

HVOF in Repair and Overhaul - Higher reliability at lower cost?

Aviation Gas Turbine Engine O&R 2000

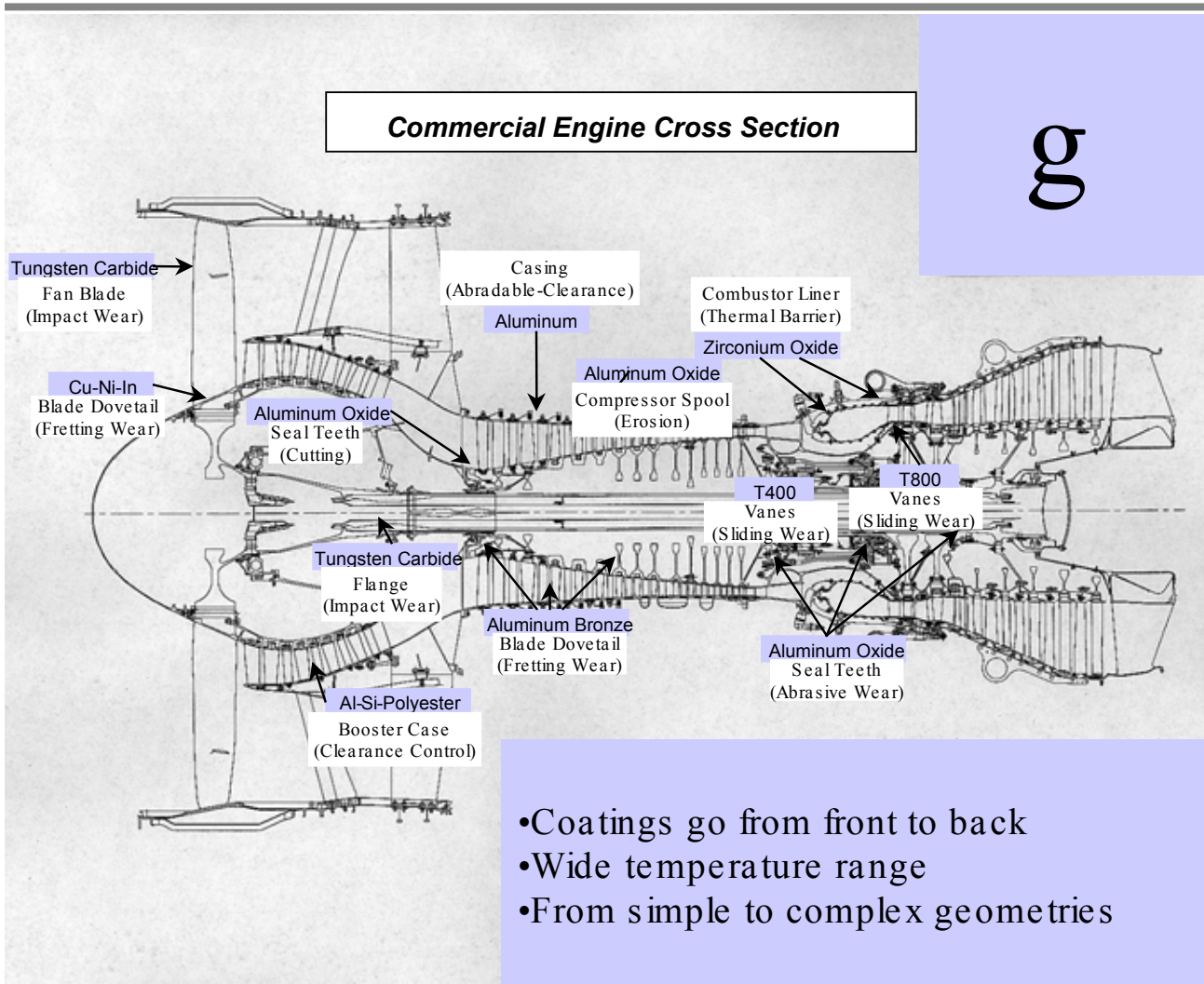
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Technical information

- ❑ **Much of the technical information in this presentation is derived from work of the Hard Chrome Alternatives Team (HCAT), with additional information derived from work done for the Joint Strike Fighter Integrated Product Team (JSF-IPT).**



Thermal spray use in GTEs



- Thermal spray already well used in GTEs

- Coatings go from front to back
- Wide temperature range
- From simple to complex geometries

D. Comassar, GEAE

Rebuilding worn components

- ❑ **Most rebuild still specifies hard chrome plating or sulfamate Ni**
- ❑ **However, we have learned a few things in the past half century**
 - **Chrome is not very reliable**
 - ❑ Heavily dependent on who does it
 - **You can get much better performance with other coatings**
 - ❑ Cost of ownership can be lower
 - ❑ Faster turnaround
 - ❑ Lower frequency of repair
 - **EPA and OSHA regs are affecting availability, risk, cost of Cr**
 - ❑ Upcoming OSHA regs likely to increase cost and liability substantially
 - **Ni is also on the EPA hit list, but a lower profile**

