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A COMPARATIVE ANALYSIS OF TWO ALTERNATIVES TO CHEMICAL AIRCRAFT PAINT STRIPPING

THESIS

GEORGE P. JOYCE II, First Lieutenant, USAF

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Presented to the Faculty of the School of Engineering

Air Education and Training Command

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in

Engineering and Environmental Management

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December, 1996

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George P. Joyce II

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Abstract

The Air Force must periodically strip and paint its aircraft to prevent the damaging effects of corrosion. The paint removal process typically involves the use of toxic chemicals such as methylene chloride which are soon to be banned as a result of impending environmental regulations and increased costs associated with handling and disposing of such material. The Air Force must choose an alternative to methylene chloride chemical stripping which complies with environmental regulations and reduces costs.

This thesis compares the life cycle costs and environmental impacts of two alternatives to chemical aircraft stripping. Plastic Media Blasting (PMB) and Modified Medium Pressure Water (MPW) are compared based on stripping a C-130 aircraft by the PMB process at the Lockheed Aircraft Service Center in Ontario, CA and the MPW process by Warner-Robins AFB, GA. The results of the study indicate that MPW has the lower life cycle costs.

A COMPARATIVE ANALYSIS OF TWO ALTERNATIVES TO CHEMICAL AIRCRAFT PAINT STRIPPING

I. Introduction

Background

All aircraft in the USAF inventory are coated with a protective paint system. The paint system is a vital component of the aircraft providing corrosion control, surface protection, aesthetics, identification and prevention from visual and electronic detection (Alford,1994:6). Unfortunately aircraft paint has a limited lifetime and must be periodically stripped and repainted in order to maintain its original characteristics.

The paint removal process occurs periodically at scheduled maintenance intervals at which times the aircraft are removed from service and inspected to identify possible structural problems caused by corrosion and/or fatigue. To facilitate the inspection process, the paint systems must be completely removed (Davis,1991:1). The paint removal process normally occurs every 4 to 7 years depending on the aircraft and the paint systems. This process, commonly referred to as depainting, has developed into a highly technological field in order to compensate for the improved durable paint systems now in use.

The Air Force spends approximately $1 billion a year on aircraft corrosion control in order to ensure the longevity of its aircraft. Corrosion is the principal element that decreases an airframe's durability by weakening the primary and secondary structural members. Corrosion is the conversion of a metal into a metal compound by a reaction between the metal and some substance in its environment (Brown,1994:124). The reactants in the environment which have a tendency to accelerate the corrosion process are atmospheric impurities such as dust or pollution, high humidity, and/ or direct contact with salt water. This can be prevented through proper maintenance activities such as periodic washing and protective painting (Then,1989:3).

In order to prevent corrosion from occurring on its aircraft, the Air Force has traditionally used methylene chloride based chemical strippers as its primary method of paint removal. Chemical paint stripping methods have been used since World War II. It was not until the early 1970's that the wastes from paint stripping were determined to be an environmental problem. This knowledge brought with it legislation in the form of environmental regulations which placed restrictions on the use and disposal of chemical methods and resulted in increased stripping costs (Weissling et al,1996:6). Methylene chloride and phenols are components of paint strippers which are regulated.

Paint stripping operations involving the use of traditional chemicals such as methylene chloride are a concern due to their deleterious effects on the environment and health of the workers using these toxic chemicals. These chemicals are stringently regulated under several environmental regulations. The application of these chemicals release volatile organic compounds (VOCs) and hazardous air pollutants(HAPs) into the atmosphere which must be contained through proper ventilation or filtering systems (Thomas,1996:3-3).

With the advent of increasing environmental awareness, the coating removal industry was forever changed. Environmental regulations placed a tremendous burden on the industry in the form of new health standards, air emission and disposal restrictions and increasing disposal costs. Chemical stripping using methylene chloride and phenols will no longer be permissible in the near future. This has forced the Air Force to evaluate alternatives which will be in compliance with future environmental legislation.

Statement of Problem

Aircraft in the Air Force's inventory must be periodically stripped of its paint for corrosion control. This amounts to around 600 aircraft in the inventory per year (Weissling et al,1996:7). The removal of paint from this number of aircraft with the use of toxic chemicals generates large volumes of hazardous waste which has grown to be very costly for the Air Force. This paint removal process is accomplished at five Air Logistic Centers (ALCs) located in various locations throughout the United States. The five Air Logistic Centers are Hill AFB, UT, Kelly AFB, TX, McClellan AFB, CA, Tinker AFB, OK, and Warner-Robins AFB, GA. Approximately 70 percent of the Air Force's hazardous wastes are generated from these five bases (Maiorano et al,1990:16).

The paint removal process is normally conducted at the ALCs with the use of methylene chloride based chemical strippers which will virtually be eliminated from use as a result of impending environmental regulations. The Air Force must find new means to remove paint from aircraft without the use of standard chemical strippers such as methylene chloride. A number of technologies have evolved as an alternative to chemical stripping. Each of the five ALCs is experimenting with several different technologies in an attempt to determine which is a suitable alternative to meet their aircraft paint removal requirements. The five Air Logistic Centers where most aircraft depainting and painting is done have not worked in concert with one another over the years in the development of new stripping technologies. As a result, several different paint removal technologies have been tested and implemented at various locations.

This has lead to the development of a program called the Coatings Technology Integration Office (CTIO) initiated by the Air Force through Wright Laboratories, OH. The CTIO has brought new direction to the ALCs and is compiling information about the different processes being used in the Air Force and industry. In addition, the CTIO is conducting its own studies in hopes of determining the optimum paint removal technology for the Air Force. The choice of paint removal technologies is a significant problem for the Air Force because of the associated budgetary and environmental implications.

Research Objective

The research objective of this study will be to aid the CTIO and the ALCs in deciding between alternatives to chemical stripping. This study will analyze two paint removal technologies and compare them based on their life cycle costs and environmental compliance. The two technologies which will be compared are plastic media blasting (PMB) and modified medium pressure water (MPW).

Investigative Questions

This study will attempt to answer the following questions as part of its research objectives.

1. With regard to stripping paint from a C-130 (the assumed base case for the analysis), how do the life cycle costs of modified medium pressure water compare to those of plastic media blasting?

2. Which categories of costs are potentially capable of reversing the choice of the optimal alternative?

3. Does modified medium pressure water have any less impact on the environment than PMB?

Thesis Overview

In chapter two, chemical stripping, plastic media blasting and modified medium pressure water are described with regard to their stripping process, facility requirements, and environmental compliance. Chapter three discusses the methodology which will be used to answer the investigative questions. Life cycle cost analysis will be discussed along with the cost breakdown structure. The Cost Comparison Model (CCM) used to calculate life cycle costs will be described along with its application to the problem. The results of applying the CCM will also be discussed in chapter three. In chapter four conclusions will be drawn from the results discussed in chapter three and areas of future research will be recommended.

II. Background

Chapter Overview

This chapter describes three paint removal methods which are currently being utilized by the Unites States Air Force. These methods are: chemical stripping, plastic media blasting (PMB), and modified medium pressure water (MPW). The paint stripping process, facility requirements, and environmental aspects are discussed for each.

Chemical Paint Stripping

Chemical paint stripping has been used by the military since the 1940's. Methylene chloride based chemical strippers are the most common. These strippers have been extremely effective in removing the enamels, lacquers, and acrylics on military and commercial aircraft. Starting in the early 1970s, the military began using polyurethane, epoxy, and flouropolymer paint coatings. These high performance coatings were developed to provide improved corrosion resistance, erosion resistance, and thermal protection. They were formulated to have; superior toughness and adhesion, to afford a life expectancy of five to seven years, and to be chemical and wear resistant. These characteristics worked against the very nature of the chemical stripping process and made existing methylene chloride strippers ineffective (Alford,1994:8-9).

In response to the improved coating systems the chemical industry added activators to the methylene chloride based strippers. These activators were added to enhance removal effectiveness and consisted primarily of phenols, cresylic acids or amines. The new strippers were not as effective in removing the high performance coatings as they were in removing the coatings of the past. Increased removal times often resulted from multiple cycles of labor intensive mechanical agitation in order to completely remove the new coating systems (Alford,1994:9).

Chemical Paint Stripping Process. The chemical stripping process is simple. The aircraft is first washed to remove any contaminants such as oil or grease on its surface. Next, the parts of the aircraft not requiring stripping are removed or masked with aluminum tape to prevent any stripper ingress. The chemical stripper is then applied to the surface of the aircraft by spraying or by brushing on the painted surface. The chemical is then left for a period of time (dwell time) ranging anywhere from 15 minutes to one hour. This provides sufficient time for the stripper to react with the paint by breaking the bond between the paint and the substrate. The softened paint and excess solvent is removed using hard rubber scrapers, followed by a water rinse to remove any residual paint and solvent. This process is repeated until the chemical stripper can no longer remove paint any further. The masking is then removed after the chemical stripping process is complete. Manual scraping with wire brushes or sandpaper is used to remove any remaining paint not removed by the chemical or under the masked areas requiring stripping (Then,1989:11,Alford,1994:15).

Chemical Facilities and Equipment. The chemical stripping facility has several requirements that it must meet in order to be a safe and productive working environment. The facility must be able to maintain an ambient air temperature of 50 degrees F to 100 degrees F. This temperature must be maintained in order for the chemical strippers to react with the organic coating systems. An appropriate ventilation system is needed to protect personnel from paint stripping fumes. The facility itself must be large enough to accommodate the largest aircraft to be stripped. It basically requires a minimum of ten feet from the aircraft tail and wings to the facility walls and six feet from the ceiling to top of aircraft (Jenkins,1995:10). Air compressors are required if spraying equipment is used to apply stripping chemicals to aircraft surface. Some form of equipment such as mobile scaffolding is needed to provide workers access to all exterior surfaces of the aircraft being depainted. Finally, the facility must meet all the safety, health promotion, and environmental requirements specified in Technical Order 42A-1-1 (Alford,1994:14).

Like all "wet" facilities a chemical stripping facility must have a sloped floor to a drain. This facility needs special sludge handling equipment and a waste water treatment system to handle the high volume of hazardous aqueous waste. It must also have space available for storage and disposal of liquid and solid hazardous waste. The environmental implications of this process have resulted in increasingly stringent regulations and rising treatment and disposal costs for the wastes generated.

Environmental Aspects. The traditional methylene chloride based chemical stripping process has emissions which impact the air, land, and water. Methylene chloride is the second largest toxic emission source, representing 40% of the total hazardous air pollutants (HAPs) from aerospace industry operations (Defense Environment Alert,1993:9). The chemical stripping process also generates large volumes of hazardous waste which must be treated, handled, transported, and disposed. The rinse water associated with the chemical stripping process requires treatment as a hazardous waste and taxes industrial wastewater treatment plants (Alford,1994:9).

Because of the enormous quantities of volatile organic compounds (VOCs) and hazardous wastes generated by the aerospace industry, numerous laws and regulations governing the generation, handling, storage, transportation and disposal of such hazardous waste have been enacted over the last 25 years (Alford,1994:9). These laws and regulations will eliminate the future use of methylene chloride in aircraft stripping operations. The main federal regulations influencing the replacement of methylene chloride chemical strippers and the transition to greener technologies are the Resource Conservation and Recovery Act (RCRA) in 1976, the Right to Know provisions of the Superfund Amendment and Reauthorization Act (SARA) in 1988, the Clean Air Act Amendments of 1990 (CAAA), the Pollution Prevention Act of 1990, and the National Emissions Standards for Hazardous Air Pollutants (NESHAP) in 1995. These regulations will be discussed in the context of the five reasons for replacing methylene chloride. These five reasons are increasing hazardous waste disposal liability and expense, reporting requirements, personnel health and safety, pollution prevention and hazardous air pollutants.

Table 1
Chronology of Major Federal Regulations Influencing the Replacement of Methylene Chloride (MC) Chemical Strippers

Federal Regulations	**Year Enacted**	**Relationship to Depainting Operations**
Resource Conservation and Recovery Act (RCRA)	1976, 1984 amendments	Governs treatment and disposal of hazardous waste, attaches "cradle to grave" liability, mandatory reductions in hazardous waste
Superfund Amendment and Reauthorization Act (SARA)	1988	Established reporting requirements for toxic chemical generators and users (TRI) encouraging waste minimization
Clean Air Act Amendments (CAAA)	1990	Major sources required to adopt a MACT for HAPs
Pollution Prevention Act	1990	Stressed source reduction and recycling whenever possible
National Emission Standards for Hazardous Air Pollutants (NESHAP)	1995	Will force reduction in air emissions of MC to the point of virtual elimination in Nov 1997

Hazardous Waste Disposal Expense. Hazardous waste generation is a major disadvantage of chemical paint stripping activities which has motivated its replacement. The 1984 amendments to the Resource Conservation and Recovery Act (RCRA) mandated that hazardous waste generators establish programs to reduce, volume, quantity, and toxicity of their hazardous wastes. The DOD took this a step further and called for a 50 percent reduction in hazardous waste generation from by 1992 based upon 1985 levels. Depainting operations were targeted since they were a major contributor at AFMC's five Air Logistic Centers where 70 percent of the Air Force's hazardous waste is generated (Maiorano,1990:16).

Currently RCRA regulations do not allow land disposal for methylene chloride. This chemical stripping waste must be treated before disposal. Incineration/thermal destruction is the most proven, straightforward treatment option (Evanoff,1990:60). Waste management and disposal incineration costs for chemical stripper wastes range anywhere from $750-$1200 per 55 gallon drum. These costs typically represent a significant percentage of the total process costs (Alford,1994:21-22). Not only does RCRA make it expensive to treat and dispose of the waste but it attaches liability for this product from "cradle to grave."

Reporting Requirements. Title III of SARA established reporting requirements in 1988 for manufacturing facilities with emissions of 300 different types of chemicals. Toxic chemical release reporting is commonly referred to as the Toxic Release Inventory (TRI). The regulation requires annual data on direct chemical releases to all environmental media. Facilities that manufacture or process more than 25,000 pounds or use more than 10,000 pounds of a chemical on the TRI list must report (EPA,1994:41).

The effort required to track and report chemicals on the TRI is significant. For this reason there is incentive to reduce emissions or usage of those particular chemicals on the TRI (which includes methylene chloride). Reducing chemical use below threshold limits exempts facilities from filing a report (EPA,1994:41).

In addition to this, the TRI data is the primary tool for tracking voluntary reduction of the 17 priority toxic chemicals identified in the EPA's 33/50 Program of voluntary reductions. Dichloromethane or methylene chloride is one of the 17 chemicals chosen because of its large production volume, opportunities for pollution prevention, and serious health and environmental risks. The program encourages voluntary reductions in releases of these chemicals. The EPA set a goal of 33% reduction by 1992 and 50% reduction by 1995 (The Hazardous Waste Consultant,1995:1.16).

