HCAT
U.S. - CANADIAN
HARD CHROME ALTERNATIVES TEAM

Hard Chrome Alternatives Team - Tri-Service Validation of HVOF Thermal Spray as a Chrome Replacement for Aircraft

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Naval Research Lab

Keith Legg

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RUST 2001

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Linking Global Technologies with Markets

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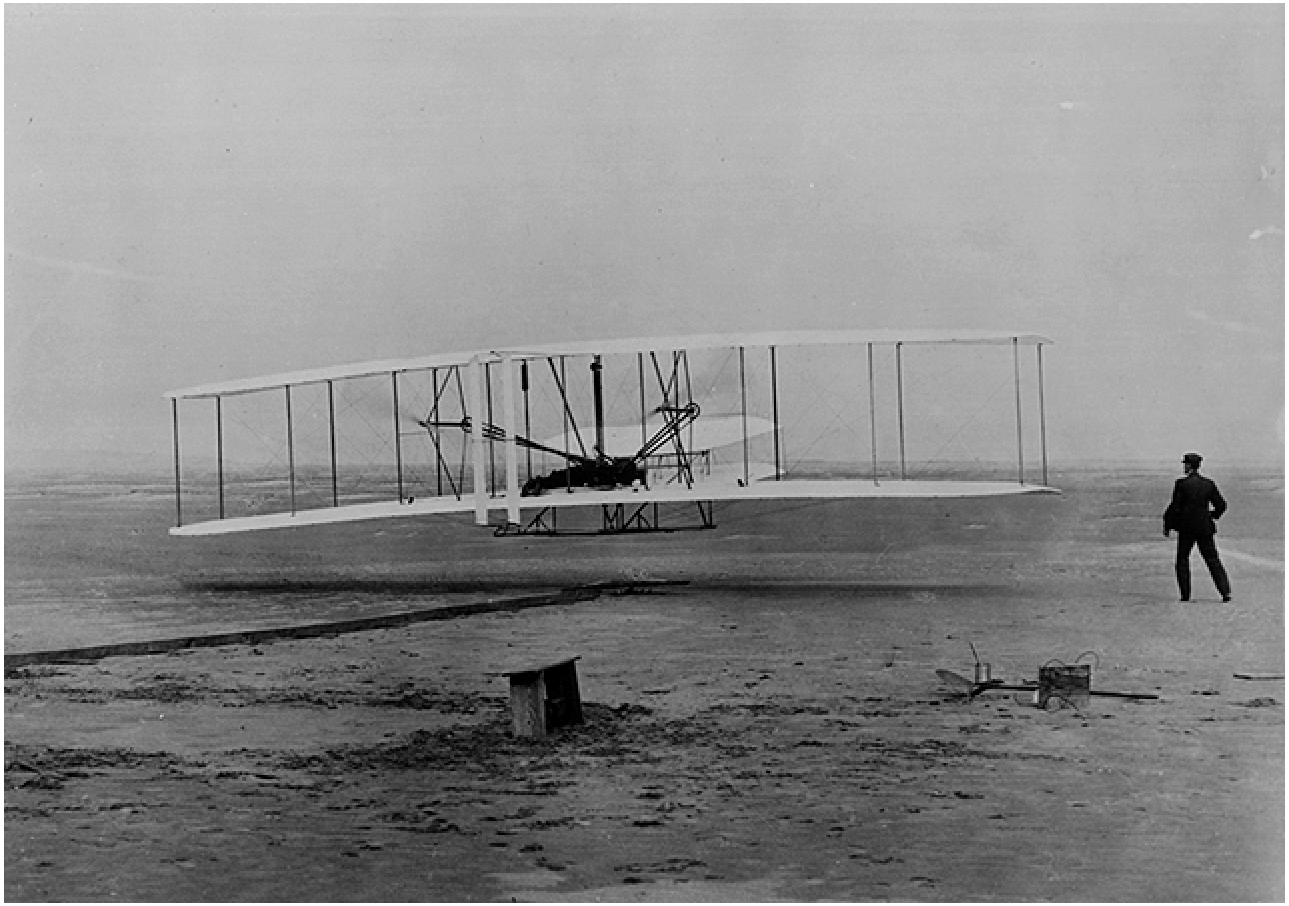
The last aircraft made without Cad and hard Cr



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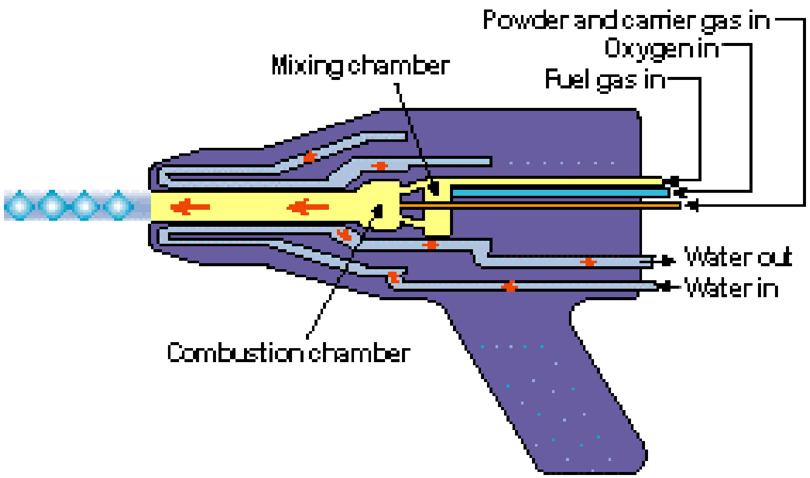
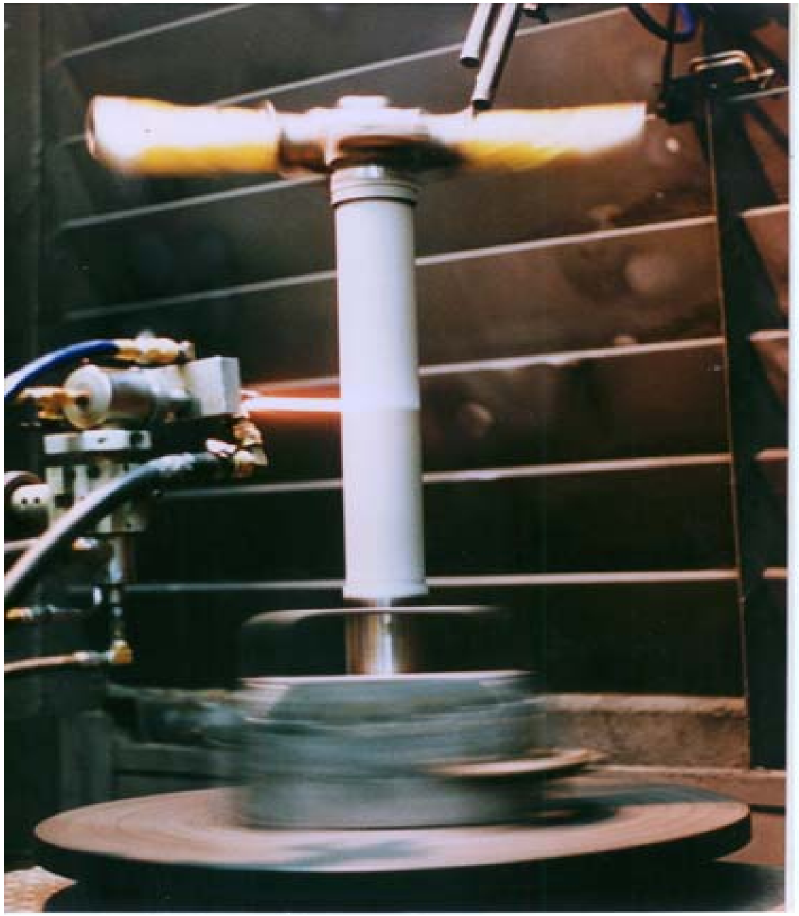
HVOF process



