

**BICARBONATE OF SODA BLASTING TECHNOLOGY
FOR AIRCRAFT WHEEL DEPAINTING**

by

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Technical Project Monitor

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NOTICE

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

Passage of the Pollution Prevention Act of 1990 marked a strong change in the U.S. policies concerning the generation of hazardous and nonhazardous wastes. This bill implements the national objective of pollution prevention by establishing a source reduction program at the EPA and by assisting States in providing information and technical assistance regarding source reduction. In support of the emphasis on pollution prevention, the "Waste Reduction Innovative Technology Evaluation (WRITE) Program" has been designed to identify, evaluate, and/or demonstrate new ideas and technologies that lead to waste reduction. These methods reduce or eliminate transportation, handling, treatment, and disposal of hazardous materials in the environment. The technology evaluation project discussed in this report emphasizes the study and development of methods to reduce waste and prevent pollution.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

ABSTRACT

This evaluation addressed product quality, waste reduction/pollution prevention and economics in replacing chemical solvent strippers with a bicarbonate of soda blasting technology for removal of paint from aircraft wheels. The evaluation was conducted in the Paint Stripping Shop at Ellington Field, National Aeronautics and Space Administration/Lyndon B. Johnson Space Center (NASA/JSC), in Houston, Texas. The evaluation used limited new test data, information from previous tests by NASA/JSC as part of their program to adopt this process as a nondestructive inspection of aircraft wheels, cost estimates for the chemical stripping and bicarbonate blasting based on facility records. Because the paint being removed contained hazardous metal constituents, the liquid and solid wastes as well as the cloud of spray generated were evaluated for metal concentrations present and their leachability. Analyses for Cd, Cr, Cu, Pb, Mn, Ni, and Zn were made as well as total metals concentrations, Ph, total suspended solids, and oil and grease. The blasting technology is effective for removing paint from aircraft wheels without significant damage to the anodized surface under the paint. Engineering improvements that avoid the need of respirators, reduce noise levels and minimize water use could enhance the application. Applications that do not contain hazardous materials in the coating being removed could be significantly more lucrative. In comparison to solvent depainting this technology reduced the amount of hazardous waste generated as well as cost savings due to operating and disposal costs, resulting in a 15% return on investment in about 4 years.

This report was submitted in partial fulfillment of Contract Number 68-C0-0003, Work Assignment 2-36, under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from June 1991 to May 1992, and the study was completed as of May 31, 1992.

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SECTION 1

PROJECT DESCRIPTION

The objective of the U.S. Environmental Protection Agency's (U.S. EPA) Waste Reduction Innovative Technology Evaluation (WRITE) Program is to evaluate, in a typical workplace environment, examples of prototype technologies with potential for reducing wastes at the source or for preventing pollution. In general, when evaluating each technology, three issues are addressed.

First, is the new technology effective? Waste reduction and pollution prevention technologies involve using either substitute materials or techniques, or recycling or reusing materials. It is important to verify that the quality of the materials and the quality of the work product are satisfactory for the intended purpose. Second, does using the technology measurably reduce waste and/or prevent pollution? Last, the economics of the new technology must be quantified and compared with the economics of the existing technology and/or the technology to be replaced. It should be noted, however, that improved economics is not the only criterion for using the prototype technology. There may be harder to quantify justifications such as reduced liability, greater safety, better morale, and improved company public relations that would encourage adoption of new operating approaches.

This evaluation involves a commercially available technology, offered by a specific manufacturer, for coating removal. The technology evaluated is marketed by CDS Group, a joint marketing venture of Church & Dwight Co., Inc. (Princeton, New Jersey) and Schmidt Manufacturing, Inc. (Fresno, Texas). Other bicarbonate of soda blasting technologies for similar applications may be commercially available from other manufacturers.

1.1 PROJECT OBJECTIVES

The goal of this study is to evaluate a bicarbonate of soda depainting technology that uses sodium bicarbonate-based blasting media, ARMEX[®], to replace chemical solvents for stripping paints from aircraft wheels. This study has three specific objectives:

1. To evaluate the effectiveness of the ARMEX[®]/ACCUSTRIP[™] process in stripping paints from aircraft wheels prior to a nondestructive inspection (NDI) for cracks and structural defects (see Section 1.4.1 and Section 2),
2. To evaluate the waste reduction/pollution prevention potential of this technology (see Section 1.4.2 and Section 3), and
3. To evaluate the cost of this technology versus that of the existing method using chemical solvents (see Section 1.4.3 and Section 4).

Because of limited resources available for the project, only a small number of experiments were performed during the on-site testing. The evaluation was designed based on the user's (NASA/JSC) requirements in terms of product quality and waste reduction/pollution control. This study evaluated the performance of the existing stripping equipment and pollution control devices and the wastestreams generated from the use of the equipment and devices. The stripping process evaluated also may be applicable to depainting, degreasing, and/or cleaning other thick-skin aircraft parts. However, the wastes generated from these processes must be examined on a case-by-case basis.

1.2 PAINT STRIPPING TECHNOLOGIES

1.2.1 Technologies to Be Replaced: Chemical Strippers

The most common approach for paint removal is application of organic solvents, mainly methylene chloride and phenol. The increasing concerns over the adverse effects of organic solvents on the environment and human health have resulted in more stringent regulations governing the use of these chemicals as paint strippers for aircraft depainting. These include bans on certain chemicals at some locations and restrictions on volatile organic compound (VOC) emissions and waste disposal.

Among the solvents, chlorinated and aromatic solvents have received the most attention because they have been widely used as paint strippers in the aerospace and aviation industry and they have been linked to numerous acute and chronic diseases, including cancers. Methylene chloride and phenols are the most common major constituents of solvent paint removers. For example, methylene chloride and several other solvents have been identified as some of the 17 priority chemicals in the 1988 Toxic Release Inventory (TRI) under Title 313 Superfund Amendments and Reauthorization Act (SARA). By 1992, the U.S. EPA wishes to reduce the release of these chemicals by one-third, and by 1995, reduce it by 50% (U.S. EPA, 1991).

Stringent environmental regulations have made the treatment and disposal of solvent-containing wastes difficult and expensive. Costs will continue to rise in the future, making it desirable to search for more environmentally and/or economically acceptable technologies for paint stripping.

1.2.2 Alternative Paint Stripping Technologies

Several new and "clean" paint stripping technologies are commercially available. These are bicarbonate of soda blasting, plastic media blasting (PMB), liquid nitrogen cryogenic blasting, carbon dioxide pellet cryogenic blasting, and nonhazardous chemical stripping. The first four technologies use

physical methods, such as abrasion, impact, and extreme cold, to remove old coatings. The last technology uses "environmentally acceptable" solvents as substitutes.

Nonhazardous chemical strippers contain no chlorinated solvents, phenols, creosols, or other highly toxic organic compounds (Ignasiak, 1991). They remove most of the common aircraft and aerospace coatings, including epoxies, polyurethanes, and epoxy primers. These strippers, however, cost more than the traditional strippers and take more time to work. Some of these strippers corrode magnesium and can cause hydrogen embrittlement of high-strength steels (Ignasiak, 1991). Therefore, workers must mask assemblies containing these alloys before stripping them.

Plastic media blasting (PMB) involves propelling pelletized plastic particles via compressed air. The particles impact the painted surface, fracturing the coatings and separating them from the substrate beneath. When used under a set of precisely controlled parameters, the plastic media impart negligible damage to the substrates and achieve fast paint removal rates (Haas, 1991). However, the media can impart significant damage to aluminum, composites, and fiberglass (Groshart, 1988). Other drawbacks of the technology include initial capital costs, the cleanliness requirement of the media, the amount of solid waste generated, and worker exposure to dust and noise.

The two cryogenic blasting technologies take advantage of extreme cold to embrittle and shrink old coatings. Nonabrasive plastic pellets or carbon dioxide pellets are then blasted to make the paint break away from the substrate. The technologies neither release toxic fumes to the atmosphere nor produce large quantities of solid wastes. Industrial applications of these technologies, however, have been limited because of their high capital costs.

Bicarbonate of soda blasting, the subject of this study, uses compressed air to deliver sodium bicarbonate media from a pressure pot to a nozzle where the media mix with a stream of water. The media/water mixture impacts the coated surface and removes old coatings from the substrate. The water used dissipates the heat generated by the abrasive process, aids the paint removal by hydraulic action, and reduces the amount of dust in the air (Lee and Kirschner, 1989). As another convenience, the workers do not need to prewash or mask the surface. The dust, unlike that of plastic media, is not an explosive hazard, nor is sodium bicarbonate toxic in this form. The airborne particulates generated from the stripping operation, however, can contain toxic elements from the paint being removed (Atkins, 1989). One manufacturer claims that liquid waste may be disposed of to Publically Owned Treatment Works (POTW) or other conventional wastewater treatment plants, and that the solid waste is suitable for a sanitary landfill (Church & Dwight Co., Inc.) but these claims remain to be verified.

The effectiveness of bicarbonate of soda blasting depends on optimizing a number of operating parameters including nozzle pressure, standoff distance, angle of impingement, media flow rate, water pressure, and traverse speed.

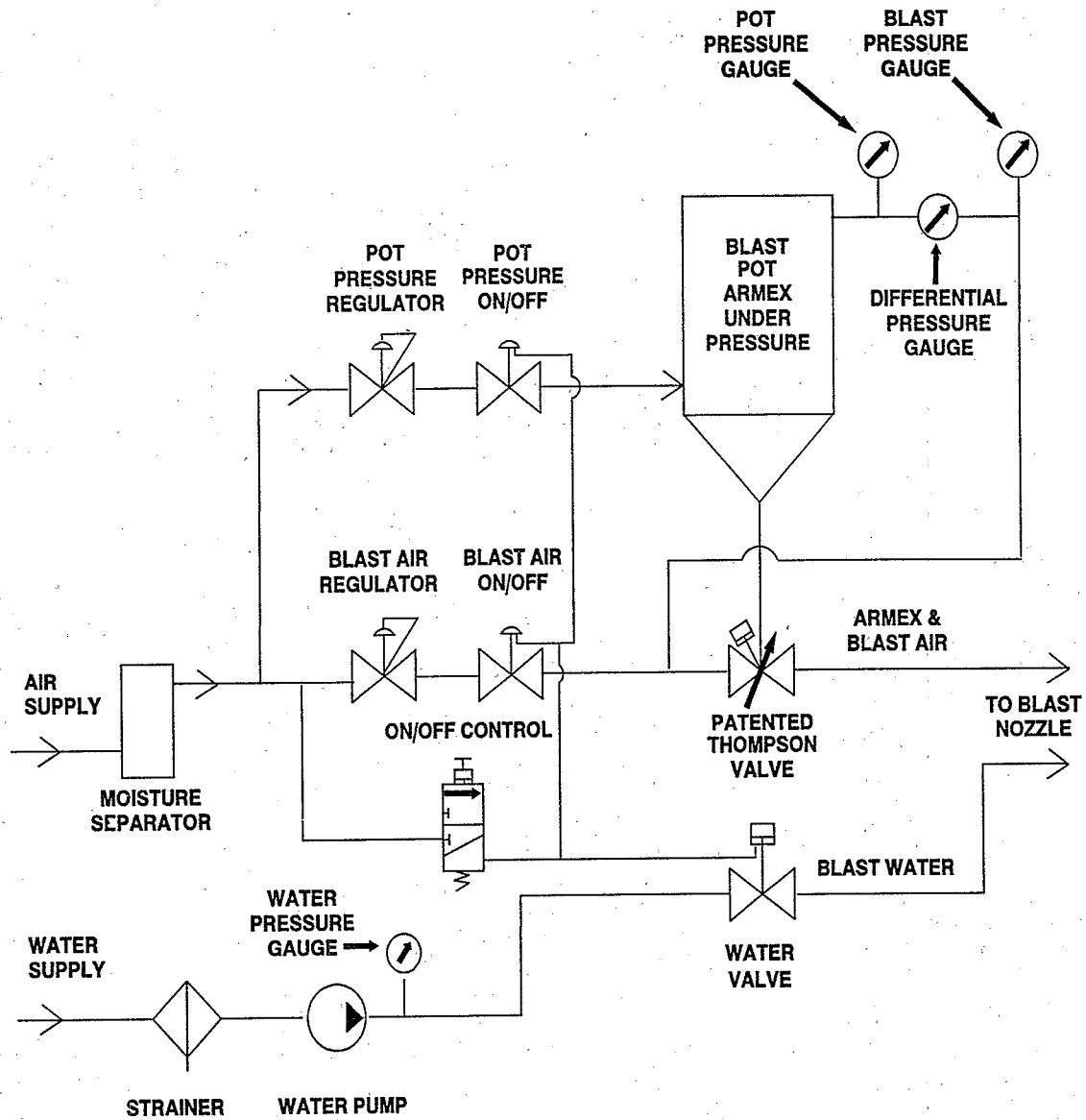
The present study evaluated the bicarbonate of soda blasting technology marketed by the CDS Group (Arcola, Texas). The evaluation was conducted in the Paint Stripping Shop (Building 137) at Ellington Field, National Aeronautics and Space Administration/Lyndon B. Johnson Space Center (NASA/JSC) in Houston, Texas.

1.2.3 Description of ARMEX[®]/ACCUSTRIP[™] Process

ARMEX[®] is a sodium bicarbonate-based blast media formulation manufactured by Church & Dwight Co., Inc. It is a white, crystalline material with a bulk density of 0.9771 g/mL (61 lb/ft³), a specific gravity of 2.22 g/mL (139 lb/ft³), and a hardness of 2.5 to 3.0 on the Mohs' scale (Lee and Kirschner, 1989). It decomposes at elevated temperatures to give various mixed bicarbonate/carbonate species, depending on time, temperature, and humidity. In aqueous solutions, it reacts with both acids and bases and maintains the pH at 8.3 over a wide range of concentrations (Stumm and Morgan, 1989).

At the time of on-site testing, three different formulas were available for the specific needs of industries. These include a composite formula (for delicate substrates such as plastics, graphites, fiberglass, etc.) at a particle size of 75 μ m, a maintenance formula (for maintenance and cleaning of process equipment and parts) at 175 μ m, and an aviation formula (for aircraft skin and airframe) at 275 μ m. The ACCUSTRIP SYSTEM[™], engineered and manufactured by Schmidt Manufacturing, Inc., blasts the sodium bicarbonate media. A typical flow diagram is illustrated in Figure 1-1. A typical ACCUSTRIP SYSTEM[™] and a wet blast head are presented in Figure 1-2. Four standard models are available; their dimensions and capacities are listed in Table 1-1.

