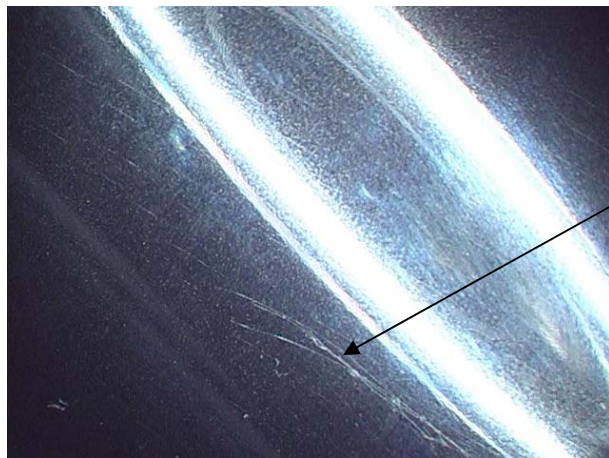
Rod #2 HVOF 20-22 Ra Ground w/ SF 2 Ra



Pre-Test (20x)



Pre-Test (100x)



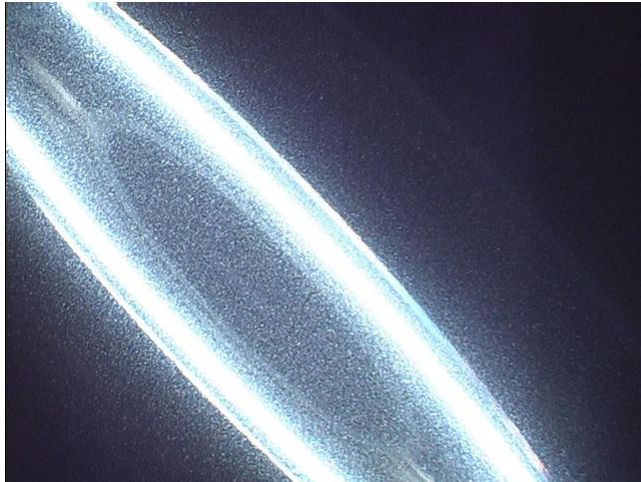
Post-Test (20x)

Post-test very fine scratches observed.

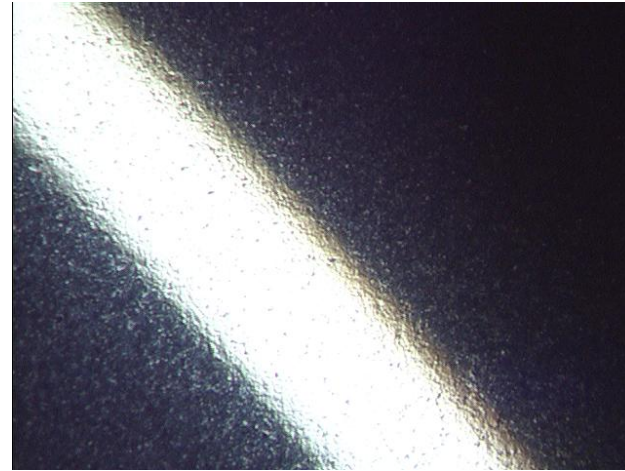


Post-Test (100x)

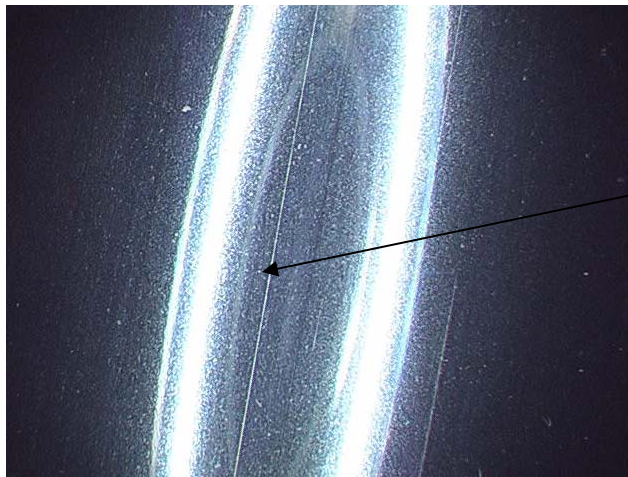
Rod #3 HVOF 8-10 Ra Ground w/ SF 2 Ra



Pre-Test (20x)

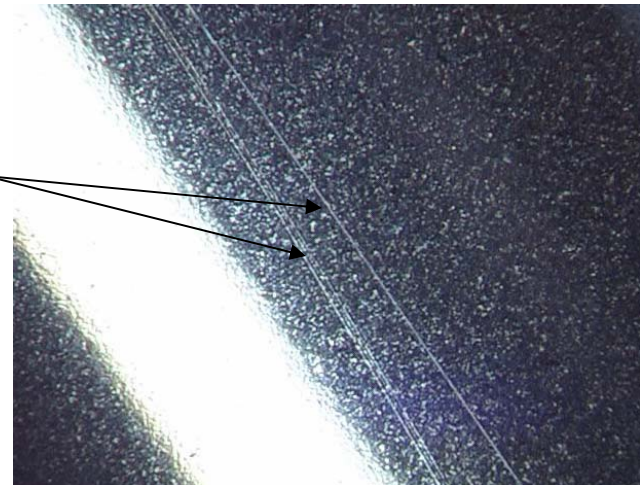


Pre-Test (100x)



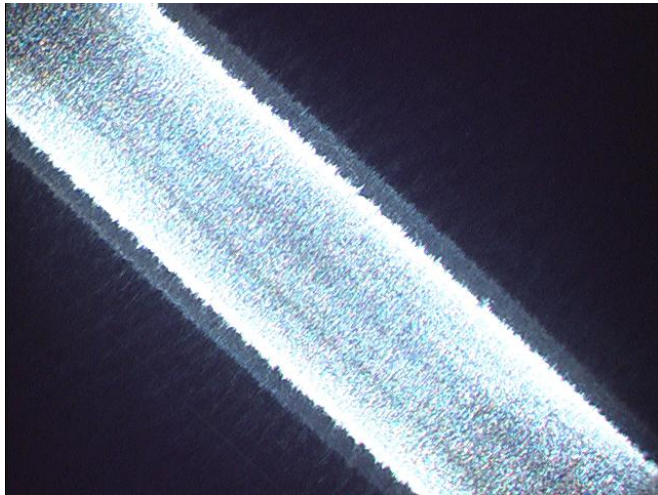
Post-Test (20x)

Post-test very fine scratches observed.