Drivers for chrome replacement

❑ Performance

- **HVOF often used where chrome inadequate**
 - ❑ Especially wear, fatigue, corrosion, seal life
- **Thicker rebuild possible**
 - ❑ Reclamation of more parts
- **Greater choice of material and performance**

❑ Environmental

- **Cr⁶⁺ reduction or elimination**
- **Weakest driver**

❑ Cost

- **Processing cost may be higher or lower**
- **Shorter processing time**
- **Better performance**
 - ❑ lower cost of ownership

❑ Risk

- **Less processing**
- **Eliminates H embrittlement**
 - ❑ not necessarily re-embrittlement

❑ Competitive

- **Increasing user demand**

More stringent regulation

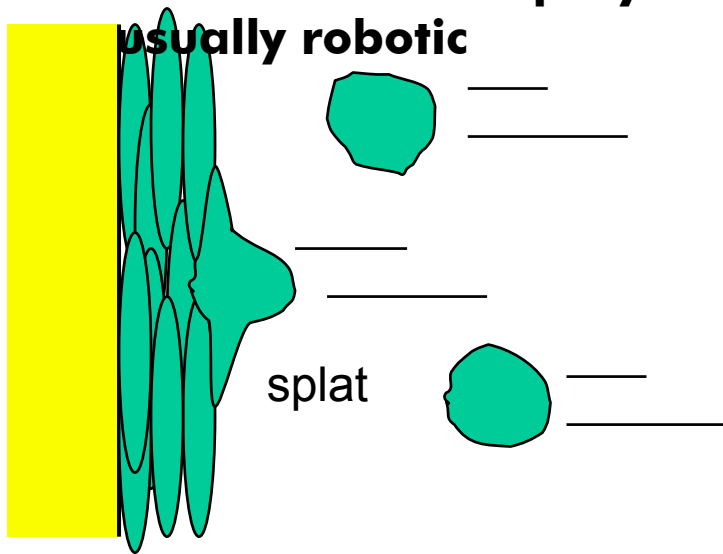
- ❑ **EPA stack emission from chrome operations**
 - **Clean air act regs issued Jan 1995, full compliance Jan 1997, greatly reduced permissible emission limits**
 - ❑ **0.03mg/dscm, small; 0.015mg/dscm, large or new**

- ❑ **OSHA pel for Cr⁶⁺**
 - **Expected to issue for comment by not too distant future (but caught in political fight)**
 - **Current 100 μ gm/m³**
 - **Expected 0.5-5 μ gm/m³**
 - ❑ **would make EPA look like a pussy cat**
 - ❑ **lowest levels would require respirators, greatly raising costs**

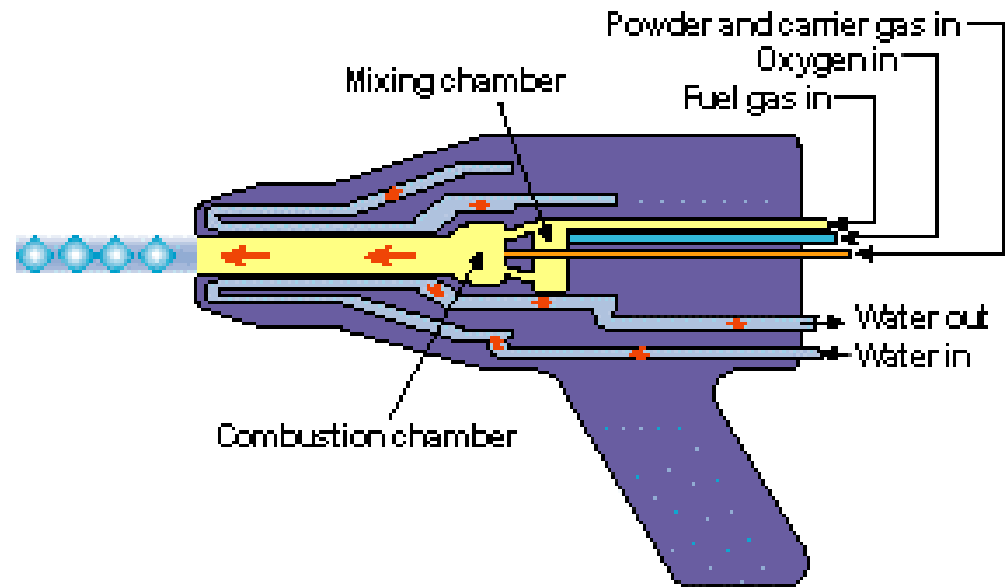
**Likely result: Fewer suppliers, higher costs
We should expect increasing cost and liability risk**

What is HVOF?

