U.S. DEPARTMENT OF DEFENSE
Environmental Security Technology Certification Program (ESTCP)
Joint Group - Pollution Prevention (JG-PP)
And
CANADA DEPARTMENT OF NATIONAL DEFENCE
INDUSTRY CANADA

JOINT TEST PROTOCOL

Validation of WC/Co,WC/CoCr HVOF or Tribaloy 800 Thermal Spray Coatings as a Replacement for Hard Chrome Plating on C-2/E-2/P-3 and C-130 Propeller Hubs & Low Pitch Stop Lever Sleeve

17 November 1999

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1.0 INTRODUCTION

The replacement of hard chromium plating in aircraft manufacturing activities and maintenance depots is a high priority for the U.S. Department of Defense and the Canadian Department of National Defence. Hard chromium plating is a technique that has been in commercial production for over 50 years and is a critical process that is used both for applying hard, wear resistant coatings to a variety of aircraft components in manufacturing operations and for general re-build of worn or corroded components that have been removed from aircraft during overhaul. In particular, chromium plating is used extensively for repair purposes on propeller hub and actuator components.

Chromium plating baths contain chromic acid, in which the chromium is in the hexavalent state, with hexavalent chromium (hex-Cr) being a known carcinogen having a level of toxicity greater than arsenic or cadmium. As a result, wastes generated from plating operations must be disposed of as hazardous waste and plating operations must abide by EPA emissions standards and OSHA permissible exposure limits (PEL). Recent studies have clearly shown that there are a significant number of excess deaths at the current PEL of 100 micrograms-per-cubic-meter ($\mu g/m^3$), which is causing OSHA to release in late 1999 new draft standards that could reduce the PEL for airborne hex-Cr by as much as two orders of magnitude.

A Navy/Industry task group under the coordination of the Naval Sea Systems Command has conducted an assessment of the technical and economic impact of such a drastic change. It concluded that the cost of compliance for all Navy operations that utilize hex-Cr (i.e., not just plating) would be as much as $46 million per year in collection, treatment, and disposal costs, plus one time facilities costs of $22 million to upgrade exhaust and ventilation equipment, personal protective gear, and industrial waste treatment facilities. In addition to the greatly increased cost that would be associated with chromium plating, turnaround times for processing of components would be significantly increased as well, impacting mission readiness.

Previous research and development efforts had established that high-velocity oxygen-fuel (HVOF) thermal spray coatings are the leading candidates for replacement of many hard chromium applications. HVOF thermal spraying can be used to deposit both metal alloy and ceramic/metal (e.g., WC/Co) coatings that are dense and highly adherent to the base material. They also can be applied to thicknesses in the same range as what is currently being used for chromium plating. Currently, there are HVOF thermal spray systems commercially available. Although there are a wide number of applications for these coatings, their qualification as an acceptable replacement for hard chromium plating has not been adequately demonstrated, particularly for fatigue-sensitive aircraft components.

The Environmental Security Technology Certification Program (ESTCP) was established as a program of the U. S. Department of Defense (DOD) in December, 1993. The ESTCP, which is managed by the Deputy Under Secretary of Defense for Environmental Security (DUSD-ES), demonstrates and validates lab-proven technologies that target the DOD's most urgent environmental needs. These technologies provide a return on investment through reduced environmental, safety, and occupational health (ESOH) risks; cost savings; and improved efficiency. The new technologies typically have broad application both to the DOD sustainment community and industry.

In order to conduct the advanced development work required for qualification of HVOF coatings, a project entitled, "Tri-Service Dem/Val of Chromium Electroplating Replacements," principally sponsored by ESTCP, was established in March 1996. A project team, designated the Hard Chromium Alternatives Team (HCAT) was established to execute the project. The following are the principal organizations that constitute the HCAT:

- Naval Research Laboratory (NRL) (Project Lead)
- Air Force Research Laboratory (AFRL)
- Naval Aviation Depot Jacksonville (NADEP-JAX)
- Naval Aviation Depot Cherry Point (NADEP-CP)
- Ogden Air Logistics Center (OO-ALC)
- Sacramento Air Logistics Center (SM-ALC)

- Corpus Christi Army Depot
- Naval Air Warfare Center, Patuxent River
- Rowan Technology Group
- GE Aircraft Engines (GEAE)
- Metcut Research, Inc.
- National Technical Systems (NTS)

During this project, HCAT helped acquire, install and train depot personnel to use HVOF systems at their respective operations. The HCAT also conducted extensive “generic” testing of HVOF WCCoCr and Tribaloy 400 coatings in comparison with hard chromium, which included axial fatigue, salt-fog and cyclic corrosion and abrasive wear testing. Base materials tested included 4340 steel, 7075 aluminum alloy, and PH13-8Mo stainless steel. In general, the HVOF coatings performed as well as or better than the hard chromium.

To enhance the technology implementation and transfer of the “Tri-Service Dem/Val of Chromium Electroplating Replacements” project, ESTCP tasked the HCAT to adapt and apply portions of the Joint Group on Pollution Prevention (JG-PP) Methodology. JG-PP was a program chartered by the Joint Logistics Commanders (JLC) to coordinate joint service pollution prevention activities during the acquisition and sustainment process. Supporting the JG-PP is the Joint Acquisition and Sustainment Pollution Prevention Activity (JASPPA), which is in partnership with the HCAT to execute several projects related to replacement of hard chromium plating on aircraft components. The Air Force Materiel Command (AFMC) is the lead organization for JASPPA for the hard chromium replacement effort.

The Canadian Government, through the Department of National Defence (DND) and Industry Canada (IC), facing environmental restrictions on chromium plating similar to the U.S., also became interested in qualifying HVOF thermal spray coatings on aircraft landing gear both for manufacturing and maintenance operations. The Canadian Government formed their own project team, designated the Canadian Hard Chrome Alternatives Team (CHCAT), and a partnership was formed between both projects. A formal Project Arrangement conducted under the auspices of the U.S.-Canadian Research and Technology Projects Memorandum of Understanding (MOU), was negotiated and executed in March 1999.

The following are the principal organizations that constitute the Canadian HCAT:

- Department of National Defence
- Industry Canada
- Technology Partnerships Canada
- Orenda Aerospace Corporation
- National Research Council of Canada

Independently, the Air Force Single Manager representative requested input from Hamilton-Standard on alternatives to the chromium plating of selected parts. Hamilton-Standard responded in a letter with control number 54H-1778, dated September 6, 1996 about several alternatives that they thought could have a high level of confidence to replace the hexavalent chromium plating. On selected high use components they identified Tungsten-carbide-cobalt (14%) chromium HVOF coatings.

In order to successfully execute the project, it was essential to define the technical and performance requirements necessary to qualify HVOF thermal spray coatings as a replacement for hard chromium plating for C-2/C-130/E-2/P-3 propeller hub components. Following the JG-PP Methodology mentioned above, primarily the following stakeholders developed this Joint Test Protocol:

- Naval Air Systems Command
- Navy PEO(A) PMAs 207, 231, and 290
- Air Force C-130 Single Manager (WR-ALC/LBR)
- Hamilton Sundstrand Division, United Technologies Corporation
- Canadian DND

Tables1 and 2 summarize the target hazardous material, current process, application, current specifications, and affected defense weapon system programs.

Table 1 HVOF Thermal Spraying Summary

Target HazMat	Current Process	Application	Current Specifications	Candidate Parts/ Substrates
Hexavalent Chromium	Hard Chromium Electroplating	Rebuilding Worn Components Wear-resistant Coating Corrosion-resistant Coating	DOD-STD-2182 MIL-C-14538C MIL-C-20218F MIL-H-83282 MIL-STD-1501C QQ-C-320B	Hamilton Standard Propeller Hubs

Table 2 HVOF Thermal Spraying Summary: System Applications

Affected Defense System Programs			
NADEP Cherry Point: C-130 E-2/C-2 P-3	Warner-Robins Air Logistics Center C-130	Canadian DND C-130 P-3	Coast Guard C-130 P-3

Section 2.0 of this JTP describes the technical and performance requirements of the HVOF coatings compared to hard chromium as applied to test coupons. These include fatigue and wear testing on defined specimens fabricated from the base materials currently used for the manufacture of propeller hub components. Section 3.0 of the JTP describes the technical and performance requirements of the HVOF coatings compared to hard chromium in both rig testing and “lead-the-fleet” flight-testing.