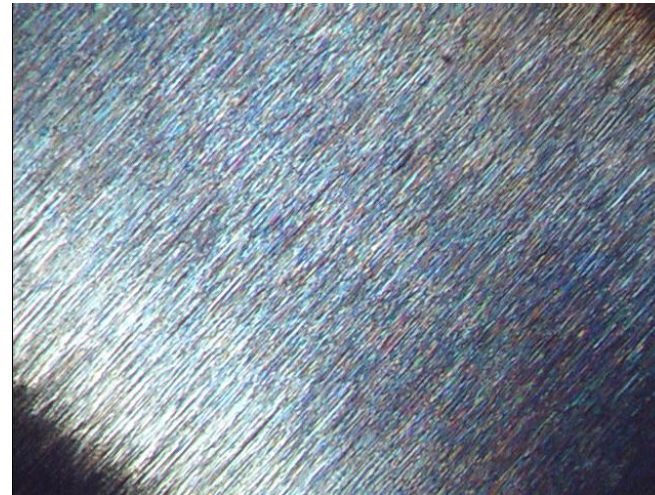


Post-Test (100x)

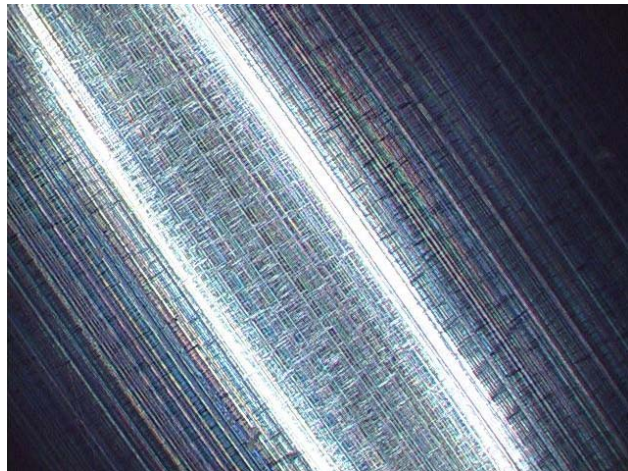
Rod #4 Chrome 12-15 Ra As-Ground



Pre-Test (20x)

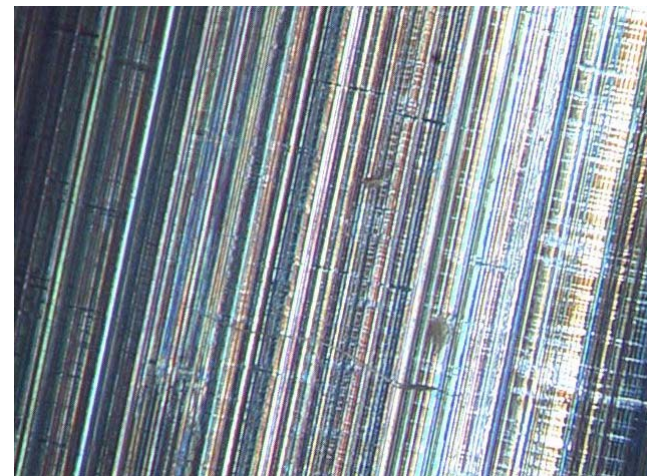


Pre-Test (100x)



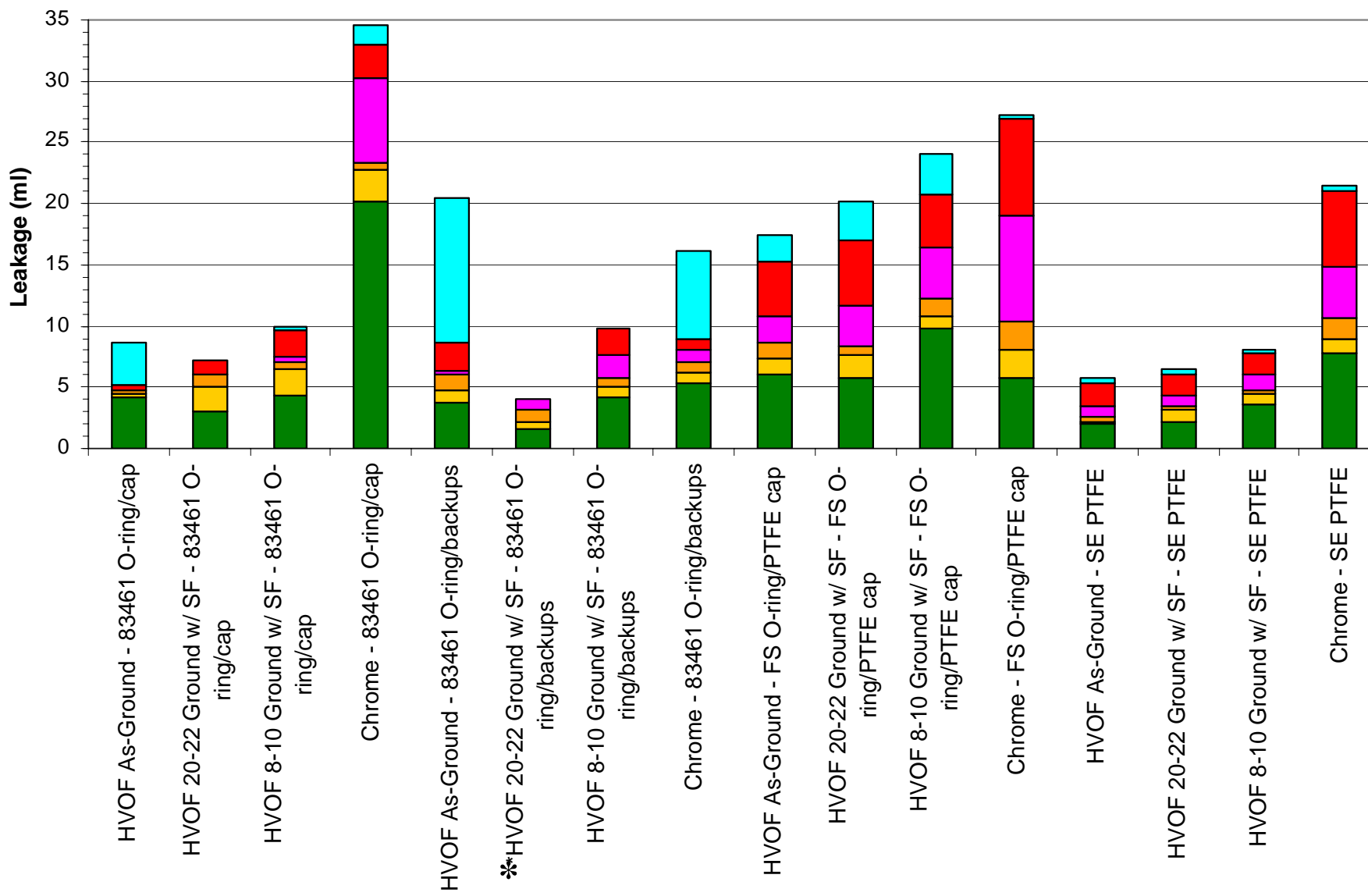
Post-Test (20x)

Post-test linear scratches observed.



