I. INTRODUCTION TO THE SECTOR NOTEBOOK PROJECT

I.A. Summary of the Sector Notebook Project

Environmental policies based upon comprehensive analysis of air, water and land pollution (such as economic sector, and community-based approaches) are becoming an important supplement to traditional single-media approaches to environmental protection. Environmental regulatory agencies are beginning to embrace comprehensive, multi-statute solutions to facility permitting, compliance assurance, education/outreach, research, and regulatory development issues. The central concepts driving the new policy direction are that pollutant releases to each environmental medium (air, water and land) affect each other, and that environmental strategies must actively identify and address these interrelationships by designing policies for the "whole" facility. One way to achieve a whole facility focus is to design environmental policies for similar industrial facilities. By doing so, environmental concerns that are common to the manufacturing of similar products can be addressed in a comprehensive manner. Recognition of the need to develop the industrial "sector-based" approach within the EPA Office of Compliance led to the creation of this document.

The Sector Notebook Project was initiated by the Office of Compliance within the Office of Enforcement and Compliance Assurance (OECA) to provide its staff and managers with summary information for eighteen specific industrial sectors. As other EPA offices, states, the regulated community, environmental groups, and the public became interested in this project, the scope of the original project was expanded. The ability to design comprehensive, common sense environmental protection measures for specific industries is dependent on knowledge of several interrelated topics. For the purposes of this project, the key elements chosen for inclusion are: general industry information (economic and geographic); a description of industrial processes; pollution outputs; pollution prevention opportunities; Federal statutory and regulatory framework; compliance history; and a description of partnerships that have been formed between regulatory agencies, the regulated community and the public.

For any given industry, each topic listed above could alone be the subject of a lengthy volume. However, in order to produce a manageable document, this project focuses on providing summary information for each topic. This format provides the reader with a synopsis of each issue, and references where more in-depth information is available. Text within each profile was researched from a variety of sources, and was usually condensed from more detailed sources pertaining to specific topics. This approach allows for a wide coverage of activities that can be further explored based upon the references listed at the end of this profile. As a check on the information included, each notebook went through an external document review process. The Office of

Compliance appreciates the efforts of all those that participated in this process and enabled us to develop more complete, accurate and up-to-date summaries. Many of those who reviewed this notebook are listed as contacts in Section IX and may be sources of additional information. The individuals and groups on this list do not necessarily concur with all statements within this notebook.

I.B. Additional Information

Providing Comments

OECA's Office of Compliance plans to periodically review and update the notebooks and will make these updates available both in hard copy and electronically. If you have any comments on the existing notebook, or if you would like to provide additional information, please send a hard copy and computer disk to the EPA Office of Compliance, Sector Notebook Project (2223-A), 401 M St., SW, Washington, DC 20460. Comments can also be sent via the web page or to notebook@epamail.epa.gov.

Adapting Notebooks to Particular Needs

The scope of the industry sector described in this notebook approximates the national occurrence of facility types within the sector. In many instances, industries within specific geographic regions or states may have unique characteristics that are not fully captured in these profiles. The Office of Compliance encourages state and local environmental agencies and other groups to supplement or re-package the information included in this notebook to include more specific industrial and regulatory information that may be available. Additionally, interested states may want to supplement the "Summary of Applicable Federal Statutes and Regulations" section with state and local requirements. Compliance or technical assistance providers may also want to develop the "Pollution Prevention" section in more detail. Please contact the appropriate specialist listed on the opening page of this notebook if your office is interested in assisting us in the further development of the information or policies addressed within this volume. If you are interested in assisting in the development of new notebooks, please contact the Office of Compliance at 202-564-2395.

II. INTRODUCTION TO THE AEROSPACE INDUSTRY

This section provides background information on the size, geographic distribution, employment, production, sales, and economic condition of the aerospace industry. Facilities described within this document are described in terms of their Standard Industrial Classification (SIC) codes.

II.A. Introduction, Background, and Scope of the Notebook

This industry sector profile provides an overview of the aerospace industry as listed under SIC industry groups 372 and 376. Establishments listed under these codes primarily manufacture and assemble aircraft, space vehicles, guided missiles, and all the associated parts.

Within the industry groups 372, Aircraft and Parts, and 376, Guided Missiles and Space Vehicles and Parts, are the following SIC codes:

- 3721- Aircraft
- 3724- Aircraft Engines and Engine Parts
- 3728- Aircraft Parts and Auxiliary Equipment, Not Elsewhere Classified
- 3761- Guided Missiles and Space Vehicles
- 3764- Guided Missile and Space Vehicle Propulsion Units and Propulsion Unit Parts
- 3769- Guided Missile and Space Vehicle Parts and Auxiliary Equipment, Not Elsewhere Classified

While this notebook covers all of the SIC codes listed above, the large number and variability of the products will not allow a detailed description of each. Instead, commonalities in the industrial processes, pollutant outputs, and pollution prevention opportunities will be identified and described in more general terms. An overview of general manufacturing processes within the industry will be presented, along with descriptions of the actual products and information on the state of the industry. Although certain products covered under these SIC codes may not be specifically mentioned, the economic, pollutant output, and enforcement and compliance data in this notebook covers all establishments producing aerospace products.

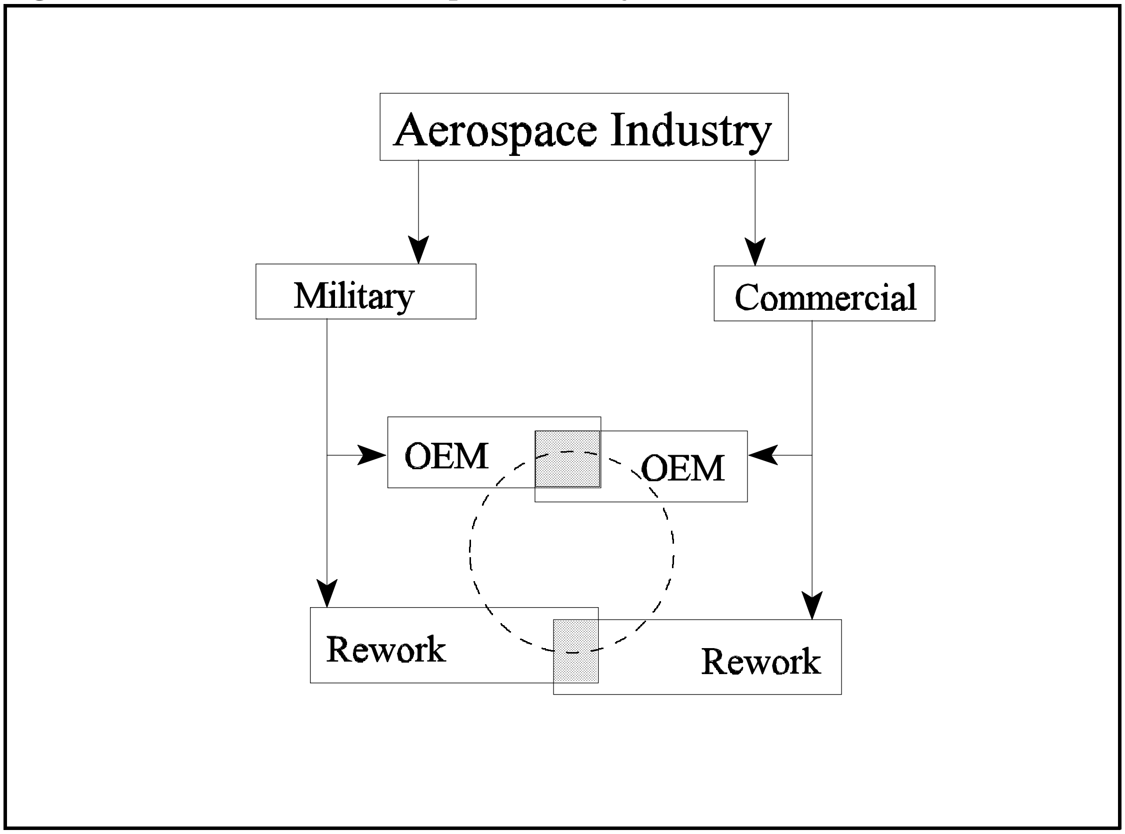
SIC codes were established by the Office of Management and Budget (OMB) to track the flow of goods and services within the economy. OMB is in the process of changing the SIC code system to a system based on similar production processes called the North American Industrial Classification System (NAICS). In the NAICS, the SIC codes for the aerospace industry correspond to the following NAICS codes:

SIC	Industry Sector	NAICS
3721	Aircraft	336411
3724	Aircraft Engines	336412
3728	Aircraft Parts	336413
3761	Guided Missiles and Space Vehicles	336414
3764	Space Vehicle Propulsion Units	336415
3769	Guided Missile and Space Vehicle Parts	336419

II.B. Characterization of the Aerospace Industry

There are many different aerospace products classified under the six aerospace SIC codes. The products produced, geographical distribution, and economic trends of the aerospace industry are discussed below. Figure 1 represents the general structure of the aerospace industry. The aerospace industry operations are often classified as either military or commercial and as either original equipment manufacturers (OEM) or rework. Most aerospace facilities specialize in either military or commercial and either rework or OEM. OEM facilities might do both military and commercial work, and likewise for rework facilities. Some facilities might even work in all areas of the industry, as indicated by the dotted circle in Figure 1.

Figure 1: Structure of the Aerospace Industry



Source: NESHAP BID, USEPA/OAQPS, May 1994.

II.B.1. Product Characterization

The aerospace industry consists of manufacturers of aircraft, aircraft engines, aircraft parts, guided missiles and space vehicles, and guided missile and space vehicle propulsion units and parts. Table 1 lists the products included in aircraft, aircraft engines, and space vehicle and missile categories. One source of manufacturer and model information is *The Aerospace Sourcebook*, published by *Aviation Week & Space Technology*.