2.0 TECHNICAL AND PERFORMANCE REQUIREMENTS – COUPON TESTING

2.1. Background

Two potential applications for replacing chromium plating on 54H60 propeller barrels have been identified. The first application is the repair of the hub Tail Shaft that exhibits fretting damage from contact with the mating AISI 4350 steel seal land. The other application is the Lever Support Sleeve ID which exhibits damage as a combination of fretting and sliding wear from contact with the mating leaded tin bronze piston ring.

The purpose of this test shall be to assess the candidate HVOF coatings for use as a replacement for chromium plating. The testing described herein shall evaluate the effects of the candidate coatings on the seal land, piston ring, and seal materials, as well as the relative wear resistance of the two candidate coatings against the aforementioned interfaces. In addition, this test shall determine the effects of the candidate coatings on the fatigue strength of the substrate material.

2.2 Wear Test

2.2.1 Substrate Material

Propeller Hub	C-2/E-2 P/N 750601-1	AISI 4350	0.08-0.012 (550# shot peen)
	P-3 P/N 577835	AISI 4350	0.08-0.012 (550# shot peen)
	C-130 P/N 526385	AISI 4350	0.08-0.012 (550# shot peen)
Sleeve-lever Support	C-2/E-2/P-3 P/N 557992	AISI 4340	0.01-0.014 (size 6, glass peen)
	C-130 P/ N 538889	AISI 4340	0.01-0.014 (size 6, glass peen)

<u>Material Acquisition:</u>
AISI 4340 specimens shall be used to simulate both tailshaft and seal land materials, per HSD letter. Aluminum bronze shall be used to evaluate piston ring wear, and a 90 Durometer Fluorocarbon Elastomer seal material shall be used to evaluate seal wear.

<u>Specimen fabrication:</u>
All plate specimens shall be fabricated from flat AISI 4340 steel plate per 12x-1768-S1 (see Figure 2a), heat treated to HRC 40-44 and coated on two sides with the candidate coatings. The two candidate test coatings are Tungsten Carbide Cobalt (WCCo) and Tribaloy T-800. The HVOF coatings shall be applied in accordance with Hamilton Sundstrand specification HS4412 Method H. Two inches at the mounting hole end of the plate specimen can be left unsprayed, but no coating runout will be allowed in this area due to clamping concerns. The chrome plating shall be applied per QQ-C-320B. The chrome plate and Tribaloy T-800 samples shall be ground to nominal surface finishes of 8 and 16 R_a. The WC-Co samples shall be ground to nominal surface finishes of 4 and 8 R_a. The specimens used to evaluate the seal land wear shall be made of AISI 4340, 40 to 44HRC, per 12x-1768-S2, see Figure 2b. The specimens used to evaluate the piston ring wear shall be made from leaded tin-bronze alloy C92800, per 12x-1768-S2. The 0.24x2 inch wear surfaces shall be ground to a 16 R_a finish for the steel specimens and a 20 R_a finish for the tin-bronze specimens. The lay of the ground surface should be parallel to the length of the specimen. The seal specimens shall be manufactured to 12x-1768-S2 with the wear surfaces left in the as molded state.

2.2.2 Test operation

Table 2.1 identifies the jointly agreed parameters. Four flat test specimens shall be installed into the test fixture for each run. Loaded against each flat side shall be two sample mating material being evaluated. The oscillating flat test panel shall be placed into a servo-hydraulic test frame similar to Figure 1 with contact between the test specimen and mating materials. After 500,000 complete cycles the samples shall be examined for wear and photographed. Weight loss measurements shall be made and wear depth shall be taken using a Tokyo Surfcom 570A. A minimum of two additional 500,000-cycle test runs shall be made measuring all wear parameters after each run. Because there will be three or more data points and the volumetric wear rate vs. cycle count is expected to be linear, the data scatter can be analyzed.

The contact loads shall be based on estimates of the pressure that act on each component in its actual operating environment. The fluid pressure on the hub Tail Shaft ranges from approximately 250 psi to 800 psi with the majority of the time at the 400-psi level. Based on this information, the two test loads selected shall be 400 and 800 psi for the seal specimens. The piston ring specimens will be tested at 175 psi. The seal land specimen stress will be based on the contact stress between the seal lands and the Tail Shaft OD. There are three seals and therefore 6 lands, all of which have the same diametrical clearance to the Tail Shaft. The load is developed by the weight of the prop control. Using Hertzian contact equations for a cylinder inside a cylinder, the contact stress is 252 psi using nominal clearances, and 357 psi using worst case clearances. Therefore the seal land materials will be evaluated at 300 psi.

The stroke type used shall model the dithering and/or sliding motion present in each of the two wear applications. Both the Tail Shaft and the Lever Support Sleeve experience a ±5 mil dither. The Lever Support Sleeve also experiences a 2 ½” sliding motion when the prop transitions from flight to ground operation. . Using a DOE philosophy steel, bronze, and seal material samples will all be tested in both a dithering motion and a stroking motion.

In the field, the Hub and the Lever Support Sleeve is currently lubricated with MIL-H-83282 hydraulic oil. The wear test shall evaluate wear life using this oil and a replacement oil, Mil-H-87257. Mil-H-83282 shall be tested both clean and with contamination. The contaminated oil shall be capable of passing through a 0.056 inch diameter TYGON LFL tube at a rate of 1 drop per second, and shall contain a slurry of the following (per gallon of hydraulic oil):
0-5 Micron Iron Oxide – 28.5mg
5-10 Micron Iron Oxide – 1.5mg
40-50 mesh Sharp Silica Sand – 1mg
50-100 mesh Sharp Silica Sand – 1mg
Course Arizona Road Dust (Conforming to A.C. Spark Plug Co. P/N 1543637)
Two surface finishes will be investigated, for each coating, a high R_a and a low R_a. All specimens will be ground to their prescribed surface finish. Lapping, honing, and super-finishing processes will not be evaluated in this series of tests, as these processes are not currently used to overhaul the hub components in question. Surface finish measurements shall be made on all specimens prior to testing. The parameters measured shall include R_a, R_{sk}, R_k, and T_p.

2.2.3 Acceptance Criteria

Test data, namely weight loss, wear depth, normal load, and frictional load, shall be noted relative to cycle count for each set of test conditions (i.e. coating thickness, contact stress, applied lubrication, surface roughness, etc.). This data will be reduced to friction coefficient, wear coefficient, and plots of wear volume vs. number of wear cycles. The coating will be considered acceptable if the wear rate of the candidate coating is equal to or less than that of EHC. A secondary consideration of acceptability will be the affect that the coating has on the interface material. In the case that the wear rate of the coating is acceptable but the interface material wear is greater than of the wear against EHC, an acceptable level of wear shall be determined. The friction coefficient data will not be a basis for acceptance or rejection, but will rather be collected and used later for design purposes.

In addition, Weibull statistics will be generated for each parameter set, using some volume of material removed as the common failure point, and the L10 number shall be determined (i.e., the cycles at which 10% of the specimens would be expected to fail). If the L10 numbers for the HVOF coatings are equal or greater than the number for the EHC coatings, then the HVOF coatings will be considered to have met the acceptance criteria.

A failure to meet the acceptance criteria for either of the above will be considered an overall failure.

2.2.4 Rationale

The stakeholders approved this wear test specified by Hamilton-Standard in a November 1998 letter based on experience that this accurately simulates actual wear conditions experienced by the parts in question.

Figure 1 Schematic of the wear test fixture.