During operation, the system delivers a mixture of blast media and water at a pressure of about 207 to 414 kPa (30 to 60 psi) through a blast nozzle. The hand-held, hand-actuated nozzle is maintained at a standoff distance (distance from the nozzle to the surface to be stripped) of 0.31 to 0.61 M (12 to 24 in) and an impingement angle of 30 to 80 degrees. The media flow rate is 0.45 to 1.8 kg/min (1 to 4 lb/min) and the water flow rate is 1.9 L/min (0.5 gal/min). The production rate is about 0.14 to 0.23 m²/min (1.5 to 2.5 ft²/min) (data based on urethane-type coatings up to 4 mils).



Source: Schmidt Manufacturing, Inc.

Figure 1-1. Typical ACCUSTRIp SYSTEM™ flow diagram.

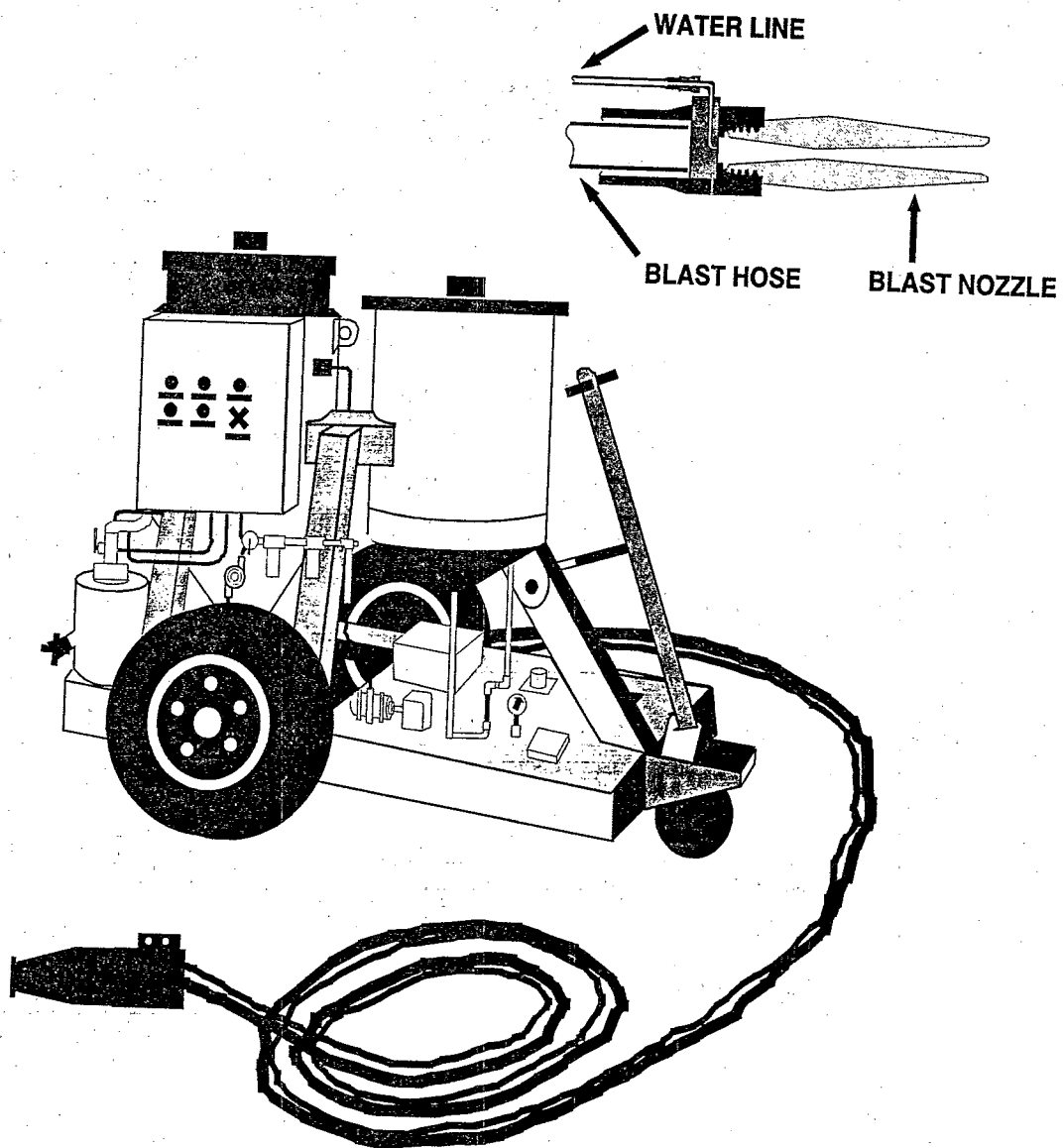


Figure 1-2. ACCUSTRIP SYSTEM™ with wet blast head.

TABLE 1-1. DIMENSIONS AND CAPACITIES OF ACCUSTRIP SYSTEM™

Model	Length		Width		Height		Approximate Weight		Media Tank		Water Tank		No. of Operators
	cm	in	cm	in	cm	in	kg	lb	m ³	ft ³	L	gal	
16W	170	66	137	54	185	64	549	1210	0.17	6	151	40	1
16	91	36	81	32	142	56	367	810	0.17	6	N/A	N/A	1
13	112	44	86	34	137	54	322	710	0.09	3	N/A	N/A	1
220	142	56	97	38	203	80	871	1920	0.57	20	N/A	N/A	2

1.3 TECHNOLOGY EVALUATION SITE

The NASA/JSC Aircraft Operation Division is responsible for maintenance and repair of a fleet of 37 aircraft (see Table 1-2) at Ellington Field. One of the many tasks is to perform nondestructive inspection (NDI) of aircraft wheels. The process involves depainting and cleaning the wheels, inspecting for cracks and structural defects, treating the surface, priming, and painting. The NDI preparation of the wheels after depainting involves ultrasonic alkaline cleaning, penetrant soaking, emulsifier soaking, water rinsing, and drying. The prepared parts are examined under fluorescent light in a dark room. Figure 1-3 shows a flow diagram of these activities.

TABLE 1-2. AIRCRAFT MAINTAINED AT THE NASA/JSC ELLINGTON FIELD

Type of Aircraft	Quantity	Function
T-38	28	Flight training
G-2	5	Shuttle training aircraft (STA) - simulating shuttle landing
G-1	1	Passenger plane
KC-135	1	Zero-gravity experiments
WB-57	2	High-altitude experiments, air sampling, experiments on O ₃ layer, etc.

Paint-Stripping Shop (Building 137)

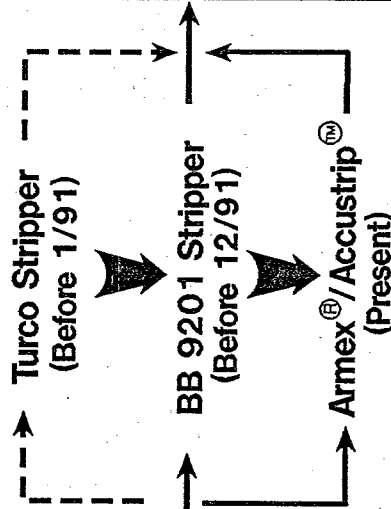
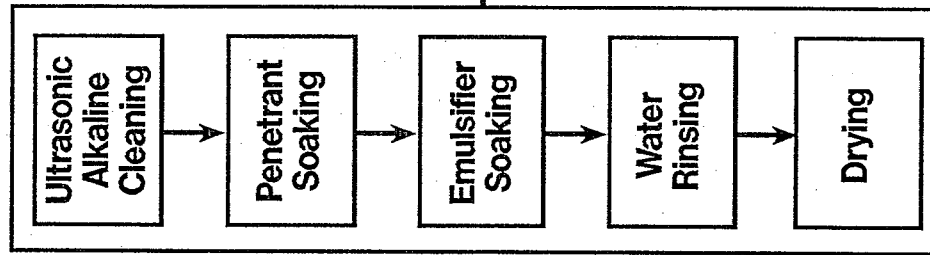
Paint Shop

NDI Building

Tireshop

Hangar

NDI*
Preparation



* NDI preparation not affected by the change of the paint stripping process.

Figure 1-3. Flow diagram of aircraft wheels maintenance program at the NASA/JSC Ellington Field.

1.3.1 Past Stripping Process

In the past, tire/wheel assemblies were removed from the aircraft in one of the three large hangars and the one small hangar and taken to a tire shop. The wheels, including outboard and inboard wheel pieces, were forwarded to the paint-stripping shop (Building 137, see layout in Figure 1-4) for depainting. The wheels were soaked in a 1.22 m x 1.22 m x 1.22 m (4 ft x 4 ft x 4 ft) tank containing BB 9201 phenolic-based stripper heated to between 32.2 and 37.8°C (90 and 100°F). (Prior to January 1991, a Turco chemical stripper containing 55% methylene chloride, 20% phenol, and 1% sodium chromate was used. However, because of lack of historical data, no comparison was made to the bicarbonate system during this evaluation study.) After a certain period of time, the wheels were removed for brushing, sanding, and rinsing on the handwork table. Repetitive soaking and handworking often were needed. The solvent-containing liquid along with the paint chips flowed into two 1.22 m x 1.22 m x 0.61 m (4 ft x 4 ft x 2 ft) vats covered with grates. After gravity settling, the liquid flowed into a sump and then was pumped to a 18,900-L (5,000-gal) storage tank located just outside of the stripping shop. The solids in the vats were manually drummed for disposal.

The spent chemical stripping fluid was hauled away for fuel blending in an incinerator. The stripping sludge solids were drummed and disposed of at a rate of 8 to 10 drums per month at a cost of about \$200 to \$300/drum. The wastewater was tanked every 3 months (about 15,000 L [4,000 gal]) for deepwell disposal at a cost of 5.3¢/L (20¢/gal).

1.3.2 Current ARMEX®/ACCUSTRIP™ Stripping Process

The paint-stripping shop was remodeled to accommodate the ARMEX®/ACCUSTRIP™ process and began operation in December 1991. As shown in Figure 1-5, the BB 9201 stripper tank remained in the stripping room and served as a backup. The ARMEX®/ACCUSTRIP SYSTEM™ (Model 16W), with necessary piping for water and air supplies, strips the wheels resting on either one of the turntables mounted atop the grates. Vats collect the liquid and solids underneath. The liquid, after gravity settling, is transferred to the 18,900-L (5000-gal) storage tank, whereas workers continue the past practice of drumming the solids manually.

An exhaust ventilation system was installed to control/remove the particulate cloud that forms as the blast media strike the surface. The exhaust system includes two ventilation hoods (three-sided exhaust enclosures measured at 1.22 m x 1.22 m x 1.22 m [4 ft x 4 ft x 4 ft]) installed on top of the vats. The average face velocity of the hood was measured to be 87 m/min (285 ft/min). Each hood is equipped with an exhaust duct at the top which draws air from the

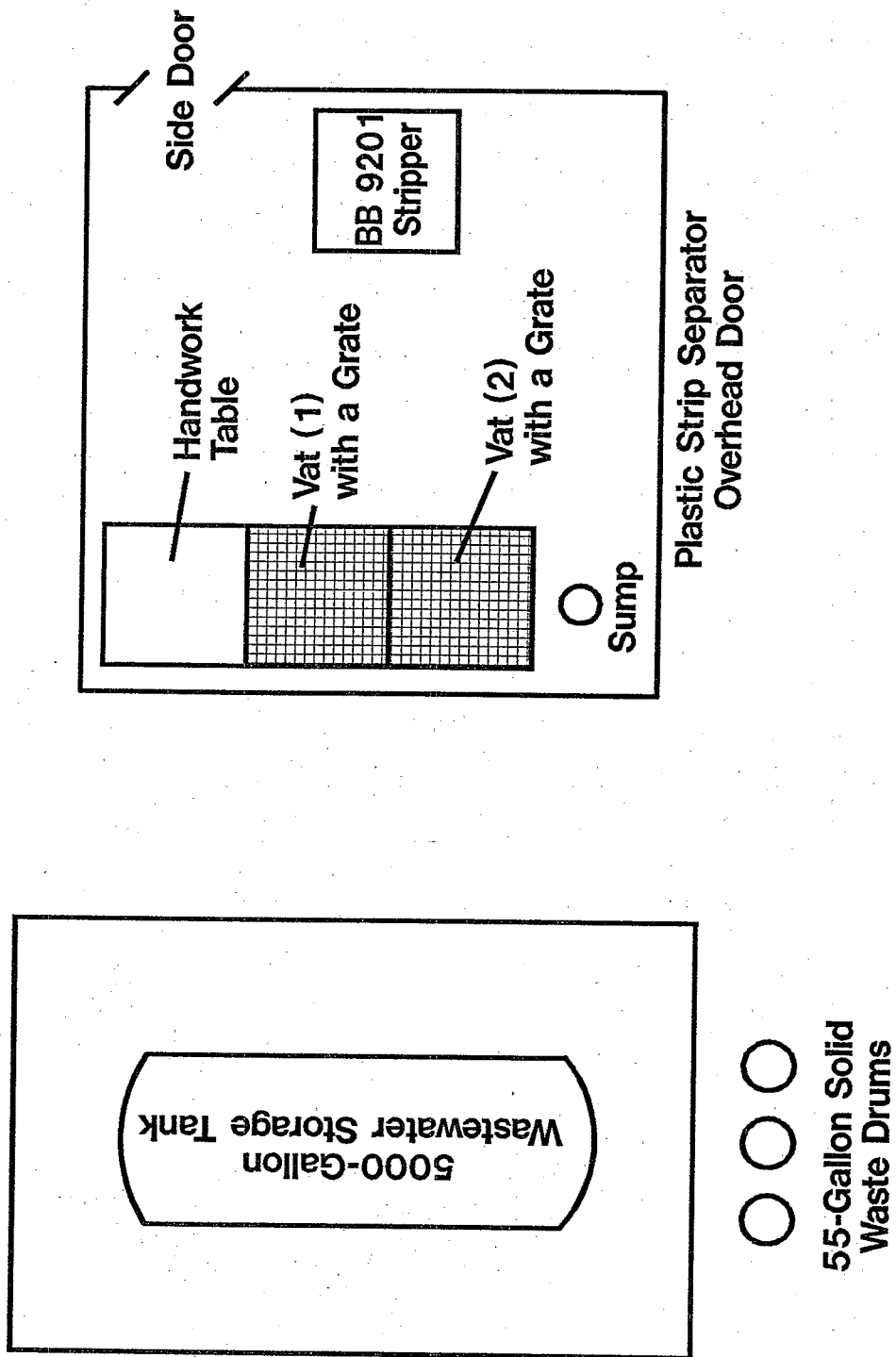


Figure 1-4. Layout of paint-stripping shop (Building 137).