Table 1: Products Included in the Aerospace Industry

Category	**Products**
Military Fixed-Wing Aircraft	Attack Bombers Cargo/Transport/Refueling Early Warning Electronic Warfare Fighters Observation Patrol ASW Reconnaissance Research/Test Bed Training Utility
Commercial Fixed-Wing Aircraft	Narrow Body Turbofans Wide Body Turbofans Turboprops
Rotary-Wing Aircraft	Naval Scout/Attack Tiltrotor Training Transport Utility
Business & General Aviation Aircraft	Turbofan Turboprop Reciprocating Engine-Powered
Gas Turbine Engines	
Unmanned Aerial Vehicles and Drones	
Space/Launch Vehicles	Manned Systems Unmanned Systems
Missiles	Air-to-Air Air-to-Surface Anti-Armor Anti-Ballistic Anti-Ship Anti-Submarine Surface-to-Air Surface-to-Surface

Source: Aerospace Source Book, Aviation Week & Space Technology, 1/12/98.

These manufacturing facilities are classified under SIC codes 372 and 376 as listed above. In order to discuss the production of these parts in a sequential manner, Sections II and III of this profile are divided into four categories: aircraft parts, aircraft assembly, aircraft rework and repair, and space vehicles and guided missiles.

The diverse nature of parts needed to produce these products requires the support of many other major U.S. industries. Many of the parts utilized by aerospace manufacturers are made by other industry sectors such as the plastics and rubber industry, the fabricated metal industry, the metal casting industry, the glass industry, the textile industry, and the electronic components industry. Manufacturing and assembling of complete units in the aerospace industry typically involves prime contractors and several tiers of subcontractors, as follows:

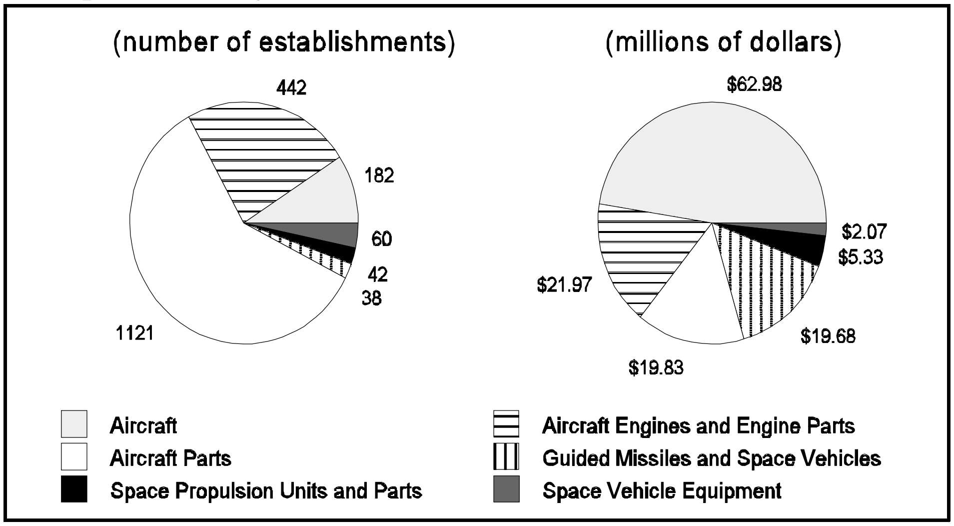
• Prime Contractors-	Design (develop) and assemble or manufacture complete units.
• First Tier Subcontractors-	Do major assembly and/or manufacture of sections of air/space craft without designing or assembling complete units.
• Second Tier Subcontractors-	Make various subassemblies and sections.
• Third Tier Subcontractors-	Produce machined components and sub-assemblies.
• Fourth Tier Subcontractors-	Specialize in the production of particular components and in specific processes.

Typically, those facilities designated as "prime contractors" are included in SIC codes 3721, 3724, 3761 and 3764. Both first and second tier subcontractors correspond to SIC codes 3728 and 3769. Third and fourth tier subcontractors may be included in a variety of industry SIC codes (EPA/OAQPS, 1994).

Figure 2 illustrates the distribution of manufacturing facilities and value of shipments within the aerospace industry. These figures show that while the aircraft parts sector of the aerospace industry is by far the largest in terms of number of establishments, the finished aircraft sector has the largest value of shipments.

The aircraft-related portion of the aerospace industry is much larger than the space vehicle and missile portion. The aircraft portion comprises 93 percent of the establishments and 79 percent of the value of shipments. However, considering the small percentage of facilities engaged in guided missile and space vehicle manufacturing (2 percent), the value of shipments is relatively high (15 percent). In general, facilities which are responsible for assembling the final aerospace products are few and their production rates are low, but the value of each of their products greatly surpasses that of the supporting industries.

Figure 2: Number of Establishments and Value of Shipments for the Aerospace Industry



Source: *1992 Census of Manufacturers*, USDOC, 1995.

Aircraft Engines and Engine Parts and Aircraft Parts and Equipment

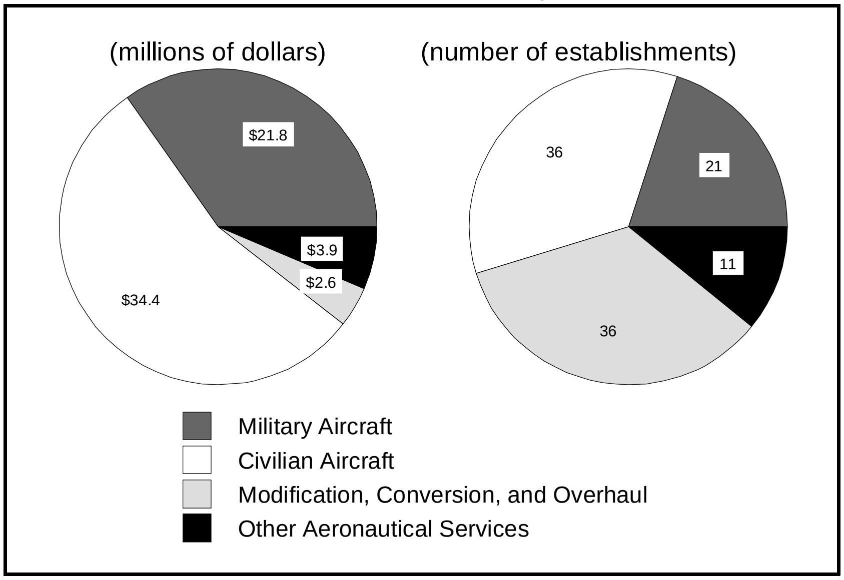
The aircraft engines, engine parts, and aircraft parts industry is classified under SIC 3724 and 3728. Facilities producing these parts employ processes similar to many other metal casting, fabricating, and finishing facilities, as well as processes from a wide range of other industries. Typical products manufactured by these facilities include: engines, exhaust systems, motors, brakes, landing gear, wing assemblies, propellers, and many other related products. The primary customers for these industries are the establishments involved in the assembly of aircraft, classified under SIC 3721.

Aircraft Assembly

The aircraft industry is made up of establishments primarily engaged in manufacturing or assembling complete aircraft and is classified under SIC 3721. This industry also includes establishments owned by aircraft manufacturers and primarily engaged in research and development on aircraft, whether from enterprise funds or on a contract or fee basis (Census, 1995). There are many different types of aircraft included in this industry, from airplanes and helicopters to blimps and balloons. However, this profile focuses primarily on the production of airplanes since they represent the largest portion of the industry. Typical products include fixed wing aircraft, helicopters, gliders, balloons, and research and development on aircraft.

The major customers of the aircraft industry are commercial airlines and transport companies and the military. Figure 3 shows the distribution within the industry of value of shipments and number of establishments. Civilian aircraft represents the largest percentages in value of shipments and number of establishments. Approximately one-third of the establishments in this industry are involved in the repair and rework of aircraft. These facilities will be discussed in Section III.

Figure 3: Value of Shipments and Number of Establishments for the Aircraft Industry



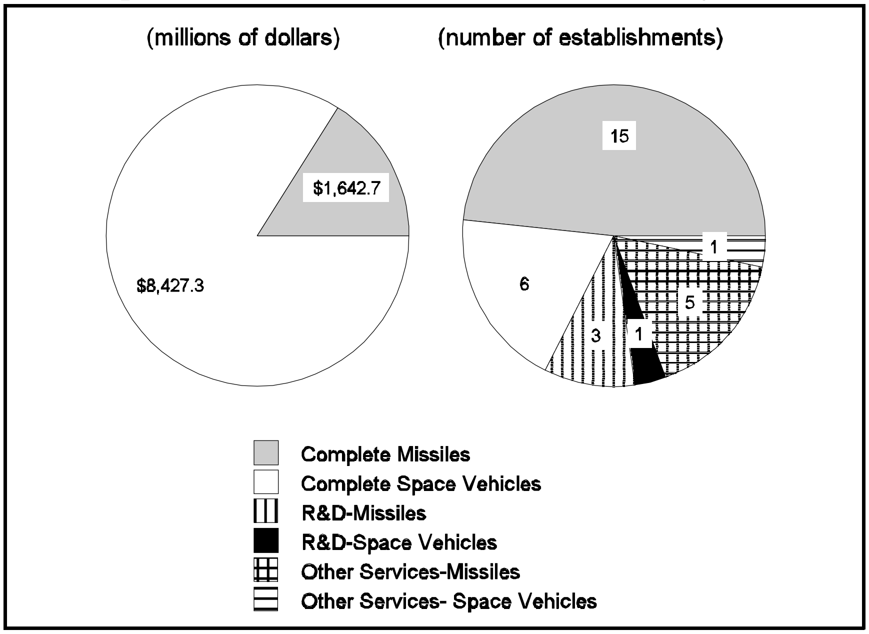
Source: 1992 Census of Manufacturers, USDOC, 1995.

Guided Missiles and Space Vehicles and Associated Parts

The guided missiles and space vehicles industry includes establishments primarily engaged in manufacturing and research and development on guided missiles and space vehicles, propulsion units, and parts. Typical products covered under SIC 3761, 3764, and 3769 include guided and ballistic missiles, space and military rockets, space vehicles, propulsion units and engines for missiles and space vehicles, airframe assemblies, and research and development on these products. The primary customer for this industry is the military, however space vehicles are also used by commercial entities for releasing communications satellites.

Figure 4 illustrates the specialization within the guided missile and space vehicle industry. The Census of Manufacturers identifies only 31 facilities in this sector. Value of shipment data is not available for facilities providing R&D and other services to protect individual facility confidentiality. Only six facilities, or less than a quarter of the facilities in this industry, are producing complete space vehicles. The value of shipments for these facilities, however, comprised more than three-quarters of the total value of shipments for the industry.