- Supersonic fuel-oxygen flame (H2, kerosene, ethylene, acetylene)
- WC-Co or alloy powder



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Successful replacements - specs and qualified components

- **Specifications**
  - BAC 5851 - new version
  - HS 4412
  - AMS 2447
  - New AMS specs for powders, coating, finishing expected 2000 - 2001

- **Qualifications - new items**
  - Boeing > 100 airframe components spec'd for thermal spray
  - Boeing 767-400 has landing gear spec'd for HVOF WC-CoCr
  - Bombardier Q400, Global Express flap tracks HVOF, replacing electroless Ni
  - Hamilton Sundstrand - F-22 thrust vectoring actuator
  - Parker - no Cr on new hydraulic actuator

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Qualifications - repair

- Boeing - HVOF approved for LG repair up to 0.010"
  - Boeing evaluating thick build-up methods
- Delta - approved HVOF for landing gear repair
  - inner cylinders and axles
- United - moving toward in-house HVOF for LG
- F-18 polygon repair
- TWI (UK) L-1011 Ti flap track repair (weld + HVOF WC-Co)

e

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Purpose of the HCAT program

- **Demonstrate and validate HVOF coatings for replacement of hard chrome on aircraft systems**
- **Incorporate all the major stakeholders to ensure that the data will lead to approval**
  - **Get all the relevant technical data**
  - **Address all major producibility issues - grinding, finishing, stripping, O&R compatibility**

Environmental Security Technology Certification Program

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Approach

- Stakeholders
  - Agreement to Joint Test Protocol by all major stakeholders
    - Approval authorities (NAVAIR, ATCOM, etc.)
    - OEMs (Boeing, Lockheed, Goodrich, etc.)
    - Depots (ALCs, NADEPs, Army depots)
      - include technical, management
- Across-the-board change will not be accepted, item-by-item too slow and expensive
- Attack by sub-system
  - common stakeholders
  - common technical issues
  - limited number of bases, suppliers
- Implementation
  - Single process initiative

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HCAT - aircraft systems being validated

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- **Landing gear**
  - Close to completion
- **Propeller hubs**
  - Close to completion
- **Hydraulic actuators**
  - Just starting - JTP being develo
- **Gas turbine engines**
  - JTP almost complete
- **Helicopter head components**
  - Planned

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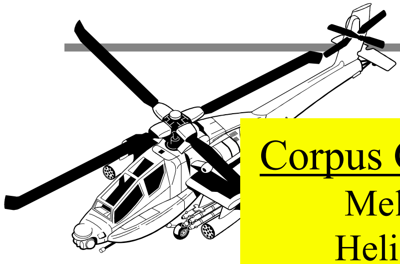
HCAT - US Team

Note: All depots have HVOF
Depot training by GEAE



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Embrittlement, impact

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C-HCAT - Canadian Team

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Producibility

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Process development

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Data being generated

Mostly landing gear

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Materials

- **Substrates**
  - 4340
  - 300M
  - Aermet 100
  - Early evaluations included
    - 7075-T6 Aluminum
    - PH 13-8Mo
    - IN 718
  - GTE evaluations will include IN 718, IN 901, AMS355, A286, 17-4PH, 4340, 9310
- **Coatings**
  - WC-17Co
  - WC-10Co4Cr
  - Tribaloy 400, 800
- **GTE evaluations will include Cr_3C_2-(Ni, Cr)**
- **Note: these are based on experience and are not the only options**

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How good is Cr anyway?

- Aircraft industry has long experience but very little hard data
  - good adhesion, wear, lubricity
  - very variable quality
  - significant fatigue debit
  - not useful for corrosion protection (microcracks)
  - hydrogen embrittlement and rapid environmental embrittlement

- Hard chrome has been in production since 1928
- But Cr is not the cat's pajam

Results

Optimization - common guns, fuels
Properties - structure, hardness, adhesion
Performance:
- Fatigue
- Corrosion
- Wear
- Impact
- Embrittlement
- Rig tests
  - landing gear fatigue, endurance
  - hydraulic cylinder
  - turbine engine
  - propeller hub
- Flight tests (commercial, DoD)