- **Dry coating process - primary chrome plating alternative, growing in use on engine and airframe components**
- **Done in air in a spray booth, usually robotic**



- **Higher performance than Cr and most other thermal sprays, usually lower life-cycle cost**
- **Available at job shops in most areas**



Cost

❑ There is no simple answer

- Depends on what is important to you and how you do your cost-accounting
- In-house or outsource
- Size and materials
- The total production process and how HVOF fits into it

Net result - Need to evaluate cost for your specific situation

❑ Cost may be 50% chrome

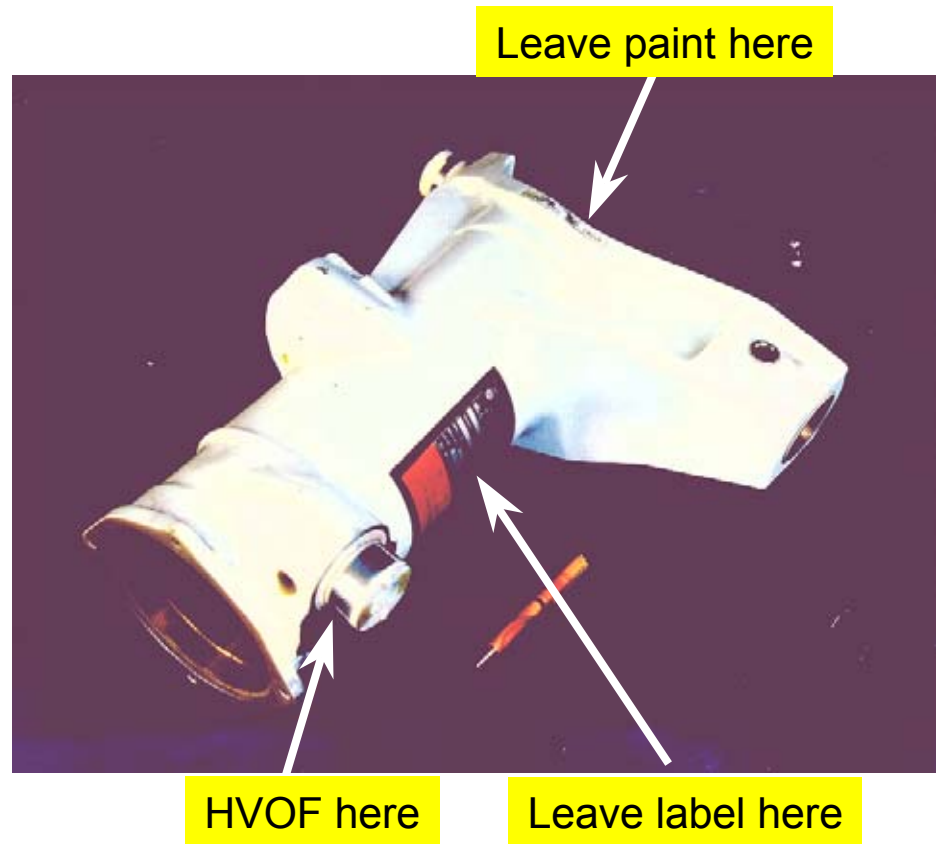
- For large items of high strength steel coated in-house