Figure 4: Value of Shipments and Number of Establishments for the Space Vehicles and Guided Missiles Industry

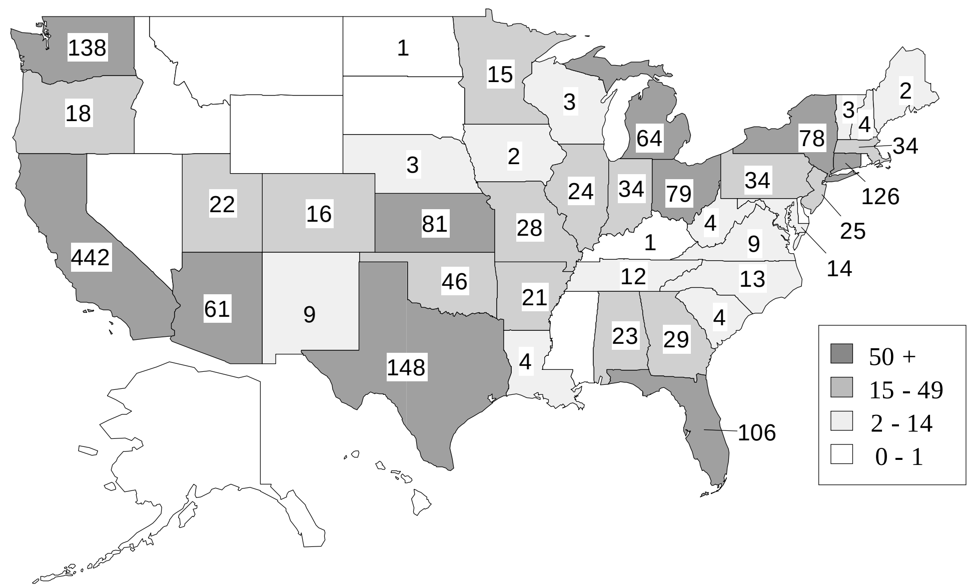


Source: *1992 Census of Manufacturers*, USDOC, 1995.

II.B.2. Industry Size and Geographic Distribution

Figure 5 shows the U.S. distribution of aerospace facilities. Generally, the geographic distribution of aerospace facilities is determined by the location of industrialized areas of the country. As with many manufacturing industries, the ease of transportation of materials, products, and skilled workers influence facility location.

Figure 5: Geographic Distribution of Aerospace Manufacturing Facilities



Source: *1992 Census of Manufacturers*, USDOC, 1995.

Table 2 lists the facility size distribution within the aerospace sectors. As previously mentioned, the aircraft and aircraft parts industry (1,745 facilities) is more than ten times larger than the space vehicles, guided missiles, and parts industry (140 facilities). Aircraft and aircraft part manufacturing generally employs less people per facility than space vehicle and guided missile manufacturing. However, the number of employees in the aircraft industries still overshadows that of the missile and space vehicle industries, 645.9 thousand and 149.6 thousand respectively.

Table 2: Facility Size Distribution for the Aerospace Industry

	Aircraft and Aircraft Engines and Parts (SIC 372)		**Aircraft (SIC 3721)**		**Aircraft Engines and Engine Parts (SIC 3724)**		**Aircraft Parts and Equipment (SIC 3728)**	
Employees per Facility	Number of Facilities	Percentage of Facilities	Number of Facilities	Percentage of Facilities	Number of Facilities	Percentage of Facilities	Number of Facilities	Percentage of Facilities
1-9	652	37%	60	33%	112	26%	480	43%
10-49	543	31%	42	23%	130	29%	371	33%
50-249	340	19%	29	16%	129	29%	182	16%
250-2499	173	10%	32	18%	63	14%	78	7%
2500 +	37	2%	19	10%	8	2%	10	1%
Total	**1,745**	100%	182	100%	442	100%	1,121	100%
	Space Vehicles, Guided Missiles, and Parts (SIC 376)		**Space Vehicles and Guided Missiles (SIC 3761)**		**Space Propulsion Units and Parts (SIC 3764)**		**Space Vehicle and Guided Missiles Parts (SIC 3769)**	
Employees per Facility	Number of Facilities	Percentage of Facilities	Number of Facilities	Percentage of Facilities	Number of Facilities	Percentage of Facilities	Number of Facilities	Percentage of Facilities
1-9	26	19%	4	10%	6	14%	16	27%
10-49	27	19%	5	13%	8	19%	14	23%
50-249	31	22%	5	13%	8	19%	18	30%
250-2499	37	26%	12	32%	15	36%	10	17%
2500 +	19	14%	12	32%	5	12%	2	3%
Total	**140**	100%	38	100%	42	100%	60	100%

Source: 1992 Census of Manufacturers, Industry Series: Aerospace Equipment, Including Parts, US Department of Commerce, Bureau of the Census, 1995.
Note: 1992 Census of Manufacturers data are the most recent available. Changes in the number of facilities, location, and employment figures since 1992 are not reflected in these data.

Table 3 further divides the geographic distribution of aerospace facilities. The top states in which the aerospace industries are concentrated are given along with their respective number of establishments.

Table 3: States with the Largest Number of Aerospace Manufacturing Facilities

	Aircraft and Aircraft Parts (SIC 372)		**Space Vehicles, Guided Missiles and Associated Parts (SIC 376)**	
	Top States	Establishments	Top States	Establishments
States in which industry is concentrated, based on number of establishments	California Texas Washington Connecticut	393 140 136 126	California Arizona Texas Alabama	49 9 8 7
Percent of Total	45%		52%	

Source: *1992 Census of Manufacturers, Industry Series: Aerospace Equipment, Including Parts,* US Department of Commerce, Bureau of the Census, 1995.

Dun & Bradstreet's *Million Dollar Directory*, compiles financial data on U.S. companies including those operating within the aerospace industry. Dun & Bradstreet ranks U.S. companies, whether they are a parent company, subsidiary or division, by sales volume within their assigned 4-digit SIC code. Table 4 lists the top 10 aerospace companies by sales.

Table 4: Top U.S. Aerospace Companies

Rank	Company	1997 Sales (millions of dollars)	SIC Code(s) Reported
1	General Electric Co.- Fairfield, CT	79,179	3724, 3511, 3612, 3641, 3632, 4833
2	Lockheed Martin Co.- Bethesda, MD	26,875	3721, 3761, 3663, 3764. 3812, 3728
3	United Technologies Corp.- Hartford, CT	23,273	3724, 3585, 3534, 3721, 3842, 3714
4	The Boeing Co.- Seattle, WA	22,681	3721, 3663, 3761, 3764, 3812, 3728
5	Hughes Electronics Corp.- Los Angeles, CA	14,772	3761, 3812, 3714, 3651, 3663, 3699
6	Allied Signal Inc.- Morristown, NJ	13,971	3724, 3812, 3728, 3761, 3714, 2824, 2821
7	McDonnell Douglas Corp*-Saint Louis, MO	13,834	3721, 3761, 3764, 3812, 6159
8	Textron Inc.- Providence, RI	9,274	3721, 3714, 3452, 3711, 6141, 6159
9	Northrop Grumman Corp.- Los Angeles, CA	8,071	3721, 3761, 3728, 3812, 3825, 4581
10	The BF Goodrich Co.- Richfield, OH	2,238	3728, 3724, 7699, 2821, 2843

Source: Dunn & Bradstreet's Million Dollar Directory, 1997.
Note: Not all sales can be attributed to the companies' aerospace operations.
*McDonnell Douglas Corp. is now part of The Boeing Co.

Readers should note that: (1) companies are assigned a 4-digit SIC code that resembles their principal industry most closely; and (2) sales figures include total company sales, including subsidiaries and operations (possibly not related to aerospace). Additional sources of company specific financial information include Standard & Poor's *Stock Report Service*, *Ward's Business Directory of U.S. Public and Private Companies*, Moody's Manuals, and company annual reports.

The Bureau of the Census publishes concentration ratios, which measure the degree of competition in a market. They compute the percentage of the value of products shipped by establishments classified within an industry of the total value of these products shipped from any establishment. Within the aerospace industry, the aircraft industry and the space vehicle and guided missile industry had the greatest coverage ratios in 1992: 97 percent each. The aircraft engine, aircraft parts, propulsion units, and auxiliary space vehicle equipment coverage ratios were 95, 74, 86, and 40 percent respectively.

II.B.3. Economic Trends

Growth in the U.S. aerospace industry will be influenced by several key factors, including constrained defense spending by the U.S. and foreign governments, increased productivity and technological innovation, foreign competition, continuing expansion of the global economy, investment in research and development, offsets and outsourcing, and support by foreign governments for their industries.

Domestic Trends

In recent years there has been considerable consolidation of aerospace companies, especially those supplying the military. This has resulted in some reductions in labor force and closing of some aerospace facilities in the U.S. However, in constant 1992 dollars, the value of U.S. shipments in 1996 of complete aircraft (all types, civil and military) rose by about six percent over the value of shipments in 1995. The value of those shipments was expected to rise further by about thirty percent in 1997 and about five percent in 1998.

<u>Military</u>

In September 1996, Congress passed a DOD budget for FY 1997 that, for the first time in more than a decade, did not reduce spending from the previous year. In addition, the legislation provided more funding for procurement of aircraft and missiles than DOD had requested. Also, DOD reduced funding for R&D, which means that private companies will have to increase their share of the total amount spent on R&D if the overall level of technology investment and advancement is to be maintained.

In the missiles sector, air-to-surface weapons should experience the most growth relative to other types of missiles. Strong focus will be placed on improving guidance capabilities, mainly through the use of the U.S. Global Positioning System (GPS) (USDOC, 1998).

Commercial

Of all the aerospace sectors, the large civil transport aircraft sector is expected to experience the fastest rate of growth from 1997 through 2001. With the significant increase in production rates undertaken by Boeing in 1996, the value of shipments in 1997 of large civil transports could be as much as sixty percent higher than that of 1996, with another increase of about ten percent expected in 1998 (USDOC, 1998).

