MILITARY AND AEROSPACE APPLICATIONS FOR POWDER COATING

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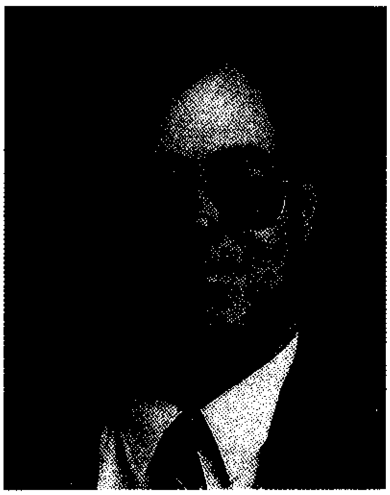

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INTRODUCTION

Regulations restricting Volatile Organic Compound (VOC) emission along with hazardous waste generation and disposal are beginning to seriously impact the painting of aerospace hardware. Use of many of the traditional aerospace paint systems such as Mil-P-23377 epoxy primer and Mil-C-83286 urethane topcoat has been effectively prohibited in many areas of the country since they exceed 420 gm/liter VOC content allowed by regulation. Some users of the new compliant paint systems have experienced significant paint-related cost increases due to increased rework, more stringent record keeping, and additional hazardous waste disposal costs.

Historically, the use of powder coatings in military and other aerospace high-performance applications has been limited. This is primarily the result of demanding specification requirements, test and development expenses, reluctant customer acceptance of powders, and relatively low production rates as compared to typical commercial uses. However, powders are rapidly gaining notice as environmental regulations and cost constraints become tighter. At Hughes Aircraft Company, powders have been investigated for use, principally on defense systems, since 1983. Today, powder coating is successfully used on a number of company programs.

Hughes Missile Systems Company (HMSC)

Hughes Missile Systems Company is a subsidiary of Hughes Aircraft Company, a unit of General Motors. Primary company facilities, including Headquarters, Research and Development, Engineering, and Manufacturing are located in Tucson, Arizona. Products produced in Tucson include missiles and other weapon systems as well as a wide range of high-performance electronic equipment, subsystems, and devices.

The standard liquid paint system used at the HMSC Tucson plant site is a Mil-P-23377 epoxy primer followed by a Mil-C-83286 urethane topcoat. Mil-C-8514 wash primer is also used on some alloys, primarily Inconel. Prior to 1986, all production hardware was painted using these or similar liquid paints which all have a high solvent content. HMSC began evaluating powder coating in 1983 and implemented several epoxy powder applications on the Phoenix and Maverick missile systems between 1986 and January 1991.

A typical conventional wet paint process flow chart is presented in Figure 1 with all VOC emission points and hazardous material (HAZMAT) generation points identified. On substrates requiring a wash primer several additional operations would be included which further add VOC emission and hazardous waste generation points to the flow chart. At present, HMSC's conventional painting process consists of at least thirteen operations, twelve of which generally produce VOC emissions and eight of which are likely to produce hazardous waste.