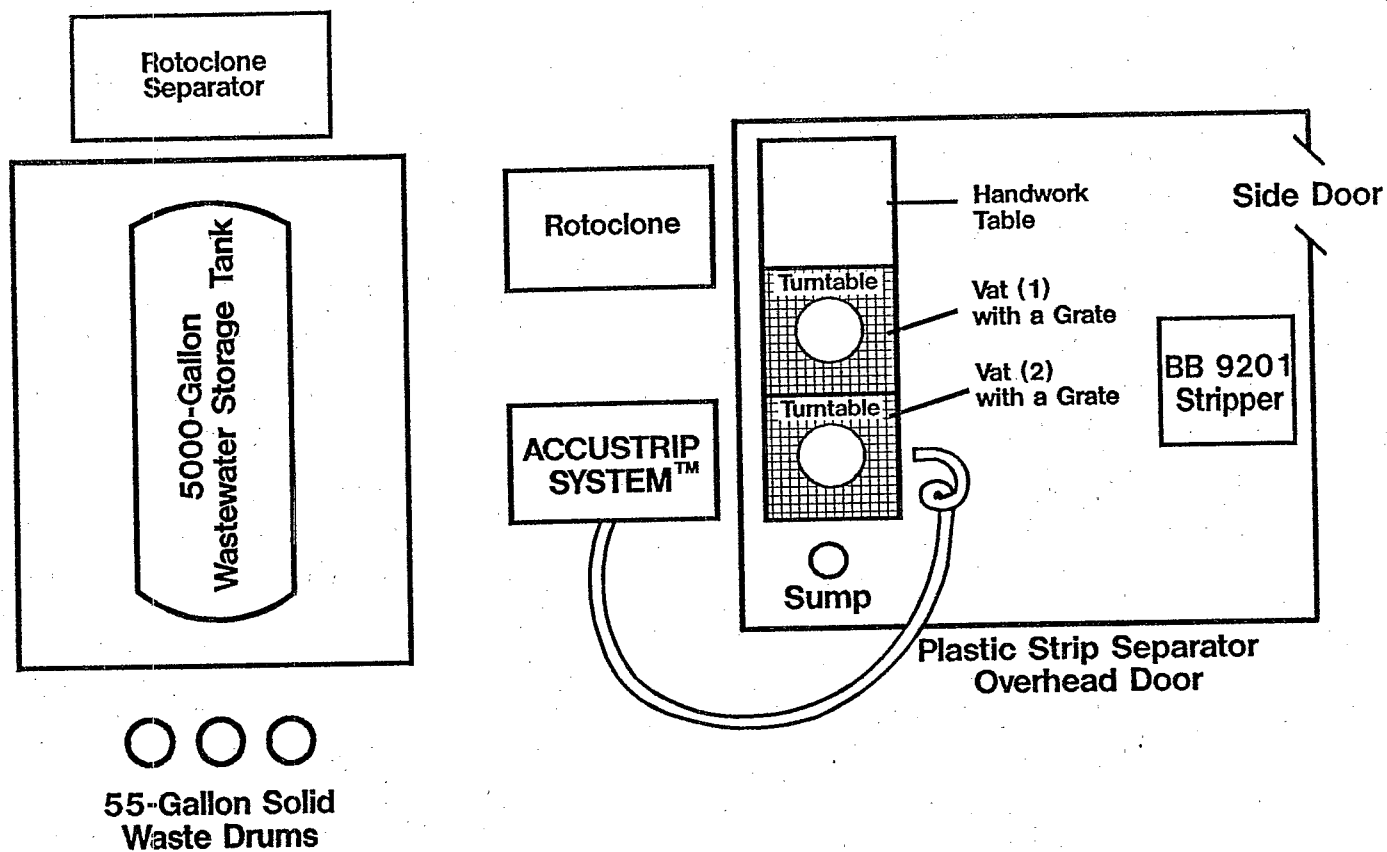


Figure 1-5. Paint-stripping shop modified for ARMEX®/ACCUSTRIP™ process.

enclosure and routes it through a rotoclone dust collection system external to the building. NASA/JSC's Environmental Health Services also requires the operators of the ACCUSTRIPE SYSTEM™ to wear a full-face air-purifying respirator (APR) with high-efficiency particulate air (HEPA) filters until the efficacy of the exhaust ventilation system can be evaluated (Atkins, 1989). The operators also must wear hearing protection.

1.4 EVALUATION APPROACH

Several measurements were performed during this evaluation study. Table 1-3 lists the measurements performed. The anodized surface damage was the only parameter measured when determining the paint removal process performance. The liquid and solid waste in the vat, the wastewater in the cyclone separator, the airborne particulates in the stripping room, and the noise generated during the blasting were analyzed and monitored to determine the waste reduction and pollution prevention potential. The time needed to strip each wheel was measured; the data were used in conjunction with other historical data for the economic assessment. The rationale for selecting these measurements is explained in the following sections.

1.4.1 Product Quality Assessment

NASA/JSC aircraft maintenance engineers determined the effectiveness of the sodium bicarbonate blasting process based on complete paint removal without damage to the wheel surface that either modified metal performance or masked any cracks during inspection. Complete paint removal could be achieved by repeatedly blasting the wheel surface. After inspecting the blasted wheels and other thick-skin parts, NASA/JSC ruled out the possibilities of metal damage (Rountree, 1991). Other studies by Lee and Kirschner (1989), McDonald (1990), Stropki (1991), and Van Sciver (1989, 1990, 1991) also suggested negligible metal damage to thin-skin substrates. Based on a fatigue crack closure study (Williams, 1991) performed by the CDS Group under the request of NASA/JSC, NASA/JSC also concluded that the blasting would not impede conventional methods of fatigue crack detection.

One additional concern was the anodized layer below the paint. This thin (around 0.00001 of an inch) electrochemical oxide layer is used to improve the corrosion resistance of the metal. Because of the relative vulnerability of this layer between the paint and the metal and because, for practical purposes, the wheels could not be reanodized in the tire shop, the condition of this layer after repeated blasting was used to determine the effect of the blasting process.

TABLE 1-3. LIST OF MEASUREMENTS PERFORMED

Objective	Matrix Type	Parameter
Product quality	Aircraft wheel	Anodized surface damage
Waste reduction/ pollution prevention potential	Liquid waste in vats	Total suspended solids (TSS)
		Oil & grease
		pH
		Cd (total)
		Cr (total)
		Cu (total)
		Pb (total)
	Solid waste in vats, Toxicity Characteristic Leaching Procedure (TCLP) test for metals including:	Mn (total)
		Ni (total)
		Zn (total)
		Volume produced per wheel
		Cd (total & leachable)
		Cr (total & leachable)
		Cu (total & leachable)
	Wastewater collected in cyclone separator	Pb (total & leachable)
		Mn (total & leachable)
		Ni (total & leachable)
		Zn (total & leachable)
		Volume produced per wheel
		pH
		TSS
	Airborne particulates in stripping room	Cd (total)
		Cr (total)
		Cu (total)
		Pb (total)
		Mn (total)
	Noise level during ARMEX/ ACCUSTRIP™ process	Ni (total)
		Zn (total)
		Cr
		Cu
		Pb
		Zn
		Noise

Although NASA/JSC did not require an anodized surface damage inspection, this evaluation study did include a test method to assess the condition of the anodized layer after blasting. The test method, as suggested by NASA/JSC, involved inspection of the same wheel pieces after they were first stripped and after they were stripped, repainted, and restripped under the same operating conditions. The procedures of this method are detailed in Appendix A.

1.4.2 Waste Reduction/Pollution Prevention Potential Assessment

Bicarbonate of soda blasting eliminates the use of solvent strippers but still generates liquid and solid wastes. Three types of wastes were generated: liquid and solid wastes collected in the vats and wastewater collected in the rotocloner separator. The liquid waste in the vats was sampled after the bulk of the solid waste gravity-settled. The wastewater in the rotocloner separator was sampled at the completion of testing. The liquid waste had to meet local discharge limits for wastewater disposal (City of Houston, 1989), so wastewater samples were quantified for pH, total suspended solids (TSS), oil and grease, and heavy metal concentrations (including Cd, Cr, Cu, Pb, Mn, Ni, and Zn).

From these analyses, it could be determined whether the wastewater could be disposed of to the POTW or had to be tanked away for treatment and/or disposal. The total waste volume produced by the bicarbonate blasting technology was required to allow comparison with that produced by the previously used solvent stripping method.

The sodium bicarbonate blasting media alone will not result in the solid waste being a RCRA hazardous waste. Pigments in the paint chips may contain metals included in the RCRA TCLP. These metals may be sufficiently leachable to cause the solid waste to exhibit a RCRA toxicity characteristic. In addition to the RCRA metals potentially in the paint chips, several other metals were included in the analysis due to their presence in paint and their potential for risks to human health and the environment. The total metal concentration also was measured to more fully characterize the solid wastestream. The metals included in the analysis were Cd, Cr, Cu, Pb, Mn, Ni, and Zn. The volume of solid waste generated also was measured. Knowing the waste volume and the leachability characteristics could allow NASA/JSC to determine a proper means of disposal.

The hazards that the new technology might pose to workers were evaluated. These included toxic airborne particulates and unsafe noise exposures. Air quality was measured in terms of airborne metal concentrations. Noise levels were measured on a sound-level meter and a dosimeter using an A-filter and a C-filter. The reading on an A-weighted scale enables one to determine if unsafe noise levels are produced; if they are, then the reading on a C-weighted scale expedites the selection of proper hearing protection.

1.4.3 Economic Assessment

Evaluating the economic worth of the current technology was a comparative process. All costs associated with the old stripping practices were identified, evaluated, and compared with those associated with changing to and maintaining the ARMEX[®]/ACCUSTRIP[™] technology. In general, cost estimation included capital, operating, and waste disposal costs.

Costs associated with the past practice included capital equipment and Turco chemical stripper costs, as well as the total man-hours spent stripping the aircraft wheels. This total work time included practicing safety procedures, soaking and scrubbing the wheels, and handling liquid and solid wastes. Changing to the current technology demanded spending for capital equipment and materials, miscellaneous startup costs, and operation and maintenance (O&M) costs. The facilities were revamped to accommodate the pressurized nozzle operation. To address the concerns over the workers' exposure to potentially toxic airborne particulates from paint removal debris, an exhaust ventilation system composed of a cyclone separator, intake piping, and two hoods was installed. Much of the economic assessment used historical data. However, certain costs cannot be determined without data on the waste volume characteristics and other performance characteristics of the bicarbonate blasting system determined by this study. To estimate disposal costs, for example, one must estimate the volume of waste generated and identify the particular disposal methods.

SECTION 2

PRODUCT QUALITY EVALUATION

The product quality was measured in terms of anodized surface damage. Anodizing is a commonly used electrochemical finishing procedure that forms an oxide coating on the metallic surface to improve corrosion resistance of that metal. The anodized film on the aircraft wheels often is less than one ten-thousandth of an inch thick. A special test method was developed to qualitatively assess the anodized surface damage resulting from bicarbonate of soda blasting. The method required visual inspection of the same wheel after it was stripped and after it was repainted and restripped under the same stripping conditions.

This study did not evaluate the effects of bicarbonate stripping on metal substrate damage and crack closure. Studies performed by the bicarbonate media manufacturer (Lee and Kirschner, 1989; McDonald, 1990; Van Sciver, 1989, 1990, 1991; Williams, 1991), an independent laboratory (Stropki, 1991), and the U.S. military (Haas, 1991; Singerman, 1991), have demonstrated negligible metal substrate damage due to media impact or substrate corrosion, and have shown no signs of impediment to conventional methods of fatigue crack detection.

The concern over the substrate corrosion caused by corrosive residues entrapped within aircraft structures and crevices has been the focus of many studies (Lee and Kirschner, 1989; McDonald, 1990; Stropki, 1991; Van Sciver, 1989, 1990, 1991), but was not known to be a problem. Sodium carbonate, a main contributing factor to metal substrate corrosion, was not detected as a chemical decomposition by-product under simulated aircraft operating conditions (Stropki, 1991).

The crack closure test was performed by the media manufacturer on 16 Al2024 T3 alclad (0.81-mm [0.32-in]) panels that were prepared according to ASTM Method E647 using a Krouse 5-Kip, DDS fatigue machine. The cracks induced were about 6.35 to 9.5 mm (0.25 to 0.375 in) long. The test procedures and scanning electron micrographs of the alclad test panels are presented in Appendix B. The electron micrographs were taken sequentially:

1. After fatigue cracks were induced (Figure B-1),
2. After the crack-induced panels were painted with military specification epoxy primer and polyurethane topcoat (Figure B-2), and
3. After the ARMEX[®] media blasting at 551 kPa (80 psi) pressure using a 60-degree blast angle, 30.5-cm (12-in) standoff, and 1.4-kg/min (3-lb/min) media flow (Figure B-3).

The results of the study indicated that the bicarbonate of soda stripping did not impede conventional methods of fatigue crack detection. Therefore, similar tests were not repeated during this evaluation study.

2.1 EXPERIMENTAL METHODS

2.1.1 Stripping of Aircraft Wheels

The wheel piece (either outboard or inboard) to be stripped was placed on the turntable mounted on top of the grates (Figure 1-5). The operator wearing the necessary safety attire (see Section 3.2.1) blasted the wheel with aviation-grade ARMEX[®] media at a media flow rate of 1.1 kg/min (2.5 lb/min), a water flow rate of 1.5-L/min (0.4 gal/min), and a nozzle pressure of 207 kPa (30 psi). The impingement angles ranged from 30 to 80 degrees and the standoff distance was about 15 to 30 cm (6 to 12 in). At times, the operator had to halt the blasting, rinse off the media from the stripped wheel, and examine the stripped area to determine if additional stripping was required. The stripping was continued until the operator believed that all paint layers had been removed from the surface of the wheel. After stripping, all eight outboard and inboard wheel pieces were cloth-dried and transferred to the tire shop for the anodized surface damage inspection.