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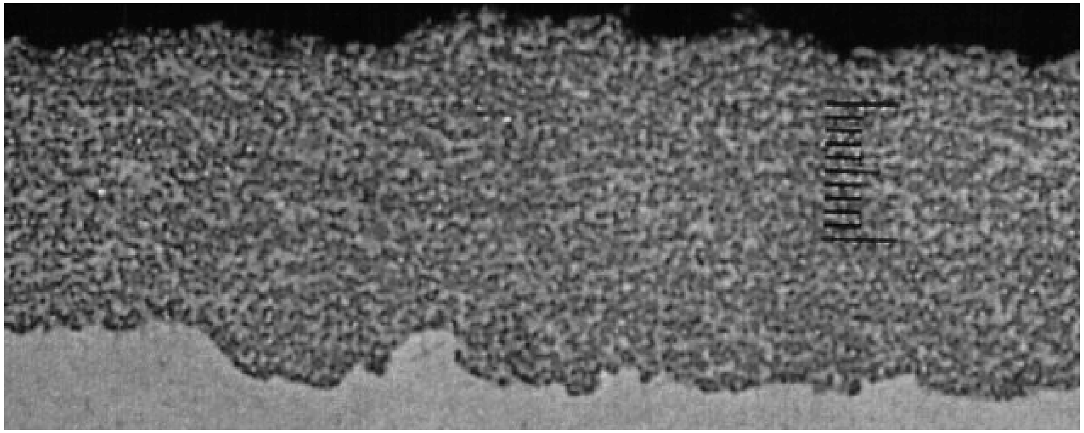
User requirements - landing gear

- **Commercial**
  - Typically 100 ksi, R=0.1, thousands of cycles
  - Maximum 170 ksi, R=0.1
- **Land-based military**
  - 190 ksi, R=-0.33, 1,000cycles (Air Force)
- **Carrier-based military**
  - NLG Pins 235 ksi launch loads, R=-0.5, 2,250 cycles, (OEMs)
  - Pistons 240 ksi, R=-1
- **OEMs**
  - 0.003”
- **Airlines**
  - 0.010” or thicker for MRO
- **Repair Depots**

Yield stresses:
4340M = 220 ksi
300M = 230 ksi
A100 = 235 ksi

Process development

- WC-Co, WC-CoCr, T400 processes developed by Design of Experiment
  - Porosity - <1% to minimize corrosion and hydraulic leakage
  - Stress - compressive to minimize fatigue debit
  - Substrate softening



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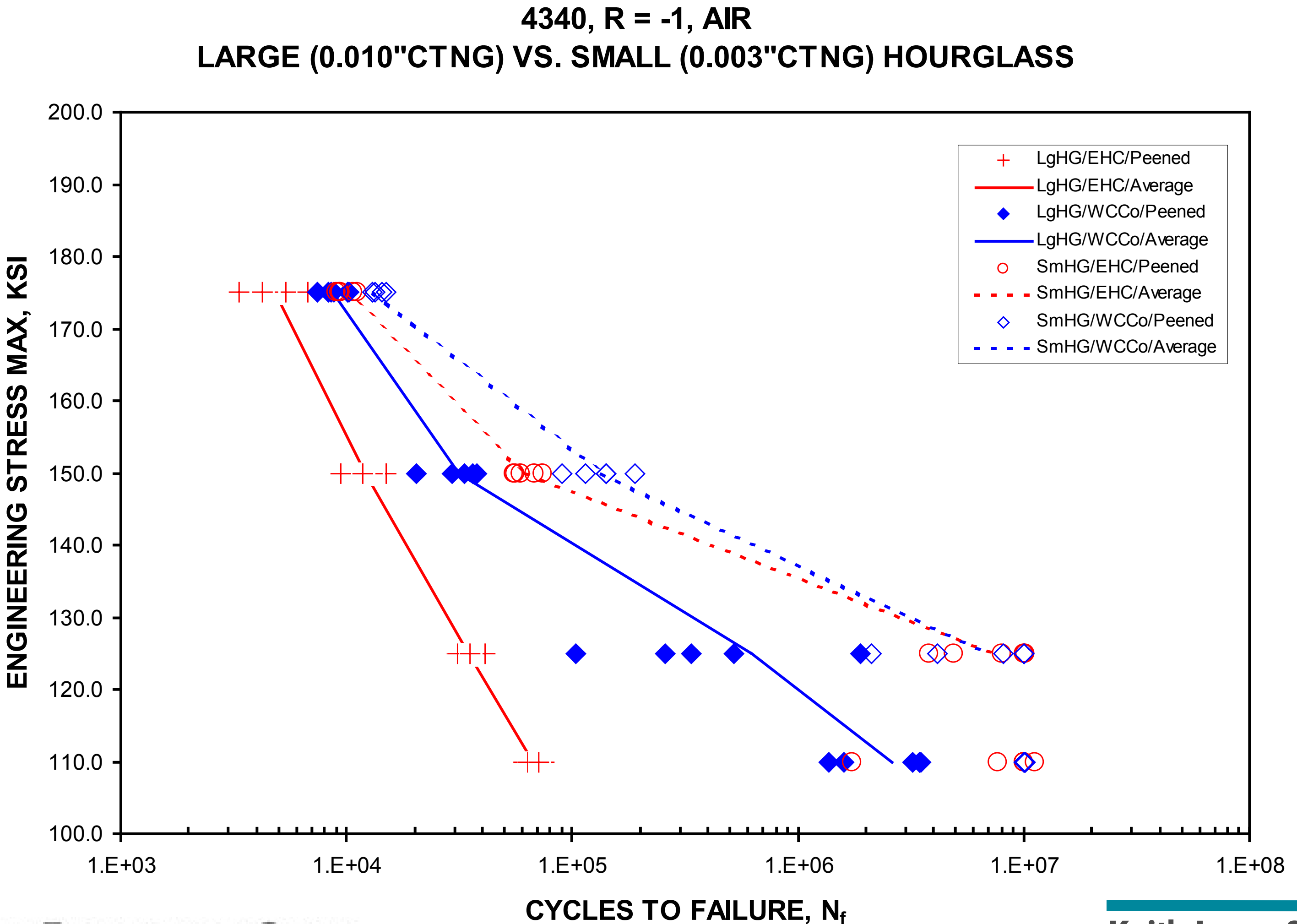
HCAT Landing gear fatigue - 4340



