

Aerospace Manufacturing and Rework Operations

Process Descriptions and Control Technologies

A. Process Descriptions

Aerospace manufacturing and rework operations consist of the following basic operations: Chemical milling maskant application, chemical milling, adhesive bonding, cleaning (e.g., hand-wipe, spray equipment, and flush), metal finishing, electrodeposition, coating application (e.g., primers, topcoats, sealants, and specialty coatings), depainting, and composite processing. In addition, most aerospace manufacturing and rework facilities generate waste and wastewater, and some facilities have storage tanks for hand-wipe cleaning solvents. An aerospace facility may conduct all of these processes in its operations, such as an original equipment manufacturer (OEM) facility that produces the entire aircraft. However, an aerospace facility may conduct only a subset of these operations, such as a facility that produces a single component or assembly, or a facility that provides a service such as chemical milling.

1. Chemical Milling Maskant Applications and Chemical Milling

Chemical milling uses etchant solutions to reduce the thickness of selected areas of metal parts in order to reduce weight. The process is typically used when the size or shape of the part precludes mechanical milling or when chemical milling is advantageous due to shorter processing time or its batch capability.

Chemical milling maskants are typically rubber- or polymeric-based coatings applied to an entire part or subassembly by brushing, dipping, spraying, or flow coating. After the chemical milling maskant is cured, it is removed from selected areas of the part where metal is to be removed during the chemical milling process. The chemical milling maskant remaining on the part protects those areas from the etchant solution. Chemical milling maskants typically contain either a toluene/xylene mixture or perchloroethylene as its solvent constituents.

Organic HAP emissions occur through evaporation of the solvent as the chemical milling maskant is applied and while it cures.

2. Adhesive Bonding (Adhesives and Adhesive Bonding Primers)

Adhesive bonding involves the joining together of two or more metal parts, such as the parts of a honeycomb core. This process is typically performed when the joints being formed are essential to the structural integrity of the aircraft. The surfaces to be bonded are first coated with an adhesive bonding primer to promote adhesion and protect from subsequent corrosion. Structural adhesives are applied as either a thin film or as a paste, and can be oven cured or cured in an autoclave. Organic HAP emissions occur

from the evaporation of solvents contained in the adhesive bonding primer and adhesive during their application, as well as during the curing step.

3. Cleaning Operations

a. Hand-wipe and flush cleaning. Aerospace components are cleaned frequently during manufacturing to remove contaminants such as dirt, grease, and oil, and to prepare the components for the next operation. Cleaning is typically performed by a hand wiping process using a wide variety of cleaning solvents. Assemblies and parts with concealed or inaccessible areas may be flush cleaned by pouring the cleaning solvent over or into the part. The cleaning solvent is then drained from the part and the procedure is repeated as many times as necessary to ensure the required cleanliness.

Organic HAP emissions from hand-wipe and flush cleaning operations occur from the evaporation of cleaning solvents during the cleaning process, including evaporation of the solvent from open containers and from solvent-soaked cloth and paper. Organic HAP emissions also occur from storage tanks used to store cleaning solvents.

b. Spray gun cleaning. Spray guns and other components of coating units must be cleaned when switching from one coating to another and when they are not going to be immediately reused. The cleaning of spray guns can be performed either manually or with enclosed spray gun cleaners. Manual cleaning involves disassembling the gun and placing the parts in a vat containing an appropriate cleaning solvent. The residual paint is brushed or wiped off the parts. After reassembling, the cleaning solvent may be sprayed through the gun for a final cleaning.

Enclosed spray gun cleaners are self-contained units that pump the cleaning solvent through the gun within a closed chamber. After the cleaning cycle is complete, the guns are removed from the chamber and typically undergo some manual cleaning to remove coating residue from areas not exposed to the cleaning solvent, such as the seals under the atomizing cap.