Even as U.S. aerospace workers are being laid off because of consolidation in some companies, workers are being hired by other firms because of increasing orders. Sales of large transport aircraft are expected to come from the retirement and replacement of aircraft plus additional aircraft to allow for air traffic growth (USDOC, 1998).

The aircraft engines and parts sectors also should see production and shipments increase as suppliers respond to increased production rates by the manufacturers of commercial transports. The market for commercial transport engines alone is expected to total from $150 billion to $175 billion between 1996 and 2005 (USDOC, 1998).

International Trends

The internationalization of aerospace programs is increasing, and the U.S. aerospace industry is dependent on exports for a third of its market. The U.S. aerospace industry is affected significantly by the economies of foreign countries. The average annual increase in world GDP is expected to be three percent from 1996 through 2005. The main barriers facing U.S. manufacturers are foreign government support for their aerospace industries through direct and indirect subsidies, tariffs, and difficult and expensive licensing procedures. Additional access could be guaranteed if efforts succeed to expand membership and broaden the disciplines of several aircraft-related trade agreements (USDOC, 1998).

Military

The situation for firms in the defense industry is mixed. While some governments, such as those of North America and Europe (with the largest defense budgets), continue to seek ways to reduce their military expenditures, governments in South America (with relatively small defense budgets) are maintaining or increasing their defense spending. However, current economic crises in Asia may reduce exports to some countries. The pace of consolidation in Europe of aerospace and defense companies, which began later than in the U.S., is escalating just as the merger rate in the U.S. appears to be slowing (USDOC, 1998).

Commercial

Overall improvement in the global economy has buoyed the fortunes of the world's airlines. World air passenger traffic rose each year from 1994 to 1996, and increased traffic by airlines all over the world produced a significant turnaround in the large transport aircraft market, the largest part of the aircraft industry. The civil aircraft sector exports 60 percent of its total production and represents about 20 percent of the overall U.S. aerospace industry (USDOC, 1998).

Asian economic problems have not had serious widespread impacts on the aerospace industry to date. Companies such as Lockheed Martin and Boeing estimate that about five percent of their contracts for the next five years are tied to that region. It is possible that, considering the strength of the industry and the economy outside of Asia, other customers may step in and eliminate lower production rates (Smith, 1998).

Commercial space launch providers also are benefiting from the improved economic situation. Consumer demand for direct-to-home television, voice and data transmission, and other satellite services is increasing the demand for satellites and therefore for space launch vehicles to place them in orbit (USDOC, 1998).

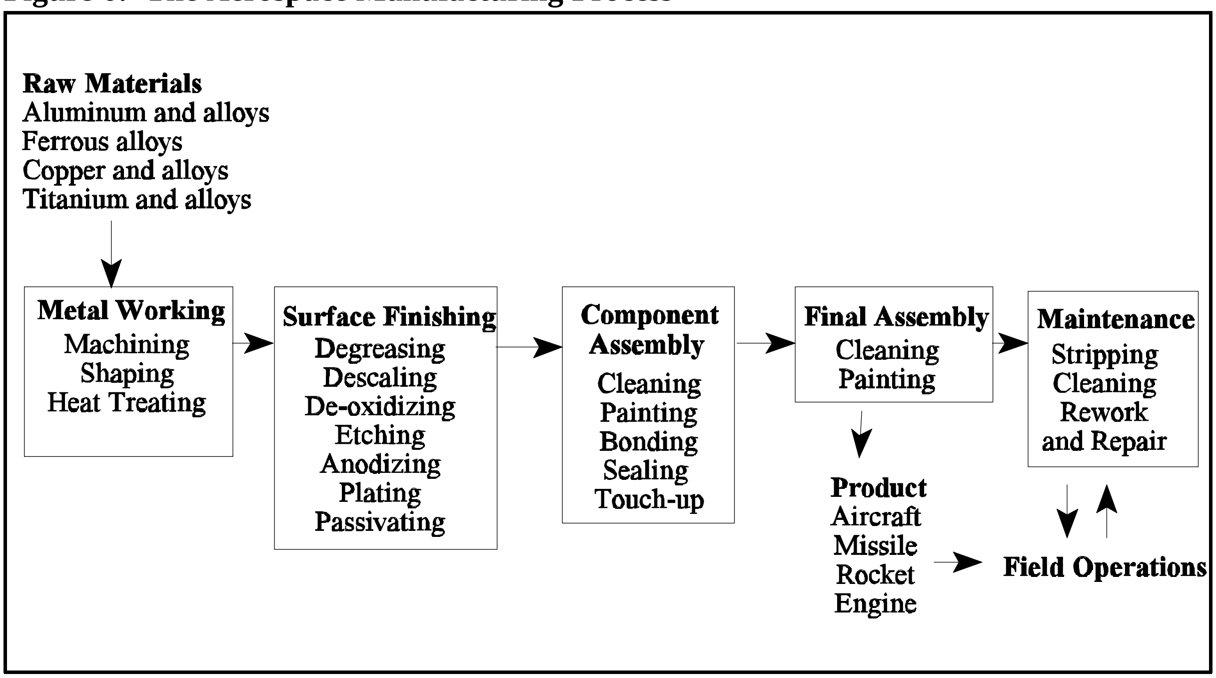
III. INDUSTRIAL PROCESS DESCRIPTION

This section describes the major industrial processes within the aerospace industry, including the materials and equipment used, and the processes employed. The section is designed for those interested in gaining a general understanding of the industry, and for those interested in the inter-relationship between the industrial process and the topics described in subsequent sections of this profile -- pollutant outputs, pollution prevention opportunities, and Federal regulations. This section does not attempt to replicate published engineering information that is available for this industry. Refer to Section IX for a list of resource materials and contacts that are available.

It is important to note that the FAA places very strict "airworthiness" guidelines on manufacturing and rework facilities for safety and quality control purposes, thus new pollution prevention alternatives may require a full evaluation and permitting process before they may be used.

This section contains a description of commonly used production processes, associated raw materials, by-products produced or released, and materials either recycled or transferred off-site. This discussion, coupled with schematic drawings of the identified processes, provide a concise description of where wastes may be produced in the process. This section also describes the potential fate (via air, water, and soil pathways) of these waste products. Figure 6 shows a general aerospace manufacturing process diagram.

Figure 6: The Aerospace Manufacturing Process



Source: Aerospace Industries Association Newsletter, October 1994.

III.A. Aircraft Engines and Parts Industry

Manufacturing processes for aircraft engines and parts may consist of the following basic operations: materials receiving, metal fabricating, machining and mechanical processing, coating application, chemical milling, heat treating, cleaning, metal processing and finishing, coating removal (depainting), composite processing, and testing. Many facilities employ all of these processes in their operations, however, a facility may also employ only a subset of these operations, as with a facility that produces a single component or a facility that provides a service such as painting (EPA/OAQPS, 1997).

In addition, there are a number of operations that may be used at aircraft engine and parts facilities but are not typical and are performed in conjunction with a variety of industries, such as foundry operations and manufacturing of electronic components. For more information on foundry operations, see the *Profile of the Metal Casting Industry*, EPA, 1997. For more information on electronics and computers, see the *Profile of the Electronics and Computer Industry*, EPA, 1995.

III.A.1. Materials

There are many different materials involved in the production of engines and parts. The most common materials are alloys of aluminum, which are used primarily for aircraft structural components and exterior skin sections. Other materials are titanium, stainless steel, magnesium, and non-metallics such as plastics, fabrics, and composite materials. Typical forms of materials are honeycomb, wire mesh, plate, sheet stock, bar cast, and forged materials.

Metallic Alloys

Aluminum is used as a primary structural material in the aerospace industry because of its light weight, and because its alloys can equal the strength of steel. The ability to resist atmospheric corrosion also favors the use of aluminum. The type of alloy metal used depends on the desired characteristics of the finished product such as strength, corrosion resistance, machinability, ductility, or weldability (Horne, 1986).

High strength alloys typically contain copper, magnesium, silicon, and zinc as their alloying elements. Other alloying agents that may be used are: lithium for lightness; nickel for strength and ductility; chromium for tensile strength and elastic limit; molybdenum for strength and toughness; vanadium for tensile strength, ductility, and elastic limit; silicon as a deoxidizer; and powder metallurgy alloys for strength, toughness, and corrosion resistance (Horne, 1986).

The development of the gas turbine and the evolution of engines required materials with great resistance to temperature, stress, and oxidation. Nickel-based alloys have a high resistance to oxidation and are used for compressor blades and guide vanes, discs, turbine blades, shafts, casings, combustion chambers, and exhaust systems. Titanium alloys have excellent toughness, fatigue strength, corrosion resistance, temperature resistance, and a lower density than steel. Titanium alloys are frequently used to make hot-end turbine components and turbine rotor blades (Horne, 1986).

Non-Metallic Materials

Plastics, carbon and glass fibers, and synthetic resins and polymers are all used in aerospace manufacturing. There are two types of plastics used, thermoplastics and thermosetting materials. Thermoplastic materials are softened by heating and will harden on cooling and can be extruded (material is pressure forced through a shaped hole), injection molded (soft material is forced into a mold through a screw injector and pressure), or thermoformed (material is cast in a mold with heat and pressure). Thermosetting plastics are hardened by heating and form rigid three dimensional structures through chemical reactions. They are typically compression molded (Horne, 1986). For more information on non-metallic materials, refer to the *Profile of the Rubber and Plastic Industry*, EPA, 1995.

Carbon and glass fibre strands are used to reinforce plastics for strength and stiffness while remaining lightweight. Synthetic resins and polymers are used as adhesives which produce smooth bonds and a stiff structure which propagates cracks more slowly than in a riveted structure (Horne, 1986).

III.A.2. Metal Shaping

Another major process in the manufacturing of aircraft and other aerospace equipment is metal shaping. Shaping operations take raw materials and alter their form to make the intermediate and final product shapes. There are two phases of shaping operations: primary and secondary. Primary shaping consists of forming the metal from its raw form into a sheet, bar, plate, or some other preliminary form. Secondary shaping consists of taking the preliminary form and further altering its shape to an intermediate or final version of the product. Examples of primary and secondary shaping are listed in Table 5 below. Brief descriptions of the most common operations follow the table.