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Fatigue summary

- HVOF can greatly reduce, or even eliminate, fatigue debit
  - Process definition and control are <u>very</u> important
    - Must ensure compressive residual stress in coating and avoid overheating
  - Coatings crack at high stress, but fatigue and corrosion fatigue remain excellent
    - Chrome is already cracked, of course
  - WC-Co and WC-CoCr coatings are brittle, and can spall if used under high stress
    - Appears significant only for carrier aircraft landing gear

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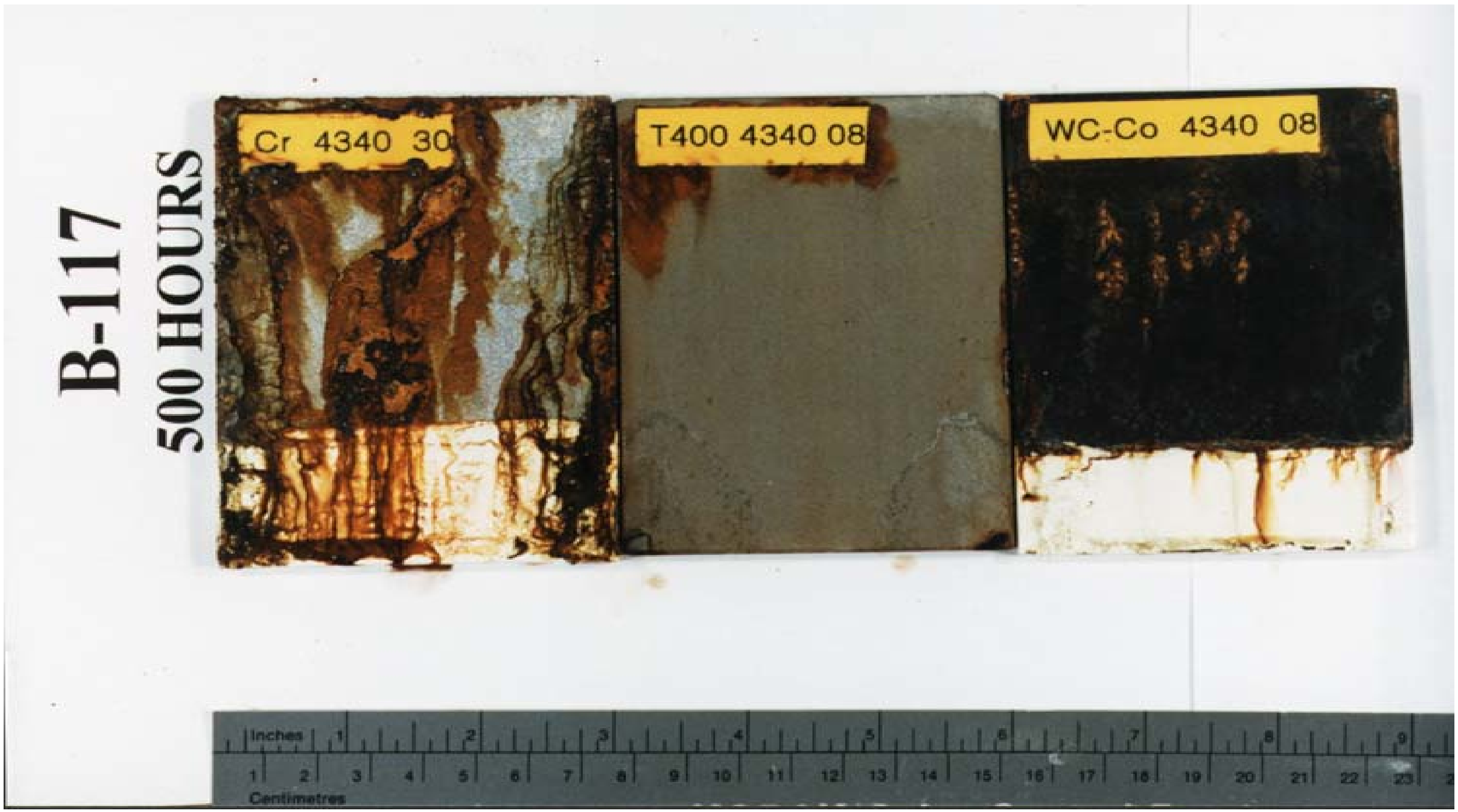
Corrosion - early B117 data