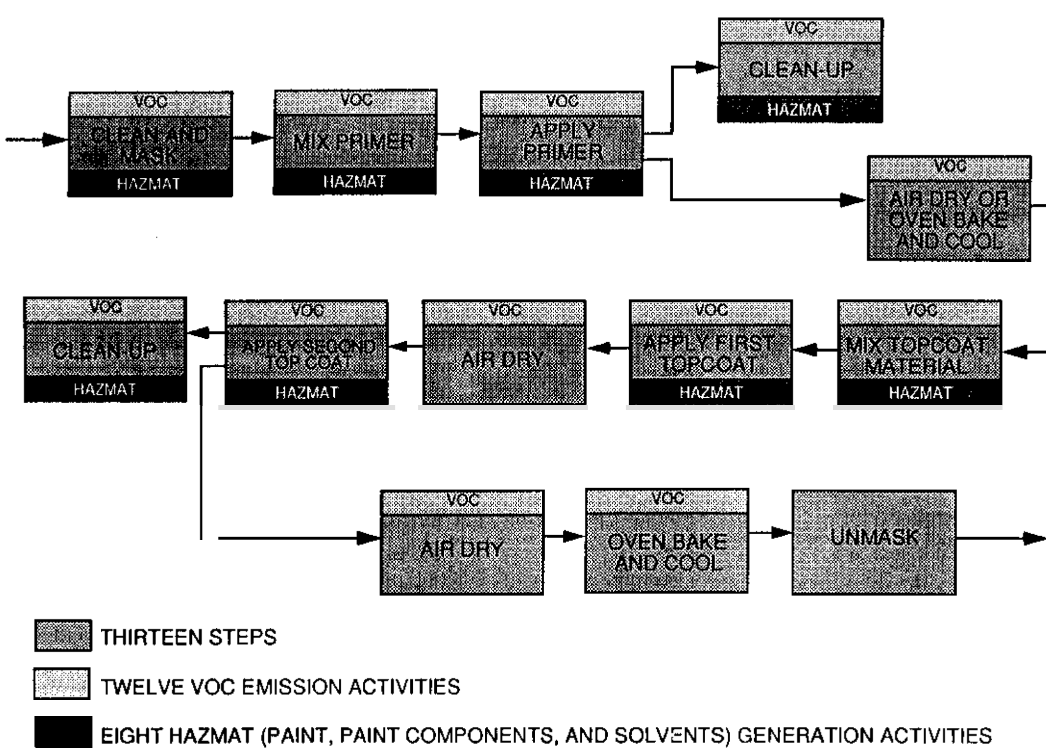

Figure 1 - Conventional Liquid Paint System Process Flow

Figure 2 shows the epoxy powder coating process which has replaced conventional wet painting on several applications at the HMSC Tucson facility. A high pressure aqueous cleaning system has been implemented to replace solvent based cleaning so even cleaning related VOC and HAZMAT generation points have been eliminated. This finishing process has *no* VOC emissions or hazardous material generation points.

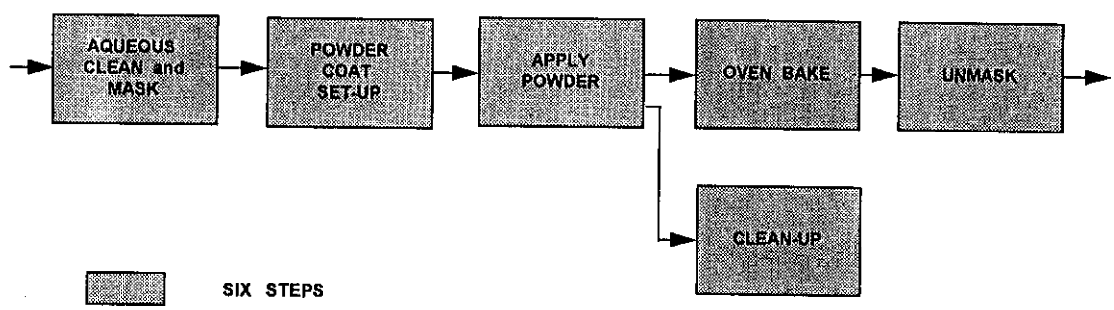

Figure 2 - Epoxy Powder Coat Process

Finish Selection and Contract Requirements

Virtually all contracts for government-purchased or military aerospace equipment impose specifications which define the performance requirements of the particular system. These requirements include operational parameters which must be demonstrated under specified environments. Details on the conditions the system will be stored and deployed under are also given. Warrantee information, deployed and operational life, and maintenance and repair expectations are provided as well.

All of these factors have an impact on the selection of finish systems for the hardware. The contract itself often imposes requirements in the form of upper-level design specifications which cover the entire system. Two common examples seen at HMSC are MIL-STD-1587 (*Materials and Processes For Air Force Weapons Systems*), and MIL-STD-454 (*Electronic Equipment, Standard General Requirements For*). These specifications, and others similar to them, invoke a myriad of lower-level drawings and specifications which "flow down" and define the design constraints of a particular program.