Table 5: Primary and Secondary Shaping Operations

Primary Shaping Operations	Secondary Shaping Operations
Abrasive Jet Machining	Stamping
Casting	Turning
Drawing	Drilling
Electrochemical Machining	Cutting and Shaping
Electron Beam Machining	Milling
Extruding	Reaming
Forging	Threading
Impact Deformation	Broaching
LASER Beam Machining	Grinding
Plasma Arc Machining	Polishing
Pressure Deformation	Planing
Sand Blasting	Deburring
Ultrasonic Machining	

Source: Pollution Prevention Options in Metal Fabricated Products, USEPA, January 1992.

Primary Shaping Operations

The most common primary shaping operations include casting, forging, extruding, rolling, cutting, coining, shearing, drawing, and spinning. Each of these operations is briefly described below.

Metal casting involves the introduction of molten metal into a mold or die having the external shape of the desired cast part. The mold or die is removed when the metal has cooled and solidified. Metal casting operations can be classified as either foundries or diecasters. The primary difference is that foundries pour molten metal relying on gravity to fill the mold and die casters use machines to inject molten metal under pressure into the mold. Foundry molds are typically used only once for each part. They are often made of sand grains bound together with chemicals or clay. Die casting molds are often reused thousands of times and are part of a larger diecasting machine that can achieve very high production rates. Foundries typically produce larger airplane parts such as engine blocks, turbine and compressor parts, and other mechanical parts from both ferrous and non-ferrous metals. Die casters typically produce smaller intricate parts from non-ferrous metals (EPA/OECA, 1995). For a more detailed discussion of metal casting operations see the *Profile of the Metal Casting Industry*, USEPA, 1997.

Once the molten metal is formed into a workable shape, shearing and forming operations are usually performed. Shearing operations cut materials into a desired shape and size, while forming operations bend or form materials into specified shapes. Shearing operations include punching, piercing, blanking, cutoff, parting, and trimming. These operations produce holes, openings, blanks, or parts. Forming operations shape parts by forcing them into a specific configuration, and include bending, extruding, drawing, spinning, coining, and forging. Bending is the simplest forming operation; the part is simply bent to a specific angle or shape and normally produce flat-shapes (EPA/OECA, 1995).

Extruding is the process of forming a specific shape from a solid blank by forcing the blank through a die of the desired shape. Complicated and intricate cross-sectional shapes can be produced by extruding. Rolling is a type of extruding that passes the material through a set or series of rollers that bend and form the part into the desired shape. Coining, another type of extruding, alters the form of the part by changing its thickness, producing a three-dimensional relief on one or both sides of the part, as found on coins (EPA/OECA, 1995).

Drawing and spinning form sheet stock into three-dimensional shapes. Drawing uses a punch to force the sheet stock into a die, where the desired part shape is formed in the space between the punch and die. In spinning, pressure is applied to the sheet while it spins on a rotating form so that the sheet acquires the shape of the form (EPA/OECA, 1995).

Forging operations produce a specific part shape, much like casting. The forging process is used in the aerospace industry when manufacturing parts such as pistons, connecting rods, and the aluminum and steel portion of wheels. However, rather than using molten materials, forging uses externally applied pressure that either strikes or squeezes a heated blank into a die of the required shape. Forging operations use machines that apply repeated hammer blows to a red-hot blank to force the material to conform to the shape of the die opening. Squeezing acts in much the same way, except it uses pressure to squeeze rather than strike the blank. Forging typically uses a series of die cavities to change the shape of the blank in increments. Depending on the shape, a forging die can have from one to over a dozen individual cavities (EPA/OECA, 1995).

Secondary Shaping Operations

Shearing (or cutting) operations include punching, piercing, blanking, cutoff, parting, shearing, and trimming. Basically, these are operations that produce holes or openings, or that produce blanks or parts. The most common hole-making operation is punching. Piercing is similar to punching, but produces a raised-edge hole rather than a cut hole. Cutoff, parting, and shearing are similar operations with different applications: parting produces both a part and scrap pieces; cutoff and shearing produce parts with no scrap; shearing is used where the cut edge is straight; and cutoff produces an edge shape rather than a straight edge. Trimming is performed to shape or remove excess material from the edges of parts (EPA/OECA, 1995).

Turning, drilling, and reaming processes typically use a lathe, which holds and spins the workpiece against the edge of a cutting tool. Drilling machines are designed for making holes and for reaming, or enlarging or finishing existing holes. Milling machines use multiple edge cutters to cut unusual or irregular shapes into the workpiece (EPA/ORD, 1990).

Broaching is a process whereby internal surfaces such as holes of circular, square or irregular shapes, or external surfaces like keyways are finished. A many-toothed cutting tool called a broach is used in this process. The broach's teeth are graded in size in such a way that each one cuts a small chip from the workpiece as the tool is pushed or pulled either past the workpiece surface, or through a leader hole. Broaching of round holes often gives greater accuracy and better finish than reaming (EPA/ORD, 1990).

Deburring involves removing metal shavings and burrs clinging to the cut edges of parts after machining has been completed. Deburring is typically done by one of two processes. Small parts can be deburred in a tumbler where the burrs are smoothed off the part by the constant friction with the tumbling media. This process, however, is not appropriate for long parts. Instead, long parts are scrubbed with an abrasive pad by hand or buffed with a power tool. The buffing operation can be performed either by hand or in an automatic operation (EPA/OAQPS, 1994).

Parts may also be honed and buffed to smooth their surfaces; spray-washed with an alkaline cleaner; and blown dry using compressed air. A protective coating of oil may be applied to parts that are stored on-site or shipped off-site to a heat-treating facility (EPA/NRMRL, 1995).

The metal working process creates much heat and friction. If the heat and friction are not reduced, the tools used in the process are quickly damaged and/or destroyed. Also, the quality of the products made is diminished because of inefficient tools and damage to the product while it is being manufactured. Coolants reduce friction at the tool/substrate interface and transfer heat away from the tools and the material being processed, reducing the time to process the metal, increasing the quality of the workmanship, and increasing tool life. The ability to transfer the heat away from the metal working process is why metal working fluids are often called coolants (Ohio EPA, 1993).

Oils are natural lubricants and provide this quality to coolants that are petroleum-based. Other coolants' ability to reduce friction comes from lubricating additives. During the metal working process, heat diffuses into the coolant. The heated coolant flows off the work area into a collection container or sump, where it cools off and then enters the cycle again. Water has excellent cooling characteristics and many coolants contain water or are primarily water. Soluble oils and semi-synthetic oils have both water and oil components. Coolants containing both oil and water require surfactants to form and maintain emulsions, a mixture of the oil and water, so that both properties can work together (Ohio EPA, 1993).

Heat Treating

Heat treating is the modification of the material's or part's metallurgical properties through the application of controlled heating and cooling cycles. For example, aluminum outer skin panels undergo a low temperature oven bake after forming to provide greater stress tolerance. Heat treating can be performed either before or after machining and includes carburizing (impregnating the surface with carbon), annealing (softening), stress relief, tempering, air furnace treating, and salt pot treating. Chemicals, such as methanol, are often used in heat treating ovens to maintain a chemically reducing atmosphere in order to obtain the proper metallurgical properties on the surface of the part being treated. After heat treating, the parts can either be cooled in ambient air or placed in a liquid quenching bath. The quench bath is typically a glycol solution, a chromate solution, or an oil (EPA/OAQPS, 1994).

Heat-treated parts can also be machined, honed, and deburred after they are returned to the plant. After machining, the parts are typically sprayed with a protective oil coating that controls corrosion until they are further processed (EPA/NRMRL, 1995).

III.A.3. Metal Finishing

Metal finishing and electroplating activities are performed on a number of metals and serve a variety of purposes; the primary purpose being protection against corrosion. Without metal finishing, products made from metals would last only a fraction of their unfinished life-span. Metal finishing alters the surface of metal products to enhance properties such as corrosion resistance, wear resistance, electrical conductivity, electrical resistance, reflectivity, appearance, torque tolerance, solderability, tarnish resistance, chemical resistance, ability to bond to rubber (vulcanizing), and a number of other special properties (e.g. electropolishing sterilizes stainless steel) (EPA/ORD, 1994).

These plating processes involve immersing the article to be coated or plated into a series of baths consisting of acids, bases, salts, etc. A wide variety of materials, processes, and products are used to clean, etch, and plate metallic and non-metallic surfaces. Typically, metal parts or work pieces undergo one or more physical, chemical, and electrochemical processes. Physical processes include buffing, grinding, polishing, and blasting. Chemical processes include degreasing, cleaning, pickling, milling, etching, polishing, and electroless plating. Electrochemical processes include plating, electropolishing, and anodizing (EPA/ORD, 1994).

Cleaning/Preparing

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 important in order to ensure the successful application of later surface treatments. There are three main types of cleaning: aqueous, organic solvent, and abrasive. Aqueous cleaning covers a wide variety of cleaning methods such as detergents, acids, and alkaline compounds to displace soil rather than dissolving it as in organic solvent cleaning. Aqueous cleaners are either sprayed or used in cleaning baths, ultrasonic baths, and in steam cleaning. Three types of aqueous cleaning favored by the aerospace industry are:

- emulsification cleaning- emulsification cleaning uses water-immiscible solvents, surfactants, and emulsifiers.
- acid cleaning- sulfuric acid or hydrochloric acid is used to remove scale from metal; acid cleaning is sometimes known as pickling baths.
- alkaline cleaning- alkaline cleaning solutions (usually hot) contain builders (sodium salts of phosphate, carbonate, and hydroxide) and surfactants (detergents and soap) (CARB, 1997).

Abrasive cleaning is mechanical cleaning using abrasives such as rough fabric scrubbing pads, sandpaper, tumbling barrels, buffing wheels, and blasting equipment. Abrasives may be added to acid or alkaline cleaning solutions to improve cleaning action (CARB, 1997).

Masking

Maskants are coatings that are applied to a part to protect the surface from chemical milling and surface treatment processes such as anodizing, plating, and bonding. Maskants are typically rubber- or polymeric-based substances applied to an entire part or subassembly by brushing, dipping, spraying, or flow coating. Two major types of maskants are used: solvent-based and waterborne. After an adequate thickness of maskant has been applied to the part, the maskant is cured in a bake oven. The maskant is then cut following a specific pattern and manually stripped away from selected areas of the part where metal is to be removed. The maskant remaining on the part protects those areas from the etching solution.