❑ Cost may be twice that of Cr

- Small items, outsourced, large batches

Cost factors - coating deposition

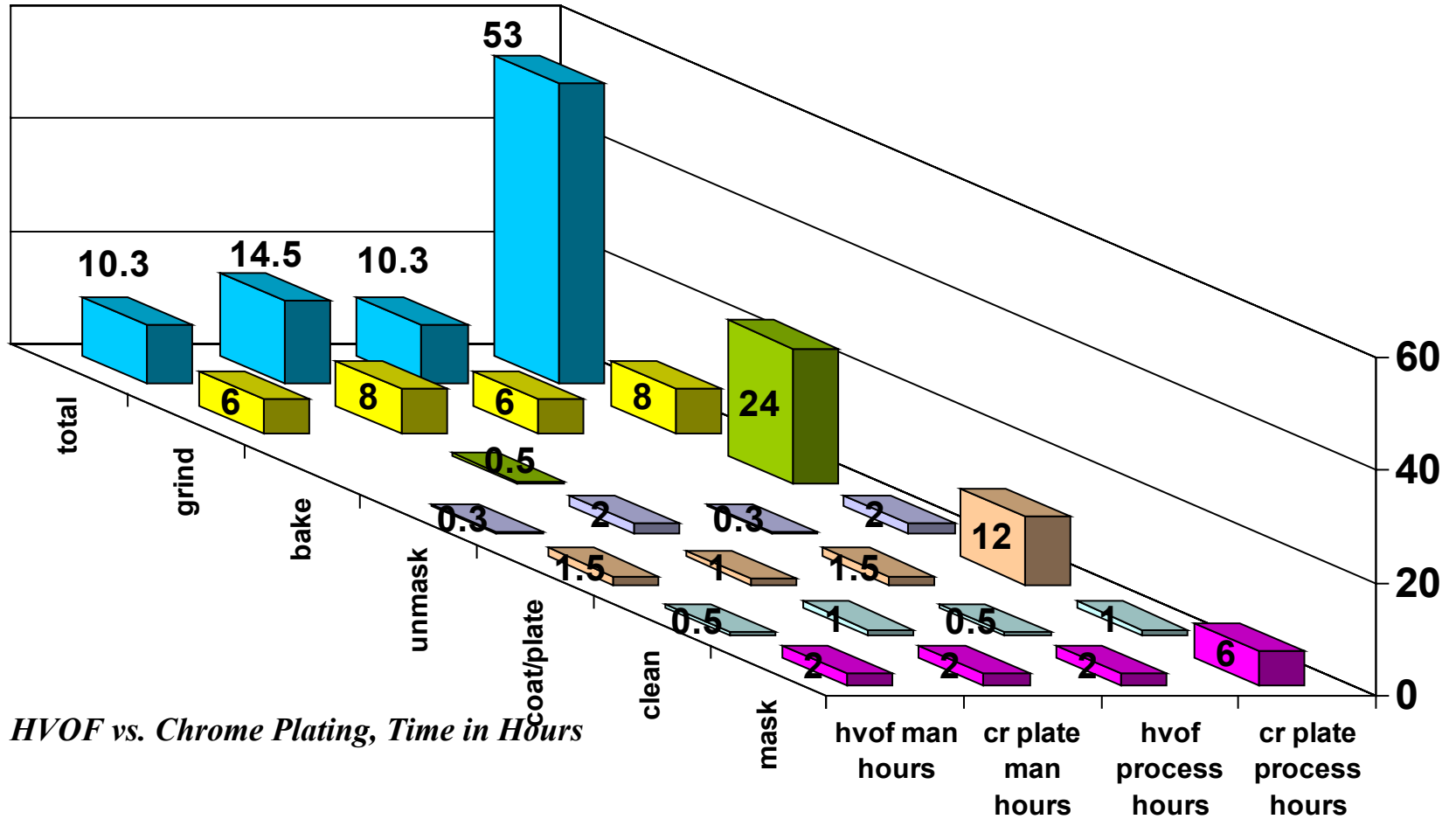
- ❑ **Materials much higher cost**
 - ❑ **Usually requires diamond grinding wheels**
 - ❑ **May require superfinishing**
 - ❑ **Small components inefficient**
 - ❑ **30 min vs 12 hr process**
 - ❑ **Masking usually simpler**
 - ❑ **No immersion, so may be no need to strip other areas**
 - ❑ **Large, HSS components most cost-effective**
- Cost raising factors Cost lowering factors



Sulzer Metco evaluation

Time Study

BOEING 737 NLG IC PISTON



Cost factors - Performance

- ❑ **Wear life typically 3x chrome (or higher)**
 - Longer maintenance cycle
 - No maintenance needed on most cycles
 - Lower parts inventory
- ❑ **Corrosion typically better than Cr, but worse than Cd**
 - Less severe pitting damage
 - Should have lower stress corrosion cracking risk
 - **Not as good as Cr + Ni strike**
- ❑ **No/low fatigue debit**
 - No effect on cost
- ❑ **Thicker rebuild (up to 0.060"?)**
 - More repairable components, less scrap



Flap and slat tracks

Cost factors - Other

❑ Accounting issues

- **Faster turnaround**
 - ❑ **Lower out-of-service time (hours vs days)**
 - ❑ **Can shave days off production of large and complex items**
- **Inventory**
 - ❑ **Longer service life, lower inventory**
 - **can be major fleet cost reduction**
- **Capital cost (in-house use)**
 - ❑ **Capital cost \$500k+ vs fully depreciated chrome tanks**
- **Qualification cost**

❑ Environmental issues

- **No contaminated solid waste or rinse water**
- **Cooling water needed**
- **Dust control and collection**

❑ Worker safety

- **Avoidance of Cr⁶⁺ risk**
 - ❑ **No Cr⁶⁺ even when using a chrome-containing coating**
 - ❑ **May become important with new OSHA pel for Cr**

Cost studies

❑ BFG - two evaluations (OEM costs)

- Assume do in-house - 40% cost reduction, taking in-factory time and cost of money into account
- Contract out - similar to 2x higher cost for different components, based on "bids" from 3 contractors including scrap, optimal batch sizes

❑ Rowan Technology Group (OEM costs)

- HVOF 50% chrome for truck piston rings based largely on lower finishing cost

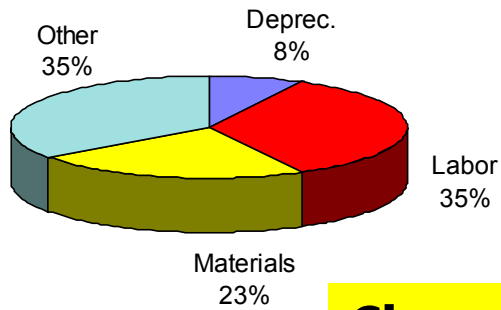
❑ Mid-Atlantic Associates (O&R)

- Transmission flange seal surface - **factor of 3** cost reduction, based on longer life, fewer replacements, thicker rebuild, reduced downtime and inventory for a fleet