Post-Test (100x)

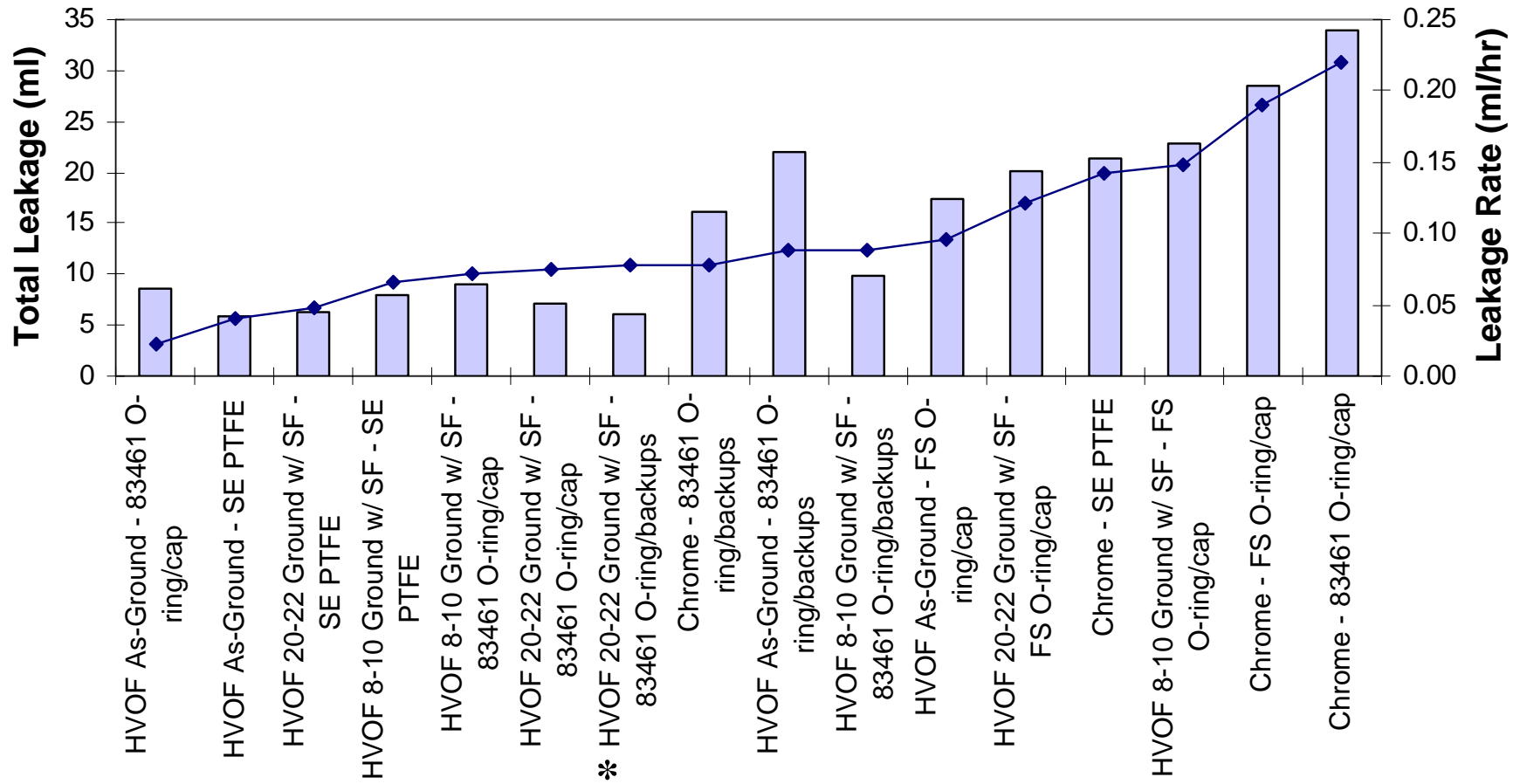
Temperature Profile Leakage



* Incomplete test duration

■ 160F; 59 hrs
 ■ 200F; 10 hrs
 ■ 225F; 10 hrs
 ■ 250F; 20 hrs
 ■ 275F; 20 hrs
 ■ -40; 5 hrs