At the onset of design all finish requirement must be fully understood and evaluated by the designer. It is often the lower-level requirements which are most obvious to the specifier of the finish. They may be general in nature, such as those contained in MIL-F-18264 (*Finishes, Organic, Weapons System, Application and Control Of*), or they may be specific to a particular material, such as MIL-C-83286 (*Coating, Urethane, Aliphatic Isocyanate, For Aerospace Applications*). The designer must also be aware of any other specifications or documents invoked in the contract flowdown which define the performance of the finish system. Commonly encountered examples include specifications covering corrosion prevention and dissimilar metals issues. Contracts also may impose program-specific design standards, and HMSC has its own complete set of internal specifications, standards, and practices.

Clearly, the designer or specifier of an aerospace finish is faced with numerous stringent limits within which to choose a material or a finishing process. At HMSC, a series of design standards have been developed which considerably simplify the selection process. These standards are arranged such that a finish system can be chosen based on the customer (or branch of service), applicable specification requirements, and other unique aspects of the program. They identify powder coating as a preferred, environmentally-friendly process. In addition, a complete "Technical Package" covering powder coating has been written under a Hughes *Design for the Environment* (DFE) effort. This Technical Package offers the designer comprehensive technical data which can be used to evaluate the suitability of powder coatings in a particular application.

Historically, the standard HMSC finish system on most aerospace contracts has been MIL-C-83286 polyurethane topcoat over MIL-P-23377 epoxy primer. These specifications tightly control the finish produced by imposing tests and requirements on the material, the application process, and the resulting coatings. For example, MIL-C-83286 contains 12 separate requirements applicable to the coating material proper, 9 requirements pertaining to the admixed coating and its application, and 19 requirements applicable to the applied and cured coating on the finished hardware.

It is these last requirements, which define the performance of the as-applied finish, which have precluded the use of powder on most HMSC military programs, even though powder has been identified as a preferred alternate in internal HMSC standards for some time. The requirements are quite varied and range from such intrinsic film properties as color and gloss, through film application evaluations including adhesion and flexibility testing, to in-service performance requirements such as humidity and corrosion resistance, fluid resistance, and accelerated weathering.

The problem is not that powders fail to meet the performance requirements of specifications such as MIL-C-83286 (which, of course, is the primary concern of the customer), but that the proper type of certified performance data is typically not available. Since most powder manufacturers and powder applicators provide powder primarily to commercial industry they only test for properties important in a commercial application. These might include items such as adhesion, color, and gloss. It would be unusual for a powder supplier to evaluate parameters of interest in the aerospace industry, such as extreme low temperature flexibility (-65F or lower), resistance to military-type fluids (such as particular fuels and hydraulic fluids), and performance under extreme corrosion conditions (like acidified salt fog). Even when aerospace test results *are* available it is usually found that the tests were not performed in accordance with the required MIL-spec's, or certain test procedures and conditions were not followed exactly. In the aerospace world certifying to the correct test *procedures* is as important as certifying compliance to manufacturing and performance standards.

HMSC Application Examples

A contractor desiring to use powders on an aerospace program, then, is faced with evaluating the performance of powders under the applicable contract and specification requirements. At HMSC, the approach has been to subject powder finishes to exactly the same *performance* requirements imposed by specifications governing solvent-based systems. For example, on the Maverick missile program the standard finish for the airframe was one coat of MIL-P-23377 primer followed by two coats of flat-gray or olive drab MIL-C-83286 topcoat. Because of environmental constraints on the finishing process an alternate was desirable, and a powder was recognized as a preferred candidate. The powder selected, an epoxy with a fusing temperature of about 325° F, was subjected to all the performance requirements of the MIL-P-23377 and MIL-C-83286 specifications. These requirements included adhesion, flexibility, corrosion resistance, and others. Other requirements such as viscosity and pot life are obviously geared towards the application of a two-component reactive liquid systems These do not apply to powders, and were not considered in the Maverick evaluation.

