0746

P 05065

24714

PDF

MCAIR

ION VAPOR DEPOSITED ALUMINUM COATINGS FOR IMPROVED CORROSION PROTECTION

by

E.R. Fannin

Presented at
AGARD Meeting
Florence, Italy
26-28 September 1978

MCDONNELL AIRCRAFT COMPANY

Box 516, Saint Louis, Missouri 63166 · Tel. (314)232-0232

MCDONNELL DOUGLAS CORPORATION

ION VAPOR DEPOSITED ALUMINUM COATINGS FOR IMPROVED CORROSION PROTECTION

by
E.R. Fannin
Program Manager - Ivadizer Technology
McDonnell Aircraft Company
St. Louis, Mo. 63166 - USA

SUMMARY

The corrosion resistant properties of metallic aluminum are well documented. However, commercial processes for the application of aluminum coatings, such as electroplating, spray metallizing, hot dipping, cladding, and others have severe limitations. Production equipment has recently been developed for plating with aluminum by ion vapor deposition (IVD) without incurring many of the problems associated with these commercial processes. The coating is called Ivadize TM and provides outstanding corrosion protection. In addition, the coating can be used at temperatures up to 925°F (496°C); and the process does not cause hydrogen embrittlement. The coating and the coating process are non toxic and do not contribute to the pollution of our environment.

Because of its performance advantages, ion vapor deposited aluminum can be used in a wide range of applications, and is particularly effective as a replacement for cadmium coatings.

INTRODUCTION

The aircraft industry, like most industries, is confronted with the challenge of protecting products from corrosion and its deleterious effects. We must meet this challenge in the face of increasingly stringent demands for improved product life and performance. Therefore, new materials and coating systems for protection against corrosion are continuously being sought.

Cadmium electroplating has been the favored method for protecting steel on aircraft structure for many years. Obvious problems with its use were minimal prior to the use of high strength steel and aluminum alloys. Cadmium electroplating on high strength steel often caused hydrogen embrittlement, and cadmium plated fasteners installed in high strength aluminum alloys helped promote exfoliation corrosion in the countersinks. More recently it has received further disfavor because it was found to cause solid metal embrittlement of titanium structure and because of its toxicity and harmful effects on the environment.

However, it was mainly for the first two reasons that McDonnell Aircraft Company (a division of McDonnell Douglas Corporation) started looking for a viable alternate for cadmium in the early 1960's. After extensive paper studies, aluminum coatings were selected as the best substitute. Being the least dissimilar to aluminum alloy structure, it is ideally compatible. Furthermore, aluminum is anodic to steel and provides galvanic protection as does cadmium.

It was quickly found that available processes for applying aluminum coatings such as metal spraying, electroplating, cladding, hot dipping and others had severe limitations such as thickness control, adhesion, size and shape of product that could be coated, and effect on substrate properties.

During this same period we had selected vacuum deposited cadmium as the coating for solving the problem of hydrogen embrittlement of high strength steel. Our production experience with the vacuum coating process was very favorable. For this reason we started looking at vacuum coating processes for aluminum. This included physical vapor deposition, ion vapor deposition, and chemical vapor deposition. Ion vapor deposition provided the best adhesion and most uniform coating thickness and with other considerations was selected for further development.

In the late 1960's the United States Air Force and Navy sponsored in-service testing of several coatings on fasteners installed in operational aircraft. (Reference 1) These tests showed that aluminum coatings provided the best protection against corrosion. These results along with numerous laboratory tests confirmed the performance advantages of ion vapor deposited aluminum.

The production feasibility of the process was demonstrated with a full scale coating system fabricated and delivered to the Naval Air Rework Facility, San Diego, in 1974. Since then a military specification has been issued and coating equipment fabricated for the U.S. Air Force. Additional coating systems for both fasteners and larger structural components have been fabricated and ion vapor deposited aluminum is being used on several production aerospace programs.

DESCRIPTION OF THE EQUIPMENT AND PROCESS

The basic equipment required for ion vapor deposition, called Ivadizer TM at McDonnell, is a steel chamber, a pumping system, an evaporation source, and a high voltage power supply. A schematic of a typical Ivadizer is shown in Figure 1.

The process sequence consists of pumping the system down to about 10^{-4} Torr. The chamber is then backfilled with an inert gas to about 10 microns and a high negative potential applied between the parts being coated and the evaporation source. The gas becomes ionized and creates a glow discharge around the parts to be coated. The positively charged gas ions bombard the surface of the parts and perform final cleaning. The clean surfaces resulting are essential for good coating adhesion.