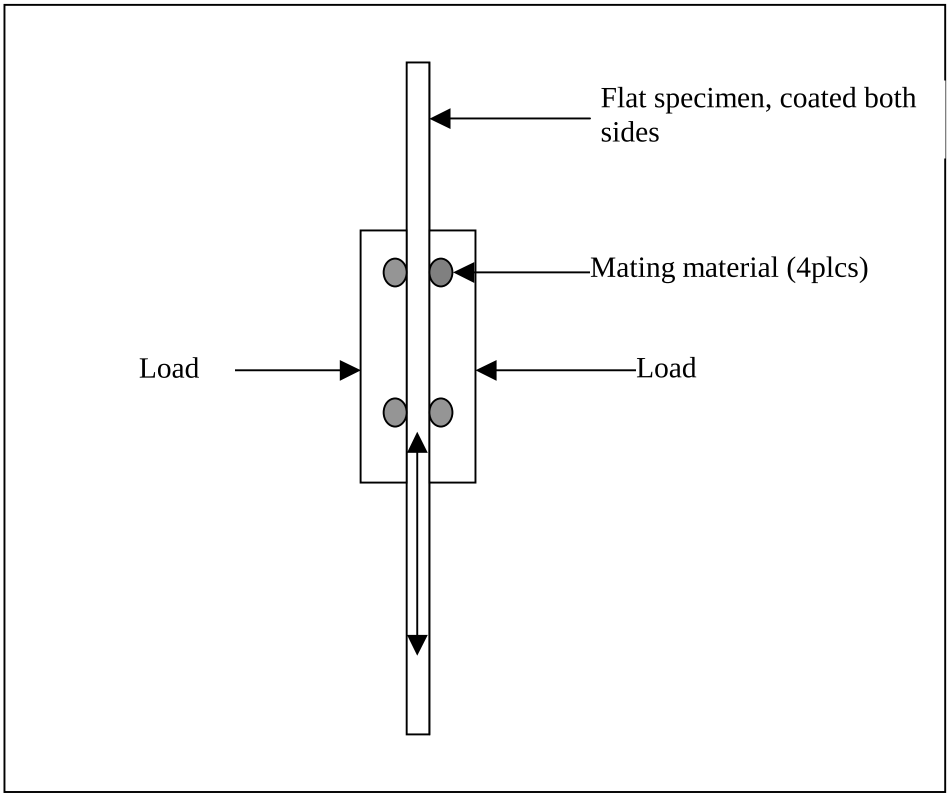
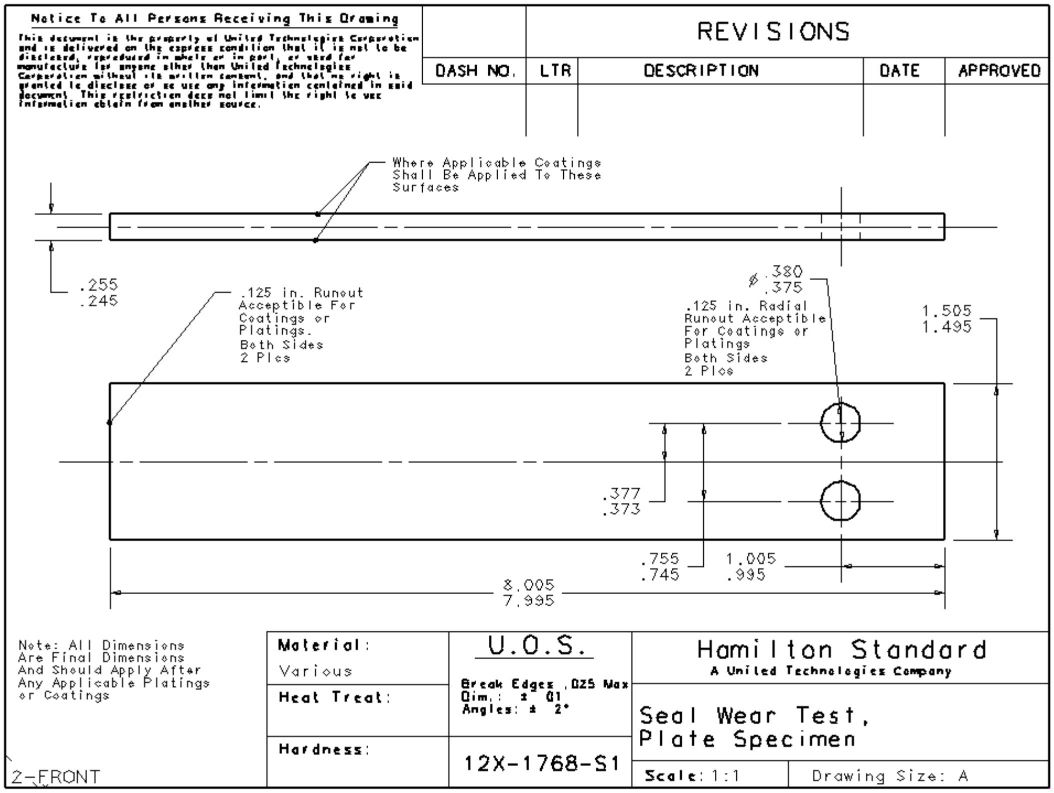


Table 3 Wear Test Matrix

Run #	Panel Specimen Coating	Small Flat Specimen	Lube Type	Contaminated Lube	Stroke Length	Normal Load	Coating Surface Finish (min, R_a)
1	Cr	AISI 4340	Mil-H-83282	No	Dither	Low	14-18
2	Cr	AISI 4340	Mil-H-83282	No	Large	High	14-18
3	Cr	AISI 4340	Mil-H-83282	No	Large	High	6-10
4	Cr	AISI 4340	Mil-H-83282	Yes	Dither	High	14-18
5	Cr	AISI 4340	Mil-H-83282	Yes	Large	Low	14-18
6	Cr	AISI 4340	Mil-H-87257	No	Large	High	14-18
7	Cr	Al Bronze	Mil-H-83282	No	Dither	High	14-18
8	Cr	Al Bronze	Mil-H-83282	No	Large	Low	14-18
9	Cr	Al Bronze	Mil-H-83282	No	Large	Low	6-10
10	Cr	Al Bronze	Mil-H-83282	Yes	Dither	Low	14-18
11	Cr	Al Bronze	Mil-H-83282	Yes	Large	High	14-18
12	Cr	Al Bronze	Mil-H-87257	No	Dither	High	14-18
13	Cr	Seal Material	Mil-H-83282	No	Dither	Low	14-18
14	Cr	Seal Material	Mil-H-83282	No	Large	High	14-18
15	Cr	Seal Material	Mil-H-83282	No	Large	High	6-10
16	Cr	Seal Material	Mil-H-83282	Yes	Dither	High	14-18
17	Cr	Seal Material	Mil-H-83282	Yes	Large	Low	14-18
18	Cr	Seal Material	Mil-H-87257	No	Large	High	14-18
19	WC-17Co	AISI 4340	Mil-H-83282	No	Dither	Low	6-10
20	WC-17Co	AISI 4340	Mil-H-83282	No	Large	High	6-10
21	WC-17Co	AISI 4340	Mil-H-83282	No	Large	High	3-5
22	WC-17Co	AISI 4340	Mil-H-83282	Yes	Dither	High	6-10
23	WC-17Co	AISI 4340	Mil-H-83282	Yes	Large	Low	6-10
24	WC-17Co	AISI 4340	Mil-H-87257	No	Large	High	6-10
25	WC-17Co	Al Bronze	Mil-H-83282	No	Dither	High	6-10
26	WC-17Co	Al Bronze	Mil-H-83282	No	Large	Low	6-10
27	WC-17Co	Al Bronze	Mil-H-83282	No	Large	Low	3-5
28	WC-17Co	Al Bronze	Mil-H-83282	Yes	Dither	Low	6-10
29	WC-17Co	Al Bronze	Mil-H-83282	Yes	Large	High	6-10
30	WC-17Co	Al Bronze	Mil-H-87257	No	Dither	High	6-10
31	WC-17Co	Seal Material	Mil-H-83282	No	Dither	Low	6-10
32	WC-17Co	Seal Material	Mil-H-83282	No	Large	High	6-10
33	WC-17Co	Seal Material	Mil-H-83282	No	Large	High	3-5
34	WC-17Co	Seal Material	Mil-H-83282	Yes	Dither	High	6-10
35	WC-17Co	Seal Material	Mil-H-83282	Yes	Large	Low	6-10
36	WC-17Co	Seal Material	Mil-H-87257	No	Large	High	6-10
37	Tribaloy T-800	AISI 4340	Mil-H-83282	No	Dither	Low	14-18
38	Tribaloy T-800	AISI 4340	Mil-H-83282	No	Large	High	14-18
39	Tribaloy T-800	AISI 4340	Mil-H-83282	No	Large	High	6-10
40	Tribaloy T-800	AISI 4340	Mil-H-83282	Yes	Dither	High	14-18
41	Tribaloy T-800	AISI 4340	Mil-H-83282	Yes	Large	Low	14-18
42	Tribaloy T-800	AISI 4340	Mil-H-87257	No	Large	High	14-18
43	Tribaloy T-800	Al Bronze	Mil-H-83282	No	Dither	High	14-18
44	Tribaloy T-800	Al Bronze	Mil-H-83282	No	Large	Low	14-18
45	Tribaloy T-800	Al Bronze	Mil-H-83282	No	Large	Low	6-10
46	Tribaloy T-800	Al Bronze	Mil-H-83282	Yes	Dither	Low	14-18
47	Tribaloy T-800	Al Bronze	Mil-H-83282	Yes	Large	High	14-18
48	Tribaloy T-800	Al Bronze	Mil-H-87257	No	Dither	High	14-18
49	Tribaloy T-800	Seal Material	Mil-H-83282	No	Dither	Low	14-18
50	Tribaloy T-800	Seal Material	Mil-H-83282	No	Large	High	14-18
51	Tribaloy T-800	Seal Material	Mil-H-83282	No	Large	High	6-10
52	Tribaloy T-800	Seal Material	Mil-H-83282	Yes	Dither	High	14-18
53	Tribaloy T-800	Seal Material	Mil-H-83282	Yes	Large	Low	14-18
54	Tribaloy T-800	Seal Material	Mil-H-87257	No	Large	High	14-18
55	WCCoCr	Teflon Seal	Mil-H-83282	Yes	Dither	High	3-5
56	WCCoCr	Teflon Seal	Mil-H-83282	No	Dither	High	3-5