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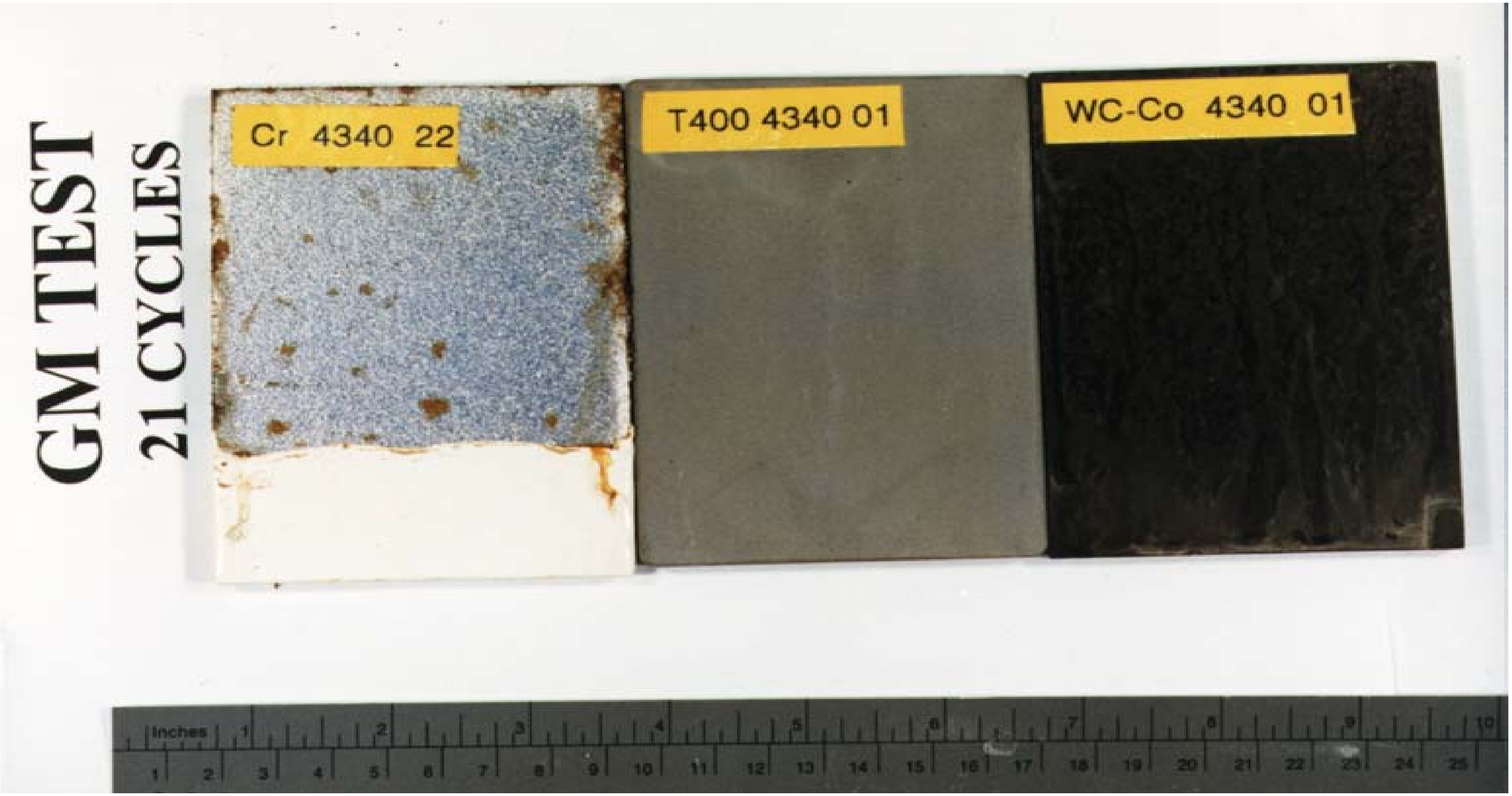
HVOF and Cr after 3 yr beach exposure and cleaning

Corrosion - GM test data



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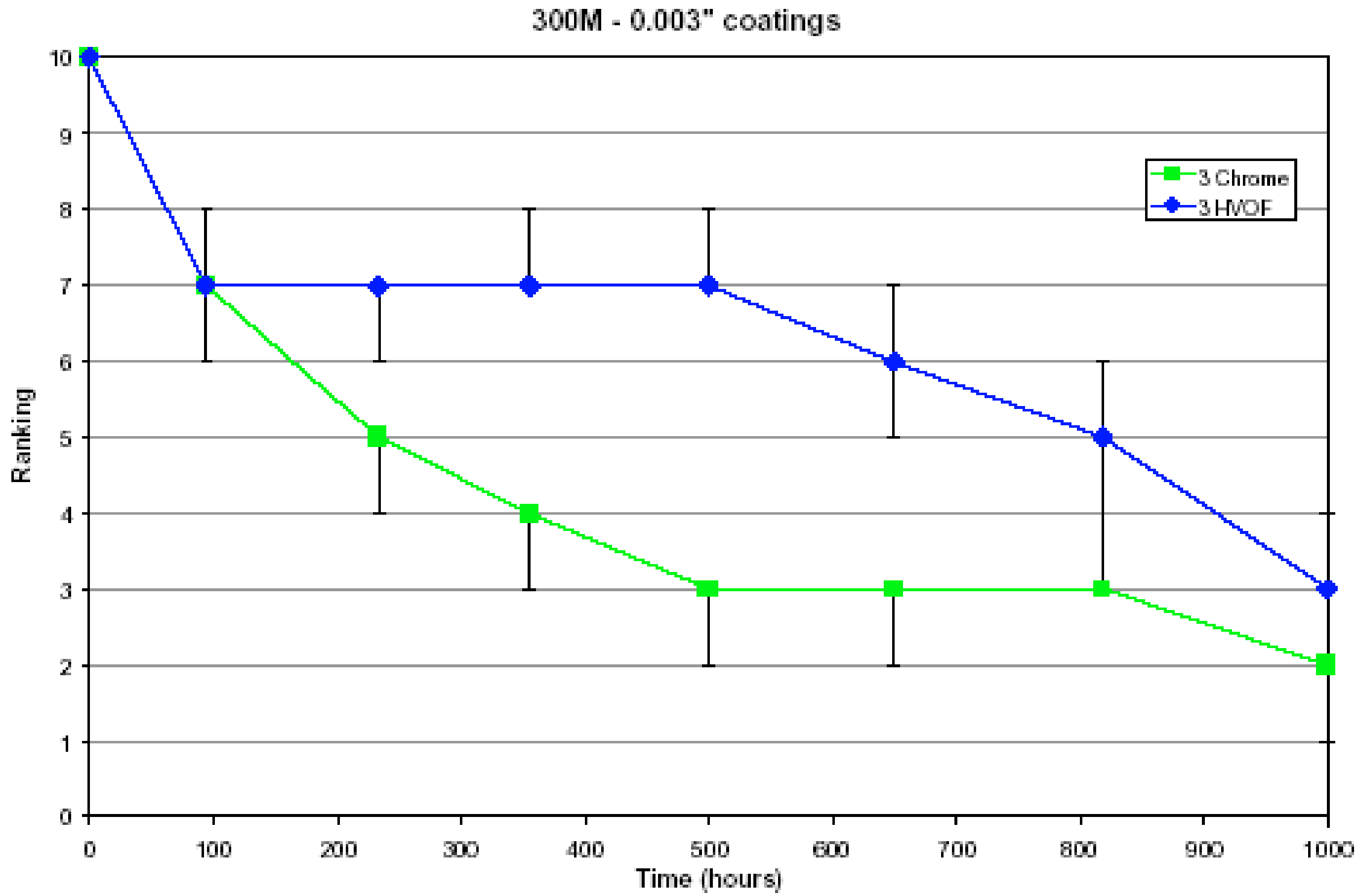
C-HCAT data