Following glow discharge cleaning, commercially available aluminum wire (1100 alloy) is evaporated by continuously feeding into resistance heated crucibles. As the aluminum vapor passes through the glow discharge, a portion of it becomes ionized. This, in addition to bombardment by the inert gas ions, accelerates the aluminum vapor toward the part surface. This results in denser coatings and also improves the coating adhesion. The ionization also provides better throwing power and allows complex shapes to be more uniformly plated. A typical plating cycle requires about 45 minutes.

After coating, parts are generally chromate treated in accordance with MIL-C-5541 (Reference 2). This provides additional protection against corrosion. It also forms a good base for paint adhesion and is a common treatment for aluminum surfaces.

COATING PERFORMANCE

Ion vapor deposited aluminum is a soft, ductile coating and has properties nearly identical to pure aluminum. We use three classes and two types of coatings. The classes reflect coating thickness and the types are I, as coated, and II, as coated with a supplementary chromate treatment. Type II is generally used for reasons previously mentioned. The corrosion resistance requirement for type II coatings is shown in Table I for the various class coatings.

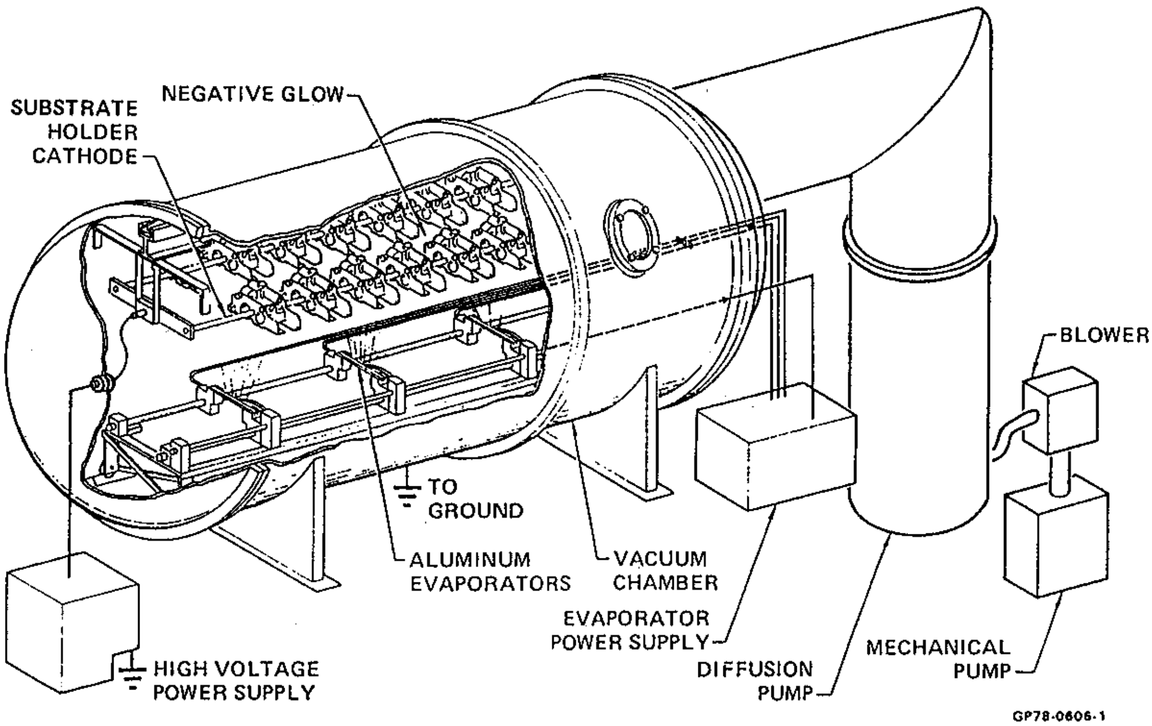


FIGURE 1
SCHEMATIC OF AN ION VAPOR DEPOSITION SYSTEM

TABLE 1
MINIMUM CORROSION RESISTANCE
REQUIREMENTS PER MIL-C-83488 (REFERENCE 3)

CLASS	MINIMUM THICKNESS		CORROSION RESISTANCE (HR)
	(IN.)	(MICRONS)	
1	0.0010	25	672
2	0.0005	13	504
3	0.0003	8	336

Class 1 coatings are used for high temperature and exterior applications where severe corrosion environments are encountered. Class 2 is recommended for interior parts where less severe environments are encountered, and Class 3 is used only when close tolerances are required such as fine threaded parts.