Figure 2 Plate Specimen



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Note: All Dimensions Are Final Dimensions And Should Apply After Any Applicable Platings or Coatings

Figure 3 Seal/Seal Land/Piston Ring Specimen

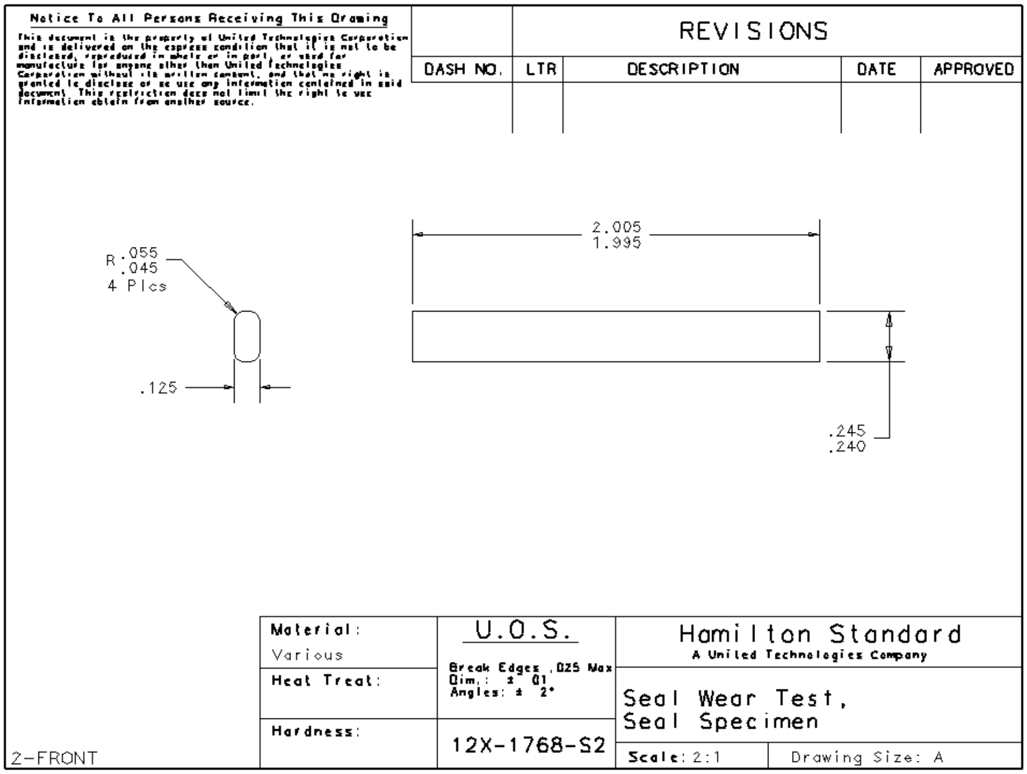

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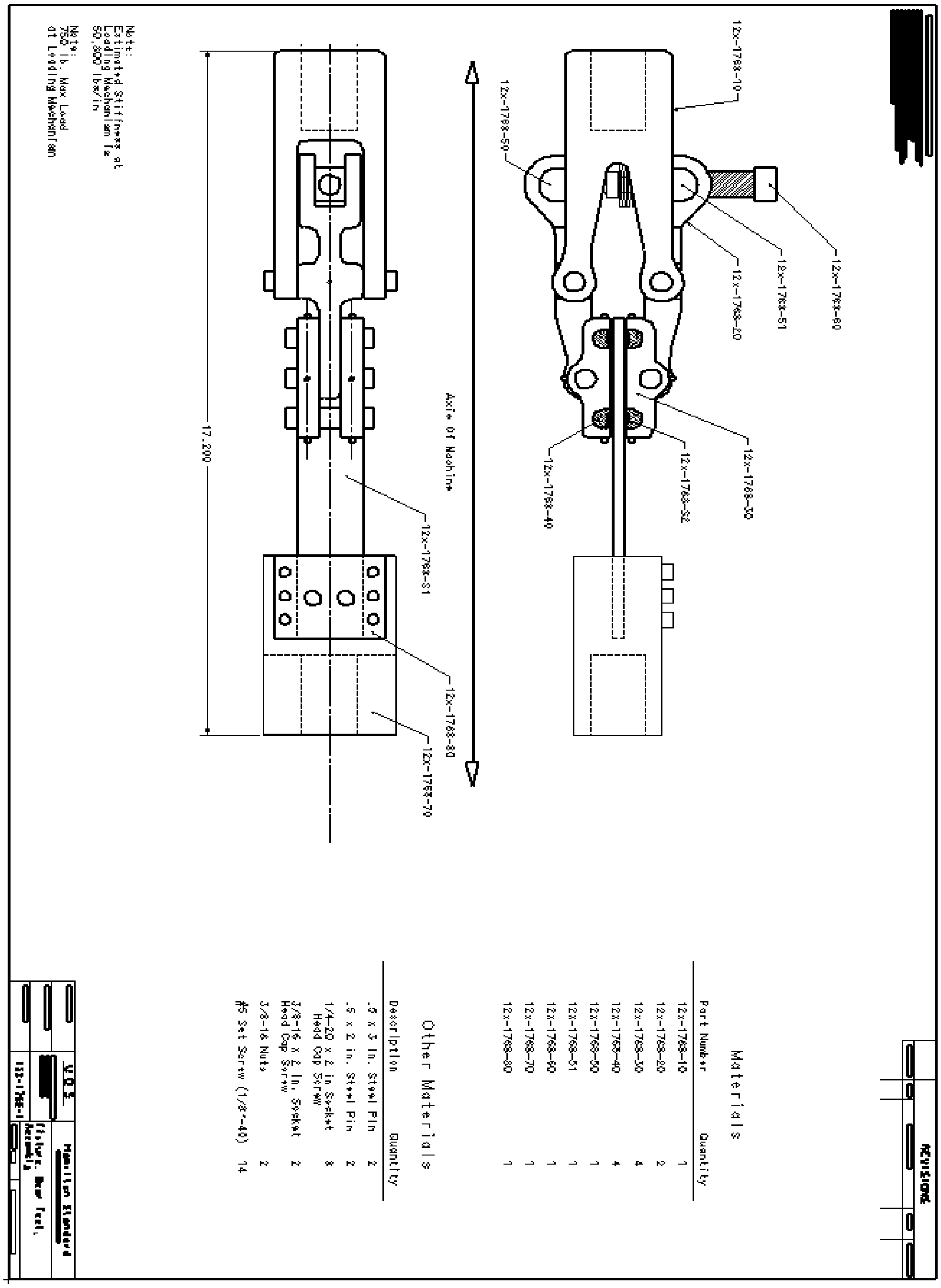
Figure 4 Fixture Assembly Drawing