0.003" HVOF - 1000 hour

0.003" Cr - 1000 hours

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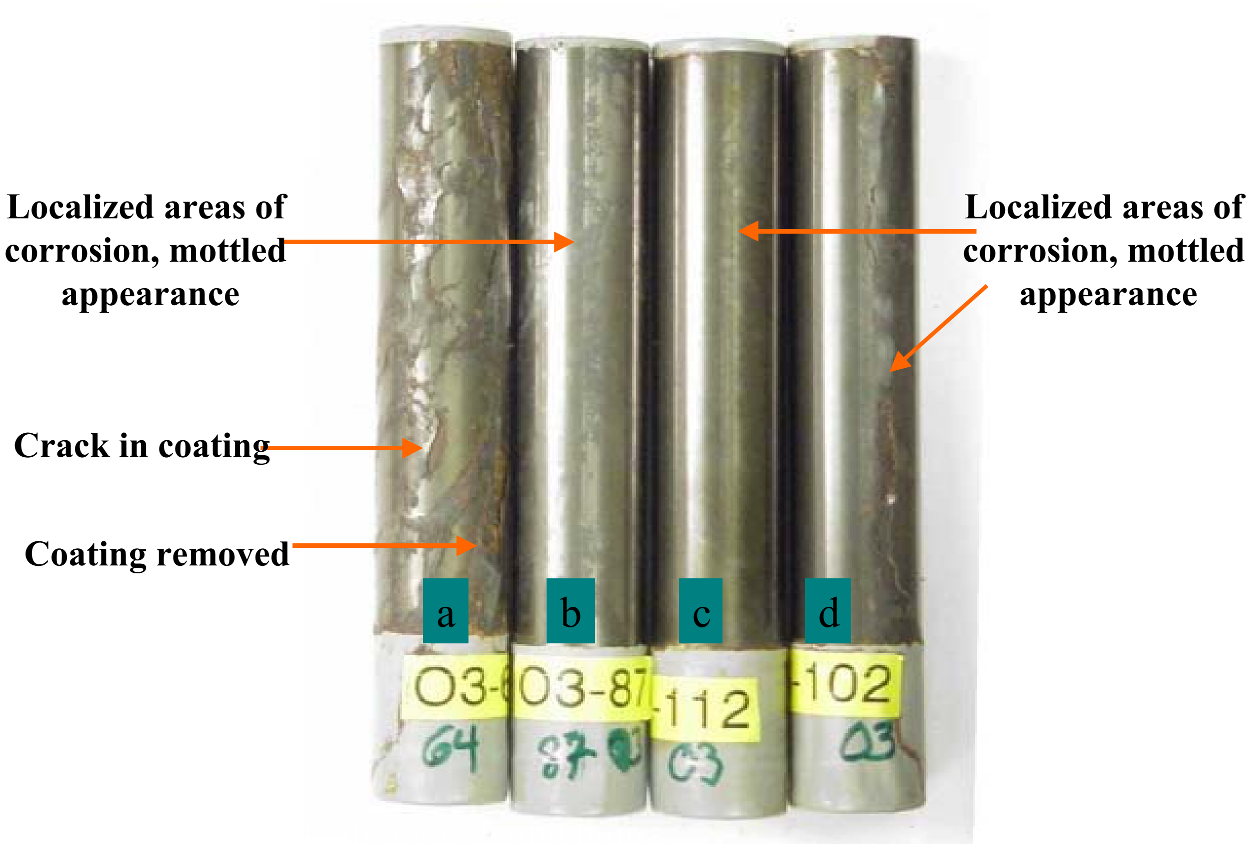
HCAT B117 on rods not consistent



- **Reason for inconsistency still being evaluated**

HVOF coatings on 4340 steel after the B117 test : a) 3mil WC/Co, b) 10 mil WC/Co,c) 10 mil WC/Co-Cr, and (d) 3 mil WC/Co-Cr

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Corrosion summary

- Lufthansa, Delta and most other commercial users have chosen WC-CoCr for landing gear because of better corrosion performance
- All flight experience shows good corrosion
- Beach exposure shows good corrosion
- C-HCAT results show HVOF better than Cr
- Most lab data shows HVOF coatings to be better in corrosion than chrome
  - Latest HCAT B117 and B117-SO_2 show HVOF worse
    - inconsistent with B117 and beach exposure
    - may be a testing problem

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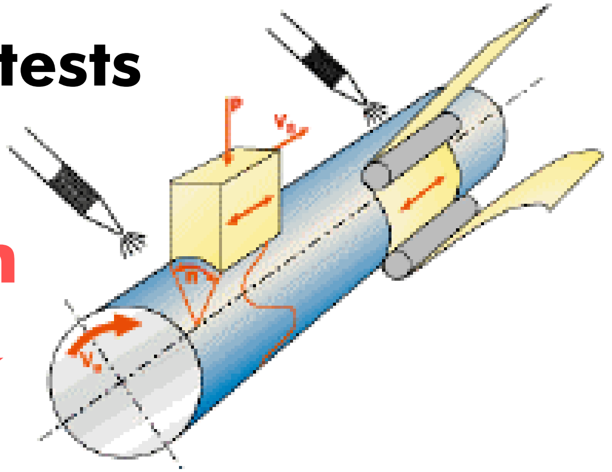
Wear

- HVOF WC-Co and WC-CoCr are hard
  - HVOF typically 1200-1400 HV
  - EHC typically 800-1000 HV
- In the field HVOF wear life is usually at least 3xEHC
  - No measurable wear in flight tests
  - Most scoring eliminated
- Critical issue is surface finish
  - Should generally be < 4μ"
  - May need superfinishing