2.1.2 Anodized Surface Damage Inspection

Two outboard and one inboard wheel pieces were selected for the anodized surface damage inspection. The anodized surface damage was assessed according to the procedures described in Appendix A. The stripped wheel pieces were first photographed from about 30 cm (1 ft) away with a camera equipped with a close-range lens capable of documenting any nicks and scratches or lack thereof. A team of three experienced NDI technicians then examined the three wheel pieces and recorded their observations on the data sheet, specifying whether any noticeable damage was observed and whether it was due to mechanical wear or incidental damage from the blasting. The data sheet includes four questions that were designed to qualitatively measure the incidental damage that wheels endured during the blasting.

After the inspection, all eight outboard and inboard wheel pieces were repainted with a zinc chromate primer and a clear aluminum finish coat mixed with an aluminum paste in the paint shop and allowed to dry for at least 12 hours. The wheel pieces were then restripped and photographed as earlier. The same inspection team then reexamined the same wheel pieces,

recorded new observations, especially signs of any new anodized surface damage, and documented their opinions regarding the cause of the new damage. This procedure compared stripping of recently dried paint with results of stripping significantly older paint and allowed effective assessment of the anodized surface damage due to bicarbonate blasting.

2.2 RESULTS AND DISCUSSION

Table 2-1 summarizes the results of the inspection. The wheel pieces selected for inspection were 6264 outboard, 6264 inboard, and 7755 outboard; their photographs after each of the two blasting sessions are presented in Figures 2-1 through 2-3. The questions were asked for each wheel piece during the inspection.

Question 1. Is there any surface damage?

The answers were unanimously yes for all wheel pieces inspected, indicating that surface damage always existed in some form.

Question 2. If yes, is it anodized surface damage? Describe other damage.

Again, the answers were yes for all wheel pieces inspected. Anodized surface damage was observed on all wheel pieces. In some cases, the damage was excessive. Other damage observed included a worn surface in areas around slots, ridges, and bead rim. This damage was believed to be caused by tool contact, wear, and tear. One inspector believed that the damage was due primarily to the paint stripping process used in the past that involved repetitive handworking such as brushing and sanding.

Question 3.1. Is the anodized surface damage due primarily to mechanical wear?

All three inspectors believed that the anodized surface damage was due primarily to mechanical wear. The mechanical wear occurred mainly around slots, the head rim area, the tire bead area, edges of the rim, holes for bolts, and areas where tools made contact. The wear was caused by tool contact, metal-to-metal contact, paint stripping in the past, and everyday tire wear.

TABLE 2-1. SUMMARY OF ANODIZED SURFACE DAMAGE INSPECTION

Question	Wheel No.	Run. No.	Inspector			Comments
			1	2	3	
1. Is there any surface damage?	6264 Outboard	1	yes	yes	yes	
		2	yes	yes	yes	
	6264 Inboard	1	yes	yes	yes	
		2	yes	yes	yes	
	7755 Outboard	1	yes	yes	yes	
		2	yes	yes	yes	
2. If yes, is it anodized surface damage?	6264 Outboard	1	yes	yes	yes	• Other damage - surface worn in areas around slots and ridges (2) ^a
		2	yes	yes	yes	• Other damage - surface worn around slots and bead rim area (2)
	6264 Inboard	1	yes	yes	yes	• Other damage - very little due to paint stripper in the past (3)
	7755 Outboard	2	yes	yes	yes	• Other damage - worn from tool contact, wear, and tear (2)
		1	yes	yes	yes	• Other damage - worn around ridges, holes, and bead areas (2)
3.1. Is the anodized surface damage due primarily to mechanical wear?	6264 Outboard	1	yes	yes	yes	• Worn around tire bead area (1)
						• Worn around edges of rim, holes for bolts and areas where tools make contact (2)
						• Worn due to paint stripper in the past (3)
		2	yes	yes	yes	• Worn around tire bead area (1)
						• Worn around edges and where there is tool contact or metal-to-metal contact (2)
		1	yes	yes	yes	• Worn around tire bead area (1)
	6264 Inboard					• Surface worn around slots and head rim area (2)
		2	Yes	Yes	Yes	• Worn around outer edges due to everyday tire wear (3)
						• Worn around tire bead area (1)

TABLE 2-1. SUMMARY OF ANODIZED SURFACE DAMAGE INSPECTION (Continued)

Question	Wheel No.	Run. No.	Inspector			Comments
			1	2	3	
3.2. Is the anodized surface damage due primarily to ARMEX® blasting?	7755 Outboard	1	yes	yes	yes	<ul style="list-style-type: none"> • Worn around ridges and holes from tool and metal-to-metal contact (2) • Worn at outer edges due to everyday tire wear (3) • Worn around tire bead area (1) • Worn at outer surface due to tire normal wear (3)
			yes	yes	yes	<ul style="list-style-type: none"> • Worn around tire bead area (1) • Worn around ridges, holes, and bead areas (2)
	6264 Outboard	1	No	No	yes ^b	
			No	No	yes ^b	
	6264 Inboard	1	No	No	No	
			No	No	N/A ^c	
3.3. Is the anodized surface damage due primarily to other causes?	7755 Outboard	1	No	No	No	• Appearance looks very good (3)
			No	No	Yes ^b	
	6264 Outboard	1	Yes	No	No	• Wheel has been stripped in a hot dip tank that deteriorated the anodized coating (1)
			No	N/A	N/A	
	6264 Inboard	1	N/A	No	No	
			No	No	N/A	
4. If this is a second run, do you notice any difference between this and the previous inspection?	7755 Outboard	1	Yes	N/A	No	• Possible use of hot dip tank deteriorated anodized coating (1)
			No	No	No	
	6264 Outboard	2	No	No	No	
			No	No	No	
	6264 Inboard	2	No	No	No	
			No	No	No	

^a Number in parentheses indicates inspector number.^b Inspector's answer inconsistent with his overall comments about the technology. "The new stripping process is much better."^c Question unanswered.

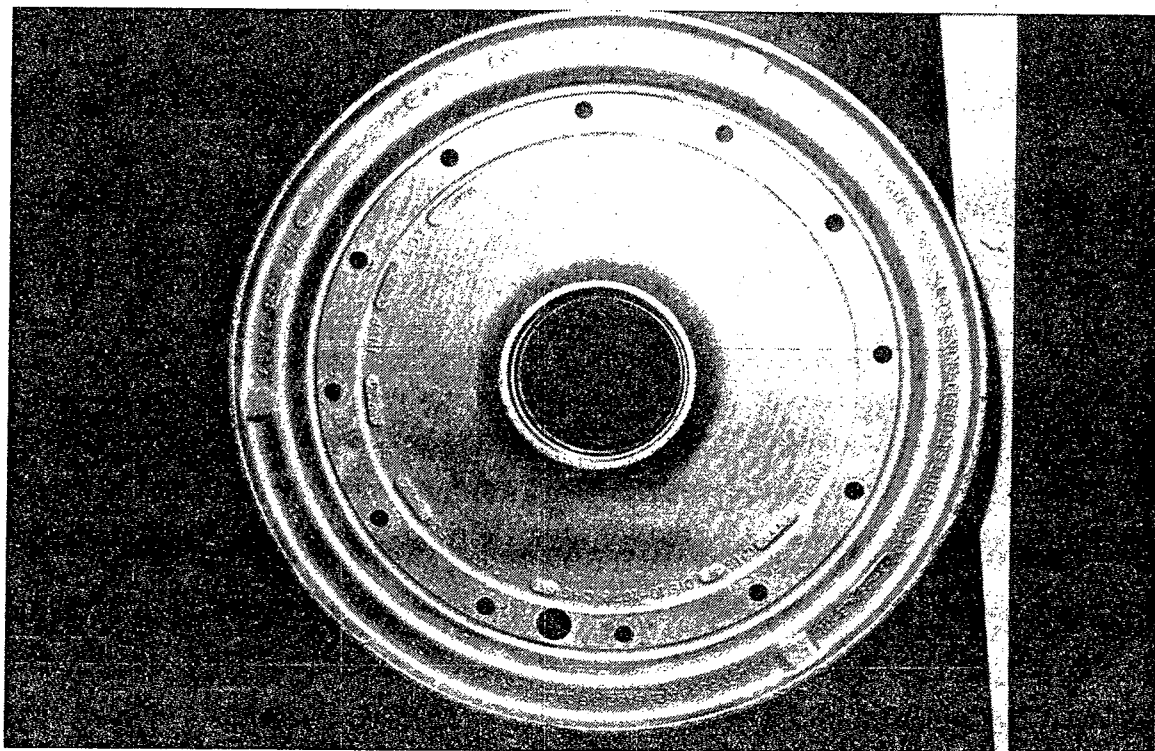
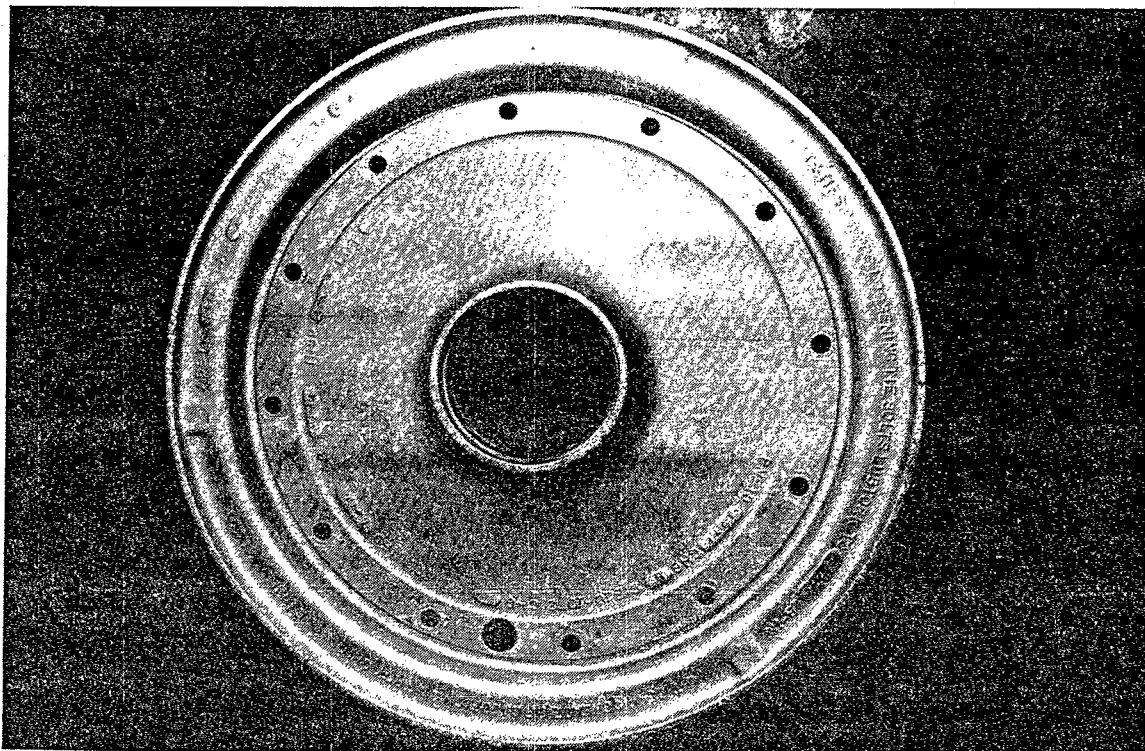


Figure 2-1. Photographs of aircraft wheel (SN 6264 outboard) taken after the first (top) and second (bottom) blasting.

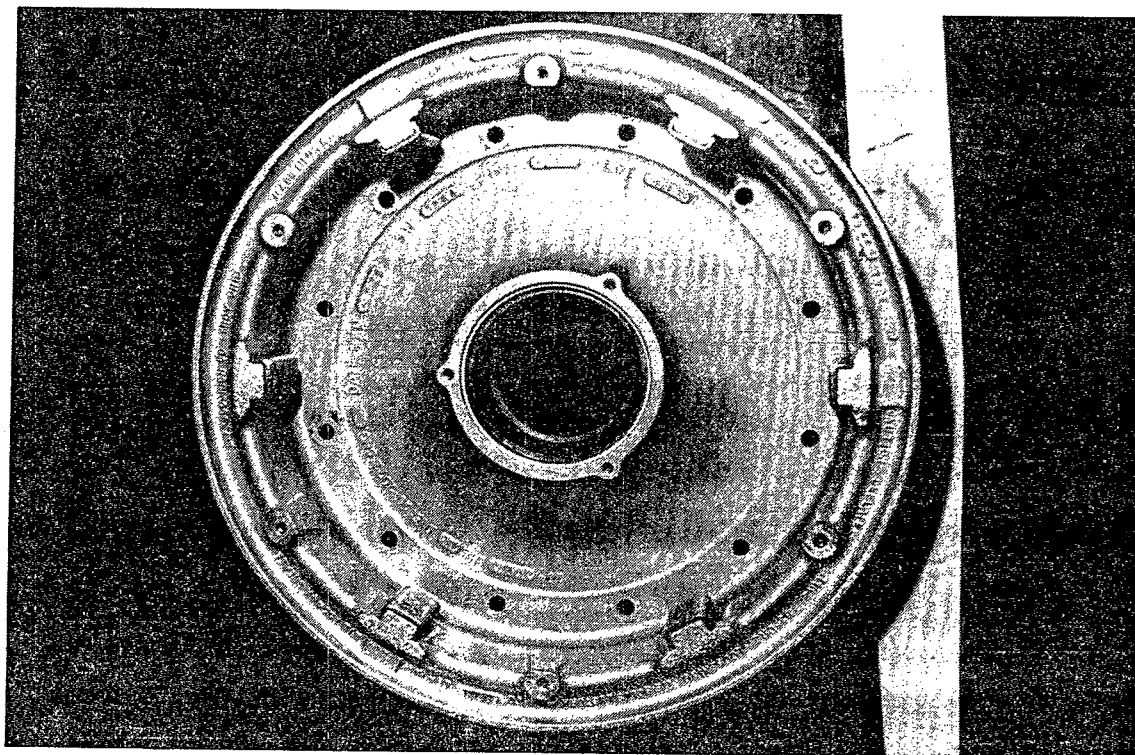
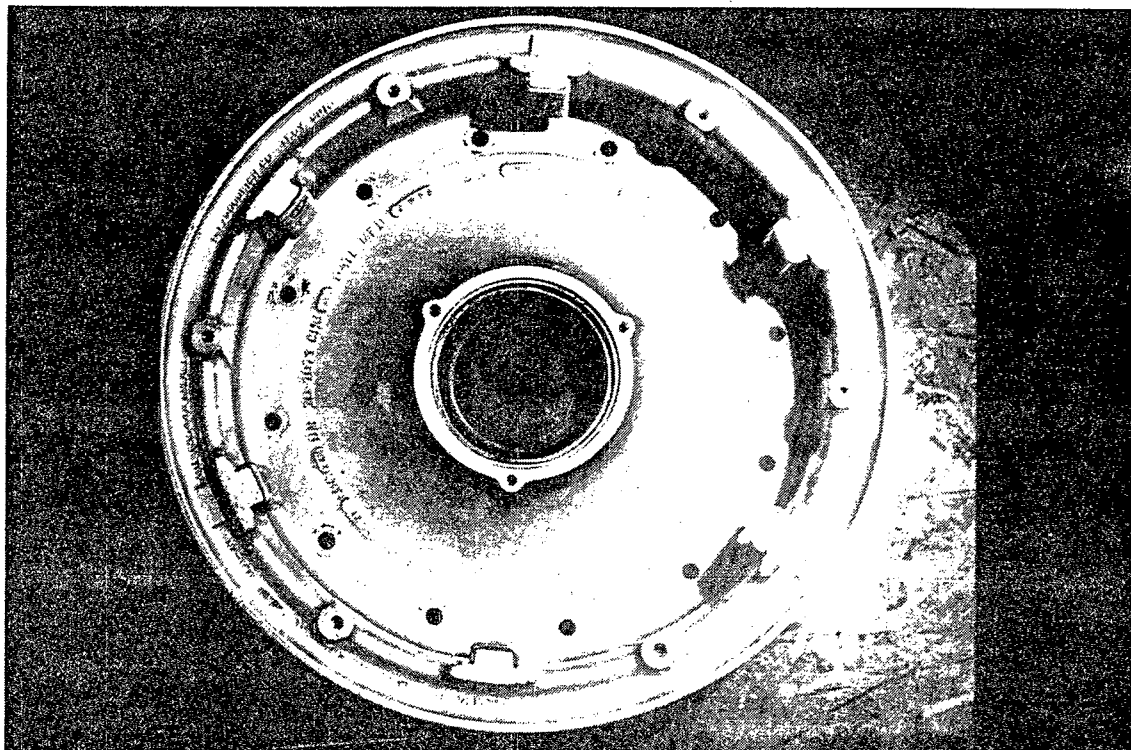