Chemical Milling

Chemical milling is used 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 parts precludes mechanical milling or when chemical milling is advantageous due to shorter processing time or its batch capability. Chemical milling is accomplished by submerging the component in an appropriate etchant. Commonly used etchants are sodium hydroxide for aluminum, nitric acid and hydrofluoric acid for titanium, dilute sulfuric acid for magnesium, and aqua regia (a mixture of nitric and hydrochloric acids) for stainless steel. The depth of the cut is closely controlled by the length of time the component is in the etchant and the concentration of the etchant. When the milling has been completed, the part is removed from the etchant and rinsed with water. Some metals may develop a smutty discoloration during the chemical milling process. A brightening solution, such as dilute nitric acid, is typically used as a final step in the process to remove the discoloration. After desmutting, the part either goes back to chemical milling for further metal removal or to the stripping area to have the maskant removed. The maskant may be softened in a solvent solution and then stripped off by hand (EPA/OAQPS, 1994).

Anodizing

Anodizing uses the piece to be coated, generally with an aluminum surface, as an anode in an electrolytic cell. Anodizing provides aluminum parts with a hard abrasion- and corrosion-resistant film. This coating is porous, allowing it to be dyed or to absorb lubricants. This method is used both in decorative application and in engineering applications such as aircraft landing gear struts. Anodizing is usually performed using either sulfuric, boric-sulfuric, or chromic acid often followed by a hot water bath, though nickel acetate or sodium potassium dichromate seal may also be used (EPA/OECA, 1995).

Passivation

Passivation is a chemical process in which parts are immersed in a solution containing a strong oxidizing agent. This forms a thin oxide layer on the part surface, providing corrosion protection and increasing adhesion of subsequent coatings. It is often used before maskant application in the chemical milling process (EPA/OAQPS, 1994).

Pickling

Pickling is a process of chemical abrasion/etching which prepares surfaces for good paint adhesion. The pickling process is used mainly for preparing pipe systems and small parts for paint. However, the process and qualities will vary by facility. The process involves a system of dip tanks. In pickling steel parts, The first tank is used to remove any oil, grease, flux, and other contaminants on the surface being pickled. The part is then immersed into a 5-8% caustic soda and water mixture (pH 8-13) maintained at temperatures of between 180°-200°F. Next, the steel is dipped into a 6-10% acid/water mixture maintained between 140°-160°F (EPA/OECA, 1997). Most carbon steel is pickled with sulfuric or hydrochloric acid, while stainless steel is pickled with hydrochloric, nitric, and hydrofluoric acids (EPA/OECA, 1995).

The fourth tank contains an acid rinse tank that is maintained at a pH of 5-7. Finally, the steel part is immersed in a rust preventative 5% phosphoric mixture. The part is then allowed to fully dry prior to paint application (EPA/OECA, 1997).

Polishing

Polishing is used at some facilities to clean and finish the outer skin of the aircraft. The polish is a lightly abrasive metal cleaner that is buffed on the metal surface, then wiped off. The polish gives a mirror-like surface finish and is usually applied instead of paint. Polishing can also be used on other metal parts as a cleaning step.

Conversion Coatings

Conversion coating is the process of changing a metal's surface characteristics by applying a reactive chemical to the metal's surface or by reacting the metal in a chemical bath. The desired result is improved coating adhesion, increased corrosion resistance, or both (EPA/OAQPS, 1994).

Aluminum surfaces are treated with various conversion coatings depending upon the anticipated environmental conditions or performance requirements such as corrosion, electrochemical insulation, and abrasion. Conversion coatings are also used to enhance bond and paint adhesion. Typical treatments include chromate phosphates, chromate oxides, anodizing, and non-chromate formulations (CARB, 1997).

Cadmium surfaces require either a phosphate or a chromate conversion coating prior to painting. The phosphate conversion is designed to be painted; the chromate conversion is designed to add corrosion resistance to the cadmium and it may also be painted (CARB, 1997).

Magnesium must be treated with a conversion coating or anodized before painting to prevent corrosion and to prevent environmental damage by abrasion. Magnesium coatings utilize sodium dichromate solutions (CARB, 1997).

Titanium must be treated with a conversion coating or anodized to protect it from corrosion and to improve adhesion bonding strength. Emersion baths for applying a conversion coating to titanium typically contain sodium phosphate, potassium fluoride, and hydrofluoric acid (CARB, 1997).

Coating/Painting

A coating is a material that is applied to the surface of a part to form a decorative or functional solid film. Coatings are used for corrosion resistance, aircraft identification and improved visibility, and friction reduction. The most common coatings are nonspecialized primers and topcoats, however there are also many specialized primers that provide characteristics such as fire resistance, flexibility, substrate compatibility, antireflection, sealing, adhesion, and enhanced corrosion protection (EPA/OAQPS, 1997).

Coatings are applied by spraying, brushing, rolling, flow coating, and dipping using a variety of application equipment including conventional air spray, high volume low pressure (HVLP) spray, and electrostatic spray. Many of the conventional methods such as rolling, flow coating, dip coating, and brushing are limited to the size and configuration of the part being painted (CARB, 1997).

Painting involves the application of predominantly organic coatings to a work piece for protective and/or decorative purposes. It is applied in various forms, including dry powder, solvent-diluted formulations, and water-borne formulations. Various methods of application are used, the most common being spray painting and electrodeposition. Electrodeposition is the process of coating a work piece by either making it anodic or cathodic in a bath that is generally an aqueous emulsion of the coating material. When applying the paint as a dry powder, some form of heating or baking is necessary to ensure that the powder adheres to the metal. These processes may result in solvent waste (and associated still bottom wastes generated during solvent distillation), paint sludge wastes, paint-bearing wastewaters, and paint solvent emissions (EPA/OECA, 1995).

Spray painting is a process by which paint is placed into a pressurized cup or pot and is atomized into a spray pattern when it is released from the vessel and forced through an orifice. Differences in spray-painting equipment are based on how the equipment atomizes paint. The more highly atomized the paint, the more likely transfer efficiency is to decrease. Transfer efficiency is the amount of paint applied to the object being painted, divided by the amount of paint used. Highly atomized paint spray can more readily drift away from the painting surface due to forces such as air currents and gravity (Ohio EPA, 1994). Cleaning solvent can only be sprayed through a gun for nonatomized and atomized cleaning using specific equipment as specified in the NESHAP.

The viscosity of paint may need adjustment before it can be sprayed. This is accomplished by reduction with organic solvents, or with water for certain water-based coatings. Using solvents for reduction requires the purchase of additional materials and increases air emissions. An alternative method of reducing the viscosity is to use heat. Benefits from the purchase of paint heaters include lower solvent usage, lower solvent emissions, more consistent viscosities, and faster curing rates (Ohio EPA, 1994).

The following types of spray application equipment may be used in the aerospace industry:

- Conventional Spray
- High-Volume/Low-Pressure (HVLP)
- Airless
- Air-Assisted
- Electrostatics
- Rotary Atomization
- Spray Booths

Electroplating

The metals used in electroplating operations (both common and precious metal plating) include cadmium, lead, chromium, copper, nickel, zinc, gold, and silver. Cyanides are also used extensively in electroplating solutions and in some stripping and cleaning solutions (EPA/OECA, 1995).

Electroless plating is the chemical deposition of a metal coating onto a metal object, by immersion of the object in an appropriate plating solution. In electroless nickel plating, the source of nickel is a salt, and a reducer is used to hold the metal ion in the solution. Immersion plating produces a metal deposit by chemical displacement. Immersion plating baths are usually formulations of metal salts, alkalies, and complexing agents (typically cyanide or ammonia) (EPA/OECA, 1995).

Occasionally, touch-up plating is done on an in-house plating line that consists of six separate tanks for cleaning, rinsing, and plating. Following touch-up plating, the parts are typically cleaned in a cold solvent-cleaning tank (EPA/NRMRL, 1995).

Equipment/Line Cleaning

Spray guns and coating lines used to apply the various coatings used at aerospace facilities must be cleaned when switching from one coating to another and when they are not going to be immediately reused. Spray guns can be cleaned 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. Paint hoses/coating lines are cleaned by passing the cleaning solvent through the lines until all coating residue is removed. 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 (EPA/OAQPS, 1997).

III.A.4. Composites Processing

The aerospace industry is increasingly substituting composites for metals in aircraft and space vehicles due to the superior strength-to-weight ratio, corrosion resistance, and fatigue life of composites. Composites are comprised of a resin matrix that bonds together layers of reinforcing material. The resultant structure has mechanical properties superior to each individual component. The resin matrix is usually a polymeric material such as epoxy, polyester, nylon, or phenolic. The reinforcing material or fiber is usually carbon (graphite), fiberglass, or Kevlar. The fibers are oriented at specific angles within the matrix to achieve desired strength characteristics. Methods of forming composites include: injection molding, compression molding, and hand lay-up (or wet lay-up). Hand lay-up can involve applying resin on pre-woven fibers or can involve stacking thin sheets of pre-impregnated (prepreg) fiber material. Steps in hand lay-up are typically: lay-up, debulking, curing, and tear-down (break-out).

Injection molding is the process of shaping a material by applying heat and utilizing the pressure created by injecting a resin into a closed mold. Compression molding is the process of filling a mold with molding compound, closing the mold, and applying heat and pressure until the material has cured. Lay-up is the process of assembling composite parts by positioning reinforcing material in a mold and impregnating the material with resin. With hand lay-up, reinforcing material with resin or prepreg can be added to an open mold until the design thickness and contours are achieved. Debulking is the simultaneous application of low-level heat and pressure to composite materials to force out excess resin, trapped air, vapor, and volatiles from between the layers of the composite, thus removing voids within the composite.

Curing is the process of changing the resin into a solid material so that the composite part holds its shape. This is accomplished by heating the lay-up assembly in order to initiate a polymerization reaction within the resin. Once the reaction is complete, the resin solidifies and bonds the layers of composite materials together. The curing process is typically performed in an autoclave (a pressurized oven), with the composite lay-up enclosed in a bag so that a vacuum can be applied. The vacuum removes air and volatilized components of the resin from within the composite structure which may otherwise be trapped and create voids. Key parameters for curing are time, pressure, vacuum, temperature, and heating and cooling rates.