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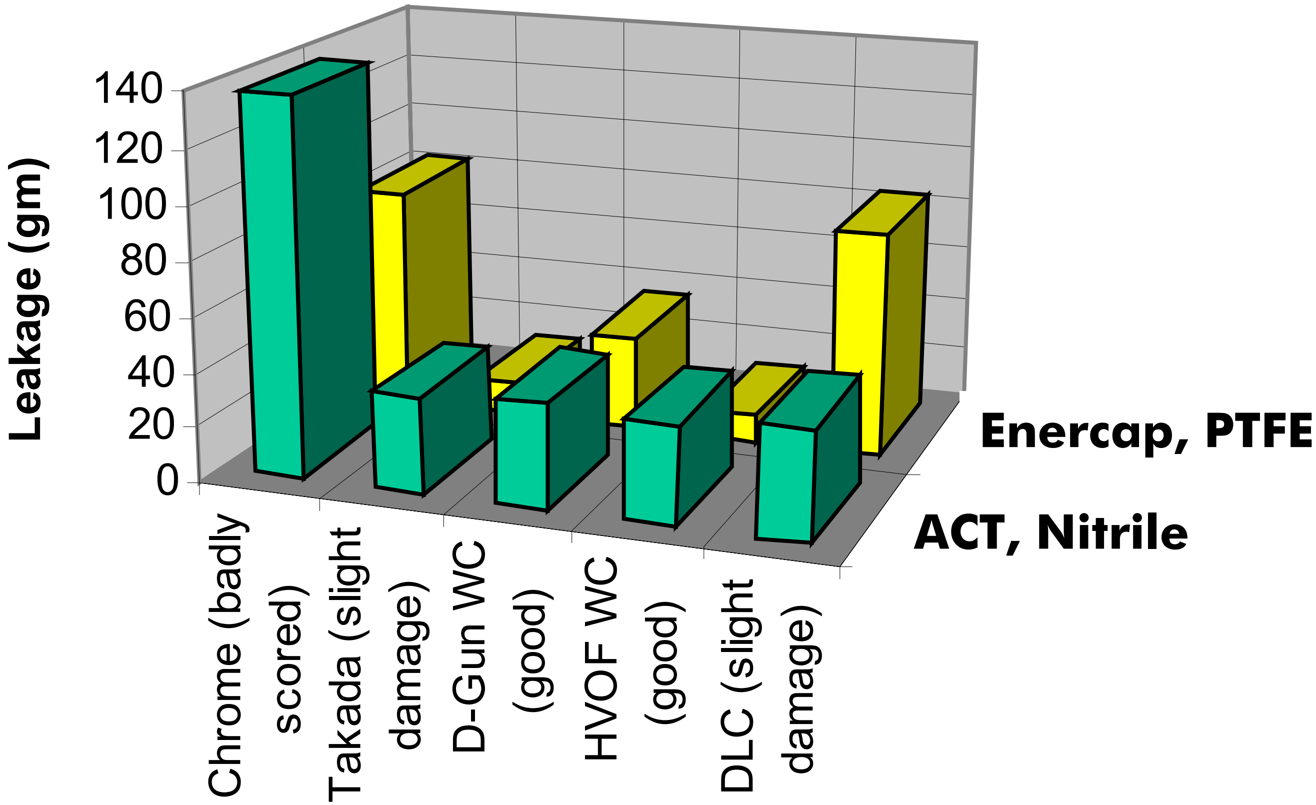
Hydraulic rig tests - initial low cycle Green, Tweed tests



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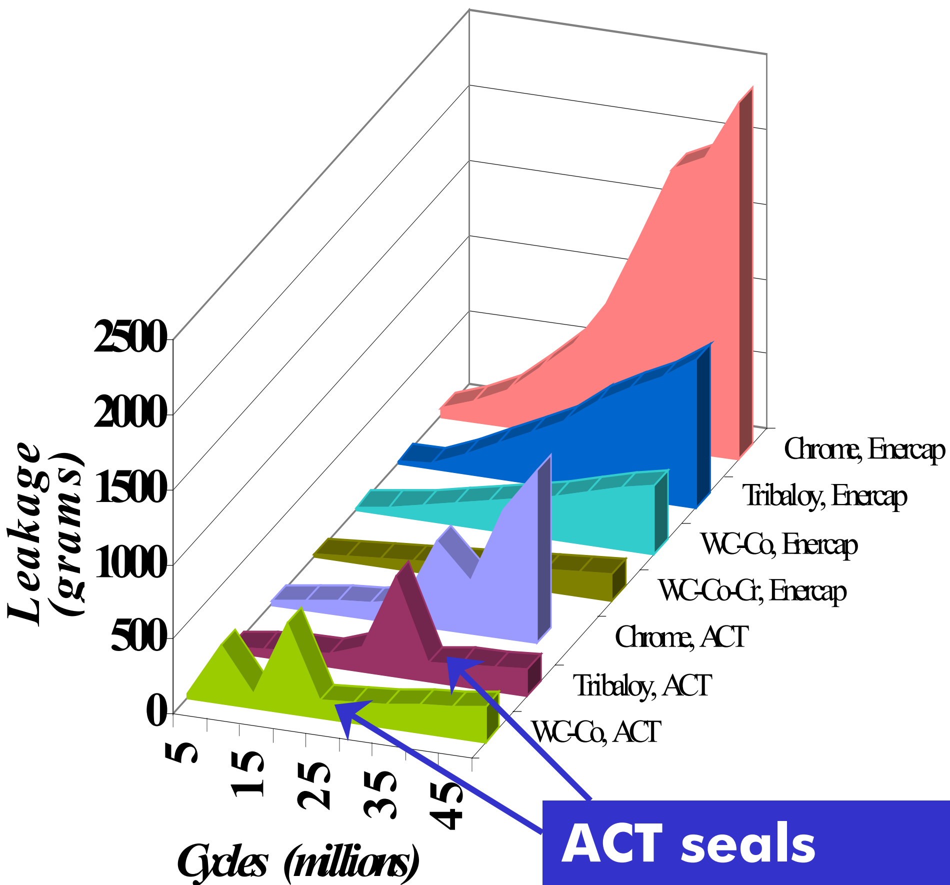
Hydraulic rod testing - Green, Tweed



- **50 million cycles**
- **Enercap (PTFE seal)**
- **ACT (Nitrile seal)**
- **<u>Cumulative</u> leakage**
- **No HVOF rod wear**
- **HVOF works well with PTFE seals**

ACT seals replaced with

Surface finish:

EHC	4μ" Ra
T 400	9 μ" Ra
WC-Co	4 μ" Ra
WC-CoCr	6.5 μ" Ra

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Hydraulic testing summary

- Surface finish must be <4μ" or superfinished
  - Every attempt to use typical chrome 16 μ" in rig or flight tests has caused rapid seal wear
- WC-Co and W-CoCr work well on flight surface-type actuators with PTFE seals, but tend to damage nitrile seals
  - However, in landing gear flight tests (and presumably utility actuators), nitrile seals work well
- T400 works better than chrome, but more wear than WC