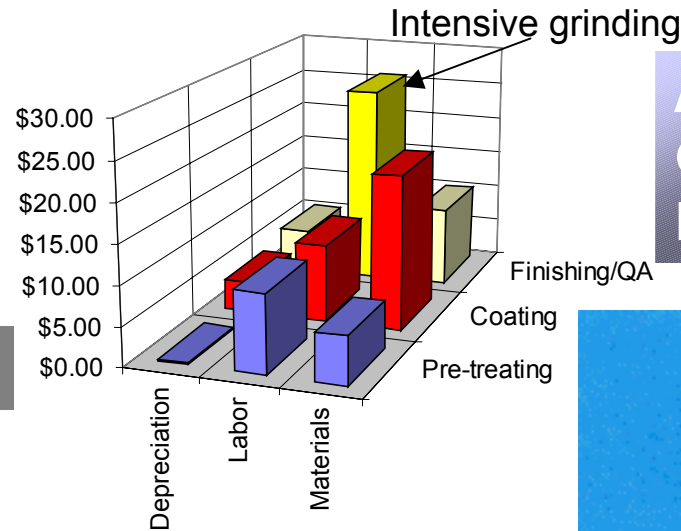
❑ Coopers and Lybrand (O&R)

- HVOF for Cr replacement at NADEP-Jacksonville. Payback in < 1 year

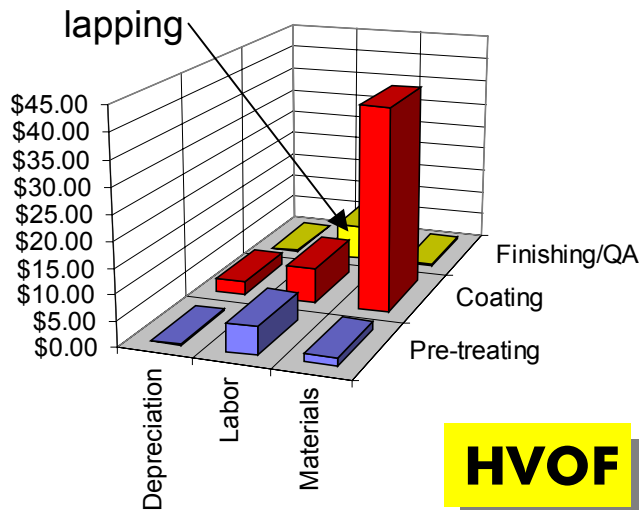
Example - detailed cost comparison for truck piston rings - new plant



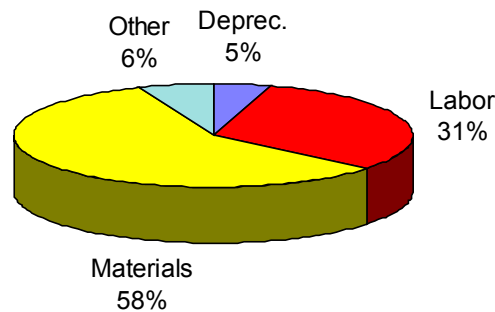
Chrome



Analysis of Cummins Piston Ring



HVOF



Cost issues summary

- ❑ **Depends on what costs are important to you and how well you can capture your costs**
 - **Cost-of-ownership vs processing cost vs acquisition cost**
 - **Capital equipment costs**
 - **Various indirect costs:**
 - ❑ **Risk - embrittlement, newer technology**
 - ❑ **Environmental (EPA, OSHA) liabilities**
 - ❑ **Overhaul - parts inventory cost**
 - ❑ **Manufacturers - in-process time, cost of money**
 - ❑ **Airlines - out-of-service revenue losses - seal replacement and major overhaul**

Net result - Need to evaluate cost for your specific situation

Growing applications of HVOF in O&R

- ❑ **Thermal spray in general, HVOF in particular, growing for O&R on airframe components**
 - **Supplanting chrome on landing gear, flap and slat tracks**
 - **Users moving from plasma spray to HVOF for higher quality**
 - ❑ **higher performance**
 - ❑ **easier grinding and finishing**
 - **From LPPS to HVOF for lower cost, e.g. HPT shrouds**
 - **Increasing usage on GTE shafts in place of chrome**
 - **Growing interest in replacing chrome with HVOF throughout engines and hydraulics**
 - ❑ **want JSF to be a Cr, Cd, VOC-free aircraft**

GTE qualification of HVOF coatings for O&R

- ❑ **HCAT/PEWG program just beginning**
 - **GE Aircraft Engines (Jerry Schell)**
 - **Rolls Royce**
 - **Pratt and Whitney**
 - **Oklahoma City ALC**
 - ❑ Chrome replacement on a variety of components, substrate materials
 - ❑ Acquisition of detailed data on wear, fatigue, corrosion, producibility
 - ❑ Aim is qualification of O&R methods and materials