Seal/Rod Combo Leakage Summary

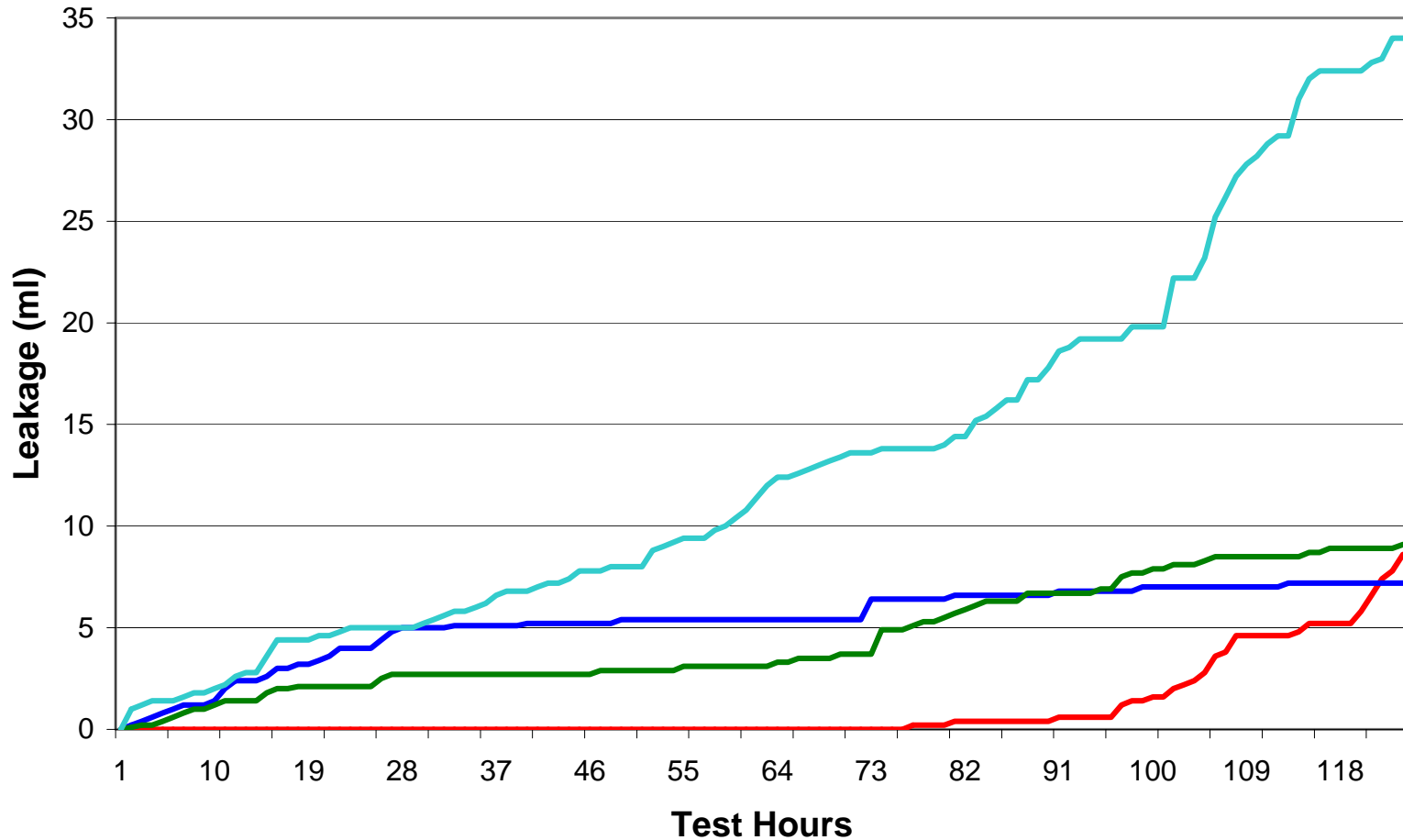


* Incomplete test duration

Total Leakage
 Leakage Rate

Rod/Seal Leakage

MIL-P-83461 O-ring w/ Capstrip Vs 4 Rods



— HVOF As-Ground — HVOF 20-22 Ground w/ SF — HVOF 8-10 Ground w/ SF — Chrome

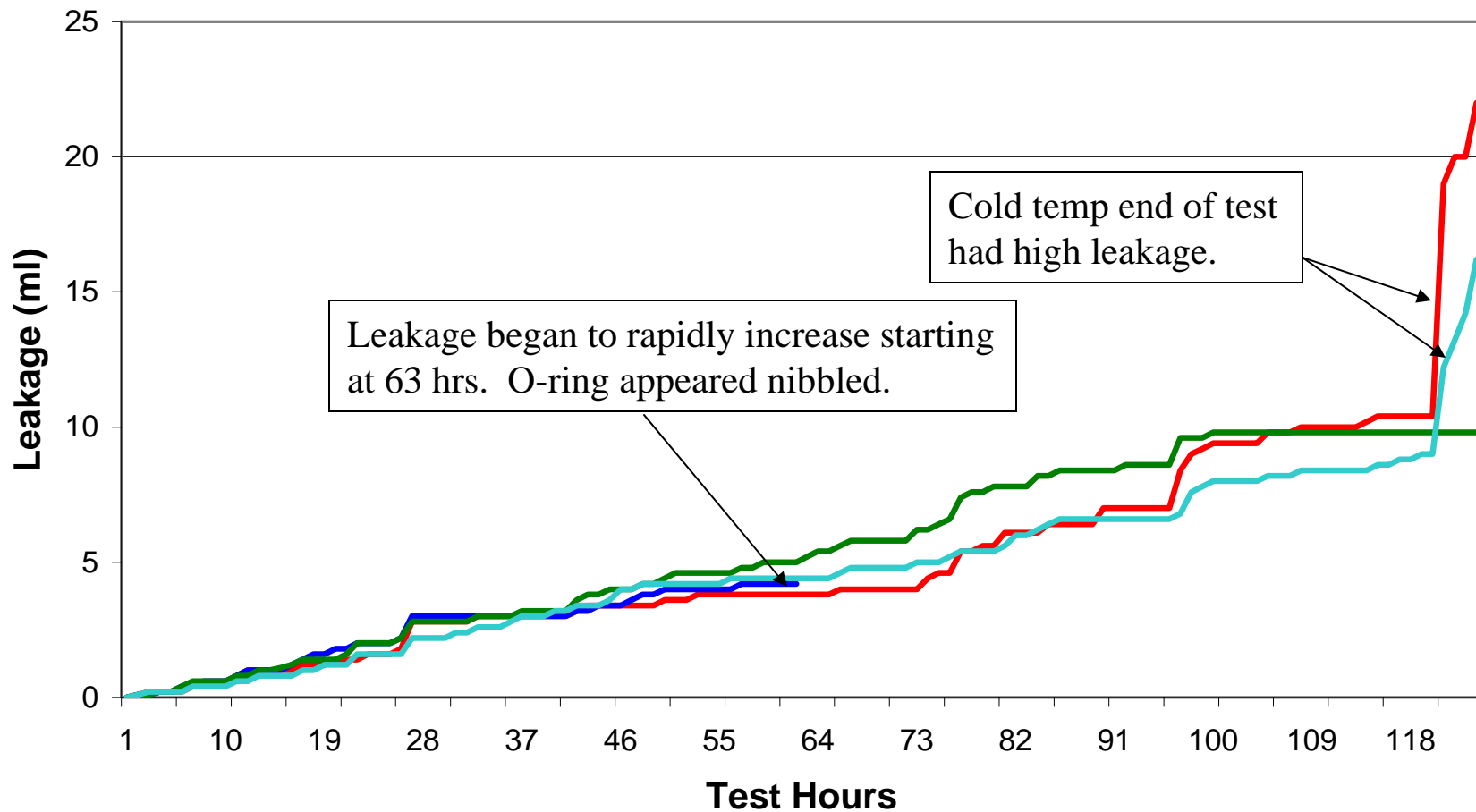
HCAT March 2005
Greensboro, NC



Jeff Gribble
NAVAIR-PAX Hydraulic Systems

Rod/Seal Leakage

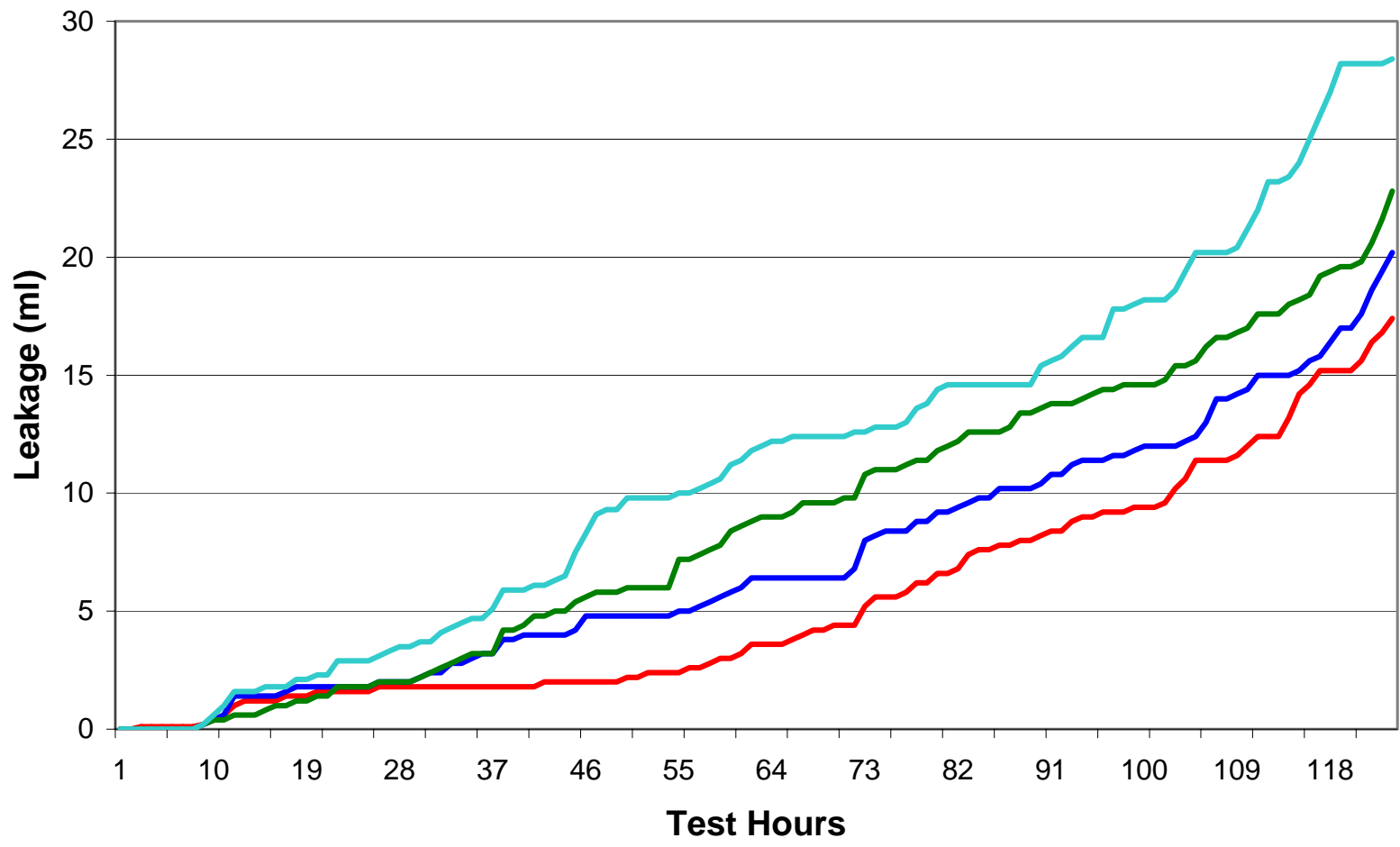
MIL-P-83461 O-ring w/ 2 backup ring Vs 4 Rods