Figure 2-2. Photographs of aircraft wheel (SN 6264 inboard) taken after the first (top) and second (bottom) blasting.

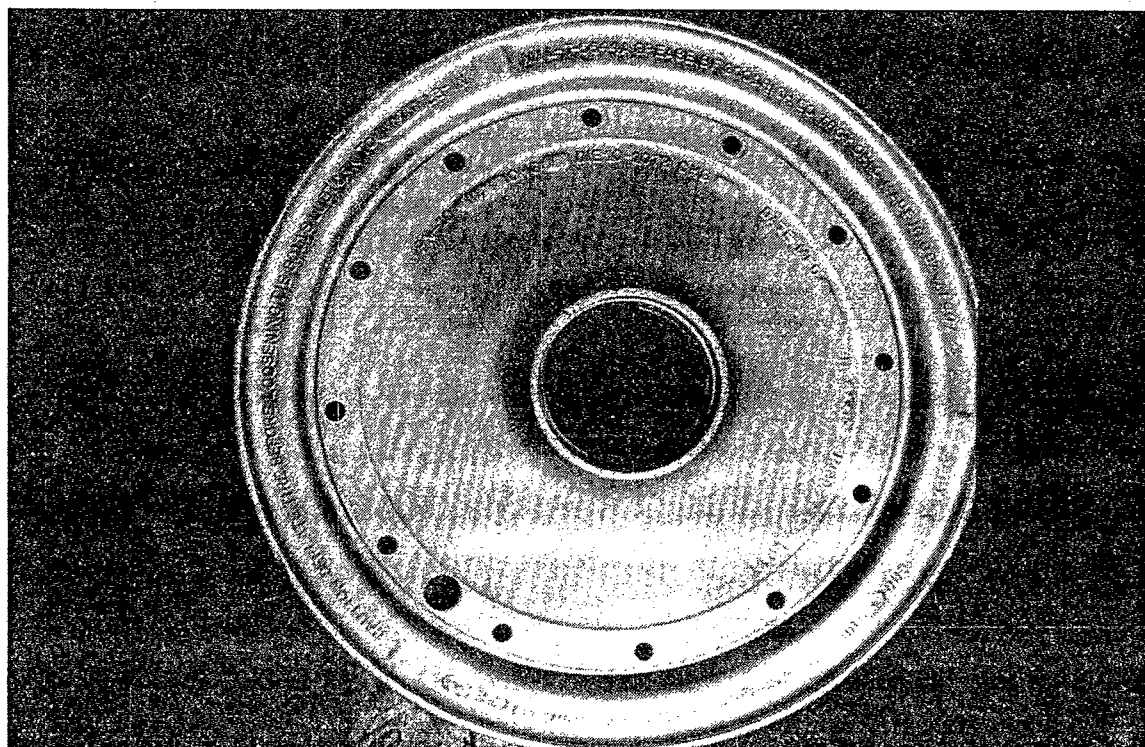
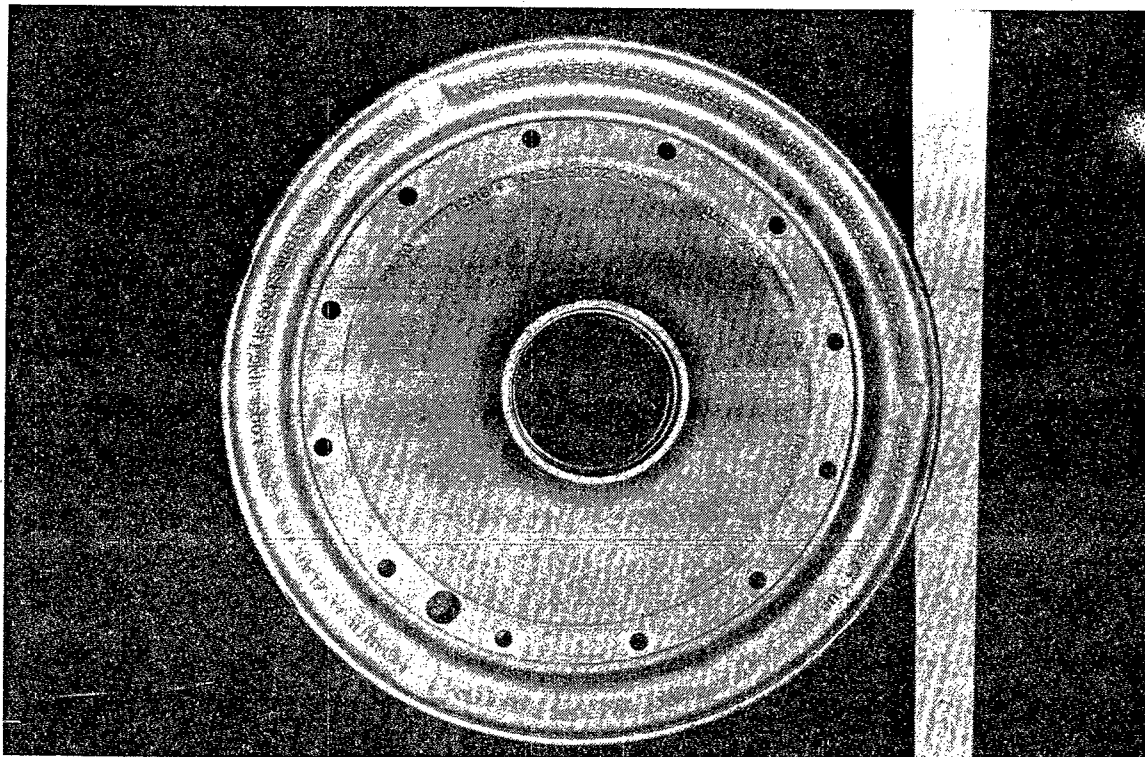


Figure 2-3. Photographs of aircraft wheel (SN 7755 outboard) taken after the first (top) and second (bottom) blasting.

Question 3.2. Is the anodized surface damage due primarily to ARMEX® blasting?

After careful examination, two inspectors did not believe that the anodized surface damage was caused by the bicarbonate of soda blasting. One inspector responded in three separate occasions suggesting adverse effects of the blasting on the anodized surface. However, his answers were inconclusive and inconsistent with his overall comment about the new stripping technology, "The new stripping process is much better."

Question 3.3. Is the anodized surface damage due primarily to other causes?

The answers to question 3.3 were mixed. One inspector believed that the hot dip stripping process in the past had caused deterioration of the anodized surface. The others, however, did not seem to concur with him in his opinion. The question was left unanswered in several occasions.

Question 4. If this is a second run, do you notice any difference between this and the previous inspection?

All three inspectors unanimously agreed that they had not found any noticeable differences on the surface of the wheels after the two separate blasting sessions.

2.3 PRODUCT QUALITY ASSESSMENT

The major objective of NASA/JSC in repainting is to allow examination of the wheels for metal fatigue cracks. The blasting technology was effective in removing paint from the aircraft wheels. More importantly, bicarbonate blasting did not rework the surface to hide the fatigue cracks.

NASA/JSC experience and the results of this test indicate that the bicarbonate blasting system was at least as effective as solvent stripping in removing topcoat and primer without masking cracks or other defects. The question of the potential for damage to the anodized surface finish, however, had not been resolved by the NASA/JSC test program and, therefore, was studied in detail in this project. The special test method developed qualitatively assessed the anodized surface damage and the results did not suggest such damage as a result of bicarbonate blasting.

SECTION 3

WASTE REDUCTION/POLLUTION PREVENTION POTENTIAL EVALUATION

Pollution prevention is achieved by reduction of waste at the source. Pollution prevention considers all waste types, for example, hazardous waste, solid waste, wastewater, air emissions, and utility consumption. Reductions must be true reductions in the volume and/or toxicity of waste and not simply a transfer of waste from one medium to another.

The waste reduction potential was measured in terms of volume reduction and toxicity reduction. The reductions were quantified by comparing waste volumes and types from solvent stripping with the wastes produced by bicarbonate stripping. Volume reduction addresses the gross wastestream, such as solvent sludge and rinsewater from solvent stripping, as compared to liquid and solid wastes in the vat and wastewater in the rotoclon separator from bicarbonate stripping. Toxicity reduction considers concentrations and types of contaminants, such as solvents, oil and grease, TSS, and heavy metals, in the gross wastestream.

The pollution prevention potential also considered hazards that the stripping technology might pose to workers. These include toxic airborne particulates and unsafe noise exposures. Air quality was measured in terms of airborne metal concentrations. Noise levels were measured on a sound-level meter and a dosimeter. The results of these measurements will determine the proper safety attire to be worn by the equipment operator.

3.1 SOLID AND LIQUID WASTE REDUCTION POTENTIAL

The bicarbonate stripping process generates wastewater, solid waste, a cloud of spray, and particulate in the vicinity of the nozzle and surface being depainted. This contaminated air is exhausted via hoods over the blast enclosures and cleaned via the rotoclon separator. In cleaning the air, the rotoclon separator generates wastewater with low concentrations of heavy metals. A full-face air-purifying respirator (APR) was worn by the operator for this application. Noise measured during this test was above Occupational Safety and Health Act (OSHA) and NASA permissible exposure limits (PELs), requiring the operator to use hearing protectors.

The previous solvent-based depainting processes generated volatile organic solvent releases to the atmosphere and, in the workplace, spent solvent, solid waste, and wastewater that required off-site treatment and/or disposal as hazardous waste. The overall volume of hazardous waste

for the previous system was larger, although the total volume of all waste (hazardous and sewerable) generated by each system is comparable. However, the significant volume of nonhazardous waste (as defined by local regulations) generated by the bicarbonate process could be reused or recycled as process water, depending on the application.

The bicarbonate blasting system completely eliminates the use of hazardous organic solvents, mainly methylene chloride and phenols. Both processes produce a sludge and wastewater. However, the volumes and characteristics are different, as analyzed in the following sections. Use of this technology for other applications can be expected to produce significant variations which need to be investigated on an individual basis. The P2 potential in substituting the system when the paint or coating itself is not hazardous appears lucrative.

3.1.1 Experimental Methods

Sampling Procedures. At the conclusion of the stripping process (see Section 2.1.1), the bulk of the solid waste in the vat had gravity-settled. The liquid waste was transferred, after sampling, from the vat to the 5,000-gal storage tank sitting just outside the paint-stripping room. Samples of liquid and solid wastes in the vat and/or the rotocloner separator were taken according to the sampling procedures described in Table 3-1. (No solid waste samples were collected from the rotocloner separator because solids were present only in a very small quantity in the bottom of the separator.) As a precaution, all sample containers were prewashed with a mixture of surfactant and deionized water, followed by deionized water alone. The number of samples collected is summarized in Table 1-3. The sample bottles were carefully labeled and placed in a sample cooler for transport to the analytical laboratory. Enough nonflammable packing material was spread around the sample bottles to ensure that they did not break. The sample cooler accompanied by a chain-of-custody form was then labeled and shipped to the analytical laboratory by Federal Express within 4 hours after sampling.

In addition to the samples collected, a field blank was taken of the blast media to assess extraneous contamination during sampling handling and shipping. For the solid waste, a field blank was taken consisting of the blast media shot directly from the nozzle into an open-mouth container. This blank served to confirm that there was no significant contribution of any of the measured analytical parameters to the samples collected from the blast system itself. The field blank also demonstrated that samples had not become contaminated during shipping.

A sample of on-site tap water also was collected for analysis. The tap water supply is the source of water for the bicarbonate blasting system, the part rinsing process, and the rotocloner separator. The background sample allows an assessment of increases in contaminants due to the process operations.

TABLE 3-1. SAMPLING PROCEDURES

Analyte	Sample Quantity	Sampling Method	Holding Time (Days)	Sample Preservation	Container ^a
<u>Liquid waste in vats</u>					
TSS	100 mL	Grab ^b	7	4°C	P
Oil & Grease	1,000 mL	Grab ^b	28	4°C, HCl to pH <2	G ^d
pH	100 mL	Grab ^b	7	4°C	P
Metals	100 mL	Grab ^b	180	Ambient, HNO ₃ to pH <2	P
<u>Solid waste in vat</u>					
Metals (total and leachable)	1,000 mL	Grab ^c	180	4°C	P
<u>Liquid waste in rotoclone separator</u>					
Metals	100 mL	Grab ^b	180	4°C	P

^a G - Glass, P - Polyethylene.