Personnel Health and Safety. Personnel health and safety is yet another concern which has forced the replacement of methylene chloride chemical stripping. Workers in chemical paint stripping facilities are regularly exposed to occupational hazards associated with the significant volumes of hazardous wastes generated in this process. The USEPA, CPSC, FDA and.NIOSH have classified methylene chloride as a potential occupational carcinogen (Niemeier,1992:1). Exposure to the stripping materials and waste through inhalation, ingestion or skin contact can have serious health affects. Recent research findings suggest that methylene chloride can be toxic to the central nervous system at concentrations much lower than previously suspected (Niemeir,1992:5). This has prompted the NIOSH to recommend the permissible exposure limit be reduced to the lowest feasible limit of 1 ppm (Lemen,1987:1). This trend is also creating health and safety standards for personnel that will make it more difficult and expensive to continue the use of methylene chloride.

Pollution Prevention. The change in ethic from end of pipe solutions to preventing pollution from occurring at the source has prompted action by the Air Force to replace methylene chloride chemical strippers. The answer to all the problems associated with the use of methylene chloride can be solved through pollution prevention. Instead of attempting to control the hazardous wastes and emissions it may well be more cost-effective to minimize or eliminate them from being generated in the first place. This possibility offers an important justification for pollution prevention policies.

The Pollution Prevention Act of 1990 emphasizes that the preferred method of preventing pollution is to reduce, at the source, the volume of generated wastes and that reuse should be performed whenever possible. Air Force Directive 19-4 went a step further by making a commitment to "...prevent at the source, to the greatest extent possible, environmentally harmful discharges to the air, land, surface water, and ground water" (Haas,1995:327). Source reduction is the optimum means of preventing pollution. Source reduction can be accomplished through technological change or process substitution and it is the avenue which the Air Force has chosen to pursue.

Hazardous Air Pollutants. The US Environmental Protection Agency plans on eliminating methylene chloride from aerospace paint stripping operations by November of 1997 (Alford,1994:21). The EPA has placed stringent requirements on the use of methylene chloride through the enactment of a NESHAP (National Emissions Standard for Hazardous Air Pollutants) in September of 1995. This standard created a MACT (Maximum Achievable Control Technology) Standard to control both organic and inorganic hazardous air pollutant (HAP) emissions in depainting operations. NESHAP has its roots in the Clean Air Act Amendments of 1990 which required that major sources adopt a MACT for 189 HAPs (EPA,1994:41). The NESHAP standard addresses primarily the outer surfaces of the aircraft and does not apply to parts normally removed from the aircraft for depainting. Other exemptions to the NESHAP requirements include facilities depainting less than six complete aircraft annually, mechanical and hand sanding operations, and the use of HAP-containing strippers for spot stripping and decal removal up to 50 gallons per military aircraft (40 CFR 63.746(a)(b)).

Those facilities still using organic HAP chemical strippers after November 1997 can do so only if controls are used. If organic HAP controls existed before the effective date of the regulation, (1 September 1995) it must be able to reduce emissions to the atmosphere by 81% or greater relative to what it generated in its base year. If no organic HAP controls existed then compliance can be achieved by using chemical strippers containing no organic HAP or by using some nonchemical depainting technique. Otherwise pollution control technology installed after the effective date of the regulation must have a removal efficiency of 95% or greater (Thomas,1996:2-18). This requirement has forced the depainting industry to abandon methylene chloride chemical strippers and replace them with alternative technologies more compatible with the environment (Bradley,1995:44).

Plastic Media Blasting

In the Air Force's and Department of Defense's pursuit of an environmentally acceptable substitute for chemical stripping, Plastic Media Blasting was developed. This process was first used by the Air Force in 1980 when it started experimenting with several methods including laser beams and air pressure blasting of painted metal and composite surfaces with various materials such as sand, glass, dry ice (carbon dioxide), and plastic media. The plastic material proved to be most effective of the materials evaluated in the study conducted at Hill Air Force Base. This led to an extended development effort which was established with plastic media blasting as part of Hill Air Force Base's PRAM (productivity, reliability, availability, maintainability) program in 1983 (Parrish,1987:64).

The PRAM project acquired PMB equipment, trained personnel for its use and developed operational parameters. Plastic media blasting was determined to meet Air Force requirements for stripping the F-4 aircraft and the first F-4 aircraft was ready for production PMB paint removal in July 1984 (Byers,1986:1-2). Today PMB is the most mature alternative stripping technology used by the Air Force. Currently, the PMB depainting process is the most widely used depainting method constituting 32 percent of the total surface area stripped for aircraft in the Air Force (Weissling et al,1995:8).

The Plastic Media Blasting Process. Plastic media blasting is very similar to the general sand blasting process where a high velocity stream of air propels granules of a hard substance against a surface to be stripped. Instead of sand, PMB utilizes small, softer and less aggressive inert plastic beads in its process. The plastic media are not actually beads but rather fragmented particles with irregular sharpened edges. The sharpened edges serve as an abrasive to break and dislodge paint coatings from the aircraft substrate. The plastic beads are softer than the aircraft substrate to afford paint removal but prevent substrate damage (Parrish,1987:64).

The process steps for PMB are very similar to those used in chemical stripping. The aircraft must first be washed to remove any grease or other foreign material from the surface. This is in turn followed by masking the areas of the aircraft which are not designated to be stripped along with preventing ingress of the plastic media into doorways and other similar crevices on the aircraft. After the aircraft has been properly prepared it is now ready for the stripping process.

The plastic media is delivered by a high velocity stream of air. In the stripping process, different blasting parameters are used to remove various types and thicknesses of paint as well as different types and thicknesses of substrate. Different pressure, velocity, distance from surface, angle of spray and dwell time (amount of time spent stripping a particular area) are used by personnel operating the manual blasting equipment (Alford et al,1994:24).

The two types of blasting equipment commonly used in the PMB process are direct pressure or suction designs. In the direct pressure blast equipment, the plastic media are stored in a pressurized container that directs the media through a hose and out the blast nozzle. In the suction design, compressed air is allowed to expand at the blast nozzle creating a suction effect. This suction effect pulls the plastic media form a storage receptacle through a hose and out the blast nozzle ("Plastic...,"1986:7-21). The paint is removed with varying strip rates depending on the aircraft and coating system. Lockheed has reported stripping rates of 2.5 to 3.0 sqft/min for the C-130 aircraft as an example (Koons,1996).

Plastic media, when propelled against the painted surface, breaks down and fragments into smaller pieces creating a plastic dust. A majority of the plastic beads are recycled for further use, but a fraction of the smallest particles are discarded along with the removed paint chips. A floor recovery system which is either mechanical or pneumatic, recovers the plastic media where they are sized and separated. During the separation process, the system distinguishes foreign particles such as dirt or paint chips from the reusable beads and discards the foreign material along with the smaller unusable beads. The larger beads are cleaned by the system and reinserted in the blasting equipment for another cycle. Manufacturers have estimated that between 90% to 95% of the plastic beads can be reclaimed after each use, and the beads can be reused between 10 to 20 times before they become too small for reclamation. A dust collection system, vital to PMB operations, extracts dust from the reclamation system where the spent beads are separated by size. It also removes dust in the blasting facility by circulating ventilated air through a filtering system ("Plastic...,"1986:22-30).

Once the PMB process is complete, any dust and other residue generated from the stripping operations must be removed from the surface of the aircraft. The masking is then removed from the aircraft and the areas that were covered must be manually sanded to remove remaining paint. The aircraft is then washed a final time to remove any remaining residue. The aircraft receives an etch coat followed by a conversion coat to renew the surface to pre-blast character for post-stripping inspections or for the application of new coating systems (Alford et al,1994:25). The steps to the entire PMB process are listed in greater detail in Air Force Technical Order 1-1-8.

<u>PMB Facility and Equipment</u>. Plastic media blasting requires a dedicated facility of its own for aircraft paint removal processes. This involves a high investment cost for system implementation. The facility itself must be large enough to house the entire aircraft and PMB equipment. Minimum clearances on each side of the aircraft are ten feet and six feet of clearance from the top of the aircraft to any ceiling obstructions (Bouillon et al,1995:10). This will allow ample space to conduct plastic media blasting

operations. The facility must be properly sealed to contain the dust generated from PMB operations and be equipped with a ventilation system capable of removing the spent plastic dust from the blast facility. This type of equipment is mandatory under the NESHAP regulation for the aerospace industry, "any air stream removed from the enclosed area must be passed through a dry particulate filter system, baghouse, or waterwash system before exhausting it to the atmosphere" (Thomas et al,1996:2-19).

The PMB facility must contain air compressors to supply the blasting equipment. The blasting equipment comes in two designs which are direct pressure and suction. This equipment consists of the blast pot and storage hopper, the media metering system, and media delivery system. The delivery system consists of various sized nozzles (Alford et al,1994:26-27). This equipment is operated manually by personnel and must be used in conjunction with scaffolding or some other means to afford access to all areas of the aircraft.

A floor recovery system must also be part of the facility design. Plastic media blasting would be much more costly without a system to reuse the plastic media. After the beads are recovered they must be put through some type of separator system to segregate the large beads from the fines and foreign material. Various media recycling designs are used such as a cyclone separator, rotary valve, vibrating screen, and magnetic separator (Alford et al,1994:26).

Finally, the means by which the aircraft is stripped is due in part to the hardness of the media. Plastic media comes basically in six types varying in hardness and specific gravity. Type II plastic media was used extensively in the aircraft industry until its more recent replacement with Type V. Type V is an acrylic or thermoplastic compound. It is softer than Type II but remains aggressive enough to remove most coating systems without damage to most substrates (Alford et al,1994:27-30).

Environmental Aspects of PMB. Plastic media blasting offers many advantages to traditional chemical stripping with methylene chloride or phenol based stripping agents. PMB eliminates the voluminous amounts of hazardous waste and toxic emissions associated with chemical stripping. From a pollution prevention standpoint, PMB has made a significant decrease in the environmental risks associated with depainting operations. It does however have environmental concerns of its own which need to be addressed.

The PMB process generates wastes that consist of the plastic media contaminated with particles of paint along with larger chips of paint themselves. The spent plastic bead residue is deemed a hazardous waste because of the heavy metal content in the paint such as chromium, lead and cadmium (Runnion et al,1995:1). These wastes are regulated under RCRA and thus the waste must be properly managed and disposed. Wastes are minimized when the plastic media is separated from the stripping waste and the media is recycled or reused.

Fugitive dust is also a problem in PMB operations. The dust generated from PMB operations can be explosive and may include toxic constituents from contaminated media and from the paint removed. A ventilation system must be in place to keep concentrations safe in the facility and at the same time keep emissions from escaping the PMB facility. The recovered dust must be managed and disposed of as hazardous waste under RCRA (Alford et al,1994: 34).

Other air emission problems can result from the use of Methyl Ethyl Ketone (MEK) to remove Type V plastic media residues from the aircraft skin. This chemical solvent is one of the 17 chemicals targeted for elimination under the USEPA Industrial Toxics Project (33/50 program) and by Air Force HAZMAT reduction initiatives. Not only does MEK produce hazardous air pollutants it also generates RCRA regulated hazardous waste in the removal process of the Type V residue (Alford et al,1994:33).

PMB has done much to reduce the environmental risks associated with chemical stripping methods. Despite this improvement there are still hazards which exist to human health. The toxic hazards of exposure to paint and coatings residue are similar to chemical stripping. Dust and noise exposures also present health hazards in PMB but to a lesser degree than chemical paint stripping. Exposure to chemicals such as MEK may still exist in some operations. Visibility and blast stream effects are unique problems to PMB which also must be addressed (Alford et al,1994:33).

Modified Medium Pressure Water

In the search for an alternative to chemical paint stripping, modified medium pressure water paint stripping was developed. Water jet technology has been a traditional part of many industrial cleaning processes for years (Johnson,1995:337). This alternative paint removal process offers less impact on the environment and decreased health and safety risks. It has evolved from several variations of using water under pressure for coating removal.

Water jet technology is used as a cleaner, degreaser, cutting tool, and as a coating removal process for aircraft. There are many variations to this type of coating removal. Water pressure, nozzle types, stripping additives, and use in combination with chemical softeners are all variables in the water jet technology field. Modified medium pressure water blasting utilizes a water pressure of 15000 psi combined with a sodium bicarbonate ($NaHCO_3$) additive which improves the stripping effectiveness.

Medium pressure water alone has proved to be too slow and ineffective as a stripping process. Other variations such as high pressure water stripping use pressures ranging from 20,000 to 28,000 psi for aircraft organic coating removal (Foster,1995:1-3,4;Weissling,1995:10). Medium pressure water is also used in conjunction with chemical paint softeners which are applied prior to MPW stripping. AQUASTRIP is a commercial process owned by the German airline LUFTHANSA which uses paint softeners prior to blasting. The paint softeners are based on biodegradable solvents such as benzyl alcohol (Foster,1995:1-3). Benzyl Alcohol softeners however only work on some types of paints. The USAF examined this process and created a variation of its own (Gould,1994:24).

Modified medium pressure water is also commonly referred to as MPW with Bicarbonate of Soda Stripping (BOSS). Bicarbonate of Soda or sodium bicarbonate ($NaHCO_3$) is nothing more than baking soda. It has been used as an abrasive by itself in mechanical blasting processes but has been combined with medium pressure water to produce very positive results. BOSS systems operate at lower water pressures. MPW with BOSS differs in that the system operates using a higher water pressure, resulting in a much lower abrasive use rate (EPA,1994:31). The granular sodium bicarbonate is water soluble and acts as an abrasive in the stripping process increasing the effectiveness of MPW. The process is generally ineffective on aircraft depainting without the use of such a type of media unless pretreatment with softeners is used as mentioned previously (Weissling et al,1995:10).

MPW aircraft paint stripping process. This process is basically divided into three steps. There are pre-strip, strip, and post-strip activities which must be accomplished to attain a high quality product. In the pre-strip stage the aircraft must be prepared for the stripping process. This includes masking and identifying parts of the aircraft which are not suitable for blasting. MPW is a more gentle mechanical stripping process than most but still requires areas to be protected from substrate damage and to prevent media intrusion. Areas which require masking include acrylic windows, antennas, radomes, composite structures, thin skinned fuselage areas (less than 0.032 inch thick), and access panel doors on the aircraft as specified in Air Force Technical Order 1-1-8 (Cundiff,1994:3). A sealing putty is used to prevent intrusion of the blast media into narrow seams around all doors, hatches and storage compartments as well as to protect door gasket/seals from blast related damage. Areas underneath the masking and tape are stripped manually with an environmentally compliant chemical remover prior to masking operations (Cundiff,1994:4).

After the aircraft has been prepped, it is ready for the paint stripping operation. A hand held wand is moved at a rate of 4 inches per second or faster across the aircraft surface identified for stripping. The fan nozzle/wand is to be held no closer than two inches to the surface and the optimum impingement angle is 60 degrees. These requirements must be followed in order to prevent substrate damage and maintain stripping efficiency. These set of blast conditions are up to the primary operator to control (Cundiff,1994:5-8).