— HVOF As-Ground — HVOF 20-22 Ground w/ SF — HVOF 8-10 Ground w/ SF — Chrome

Rod/Seal Leakage

Fluorosilicone O-ring w/ PTFE Cap Vs 4 Rods



— HVOF As-Ground
 — HVOF 20-22 Ground w/ SF
 — HVOF 8-10 Ground w/ SF
 — Chrome

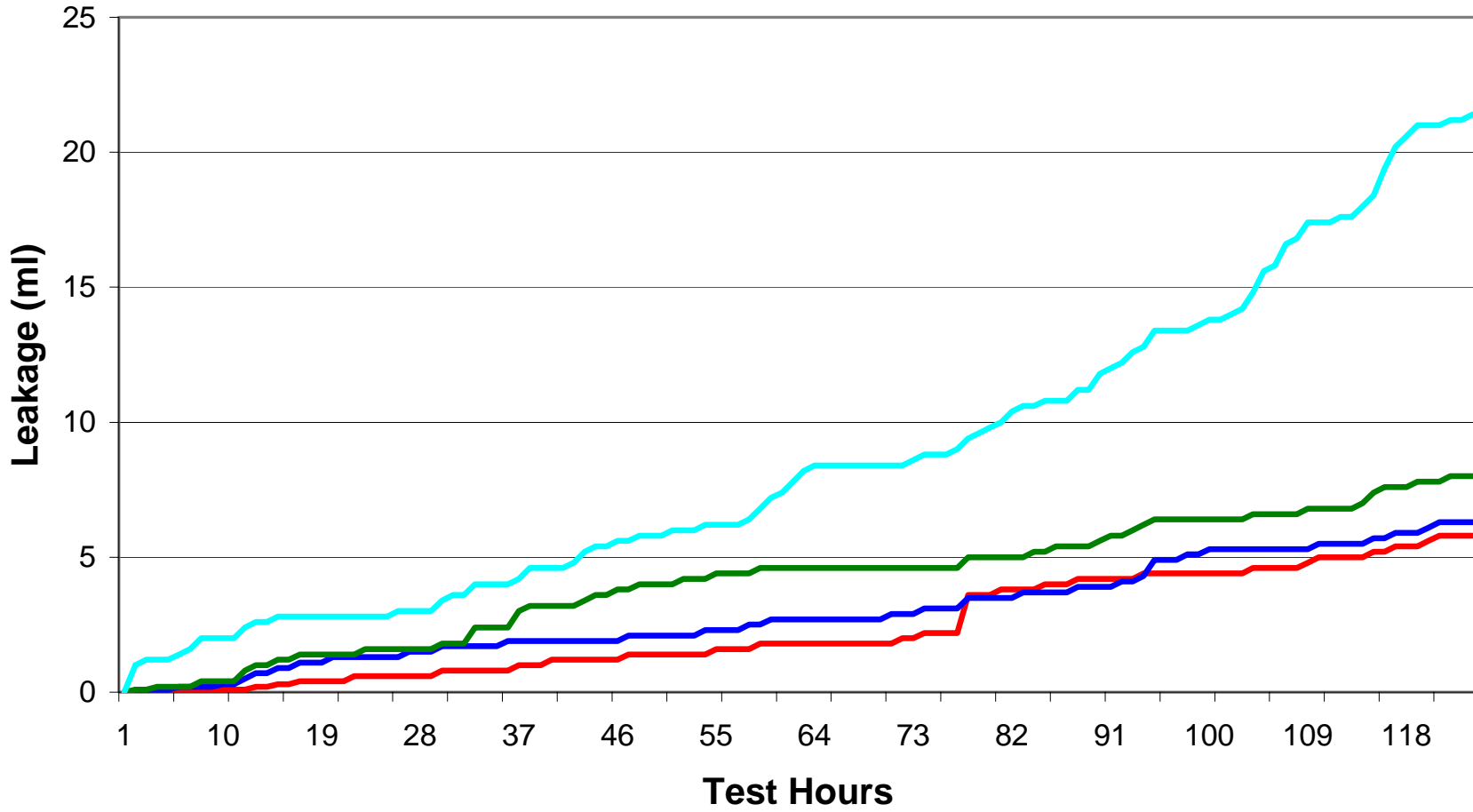
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Jeff Gribble
NAVAIR-PAX Hydraulic Systems

Rod/Seal Leakage

Spring Energized PTFE Vs 4 Rods



— HVOF As-Ground
 — HVOF 20-22 Ground w/ SF
 — HVOF 8-10 Ground w/ SF
 — Chrome

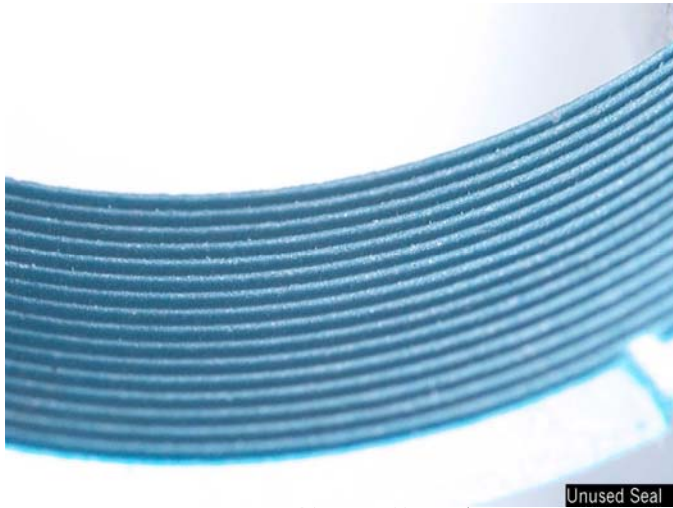
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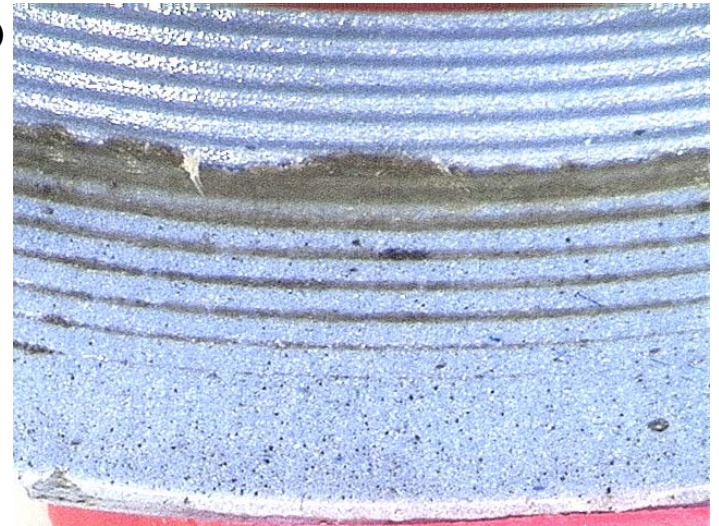
PTFE Cap Seal Wear