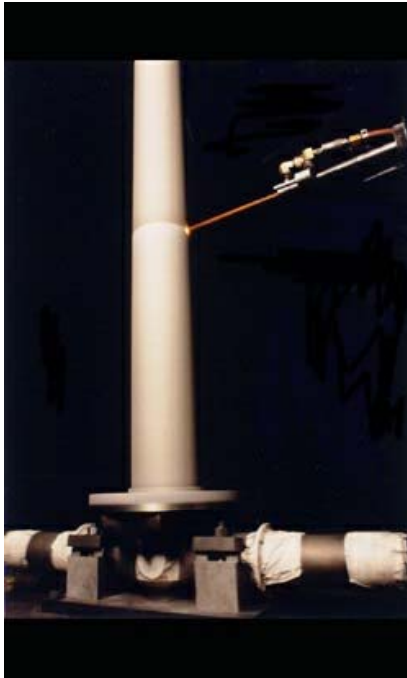


Other systems for which HVOF is being qualified for O&R

- ❑ **Landing gear**
 - **BFG, Messier-Dowty, Heroux, Orenda, several depots**
- ❑ **Hydraulic actuators**
 - **Parker Hannifin, Moog, etc.**
- ❑ **Propeller hubs**
 - **Hamilton Sundstrand, Cherry Point NAD**
- ❑ **Helicopter dynamic components**
 - **Jacksonville NAD**

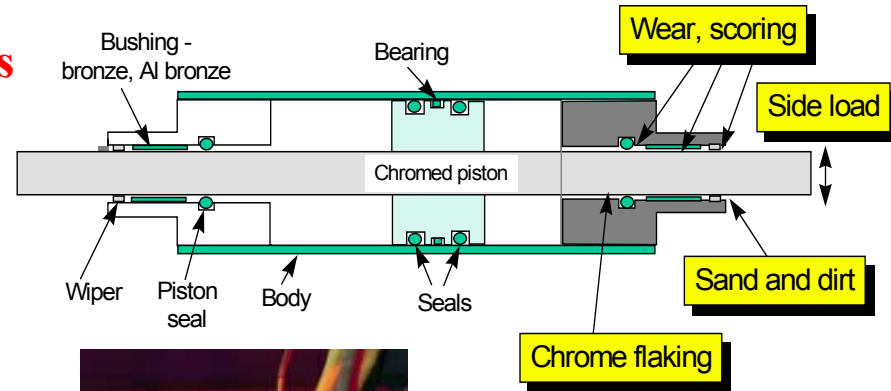


Aerospace Applications



Actuators

Landing gear



Engine shafts



Slat and flap tracks

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
- AWS spec in progress



❑ Qualifications - new items

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

Qualifications - repair

- ❑ **Boeing - HVOF approved for repair up to 0.010"**
 - Boeing evaluating thick build-up methods
 - Not yet complete but looking very good
- ❑ **Wide usage on slat and flap track repair**
- ❑ **Delta - approved HVOF for landing gear repair**
 - inner cylinders and axles
 - O&R turnaround and lower maintenance costs
- ❑ **United - moving toward in-house HVOF**
- ❑ **TWI (UK) L-1011 Ti flap track repair (weld + HVOF WC-Co)**
- ❑ **CH 53 - blade damper**
- ❑ **F-18 polygon repair**