Corrosion testing of bright, electroplated cadmium on steel panels along with IVD aluminum of comparable thickness in 5% salt spray per ASTM Method B-117 will generally show cadmium to be better. However, if a scratch is made through the coatings to the substrates, the cadmium will generally sacrifice itself more quickly and allow red rust to form before the IVD aluminum.

Results obtained in laboratory tests when cadmium and IVD aluminum coated steel fasteners were installed in 7075-T6 aluminum alloy and exposed to SO_2 - salt spray for 168 hours are shown in Figure 2. The cadmium plated fastener heads are more severely rusted. More important is the condition of the countersinks in the aluminum. The IVD aluminum has provided protection to the countersinks while the cadmium coated fasteners appear to have promoted corrosion of the countersinks.

There are also advantages for IVD coating titanium fasteners installed in aluminum structure. A comparison was made between IVD aluminum coated titanium fasteners installed dry, and bare titanium fasteners installed with wet epoxy primer. The latter is a standard procedure used on aircraft. These fasteners were installed in 7075-T6 aluminum alloy that had been MIL-C-5541 treated. After fastener installation the panel was sprayed with one coat of MIL-C-23377 primer and exposed to SO_2-salt spray for 28 days. Visual examination showed that the blistering of primer around the peripheries of the fasteners installed with wet primer was more severe than around the IVD aluminum coated fasteners. Examination of the countersinks after fastener removal also showed less corrosion resulted where IVD coated fasteners were installed (Figure 3). Studies at McDonnell have also shown a cost advantage of using IVD aluminum coated fasteners in lieu of wet installation.

Coating adhesion and thickness uniformity are comparable to electroplating. The adhesion requirements are the same as those specified in Reference 4 for cadmium electroplating. An example of the coating uniformity on a fastener is illustrated in Figure 4.

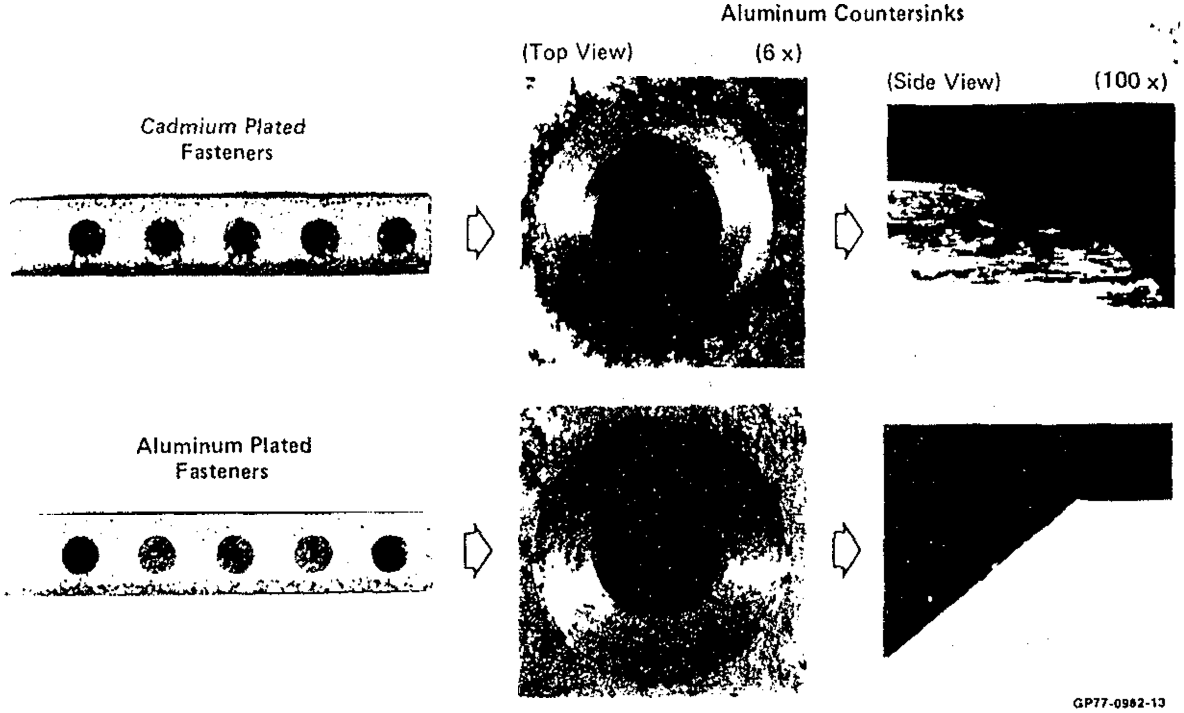


FIGURE 2
IVD ALUMINUM AND CADMIUM COATED STEEL FASTENERS INSTALLED IN 7075-T6 ALUMINUM ALLOY AND EXPOSED TO 168 HOURS OF SO_2 - SALT SPRAY