(FS O-ring with PTFE Cap)

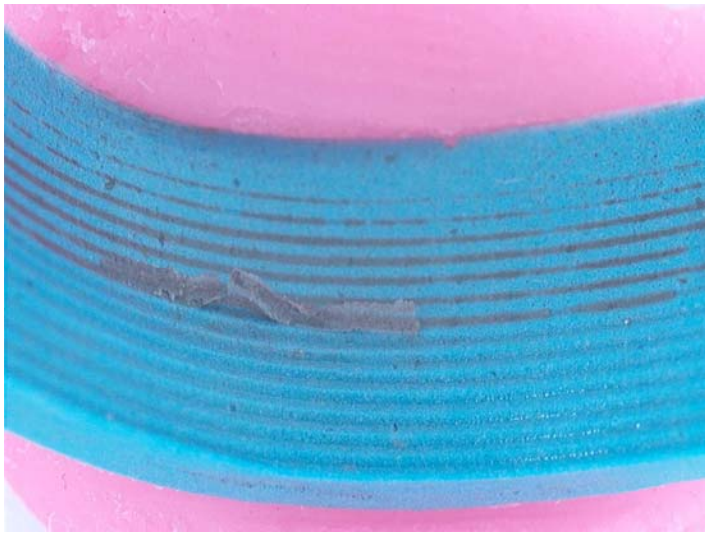


New Cap Seal

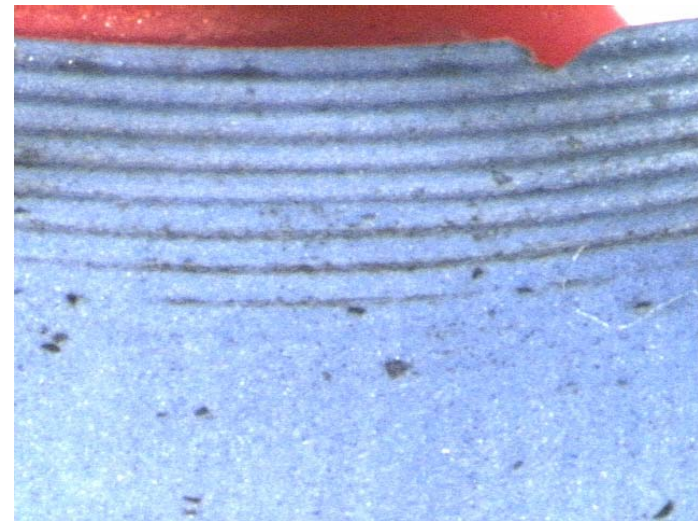
Unused Seal



Cap with HVOF 8-10 Ground w/ SF Rod



Cap with HVOF 20-22 Ground w/ SF Rod



Cap with Chrome Rod

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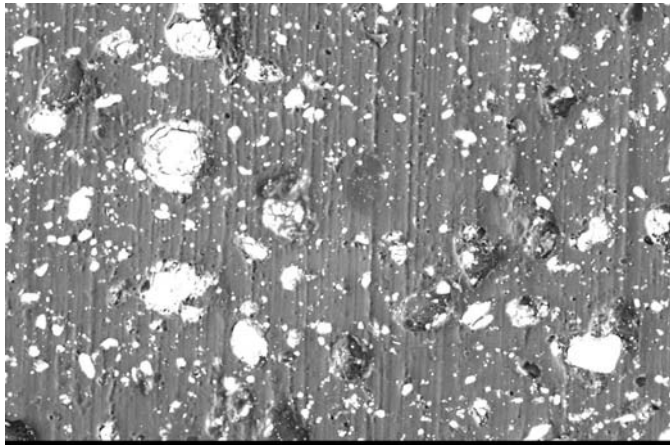


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SEM Axial Scratches

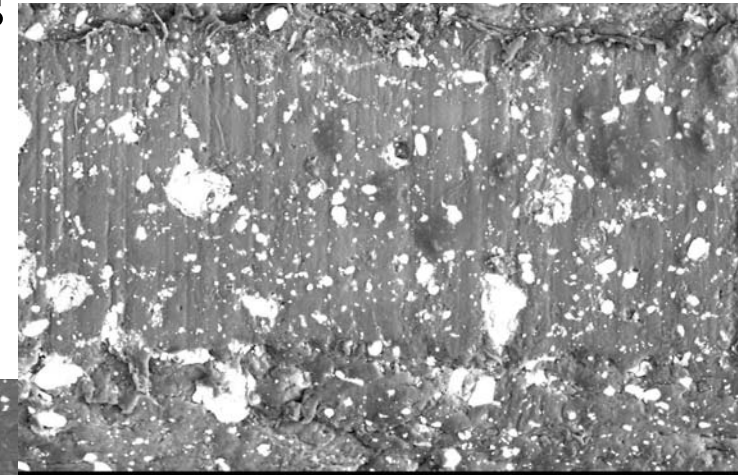
PTFE Cap Seal

(FS O-ring/PTFE Cap)