Organic HAP emissions from spray gun cleaning occur from the evaporation of cleaning solvents during the cleaning cycle, such as while hand cleaning the guns in an open vat. Organic HAP emissions also occur from enclosed spray gun cleaners when they are opened to remove the guns.

4. Metal Finishing and Electrodeposition

Metal finishing processes are used to prepare the surface of a part for better adhesion, improved surface hardness, and improved corrosion resistance. Typical metal finishing operations include conversion coating, anodizing, desmutting, descaling, and any operation that chemically affects the surface layer of a part.

Electrodeposition, or metal plating, is an additive process for metal substrates in which another metal layer is added to the substrate in order to enhance corrosion and wear resistance necessary for the successful performance of the component. The two types of electrodeposition typically used are electroplating and plasma arc spraying.

HAP emissions from metal finishing operations occur in the form of gases or vapors that evaporate from the surface of processing solutions. Evaporation of solution also occurs from the parts as they are removed from the processing tanks.

5. Coating Application

A coating is a material that is applied to the surface of a part to form a decorative or functional solid film. The most common coatings are the broad categories of non-specialized primers and topcoats. There are also numerous specialty coatings ranging from temporary protective coatings to radiation effect coatings designed to shield aircraft from radar detection.

Coatings are applied to aerospace vehicles and components using several methods of application. The methods most commonly used are spraying, brushing, rolling, flow coating, and dipping. Spray application systems include conventional air spray, airless spray, air-assisted airless, electrostatic, and high volume low pressure (HVLP) spray. These latter two methods are generally accepted as having better transfer efficiency than other spraying methods and are gaining increased use as a means of using less coating and, hence, reducing emissions.

Nearly all aerospace coatings contain a mixture of organic solvents. Organic HAP emissions from coating application occur from the evaporation of the solvents during mixing, application, and drying. Inorganic HAP emissions of metal compounds (e.g., chromium and cadmium) also occur from overspray, which is exhausted from spray booths or paint spray hangars.

6. Depainting

The depainting operation involves the removal of coatings from the outer surface of aircraft. The two basic depainting methods are chemical depainting and blast depainting. Chemical depainting agents are applied to the aircraft, allowed to degrade the coating, and then scraped or washed off with the coating residue. Blast depainting methods utilize a media such as plastic, wheat starch, carbon dioxide, or high pressure water to remove coatings by physically abrading the coatings from the surface of the aircraft.

Organic HAP emissions from chemical depainting occur from evaporation of the solvents in the stripping solution. The amount of emissions from the process is directly related to the surface area being stripped, the type and thickness of coating to be removed, and the effectiveness of the stripper. Inorganic HAP emissions occur from the various blast depainting methods. The inorganic HAP are contained in the coatings being removed (trace amounts of inorganic HAP may also be found in some blast media) and are emitted as particulates.

7. Composite Processing

Composite processing consists of seven basic operations: Layup, thermal forming, debulking, curing, break-out, compression molding, and injection molding. Layup is the process of assembling the layers of the composite structure by positioning composite

material in a mold and impregnating the material with a resin. Thermal forming is the process of forming the layup in a mold, which usually takes place in an autoclave. During the thermal forming process, debulking also may occur, which is the simultaneous application of low-level heat and pressure to the composite structure to force out excess resin, trapped air, vapor, and volatiles from between the layers of the composite structure. The curing step, which is the process of changing the resin into a solid material through a polymerization reaction, also occurs in the autoclave. After curing and removal from the autoclave, the break-out process removes the composite structure from the molds or curing fixtures.

Two other methods of forming composite structures are compression molding and injection molding. Compression molding is the process of filling one half of a mold with a molding compound, closing the mold, and applying heat and pressure until the material is cured. Injection molding uses a closed mold, where the molding compound is injected into the mold, maintained under pressure, and then cured by applying heat.

Organic HAP emissions from composite processing occur from volatilization of a small portion of the solvent components during curing, because the majority of these solvents are consumed in the curing reaction of the resin.