Break-out is the removal of the composite materials from the molds or curing fixtures (includes the application of release agents prior to filling the mold).

III.B. Aircraft Assembly

Aircraft assembly requires the coordination of thousands of parts coming together to form one large final product. The total assembly process of a complete aircraft can be close to two years. The relatively small number of finished products does not allow for a great deal of automation in the assembly process. Considerable coordination is needed between materials delivery and the production schedule in order to achieve efficient assembly.

Assembly Equipment

Typical materials handling equipment includes conveyors, cranes, industrial vehicles (e.g., forklifts, flatbeds, carts, special lift vehicles, etc.), and containers (EPA/OECA, 1997). Assembly facilities may also use jigs to aid in lining up or joining pieces.

Assembly jigs are essential for the successful assembly or large aerospace products. Their main function is to identify the precise location of fittings for attachment of one component to another. Assembly jigs should be constructed in a manner which allows them to be removed upon completion of the work without breaking down the entire jig structure. They require materials which will not bend or distort over a period of time or during assembly operations. They must also provide easy access to locations where manual joining operations are needed (Horne, 1986).

Pin jigs are used to assemble the curved sheets that form the outside of the fuselage's curved surface. The pin jig is simply a series of vertical screw jacks that support curved pieces during construction. A pin jig is set up specifically for the curved piece under construction. The jig heights are determined from the engineering drawings and plans (EPA/OECA, 1997).

Specially designed locating jigs are required for skins to which stiffeners are to be riveted, such as airplane wings. Stiffeners are first placed in the jigs and then locked in the required position on the completed wings. Wing skins are then placed on the jig and held to a contoured shape with metal bands in order to make contact with the stringers. Holes are drilled through the skin and stringers by using templates to locate hole positions. When all of the holes have been drilled, they are filled with clamping bolts and the metal bands are released. The skin is taken out of the jig and the clamping bolts hold the skin in the desired shape until it is riveted together (Horne, 1986).

Fuselage assembly operations may follow these steps:

- bond stringers to fuselage skin
- fit formers to assembly jig
- assemble skin, drill flanges, and fit riveting clamps

- replace clamps with rivets and remove panel from the jig
- assemble panels and formers on fuselage assembly jig (Horne, 1986).

Welding/Riveting

Fusion Welding

Fusion welding is performed with a metal arc in the presence of an inert gas which prevents the oxidation of the metals to be welded. An alternating or direct current, depending on the type and thickness of the metal, is typically applied through an electrode. The ideal current and pulse duration is selected according to the wire composition, shielding gas, welding position, and wire size (Horne, 1986).

Resistance Welding

Resistance welding requires: a primary electrical circuit from a transformer; a secondary circuit and electrodes to conduct the current to the desired spot; a mechanical system to hold the components and apply force; and control equipment to measure duration and magnitude of the electrical current. Press-type machines have a moveable welding head and force is applied by air through hydraulic cylinders. Seam welding is performed by power-driven roller electrodes instead of the pointed electrodes used for spot welding. Leak-proof and pressure-tight welds are formed by the seam welding process, where each weld overlaps the previous one (Horne, 1986).

Pre-pressure jig welding uses a jig to clamp the components together to relieve the electrodes from clamping stress. This ensures that the desired electrode pressure is available (Horne, 1986).

Electron Beam Welding

Electron beam welding is achieved by concentrating a beam of high velocity electrons onto the surfaces to be joined. The electrons are produced and accelerated by an electron beam gun which consists of a filament emitter, a bias electrode, and a positively charged anode. The electrons are generated by thermionic emission from a filament. Their attraction to an anode gives them speed and direction, and a bias electrode cup surrounding the emitter electrostatically shapes ejected electrons into a beam. An electromagnetic lens system reconverges the beam once its left the anode and focusses it on the work piece (Horne, 1986).

Riveting

Riveted joints are usually in sheet metal parts where the rivets take a shearing load. Riveted joints may be in single, double, triple, or quadruple rows and either chain or zigzag (Horne, 1986).

Sealing/Bonding

Sealants, predominantly composed of polysulfide, are applied throughout the aerospace vehicle structure primarily to seal out moisture and contaminants. This helps prevent corrosion, particularly on faying (i.e., closely or tightly fitting) surfaces, inside holes and slots, and around installed fasteners. Sealants are also used to seal fuel tanks and pressurized components. They are applied using tubes, spatulas, brushes, rollers, or spray guns. Sealants are often stored frozen and thawed before use, and many are two-component mixtures that cure after mixing. Typically, a sealant is applied before assembly or fastener installation, and the excess is squeezed out or extruded from between the parts as the assembly is completed. This ensures a moisture-tight seal between the parts (EPA/OAQPS, 1997).

Adhesive bonding involves joining together two or more metal or nonmetal components. This process is typically performed when the joints being formed are essential to the structural integrity of the aerospace vehicle or component. Bonding surfaces are typically roughened mechanically or etched chemically to provide increased surface area for bonding and then treated chemically to provide a stable corrosion-resistant oxide layer. The surfaces are then thinly 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. The parts are joined together and cured either at ambient temperature, in an oven, or in an autoclave to cure the adhesive and provide a permanent bond between the components (EPA/OAQPS, 1997).

Nonstructural adhesives are used to bond materials that are not critical to the structural integrity of the aerospace vehicle or component, such as gaskets around windows and carpeting or to nonstructurally joined components. These adhesives are applied using tubes, brushes, and spray guns (EPA/OAQPS, 1997).

Testing

A wide variety of tests are performed by the aerospace industry to verify that parts meet manufacturing specifications. Leak tests are performed on assemblies such as wing fuel tanks. These parts are filled with an aqueous solution or a gas to check seams and seals. Dye penetrant is used following chemical milling and other operations to check for cracks, flaws, and fractures. Many different kinds of penetrants, fluids, dyes, and etchants can be applied to the surface of metal parts to aid in the detection of defects. Hydraulic and fuel system checks are other typical testing operations. Weight checks are performed to verify the balance of certain structures, such as propeller blades and vertical tail rudders. Some critical areas on the assembled components are checked for flaws, imperfections, and proper alignment of parts by X-ray (EPA/OAQPS, 1994).

III.C. Repair/Rework Operations

Repair operations generally include all conversions, overhauls, maintenance programs, major damage repairs, and minor equipment repairs. Although specific repair methods vary from job to job, many of the operations are identical to new construction operations. Repair operations, however, are typically on a smaller scale and are performed at a faster pace. Jobs can last anywhere from one day to over a year. Repair jobs often have severe time constraints requiring work to be completed as quickly as possible in order to get the aircraft, missile, or space vehicle back in service. In many cases, piping, ventilation, electrical, and other machinery are prefabricated prior to the major product's arrival. Typical maintenance and repair operations include:

- Cleaning and repainting the aircraft's surfaces, superstructure, and interior areas
- Major rebuilding and installation of equipment such as turbines, generators, etc.
- Systems overhauls, maintenance, and installation
- System replacement and new installation of systems such as navigational systems, combat systems, communication systems, etc.
- Propeller and rudder repairs, modification, and alignment (EPA/OECA, 1997)

The depainting operation involves the removal of coatings from the outer surface of the aircraft. The two basic types are chemical depainting and blast depainting. Methylene chloride is the most common chemical stripper solvent; however, the particular solvent used is highly dependent on the type of coating to be removed. 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 (dry ice), or high pressure water to remove coatings by physically abrading the coatings from the surface of the aircraft. Grit blasting and sand/glass blasting are also included in this category. High intensity ultraviolet light stripping has been developed for use in conjunction with carbon dioxide methods and is under development at several facilities (EPA/OAQPS, 1994). However, FAA has strict guidelines for safety and quality control purposes which dictate the types of solvents and materials that may be used in aerospace operations. Thus, any alternative must go through a comprehensive study before it is approved for use. *(See Section V- Pollution Prevention Opportunities)*

In addition, some larger facilities are capable of large repair and conversion projects that could include: converting passenger planes to cargo planes, replacing segments of an aircraft that has been damaged, structural reconfiguration and outfitting of combat systems, major remodeling of interiors or exteriors (EPA/OECA, 1997).

III.D. Space Vehicles and Guided Missiles

Many of the industrial processes involved in the production of space vehicles and guided missiles are similar to those discussed above in the production of aircraft parts and assembly. Because the number of establishments involved in the production of space vehicles, guided missiles, and their associated parts is less than 10 percent of the total industry, no additional information on industrial processes will be presented here. Also, due to the confidential nature of some of these products, there is little information available on production technologies.

III.E. Raw Materials Inputs and Pollution Outputs

The Aerospace Industries Association estimates that there are 15,000 to 30,000 different materials used in manufacturing, many of which may be potentially toxic, highly volatile, flammable, contain chloroflourocarbons, or contribute to global warming (AIA, 1994). Material inputs for aerospace manufacturing include metals, solvents, paints and coatings, and plastics, rubbers, and fabrics. Metals used in manufacturing include steel, aluminum, titanium, and many specialty alloys. There is also a wide variety of paints, solvents, and coatings available to the aerospace industry. Many of these materials are specifically required by FAA guidelines.

Pollutants from metal fabricating processes are dependant on the metal and machining techniques being used. Larger pieces of scrap metal are usually recovered and reintroduced to the process, while smaller shavings may be sent off-site for disposal or recovery.

Surface preparation operations generate wastes contaminated with solvents and/or metals depending on the type of cleaning operation. Degreasing operations may result in solvent-bearing wastewaters, air emissions, and materials in solid form. Chemical surface treatment operations can result in wastes containing metals. Alkaline, acid, mechanical, and abrasive cleaning methods can generate waste streams such as spent cleaning media, wastewaters, and rinse waters. Such wastes consist primarily of the metal complexes or particles, the cleaning compound, contaminants from the metal surface, and water. In many cases, chemical treatment operations are used in conjunction with organic solvent cleaning systems. As such, many of these wastes may be cross-contaminated with solvents (EPA/OECA, 1995).

Surface finishing and related washing operations account for a large volume of wastes associated with aerospace metal finishing. Metal plating and related waste account for the largest volumes of metal (e.g., cadmium, chromium, copper, lead, mercury, and nickel) and cyanide bearing wastes (EPA/OECA, 1995).