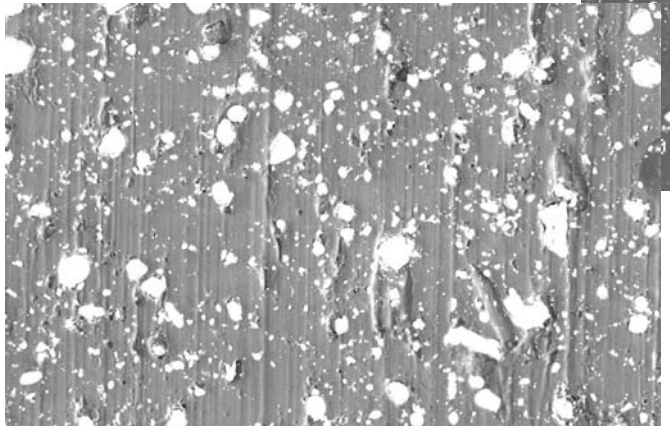
20kV X250 100µm 0000 NAVAIR-PAX

Cap with HVOF 8-10
Ground w/ SF Rod



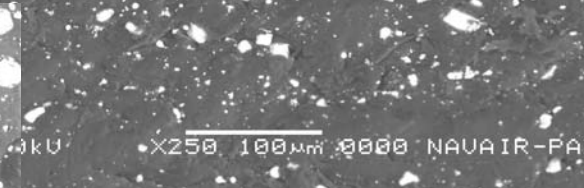
20kV X250 100µm 0000 NAVAIR-PAX

Cap with HVOF 20-22
Ground w/ SF Rod

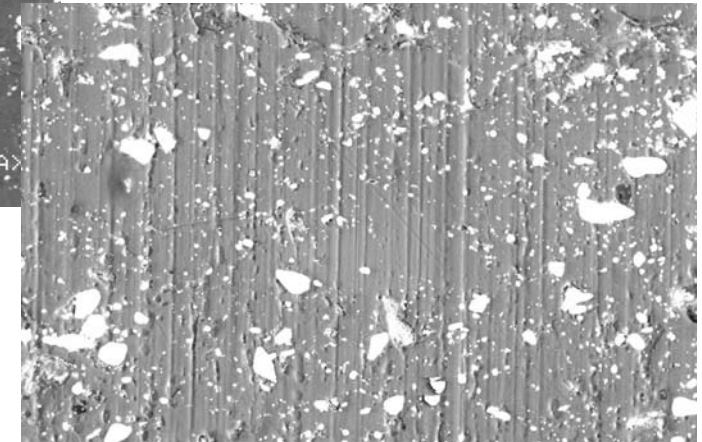


20kV X250 100µm 0000 NAVAIR-PAX

Cap with HVOF As-Ground Rod



New Cap Seal



20kV X250 100µm 0000 NAVAIR-PAX

Cap with Chrome Rod

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Relative Comparison of Rod / Seal Configurations

SEAL/ROD CONFIGURATIONS	COLD TEMP (-40 F) LEAKAGE	HOT TEMP (250 and 275 F) LEAKAGE	TOTAL LEAKAGE	TREND LEAKAGE RATE
HVOF As-Ground - MIL-P-83461 O-Ring w/ Cap	Moderate	Low	Low	Low
HVOF 20-22 Ground w/ SF - MIL-P-83461 O-Ring w/ Cap	None	Low	Low	Low
HVOF 8-10 Ground w/ SF - MIL-P-83461 O-Ring w/ Cap	Low	Low	Moderate	Low
Chrome - MIL-P-83461 O-Ring w/ Cap	Low	High	High	High
HVOF As-Ground - MIL-P-83461 O-Ring w/ 2 Backup Rings	High	Low	High	Moderate
HVOF 20-22 Ground w/ SF - MIL-P-83461 O-Ring w/ 2 Backup Rings	N/A	N/A	N/A	Low
HVOF 8-10 Ground w/ SF - MIL-P-83461 O-Ring w/ 2 Backup Rings	None	Moderate	Moderate	Moderate
Chrome - MIL-P-83461 O-Ring w/ 2 Backup Rings	High	Low	Moderate	Low
HVOF As-Ground - Fluorosilicon O-ring w/ PTFE Cap	Low	Moderate	Moderate	Moderate
HVOF 20-22 Ground w/ SF - Fluorosilicon O-ring w/ PTFE Cap	Moderate	High	High	Moderate
HVOF 8-10 Ground w/ SF - Fluorosilicon O-ring w/ PTFE Cap	Moderate	High	High	High
Chrome - Fluorosilicon O-ring w/ PTFE Cap	Low	High	High	High
HVOF As-Ground - Spring Energized PTFE	Low	Low	Low	Low
HVOF 20-22 Ground w/ SF - Spring Energized PTFE	Low	Low	Low	Low
HVOF 8-10 Ground w/ SF - Spring Energized PTFE	Low	Moderate	Low	Low
Chrome - Spring Energized PTFE	Low	High	High	High
<u>HOT/COLD TEMP LEAKAGE</u>	<u>TOTAL LEAKAGE</u>		<u>TREND LEAKAGE RATE</u>	
Low – less than 3 ml	Low – less than 9 ml		Low – less than 0.08 ml/hr	
Moderate – 3 to 7 ml	Moderate – 9 to 20 ml		Moderate – 0.08 to 0.14 ml/hr	
High – greater than 7 ml	High – greater than 20 ml		High – greater than 0.14 ml/hr	

Ranking	Rod/Seal Configuration
Superior Performance	HVOF 20-22 Ground w/ SF with MIL-P-83461 O-Ring/Cap HVOF As-Ground with Spring Energized PTFE HVOF 20-22 Ground w/ SF with Spring Energized PTFE HVOF 8-10 Ground w/ SF with Spring Energized PTFE HVOF As-Ground with MIL-P-83461 O-Ring/Cap HVOF 8-10 Ground w/ SF with MIL-P-83461 O-Ring/Cap
Fair Performance	* HVOF 8-10 Ground w/ SF with MIL-P-83461 O-Ring/2 Backup Rings HVOF As-Ground with Fluorosilicon O-ring/PTFE Cap * Chrome with MIL-P-83461 O-Ring/2 Backup Rings * HVOF As-Ground with MIL-P-83461 O-Ring/2 Backup Rings HVOF 20-22 Ground w/ SF with Fluorosilicon O-ring/PTFE Cap
Worst Performance	Chrome with MIL-P-83461 O-Ring/Cap Chrome with Fluorosilicon O-ring/PTFE Cap Chrome with Spring Energized PTFE HVOF 8-10 Ground w/ SF with Fluorosilicon O-ring/PTFE Cap

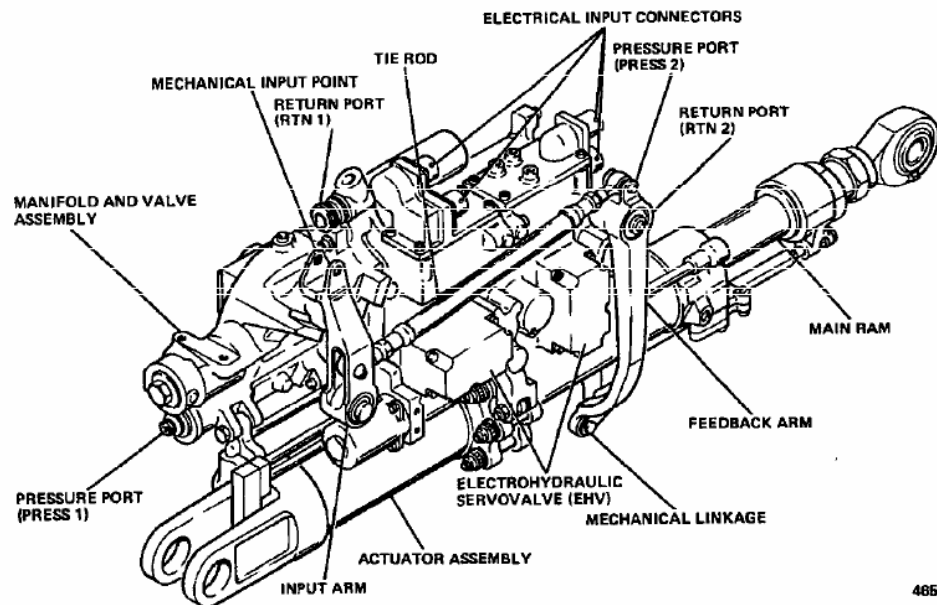
* O-ring w/ backup ring config had seals replaced during test.