After completion of the stripping process the aircraft must be rinsed to remove all blast residue to prepare for proper paint adhesion. Hot water not exceeding 140 degrees Fahrenheit should be used if available. Otherwise tap water can be used but may require additional rinsing to remove all of the sodium bicarbonate and/or chemical residues. De-masking occurs where all barrier tape, masking materials, and sealing putty are removed. All covers and or crevices are opened and flushed of all blast media which may have been entrapped from the stripping process. Any partial disassembly occurs at this time to remove other ingressed media. Then a final wash is completed on the aircraft and it is inspected for any quality deficiencies before being sent to be repainted (Cundiff,1994:8-9).

MPW Equipment. The equipment and sodium bicarbonate media used in this process consists of a 15,000 psi, 3.2 gpm high-pressure water pump and a bicarbonate of soda ($NaCHCO_3$), or other abrasive, injection system with controls and other auxiliary equipment. A hand-held wand with various nozzle configurations is available for different functions. The fan nozzle is approved for the C-130 and C-141 aircraft. The mobile units are available in an electric model E25 or diesel-powered model (D-44) with towing capability. The electric model requires shop air and a potable water supply. The diesel model is self-contained except for water supply. Enhancements to the units provide a more precise feed and measuring system for the sodium bicarbonate and the upstream chemical injection and metering system (Cundiff,1994:10). A corrosion inhibitor is used in the chemical injection system to prevent the breakdown of sodium bicarbonate. The enhanced system (E-25M) is beneficial for aircraft stripping which require this type of precision on the media flow (Carolina Equipment & Supply 1996).

Facility Requirements. The major advantage to modified medium pressure water is the fact that it can be used in existing chemical stripping and washing bays that are equipped with waste water treatment facilities (Weissling et al,1995:41). At a minimum this technology requires a sloping floor to a drain. This drain must be connected to a system which can treat the water containing the sodium bicarbonate and paint residue which is deemed hazardous. This process produces a high volume of waste to treat because the paint chips (solid waste) contain hazardous materials. Utilities required in the facility include 30 scfm at 100 psi of compressed air, 6 GPM at 45 psi clean water, 70 amp service of 460 volt, and 40 cycle 3 phase electricity to operate all the MPW equipment (Aqua Miser,1996). The facility also requires scaffolding for access to the aircraft (Jenkins,1995:5).

Because existing facilities can be utilized for this process there are potentially significant savings in investment costs. Only the moderately expensive equipment for stripping needs to be purchased. This stripping equipment is mobile and thus offers some flexibility in how it can be used. Should a mission change or a depot close, this type of equipment could be moved elsewhere because it does not require a dedicated facility like Plastic Media Blasting operations require.

In a study by James Jenkins, Vice President of Bouillon Christofferson & Schairer Inc., he determined that modification work to existing facilities to support new processes or technologies such as MPW may be approximately 15 to 50 percent of the cost of a totally new facility. The potential for minimal expense for modification of existing facility works is a real possibility according to Jenkins. Hangar conversion costs for new stripping technologies ranged from forty-two dollars per square foot for a 34,000 sf hangar floor area to fifty-six dollars per square foot for a 55,000 sf hangar floor area (Jenkins,1995:12). Medium pressure water requires the minimum hangar clearance dimensions of ten feet from each point of the aircraft.

Stripping Effectiveness. Modified medium pressure water is a viable alternative to chemical stripping and plastic media blasting. This process has demonstrated strip rates of 1.1 to 1.5 ft^2/minute on laboratory-prepared test panels in a study performed by Battelle (Cundiff,1994:2). The same study also concluded that the MPW process was accomplished with none or minimal substrate degradation. A few exceptions were noted to the last statement but they were not deemed severe enough to warrant additional testing. Modified MPW paint stripping process was approved to replace chemical stripping of the C-130 and C-141 at Warner-Robins Air Force Base, Georgia.

The Battelle report also found that strip rates varied as a result of the individual operator(s) and the type/thickness/quality of the paint. Strip rates were generally in the 1 to 2 ft^2/minute range for epoxy and polysulfide primed aircraft (Cundiff,1994:5). It was also noted that significant cost savings and improved aircraft paint removal flow-through times could be achieved if the operation/maintenance techniques of the operators improved along with the reliability and maintenance of the MPW blasting equipment (Cundiff,1994:6).

Environmental Aspects. A pollution prevention benefit of medium pressure water blasting is that it eliminates the use of chemical strippers containing hazardous air pollutants (HAPs). This is an example of source reduction which is the optimum method of pollution prevention. Another benefit exists when compared to dry stripping is that a wet stripping process such as MPW does not generate dust (EPA,1994:31). However, this process is not without its own drawbacks.

Medium pressure water generates a large volume of wastewater containing paint debris. This water must then be collected and processed for reuse or treated for disposal. This water may also contain small quantities of alcohol or other similar organic solvents used in the stripping process.

Medium pressure water paint stripping also has a few potential environmental hazards to handle. The coating debris sludge remaining after wastewater treatment may be hazardous waste. This will make the process susceptible to RCRA legislation regarding the handling and disposal of hazardous materials. The toxicity of the coating and pigments being removed will determine the wastewater and residue disposal requirements. A system which will collect, filter and recycle stripping water containing the paint debris, abrasives, and alcohol softener must be in place in order for the MPW process to operate (EPA,1994:32).

Medium pressure water blasting is a compatible process for facilities with an existing wastewater treatment system in place. Wastewater can be processed and recycled during depainting operations decreasing the total wastewater volume needed to be absorbed by the existing treatment system. The only other emissions or wastes of concern for this process are some airborne particulates and noise. The airborne particulates are produced from the coating systems being removed during blasting operations. For this reason OSHA requires the use of respiratory equipment for personnel when operating the MPW equipment (EPA,1994:11).

III. Methodology

Chapter Overview

This chapter examines the life cycle costs (LCC) of plastic media blasting (PMB) and modified medium pressure water (MPW). The life cycle costs are broken down into four categories of costs which include research and development, investment, operating and support and disposal (Gill,1996:52). Operating costs will be directly compared using the Cost Comparison Model (CCM) adopted by the Air Force Coatings Technology Integration Office(CTIO) and developed by Randy Ivey of Warner-Robins AFB. A life cycle cost model is used incorporating data from the CCM and all other life cycle costs discussed in this chapter to determine the life cycle costs for both PMB and MPW. The method used to evaluate the environmental impact of each process will also be discussed.

Design of the Analysis

In order to conduct a more accurate comparison of the technologies a single aircraft was chosen upon which to base the analysis. Because the aircraft is the same, a direct comparison of costs can be made. The Lockheed C-130 Hercules is the designated aircraft in this analysis. The C-130 is presently being stripped by both PMB and MPW. It is stripped using PMB at the Lockheed Martin Aircraft Service located in Ontario, CA. They strip around 10 C-130s per year. The C-130 is also presently stripped using MPW at Warner-Robins AFB, GA where they strip around 30 C-130s per year.

For the purposes of this analysis, it will be assumed that minimal or no substrate damage occurs as a result of stripping with PMB or MPW. Tests performed by Battelle indicated no, or minimal substrate damage incurred as a result of stripping with MPW (Cundiff et al,1994:2). Type V PMB has also been found not to result in a significant decrease in the fatigue life of the substrate (Whitney et al,1995:11). This will eliminate any costs associated with a decreased lifetime or potential to damage the aircraft surface.

Methodology Procedure

Life Cycle Costs. Table 2 lists the categories of life cycle costs which pertain to aircraft paint removal. The life cycle costs of both plastic media blasting and modified medium pressure water are examined assuming 30 aircraft stripped annually. Thirty aircraft is a reasonable assumption based upon Warner-Robins AFB having stripped 30 of the 54 C-130s depainted by the Air Force in 1995.

TABLE 2
AIRCRAFT PAINT REMOVAL LIFE CYCLE COST CATEGORIES

Research and Development (R&D)
Investment
Stripping Units
Compressors
Recovery systems
Ventilation systems
Facilities
Operation and Support
Manpower
Materials
Operation and maintenance (O&M)
Waste disposal
Time out of Service
Disposal
Facilities

A discount rate of 2.8 percent and an equipment lifetime of fifteen years was used in the cost analysis as specified in Air Force Manual 65-506, 1 July 1995. This "real" discount rate represents the governments cost of borrowing minus the expected inflation rate, based on the interest rates on Treasury notes and bonds with maturities corresponding to the period of the analysis (Hosey,1996:WWWeb). Midyear, instead of end-of year discount factors are used which more closely approximate actual disbursement patterns of funds which are typically spent throughout the fiscal year as opposed to all being spent at the beginning or end (AFMAN 65-506,1995:7). For example the discount factor to find the present value of operating and support costs spent in the fifth year of operation would be calculated using the following formula: $(1/((1+R)^{\wedge}(N-.5)))$, where R equals the discount rate (0.028) and N is the period (5). This produces a discount factor equal to 0.8831.

Research and Development Costs. Research and Development costs are not included in this analysis because they are sunk costs. Sunk costs are expenditures which are irretrievable regardless of any present decision one makes. The research and development costs have already been incurred for both PMB and MPW.

Investment Costs. Both PMB and MPW have significant investment costs associated with each of their processes. These investment costs are fixed costs which do not change as a result of increases in process capacity. Both paint removal alternatives must purchase the blasting apparatus and compressors which are different for each process. PMB requires a floor recovery system to capture and recycle the plastic media. MPW also requires a recovery system capable of recycling and/or treating the waste water. PMB requires a ventilation system for its operations to contain the dust generated during the paint removal process. This piece of equipment is not required by MPW. These are the significant pieces of equipment which make up the investment costs for the two alternatives which will be evaluated.

The largest investment cost difference between the two processes are the facility costs. PMB requires either its own facility to be constructed or modifications to be made to an existing hangar if one is available and large enough to house the aircraft for paint removal activities. Lockheed converted Hangar 19 North at its Ontario plant into its current PMB facility for aircraft up to the size of the C-130 (Raffaele et al,1992:5). Modifications to the hangar for PMB implementation were approximately $200,000 (Pauli,1996). This cost will vary for other facilities depending on what currently exists in the hangar to support PMB operations. MPW is capable of being used in existing facilities that may have been formerly used for chemical stripping with minimal investment costs. MPW is essentially a drop-in replacement because the equipment is portable and requires no installation (Ivey,1996). This makes the investment costs for MPW typically less expensive than those required for PMB. This assumes that the shop air and electric utilities are of sufficient capacity to support the MPW equipment in the existing hangar.

Operating and Support Costs. The costs which are incurred annually to sustain paint removal operations are operating and support costs. These are variable costs which change depending on different process capacity, such as the number of aircraft stripped per year. Operating and support costs for PMB and MPW include manpower, materials, operation and maintenance, waste disposal, and time out of service. Shared materials for both alternatives include such things as masking, tape, sealing putty, water, soap, and etch and conversion coat chemicals. The materials which differ between the two alternatives are the blasting media. PMB requires a replenishment of plastic beads and MPW requires a replenishment of sodium bicarbonate and water. Operation and maintenance costs are those costs spent on maintaining the stripping equipment and facility. Waste disposal consists of properly disposing of plastic media and paint chips for PMB and paint chip sludge for MPW. These are all the explicit operating and support costs of significance to this cost analysis.

An implicit operating and support cost is the time out of service for the aircraft which is being stripped. There is an opportunity cost associated with the aircraft being out of service. This aircraft is no longer able to perform its usual duties. This results in a decrease in readiness for the particular unit missing the aircraft being stripped. The longer the aircraft is out of service obviously the greater the opportunity cost. The fraction of time each aircraft is taken out of service to be stripped over the years is comparable to having fewer aircraft at the Air Force's disposal. This implicit cost can be quantified by finding the uniform annual cost of the aircraft and multiplying by the number of days out of service for paint removal per year. This is demonstrated in the equation below:

Time out of service opportunity cost per aircraft	= % of time aircraft is out of service per year	X	Annualized Cost of aircraft

Figure 1. Time out of Service Equation

Disposal Costs. The equipment and facilities will both suffer economic depreciation over the period of the analysis. A straight-line depreciation method is used to estimate any residual value of the equipment or facility. The useful life of the equipment is assumed to be fifteen years which is equal to the period of the analysis. The equipment is depreciated at a rate of 1/15 of its value per year resulting in zero cost of disposal for the equipment. The useful life of the facility on the other hand is assumed to be thirty years. Therefore, if the depainting process is operated for 15 years one half of the value of the asset remains. To calculate this residual value, the cost of the facility is multiplied by one half and discounted by the real rate over the 15 years of operation to come up with its present value. The residual value of the facility is then subtracted from the total life cycle costs.

Use of Cost Comparison Model. Cost data for stripping the C-130 is inputted in the Cost Comparison Model for both

PMB and MPW as displayed in Appendix B. The model developed by Randy Ivey of Warner-Robins Air Force Base, GA was adopted by the Air Force Coatings Technology Integration Office. The cost model calculates the overall operating and support costs for stripping the C-130. Cost data inputs are placed in a spreadsheet which proceeds step-by-step through the paint removal process. It calculates the total manhours for all pre-strip, strip and post-strip operations. The model includes inputs for amounts of materials consumed in the operation to include preparation materials, stripping media, and post-strip chemicals. The actual flow time of the aircraft is determined as a function of the strip rate, number of workers and shifts per day. Flow time is the actual number of days the aircraft is out of service.

The operating and support costs can then be placed into a life cycle framework to determine which technology is most cost effective over the life cycle. The life cycle cost model is developed through the use of a spreadsheet which has the various life cycle costs broken down into the applicable life cycle cost categories of investment, operating and support and disposal. This model uses constant dollars and displays all costs in present value form over the 15 year period of the life cycle. The results of the data used in this analysis are compared to the results of the data originally developed at Warner-Robins Air Force Base by the Air Force in the CCM in Appendix C.

Data Collection

The data collection was obtained by two separate means. The cost data for MPW was taken from a report produced by Battelle for the Air Force in 1993. In this report, an economic analysis was conducted on data collected from 10 C-130 aircraft depainted by MPW. This MPW depainting process was observed at Warner-Robins AFB, GA. Battelle observed the process for six months in its prototype stage before full production as it is currently utilized (Stropki et al,1994:2).

The cost data collected for PMB was obtained through the use of a survey instrument (Appendix A). This survey solicited cost parameters associated with the PMB process at Lockheed Martin Aircraft Service in Ontario, CA. The survey was developed from the input parameters of the Cost Comparison Model. The cost data was collected by Glen Koons, the Ontario plant engineer for PMB.

Environmental Compliance Methodology

It is difficult to determine which technology has the absolute least impact on the environment. A table will be constructed to compare the technologies and their environmental attributes qualitatively. The table will be not be used to determine the better alternative but rather to show the similarities and differences of each process and displaying all the considerations which must be weighed in this evaluation.

IV. Results and Analysis

Life Cycle Cost Results

The life cycle costs for the PMB process of the Lockheed plant and the MPW process at Warner-Robins AFB are shown below in Table 3. The numbers in the table are in thousands of dollars and represent real dollars. Each line item will be discussed in detail in the following paragraphs.