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Critical issue with all hydraulics

- **Surface finish is critical!**
  - **The most wear resistant coating in the world is worthless if it just wears out the seals**

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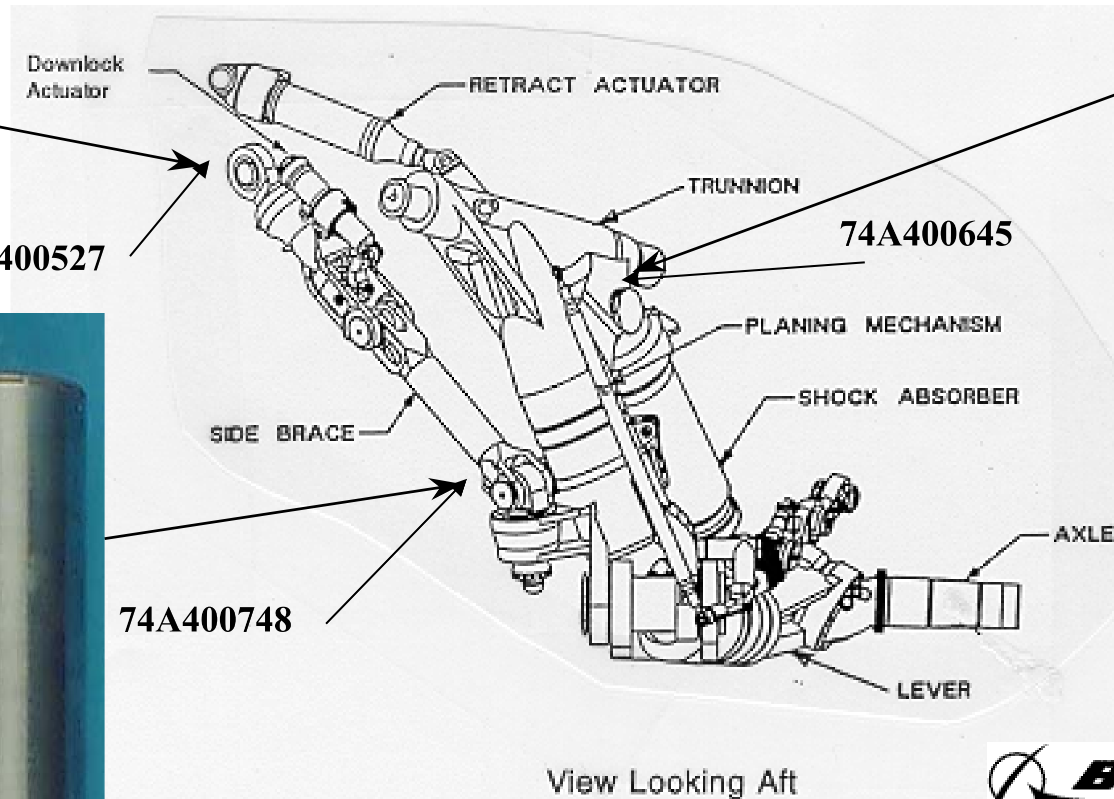
F-18 E/F landing gear rig test - HVOF WC-17Co pins after 14,000 SFH



Passed, better than Cr
But need full scale rig

BOEING tests

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Flight tests

- Commercial flight tests by Lufthansa, Boeing, 2-year Delta
  - All successful - little or no wear on pistons or axles, or seals (when superfinished)
- Landing gear flight tests
  - P-3 Orion (Navy, under way)
  - EA-6B (Navy, awaiting OK)
  - Dash 8 (Bombardier, plan)
  - C-130 (Canadian Air Force, plan)

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Finishing, stripping

- **Finishing**
  - Must grind with diamond wheel
  - Superfinishing removes debris
  - Small level of porosity appears to hold fluid
- **Stripping of WC**
  - Standard electrochemical Rochelle salt - benign
  - Cannot be water jet stripped
  - T400 difficult to strip - no simple methods

Component	Value	Notes
Anhydrous sodium carbonate	20 - 30 oz/gal water	
Sodium potassium tartrate (Rochelle Salt)	8 - 12 oz/gal water	
Temperature	104 - 150°F	130 -150 °F optimal
pH	11 - 12	
Voltage	4 - 6 V DC	
Current density	4 - 8 A/sq in	Parts are anodic (positive)

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Other interesting issues

- Appears to be very difficult to grind burn - very low thermal conductivity
  - Might well prevent axle burn on stopping
- Looks as though will be able to rebuild to 0.060" by use of duplex coatings (e.g. build up with NiAl, cap with WC-Co)
  - Equivalent to sulfamate Ni + chrome
  - Requires no grinding of build-up layer

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Conclusions

- HVOF works better than chrome in almost all respects
- Cost of HVOF 1 - 1.5x EHC
  - Likely much lower life-cycle cost - less wear
- Remaining issues
  - Corrosion data need to be clarified
  - Coating integrity - spalling at high load and R ratio issue to be resolved for use on landing gear pistons, especially on carrier-based aircraft
    - pins and axles are fine

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Critical issues with use of HVOF

- Process development
  - Process must produce coating to match application
    - Must optimize properly for the most important properties
      - Don't use a wear coating for a fatigue application
  - Proper specs
    - Must specify structure, porosity, substrate temperature, stress
    - Grinding, finishing
- Process control
  - Deposition conditions
    - Stable, well-controlled equipment
    - Particle velocity, temperature
    - Coating stress
  - Temperature of component
- NDI for cracks in steel
  - FPI, Barkhausen work
  - Eddy current can work, but must be very sensitive
  - MPI does not work

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Courtesy U.S. Navy. Photo by Ensign John Gay

Use of Thermal Spray as an Aerospace Chrome Plating Alternative

Report to:
William Green
Geo-Centers

Rowan Project #: 3105JSF3

Contract Number: N00173-98-D-2006, D.O. 0002
Subcontract Number: GC-3363-99-004
P.O. Number: 28578MK

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