Proving powders as a replacement for traditional liquid systems at HMSC may also involve testing *beyond* material specification requirements. On Maverick, a *Finish Specification* existed as a separate contractual document. This finish specification defined color and marking of Maverick variants, cleaning and pretreatment procedures, and standard finishes (both organic and inorganic) for all program substrates. Likewise, a unique Maverick *Corrosion Prevention and Control Plan* was imposed at the contractual level which defined other performance requirements and the exact approach to corrosion prevention.

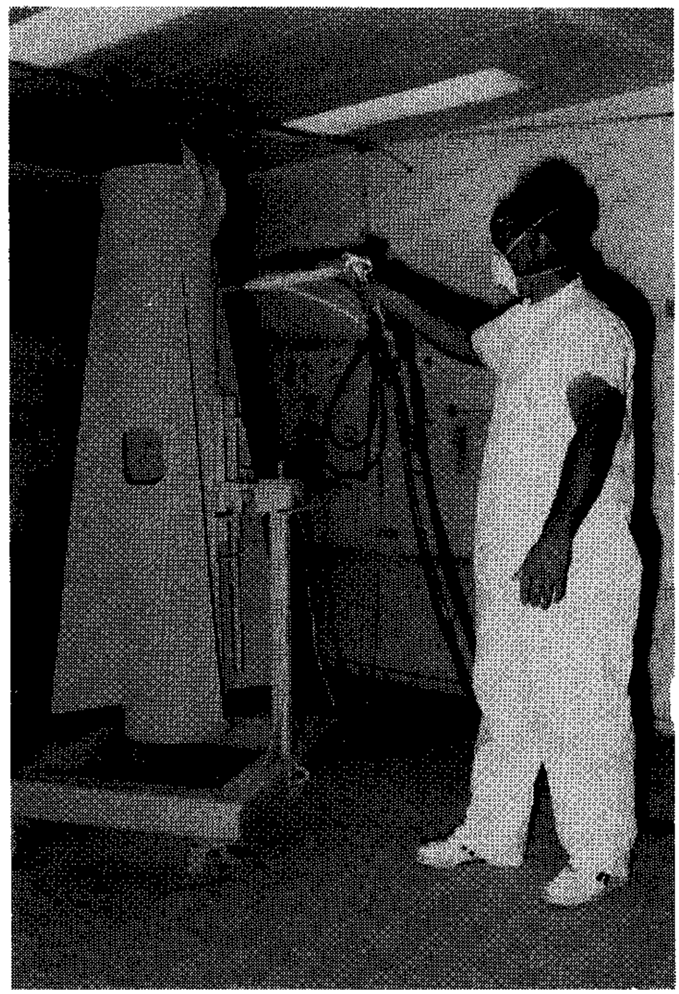

Figure 3 - Powder Painting a Maverick Airframe

Complying with requirements imposed by these additional documents mandated a number of extra tests to prove the use of powder on Maverick at HMSC. Testing not only confirmed conformance to the salt spray and humidity criteria contained in MIL-C-83286, but also demonstrated compliance to additional Maverick *Finish Specification* and the *Corrosion Prevention and Control Plan* corrosion requirements. Since the new powder system did not include a sacrificial primer (such as MIL-P-23377 used in the previous design) the Maverick customer was particularly concerned about under-film corrosion, especially filiform corrosion. In this case a filiform test series was included in the Maverick powder qualification, even though such a requirement had never been applied to the system before.

During the evaluation of contract requirements and the performance of tests, issues may arise which are unique to the hardware and finish at hand. These may require a fresh look and an open mind on the part of both contractor and customer. On Maverick this situation was encountered with respect to the powder cure temperature. Since the primary Maverick substrate to be coated was aluminum, the relatively high cure temperature of the selected powder (340° F) was a concern due to potential mechanical degradation of the hardware. This was an issue which had not been encountered on Maverick before. Tests showed that there *was* a slight metallurgical change in the aluminum during cure. After careful review both HMSC and the Maverick customer agreed that the change did not produce significant mechanical property degradation and was negligible.