Materials

Part Number	Quantity
12x-1768-10	1
12x-1768-20	2
12x-1768-30	4
12x-1768-40	4
12x-1768-50	1
12x-1768-51	1
12x-1768-60	1
12x-1768-70	1
12x-1768-80	1

Other Materials

Description	Quantity
.5 x 3 In. Steel Pin	2
.5 x 2 in. Steel Pin	2
1/4-20 x 2 in Socket Head Cap Screw	8
3/8-16 x 2 In. Socket Head Cap Screw	2
3/8-16 Nuts	2
#5 Set Screw (1/8"-40)	14

Note:
Estimated Stiffness at
Loading Mechanism Is
50,800 lbs/in

Note:
750 lb. Max Load
at Loading Mechanism

2.3 Fatigue Testing

2.3.1 Substrate Material

Tail Shaft hub (#538714)	AISI 4350	0.08-0.012 (550# shot peen)
Sleeve-lever Support (#538889)	AISI 4340	0.01-0.014 (size 6, glass peen)

Material Acquisition:
AISI 4340 specimens shall be used to simulate both materials, per a HSD letter.

Specimen fabrication:
All test specimens shall be fabricated from AISI 4340 steel heat-treated to HRC 40-44. Each specimen will be coated with one of the test coatings to the nominal thickness specified in Table 2.2. The two candidate test coatings are Tungsten Carbide 17%-Cobalt (WCCo) and Tribaloy T-800. The smooth fatigue specimens shall be as shown in Appendix A drawing 12X-1790. The notched fatigue specimen shall be as shown in Appendix B drawing 12X-1791.

2.3.2 Test Operation

Stress Levels shall be determined at the time of testing. The first group of specimens will be used as scout specimens. These specimens will be used to establish the general shape of the S-N curve, and determine where to run the HCF specimens in order to get runouts. The stress levels for these scout specimens will be set such that they will fail just past the transition fatigue life of the material. These scout specimens can also be used as LCF specimens.

Low Cycle Fatigue:
Five specimens will be tested at each of 3 stress levels for a total 15 specimens per LCF run.

High Cycle Fatigue:
Six specimens tested at three different stress levels for a total of 6 specimens per HCF run.

Testing Environment: The test procedure shall utilize a standard axial fatigue test at R=0.1 and the test shall be conducted at room temperature.

2.3.3 Acceptance Criteria

S-N curves shall be generated for each run. If the curves for the HVOF coatings show equivalent or superior fatigue properties to the EHC, the HVOF coatings will be considered to have met the acceptance criteria.

Data analysis shall also determine the following:

- Compare HVOF vs. EHC fatigue debit
- Effect of coating thickness on fatigue strength
- Effect of peening to recover fatigue debit
- Fatigue Notch Factor for WC-17%Co and Tribaloy T-800
- Effect of surface finish on fatigue strength

In addition, Weibull statistics will be generated for each parameter set and the L10 number shall be determined (i.e., the cycles at which 10% of the specimens would be expected to fail). If the L10 numbers for the HVOF coatings are equal or greater than the number for the EHC coatings, then the HVOF coatings will be considered to have met the acceptance criteria.

Failure to meet the acceptance criteria for either of the above will constitute a test failure.

2.3.4 Rationale

The stakeholders approved this Hamilton Standard recommended test to actually simulate conditions expected on the hub components. The test matrix covers all variables that the stakeholders have identified as critical. The variables include: coating types and control, coating thickness, notch K_t, specimen type, surface stress state, and surface finish.

Table 4 Matrix of Fatigue Test Samples

Quantity	HCF	LCF	WC Co	Triabaloy	Cr Plate	0.003	0.01	0.015	Smooth	Notched	Peened*	Not Peened	Triballoy/Cr		WCCo	
													8 Ra	16Ra	4 Ra	16Ra
6	X		X			X			X			X	X		X	
6	X		X				X		X			X	X		X	
6	X		X					X	X			X	X		X	
6	X			X		X			X			X	X		X	
6	X			X			X		X			X	X		X	
6	X			X				X	X			X	X		X	
6	X				X	X			X			X		X		X
6	X				X		X		X			X		X		X
6	X				X			X	X			X		X		X
6	X		X			X			X		X		X		X	
6	X		X				X		X		X		X		X	
6	X		X					X	X		X		X		X	
6	X			X		X			X		X		X		X	
6	X			X			X		X		X		X		X	
6	X			X				X	X		X		X		X	
6	X				X	X			X		X			X		X
6	X				X		X		X		X			X		X
6	X				X			X	X		X			X		X
15		X	X			X			X		X		X		X	
15		X	X				X		X		X		X		X	
15		X	X					X	X		X		X		X	
15		X		X		X			X		X		X		X	
15		X		X			X		X		X		X		X	
15		X		X				X	X		X		X		X	
15		X			X	X			X		X			X		X
15		X			X		X		X		X			X		X
15		X			X			X	X		X			X		X
6	X		X				X			X		X	X		X	
6	X			X			X			X		X	X		X	
15		X	X				X			X		X	X		X	
15		X		X			X			X		X	X		X	
6	X		X				X		X		X			X		X
6	X			X			X		X		X			X		X
15		X	X				X		X		X			X		X
15		X		X			X		X		X			X		X
327	**Total**		Peening intensity shall be 0.008 - 0.012 C2 per MIL -S- 13165 using # 550 shot													

2.4 Toxicity Leaching Characteristic Determination

2.4.1 Toxicity Leaching Characteristic Test (EPA Method 1311)

If the procedure described herein is in conflict with the current EPA Method 1311, as defined by EPA, the current EPA Method 1311 shall take precedence.

2.4.1.1 Test materials

A minimum 200 grams of spent WCCoCr, Triballoy 400 and Triballoy 800 spray coating waste shall be provided for analysis.

2.4.1.2 Equipment needed

The following equipment is called out in this test procedure.
The container shall have an agitation apparatus that has the capability of rotating the extraction vessel in an end-over-end fashion at 30±2 rpm. EPA suggested suitable devices have been identified in Table 2 of their test method.
Filter Holder. Any filter holder that can support the glass fiber filter and be able to withstand the pressure needed to accomplish separation.
Bottle extraction Vessel. Can be made of borosilicate glass, polytetrafluoroethylene (PTFE), 310 stainless steel, high density polyethylene (HDPE), polyvinylchloride (PVC), or polypropylene (PP).
pH Meters. Meter should be accurate to ± 0.05 units at 25 degrees C.
Magnetic stirrer.
Fiber filters. Shall be made of borosilicate glass fiber containing no binder materials and having an effective pore size of 0.5 to 0.8 μm, or equivalent. EPA has a listing of approved suppliers. Pre-filters must not be used. Filters must be acid washed prior to use by rinsing with 1N HNO_3 followed by three consecutive rinses with deionized water (a minimum of 1L per rinse is recommended). Glass fiber filters are fragile and should be handled with care.
Laboratory Balance. Any laboratory grade balance with accuracy ±0.01 grams. All recorded weights shall be ±0.1 gram.

2.4.1.3 Extraction Liquid Determination

Weigh out approximately 5.0 grams of the test-coating specimen. The particle size of the coatings to be tested shall be 1mm in diameter or less. Place the 5 grams of test specimen into a 500mL beaker or Erlenmeyer flask. Add 95.5mL of reagent grade water into the beaker, cover with a watchglass, and stir vigorously for 5 minutes using a magnetic stirrer. Measure and record the pH. If the pH is <5.0, use extraction fluid #1. If the pH is >5.0, add 3.5mL 1N NCl, slurry briefly, cover with watchglass, heat to 50 degrees C and hold at 50 degrees C for 10 minutes. Let solution cool to room temperature and record pH. If pH is <5.0, use extraction fluid #1. If pH is >5.0, use extraction fluid #2.