HCAT Landing gear fatigue - 4340

4340, R = -1, AIR
LARGE (0.010"CTNG) VS. SMALL (0.003"CTNG) HOURGLASS

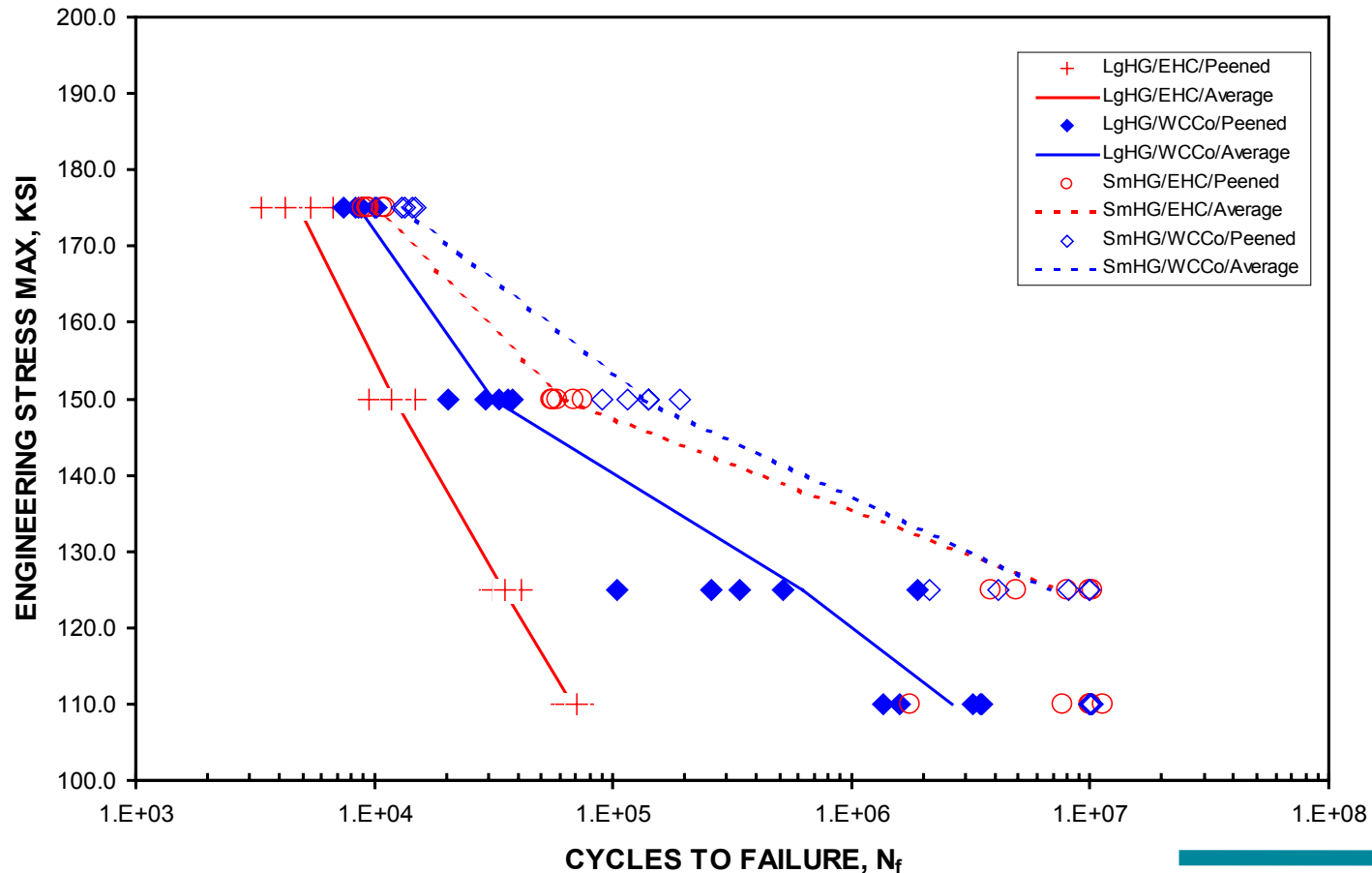
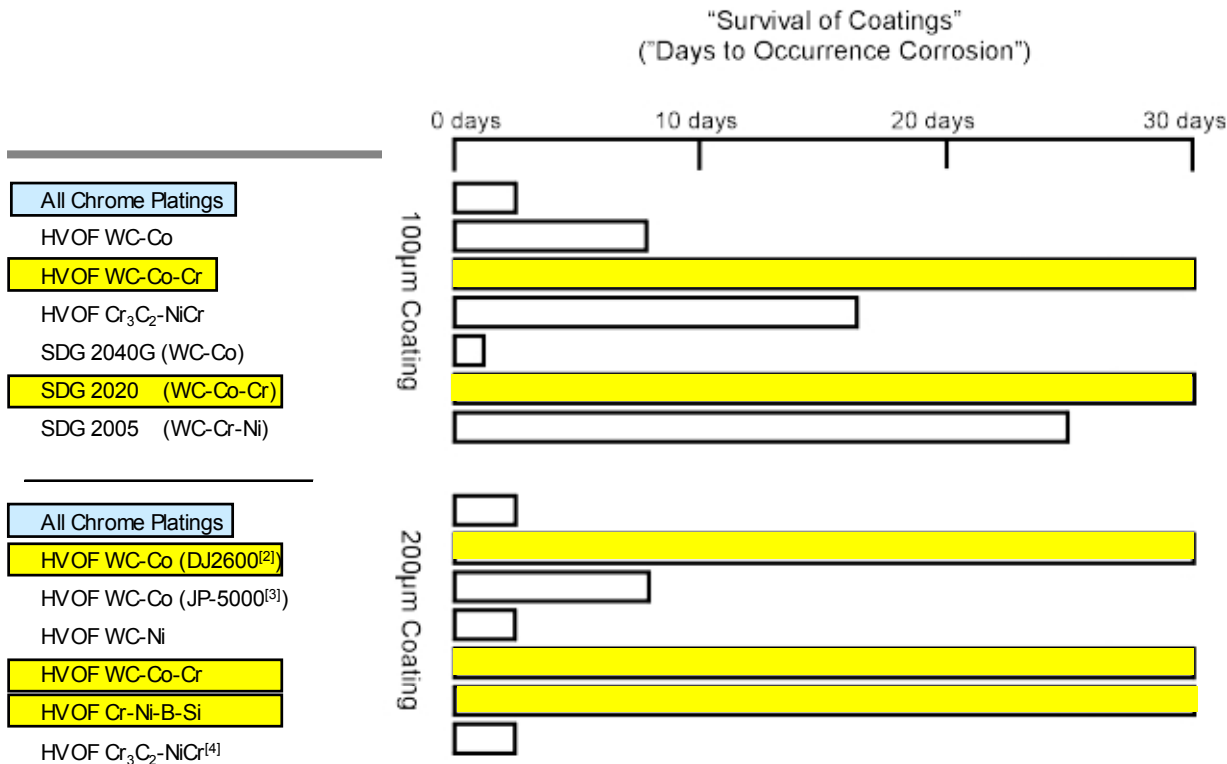


Table 1. Summary of corrosion ratings for coatings tested by Lufthansa.