Another "out of the ordinary" concern, at least for HMSC, was weathering of the finish. Early in the evaluation program it became clear an epoxy powder was the leading contender. Epoxies, however, tend to "chalk" when exposed to ultraviolet light, especially in sunlit, outdoor environments. This chalking often leads to the formation of a light-colored, powdery film on the finish surface. Whether this phenomena is detrimental, aside from appearance, is a source of some disagreement within the finishing industry.

HMSC faced a dilemma with respect to this weathering and chalking. On the one hand, the physical properties of the leading contender (epoxy) were very good, generally exceeding those of the current solvent-based finish. On the other hand, it was clear the epoxy would chalk if exposed to long-term weathering. Fortunately, this type of exposure is not very likely for a tactical missile system such as Maverick. Mavericks are normally transported and stored in closed containers which offer protection from the external environment. The only exposure to weathering is at the point of use, as the missile is loaded onto an aircraft, flown to the target, and fired. This exposure is much too short to produce chalking of the finish. In this light HMSC felt the chalking problem was inconsequential, and the customer ultimately agreed.

With any new and developing technology a sound "global" knowledge of the intricacies of the proposed application is required. Although for tactical Mavericks weathering was not a concern, this has not been the case on all HMSC hardware. For example, many variants of a missile are designed and manufactured, including training missiles which are used to simulate everything from loading and maintenance to actual flight and combat conditions. These training missiles have long, multi-mission lives and are subject to normal flightline environments for periods approaching continuous outdoor exposure. In this case chalking might be a greater issue, even when it not a concern for the tactical versions (which are in protected storage). At HMSC the practice has been to remain with conventional solvent-borne coatings for these long-exposure products, although evaluations of improved-weathering powders are on-going.

An underlying aspect of aerospace work illustrates other problems which are encountered with powder coatings. Compared to most commercial applications aerospace programs, especially weapons systems, involve relatively low production rates and low total production. The development of a new missile system, for example, may span 5 to 10 years from the time of initial concept until full production is reached. During this time research, development, testing and proofing, and various stages of low-rate production may yield no more than a few hundred missiles.

As an example, HMSC is developing the seeker (the "eyes" and the "brain") of the ASRAAM (Advanced Short-Range Air-to-Air Missile). The first deliveries, for evaluation hardware include a relatively small number of missiles. Even at full-rate production the total number of systems delivered over the life of the program does not even approach that of a typical commercial product.

From the beginning HMSC considered powder the preferred finish on ASRAAM. With some foresight, HMSC asked to change, or "tailor," the contract to allow the use of powders in lieu of the originally-required wet finishes. Even so, a number of problems were encountered prior to eventual use of a powder finish on the program. The two most important related to the quantity of powder required and the payback of development and test costs to powder suppliers.

On many aerospace programs the total amount of powder used throughout full-rate production might not even equal that used by a large commercial furniture manufacturer in a month. Quantities early in an aerospace program are even lower. On ASRAAM few powder manufacturers were interested in providing the small quantities of powder required for the first stages of the program. Complicating this was the requirement for a color that met an imposed British standard which was not available "off the shelf" from any powder manufacturer. This made any powder a custom formulation, with unique compounding and dedicated production runs.

Eventual pay-back of research and development costs (both for the contractor and the powder manufacturer) is also often a stumbling block for powders in aerospace applications. With typical commercial end-items the powder maker can expect sales to increase to relatively high rates very quickly, generating profit in a fairly short order. Under these circumstances, the manufacturer can afford to be somewhat flexible in pricing, often carrying forward development costs into a time period in which delivery rates are high. At this point, the percentage of the total system cost which represents the finish is relatively low, even if R&D costs are included. An aerospace program, on the other hand, presents less opportunity to be flexible in powder pricing as full-rate production may be several years away, and the quantity of powder sold in any case might be relatively low.