TABLE 3
LIFE CYCLE COST RESULTS

	PMB '96 Lockheed (thousands of $)	MPW '93 Warner-Robins (thousands of $)
Investment Costs		
Stripping Unit costs	290.0	403.5
Recovery system	a	37.0
Compressor costs	47.0	20.0
Ventilation system	165.0	0.0
Facility	2,496.0	2,496.0
Facility conversion costs	200.0	0.0
Total Investment Costs	**3,198.0**	**2,956.5**
Operation & Support Costs (Present Value over 15 years)		
Manpower costs	7,665.0	9,803.8
Materials	5,238.3	2,467.6
O & M	294.7	565.5
Waste disposal	645.7	301.5
Time out of Service (Implicit cost)	630.8	665.1
Total O & S Costs	**14,474.5**	**13,803.6**
Disposal Costs		
Facility	-836.2	-836.2
Life Cycle Costs	**16,836.3**	**15,923.9**

Note: a. Costs for the recovery system are included in the stripping unit investment costs as part of a package

Investment Costs

The investment costs in Table 3 are based on the actual PMB process at Lockheed and the MPW process at Warner-Robins.

Stripping Unit Costs. The investment cost for the PMB stripping units are for a PRAM V, 5-nozzle blast, recovery and reclaim unit (Pauli & Griffin,1991). This is a package cost of $290 thousand that was not broken down into itemized costs and therefore the recovery system cost is not separate from the stripping units as shown in Table 2. The stripping unit cost for MPW is greater because it is for 6 self contained portable stripping units costing $403.5 thousand as opposed to one 5 nozzle permanently installed piece of equipment used for PMB costing $290 thousand.

Recovery, Compressor and Ventilation Systems Costs. The recovery system for PMB as stated before is part of the PRAM V PMB equipment package and is part of the $290 thousand listed under stripping unit investment costs. MPW has a recovery system to collect the waste water which costs $37 thousand. Compressor costs are greater for PMB because two compressors costing $47 thousand are required instead of one compressor costing $20 thousand for MPW. A ventilation system is only required for PMB and thus makes a large difference in investment costs of $165 thousand.

Facility Costs. A hangar existed at both locations in this analysis that was able to be utilized for the paint removal process. However, there is an opportunity cost associated with the use of existing facilities because it could be used for another purpose. For this analysis, it is assumed that the opportunity cost is the same for PMB and MPW and it is therefore a wash cost which plays no part in deciding between alternatives. However, it is included in this analysis to give a better idea of the entire costs of the process since it represents a large percentage of the life cycle costs. The cost of constructing a new hangar was calculated by assuming the minimum amount of hangar floor space area to accommodate both processes. A 19.2 thousand square feet hangar was used with dimensions of 160 feet by 120 feet. At a construction cost of $130/SF, the hangar cost was estimated to be $2.496 million (Jenkins,1995:12). There were no facility conversion costs for the implementation of the MPW process at Warner-Robins AFB. The Aqua-Miser MPW system used is essentially a drop-in replacement. The Lockheed plant on the other hand spent $200 thousand converting an existing hangar to accommodate PMB operations.

The total investment costs for PMB and MPW excluding facility costs are very similar. The investment costs for PMB equipment are $502 thousand and $460 thousand for MPW equipment. Both represent less than five percent of the total life cycle costs when facility construction costs are not included in the analysis.

Operating and Support Costs

Operating and Support costs were calculated by summing the annual costs over fifteen years and using a discount rate of 2.8 percent to bring the costs back to present value. The operating and support costs for PMB are $14.47 million and the operating and support costs for MPW are $13.80 million.

Manpower Costs. A labor rate of $30 an hour was assumed for purposes of comparison. PMB had manpower costs of $7.67 million compared to the manpower costs of MPW of $9.80 million. MPW is the more labor intensive of the two processes. PMB has a higher strip rate allowing stripping operations to be completed in one third the time of MPW. However, PMB also requires extensive masking and post-strip time to be included in its labor costs making the higher strip rate less significant. Manpower costs for PMB were 22% less than the manpower costs for MPW.

Material Costs. Material costs for PMB were $5.24 million while material cost were significantly less for MPW being only $2.47 million. MPW material costs are over fifty percent less than material costs for PMB. This is primarily a result of the blasting media being cheaper for MPW (sodium bicarbonate and water) and less prep materials are needed in the process as well. Energy costs for stripping are included in material costs. The energy costs for MPW represent less than four percent of the total material costs and less than one percent for PMB. However, the only energy costs captured in the CCM are the electricity costs associated with supporting the stripping units for each process. Electricity costs associated with the recovery, ventilation, or treatment of waste is not captured.

Operation and maintenance costs. Operation and maintenance (O&M) costs for PMB were obtained based on the actual stripping of ten C-130 aircraft per year at Lockheed's Ontario plant. Since the life cycle analysis assumes that both processes strip 30 aircraft per year, operation and maintenance costs for PMB were assumed to be a linear relationship and were therefore tripled making them $24 thousand annually. This equates to a life cycle present value of $295 thousand. Even after making this assumption the operation and maintenance costs for PMB are 48 percent less than those for MPW which are $566 thousand. The O&M costs for PMB are low in comparison to the O&M costs for MPW. The disparity between the costs may be found in how they are calculated. Annual O&M costs for MPW were calculated by assuming they were ten percent of the investment costs minus the facility costs. This same assumption was not used by Lockheed who simply provided a cost that they believed to be accurate based on stripping ten C-130 aircraft. This represented only 1.7% of the investment costs for PMB. If this same rule of ten percent of the equipment investment costs was applied to PMB it would have life cycle O&M costs of $616.5 thousand. This would make PMB have the greater O&M costs and further increase the difference in total operations and support costs in favor of MPW.

Waste Disposal Costs. The cost of waste disposal for PMB is $645.7 thousand compared to a waste disposal cost of $301.5 thousand for MPW. Disposal costs for PMB represent less than four percent of the life cycle costs and less than two percent for MPW. With the elimination of large quantities of toxic chemicals used for stripping, disposal costs have been cut significantly. Lockheed presently does not pay for any disposal of its PMB waste because its freight is paid for by a company in Columbus, OH which makes plastic countertops and other useful products with this recyclable material. For the analysis, the cost of disposing of this material was included to illustrate what it would cost to dispose of properly as hazardous waste. This was done because the practice of reusing the spent plastic media in an agreement such as Lockheed has worked out is the exception and perhaps not a permanent one. Most PMB users do not have this opportunity due a limited market demand for this product. Even without the cost of disposing of the plastic and paint chips generated from the stripping process, the choice between the two alternatives would not change.

Time out of Service. The time out of service cost for PMB was $630.7 thousand while the time out of service cost for MPW was slightly higher at $665.1 thousand. The costs for PMB are calculated in Figure 2 using the following equation as an example. It is assumed that the minimum opportunity cost for the time out of service is at least equal to what the Air Force paid for the aircraft. In some situations it could be worth more than the annuitized rate. This would be possible in times of war where the cost of not having the aircraft available could result in the loss of many lives or critical resources. The percentage the time the aircraft is out of service per year is the flow days assuming 3 shifts per day divided by the number of days in a year. The annualized cost of the aircraft is the purchase price divided by a present value factor for a discount rate of ten percent over 20 years. It is assumed that on average each C-130 has at least 20 more years of service left. The time out of service opportunity cost per aircraft for PMB is $21 thousand. For the life cycle time out of service cost the cost per aircraft must be multiplied by the number of aircraft stripped per year producing a cost of $630.8 thousand.

$$\text{Time out of service opportunity cost per aircraft} = \text{\% of time aircraft is out of service per year} \times \text{Annualized Cost of aircraft}$$

PMB

$$\text{Time out of service opportunity cost per aircraft} = \frac{(5.15 \text{ flow days})}{(365 \text{ days/year})} \times \frac{(\$22.9 \text{ million})}{(15.3671)} = \$21{,}026$$

$$\$21{,}026 \times 30 \text{ aircraft per year} = \$630{,}780$$

Figure 2. Time out of service calculation

This implicit opportunity cost is estimated to be a significant cost in proportion to the other operating and support costs and the life cycle analysis as a whole. However, because the flow times for the two alternatives were so similar the opportunity cost for the time out of service costs of the aircraft are not substantially different.

Disposal Costs

The facility for both PMB and MPW has a residual value of $836 thousand. This cost is a wash cost in the analysis playing no role in effecting a decision between the two alternatives. The equipment in the analysis have zero residual value at the end of 15 years.

Analysis of Life Cycle Costs

When making a decision about which paint removal process to use, the difference in life cycle costs can be highly variable depending upon the nature of the facilities which currently exist. Without knowing the exact investment costs, it is possible to determine what the overall investment costs must be to offset the operating and support costs and change the lower life cycle cost alternative. In the case of choosing between PMB and MPW when neither operation currently exists, the investment costs for PMB would have to be $671 thousand less than the investment costs for MPW in order for it to be chosen as the lower life cycle cost alternative. We can see in Figure 3 as the time period increases so does the difference in the operating and support costs between the two stripping alternatives. Figure 3 indicates the difference in operating and support costs which would have to be offset by lower investment costs for PMB before it can become the least life cycle cost alternative. If PMB is already in place, looking at the difference in operating and support costs between the two technologies, it can be determined that it is not cost effective to switch to MPW unless its net investment costs are less than $671 thousand.

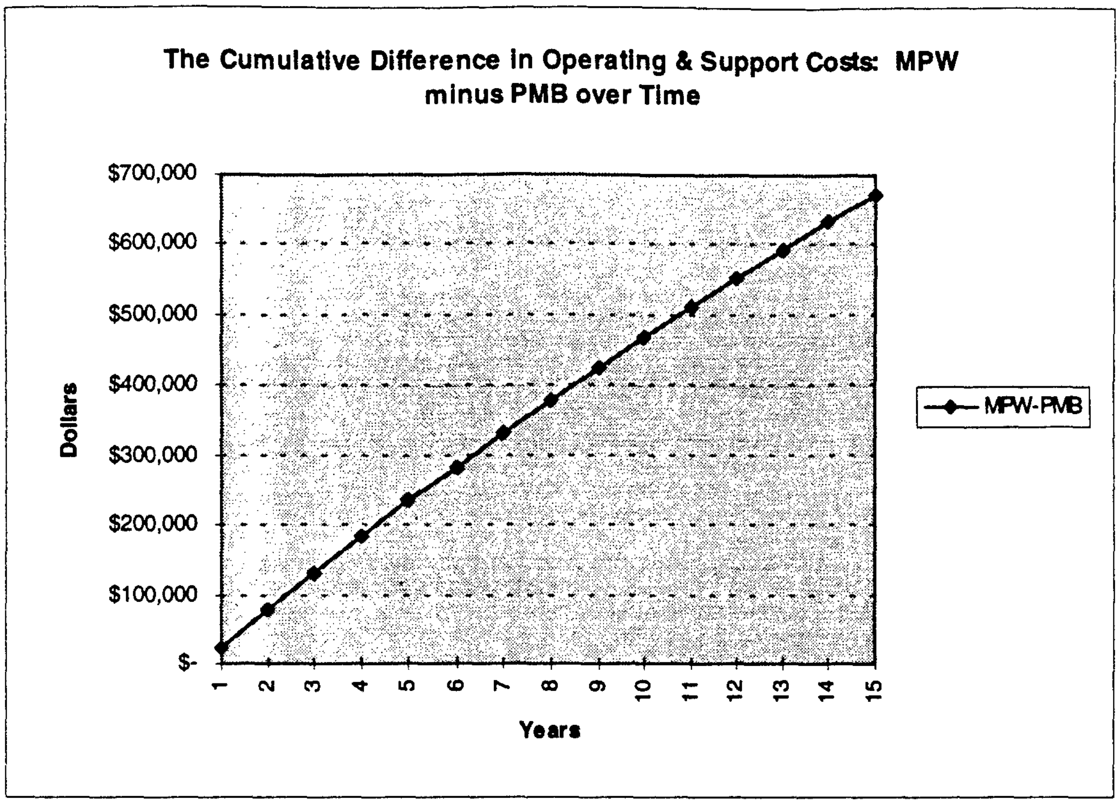

Figure 3. The Cumulative Difference in Operating & Support Costs

<u>Sensitivity to the Real Discount Rate</u>. A sensitivity analysis was run on the difference in operating and support costs for the two alternatives with respect to the discount rate.

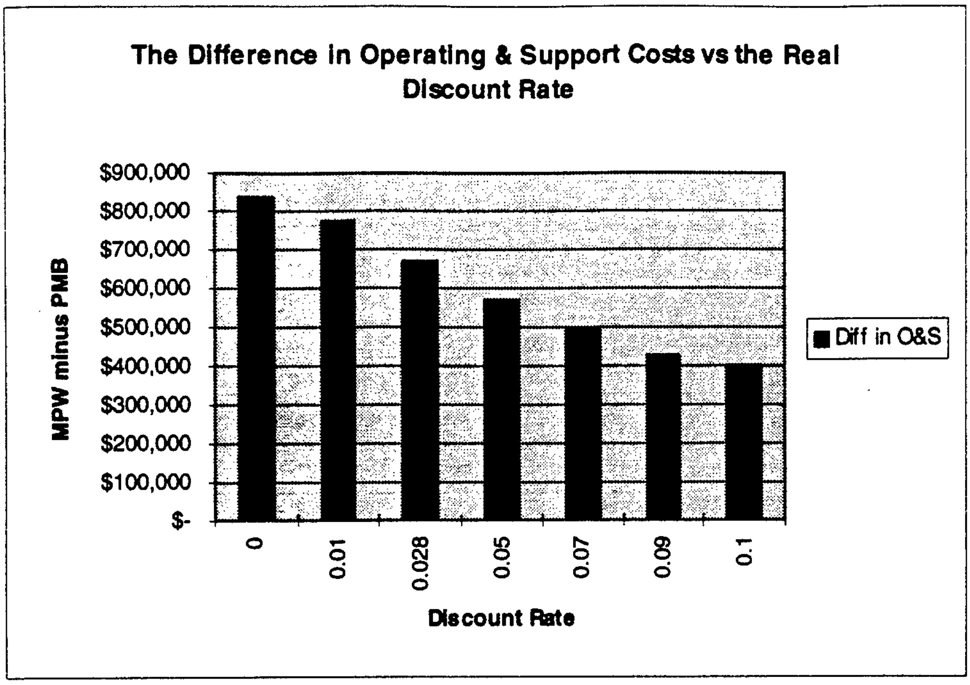

Figure 4. The Sensitivity of the Difference in O&S to the Real Discount Rate

As is shown in Figure 4, the greater the future is discounted the smaller the difference in operating and support costs. Figure 4 shows how much less the investment costs for PMB must be to change the decision from MPW to PMB. Investments cost difference for PMB can be less with a higher discount rate to offset the savings made by MPW in operating and support costs.

<u>Sensitivity to Number of Aircraft</u>. The life cycle costs were also tested to determine if they were sensitive to changing the number of aircraft stripped per year. The sensitivity analysis indicated that MPW is dominant having the lower life cycle costs regardless of the number of aircraft being stripped. The life cycle costs start out

very close when stripping a small number of aircraft per year but as the number of aircraft per year increases, the two alternatives grow farther apart from one another. PMB has a steeper LCC slope than MPW.