8. Wastewater

Nearly every aerospace manufacturing and rework operation has the potential to generate wastewater. For example, metal finishing operations use water to rinse parts after each processing step. These rinse steps are typically carried out in large tanks with either a continuous or intermittent water flow. The wastewater generated is usually treated to some extent at the facility, then discharged.

HAP emissions from wastewater result from the evaporation of volatile components in the water. Evaporation may occur in open trenches, storage tanks, and treatment operations.

9. Handling and Storage of Waste

Waste is produced primarily from cleaning, coating, and repainting operations. Cleaning operations produce solvent laden cloth and paper and spent solvent which can emit organic HAP from the evaporation of the solvents. Coating operations produce waste paint and waste solvent thinner that also emit organic HAP through evaporation. Repainting operations can produce either a liquid or solid waste stream depending on the type of process used. Chemical repainting processes produce a liquid sludge that consists of the stripper solution and paint residue. Emissions occur from the evaporation of the solvent from the stripper solution. Blast repainting processes produce a solid waste stream that consists of paint chips and spent blasting media. Emissions do not directly occur from this waste stream, although particulate emissions are generated during the blasting process.

10. Storage of Hand-Wipe Cleaning Solvents

Many large aerospace facilities use storage tanks for hand-wipe cleaning solvents. According to data obtained through responses to EPA questionnaires under section 114 of the Act (section 114 questionnaires), these tanks are primarily above ground, fixed-roof type ranging in size from 350 to 6800 gallons in size. Emissions from these tanks occur from evaporation of the cleaning solvents, as well as breathing and working losses.

B. Control Techniques

The principal techniques used by the aerospace industry to control organic HAP emissions are preventative measures and control devices. For the control of inorganic emissions, control devices such as filters and waterwash are used. Preventative measures are any action, product modification, process modification, or equipment change designed to eliminate or reduce the generation of emissions. Control devices do not prevent the generation of emissions, but rather capture or destroy the emissions generated by a source.

Preventative measures are usually the most desirable method to reduce emissions since they eliminate or reduce the actual generation of pollutants. Typically, the emission reduction is obtained using less energy and producing less waste than using a control device to achieve the same emission reductions. Preventative measures used by the industry are: (1) Product reformulations that replace products containing high levels of HAP and VOC with products containing less HAP and VOC or that eliminate the HAP or VOC content completely, such as chemical strippers that contain no organic HAP for depainting; (2) product reformulations, such as higher solids content coatings, that reduce the amount of the HAP- and VOC-containing product used; (3) equipment changes that result in emission reductions, such as replacing conventional spray guns with HVLP spray guns; and (4) work practice standards, such as housekeeping.

Control devices are typically used where product reformulation is not feasible or where the concentration of the exhaust stream is sufficiently high to warrant their use. Control devices may destroy the HAP and VOC, as with an incinerator, or capture the HAP and VOC, as with a carbon adsorber. Often, the compounds captured by a control device can be recovered for reuse. Control devices in predominant use by the industry for the reduction of organic HAP emissions are: (1) Carbon adsorbers, (2) incinerators, and (3) ultraviolet oxidation. Activated carbon fiber adsorbents to concentrate VOC emissions are frequently used in conjunction with incinerators. For inorganic HAP particulate emissions, reduction is achieved predominantly through the use of filtration devices.

1. Preventative Measures

a. Product reformulation. HAP and VOC emissions may be controlled by replacing products containing high concentrations of HAP and VOC with ones that have reduced or eliminated HAP and VOC entirely. Each individual facility must evaluate the ability of the new product to maintain standards of quality and performance. In addition, the potential overall environmental benefit of the reformulated products must be carefully evaluated.

(1) Product reformulation-coatings. Product reformulations for coatings can be generally classified as waterborne, higher solids, powder, and self-priming topcoats. Each category is discussed below.