^b EPA Method III - 1, Sampling Surface Waters Using a Dipper or Other Transfer Device.

^c EPA Method II - 3, Collection of Sludge or Sediment Samples with a Scoop.

^d Borosilicate glass.

Analytical Measurements. Table 3-2 lists all the analytes, their corresponding analytical methods, and the expected quality assurance objectives. In accordance with the U.S. EPA (1987) requirements, officially approved and validated methods were selected for these analyses. Total suspended solids (TSS) are nonfilterable residues; TSS were measured gravimetrically using EPA Method 160.2. Oil and grease were measured by infrared spectrophotometry (EPA Method 413.2), which has greater accuracy than gravimetric analysis. Acidity was measured using EPA Method 150.1 to ensure that the pH level met proper disposal standards. Concentrations of metals (i.e., Cd, Cr, Cu, Pb, Mn, Ni, and Zn) from paint residue were monitored, as well, according to EPA Method 6010. Solid wastes collected from the vat were measured for the same total and leachable metals using the TCLP test (EPA Method 1311) and EPA Method 6010. These analyses were performed to determine the mobility of heavy metals. All analytical measurements were performed by an independent laboratory. Instruments were carefully calibrated according to the specified standard methods before sample analyses.

3.1.2 Results and Discussion

Liquid Waste in the Vat. About 114 L (30 gal) of wastewater (exclusive of the rotoclone separator) were generated during each of the two blasting sessions, or about 28.4 L (7.5 gal/wheel). Samples of the wastewater were collected at the conclusion of the first blasting session and analyzed for oil and grease, TSS, pH, and total metals; the results are presented in Table 3-3. The only measurement that exceeded the planned deviation for precision was oil and grease (mean value, 49.1 mg/L; standard deviation, 13.8 mg/L for a relative percent deviation of 28%). The variation was expected because samples collected sequentially from the vat might contain different amounts of insoluble oil and oil sheen. The TSS was 253 mg/L. The pH measured in the wastewater was 8.37, indicating an NaHCO_3 -saturated solution. The average total metal concentrations were 0.033, 8.090, 1.240, 1.430, 0.022, 0.006, and 5.990 mg/L for Cd, Cr, Cu, Pb, Mn, Ni, and Zn, respectively. The Cr concentration did not meet the local discharge limits (City of Houston, 1989), so the wastewater could not be disposed of to the POTW. Consequently, the liquid waste had to be temporarily stored in the 19,000-L (5,000-gal) storage tank before off-site disposal.

Solid Waste in the Vat. The amount of the solid waste settled to the bottom of the vat after the first blasting session was about 8 gal (or 2 gal per wheel), based on the following data/assumptions:

- Media flow rate – 1.1 kg/min (2.5 lb/min)
- Stripping and rinsing time – 12 min/wheel set
- Total nozzle blast time – 75%
- Moisture content of the solid waste – 50% (based on laboratory analysis)
- Media density – 2.22 g/cc
- Solubility of NaHCO_3 – 1 in 10 parts of water.

Samples of the solid waste were taken for total metal and TCLP analyses. As shown in Table 3-4, 2.73, 146.07, 32.97, 70.87, 2.77, 0.72, and 281.33 mg/kg of Cd, Cr, Cu, Pb, Mn, Ni, and Zn, respectively, were found in the solid waste. Among these amounts of metal, only a very small fraction was leachable under the TCLP conditions. TCLP requires the waste to meet limits of 1.0 mg/L Cd, 5.0 mg/L Cr, and 5.0 mg/L Pb. No regulations have been set for Cu, Mn, Ni, and Zn. The results of the study indicated that the metals analyzed were in lower concentrations than the established limits. No analyses were made for As, Ba, Hg, or Se, because for the purposes of this application they were not considered as important.

TABLE 3-2. QUANTITATIVE QUALITY ASSURANCE OBJECTIVES

Matrix Type (%)	Analyte	Methods	Precision (%)	Accuracy (% Recovery)	Minimum Detection Limit	Completeness
Aircraft wheel	Anodized surface damage	Section 2.1.2	N/A	N/A	None	100
Liquid waste in vats	TSS	EPA 160.2	±25	N/A	10 mg/L	100
	Oil & grease	EPA 413.2	±25	75 - 125	2 mg/L	100
	pH	EPA 150.1	±0.1 pH unit		0.1 pH unit	100
	Cd (total)	EPA 6010	±25	75 - 125	0.05 mg/L	100
	Cr (total)	EPA 6010	±25	75 - 125	0.05 mg/L	100
	Cu (total)	EPA 6010	±25	75 - 125	0.02 mg/L	100
	Pb (total)	EPA 6010	±25	75 - 125	0.20 mg/L	100
	Mn (total)	EPA 6010	±25	75 - 125	0.01 mg/L	100
	Ni (total)	EPA 6010	±25	75 - 125	0.04 mg/L	100
	Zn (total)	EPA 6010	±25	75 - 125	0.02 mg/L	100
	Volume produced per wheel	Section 3.1	N/A	N/A	N/A	100
Solid waste in vats	TCLP test for metals including:	EPA 1311, EPA 6010				
	Cd (leachable & total)	EPA 6010	±25	75 - 125	0.05 mg/L	100
	Cr (leachable & total)	EPA 6010	±25	75 - 125	0.05 mg/L	100
	Cu (leachable & total)	EPA 6010	±25	75 - 125	0.02 mg/L	100
	Pb (leachable & total)	EPA 6010	±25	75 - 125	0.20 mg/L	100
	Mn (leachable & total)	EPA 6010	±25	75 - 125	0.01 mg/L	100
	Ni (leachable & total)	EPA 6010	±25	75 - 125	0.04 mg/L	100
	Zn (leachable & total)	EPA 6010	±25	75 - 125	0.02 mg/L	100
	Volume produced per wheel	Section 3.1	N/A	N/A	N/A	100

TABLE 3-2. QUANTITATIVE QUALITY ASSURANCE OBJECTIVES (Continued)

Matrix Type (%)	Analyte	Methods	Precision (%)	Accuracy (% Recovery)	Minimum Detection Limit	Completeness
Liquid waste in cyclone separator	Cd (total)	EPA 6010	±25	75 - 125	0.05 mg/L	100
	Cr (total)	EPA 6010	±25	75 - 125	0.05 mg/L	100
	Cu (total)	EPA 6010	±25	75 - 125	0.02 mg/L	100
	Pb (total)	EPA 6010	±25	75 - 125	0.20 mg/L	100
	Mn (total)	EPA 6010	±25	75 - 125	0.01 mg/L	100
	Ni (total)	EPA 6010	±25	75 - 125	0.04 mg/L	100
	Zn (total)	EPA 6010	±25	75 - 125	0.02 mg/L	100
Airborne particulates in operator's breathing zone	Cr (total)	NIOSH 7300	±25	75 - 125	0.001 mg/m ³	100
	Cu (total)	NIOSH 7300	±25	75 - 125	0.05 mg/m ³	100
	Pb (total)	NIOSH 7300	±25	75 - 125	0.025 mg/m ³	100
	Zn (total)	NIOSH 7300	±25	75 - 125	1.00 mg/m ³	100
Noise level during ARMEX/ACCUSTRIIP process	Noise	29 CFR XVII Section 1910.95	^a	^a	^a	100
Stripping time	Time (per wheel)	Stopwatch	N/A	N/A	N/A	100

^a Manufacturer-specified.

TABLE 3-3. OIL AND GREASE, TSS, pH, AND METAL CONTAMINANTS IN WASTEWATER COLLECTED FROM THE VAT

Parameter	Field Background	Replicate			Mean	Std. Dev.	Local ^{15,a} Discharge Limit
		1	2	3			
Oil and grease (mg/L)	<0.5	33.2	56.0	58.0	49.1	13.8	200
TSS (mg/L)	<10	246	251	261	253	7.6	365
pH	7.65	8.371	8.365	8.365	8.367	0.003	6-10
Cd ^b (mg/L)	0.005	0.0317	0.034	0.032	0.033	0.001	0.2
Cr ^b (mg/L)	0.007	8.2000	8.110	7.960	8.090	0.121	5.0
Cu ^b (mg/L)	0.032	1.2700	1.240	1.220	1.240	0.025	2.0
Pb ^b (mg/L)	0.017	1.4700	1.420	1.410	1.430	0.032	1.5
Mn ^b (mg/L)	0.003	0.0224	0.022	0.022	0.022	0.0004	3.0
Ni ^b (mg/L)	0.005	0.0066	0.005	0.006	0.005	0.001	3.0
Zn ^b (mg/L)	0.099	6.2300	5.860	5.880	5.990	0.208	6.0

^a Maximum allowable limits for grab samples, Industrial Waste Permit No. 1030, City of Houston, Texas, March 10, 1989.^b Total metal.

Liquid Waste in Rotoclon Separator. The wastewater in the rotoclon separator was sewerable. It contained less than detection limit of TSS and a very small amount of heavy metals, ranging from 0.005 mg/L of Cd to 0.489 mg/L of Zn (see Table 3-5). The pH of the wastewater was 8.23. The amount of wastewater generated from each of the two blasting sessions was about 980 L (260 gal). At this location, the wastewater was sent to the sewer without treatment. Potentially this water could be reused or recycled as process water, depending on the application.

3.2 AIR AND NOISE POLLUTION PREVENTION POTENTIAL

The air and noise levels around the operator of the bicarbonate blasting were monitored to quantify the occupational hazards. Bicarbonate of soda does not pose health risks, but the blasting may release toxic metals to the ambient air from the paint chips. Based on the concentrations of metals in air samples and considering exposure time, estimates of the health risk were made for bicarbonate blasting. Also, A-weighted dosimeter readings were converted to time-weighted averages to determine if sound levels exceeded federal regulations. If they did, C-weighted readings were used to determine the proper noise reduction rating (NRR) of the hearing protection.

3.2.1 Experimental Methods

Airborne Metals Exposure Study. During the blasting process, the operator wore a North full-face APR with stacked high-efficiency particulate air (HEPA) and organic vapor cartridges. Earplugs, earmuffs, gloves, and a waterproof slicker outfit were also worn. During blasting, the debris and media formed a wet cloud that extended outside the confines of the exhaust hood and partially over the operator during blasting. Most of the cloud was drawn back into the hood by the ventilation system. No particulates were observed escaping the building.

NASA/JSC Environmental Health Services (EHS) collected air samples during the two blasting sessions. One primary and two replicate samples were taken from the breathing zone of the operator on each occasion (Atkins, 1992a). One background sample was collected one day before the first test blasting occurred. Calibrated Gillian pumps, model HFS 513A, and 37 mm, 0.8 micron, and mixed cellulose ester membrane filter cassettes were used for sample collection. Samples were collected at 2.96 to 3.13 L/min. The sample collection and analyses were performed following the National Institute for Occupational Safety and Health (NIOSH) Method 7300 for the analysis of metals by inductively coupled plasma (ICP) atomic emission spectroscopy (AES). The samples were analyzed for Cd, Cr, Cu, Pb, and Zn at NASA/JSC EHS Laboratory.

TABLE 3-4. TOTAL AND LEACHABLE METALS IN SOLID WASTE COLLECTED FROM THE VAT

Metal	Field Blank	Total metal (mg/kg)			Std. Dev.	Leachable Metal (mg/L)			Std. Dev.	
		Replicate				Replicate				
		1	2	3		1	2	3		
Cd	0.50	2.7	1.7	3.8	2.72	0.038	0.036	0.032	0.353	0.003
Cr	0.69	107.0	142.2	189.0	146.07	1.940	2.800	1.900	2.210	0.508
Cu	1.30	20.8	25.0	53.0	32.97	0.386	0.3518	0.315	0.396	0.107
Pb	1.70	87.10	44.3	81.2	70.87	0.626	0.495	0.555	0.559	0.066
Mn	0.19	3.4	1.3	3.6	2.77	0.008	0.007	0.008	0.008	0.001
Ni	0.50	0.80	0.57	0.80	0.72	0.009	0.006	0.005	0.007	0.002
Zn	1.90	181.0	282.0	381.0	281.33	3.820	4.810	4.390	4.340	0.497

TABLE 3-5. pH, TSS, AND METAL CONTAMINANTS IN WASTEWATER COLLECTED FROM ROTOCONE SEPARATOR

Parameter	Field Background	Replicate			Mean	Std. Dev.
		1	2	3		
pH	7.011	8.233	8.219	8.229	8.227	0.007
TSS (mg/L)	< 10	20	< 10	< 10	< 20	--
Cd ^a (mg/L)	0.005	0.005	0.005	0.005	0.005	0.000
Cr ^a (mg/L)	0.007	0.344	0.330	0.336	0.337	0.007
Cu ^a (mg/L)	0.032	0.061	0.058	0.060	0.060	0.001
Pb ^a (mg/L)	0.017	0.033	0.033	0.032	0.033	0.001
Mn ^a (mg/L)	0.003	0.006	0.006	0.006	0.006	0.000
Ni ^a (mg/L)	0.005	0.016	0.005	0.006	0.009	0.006
Zn ^a (mg/L)	0.099	0.500	0.476	0.491	0.489	0.012

^a Total metal.

Noise Exposure Study. Significant levels of noise were generated by the bicarbonate of soda blasting. NASA/JSC EHS evaluated the operator's exposure to the potential noise hazards (Atkins, 1992b). The two main sources of noise to the operator were the blast nozzle and the ventilation system. The operator opted to wear double hearing protection in the form of foam plugs and muffs for the duration of the process. The combined noise reduction rating for the double hearing protection was 40 decibels (dB).

Noise exposure monitoring was performed during the two separate blasting sessions. The first session lasted 59 min and the second 70 min. Sound-level measurements were made with a calibrated Bruel and Kjaer (B & K) Model 2230 sound-level meter, which conforms to the requirements for a Type 1 sound-level meter as specified in American National Standards Institute (ANSI) S1.4-1971. Several periodic measurements were made in the immediate area of the process. These measurements represent noise produced by the blast nozzle and the ventilation systems. In addition, two calibrated Metrosonics Model db-308 sound-level dosimeter/analyzers were placed on the operator to log sound-level exposures while stripping wheels. The dosimeters met the requirements of ANSI S1.25-1978 and were programmed to integrate sound levels from 80 to 130 dB. Two dosimeters were used so measurements could be collected in both "A" and "C" scales. The dosimeter microphones were clipped vertically within the operator's hearing zone with the data-loggers secured at the waist. These measurements represent noise produced by the blast nozzle, the ventilation systems, and all other noise created in the proximal environment during the blasting session.