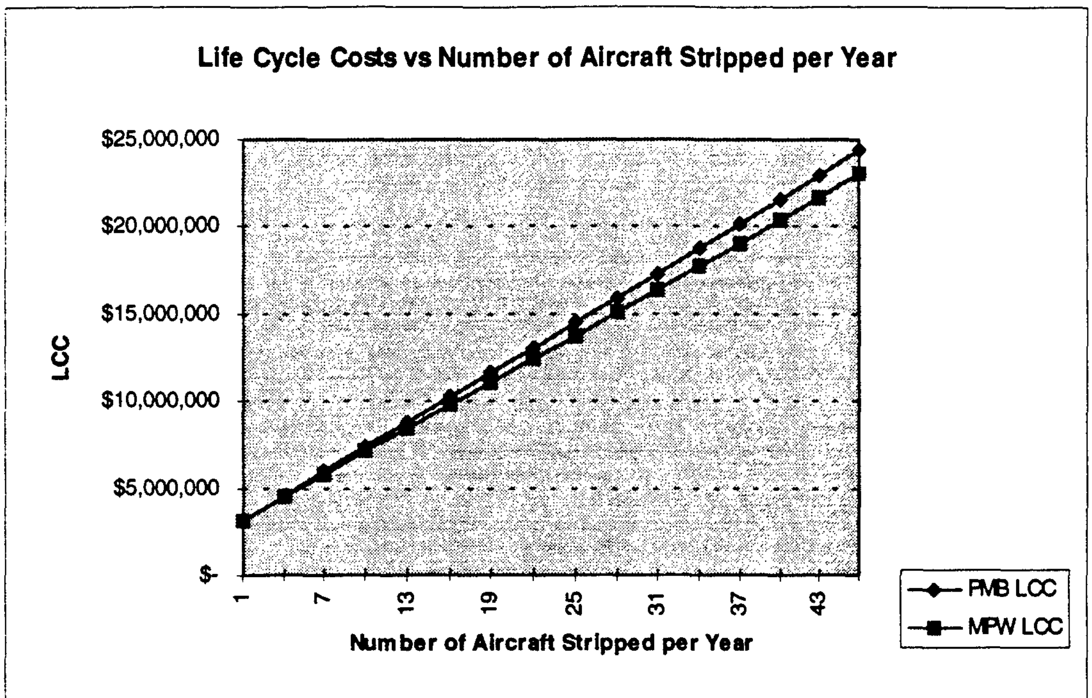

Figure 5. LCC Sensitivity with respect to number of aircraft

<u>Sensitivity to Waste Disposal Costs</u>. Life cycle costs were also tested for sensitivity to a rise in waste disposal costs. Both alternatives have the same amount of paint to dispose. The only difference in disposal requirements is PMB must also dispose of the spent plastic while MPW must dispose of the water and sodium bicarbonate. The treatment/disposal costs for the waste water in the MPW process would have to increase over 700 percent before PMB would have lower operating and support costs. Waste

disposal costs end up playing a very small role in the overall life cycle costs for these two alternatives.

Sensitivity to Strip Rate. PMB requires a strip rate of 3.13 ft^2/min in order change the decision from MPW as the lower life cycle cost alternative to PMB. The PMB equipment at Lockheed currently strips between 2.5 and 3.0 ft^2/min (Koons,1996). An average strip rate of 2.75 ft^2/min is used in the model to represent PMB. If the same strip rate was used for both depainting processes, the operating and support costs for MPW would be even less. Using a strip rate of 2.75 ft^2/min for MPW, the operating and support costs decreased from $15.924 million to $15.854 million increasing the difference in operating and support costs between PMB and MPW.

Environmental Results

Both MPW and PMB significantly reduce the amount of hazardous waste, hazardous air pollutants, and occupational risk associated with aircraft paint stripping. It is difficult to determine whether PMB or MPW has the absolute least impact on the environment, or which is more environmentally compliant. A comparison of the environmental attributes broken down into waste products and emissions, energy use, treatment options and pollution prevention benefits are displayed in Table 3 and discussed in the following paragraphs.

The waste produced by each technology is of the same toxicity, but is spread into different media. PMB is a dry process and so it deposits the paint chips in the air and as part of the plastic solid waste. Therefore no water treatment is necessary as a result of the stripping process. MPW sends its paint waste into primarily the water polluting it and allowing a limited amount to enter the air. The water retains the majority of the paint chips and prevents it from entering the air limiting the dust generation and the need for a dust collection system. The water however is easily treated and is usually compatible with standard wastewater treatment systems.

Energy use must also be considered when comparing the two different technologies. MPW uses double the electricity of PMB for stripping operations however it does not require the energy to recover and recycle the plastic media or run a dust collection and ventilation system. Chemical stripping from an energy use perspective was a better alternative than both of the mechanical methods examined in this analysis. It simply allowed the chemicals to set in and react with the paint to perform the stripping operations.

Both technologies require the same amount of protective gear in the stripping operations. Both eye and respiratory equipment are required to operate the equipment safely and prevent injury. Both have high noise levels as well which require hearing protection. Only PMB operators however face the risk of the explosive nature of plastic media dust if not ventilated properly.

The treatment options and use of the wastes are very different for the two processes. PMB offers the unique prospect of totally recycling all its solid waste whether it be deemed hazardous waste or not. The spent plastic media is able to be reused in the manufacturing of various plastic products. This is a significant benefit to PMB if a market can be captured for this material. If this were a universal reality for all PMB processes then it stands to be the optimum environmental process generating no solid or hazardous waste other than what is collected through the air emissions. Generally, this is not a reality for most PMB users. Incineration is also a possibility for PMB waste which can be used to recover energy in the process. However, there are air quality issues which must be addressed. Finally, disposal in a landfill or specially designated hazardous waste repository if appropriate is an option.

Modified medium pressure water uses standard wastewater treatment systems. The paint chip residue and sodium bicarbonate sludge are separated and disposed of appropriately in a landfill for hazardous waste if necessary. The wastewater is treated in a standard wastewater treatment system.

There are numerous pollution prevention benefits for each technology. PMB and MPW share the benefits of eliminating the production of VOCs and HAPs. Both plastic media and sodium bicarbonate and water are nontoxic media used in the stripping process. PMB and MPW significantly reduce the amount of hazardous waste previously generated from using chemical strippers. PMB also eliminates the use of tens of thousands of gallons of water in its stripping process needing no wastewater treatment besides that used to initially wash and rinse the aircraft. Plastic media is also recyclable and able to be reused several more times in the stripping process before it becomes inadequate. However, the spent media is able to be used in the manufacture of plastic products when a market for this good is captured leaving no solid or hazardous wastes behind except what is captured in the dust collection system.

Table 4
Comparison of Environmental Aspects

	PMB	MPW
Waste Products and Emissions	- Solid paint residue and spent plastic media waste (possible hazardous waste) - Airborne particulates - Noise - Toxicity of waste determined by the paint	- Liquid waste containing paint residue and sodium bicarbonate sludge (possible hazardous waste) - Wastewater - Some airborne particulates - Noise - Toxicity of waste determined by the paint
Energy Use	- Compressed air for blasting media - Media recovery and recycle, dust collection, and ventilation system	- Compressed air and water supply for blasting media
Occupational Hazards	- respiratory and eye protection equipment required - High noise levels requiring ear protection - Dust generation has explosive potential	- respiratory and eye protection equipment required - High noise levels requiring ear protection
Treatment Options	- Reuse of spent plastic media with coated residue in various plastic products - Incineration - Disposal	- Wastewater treatment and disposal of sodium bicarbonate sludge and paint chips
Pollution Prevention Benefits	- Eliminates VOCs and HAPs - Uses nontoxic media - Significant hazardous waste reduction - No water use besides initial wash & rinse since it is a dry process - Spent plastic media are separated from paint chips and recycled for repeated paint stripping - Recyclable to be used in manufacture of plastic products	- Eliminates VOCs and HAPs - Uses nontoxic media - Significant hazardous waste reduction

IV. Conclusions and Recommendations

Conclusions

MPW has lower life cycle costs than PMB for stripping the C-130 in this analysis. Both the investment and operating and support costs proved to be lower for MPW. Disposal costs for hazardous waste is not a cost driver in this analysis. The cost drivers for this analysis are the operating and support costs and more specifically manpower which represents the largest portion of the life cycle costs. This leads to the belief that an increase in operational efficiencies could have a significant impact on the choice of alternatives. Facility costs were not a cost driver in this analysis but could be when choosing between these two alternatives and construction of a facility is necessary.

Both MPW and PMB significantly reduce the amount of hazardous waste, hazardous air pollutants, and occupational risk associated with aircraft paint stripping. It is difficult to determine whether PMB or MPW has the absolute least impact on the environment, or which is more environmentally compliant. The waste produced by each technology is of the same toxicity, but is spread into different media. PMB is a dry process and so it deposits the paint chips in the air and as part of the plastic solid waste. MPW sends its paint waste into water polluting it and allowing a limited amount to enter the air. This however is easily treated with standard wastewater treatment systems.

Recommendations for Further Research

This same analysis could be done comparing other depainting technologies. Several less mature technologies are in the development stage which offer even greater pollution prevention benefits but at a high investment cost. Different aircraft could be examined to determine if the C-130 is representative of all aircraft or if the type of aircraft has an effect on the type of paint removal technology chosen.

The other side of the problem from a pollution prevention aspect could be examined. The question of how to reduce the amount of stripping and repainting altogether could be addressed. Could different substrates be used more in the future which are corrosive resistant such as using more composites? Some research could go into strictly enforcing the paint/depaint cycle in the Air Force technical orders, showing the possible savings in depaint/paint costs along with the pollution prevention benefits gained.

APPENDIX A

COST MODEL INPUT SURVEY

These are the inputs I would like to obtain from your PMB process. The first column is seperates the depaint process into pre-strip, stripping and post-strip parameters to be measured. The second column are inputs I will assume to be the same for all depainting technologies for purposes of comparison. I would still like to get an idea of what it costs you in your particular region of the country. I would also like an idea of what investment costs were made in constructing the PMB facility. If you could fill in the cells to the right of the data inputs it would greatly help my research efforts.

measure		**assumptions**	
1. Strip rate		Depaint area	
2. A/C Wash manhours		Labor rate	
3. A/C Wash # of persons			
4. A/C Wash Gal of soap		Cost of Soap/Gal	
5. A/C Wash Waste Gal		Disposal Cost $/Gal	
6. Component removal manhours			
7. Component removal # person		lbs of paint per A/C	
8. Mask/Plug Manhours			
9. Mask/Plug # pers		Electricity cost $/Kw	
10. Mask/Plug material cost			
Stripping operation		Etch chem $/gal	
11. # of Nozzels used		Etch waste $/gal	
12. Pellets lb/hr/Noz			
13. Fraction of time working			
14. Fraction of time effective		Conv Coat chem $/gal	
15. Fraction of media discarded		Conv Coat waste $/gal	
16. Cost of media $/gal or lb			
17. Disposal cost dol/lb or gal			
18. Paint disposal cost $/#			
19. Air volume CUFT/min/Noz			
20. air pressure PSI			
21. other equipment kilowats/Noz			
22. misc supply costs			
Post Strip		**Investment Costs**	
23. Demask manhours		Cost/ stripping unit	
24. Demask # persons		Compressor costs	
25. Seam STrip manhours		Recovery system	
26. seam strip # persons		ventilation cost	
27. A/C wash manhours			
28. A/C wash # of persons		Maintenance $/yr	
29. A/C wash Gal of soap			
30. A/C wash waste gal			
31. Etch manhours			
32. Ethch # persons			
33. Etch gal of chem			
34. Etch waste gal			
35. Conv Caot manhours			
36. Conv Coat # persons			
37. Conv Coat gal of chem			
38. Conv coat waste gal			
39. shifts/day			
40. aircraft per year			

APPENDIX B

AIR FORCE DEPAINTING COST COMPARISON MODEL

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WEAPON SYSTEM	(PROCESS) DEPAINT AREA SQ FT DATA	MANPOWER COST $/HR DATA	STRIP RATE SQ FT/MIN/NOZ DATA	PRE-STRIP A/C WASH MANHOURS DATA	PRE-STRIP A/C WASH NO. OF PERS DATA	PRE-STRIP A/C WASH MANPOWER $ COMPUTED	PRE-STRIP A/C WASH GAL OF SOAP DATA	PRE-STRIP A/C WASH SOAP $/GAL DATA	PRE-STRIP A/C WASH TOT SOAP $ COMPUTED	PRE-STRIP A/C WASH WASTE GAL DATA	PRE-STRIP DISPOSAL COST DOL /GAL DATA
	(CHEMICAL)										
C/KC-135	10,000.00	30.00	N/A	0.00	8.00	0.00	0.00	2.21	0.00	0.00	0.01
C/KC-135 SM	10,000.00	30.00	N/A	89.50	4.00	2,685.00	110.00	2.21	243.10	11,000.00	0.01
F-15	2,200.00	30.00	N/A	16.00	4.00	480.00	20.00	2.21	44.20	2,000.00	0.01
C-130	12,950.00	30.00	N/A	32.00	8.00	960.00	60.00	2.21	132.60	6,000.00	0.01
C-141	17,424.00	30.00	N/A	60.00	10.00	1,800.00	110.00	2.21	243.10	11,000.00	0.01
	(ROBOT HI H2O)										
C/KC-135*	10,000.00	30.00	1.77	0.00	8.00	0.00	0.00	2.21	0.00	0.00	0.01
	(PMB)										
F-16	1,850.00	30.00	1.50		4.00	0.00		2.21	0.00		0.01
F-15	2,200.00	30.00	1.00	16.00	4.00	480.00	20.00	2.21	44.20	2,000.00	0.01
F-15 SM	2,200.00	30.00	1.00	20.00	2.00	600.00	20.00	2.21	44.20	2,000.00	0.01
A-10	2,500.00	30.00	1.00	20.00	2.00	600.00	20.00	2.21	44.20	2,000.00	0.01
C-130	12,950.00	30.00	1.50	32.00	8.00	960.00	60.00	2.21	132.60	6,000.00	0.01
C-130 Lockheed	12,950.00	30.00	2.75	36.00	6.00	1,080.00	45.00	2.21	99.45	6,000.00	0.01
C-5	32,000.00	30.00	1.35		10.00	0.00		2.21	0.00		0.01
	(ROBOT CO2/N2)										
F-15*	2,200.00	30.00	0.49	0.00	4.00	0.00	0.00	2.21	0.00	0.00	0.01
	(ROBOT FLASH)										
F-15*	2,200.00	30.00	1.50	0.00	4.00	0.00	0.00	2.21	0.00	0.00	0.01
C-130*	12,950.00	30.00	3.00	0.00	8.00	0.00	0.00	2.21	0.00	0.00	0.01
	(MED PRES H2O)										
F-15*	2,200.00	30.00	0.05	0.00	4.00	0.00	0.00	2.21	0.00	0.00	0.01
C-130*	12,950.00	30.00	2.00	0.00	8.00	0.00	0.00	2.21	0.00	0.00	0.01
C-141*	17,424.00	30.00	2.00	0.00	10.00	0.00	0.00	2.21	0.00	0.00	0.01
	(MED H2O BICARB)										
F-15*	2,200.00	30.00	1.50	0.00	4.00	0.00	0.00	2.21	0.00	0.00	0.01
C-130*	12,950.00	30.00	2.00	0.00	8.00	0.00	0.00	2.21	0.00	0.00	0.01
C-130 Battelle	12,950.00	30.00	2.00	0.00	8.00	0.00	0.00	2.21	0.00	0.00	0.01
C-141*	17,424.00	30.00	2.00	0.00	10.00	0.00	0.00	2.21	0.00	0.00	0.01
	(MED H2O SOFT)										
C/KC-135*	10,000.00	30.00	5.00	0.00	8.00	0.00	0.00	2.21	0.00	0.00	0.01
	(WHEAT)										
F-15	2,200.00	30.00	0.70	16.00	4.00	480.00	20.00	2.21	44.20	2,000.00	0.01
C-130	12,950.00	30.00	1.00	32.00	8.00	960.00	60.00	2.21	132.60	6,000.00	0.01
C-141	17,424.00	30.00	1.00	60.00	10.00	1,800.00	110.00	2.21	243.10	11,000.00	0.01