<u>Extraction #1.</u>
Add 5.7 mL of ACS reagent grade Glacial Acetic acid (CH_3CH_2OOH) to 500mL of reagent water, add 1N NaOH, and dilute to a volume 1 of liter. When correctly prepared, the pH of fluid will be 4.88 ±0.05.

<u>Extraction #2.</u>
Add 5.7 mL of ACS reagent grade Glacial Acetic acid (CH_3CH_2OOH) with reagent water to a volume 1 liter. When correctly prepared, the pH of fluid will be 2.88 ±0.05.

2.4.1.4 Sample Preparation

Weigh out a maximum 25 grams of each coating to be tested and record weight. The test specimens shall be crushed, ground, or cut, as needed, so the sample surface area per gram of material equals or exceeds 3.1 cm^2 or is smaller than 1 cm in its narrowest dimension (i.e. able to pass through a standard 9.5mm (0.375 inch) sieve). The wastes and appropriate reduction tools used should be refrigerated, if possible to 4 degrees C prior to particle reduction step. The particle reduction step should not generate heat in and of itself. During specimen reduction, solid samples shall have limited atmospheric exposure, to the maximum extent possible.

2.4.1.5 Leachate Testing Procedure

Transfer the solid test specimens into an extractor bottle. Determine the amount of extraction fluid by using the following formula:

$$\text{Weight (extraction fluid)} = \frac{20 \times 100\ (\%\ \text{solids}) \times \text{weight of waste tested}}{100}$$

Slowly add the extraction fluid into the extractor bottle containing the test specimen. Close the extractor bottle tightly (teflon® tape is recommended to ensure tight seal). Secure to agitation device and rotate at 30 ± 2 rpm for 18 ± 2 hours. Ambient room temperature shall be maintained at 23 ± 2 degrees C during the extraction period. After running the 18 ± 2 hour extraction time, separate the extractor vessel into its component liquid and solid phases by filtering through a new acid washed glass fiber filter defined in 2.4.2.1. For the final filtration a new acid washed fiber filter may be used.

2.4.1.6 Leachate Extract Preparation

Collect the filtered leachate solution from the previous step. Immediately test and record the pH of the resultant leachate solution. Separate out a small fraction of leachate solution and add HNO_3 until pH<2 is recorded. If the leachate solution starts precipitating, discontinue adding the HNO_3, and immediately test the remaining solution for metal analysis. Store all leachate solutions, when not subject to testing, at 4 degrees C. The leachate solutions shall be acid digested except in those instances where digestion causes loss of metallic analytes. If the analysis of the undigested solution shows that the concentration of any regulated metallic analyte exceeds the regulatory level, then the waste is hazardous and digestion of the extract is not necessary. However, data on undigested extracts alone cannot be used to demonstrate that the waste is not hazardous. If the individual phases were analyzed separately, determine the volume of the individual phases (to ± 0.5%), conduct the appropriate analyses and combine the results mathematically by using a simple volume-weighted average:

$$\text{Final Analysis Concentration} = \frac{V(1)C(1) + V(2)C(2)}{V(1)+V(2)}$$

Where:
V(1) = volume of the first phase (L)
C(1) = the concentration of the first phase (mg/L)
V(2) = volume of the second phase (L)
C(2) = the concentration of the second phase (mg/L)

2.4.1.7 TCLP Procedures

The leachate solution shall then be subjected to methods approved by EPA for determining metal composition.

2.4.1.7.1 Chromium.

EPA approves various methods including, but not limited to:

AA direct aspiration, AA furnace…	ASTM D1687
DCP Method…………………… ..	ASTM D4190

2.4.1.7.2 Nickel.

EPA approves various methods including, but not limited to:

AA direct aspiration, AA furnace…	ASTM D1886
DCP Method………………………..	ASTM D4190

2.4.1.8 TCLP Determination

Compare the resultant concentration number with the found in 40 CFR 261.24. If the calculated resultant is greater than the one found in the 40CFR 261.24, then the material regulated for that constituent. Since EPA doesn't regulate Nickel at this time, the number is for future reference.

2.4.1.9 Test Report

The organization performing this test must provide a formal test report in a format consistent with typical commercial requirements potentially requiring submission to the EPA for review. As a minimum the test report must include the following items:

- Firm's name, mailing address, telephone and fax number.
- Brief executive Summary.
- Origin of sample. (data will be provided)
- Complete documentation of the procedure(s) followed.
- Complete documentation of the EPA approved method used.
- Comparison to 40CFR 261.
- Final results.

2.4.2 Rationale

This test's purpose shall be to determine if production scrap or waste and used components coated with Tungsten Carbide Cobalt Chrome (WCCoCr), Triballoy 400 and Triballoy 800, being tested in this and other HCAT JTPs, are classified as hazardous waste by the U.S. Environmental Protection Agency (EPA) and therefore regulated under 40 CFR Part 261 Subpart C.

2.5 Corrosion Test

2.5.1 Purpose

The repair manual for the E-2 propeller hub defines a nickel plate procedure to restore dimensional size to the rocking lands as a result of service wear. Due to environmental concerns over nickel plating solutions, a thermal spray coating is proposed as a replacement. The following testing is designed to evaluate the corrosion characteristics of the current nickel plate and proposed HVOF coating. The test matrix below establishes the type and quantity of test panels for salt spray testing per ASTM B-117.

2.5.2 Test Specimens.

2.5.2.1 As-Plated

Plating/Coating	Thickness	No. of Samples
Nickel Plate per QQ-N-290, CL. 2, 500Hv min, compressive. stress 10,000psi max	0.010 in	3 each
	0.005 in	
	0.001 in	
WC-17Co	0.010 in	3 each
	0.005 in	
	0.001 in	
WC-CoCr	0.010 in	3 each
	0.005 in	
	0.001 in	
Tribaloy T-800	0.010 in	3 each
	0.005 in	
	0.001 in	

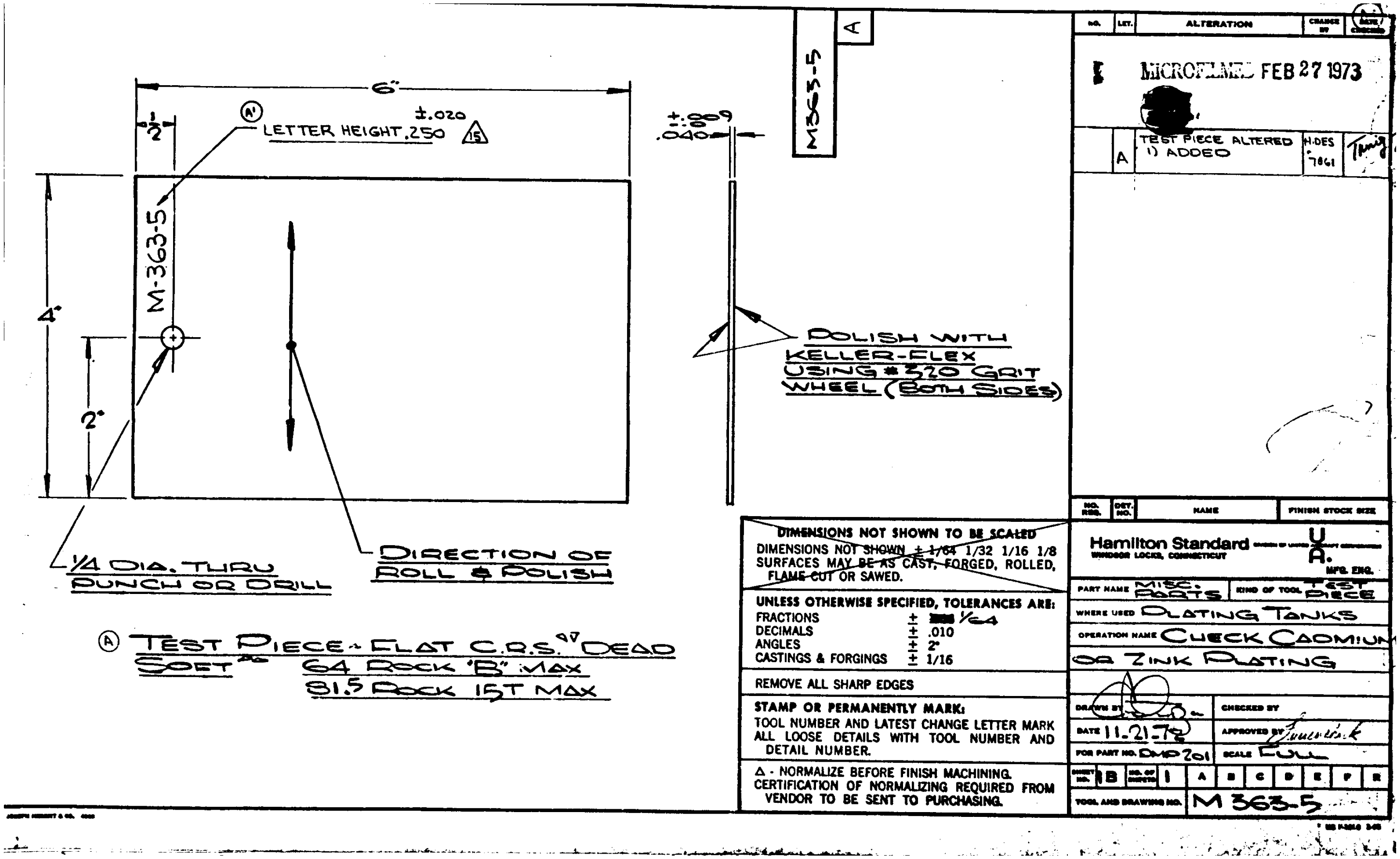
2.5.2.2 Machined (0.002 type stock removal)