Air Emissions

Air emissions, primarily volatile organic compounds (VOCs), result mainly from the sealing, painting, depainting, bonding, finishing application processes including material storage, mixing, applications, drying, and cleaning. These emissions are composed mainly of organic solvents which are used as carriers for the paint or sealant and as chemical coating removers. Most aerospace coatings are solvent-based, which contain a mixture of organic solvents, many of which are VOC's. The most common VOC solvents used in coatings are trichloroethylene, 1,1,1-trichloroethane, toluene, xylene, methyl ethyl ketone, and methyl isobutyl ketone. The most common VOC solvent used for coating removal is methylene chloride. The VOC content ranges differ for the various coating categories. Air emissions from cleaning and degreasing operations may result through volatilization during storage, fugitive losses during use, and direct ventilation of fumes. Releases to the air from metal shaping processes contain products of combustion (such as fly ash, carbon, metallic dusts) and metals and abrasives (such as sand and metallic particulates).

Wastewater

Wastewater is produced by almost every stage of the manufacturing process. Metalworking fluids, used in machining and shaping metal parts, are a common source of wastewater contamination. Metalworking fluids can be petroleum-based, oil-water emulsions, or synthetic emulsions that are applied to either the tool or the metal being tooled to facilitate the shaping operation. Waste cooling waters can be contaminated with metalworking fluids (EPA/OECA, 1995).

Surface preparation, cleaning, and coating removal often involves the use of solvents which can also contribute to wastewater pollution. The nature of the waste will depend upon the specific cleaning application and manufacturing operation. Solvents may be rinsed into wash waters and/or spilled into floor drains (EPA/OECA, 1995).

Wastewater may also be generated in operations such as quenching and deburring. Such wastewater can be high in oil and suspended solids. Wastewater from metal casting and shaping mainly consists of cooling water and wet scrubber effluent. The scrubber water is typically highly alkaline (EPA/OECA, 1997).

Wastewater contaminated with paints and solvents may be generated during equipment cleaning operations; however, water is typically only used in cleaning water-based paints. Wastewater is also generated when water curtains (water wash spray booths) are used during painting. Wastewater from painting water curtains commonly contains organic pollutants as well as certain metals (EPA/OECA, 1997).

Electroplating operations can result in solid and liquid waste streams that contain toxic constituents. Aqueous wastes result from work piece rinses and process cleanup waters. In addition to these wastes, spent process solutions and quench baths are discarded periodically when the concentrations of contaminants inhibit proper function of the solution or bath. When discarded, process baths usually consist of solid-phase and liquid-phase wastes that may contain high concentrations of toxic constituents, especially cyanide. Rinse water from the electroplating process may contain zinc, lead, cadmium, or chromium (EPA/OECA, 1995).

Solid/Hazardous/Residual Waste

Solid, hazardous, and residual wastes generated during aerospace manufacturing include contaminated metalworking fluids, scrap metal, waste containers, and spent equipment or materials. Scrap metal is produced by metal shaping operations and may consist of metal removed from the original piece (e.g., steel or aluminum). Scrap may be reintroduced into the process as a feedstock or recycled off-site.

Various solid and liquid wastes, including waste solvents, blast media, paint chips, and spent equipment may be generated throughout painting and depainting operations. These solid and liquid wastes are usually the result of the following operations:

- Paint applications- paint overspray caught by emissions control devices (e.g., paint booth collection systems, ventilation filters, etc.)
- Depainting- spent blast media, chips, and paint and solvent sludges
- Cleanup operations- cleaning of equipment and paint booth area
- Disposal- discarding of leftover and unused paint as well as containers used to hold paints, paint materials, and overspray

Solvents are also used during cleanup processes to clean spray equipment between color changes, and to clean portions of the spray booth. The solvent utilized during cleaning is generally referred as "purge solvent" and is often composed of a mixture of dimethyl-benzene, 2-propanone (acetone), 4-methyl-2-pentanone, butyl ester acetic acid, light aromatic solvent naphtha, ethyl benzene, hydrotreated heavy naphtha, 2-butanone, toluene, and 1-butanol (EPA/OECA, 1995).

Metalworking fluids typically become contaminated and spent with extended use and reuse. When disposed, these oils may contain toxics, including metals (cadmium, chromium, and lead), and therefore must be tested to determine if they are considered a RCRA hazardous waste. Many fluids may contain chemical additives such as chlorine, sulfur, phosphorous compounds, phenols, cresols, and alkalines. In the past, such oils have commonly been mixed with used cleaning fluids and solvents (including chlorinated solvents) (EPA/OECA, 1995).

If metal coating operations use large quantities of molding sand, spent sand may be generated. The largest waste by volume from metal casting operations is waste sand. Other residual wastes may include dust from dust collection systems, slag, and off-spec products. Dust collected in baghouses may include zinc, lead, nickel, cadmium, and chromium. Slag is a glassy mass composed of metal oxides from the melting process, melted refractories, sand, and other materials (EPA/OECA, 1997).

Centralized wastewater treatment systems are common and can result in solid-phase wastewater treatment sludges. Any solid wastes (e.g., wastewater treatment sludges, still bottoms, cleaning tank residues, machining fluid residues, etc.) generated by the manufacturing process may also be contaminated with solvents (EPA/OECA, 1995).

Table 6 summarizes the material inputs and pollutant outputs from the various aerospace manufacturing operations.

Table 6: Material Input and Pollutant Outputs

Process	Material Input	Air Emissions	Wastewater	Solid/Hazardous/ Residual Wastes
Metal Shaping	Cutting oils, degreasing and cleaning solvents, acids, metals	Solvent wastes (e.g., 1,1,1-trichloroethane, acetone, xylene, toluene, etc.)	Acid/alkaline wastes (e.g., hydrochloric, sulfuric, and nitric acids), waste coolant water with oils, grease, and metals	Scrap metal, waste solvents
Grinding/ Polishing	Metals, abrasive materials, machining oils	Metal shavings/ particulates, dust from abrasive materials	Wastewaters with oil, grease, and metal from machining	Abrasive waste (e.g., aluminum oxide, silica, metal), metal shavings, dust
Plating	Acid/alkaline solutions, metal bearing and cyanide bearing solutions	Volatized solvents and cleaners	Waste rinse water containing acids/alkalines cyanides, and solvents	Metal wastes, solvent wastes, filter sludges (silica, carbides) wasted plating material (copper, chromium, and cadmium)
Painting	Solvent based or water based paints	Paint overspray, solvents	Cleaning water containing paint and stripping solutions	Waste paint, empty containers, spent paint application equipment
Cleaning, depainting, and vapor degreasing	Acid/alkaline cleaners and solvents	Solvent wastes, acid aerosols, paint chips and particulates	Wastewater containing acids/alkalines, spent solvents	Spent solvents, paint/solvent sludges, equipment and abrasive materials, paint chips

Source*: Pollution Prevention Assessment for a Manufacturer of Aircraft Landing Gear*, EPA, August 1995 and *Guides to Pollution Prevention, The Fabricated Metal Products Industry*, EPA, July 1990.

III.F. Management of Chemicals in Wastestream

The Pollution Prevention Act of 1990 (PPA) requires facilities to report information about the management of Toxic Release Inventory (TRI) chemicals in waste and efforts made to eliminate or reduce those quantities. These data have been collected annually in Section 8 of the TRI reporting Form R beginning with the 1991 reporting year. The data summarized below cover the years 1994-1997 and are meant to provide a basic understanding of the quantities of waste handled by the industry, the methods typically used to manage this waste, and recent trends in these methods. TRI waste management data can be used to assess trends in source reduction within individual industries and facilities, and for specific TRI chemicals. This information could then be used as a tool in identifying opportunities for pollution prevention and compliance assistance activities.

While the quantities reported for 1995 and 1996 are estimates of quantities already managed, the quantities listed by facilities for 1997 and 1998 are projections only. The PPA requires these projections to encourage facilities to consider future source reduction, not to establish any mandatory limits. Future-year estimates are not commitments that facilities reporting under TRI are required to meet

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Table 7 shows that the TRI reporting aerospace facilities managed about 37 million pounds of production related wastes (total quantity of TRI chemicals in the waste from routine production operations in column B) in 1996. Production related wastes were projected to continue to decrease slightly in 1997 and 1998. Note that the effects of production increases and decreases on the quantities of wastes generated are not evaluated here, but production has generally been increasing in recent years.

In 1995, about 34 percent of the industry's TRI wastes were managed on-site through recycling, energy recovery, or treatment as shown in columns C, D, and E, respectively. This decreased to 25 percent in 1996 and was expected to slightly increase to over 30 percent in 1998. The majority of these on-site managed wastes were recycled on-site in 1995. About 39 percent of the industry's TRI wastes were transferred off-site for recycling, energy recovery, or treatment as shown in columns F, G, and H. This increased to 50 percent in 1996. Most of the off-site managed wastes were recycled as well. The remaining portion of the production related wastes, shown in column I, (31 percent in 1995 and 27 percent in 1996) is either released to the environment through direct discharges to air, land, water, and underground injection, or is transferred off-site for disposal.

Table 7: Source Reduction and Recycling Activity for Aerospace Manufacturers Facilities (SICs 372 or 376) as Reported within TRI

A	B	On-Site			Off-Site			I
		C	D	E	F	G	H	
Year	Quantity of Production-Related Waste (10^6 lbs.)[a]	% Recycled	% Energy Recovery	% Treated	% Recycled	% Energy Recovery	% Treated	% Released and Disposed[c] Off-site
1995	40.6	22%	0%	12%	26%	3%	10%	31%
1996	36.5	14%	0%	11%	36%	4%	10%	27%
1997	35.2	14%	0%	12%	36%	4%	10%	24%
1998	33.3	19%	0%	12%	33%	3%	10%	21%

Source: *1996 Toxics Release Inventory Database.*

[a] Within this industry sector, non-production related waste < 1% of production related wastes for 1995.

[b] Total TRI transfers and releases as reported in Section 5 and 6 of Form R as a percentage of production related wastes.

[c] Percentage of production related waste released to the environment and transferred off-site for disposal.