PRE-STRIP A/C WASH DISPOSAL $ TOT COMPUTED	PRE-STRIP A/C WASH FLOW TIME COMPUTED	PRE-STRIP A/C WASH TOT COST $ COMPUTED	PRE-STRIP COMPONENT REMOVAL MANHOUR DATA	PRE-STRIP COMPONENT REMOVAL NO. OF PERS DATA	PRE-STRIP COMPONENT REMOVAL MANPOW COST $ COMPUTED	PRE-STRIP COMPONENT REMOVAL FLOW TIME COMPUTED	PRE-STRIP MASK/PLUG MANHOURS DATA	PRE-STRIP MASK/PLUG NO. OF PERS DATA	PRE-STRIP MASK/PLUG MANPOW $ COMPUTED	PRE-STRIP MASK/PLUG FLOW TIME COMPUTED	PRE-STRIP MASK/PLUG MATERIAL $ COMPUTED
0.00	0.00	0.00	0.00	0.00	0.00	0.00	565.00	8.00	16,950.00	70.63	904.00
121.00	22.38	3,049.10	0.00	0.00	0.00	0.00	180.00	6.00	5,400.00	30.00	850.00
22.00	4.00	546.20	0.00	0.00	0.00	0.00	96.00	4.00	2,880.00	24.00	604.05
66.00	4.00	1,158.60	0.00	0.00	0.00	0.00	240.00	10.00	7,200.00	24.00	914.10
121.00	6.00	2,164.10	80.00	0.00	2,400.00	0.00	288.00	12.00	8,640.00	24.00	1,424.76
0.00	0.00	0.00	0.00	8.00	0.00	0.00	32.00	4.00	960.00	8.00	904.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	5.00	3,000.00	20.00	300.00
22.00	4.00	546.20	40.00	4.00	1,200.00	10.00	80.00	4.00	2,400.00	20.00	1,000.00
22.00	10.00	666.20	0.00	4.00	0.00	0.00	144.00	4.00	4,320.00	36.00	875.00
22.00	10.00	666.20	38.00	4.00	1,140.00	9.50	130.00	4.00	3,900.00	32.50	1,000.00
66.00	4.00	1,158.60	120.00	8.00	3,600.00	15.00	160.00	8.00	4,800.00	20.00	2,000.00
66.00	6.00	1,245.45	0.00	8.00	0.00	0.00	196.00	6.00	5,880.00	32.67	700.00
0.00	0.00	0.00		8.00	0.00	0.00	1,110.00	16.00	33,300.00	69.38	2,000.00
0.00	0.00	0.00	40.00	4.00	1,200.00	10.00	30.00	4.00	900.00	7.50	300.00
0.00	0.00	0.00	20.00	4.00	600.00	5.00	30.00	4.00	900.00	7.50	300.00
0.00	0.00	0.00	60.00	8.00	1,800.00	7.50	60.00	8.00	1,800.00	7.50	1,200.00
0.00	0.00	0.00	40.00	4.00	1,200.00	10.00	50.00	4.00	1,500.00	12.50	300.00
0.00	0.00	0.00	80.00	8.00	2,400.00	10.00	80.00	8.00	2,400.00	10.00	1,200.00
0.00	0.00	0.00	80.00	8.00	2,400.00	10.00	100.00	8.00	3,000.00	12.50	1,200.00
0.00	0.00	0.00	40.00	4.00	1,200.00	10.00	100.00	4.00	3,000.00	25.00	300.00
0.00	0.00	0.00	80.00	8.00	2,400.00	10.00	180.00	8.00	5,400.00	22.50	1,200.00
0.00	0.00	0.00	0.00	8.00	0.00	0.00	10.00	5.00	300.00	2.00	600.00
0.00	0.00	0.00	80.00	8.00	2,400.00	10.00	288.00	8.00	8,640.00	36.00	1,200.00
0.00	0.00	0.00	80.00	8.00	2,400.00	10.00	565.00	8.00	16,950.00	70.63	904.00
22.00	4.00	546.20	40.00	4.00	1,200.00	10.00	100.00	4.00	3,000.00	25.00	1,000.00
66.00	4.00	1,158.60	120.00	8.00	3,600.00	15.00	160.00	8.00	4,800.00	20.00	2,000.00
121.00	6.00	2,164.10	80.00	8.00	2,400.00	10.00	180.00	8.00	5,400.00	22.50	2,000.00

STRIPPING OPERATION NO. NOZ DATA	STRIPPING OPERATION PELLETS LB/HR/NOZ DATA	STRIPPING OPERATION MEDIA CONV. DATA	STRIPPING OPERATION PEL REQ'D LB/HR/NOZ COMPUTED	STRIPPING OPERATION FRACT OF TIME WORKING DATA	STRIPPING OPERATION FRACT OF TIME EFFECTIVE DATA	STRIPPING OPERATION NET STRIP RATE SQ FT/MIN/NOZ COMPUTED	STRIPPING OPERATION GAL OR # OF MEDIA PER A/C COMPUTED (DATA FOR CHEM)	STRIPPING OPERATION FRACT OF MED DISCARDED DATA	STRIPPING OPERATION MAKEUP MEDIA REQ'D # OR GAL COMPUTED	STRIPPING OPERATION COST OF MEDIA DOL/GAL OR # DATA	STRIPPING OPERATION MAKEUP MEDIA COST $ COMPUTED
N/A	N/A	N/A	N/A	N/A	N/A	N/A	1,875.00	1.00	1,875.00	5.210	9,768.75
N/A	N/A	N/A	N/A	N/A	N/A	N/A	820.00	1.00	820.00	4.640	3,804.80
N/A	N/A	N/A	N/A	N/A	N/A	N/A	660.00	1.00	660.00	4.000	2,640.00
N/A	N/A	N/A	N/A	N/A	N/A	N/A	1,100.00	1.00	1,100.00	4.000	4,400.00
N/A	N/A	N/A	N/A	N/A	N/A	N/A	1,650.00	1.00	1,650.00	4.000	6,600.00
1.00	480.00	1.00	480.00	0.80	0.95	1.35	47,576.57	1.00	47,576.57	0.001	47.58
6.00	550.00	1.00	550.00	0.27	0.80	0.32	14,131.94	0.08	1,130.56	2.550	2,882.92
4.00	450.00	1.00	450.00	0.50	0.80	0.40	20,625.00	0.10	2,062.50	1.650	3,403.13
4.00	550.00	1.00	550.00	0.29	0.80	0.23	25,208.33	0.05	1,134.38	1.250	1,417.97
4.00	550.00	1.00	550.00	0.31	0.80	0.25	28,645.83	0.05	1,289.06	1.250	1,611.33
8.00	450.00	1.00	450.00	0.50	0.80	0.60	80,937.50	0.10	8,093.75	1.650	13,354.69
5.00	600.00	1.00	600.00	0.65	0.50	0.89	94,181.82	0.05	4,709.09	2.500	11,772.73
20.00	550.00	1.00	550.00	0.49	0.80	0.52	271,604.94	0.03	7,061.73	1.150	8,120.99
4.00	600.00	2.00	1,200.00	0.80	0.95	0.37	95,104.29	1.00	95,104.29	0.030	2,853.13
1.00	1,000.00	2.00	2,000.00	0.80	0.95	1.14	51,461.99	1.00	51,461.99	0.030	1,543.86
2.00	1,000.00	2.00	2,000.00	0.80	0.95	2.28	151,461.99	1.00	151,461.99	0.030	4,543.86
4.00	600.00	1.00	1,000.00	0.50	0.80	0.02	916,666.67	1.00	916,666.67	0.001	916.67
3.00	600.00	1.00	1,000.00	0.50	0.80	0.80	134,895.83	1.00	134,895.83	0.001	134.90
8.00	600.00	1.00	1,000.00	0.50	0.80	0.80	181,500.00	1.00	181,500.00	0.001	181.50
3.00	1,000.00	1.00	1,000.00	0.50	0.80	0.60	30,555.56	1.00	30,555.56	0.001	30.56
4.00	1,000.00	1.00	1,000.00	0.50	0.80	0.80	134,895.83	1.00	134,895.83	0.001	134.90
6.00	192.00	1.00	192.00	0.34	0.50	0.34	41,440.00	1.00	41,440.00	0.001	20.72
8.00	1,000.00	1.00	1,000.00	0.50	0.80	0.80	181,500.00	1.00	181,500.00	0.001	181.50
3.00	600.00	1.00	1,000.00	0.50	0.80	2.00	41,666.67	1.00	41,666.67	0.001	41.67
6.00	450.00	1.00	450.00	0.50	0.80	0.28	29,464.29	0.05	1,473.21	1.650	2,430.80
12.00	450.00	1.00	450.00	0.50	0.80	0.40	121,406.25	0.05	6,070.31	1.650	10,016.02
24.00	450.00	1.00	450.00	0.50	0.80	0.40	163,350.00	0.05	8,167.50	1.650	13,476.38

STRIPPING OPERATION POUNDS MEDIA REQ'N DISPOSAL COMPUTED	STRIPPING OPERATION DISPOSAL COST DOL/LB OR GAL DATA	STRIPPING OPERATION DISPOSAL COST $ COMPUTED	STRIPPING OPERATION POUNDS OF PAINT PER A/C DATA	STRIPPING OPERATION PAINT DISPO COST $/# DATA	STRIPPING OPERATION PAINT DISPO TOT COST COMPUTED	STRIPPING OPERATION AIR VOLUME CUFT/MIN/NOZ DATA	STRIPPING OPERATION AIR PRESSURE PSI DATA	STRIPPING OPERATION HORSE POWER PER NOZ/HR COMPUTED	STRIPPING OPERATION COMP AIR KILOWATS/NOZ/HR COMPUTED	STRIPPING OPERATION OTHER EQUIP KILOWATS/NOZ/HR DATA	STRIPPING OPERATION KILOWATTS TOTAL COMPUTED
WATER											
80,000.00	0.00	386.00	3,000.00	1.48	4,440.00	N/A	N/A	N/A	N/A	N/A	N/A
3,600.00	0.44	1,584.00	0.00	2.00	0.00	N/A	N/A	N/A	N/A	N/A	N/A
6,600.00	2.00	13,200.00	240.00	2.00	480.00	N/A	N/A	N/A	N/A	N/A	N/A
11,000.00	2.00	22,000.00	500.00	2.00	1,000.00	N/A	N/A	N/A	N/A	N/A	N/A
16,500.00	2.00	33,000.00	1,000.00	2.00	2,000.00	N/A	N/A	N/A	N/A	N/A	N/A
47,576.57	0.01	523.34	1,650.00	0.27	445.50	0.00	80.00	0.00	0.00	30.00	2,973.54
1,130.56	0.00	0.00	240.00	0.00	0.00	180.00	64.70	21.25	15.84		407.13
2,062.50	0.27	556.88	240.00	0.27	64.80	180.00	64.70	21.25	15.84		726.23
1,134.38	0.58	657.94	0.00	0.27	0.00	180.00	64.70	21.25	15.84		726.23
1,289.06	0.58	747.66	0.00	0.27	0.00	180.00	64.70	21.25	15.84		825.26
8,093.75	0.27	2,185.31	600.00	0.27	162.00	180.00	64.70	21.25	15.84		2,849.90
4,709.09	0.27	1,271.45	600.00	0.27	162.00	220.00	40.00	16.32	12.17		1,910.65
7,061.73	0.58	4,095.80	0.00	0.27	0.00	180.00	64.70	21.25	15.84		7,824.68
95,104.29	0.00	0.00	240.00	0.27	64.80	300.00	314.70	93.81	69.95	7.70	6,154.30
51,461.99	0.00	0.00	240.00	0.27	64.80	300.00	180.00	70.14	52.31	15.40	1,742.15
151,461.99	0.00	0.00	600.00	0.27	162.00	600.00	180.00	140.29	104.61	15.40	9,088.68
916,666.67	0.01	10,083.33	240.00	0.27	64.80	1.00	80.00	0.14	0.00	15.40	14,116.67
134,895.83	0.01	1,483.85	600.00	0.27	162.00	1.00	80.00	0.14	0.10	15.40	2,091.42
181,500.00	0.01	1,996.50	1,200.00	0.27	324.00	1.00	80.00	0.14	0.10	15.40	2,813.97
30,555.56	0.01	336.11	240.00	0.27	64.80	1.00	80.00	0.14	0.00	15.40	470.56
134,895.83	0.01	1,483.85	600.00	0.27	162.00	1.00	80.00	0.14	0.10	15.40	2,091.42
41,440.00	0.01	414.40	600.00	0.27	162.00	28.00	90.00	4.25	3.17	15.40	4,007.89
181,500.00	0.01	1,996.50	1,200.00	0.27	324.00	1.00	80.00	0.14	0.10	15.40	2,813.97
41,666.67	0.01	458.33	600.00	0.27	162.00	1.00	80.00	0.14	0.10	15.40	646.00
1,473.21	0.27	397.77	240.00	0.27	64.80	220.00	40.00	16.32	12.17		796.98
6,070.31	0.27	1,638.98	600.00	0.27	162.00	220.00	40.00	16.32	12.17		3,283.93
8,167.50	0.27	2,205.23	1,200.00	0.27	324.00	220.00	40.00	16.32	12.17		4,418.47