3.2.2 Results and Discussion

Airborne Metals Exposure Study. The Occupational Safety and Health Administration (OSHA) and the American Conference of Governmental Industrial Hygienists (ACGIH) have established PELs and Threshold Limit Values (TLVs) for the airborne metal contaminants of concern in this study. The PELs and TLVs are listed in Table 3-6. Excluding chromates, all specified PELs and TLVs are based on an 8-hr time-weighted average (TWA) exposure. The OSHA PEL for chromates is based on a ceiling concentration. Cadmium has both an 8-hr PEL and a ceiling concentration limit. Because of the number of primary and replicate samples required for this study, only the 8-hr TWA was considered for the zinc chromate and cadmium fractions. The ceiling limits for zinc chromate and cadmium were not evaluated during this study.

The results of the airborne metal exposure study are presented in Table 3-6. The results indicate that 8-hr TWA exposures to the airborne metals were below specified OSHA and ACGIH limits. Regardless of sample types (i.e., primary and replicate samples, background sample, and field blanks)

no metals were detected by ICP/AES. The ICP/AES detection limits were 0.001 mg for Cd; 0.005 mg for Cr, Cu, and Pb; and 0.009 mg for Zn.

A similar experiment (Atkins, 1989), conducted earlier by NASA/JSC EHS inside a hangar with the hangar doors closed, resulted in a serious overexposure to Cr (i.e., 0.4 mg/m³). Exposures to the other contaminants such as Cu, Pb, and Zn did not exceed the PELs, but the reported concentrations of Cu and Zn were as high as 0.47 and 0.83 mg/m³, respectively. (The Pb concentrations were below the detection limit for the analytical method and time period sampled.) The results of this study prompted NASA/JSC EHS to recommend that the blasting process not be performed in hangars or situations where the waste and/or particulate cloud could not be contained and that operators of this blasting equipment be required to wear a full-face APR with HEPA filters. Meanwhile, NASA/JSC EHS endorsed plans to construct the exhaust ventilation system in place during this test.

Noise Exposure Study. Sound levels measured periodically in the operator's hearing zone during the two separate blasting sessions ranged from 76.8 dB on the "A"-weighted scale (dBA) to 120.0 dBA. Levels ranging from 64.6 to 67.4 dBA were measured outside the flapped doors of the stripping room. Dosimetry samples integrated cumulative noise exposures of 106.6 and 101.7 dBA for the first and the second blasting session, respectively. These samples are based on 8-hr TWA calculated from dosimetry results recorded during the period sampled. If the actual work period were increased to a full 8 hr, the projected 8-hr TWAs would be 121.3 and 115.9 dBA, respectively. A peak level of 146 dB, the maximum level the dosimeter is capable of measuring, was recorded during both periods sampled.

According to 29 CFR 1910.95 (OSHA, 1990) the OSHA PEL for noise exposure is 90 dBA per 8-hr day as a TWA. OSHA also requires that any worker exposed to an action level of 85 dBA (TWA), or greater, be included in a hearing conservation program. Hearing protectors must attenuate employee exposure at least to an 8-hour TWA of 90 decibels. The NASA Health Standard on Hearing Conservation, NHS/IH-1845.4 specifies 85 dBA (TWA) as a PEL per 8-hr day and requires any worker exposed to an action level of 80 dBA (TWA), or greater, 30 days or longer per year, to be included in a hearing conservation program. The NASA standard states that hearing protectors must attenuate employee exposure to a level of 85 dBA or lower. Both standards require engineering controls to be used as a primary means of exposure control and additional hearing protector attenuation for workers experiencing a standard threshold shift based on audiometric testing.

TABLE 3-6. AIRBORNE METALS COLLECTED DURING BICARBONATE PAINT REMOVAL

Sampling No.	Date Collected	Sample Type	Sampling Duration (min)	Volume (L)	Metal	Lab Result (mg/filter)	Airborne Concentration (mg/m ³)	8-hour TWA (mg/m ³)	Regulatory Limit	
									OSHA (mg/m ³)	ACGIH (mg/m ³)
Metal 5151	12/17/91	Field blank ^a	N/A ^a	N/A	Cd	<0.001	N/A	N/A	0.2 ^d	0.05
					Cr	<0.005	N/A	N/A	0.1 ^e	0.01
					Cu	<0.005	N/A	N/A	1.0	1.0
					Pb	<0.005	N/A	N/A	0.05	0.15
					Zn	<0.005	N/A	N/A	0.1 ^f	0.01 ^g
Metal 5152	12/17/91	Field blank	N/A	N/A	Cd	<0.001	N/A	N/A	0.2	0.05
					Cr	<0.005	N/A	N/A	0.1	0.01
					Cu	<0.005	N/A	N/A	1.0	1.0
					Pb	<0.005	N/A	N/A	0.05	0.15
					Zn	<0.009	N/A	N/A	0.1	0.01
Metal 5147	12/16/91	Background ^c	90	272	Cd	<0.001	<0.004	N/A	0.2	0.05
					Cr	<0.005	<0.018	N/A	0.1	0.01
					Cu	<0.005	<0.018	N/A	1.0	1.0
					Pb	<0.005	<0.018	N/A	0.05	0.15
					Zn	<0.009	<0.033	N/A	0.1	0.01
Metal 5148	12/17/91	Primary	65	196	Cd	<0.001	<0.005	<0.0007	0.2	0.05
					Cr	<0.005	<0.025	<0.003	0.1	0.01
					Cu	<0.005	<0.025	<0.003	1.0	1.0
					Pb	<0.005	<0.025	<0.003	0.05	0.15
					Zn	<0.009	<0.046	<0.006	0.1	0.01
Metal 5149	12/17/91	Replicate	65	192	Cd	<0.001	<0.005	<0.0007	0.2	0.05
					Cr	<0.005	<0.026	<0.003	0.1	0.01
					Cu	<0.005	<0.026	<0.003	1.0	1.0
					Pb	<0.005	<0.026	<0.003	0.05	0.15
					Zn	<0.009	<0.046	<0.006	0.1	0.01
Metal 5150	17/19/91	Replicate	65	203	Cd	<0.001	<0.005	<0.0007	0.2	0.05
					Cr	<0.005	<0.024	<0.003	0.1	0.01
					Cu	<0.005	<0.024	<0.003	1.0	1.0
					Pb	<0.005	<0.024	<0.003	0.05	0.15
					Zn	<0.009	<0.046	<0.006	0.1	0.01
Metal 5156	12/19/91	Field blank	N/A	N/A	Cd	<0.001	N/A	N/A	0.2	0.05
					Cr	<0.005	N/A	N/A	0.1	0.01
					Cu	<0.005	N/A	N/A	1.0	1.0
					Pb	<0.005	N/A	N/A	0.05	0.15
					Zn	<0.009	N/A	N/A	0.1	0.01

TABLE 3-6. AIRBORNE METALS COLLECTED DURING BICARBONATE PAINT REMOVAL (Continued)

Sampling No.	Data Collected	Sample Type	Sampling Duration (min)	Volume (L)	Metal	Lab Result (mg/filter)	Airborne Concentration (mg/m ³)	8-hour TWA (mg/m ³)	Regulatory Limit	
									OSHA (mg/m ³)	ACGIH (mg/m ³)
Metal 5157	12/19/91	Field blank	N/A	N/A	Cd	<0.001	N/A	N/A	0.2	0.05
					Cr	<0.005	N/A	N/A	0.1	0.01
					Cu	<0.005	N/A	N/A	1.0	1.0
					Pb	<0.005	N/A	N/A	0.05	0.15
					Zn	<0.009	N/A	N/A	0.1	0.01
Metal 5153	12/19/91	Primary	60	181	Cd	<0.001	<0.005	<0.0006	0.2	0.05
					Cr	<0.005	<0.028	<0.003	0.1	0.01
					Cu	<0.005	<0.028	<0.003	1.0	1.0
					Pb	<0.005	<0.028	<0.003	0.05	0.15
					Zn	<0.009	<0.049	<0.008	0.1	0.01
Metal 5154	12/19/91	Replicate	60	178	Cd	<0.001	<0.005	<0.0006	0.2	0.05
					Cr	<0.005	<0.028	<0.003	0.1	0.01
					Cu	<0.005	<0.028	<0.003	1.0	1.0
					Pb	<0.005	<0.028	<0.003	0.05	0.15
					Zn	<0.009	<0.049	<0.008	0.1	0.01
Metal 5155	12/19/91	Replicate	60	188	Cd	<0.001	<0.005	<0.0006	0.2	0.05
					Cr	<0.005	<0.028	<0.003	0.1	0.01
					Cu	<0.005	<0.028	<0.003	1.0	1.0
					Pb	<0.005	<0.028	<0.003	0.05	0.15
					Zn	<0.009	<0.049	<0.008	0.1	0.01

a Field blanks utilized filters in cartridges without being exposed to the on-site ambient air.

b N/A - not applicable.

c Background sample was collected one day before the first test blasting occurred.

d Ceiling concentration limit is 0.6 mg/m³.

e Based on ceiling concentration.

f Zn is bound to chromate, therefore, PEL of Cr (as chromate) fraction is used for standards comparisons.

g PEL of Cr (as chromium) fraction is used for standards comparison.

Noise exposure may be controlled by means of work duration limitations through administrative control or by use of personal protective equipment, or both, while engineering controls are being developed or are not feasible. Due to the variation of actual time spent by workers operating the blasting equipment, Table 3-7 was developed listing the projected noise exposures based on increased work periods and hearing protector attenuation requirements as a function of work duration. The attenuation required was calculated based on 29 CFR 1910.95, Appendix B, "Methods for Estimating the Adequacy of Hearing Protector Attenuation," Method (ii). The attenuation required ranges from 23.6 to 38.3 dBA under the OSHA criterion, and from 28.3 dBA to 43.3 dBA under the NASA criterion. The double hearing protection worn by the operator during blasting reduced exposures to below regulatory limits.

TABLE 3-7. PROJECTED 8-HOUR NOISE EXPOSURES AND REQUIRED NOISE ATTENUATION

Work Duration (hr)	Noise Exposure 8-hour TWA ^a (dBA)		Attenuation Required (dBA)	
	OSHA	NASA	OSHA	NASA ^c
0.995 (Actual)	106.6	106.3	23.6	28.3
2	111.6	111.3	28.6	33.3
4	116.6	116.3	33.6	38.3
6	119.5	119.3	36.5	41.3
8	121.3	121.3	38.3	43.3

^a Based on 0.995-hr average of 121.3 dBA.

^b 90 dBA criterion.

^c 85 dBA criterion.

3.3 WASTE REDUCTION/POLLUTION PREVENTION ASSESSMENT

Pollution prevention benefit is the net difference between the old system and the new. In this case, a solvent paint removal system was replaced with bicarbonate blasting. Because the types of wastestreams generated by each system vary in species, concentrations, amounts released, and the associated health and ecological impacts, a direct comparison of reductions of similar wastes is not possible. There is no common denominator to determine improvements on an absolute scale. We can list the two sets of data and draw relative significance, as shown in Table 3-8.

TABLE 3-8. SUMMARY OF POLLUTION PREVENTION POTENTIAL FOR BICARBONATE PAINT REMOVAL

Environmental Media/Concern	Bicarbonate Blasting	Solvent
Solvent Liquid	<ul style="list-style-type: none"> • None 	<ul style="list-style-type: none"> • Spent solvent 220 gallons/year
Solid Waste	<ul style="list-style-type: none"> • Bicarbonate and paint debris 610 gallons/year 	<ul style="list-style-type: none"> • Solvent sludge and paint debris 6,600 gallons/year
Water	<ul style="list-style-type: none"> • Water from blasting and floor rinse 5,000 gallons/year (exceeds POTW limits) • Water from off-gas treatment scrubber (rotoclone) 36,000 gallons/year (does not exceed POTW limits) 	<ul style="list-style-type: none"> • Rinsewater 16,000 gallons/year (exceeds POTW limits)
Air Emissions	<ul style="list-style-type: none"> • Particulates (metals in room air below detection limits) 	<ul style="list-style-type: none"> • Organic vapors
Noise	<ul style="list-style-type: none"> • Potential for > 90 dBA hearing protection or administrative limits on work time required 	<ul style="list-style-type: none"> • Ambient levels maintained

The most obvious pollution prevention benefit gained by using bicarbonate blasting is the complete elimination of solvent use, which eliminates generation of spent solvent wastes and releases. In addition, the quantity of stripping media/solvent waste and paint debris is reduced by a factor of 10. When using bicarbonate blasting, the operator can observe paint removal progress, make control adjustments, and typically complete the removal in a single pass. With solvent stripping, the part is soaked in solvent and then scrubbed with brushes and/or abrasive materials supplemented by rinsewater. The soak and clean process usually is repeated several times. The multiple soak/clean cycles and combination of solvent and flushing water produce a large volume of organic sludge and wastewater.

The bicarbonate blasting process produces a greater total volume of wastewater. However, the volume of water containing metal concentrations above POTW limits is smaller. The bulk of the wastewater from bicarbonate blasting is produced by the rotoclone off-gas cleaning equipment. The metal content of this water is near the background for local tap water.

The main drawbacks to bicarbonate blasting are the production of particulate emissions and the increased noise levels. Particulates and noise have been controlled at the NASA/JSC installation by a combination of engineered features and administrative controls.

The exhaust ventilation system reduced the hazardous airborne metals concentrations outside of the three-sided exhaust enclosure to acceptable levels. However, a considerable amount of blast media and debris was observed to be deflected onto the operator's APR and protective clothing during blasting. The full-face APR used in the study provided adequate protection and should be continued to be used. Meanwhile, modifications to the system to reduce the cloud of spray and reducing wastewater generation should be investigated. These include installing baffles to reduce the amount of visible particulate cloud observed outside the enclosure and adding lighting fixtures to provide good visibility inside the enclosure. Possible designs to handle debris and spray that require no rotocloning should also be considered.