(a) Waterborne coatings. Waterborne coatings utilize a resin system that is dispersible in water. A portion of the organic solvent is then replaced with water. The organic solvent may be 5 to 40 percent by weight of the waterborne coating, compared to a conventional organic solvent-based coating containing as much as 80 percent by weight solvent.

In addition to the lower solvent content, waterborne coatings have other advantages over solvent-based coatings. Less overspray and improved spray transfer efficiency may be achieved with waterborne coatings than with conventional coatings that utilize solvents with a density less than that of water. Additionally, because of the reduced solvent content, waterborne coatings may be less toxic and present a reduced fire hazard.

Waterborne coatings have limitations such as requiring spray guns with specific materials of construction, protection from freezing, and better control of temperature and humidity during application. In addition, waterborne coatings generally require longer drying times, are more sensitive to substrate material and cleanliness, and have lower salt spray resistance.

(b) Higher solids. Higher solids coatings are solvent-based coating formulations that have been modified to lower the solvent-to-solids ratio. The coatings usually contain 50 to 65 percent by volume solids, compared to conventional solvent-based coatings that may contain up to 40 percent by volume solids. The increased solids content gives greater surface area coverage per gallon of coating, which reduces the total volume of coating required. Consequently, solvent emissions are also reduced when higher solids coatings are used to apply the same volume of solids that are applied with a conventional solvent-based coating.

Higher solids coatings generally have higher viscosities and longer drying times than conventional solvent-based coatings. The higher viscosity tends to make spray application more difficult because it is harder to control gloss and film thickness, and may require the coating to be heated before application. Higher solids coatings typically are not used as dip coatings due to the difficulty in maintaining a uniform dispersion of solids in the dip tank.

(c) Powder. Powder coatings are a class of coatings applied electrostatically in dry form and then baked to cure. The coatings consist of fine, dry particles of paint solids. During the curing step, the particles fuse to create a continuous film. Use of powder coatings requires that the substrate must be able to withstand the high temperatures (typically greater than 121 °C (250 °F) and frequently greater than 177 °C (350 °F)) necessary to cure the paint.

The major advantage of using powder coatings is greatly reduced solvent emissions. The lack of a solvent base also reduces fire hazard, toxicity, and the make-up air requirements of the spray booth.

Powder coatings must be applied electrostatically, so they cannot be used on non-conductive parts such as composites. Other reported disadvantages of

powder coatings are the difficulty in obtaining a high quality appearance, production must be shut down for color changes, the powder must remain dry at all times prior to application, and higher energy costs. As noted above, the high curing temperatures of powder coatings precludes their use on temperature-sensitive substrates.

(d) Self-priming topcoats. Self-priming topcoats eliminate the need to apply a primer coat between the substrate and the topcoat. Self-priming topcoats have the adhesion and corrosion characteristics of a conventional primer and the environmental resistance and functional fluid resistance of a conventional topcoat. These coatings also eliminate the need for chrome-containing primers.

(2) Product reformulation-hand-wipe cleaning solvents. Product reformulations for hand-wipe cleaning that are prevalent in the aerospace industry can be classified as aqueous, hydrocarbon-based, and non-chemical. Each category is discussed below:

(a) Aqueous. Aqueous cleaners contain at least 80 percent water, are non-flammable and non-combustible, and are completely soluble in water. Other components may include corrosion inhibitors, alkalinity builders, organic surfactants, and bioenzyme mixtures and nutrients depending on the desired soil removal properties. Aqueous cleaners have been used in non-critical areas where strict cleanliness requirements do not have to be met, or where there are no confined spaces that may trap residues of the cleaner.

(b) Hydrocarbon-Based. Hydrocarbon-based cleaners are nonsemi-aqueous cleaners that are composed of a mixture of hydrocarbons and oxygenated hydrocarbons. These cleaners have a maximum vapor pressure of 7 mm Hg at 20 °C (3.75 in. H₂O at 68 °F) and contain no HAP or ozone depleting compounds.