F/A-18 C/D Stabilator Actuator

- Based on laboratory results, fluorocarbon static seals and PTFE spring energized dynamic seals in primary and secondary glands were selected.
- Rebuild kits for F/A-18 C/D stabilator actuator were developed by three seal vendors using hardware dimensions.
- Seal kits showed no external leakage and acceptable internal leakage after endurance testing. Post-test leakage was within ATP limits.
- Follow-on testing evaluated HVOF coated rod against these seals.
 - HVOF Coat short external end with WC/Co/Cr 86/10/4
 - HVOF Coat longer internal end with WC/Co 83/17
 - Ground to 8 - 16 μin Ra finish and superfinish to ≤ 2 μin Ra finish
- Leakage performance was equivalent to chrome plated rod.

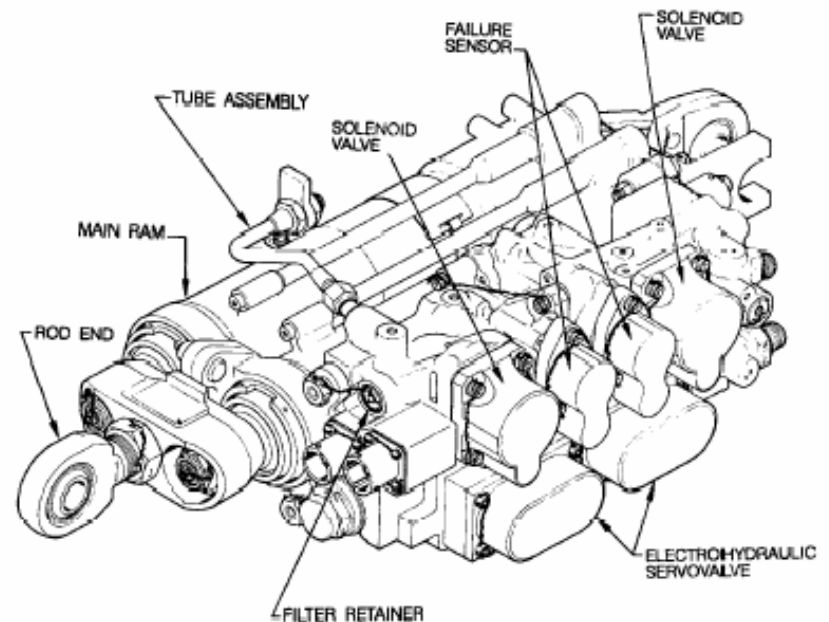
F/A-18 C/D Stabilator Actuator Continued

- STAB actuator testing is complete and report is finalized by NAVAIR.
- ECP-950 validation is complete. Verification (reviewing component process procedure) has not been performed. Currently have seal kits and are awaiting installation tooling. This will be done at JAX.



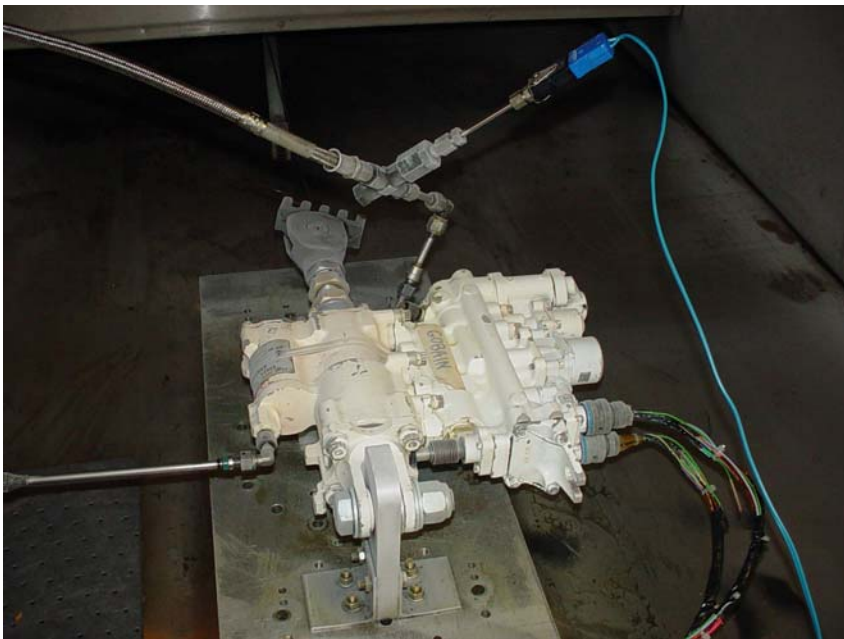
F/A-18 C/D Trailing Edge Flap

- Same dynamic and static seal materials used for TEF as proven on STAB.
- Side by side design allows one chrome rod and one HVOF rod to evaluate seals against both rod surfaces.
 - HVOF Coat OD of Piston Rod with WC/Co/Cr 86/10/4
 - Ground to 8 - 16 μin Ra finish and superfinish to $\leq 2 \mu\text{in}$ Ra finish
- Endurance testing of TEF is complete and report is currently being written.
- ECP validation and verification is not complete. Awaiting seal kits at NADEP North Island.



F/A-18 C/D Rudder and Aileron

- End gland for the chrome piston rod have a SE PTFE in the primary gland. The secondary gland is an o-ring with PTFE capstrip.
- Testing began this week at PAX.
- Seal upgrade may need further delta testing with HVOF coated rod qualification or similarity qualification may be acceptable with analysis.



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 **HCAT**
U.S. - CANADIAN
HARD CHROME ALTERNATIVES TEAM

Jeff Gribble
NAVAIR-PAX Hydraulic Systems

H-60 Main Rotor Servo-Actuator

- Investigate, evaluate, and qualify improved technology seals with HVOF rod coatings for joint Armed Services. Leveraging data from F/A-18 seal efforts to provide candidates for H-60.
- OEM perform Engineering Investigation on both Army and Navy primary and tail rotor servos to substantiate reliability data, determine root cause of leakage, and determine if additional changes would be recommended.
 - EI includes: test fluid sample, conduct ATP, analyze dynamic seals, provide final report.
 - Current proposal includes piston gland change, new seal material and configuration, and utilization of tungsten carbide cobalt chrome rod coating vice existing chrome.
 - Perform qualification test of current configuration in parallel with modified servo to establish baseline and quantify performance improvement of modifications.
 - Proposed Qual test includes: ATP (pre and post test), fully loaded endurance testing with sand, dust, salt fog and temps from -65 to 275 degrees F.

Functional Rod/Seal Test Phase II Plan Ahead

- Decide on seal and rod configurations to be evaluated.
- Petition seal vendors for seals and obtain desired rods to support test.
- Order up a new control valve and positioning sensor.
- Setup and begin testing by August 2005.
- Report Phase II results at Jan 2006 HCAT Conference.
- Document Phase I and II results in final report. Results to include the characterization of the rods and seals, measurements of fluid leakage, and noteworthy seal wear and rod finish traces.