Sealing HVOF makes no difference

WC-Co - Cobalt dissolution and

WC-CoCr - No corrosion, no matrix dissolution

[1] Please note that this graphic shows an "average" of days to occurrence of corrosion with regard to the coating type. Of each coating type, at least four specimens had been tested which generally did not fail at the same testing time. For exact data, please refer to Figure 17 (100µm thick coatings) and figure 18 (200µm thick coatings).

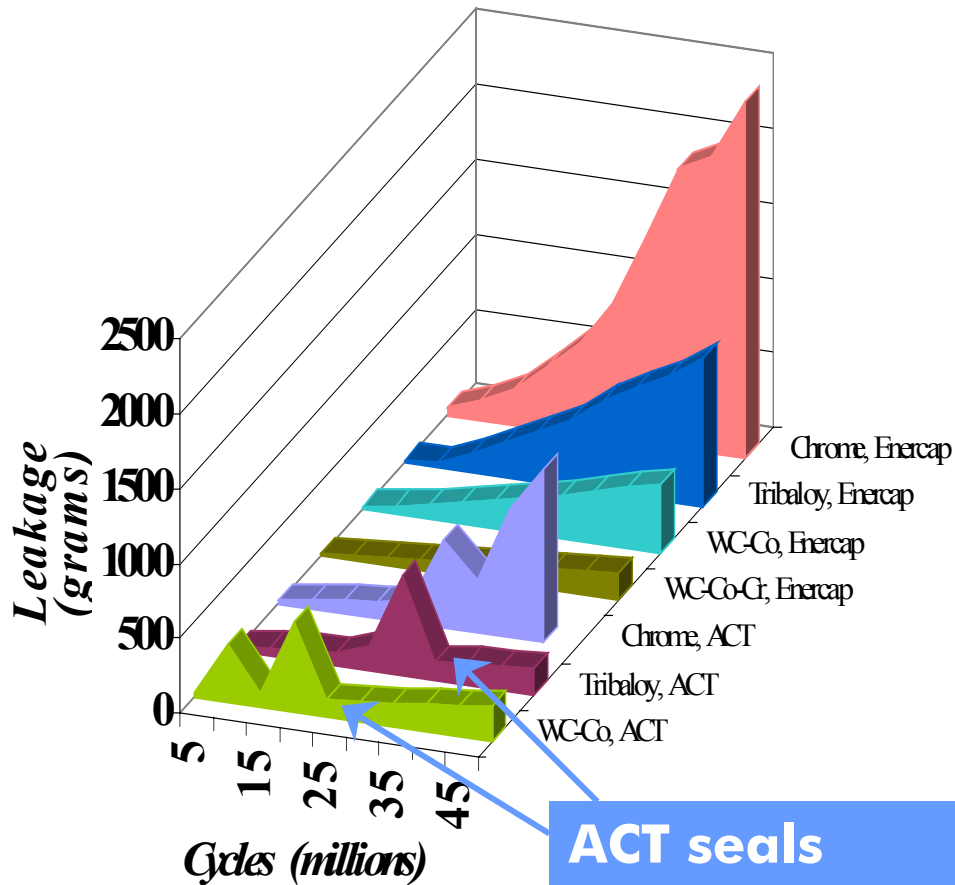
[2] This WC-Co coating (Diamalloy 2005, DJ2600 sprayed at LHT) passed the test, whereas all other WC-CO coatings failed.

[3] In contrast to [2], the WC-Co coating applied by the JP-5000 using powder AWN 3073 failed after approx. one week due to base material corrosion.

[4] This coating was incorrectly sprayed, i.e. too much powder was fed to the gun, resulting in a poor microstructure.

Please note that "thinner" coatings of the same chemistry revealed a distinct better corrosion performance.

Hydraulic testing - Green, Tweed



ACT seals replaced with

- ❑ **50 million cycles**
- ❑ **Enercap**
 - **PTFE seal**
- ❑ **ACT**
 - **Nitrile seal**
- ❑ **Cumulative leakage**
- ❑ **No HVOF rod wear**

Surface finish:

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

Flight tests

- ❑ **Flight tests by Lufthansa, Boeing, Delta**
 - All successful
- ❑ **Landing gear flight tests planned**
 - P-3 Orion (Navy)
 - Dash 8 (Bombardier)
 - C-130 (Canadian Air Force)



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)

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**
 - **Better methods being developed**

Growth potential

- ❑ **Use of HVOF on landing gear, engines, and other aircraft components likely to increase as**
 - **Users and customers see more benefits from lower life-cycle cost and quicker O&R turnaround**
 - **HVOF is used to reclaim more heavily-worn parts**
 - **Increasing cost and concern over Cr and Cd**
 - ❑ **especially in Europe**
 - ❑ **cost and risk of Cr will rise much higher if OSHA pel standards are set low**

❑ **Higher reliability?**

➔ **Almost certainly**

❑ **Lower cost?**

➔ **Probably, but you have to check it out**