Additionally, the market for aerospace products is currently rather uncertain. There are no hard guarantees a program will ever go into high-rate production, or even be produced at all. Normally, the colors required are not commercial standard, and there is little or no demand for them outside of aerospace work, so the manufacturer cannot justify developing the powder as an addition to their commercial product line. In this light most powder manufacturers understandably try to recover their up-front costs during the first few powder deliveries. In essence, the research and development and dedicated manufacturing costs which might have been substantially borne by the manufacturer on a commercial or "product line" powder is forced on the defense contractor at the worst possible time -- early in the product life cycle.

This early cost leads to a significant problem for the contractor who is struggling to sell the concept of powders to its customer. It is difficult to demonstrate the overall cost advantage of powders when raw material costs, in low volumes, are high. Program viability depends more on cost today than ever before due to intense competition and cost pressures related to aerospace work. It must be recognized, by both the contractor and customer, that due to their environmental benefits, low labor and energy costs, and other advantages powder finishes are cost-effective in the long run.

HMSC has been fortunate to team with powder manufacturers who have been willing to custom-formulate powders in the correct colors and who understand the realities of aerospace contracting related to cost. In many cases HMSC has found it advantageous to work with smaller suppliers who are trying to gain a foothold in the expanding niche market of aerospace powder coatings. Even so, the initial price per pound of production ASRAAM powder was approximately an order of magnitude greater than a commercial, "off the shelf" powder.

Recurring Savings

Overall, HMSC has found powder coating offers several potential economic advantages when compared to conventional liquid finishing technologies. Savings can be realized in the areas of labor, energy, material, hazardous waste disposal, and safety. Although the savings in certain areas are sometimes difficult to quantify, the powder system usually offers a significant cost advantage over solvent-borne coating systems.

Labor savings associated with powder coating result from several factors. First, powder coatings are delivered ready-to-use and require no mixing with solvents or catalysts. This eliminates an entire operation usually associated with liquid coatings. Additionally, monitoring and maintaining many process parameters associated with liquid painting (viscosity, pH, solvent content, percent solids, etc.) is unnecessary. Powder coating is usually a one coat application, and significant labor savings result from eliminating multiple applications of primer and topcoat. Since the powder particles can be removed from the part with compressed air prior to curing it is very easy to rework parts. After the parts are cured, any required touch-up can be performed using a compatible liquid paint. Clean-up of the spray gun and booth is much easier with powder coatings. It requires only a broom, compressed air, and a vacuum cleaner instead of the solvents and wipe cloths required to clean-up after solvent-based liquid painting. In certain applications powder coating can eliminate up to 75% of the labor required for liquid painting.

Significant energy savings can be realized from the implementation of powder coating. Since the quantity of volatiles in powder coating is minimal and no low-flashpoint solvents are present, makeup air requirements can be dramatically reduced. Also, no makeup air is required for the powder coating booth and only a small amount is required to vent the ovens used for curing. This translates into significant savings in air conditioning and/or heating. While the oven temperatures required for powder coating are normally higher than those used to cure liquid coatings, the cure time is usually shorter. This results in a energy savings on a per-part basis which favors powder over traditional solvent-borne finishes.

The nature of powder coating also leads to material cost advantages due to nearly 100 percent material consumption. An electrostatically applied powder coating will achieve approximately 65 percent first-pass material utilization. The over-sprayed powder can be collected, screened and then mixed with virgin powder for reuse. Since less than one percent of the as-delivered powder is volatile, powders easily achieve material utilization rates of 95 percent or better. Liquid systems usually achieve overall material utilization rates of between 20 to 60 percent, since the sprayed material contains large quantities of volatile solvents which are lost up the stack and since liquid coating overspray cannot be reclaimed.

Since drips and runs are nonexistent with powder coating, the reject rate is low, resulting in higher yields. The cured powder paint film also usually has better abrasion characteristics than liquid paints. This enables powder coated parts to withstand handling and assembly with less paint damage, again resulting in reduced rework. Additionally, cleanup of spray guns and paint booths used for powder coating requires no solvents, further reducing costs.