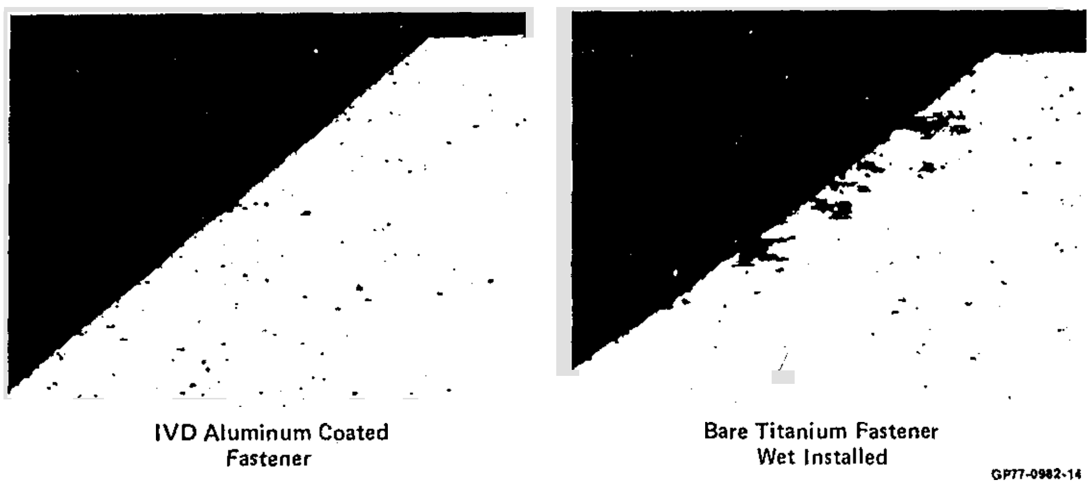


FIGURE 3
CORROSION TESTS OF IVD COATED AND WET INSTALLED TITANIUM FASTENERS IN 7075-T6 ALUMINUM ALLOY COUNTERSINKS

A lot of fastener qualification data has been generated on the use of IVD aluminum (Reference 5). A summary of the tests performed is listed in Table 2. This data is too voluminous to present here, however the conclusions can be summarized as follows:

1. The aluminum coating does not produce any detrimental effects on mechanical properties.
2. The coefficient of friction of aluminum is higher than cadmium, therefore, higher installation forces are required. These higher values, however, are within the working ranges presently used for cadmium in most cases. Interference fit fasteners may require closer attention to the type of lubricants used.

Ion vapor deposited aluminum has also been evaluated on gas turbine components. (Reference 6). In the low temperature sections, less than 850°F (454°C), it is being considered as a replacement for diffused nickel cadmium and aluminum pigmented paints.

It has also been evaluated in the hotter sections. There it also shows promise as a replacement for pack cementation. In this case the aluminum is applied to the nickel base alloy components by ion vapor deposition and then diffused to form the nickel aluminide coating. This approach results in a more uniform coating and does not require the use of noxious chemicals. Only preliminary testing has been completed in the hotter sections.