(c) Non-chemical. Several aerospace facilities have demonstrated the viability of using non-chemical methods such as dry media blasting for cleaning operations. These methods are typically used to remove dry, scale-like deposits such as carbon residue on engine components. Dry media blasting can usually be used only on components that can withstand the force of blasting without deformation.

b. Equipment changes. The aerospace industry has implemented several equipment changes that directly reduce the level of HAP emissions. While there are equipment changes that affect emissions from every process, the three changes predominantly used in the industry are high transfer efficiency spray guns, enclosed spray gun cleaners, and proportional paint mixers. Each of these equipment changes are discussed below.

(1) High transfer efficiency spray guns. Emissions from spray coating operations can be reduced through the use of spraying systems with higher transfer efficiency than conventional spray guns. Transfer efficiency, expressed as a percentage, can be defined as the ratio of coating solids actually applied to the surface of the component being coated to the amount of solids released from the spray gun. Spraying systems with a higher transfer efficiency can coat the same surface area using less coating. Therefore, the HAP emissions resulting from the use of this equipment are reduced compared to applying the same coating with conventional spray equipment.

High volume low pressure (HVLP) and electrostatic spraying systems are the primary high efficiency spray methods used by the industry. HVLP spray guns use high volumes (10 to 25 standard cubic feet per minute (scfm)) of low pressure (2 to 10 pounds per square inch gauge (psig)) air to deliver the paint. The lower air pressure creates a lower particle speed, resulting in a more controlled spray pattern with less overspray and bounce back from the substrate. With electrostatic spray systems, atomized particles of coating acquire an electric charge as they pass through a high voltage field at the end of the spray nozzle. This electric charge causes the particles to be attracted to the parts being painted, which are electrically grounded.

(2) Enclosed spray gun cleaners. Spray guns are typically cleaned at the end of every job, as well as between color changes. Manual cleaning of spray guns involves disassembling the gun and placing the parts in a tray containing an appropriate cleaning solvent. The residual paint is brushed or wiped off the parts, then the cleaning solvent is sprayed through the gun after it is reassembled. Enclosed spray gun cleaners, however, are completely enclosed units that spray the cleaning solvent through and over the spray gun. The enclosed unit eliminates most of the exposure of the cleaning solvent to the air, thereby greatly reducing the organic HAP emissions from evaporation.

(3) Proportional paint mixers. The majority of coatings used in the aerospace industry are multi-component mixtures, consisting of a base component and one or more catalyst components. The components must be thoroughly mixed in the proper ratio immediately before application. When this mixing is performed manually, a greater volume of coating is mixed than will actually be used to ensure that there is enough coating available to complete the job. In contrast, proportional paint mixers pump each component of the coating directly to the spray gun, where it is mixed and immediately applied. This results in reduced coating waste and, consequently, reduced emissions.

c. Work practice standards. Work practice standards are changes in the method of operation that do not affect the products used in the process or the process itself, but result in a reduction in emissions. The aerospace industry has implemented work practice standards programs for housekeeping measures and managed chemical distribution systems.

Emissions of organic HAP compounds, particularly solvents, can be reduced by limiting both the amount of the material exposed to the atmosphere and the length of the exposure. The emission reductions can be achieved by implementing housekeeping measures whereby solvent-soaked cloth or paper used for hand-wipe cleaning are placed into bags or containers that are kept closed. This eliminates the continual evaporation of the solvent from the cloth or paper when they are not in use. The bags or containers can then be collected and disposed in such a manner (e.g., by incineration) to eliminate any further solvent emissions.

Managed chemical distribution systems centralize the distribution of solvents and coatings and control the amount of these materials allowed to be used for a particular

task. In this way, waste solvent and coatings are reduced, and emissions from these waste materials are reduced.