STRIPPING OPERATION ELECTRICITY COST $/KW DATA	STRIPPING OPERATION TOT ELECT COST COMPUTED	STRIPPING OPERATION STRIP FLOW TIME HR COMPUTED (DAT 4 CHEM)	STRIPPING OPERATION STRIP MANHOURS HR COMPUTED (DAT 4 CHEM)	STRIPPING OPERATION STRIP MANPOW $ COMPUTED	STRIPPING OPERATION ?THER CONSUMABLES (DESCRIPTION) DATA	STRIPPING OPERATION DATA	STRIPPING OPERATION COMPUTED	STRIPPING OPERATION CONSUMABLES $/PLANE COMPUTED	POST STRIP DEMASK MANHOURS DATA	POST STRIP DEMASK MANPOW $ COMPUTED	POST STRIP DEMASK NO PERSONS DATA
N/A	N/A	72.00	300.00	9,000.00				0.00	160.00	4,800.00	7.00
N/A	N/A	148.00	811.30	24,339.00				0.00	15.00	450.00	7.00
N/A	N/A	120.00	480.00	14,400.00	NONE			0.00	16.00	480.00	4.00
N/A	N/A	72.00	300.00	9,000.00				0.00	80.00	2,400.00	10.00
N/A	N/A	80.00	410.00	12,300.00				0.00	120.00	3,600.00	12.00
0.07	193.28	123.90	495.59	14,867.68				0.00	32.00	960.00	4.00
0.07	26.46	15.86	95.16	2,854.94				0.00	40.00	1,200.00	4.00
0.07	47.20	22.92	91.67	2,750.00				0.00	60.00	1,800.00	4.00
0.07	47.20	39.51	158.05	4,741.38				0.00	51.00	1,530.00	6.00
0.07	53.64	42.00	168.01	5,040.32				0.00	51.00	1,530.00	6.00
0.07	185.24	44.97	359.72	10,791.67				0.00	120.00	3,600.00	10.00
0.07	124.19	48.30	241.49	7,244.76				0.00	48.00	1,440.00	6.00
0.07	508.60	50.91	1,018.20	30,546.01				0.00	770.00	23,100.00	16.00
					N2 $/GAL	N2 GAL/NOZ/MIN	N2 GAL/PLANE	N2 $/PLANE			
0.07	400.03	24.77	49.53	1,486.00	0.29	1.90	9,034.91	2,620.12	16.00	480.00	4.00
					LAMP COST $/LAMI	LAMP LIFE HOURS	LAMPS/PLANE	$/PLANE			
0.07	113.24	32.16	32.16	964.91	650.00	80.00	0.32	209.06	16.00	480.00	4.00
0.07	590.76	47.33	94.66	2,839.91	650.00	80.00	0.95	615.31	60.00	1,800.00	10.00
0.07	917.58	458.33	1,833.33	55,000.00				0.00	50.00	1,500.00	4.00
0.07	135.94	89.93	269.79	8,093.75				0.00	100.00	3,000.00	8.00
0.07	182.91	45.38	363.00	10,890.00				0.00	100.00	3,000.00	8.00
					BICARB $/LBS	LBS/PLANE	MISC.SUP.	$/PLANE			
0.07	30.59	20.37	61.11	1,833.33	0.37	2,750.00		1,017.50	100.00	3,000.00	4.00
0.07	135.94	67.45	269.79	8,093.75	0.37	12,140.63		4,492.03	180.00	5,400.00	8.00
0.07	260.51	105.80	735.00	22,050.00	0.36	9,065.00	1,000.00	4,263.40	10.00	300.00	3.00
0.07	182.91	45.38	363.00	10,890.00	0.37	16,335.00		6,043.95	288.00	8,640.00	8.00
					(CHEM GAL/PL)		COST/GAL				
0.07	41.99	27.78	83.33	2,500.00	275.00		22.00	6,050.00	100.00	4,800.00	8.00
0.07	51.80	21.83	130.95	3,928.57				0.00	100.00	3,000.00	4.00
0.07	213.46	44.97	539.58	16,187.50				0.00	180.00	5,400.00	10.00
0.07	287.20	30.25	726.00	21,780.00				0.00	288.00	8,640.00	12.00

POST STRIP DEMASK TIME HR COMPUTED	POST STRIP SEAM STRIP MANHOUR DATA	POST STRIP SEAM STRIP NO. OF PERS DATA	POST STRIP SEAM STRIP MANPOW COST $ COMPUTED	POST STRIP SEAM STRIP FLOW TIME COMPUTED	POST STRIP A/C WASH MANHOURS DATA	POST STRIP A/C WASH NO. OF PERS DATA	POST STRIP A/C WASH MANPOWER $ COMPUTED	POST STRIP A/C WASH GAL OF SOAP DATA	POST STRIP A/C WASH SOAP $/GAL DATA	POST STRIP A/C WASH TOT SOAP $ COMPUTED	POST STRIP A/C WASH WASTE GAL DATA
22.86	0.00	8.00	0.00	0.00	68.00	11.00	2,040.00	63.00	2.88	181.44	2,835.00
2.14	0.00	8.00	0.00	0.00	49.00	10.00	1,470.00	110.00	2.21	243.10	11,000.00
4.00	40.00	4.00	1,200.00	10.00	16.00	4.00	480.00	20.00	2.21	44.20	2,000.00
8.00	120.00	8.00	3,600.00	15.00	32.00	8.00	960.00	60.00	2.21	132.60	6,000.00
10.00	120.00	8.00	3,600.00	15.00	60.00	10.00	1,800.00	110.00	2.21	243.10	11,000.00
8.00	0.00	8.00	0.00	0.00	0.00	0.00	0.00	0.00	2.21	0.00	0.00
10.00	8.00	1.00	240.00	8.00	13.00	4.00	800.00	3.00	7.82	23.45	1,000.00
15.00	40.00	4.00	1,200.00	10.00	16.00	4.00	800.00	20.00	2.21	200.00	2,000.00
8.50	20.00	2.00	600.00	10.00	20.00	4.00	800.00	20.00	2.21	200.00	2,000.00
8.50	20.00	2.00	600.00	10.00	20.00	4.00	800.00	20.00	2.21	200.00	2,000.00
12.00	80.00	8.00	2,400.00	10.00	32.00	8.00	1,600.00	60.00	2.21	600.00	6,000.00
8.00	100.00	6.00	3,000.00	16.67	36.00	6.00	1,600.00	80.00	2.21	600.00	6,000.00
48.13	130.00	8.00	3,900.00	16.25	0.00	10.00	0.00	0.00	2.21	0.00	0.00
4.00	10.00	4.00	300.00	2.50	0.00	0.00	0.00	0.00	2.21	0.00	0.00
4.00	20.00	4.00	600.00	5.00	0.00	0.00	0.00	0.00	2.21	0.00	0.00
6.00	40.00	8.00	1,200.00	5.00	0.00	0.00	0.00	0.00	2.21	0.00	0.00
12.50	40.00	4.00	1,200.00	10.00	0.00	0.00	0.00	0.00	2.21	0.00	0.00
12.50	80.00	8.00	2,400.00	10.00	0.00	0.00	0.00	0.00	2.21	0.00	0.00
12.50	80.00	8.00	2,400.00	10.00	0.00	0.00	0.00	0.00	2.21	0.00	0.00
25.00	40.00	4.00	1,200.00	10.00	0.00	0.00	0.00	0.00	2.21	0.00	0.00
22.50	80.00	8.00	2,400.00	10.00	0.00	0.00	0.00	0.00	2.21	0.00	0.00
3.33	40.00	8.00	1,200.00	5.00	37.00	5.00	1,110.00	0.00	2.21	0.00	5,000.00
36.00	80.00	8.00	2,400.00	10.00	0.00	0.00	0.00	0.00	2.21	0.00	0.00
12.50	80.00	8.00	2,400.00	10.00	68.00	11.00	2,040.00	63.00	2.88	181.44	2,835.00
25.00	40.00	4.00	1,200.00	10.00	16.00	4.00	800.00	20.00	2.21	200.00	2,000.00
18.00	80.00	8.00	2,400.00	10.00	32.00	8.00	1,600.00	60.00	2.21	600.00	6,000.00
24.00	120.00	8.00	3,600.00	15.00	60.00	10.00	900.00	110.00	2.21	243.10	11,000.00

POST STRIP A/C WASH DOL /GAL DATA	POST STRIP A/C WASH DISPOS $ TOT COMPUTED	POST STRIP A/C WASH FLOW TIME COMPUTED	POST STRIP A/C WASH TOT COST $ COMPUTED	POST STRIP ETCH MANHOURS DATA	POST STRIP ETCH NO. OF PERS DATA	POST STRIP ETCH MANPOWER $ COMPUTED	POST STRIP ETCH GAL OF CHEM DATA	POST STRIP ETCH CHEM $/GAL DATA	POST STRIP ETCH TOT CHEM $ COMPUTED	POST STRIP ETCH WASTE GAL DATA	POST STRIP ETCH WASTE $/GAL DATA
0.08	226.80	6.18	2,448.24	0.00	8.00	0.00	0.00	2.73	0.00	0.00	0.01
0.01	121.00	4.90	1,834.10	60.00	10.00	1,800.00	110.00	2.73	300.30	11,000.00	0.01
0.01	22.00	4.00	546.20	8.00	4.00	240.00	20.00	2.73	54.60	2,000.00	0.01
0.01	66.00	4.00	1,158.60	32.00	8.00	960.00	60.00	2.73	163.80	6,000.00	0.01
0.01	121.00	6.00	2,164.10	60.00	10.00	1,800.00	110.00	2.73	300.30	11,000.00	0.01
0.01	0.00	0.00	0.00	32.00	8.00	960.00	60.00	2.73	163.80	6,000.00	0.01
0.01	22.00	3.25	1,022.00	8.00	4.00	240.00	20.00	2.73	54.60	2,000.00	0.01
0.01	22.00	4.00	1,022.00	8.00	4.00	240.00	20.00	2.73	54.60	2,000.00	0.01
0.01	22.00	5.00	1,022.00	8.00	4.00	240.00	20.00	2.73	54.60	2,000.00	0.01
0.01	22.00	5.00	1,022.00	8.00	4.00	240.00	20.00	2.73	54.60	2,000.00	0.01
0.01	66.00	4.00	2,266.00	32.00	8.00	960.00	60.00	2.73	163.80	6,000.00	0.01
0.01	66.00	6.00	2,266.00	18.00	6.00	540.00	60.00	2.73	163.80	6,000.00	0.01
0.01	0.00	0.00	0.00	120.00	16.00	3,600.00	220.00	2.73	600.60	11,000.00	0.01
0.01	0.00	0.00	0.00	8.00	4.00	240.00	20.00	2.73	54.60	2,000.00	0.01
0.01	0.00	0.00	0.00	8.00	4.00	240.00	20.00	2.73	54.60	2,000.00	0.01
0.01	0.00	0.00	0.00	32.00	8.00	960.00	60.00	2.73	163.80	6,000.00	0.01
0.01	0.00	0.00	0.00	8.00	4.00	240.00	20.00	2.73	54.60	2,000.00	0.01
0.01	0.00	0.00	0.00	32.00	8.00	960.00	60.00	2.73	163.80	6,000.00	0.01
0.01	0.00	0.00	0.00	60.00	10.00	1,800.00	110.00	2.73	300.30	11,000.00	0.01
0.01	0.00	0.00	0.00	8.00	4.00	240.00	20.00	2.73	54.60	2,000.00	0.01
0.01	0.00	0.00	0.00	32.00	8.00	960.00	60.00	2.73	163.80	6,000.00	0.01
0.01	55.00	7.40	1,165.00	36.00	8.00	1,080.00	60.00	2.73	163.80	6,000.00	0.01
0.01	0.00	0.00	0.00	60.00	10.00	1,800.00	110.00	2.73	300.30	11,000.00	0.01
0.08	226.80	6.18	2,448.24	32.00	8.00	960.00	60.00	2.73	163.80	6,000.00	0.01
0.01	22.00	4.00	1,022.00	8.00	4.00	240.00	20.00	2.73	54.60	2,000.00	0.01
0.01	66.00	4.00	2,266.00	32.00	8.00	960.00	60.00	2.73	163.80	6,000.00	0.01
0.01	121.00	6.00	1,264.10	60.00	10.00	1,800.00	110.00	2.73	300.30	11,000.00	0.01

POST STRIP ETCH WASTE TOT $ COMPUTED	POST STRIP ETCH FLOW TIME COMPUTED	POST STRIP ETCH TOT COST $ COMPUTED	POST STRIP CONV COAT MANHOURS DATA	POST STRIP CONV COAT NO. OF PERS DATA	POST STRIP CONV COAT MANPOWER $ COMPUTED	POST STRIP CONV COAT GAL OF CHEM DATA	POST STRIP CONV COAT CHEM $/GAL DATA	POST STRIP CONV COAT TOT CHEM $ COMPUTED	POST STRIP CONV COAT WASTE GAL DATA	POST STRIP CONV COAT WASTE $/GAL DATA	POST STRIP CONV COAT WASTE COST TOT $ COMPUTED
0.00	0.00	0.00	0.00	8.00	0.00	0.00	12.63	0.00	0.00	0.01	0.00
121.00	6.00	2,221.30	60.00	10.00	1,800.00	200.00	12.63	2,526.00	20,000.00	0.01	220.00
22.00	2.00	316.60	8.00	4.00	240.00	40.00	12.63	505.20	2,000.00	0.01	22.00
66.00	4.00	1,189.80	32.00	8.00	960.00	110.00	12.63	1,389.30	11,000.00	0.01	121.00
121.00	6.00	2,221.30	60.00	10.00	1,800.00	200.00	12.63	2,526.00	20,000.00	0.01	220.00
66.00	4.00	1,189.80	32.00	8.00	960.00	110.00	12.63	1,389.30	11,000.00	0.01	121.00
22.00	2.00	316.60	8.00	4.00	240.00	40.00	12.63	505.20	2,000.00	0.01	22.00
22.00	2.00	316.60	8.00	4.00	240.00	40.00	12.63	505.20	2,000.00	0.01	22.00
22.00	2.00	316.60	8.00	4.00	240.00	40.00	12.63	505.20	2,000.00	0.01	22.00
22.00	2.00	316.60	8.00	4.00	240.00	40.00	12.63	505.20	2,000.00	0.01	22.00
66.00	4.00	1,189.80	32.00	8.00	960.00	110.00	12.63	1,389.30	11,000.00	0.01	121.00
66.00	3.00	769.80	18.00	6.00	540.00	60.00	12.63	757.80	11,000.00	0.01	121.00
121.00	7.50	4,321.60	120.00	16.00	3,600.00	400.00	12.63	5,052.00	20,000.00	0.01	220.00
22.00	2.00	316.60	8.00	4.00	240.00	40.00	12.63	505.20	2,000.00	0.01	22.00
22.00	2.00	316.60	8.00	4.00	240.00	40.00	12.63	505.20	2,000.00	0.01	22.00
66.00	4.00	1,189.80	32.00	8.00	960.00	110.00	12.63	1,389.30	11,000.00	0.01	121.00
22.00	2.00	316.60	8.00	4.00	240.00	40.00	12.63	505.20	2,000.00	0.01	22.00
66.00	4.00	1,189.80	32.00	8.00	960.00	110.00	12.63	1,389.30	11,000.00	0.01	121.00
121.00	6.00	2,221.30	60.00	10.00	1,800.00	200.00	12.63	2,526.00	20,000.00	0.01	220.00
22.00	2.00	316.60	8.00	4.00	240.00	40.00	12.63	505.20	2,000.00	0.01	22.00
66.00	4.00	1,189.80	32.00	8.00	960.00	110.00	12.63	1,389.30	11,000.00	0.01	121.00
66.00	4.50	1,309.80	19.00	8.00	570.00	110.00	12.63	1,389.30	11,000.00	0.01	121.00
121.00	6.00	2,221.30	60.00	10.00	1,800.00	200.00	12.63	2,526.00	20,000.00	0.01	220.00
66.00	4.00	1,189.80	32.00	8.00	960.00	110.00	12.63	1,389.30	11,000.00	0.01	121.00
22.00	2.00	316.60	8.00	4.00	240.00	40.00	12.63	505.20	2,000.00	0.01	22.00
66.00	4.00	1,189.80	32.00	8.00	960.00	110.00	12.63	1,389.30	11,000.00	0.01	121.00
121.00	6.00	2,221.30	60.00	10.00	1,800.00	200.00	12.63	2,526.00	20,000.00	0.01	220.00