Significant quantities of flammable hazardous materials, including cleaning and reducing solvents, mixed paint, and catalysts are associated with liquid painting systems. These require special handling, storage, and disposal. The need for solvents and other hazardous materials is eliminated when using powder coatings. The quantity and type of hazardous waste generated from a powder coating operation is dependent on the type of powder, resin formulation and pigmentation (especially metallic) constituents. Powder coating formulation sources indicate that modern powder coating are expected to pass Toxicity Characteristic Leaching Procedure (TCLP) testing. In this case alternatives to disposing of excess or used powder as hazardous waste may be available, depending on local regulations. To ensure proper disposal the waste classification or listing of spent or unused powders must be determined on a case by case basis.

Powders have significant environmental advantages when compared to solvent-based liquid coating systems. These advantages, including greatly reduced solvent use, lower fire hazard, reduced handling and disposal costs, and increased operator safety, provide a competitive advantage when comparing powder coating to other finishing systems. The cost and liability associated with waste generated from a powder coating process may be considerably less than a solvent-based painting system.

In many areas, the use of certain liquid coatings is either prohibited or requires the installation and operation of expensive adsorption systems to remove VOC's from paint booth and oven exhausts. The lack of volatiles in powder coating eliminates this problem and may significantly reduce the fire risk. Powder coatings also result in a much cleaner environment for paint shop employees, and may lower labor costs by reducing the overhead associated with safety equipment. In addition, in some cases a less skilled operator is required to apply powder, resulting in further labor cost savings.

Powder Coating Specifications

To date the only MIL-Spec covering powder coating is MIL-C-24712 (*Coatings, Powdered Epoxy*) issued by the Naval Sea Systems Command in February 1989. This specification is intended for both interior applications (such as steel and aluminum equipment, furniture, and electrical boxes), as well as exterior steel and aluminum surfaces exposed to marine environments. The first revision of this specification is scheduled to be issued in the near future and will add polyester powder coatings for improved exterior UV resistance. Paints meeting MIL-C-24712 are available from several sources. Other government specifications such as WS 22351 for the Mark 48 torpedo cover powder coating for specific weapon systems. This specification was issued by the Naval Underwater Systems Center and covers the powder materials, application processes and test requirements for the Mark 48 Advanced Capability (ADCAP) torpedo.

In most cases the aerospace contractor is faced with writing a unique specification which covers a powder coating application, since no MIL-spec applies. At HMSC a number of specification and source control drawings have been generated covering a variety of powders. One significant drawback to writing in-house specifications is that they are normally limited to use on a single program. This requires duplicate specifications be written for each program, at considerable engineering expense.

CONCLUSIONS

Increasingly stringent environmental regulations tend to favor the long term development and implementation of powder coating. The elimination of VOC emissions and the reduction of hazardous wastes generated are significant advantages. Although there are problems working with powder in the aerospace environment, especially with test and documentation issues, experience at the HMSC Tucson plant site has demonstrated powder coating consistently reduces the cost of finishing a product. The cost savings and quality improvements associated with powder coating have enabled HMSC to be proactive in developing and implementing this environmentally-friendly process in today's competitive environment.

BIOGRAPHY

Larry Brown is an Engineering Specialist with the Advanced Manufacturing Technology Department at Hughes Missile Systems Company. He received his BS degree in Industrial Engineering from Texas A&M University. During the last 15 years at HMSC he has specialized in the areas of material handling and manufacturing engineering. Since 1988 he has been the project manager or principal investigator for several powder paint projects concentrating on developing and implementing powder paint technology in aerospace applications.

Don Martin is an Engineering Specialist with the Components and Materials Engineering Department at HMSC, and leads the Materials and Processes Applications Engineering Group. He specializes in environmental aspects of engineering design, and represents HMSC on the Hughes Corporate Design for the Environment Working Group. Don has been involved in the selection and testing of powder coatings in aerospace applications since the mid-1980's.