2. Control Devices

a. Carbon adsorbers. Adsorption systems are used to remove organic compounds from gas streams when strict limits on the outlet concentration must be met, or when recovery of the compound is desired. Adsorption is effective on inlet concentrations ranging from a few parts per billion to several thousand parts per million, and a flow rate of several hundred to several hundred thousand cubic feet per minute. Carbon adsorbers typically have a removal efficiency of 95 to 99 percent.

Once the carbon reaches saturation, it can be removed from the adsorber vessel and disposed or regenerated. The carbon can also be regenerated with steam within the adsorber vessel. This option readily allows for the recovery of the organic compounds for recycling.

b. Incinerators. Two basic types of incinerators, thermal and catalytic, are used in the aerospace industry to remove organic contaminants. Each type is discussed below.

(1) Thermal incinerators. Thermal incinerators can be generally used on air streams with a wide concentration range of organics. These control devices have minimal dependence on the characteristics of the organic contaminants, so they can be used to control a wide variety of emission streams. Thermal incinerators can achieve removal efficiencies of 98 percent and higher.

The basic operation of thermal incinerators involves raising the inlet air stream to the incineration temperature of the contaminants and maintaining the temperature for a specific residence time. The waste heat content of the incinerator exhaust stream is used to preheat the inlet air stream. An auxiliary fuel is then typically required to raise the air stream temperature to the incineration temperature.

(2) Catalytic incinerators. Catalytic incinerators are similar to thermal incinerators except that they use a catalyst (a substance that accelerates the rate of oxidation without undergoing a chemical change itself) to assist in the oxidation of organic compounds to carbon dioxide and water. These incinerators are typically used for air streams with a low concentration of organics. The removal efficiency of catalytic incinerators can be as high as 98 percent.

c. Ultraviolet oxidation. An ultraviolet light oxidation (UVOX) system has been developed as an abatement device for air streams with low concentrations of organic compounds. The air stream passes through particulate filters, then enters a reactor where it is exposed to ultraviolet light which initiates the oxidation of the organics. Ozone and other oxygen-based oxidants are injected into the reactor to react with the organics in the air stream to begin the oxidation of organics into carbon dioxide and water. A typical removal efficiency for UVOX is reported to be 95 percent.

d. Activated carbon fiber adsorbent. Another technology has been developed to control low concentration organic compound emissions (e.g., paint spray booths). This technology utilizes an activated carbon fiber adsorbent to initially capture the organic emissions, the concentration of which is too low to be removed by a control device

such as an incinerator. The adsorbent system consists of a honeycomb structure element made of activated carbon fiber paper in corrugated form. This structure adsorbs the organics in the exhaust stream. As the activated carbon structure becomes saturated, the organics are desorbed using hot air. This concentrated air stream can then be sent to an incinerator or other control device. The portion of the activated carbon structure that was regenerated then begins the adsorption cycle again.

e. Catalyst-coated filter media. Low concentration organic emissions (e.g., paint spray booths) can be controlled through the use of a catalyst-coated filter media. The catalyst material is impregnated onto the fibers of a dry filter which can then be used wherever conventional dry filters are used. The catalyst material, unlike activated carbon, permanently binds the organic material into its crystalline matrix so that it will not later desorb. In addition to the coated filters, the catalyst material can be used in a granular form to control emissions.

f. Filtration systems for inorganic HAP particulate emissions. Coating operations and blast depainting operations emit inorganic HAP in the form of particulates. For coating operations, panel-type dry particulate filters and waterwash spray booths are used to control these emissions. For blast depainting operations, panel-type dry particulate filters are also used, as well as baghouses.

The dry filters and baghouses capture particulates by trapping them as they try to pass through the small passages in the filter media. The efficiency of the filter media is a function of the particle size, size of the passages in the filter media, air flow through and pressure drop across the filter media, and physical characteristics of the particle.

Waterwash spray booths capture particles by forcing the air stream to pass through a spray or curtain of water. The particles are trapped by the water and eventually collect as a sludge in the sump of the spray booth.