POST STRIP CONV COAT FLOW TIME COMPUTED	POST STRIP CONV COAT TOT COST $ COMPUTED	OVERALL SUMMARY FLOW TIME HOURS COMPUTED	OVERALL SUMMARY SHIFTS/DAY DATA	OVERALL SUMMARY FLOW TIME DAYS COMPUTED	OVERALL SUMMARY MATERIAL COST COMPUTED	OVERALL SUMMARY MANHOURS COMPUTED	OVERALL SUMMARY MANPOWER COST COMPUTED	OVERALL SUMMARY WASTE DISPOSAL COST COMPUTED	OVERALL SUMMARY TOTAL COST PER AIRCRAFT COMPUTED	OVERALL SUMMARY COST/SQ FT COMPUTED	OVERALL SUMMARY AIRCRAFT PER YEAR DATA
0.00	0.00	171.66	3.00	7.15	10,854.19	1,093.00	32,790.00	5,052.80	48,696.99	4.87	52.00
6.00	4,546.00	219.42	3.00	9.14	7,967.30	1,264.80	37,944.00	2,167.00	48,078.30	4.81	36.00
2.00	767.20	170.00	3.00	7.08	3,892.25	680.00	20,400.00	13,768.00	38,060.25	17.30	100.00
4.00	2,470.30	135.00	3.00	5.63	7,132.40	868.00	26,040.00	23,319.00	56,491.40	4.36	50.00
6.00	4,546.00	153.00	3.00	6.38	11,337.26	1,258.00	37,740.00	35,583.00	84,660.26	4.86	50.00
4.00	2,470.30	147.90	3.00	6.16	2,697.96	623.59	18,707.68	1,155.84	22,561.48	2.26	52.00
2.00	767.20	61.11	3.00	2.55	3,792.63	272.16	8,164.94	66.00	12,023.57	6.50	150.00
2.00	767.20	89.92	3.00	3.75	5,254.33	359.67	10,790.00	709.68	16,754.00	7.62	100.00
2.00	767.20	113.01	3.00	4.71	3,144.17	429.05	12,871.38	745.94	16,761.49	7.62	24.00
2.00	767.20	121.50	3.00	5.06	3,468.97	463.01	13,890.32	835.66	18,194.95	7.28	65.00
4.00	2,470.30	117.97	3.00	4.92	17,825.63	967.72	29,031.67	2,666.31	49,523.61	3.82	50.00
3.00	1,418.80	123.63	2.00	10.30	14,217.97	693.49	20,804.76	1,752.45	36,775.18	2.84	30.00
7.50	8,872.00	199.66	3.00	8.32	16,282.19	3,268.20	98,046.01	4,436.80	118,765.00	3.71	42.00
2.00	767.20	52.77	3.00	2.20	6,733.08	161.53	4,846.00	108.80	11,687.89	5.31	100.00
2.00	767.20	57.66	3.00	2.40	2,725.96	134.16	4,024.91	108.80	6,859.68	3.12	100.00
4.00	2,470.30	81.33	3.00	3.39	8,503.04	378.66	11,359.91	349.00	20,211.95	1.56	50.00
2.00	767.20	507.33	3.00	21.14	2,694.05	2,029.33	60,880.00	10,192.13	73,766.18	33.53	100.00
4.00	2,470.30	140.43	3.00	5.85	3,023.94	673.79	20,213.75	1,832.85	25,070.54	1.94	50.00
6.00	4,546.00	102.38	3.00	4.27	4,390.71	843.00	25,290.00	2,661.50	32,342.21	1.86	50.00
2.00	767.20	94.37	3.00	3.93	1,938.44	357.11	10,713.33	444.91	13,096.69	5.95	100.00
4.00	2,470.30	140.45	3.00	5.85	7,515.97	853.79	25,613.75	1,832.85	34,962.57	2.70	50.00
2.38	2,080.30	130.41	2.00	10.87	6,697.73	887.00	26,610.00	818.40	34,126.13	2.64	30.00
6.00	4,546.00	149.38	3.00	6.22	10,434.66	1,219.00	36,570.00	2,661.50	49,666.16	2.85	50.00
4.00	2,470.30	145.08	3.00	6.05	8,772.20	1,040.33	31,210.00	1,034.13	41,016.33	4.10	24.00
2.00	767.20	103.83	3.00	4.33	4,286.61	458.95	13,768.57	550.57	18,605.75	8.46	100.00
4.00	2,470.30	123.97	3.00	5.17	14,515.17	1,207.58	36,227.50	2,119.98	52,862.66	4.08	50.00
6.00	4,546.00	125.75	3.00	5.24	19,076.08	1,634.00	49,020.00	3,112.23	71,208.30	4.09	50.00

OVERALL SUMMARY TOTAL COST PER YEAR COMPUTED	IMPLEMENT COST STRIPPING UNITS REQ'D DATA (CAN COMPUT FROM # NOZS)	IMPLEMENT COST $/UNIT DATA	IMPLEMENT COST TOTAL STRIP UNIT COST COMPUTED	IMPLEMENT COST COMPRESSORS REQ'D DATA	IMPLEMENT COST $/COMP DATA	IMPLEMENT COST TOTAL COMP COST COMPUTED	IMPLEMENT COST RECOVERY SYS COST COMPUTED	IMPLEMENT COST VENTILATION COST COMPUTED	IMPLEMENT COST ROBOT MANIP COST COMPUTED	IMPLEMENT COST OTHER COST (SPECIFY) DATA	IMPLEMENT COST IMPLEMENTATION COST $ COMPUTED
2,532,243.48	4.00	3,000.00	12,000.00	O	O	0.00	O		0.00	0.00	12,000.00
1,730,818.80	7.00	3,000.00	21,000.00	O	O	0.00	O		0.00	0.00	21,000.00
3,806,025.00	2.00	3,000.00	6,000.00	O	O	0.00	O		0.00	0.00	6,000.00
2,824,570.00	5.00	3,000.00	15,000.00	O	O	0.00	O		0.00	0.00	15,000.00
4,233,013.00	7.00	3,000.00	21,000.00	O	O	0.00	O		0.00	0.00	21,000.00
										SITE PREP/CONST	
1,173,196.77	1.00	100,000.00	100,000.00	0.00	0.00	0.00	150,000.00	0.00	3,900,000.00	1,170,000.00	5,320,000.00
1,803,535.24	4.00	25,000.00	100,000.00	1.00	100,000.00	100,000.00	200,000.00	275,000.00	0.00	0.00	675,000.00
1,675,400.48	4.00	70,000.00	280,000.00	2.00	20,000.00	40,000.00	220,000.00	220,000.00	0.00	0.00	760,000.00
402,275.77	4.00	70,000.00	280,000.00	2.00	20,000.00	40,000.00	220,000.00	220,000.00	0.00	0.00	540,000.00
1,182,671.67	4.00	70,000.00	280,000.00	2.00	20,000.00	40,000.00	250,000.00	250,000.00	0.00	0.00	570,000.00
2,476,180.50	8.00	70,000.00	560,000.00	4.00	20,000.00	80,000.00	1,295,000.00	400,000.00	0.00	0.00	2,335,000.00
1,103,255.38	5.00	58,000.00	290,000.00	2.00	23,500.00	47,000.00	0.00	165,000.00	0.00	0.00	502,000.00
4,988,130.19	20.00	70,000.00	2,500,000.00	1.00	100,000.00	100,000.00	0.00	400,000.00	0.00	0.00	3,000,000.00
										TANKS	
1,168,788.61	2.00	265,000.00	530,000.00	2.00	125,000.00	250,000.00	110,000.00	0.00	5,000,000.00	250,000.00	6,140,000.00
										TANKS	
685,967.61	1.00	1,500,000.00	1,500,000.00	1.00	100,000.00	100,000.00	18,000.00	0.00	2,500,000.00	250,000.00	4,368,000.00
1,010,597.51	2.00	1,500,000.00	3,000,000.00	2.00	100,000.00	200,000.00	36,000.00	0.00	5,000,000.00	250,000.00	8,486,000.00
							(FILTER)				
7,376,618.33	4.00	45,000.00	180,000.00	1.00	20,000.00	20,000.00	100,000.00	0.00	0.00	0.00	300,000.00
1,253,527.11	3.00	45,000.00	135,000.00	1.00	20,000.00	20,000.00	100,000.00	0.00	0.00	0.00	255,000.00
1,617,110.39	4.00	45,000.00	180,000.00	1.00	20,000.00	20,000.00	100,000.00	0.00	0.00	0.00	300,000.00
							(FILTER)				
1,309,668.61	4.00	45,000.00	180,000.00	1.00	20,000.00	20,000.00	100,000.00	0.00	0.00	0.00	300,000.00
1,748,128.67	4.00	45,000.00	180,000.00	1.00	20,000.00	20,000.00	100,000.00	0.00	0.00	0.00	300,000.00
1,023,783.98	6.00	67,250.00	403,500.00	1.00	20,000.00	20,000.00	37,000.00	0.00	0.00	0.00	460,500.00
2,483,307.89	5.00	45,000.00	225,000.00	1.00	20,000.00	20,000.00	100,000.00	0.00	0.00	0.00	345,000.00
	FROM # NOZS)						(H20 RECYC EQT)				
984,391.92	3.00	33,000.00	99,000.00	1.00	20,000.00	20,000.00	300,000.00	0.00	0.00	0.00	419,000.00
1,860,574.67	6.00	85,000.00	510,000.00	3.00	30,000.00	90,000.00	220,000.00	220,000.00	0.00	0.00	820,000.00
2,643,132.77	12.00	85,000.00	1,020,000.00	6.00	30,000.00	180,000.00	1,295,000.00	1,295,000.00	0.00	0.00	2,495,000.00
3,560,415.03	14.00	85,000.00	1,190,000.00	7.00	30,000.00	210,000.00	1,742,400.00	1,742,400.00	0.00	0.00	3,142,400.00

MAINTENANCE COST PER YEAR	PAYBACK YEARS COMPUTED	EQUIPMENT LIFE (YEARS) DATA	TOTAL LIFE CYCLE COSTS COMPUTED	LIFE CYCLE COST PER SQ FOOT
1,200.00		15.00	38,013,652.20	4.87
2,100.00		15.00	26,014,782.00	4.82
600.00		15.00	57,105,375.00	17.30
1,500.00		15.00	42,406,050.00	4.37
2,100.00		15.00	63,547,695.00	4.86
415,000.00		15.00	29,142,951.51	3.74
67,500.00		15.00	28,740,528.58	6.90
76,000.00		15.00	27,031,007.26	8.19
54,000.00		15.00	7,384,136.54	9.32
57,000.00		15.00	19,165,075.10	7.86
233,500.00		15.00	42,980,207.43	4.43
8,000.00		15.00	17,170,830.70	2.95
300,000.00		15.00	82,321,952.78	4.08
614,000.00		15.00	32,881,829.13	9.96
436,800.00		15.00	21,209,514.11	6.43
848,600.00		15.00	36,373,962.70	3.75
30,000.00		15.00	##############	33.76
25,500.00		15.00	19,440,406.58	2.00
30,000.00		15.00	25,006,655.80	1.91
30,000.00		15.00	20,395,029.17	6.18
30,000.00		15.00	26,971,930.01	2.78
46,050.00		15.00	16,508,009.72	2.83
34,500.00		15.00	38,112,118.30	2.92
41,900.00		15.00	15,813,378.74	4.39
82,000.00		15.00	29,958,620.09	9.08
249,500.00		15.00	45,884,491.61	4.72
314,240.00		15.00	61,262,225.48	4.69

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APPENDIX C

A LIFE CYCLE COST COMPARISON OF NUMBERS USED IN THE ANALYSIS VS WARNER-ROBINS ESTIMATES

	PMB '94 WR CCM Estimates	MPW '94 WR CCM Estimates	PMB '96 Lockheed	MPW '93 Battelle
Investment Costs				
Stripping Unit costs	$560,000	$180,000	$290,000	$403,500
Compressor costs	$80,000	$20,000	$47,000	$20,000
Recovery system	$1,295,000	$100,000	a	$37,000
Ventilation system	$400,000	$0	$165,000	$0
Facility cost	$2,496,000	$2,496,000	$2,496,000	$2,496,000
Facility conversion costs			$200,000	$0
Total Investment Costs	**$4,831,000**	**$2,796,000**	**$3,198,000**	**$2,956,500**
Operation & Support Costs				
Manpower costs	$10,696,050	$9,436,797	$7,665,034	$9,803,842
Materials	$6,567,444	$2,769,086	$5,238,284	$2,467,626
O & M	$2,867,590	$368,427	$294,742	$565,535
Waste disposal	$982,342	$675,273	$645,652	$301,521
Time out of Service (Implicit cost)	$602,611	$716,519	$630,782	$665,077
Total O & S Costs	**$21,716,036**	**$13,966,102**	**$14,474,492**	**$13,803,601**
Disposal Costs				
Facility	($836,160)	($836,160)	($836,160)	($836,160)
Life Cycle Costs	**$25,710,876**	**$15,925,942**	**$16,836,332**	**$15,923,941**
Notes: a. Recovery costs included in cost of stripping unit investment costs				

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13. ABSTRACT *(Maximum 200 words)*

The Air Force must periodically strip and paint its aircraft to prevent the damaging effects of corrosion. The paint removal process typically involves the use of toxic chemicals such as methylene chloride which are soon to be banned as a result of impending environmental regulations and increased costs associated with handling and disposing of such material. The Air Force must choose an alternative to methylene chloride chemical stripping which complies with environmental regulations and reduces costs. This thesis compares the life cycle costs and environmental impacts of two alternatives to chemical aircraft stripping. Plastic Media Blasting (PMB) and Modified Medium Pressure Water (MPW) are compared based on stripping a C-130 aircraft by the PMB process at the Lockheed Aircraft Service Center in Ontario, CA and the MPW process by Warner-Robins AFB, GA. The results of the study indicate that MPW has the lower life cycle costs.

14. SUBJECT TERMS

aircraft paint stripping, paint stripping, plastic media blasting, PMB, modified medium pressure water, MPW, depainting, life cycle costs, environmental, chemical stripping

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