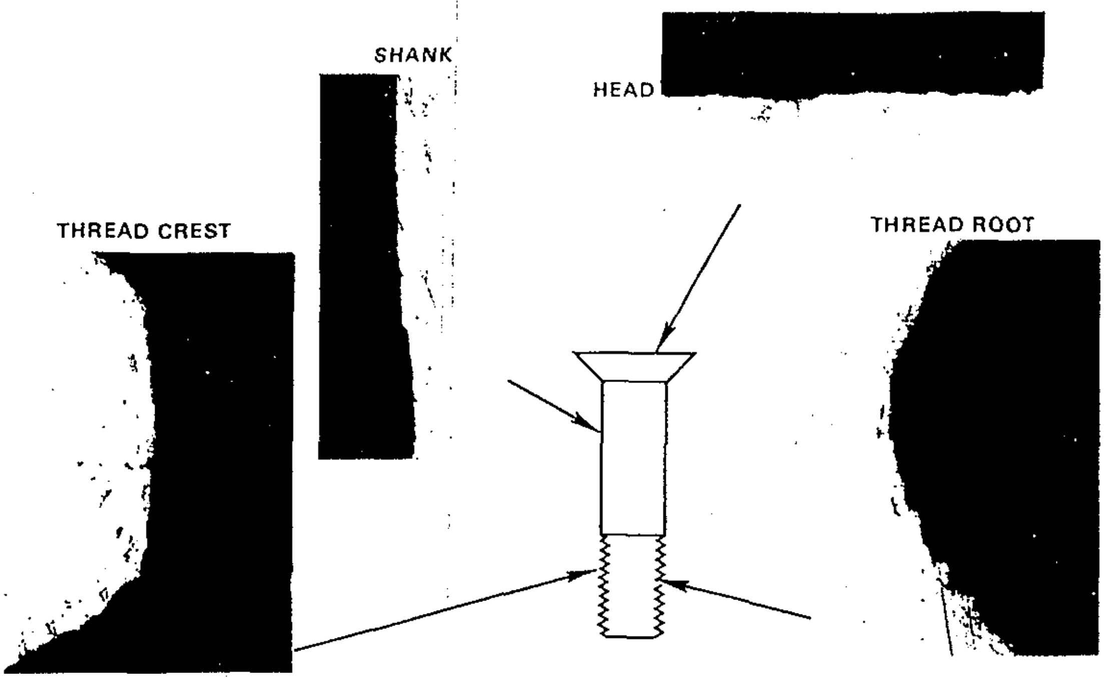


FIGURE 4
IVD ALUMINUM THICKNESS DISTRIBUTION ON A FASTENER

TABLE 2
FASTENER QUALIFICATION TESTS

Mechanical	Installation
Tensile Strength	Torque Tension
Double Shear	Locking Torque
Tension Fatigue	Reuseability
Stress Durability	Interference Fit
Stress Rupture	

Another potential application exists for IVD aluminum on titanium components in gas turbine engines. Tests have shown that the Ivadize coating significantly improved the resistance of Ti-8-1-1 alloy to ignition (Reference 7).

Test specimens after laser impingement are shown in Figure 5.

PRODUCTION STATUS

The first production size coater was sponsored by the Naval Air System Command and delivered to the Naval Air Rework Facility at North Island, San Diego, in April 1974. During this contract period, a number of our aircraft parts, both steel and aluminum components, were plated and evaluated. Coating uniformity, adhesion and corrosion performance were all very satisfactory. This unit is 4 feet in diameter and 8 feet long and is shown in Figure 6.

At about this same time a new approach was conceived for coating small parts on a more economical basis. The technique is similar to barrel electroplating in that parts are placed in rotating barrels over the aluminum evaporation source. Following conceptual verification in the laboratory, a 4 foot diameter by 6 foot long system was designed and fabricated. The unit has been used to demonstrate the process and as a test bed for design development. The system has evolved from one to two barrels per unit, doubling the output. Production capacity was increased further by placing vacuum locks on the feed and discharge ends of the system (Figure 7). This allows fasteners to be loaded and unloaded without breaking the vacuum and reduces the total coating cycle by about 50 percent. A similar unit installed this year at a fastener manufacturer, The Voi-Shan Corporation, is also shown in Figure 6.

Early in 1976 a large detail parts coater 7 feet in diameter and 12 feet long was installed in our manufacturing facility. (Figure 6) Approval had been obtained from the Air Force to use ion vapor deposited aluminum coatings on the F-15 Eagle. Fatigue improvement and economics were the motivating reasons. Sulfuric acid anodize coatings were replaced on fatigue critical aluminum wing skins. This resulted in a fatigue improvement without a design configuration change. It also eliminated a shot peening operation, resulting in a cost savings. In addition, IVD coated low alloy steel was used to replace higher cost stainless steel components.

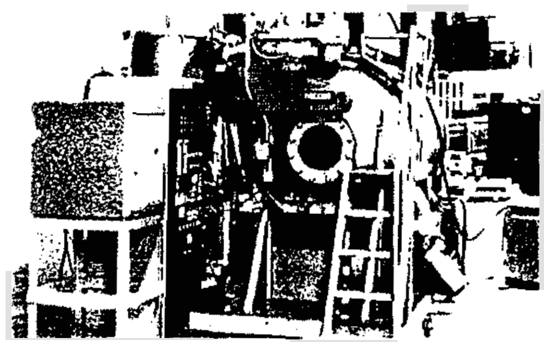
IVD aluminum is presently being used on the F-4 Aircraft and is required for use on the Harrier and the F-18 Hornet. It will be the primary corrosion protective plating on the F-18. On this aircraft it will be utilized on all fatigue critical aluminum structure, all high strength steel structure and on titanium and low alloy steel fasteners.