Plating/Coating	Thickness	No. of Samples
Nickel Plate per QQ-N-290, CL. 2, 500Hv min, compressive stress 10,000psi max	0.010 in	3 each
	0.005 in	
	0.001 in	
WC-17Co	0.010 in	3 each
	0.005 in	
	0.001 in	
WC-CoCr	0.010 in	3 each
	0.005 in	
	0.001 in	
Tribaloy T-800	0.010 in	3 each
	0.005 in	
	0.001 in	

2.5.3 Rationale

Corrosion has not been a significant concern for the Low Pitch Stop Sleeve and Hub tailshaft since these are bathed in hydraulic fluid during operation. The exception is the Navy's E-2 hub rocking lands. This area of the E-2 hub is exposed to the outside environment and is therefore susceptible to corrosion attack. The current Hamilton-Sundstrand repair manual allows the use of Electrodeposited Nickel to restore size when wear is evident. Since most documentation to-date has been on chromium plate, this test was required to validate the substitution of an HVOF coating for this area of the E-2 hub. The AF agrees that this would be useful information.

Figure 5 Corrosion Test Panel



~~DIMENSIONS NOT SHOWN TO BE SCALED~~
~~DIMENSIONS NOT SHOWN ± 1/64 1/32 1/16 1/8~~
~~SURFACES MAY BE AS CAST, FORGED, ROLLED, FLAME CUT OR SAWED.~~

UNLESS OTHERWISE SPECIFIED, TOLERANCES ARE:

FRACTIONS	± 1/64
DECIMALS	± .010
ANGLES	± 2°
CASTINGS & FORGINGS	± 1/16

REMOVE ALL SHARP EDGES

STAMP OR PERMANENTLY MARK:
TOOL NUMBER AND LATEST CHANGE LETTER MARK ALL LOOSE DETAILS WITH TOOL NUMBER AND DETAIL NUMBER.

Δ - NORMALIZE BEFORE FINISH MACHINING. CERTIFICATION OF NORMALIZING REQUIRED FROM VENDOR TO BE SENT TO PURCHASING.

3.0 COMPONENT PERFORMANCE TESTS

3.1 Background

The purpose of the component tests is to assess the candidate HVOF coatings in a simulated operating environment.

3.2 Surface preparations and Coating Parameters

The substrates and coatings shall be processed in accordance to requirements identified in paragraphs 2.2.1 and 2.3.1 for their respective components.

3.3 54H60 Low Pitch Stop Lever Sleeve

3.3.1 Purpose

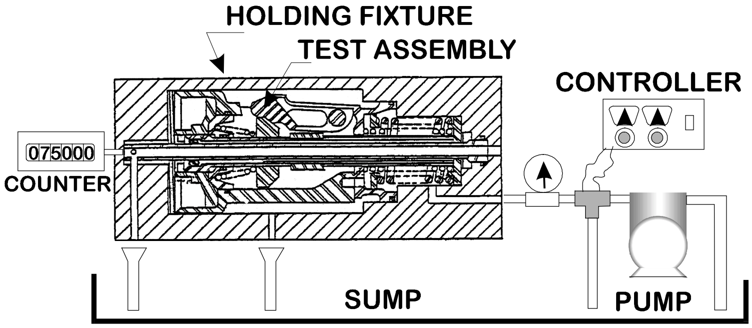
The test is designed to evaluate the endurance characteristics of the HVOF coating in a simulated service environment using actual propeller hardware.

Two HVOF materials are under consideration to replace chrome plate in this application: Tungsten Carbide 17% Cobalt (WCCo) and Tribaloy T-800. Only one of these candidates will be selected for component test and will be chosen based on the outcome of specimen wear and specimen fatigue tests.

3.3.2 Test Description

3.3.2.1 Test Fixture

The test apparatus will consist of a holding fixture, controller and hydraulic test stand. The holding fixture and test schematic are shown below.



3.3.2.2 Test Hardware

The test hardware will consist of two full-up Low Pitch Stop Assemblies, P/N 774474. The lever sleeve, P/N 538889, will be customer supplied with either chromium plate or HVOF coating applied to the piston bore area. The HVOF material will be <u>either</u> Tungsten Carbide 17% Cobalt or Tribaloy T-800 per HS4412. The HVOF candidate chosen will be based on the results of specimen wear and fatigue testing performed in Section 2 of this Test Plan Chromium plate will be applied to the other lever sleeve per QQ-C-320, Class 2.

3.3.3 Test Assumptions and Acceptance Criteria

3.3.3.1 Test Assumptions

The following assumptions were used to estimate the duration (cycles):

Assumptions:
Each flight = one hour
The low pitch stop is activated 10 times per flight.
The propeller life is 7,500 hours (before overhaul)

Calculations:
The low pitch stop is activated 10 times/~~flight~~ x 1 ~~flight~~/hour = 10 times/hour.
The low pitch stop is activated 7,500 ~~hours~~ x 10 times/~~hour~~ = 75,000 times during the prop life.
The test stand will activate the low pitch stop every 8 seconds.
8 sec / stroke x 75,000 strokes = 600,000 seconds
600,000 sec x 1 hr / 3,600 sec ≈167 hours
167 hr x 1 day / 16 hr ≈11 days

To simulate the operating environment, Mil-H-5606, Mil-H-83282 or Mil-H-6083 hydraulic fluid will be used at a temperature of 150 ±10°F. The piston will be actuated using a pressure of 310 ±5psi.

3.3.3.2 Test Acceptance

Comparison of HVOF and control specimens must show that the HVOF coated specimen exhibits equal to or improved wear characteristics.

3.3.4 Rationale

This test was developed to adequately simulate the operational conditions and wear seen by the 54H60 Low Pitch Stop Lever Sleeve in actual flight conditions.

3.4 P-3 Propeller Full Scale Test

3.4.1 Purpose

The purpose of this flight test is to verify that after all the seal wear tests have been accomplished that the coating adequately performs on the actual airframe.

3.4.2 Test Specimens

One complete propeller test assembly will be provided for testing on a single airframe. The test assembly, the tail shaft hub (P/N 538714) and sleeve-lever support (P/N 538889), shall be coated with the preferred coating after reviewing the wear test results (JTP paragraph 2.2). The complete propeller test assembly then is mounted on a single P-3 airframe. The position of the test assembly mounted on the airframe should not impact the results in this test.

3.4.3 Test Duration

The one test aircraft shall run their normal duty operations. After 275 flight hours, the test aircraft propeller assembly shall be field inspected.

3.4.4 Inspection and Documentation

During the testing period the maintenance or flight crew, if away from home base, shall visually inspect the test assembly for oil leakage/seepage. During the operational testing any leakage noted shall be documented using Form 1 with as many facts as possible (when first noted, approximate volume, condition of other engines (if relevant)) and sent to NAVDEP Cherry Point.