FAL 41693 FAL 41694 FAL 41695 FAL 41682

Ti 8-1-1 Ti 6-4 Ti 6-6-2 Ti 8-1-1 + Al

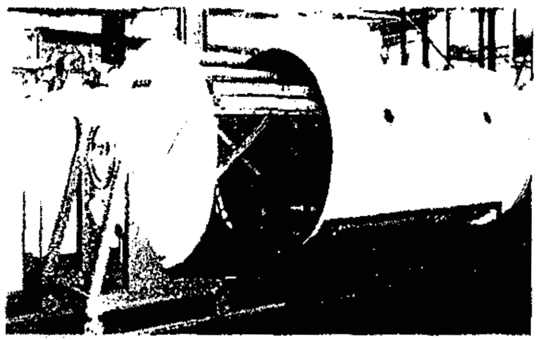
FIGURE 5
APPEARANCE OF TEST SPECIMENS AFTER LASER IMPINGEMENT
240°C (400°), 0.62 MPa (90 psia), 122 m/Sec (400 Ft/Sec) Airstream

Naval Air Rework Coater



Barrel Coater

McDonnell Production Coater



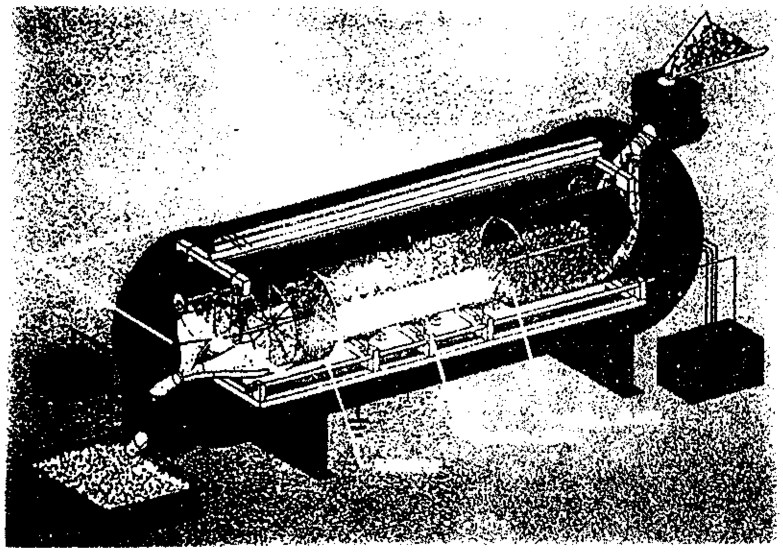
Air Force Coater

GP77-0982-15

FIGURE 6
PRODUCTION COATERS

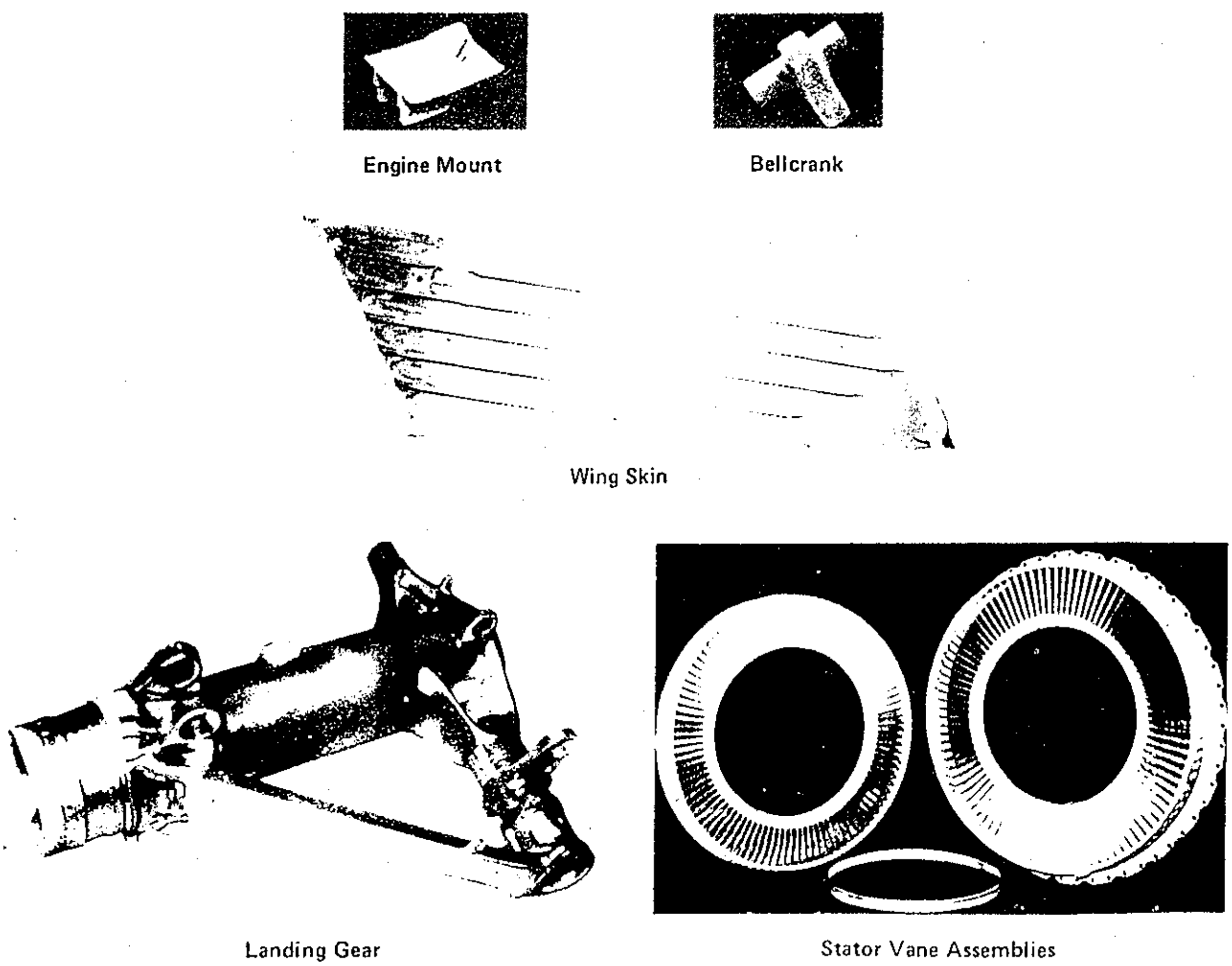
A unit has also been fabricated under contract with the Air Force Materials Laboratory, Manufacturing Technology Division. This unit was used to develop optimum parameters and fixturing for coating both aircraft and engine parts. It will be utilized mainly as a replacement for vacuum deposited cadmium on high strength steel parts. This unit is 6 feet in diameter and 10 feet long (Figure 6) and was delivered to Hill Air Force Base in March 1978.

Photographs of a few of the aircraft and engine parts that have been coated at McDonnell are shown in Figure 8. There is also a lot of interest in aluminum coatings outside the aircraft industry. A few examples include computer discs, consumer hardware, automotive parts, space systems, electrical components, appliances, etc. Examples of sample parts coated for evaluation are shown in Figure 9.