3.4.4.1 Leakage

NAVDEP Cherry Point, AFMC and the other stakeholders shall then review field documentation and categorized leakage as acceptable/routine or serious. If acceptable/routine, then the test should go on. If serious, the stakeholders shall determine appropriate plan of action. This plan of action can include, but not limited to, repair on the wing, removal and disassembly for failure analysis. NAVDEP Cherry Point shall determine location that propeller hub disassembly is performed. Excessive seal wear, with leakage the common symptom, directly attributed to the coating shall constitute a test failure. If the failure analysis identifies testing anomalies, that fact shall be taken into account by the stakeholders before declaring the test a failure or repeated.

3.4.4.2 Passing

As the test assembly approaches the end of the test duration, NAVDEP Cherry Point shall consult with the other stakeholders to determine time and location for a final inspection of the test assembly, as deemed appropriate.

3.4.5 Rationale

This test was developed by the stakeholders to verify that the previous testing performed adequately covered the wear and gasket sealing requirements needed to successfully convert the subject components to HVOF coatings.

Figure 6 Tension-Tension Fatigue Specimen (12X1790)

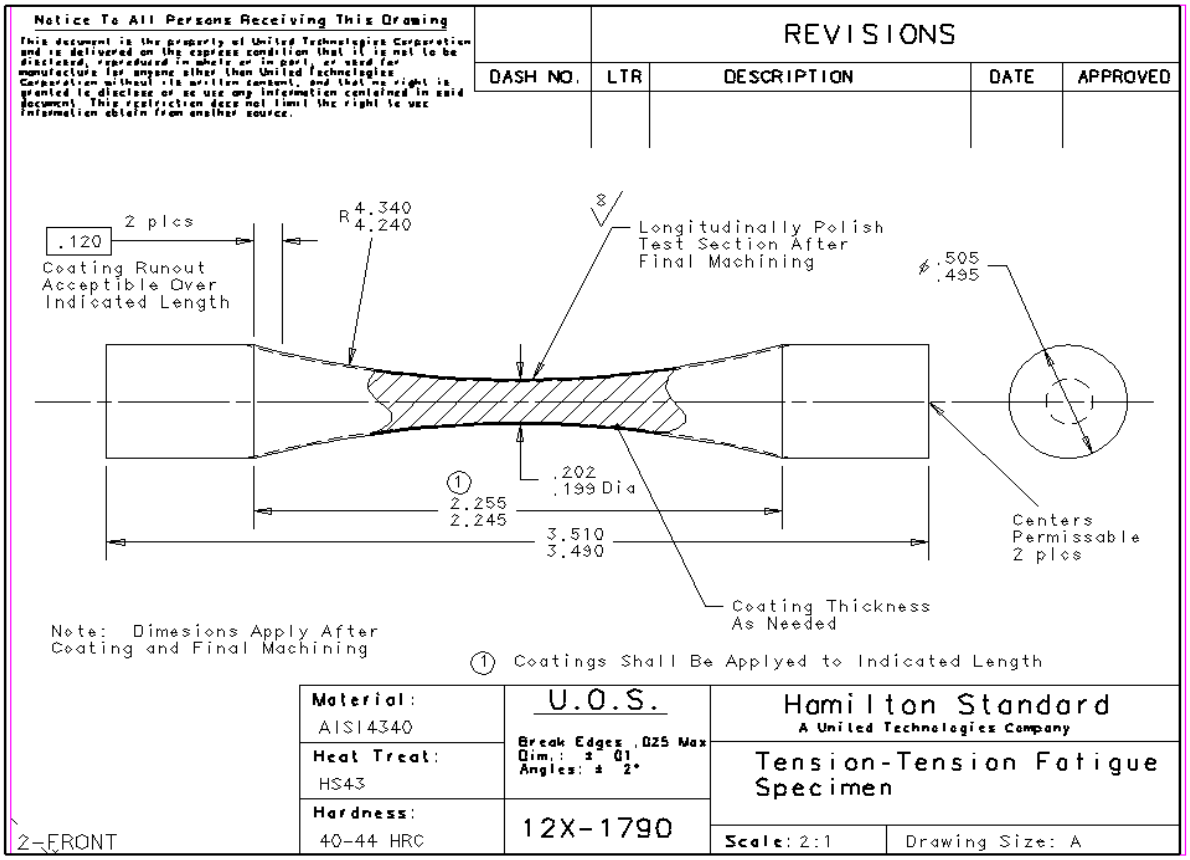


Figure 7 Tension-Tension Fatigue Specimen- Notched (12X-179

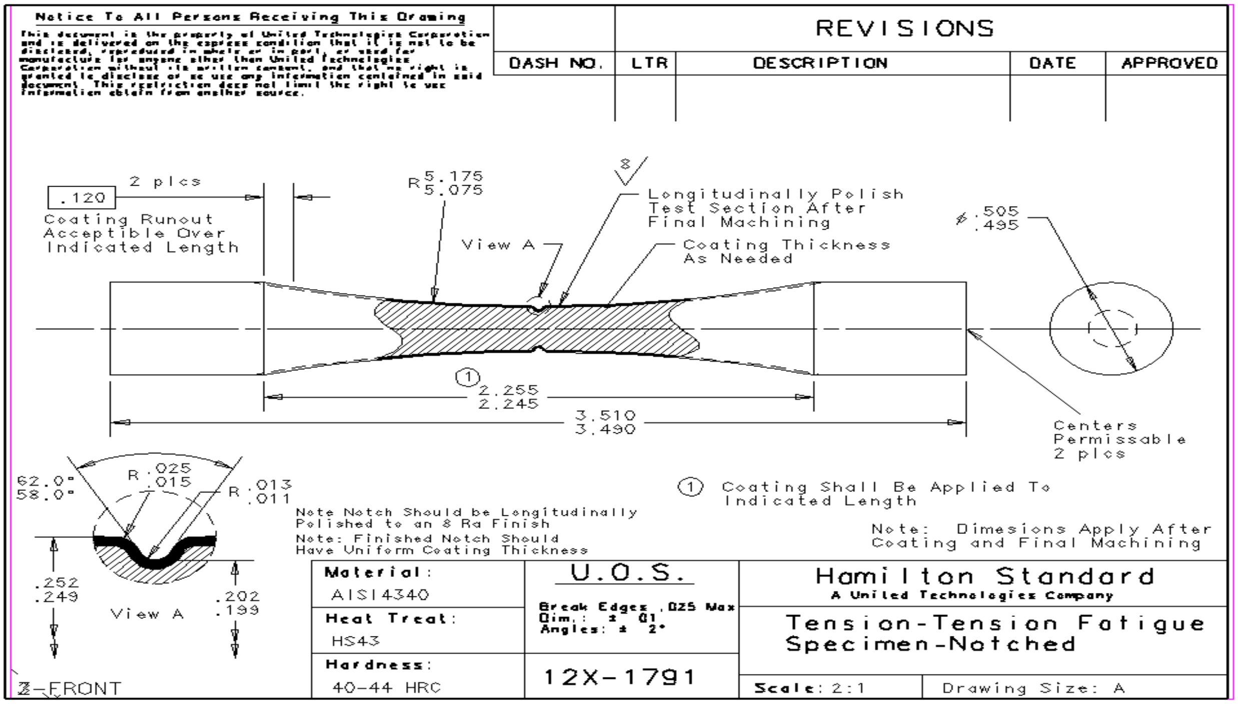


Figure 8 Proposed Operational Test Form

AEROSPACE VEHICLE—TEST RECORD (HVOF Propeller Hub Assembly)

AIRCRAFT TYPE AND SERIAL NUMBER:	PROPELLER TYPE AND MODEL NUMBER:
AIRCRAFT BASE LOCATION:	INSTALLED AT TOTAL AIRCRAFT HOURS:
CREW CHIEF NAME	

DATE	AIRFRAME FLYING TIME	OIL ✓	Quantity Added	OBSERVATION/ DISCREPANCY

UPON COMPETION OF FORM TRANSCRIBE LAST ENTRY TO NEXT COPY. FORWARD FORM TO NAVDEPCP (4.4.6) Attn: D. Hayworth

Test Form 1