GP77-0982-16

FIGURE 7
SCHEMATIC OF BARREL COATER



GP77-0982-17

FIGURE 8
IVD ALUMINUM COATED AIRCRAFT AND ENGINE PARTS

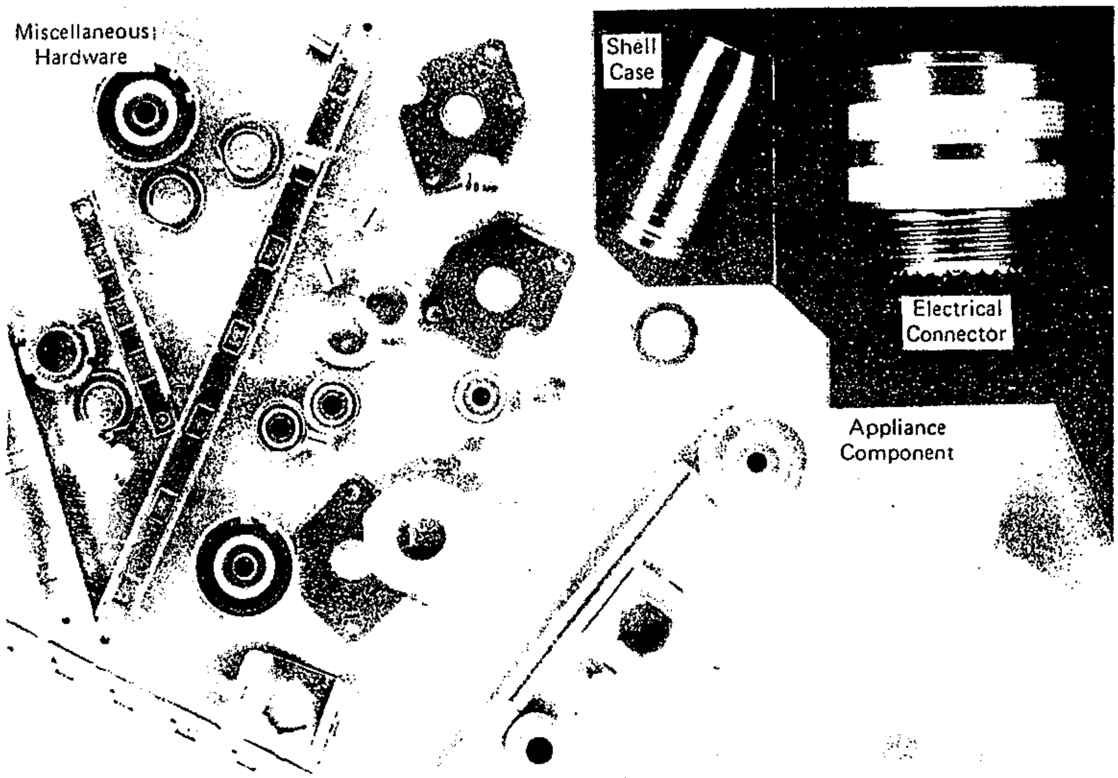


FIGURE 9
MISCELLANEOUS PARTS IVD COATED

CONCLUSIONS

Equipment has been developed and is commercially available for ion vapor deposition of aluminum. The coating, after undergoing extensive laboratory and in-service testing on aircraft, has been verified as an environmentally clean, high performance corrosion protection finish. Specific advantages include:

(a) It outperforms cadmium and other coatings in actual service tests.

(b) It has a useful temperature to 925°F (496°C).

(c) It can protect steels of all strength levels because there is no hydrogen embrittlement.

(d) It does not cause solid metal embrittlement of titanium.

(e) It can be used in contact with fuel.

(f) It provides galvanic protection to aluminum alloys and does not cause fatigue reduction.

(g) It can be applied thinner than alclad on aluminum alloys resulting in weight savings and is not limited to rolled forms.

(h) Neither the process nor the coating involve toxic materials, therefore, there is no clean-up or ecology problems.

With these advantages, ion vapor deposited aluminum provides an effective means for meeting many of today's challenges in the fight against corrosion.

REFERENCES

1. F.H. Meyer, Jr. and E. Jankowsky, "Corrosion Performance of New Fastener Coatings on Operational Military Aircraft", International Corrosion Forum, NACE, March 1973.
2. Military Specification, MIL-C-5541, "Chemical Conversion Coating for Aluminum Alloys".
3. Military Specification, MIL-C-83488 (USAF), 23 September 1976, "Coating, Aluminum, Ion Vapor Deposited".
4. Federal Specification, QQ-P-416, "Cadmium Plating (Electrodeposited)".
5. McDonnell Aircraft Company M&PD R&D Report No. 118, 16 February 1975.
6. R. Fishter, Pratt & Whitney Aircraft Group, "IVD Aluminum Coatings for Protection of Steel Turbine Components," 1978, Report No. FR 9865.
7. V.G. Anderson, B.A. Manty, Pratt & Whitney Aircraft Group, "Titanium Alloy Ignition and Combustion", 1978, Report No. NADC-76083-30.

AUTOCLAVE TOLL SERVICES LTD.
Rural Rte. 6, Box 141 • Princeton, Kentucky 42445

Telephone:
800-365-3688
(502) 365-0100

830691

Improved Equipment Productivity Increases Applications for Ion Vapor Deposition of Aluminum

D. E. Muehlberger and J. J. Reilly
McDonnell Aircraft Co.
McDonnell Douglas Corp.

SAE The Engineering Resource For Advancing Mobility
REPRINT

Reprinted from:
P-127—Proceedings of the 19th Annual
Airline Plating & Metal Finishing Forum

SAE
400 Commonwealth Drive
Warrendale, PA 15096 U.S.A.