Noise measurements performed clearly indicate that, under the conditions encountered during this study, hazardous noise exposures can result from this process. Therefore, engineering control of noise exposures should be investigated. Hearing protection devices for all personnel who operate or work in the vicinity of the operation should be provided. Evaluation of the hearing protectors used during the actual times worked during this study indicate that the protectors reduced exposures to below the OSHA and NASA permissible exposure limits. For compliance with the NASA NHS/IH-1845.4, work durations using the blasting equipment and the hearing protectors assigned should not exceed 5 hr in an 8-hr work shift (Atkins, 1992b). NHS/IH-1845.4 requires use of both plugs and muffs when exposures equal or exceed 110 dBA. NASA EHS also requires all personnel who routinely operate the blasting equipment to be placed in a hearing testing and evaluation program at the NASA/JSC clinic.

Beyond this application, depainting via bicarbonate blasting could be considered as a substitute for a spectrum of other operations requiring removal of paint, coatings or surface contaminants. Paints or coatings and substrates, themselves containing no hazardous constituents, could produce non-hazardous waste and totally eliminate the related concern and expense involved with handling and disposition. The residue and waste water then could be candidates for reuse and recycling. It should be noted that this is one of a number of potential substitutes for toxic solvent use. Each application should consider the best fit for its requirements.

SECTION 4 ECONOMIC EVALUATION

The comparison of costs between bicarbonate blasting and solvent stripping included the use of data on stripping time per wheel using bicarbonate blasting, NASA/SJC's historical data on chemical stripping and complimentary information from the vendor regarding the blasting system. The capital investment, operating costs, and payback period were calculated according to the worksheets provided in the Waste Minimization Opportunity Assessment Manual (U.S. EPA, 1988).

4.1 CAPITAL INVESTMENT

The following lists the capital investment and capital cost inputs used in the worksheet (see Table 4-1):

- Equipment costs include \$15,000 for an ACCUSTRIP SYSTEM™ Model 16W and \$17,375 for an INGERSOL-RAND trailer-mounted diesel-powered compressor, plus 10% for freight charges, taxes, spare parts, etc.
- Materials and installation costs include piping, valves, fittings, and electrical and water supplies for the blasting system, plus the costs for building and facility modification and installation of pollution prevention equipment including a No. 12 Type W rotoclone, a separator, two hoods with exhaust ducts, and a storage cabinet.
- Plant engineering costs are assumed to be 15% of the sum of the equipment, materials, and installation costs.
- Contingency costs are assumed to be 10% of all of the above costs (or fixed-capital investment).
- Working capital is based on 1 month's supply of ARMEX® blast media (assuming that blasting is performed monthly for 10 hours and 70% of the stripping time is nozzle blast time; the media flow rate is 2.5 lb/min; and the media price is \$0.68/lb).
- Startup costs are based on 10% of the fixed capital investment.
- Equity of 100% is assumed because this is a government-funded project and there was no money-lending involved. If a loan were taken, the percent debt and interest rate would have been entered here.
- Because NASA/JSC does not incur taxes, no tax rate is included.
- The depreciation period is assumed to be 7 years, and the escalation rate and cost of capital are assumed to be 5% and 15%, respectively.

TABLE 4-1. INPUTS AND OUTPUTS FOR CAPITAL COSTS

Input		Output Capital Requirement	
Capital Cost		Construction Year	1
Equipment	\$35,613	Capital Expenditures	
Materials and Installation	\$127,900	Equipment	\$35,613
Plant Engineering	\$24,527	Materials and Installation	\$127,900
Contractor/Engineering	\$0	Plant Engineering	\$24,527
Permitting Costs	\$0	Contractor/Engineering	\$0
Contingency	\$18,804	Permitting Costs	\$0
Working Capital	\$1,020	Contingency	\$18,804
Startup Costs	\$18,804	Startup Costs	\$18,804
		Depreciable Capital	\$225,648
% Equity	100%	Working Capital	\$1,020
% Debt	0%	Subtotal	\$226,668
Interest Rate on Debt, %	0.00%	Interest on Debt	\$0
Debt Repayment, years	0	Total Capital	\$226,668
Depreciation period	7	Equity Investment	\$226,668
Income Tax Rate, %	0.00%	Debt Principal	\$0
		Interest on Debt	\$0
Escalation Rates, %	5.0%	Total Financing	\$226,668
Cost of Capital	15.00%		

4.2 OPERATING COSTS

The operating costs of stripping aircraft wheels using the ACCUSTRIIP SYSTEM™ are calculated based on the following data and assumptions:

- Total working days per year are 250 days.
- Media cost is \$0.68/lb.
- Media flow rate is 2.5 lb/min.
- Media density is 2.22 g/cc.

- Media solubility in water is 1 in 10 parts of water.
- Stripping time includes time for nozzle blasting (75%), rinsing-off blast media from the stripped surface (15%), and inspecting (10%).
- Moisture content of the solid waste collected from the vat is 50%.
- Water usage for blasting and rinsing off is 1 gal/min. Water flow rate during blasting is 0.4 gal/min. Rinsing-off flow rate is assumed to be 0.6 gal/min of nozzle blasting.
- Water consumed for floor washdown is 10 gal/day.
- Rotocloner water flow rate is 5 gal/min.
- Total system operation time is twice the stripping time.
- Water cost is \$6.12/1,000 gal (including \$2.16/1,000 gal of potable water and \$3.96/1,000 gal of sewage discharge).
- Electricity required to operate rotocloner is 4.15 kW/hr.
- Diesel fuel required to operate the INGERSOLL-RAND compressor is 25 gal/month. The diesel fuel cost is \$0.684/gal.
- Cost of one reconditioned drum is \$20.
- Cost to dispose of one drum of nonhazardous solid waste is \$80.
- Cost to dispose of nonhazardous liquid waste is \$0.20/gal.
- The labor cost is \$18.14/hr.

Table 4-2 summarizes the man-hours required for stripping the wheels done annually for the NDI, and the quantity of solid and liquid wastes generated as a result of the bicarbonate blasting. About 60 hours are needed to strip all wheels. About 610 gal of settled bicarbonate media and paint debris sludge and 2,500 gal of bicarbonate media propellant water will be produced as solid and liquid wastes, respectively. Furthermore, 2,500 gal of floor washdown will be combined into the liquid waste for off-site disposal. Therefore, the total quantity of the liquid waste produced and required off-site disposal will be 5,000 gal annually. The disposal costs (including costs for drums and waste disposal) for the solid and liquid wastes are \$1,300 and \$1,000, respectively, per year.

TABLE 4-2. MAN-HOURS REQUIRED AND SOLID AND LIQUID WASTE GENERATED ANNUALLY

Type of Wheel	Quantity	Nozzle Blast Time (min)	Man-Hours Required		Solid Waste Generated in the Vat		Liquid Waste Generated in the Vat	
			per Wheel ^a (min)	Total (hr)	per Wheel ^b (lbs)	Total (lbs)	per Wheel ^b (gal)	Total (gal)
T-38	114	9	12	22.8	22.5	2565	9	1026
G-1	20	7.5	10	3.3	18.8	376	7.5	150
G-2	66	7.5	10	11.0	18.8	1241	7.5	495
B-57	8	18	24	3.2	45.0	360	18	144
KC-135	12	45	60	12.0	112.5	1350	45	540
KC-97	8	18	24	3.2	45.0	360	18	144
Total				55.5		6252		2499
						≅ 610 gal ^b		≅ 2500 gal

^a Time required to strip one wheel includes nozzle blasting time (70%), rinsing-off time (15%), and inspecting time (15%).

^b See Section 4.2 for assumptions.

As shown in Table 4-3, the time required to strip a wheel piece and to rinse off blast media and debris from the stripped wheel piece ranges from 3.65 to 8.62 min for an outboard and from 4.5 to 9.23 min for an inboard. The average stripping time per wheel set (one outboard and one inboard) is about 12 min. One earlier NASA/JSC (1989) study reported a 20-min stripping time for one KC-97 wheel by bicarbonate blasting versus 8 hours by chemical strippers. The time saved in that study was more than 95%.

TABLE 4-3. STRIPPING TIME

Serial Number	Outboard/Inboard	Stripping Time ^a (min)		
		First Stripping	Second Stripping	Average
6264	o ^b	5.13	4.45	4.79
	i ^c	5.63	5.73	5.68
2188	o	7.68	8.62	8.15
	i	6.80	9.23	8.02
8312	o	3.70	3.85	3.78
	i	4.50	6.12	5.31
7755	o	3.65	4.08	3.87
6748	i	6.53	8.25	7.39

^a Including time to flush blast media from stripped wheels.

^b Outboard.

^c Inboard.

Average_o = 5.15

Average_i = 6.60

The liquid waste produced from the rotoclone operation is 36,000 gal per year. The wastewater can be discharged into the POTW; therefore, no extra costs will be incurred.

The operating costs for bicarbonate blasting are compared with those for the old chemical stripping process. Four drums (55 gal) of spent chemical stripping fluid were used annually. Disposal costs were \$400/drum. The disposal of the spent stripper was \$500/drum (including \$20 for a reconditioned drum). The wastewater volume produced was about 16,000 gal, which was disposed of at a rate of 4,000 gal every 3 months. Due to the presence of paint debris and solvent, the wastewater was treated as hazardous and was tanked away for disposal at \$0.20/gal. Solvent sludge and paint debris were drummed for off-site disposal. About 10 drums of stripping sludge were produced every month, and the disposal costs were about \$300/drum.

Other operating cost inputs used in the worksheet include (see Table 4-4):

- Raw material costs are based on an annual supply of ARMEX[®] blast media and B&B 9201 chemical stripper.
- Operating labor hours for the blasting and chemical stripping processes are 120 and 886 hours, respectively.
- The operating supplies and maintenance costs are assumed to be similar for both processes.
- Operating supplies are assumed to be 30% of the operating labor costs.
- Maintenance labor costs are assumed to be 2% of the capital cost, and the maintenance material costs are 1% of the capital cost.
- Other labor costs include supervision (30% of O&M labor), plant overhead (25% of O&M labor and supervision costs), and labor burden (28% of O&M labor and supervision costs).

4.3 RESULTS OF ECONOMIC ANALYSIS

Tables 4-5 and 4-6 present the results of the economic analysis. A return on investment (ROI) greater than 15% (which is the cost of capital) is obtained in 4 years. This implies that the payback period for NASA/JSC is 4 years. The relatively fast payback period occurs primarily because waste disposal costs can be reduced by \$38,900 per year.

4.4 ECONOMIC ASSESSMENT

Bicarbonate of soda blasting has good potential for reducing paint removal costs. Paint stripping shops may find this technology highly beneficial, especially as more stringent federal and local regulations are being implemented to govern the disposal of toxic solvent-contaminated wastes. Cost reductions were realized from the decrease in hazardous waste and reduced labor. Savings in elimination of solvent purchases are offset by blast media costs.

Applications that generate no hazardous waste when switching to the blasting process (i.e. no toxics in the paints or coatings removed) may be more lucrative.

**TABLE 4-4. ANNUAL OPERATING COSTS AND SAVINGS OF BICARBONATE BLASTING
COMPARED TO SOLVENT STRIPPING**

Operating Cost/Revenue			
Marketable By-Products		Operating Labor, Savings	
Rate	\$0	Operator hr/yr	766
Price	\$0	Wage rate, \$/hr	\$18.14
Total \$/yr	\$0		
Utilities (per year)		Operating Supplies	
Gas	\$0	(% of Operating Labor)	30%
Electric	\$0		
Fuel Oil	\$205	Maintenance Costs	
Process Water	\$110	(% of Capital Costs)	
Total \$/yr	\$315	Labor	2.00%
		Materials	1.00%
Raw Materials		Supervision	
Total, \$/yr	\$2,651	(% of O&M Labor)	30.0%
Waste Disposal Savings		Overhead Costs	
Off-site Fees, \$	\$38,900	(% of O&M Labor + Super.)	
Storage Drums, \$	\$0	Plant Overhead	25.0%
Total Disposal Savings	\$38,900	Home Office	0.0%
		Labor Burden	28.0%

TABLE 4-5. ANNUAL OPERATING SAVINGS FROM BICARBONATE BLASTING COMPARED TO SOLVENT STRIPPING

Revenue and Cost Factors						
Operating Year Number	1	2	3	4	5	6
Escalation Factor	1.000	1.050	1.103	1.158	1.216	1.340
Increased Revenues						
Increased Production	\$0	\$0	\$0	\$0	\$0	\$0
Marketable By-Products	\$0	\$0	\$0	\$0	\$0	\$0
Annual Revenue	\$0	\$0	\$0	\$0	\$0	\$0
Operating Savings (Numbers in parentheses indicate net expense)						
Raw Materials	(\$2,784)	(\$2,923)	(\$3,069)	(\$3,222)	(\$3,383)	(\$3,553)
Disposal Costs	\$40,845	\$42,887	\$45,032	\$47,283	\$49,647	\$52,130
Maintenance Labor	\$3,434	\$3,605	\$3,786	\$3,975	\$4,174	\$4,382
Maintenance Supplies	\$1,717	\$1,803	\$1,893	\$1,988	\$2,087	\$2,191
Operating Labor	\$14,590	\$15,320	\$16,085	\$16,890	\$17,734	\$18,621
Operating Supplies	\$4,377	\$4,596	\$4,826	\$5,067	\$5,320	\$5,586
Utilities	(\$331)	(\$347)	(\$365)	(\$383)	(\$402)	(\$422)
Supervision	\$5,407	\$5,677	\$5,961	\$6,259	\$6,572	\$6,901
Labor Burden	\$6,561	\$6,889	\$7,233	\$7,595	\$7,975	\$8,373
Plant Overhead	\$5,858	\$6,151	\$6,458	\$6,781	\$7,120	\$7,476
Home Office Overhead	\$0	\$0	\$0	\$0	\$0	\$0
Total Operating Savings	\$79,674	\$83,658	\$87,840	\$92,232	\$96,844	\$101,686

TABLE 4-6. RETURN ON INVESTMENT FOR CHANGE FROM SOLVENT STRIPPING TO BICARBONATE BLASTING

RETURN ON INVESTMENT							
Construction Year	1						
Operating Year		1	2	3	4	5	6
Book Value	\$225,648	\$161,177	\$115,127	\$82,233	\$49,998	\$17,762	\$0
Depreciation (by straight-line)		\$32,235	\$32,235	\$32,235	\$32,235	\$32,235	\$32,235
Depreciation (by double DB)		\$64,471	\$46,051	\$32,893	\$23,495	\$14,285	\$5,075
Depreciation		\$64,471	\$46,051	\$32,893	\$32,235	\$32,235	\$17,762
Cash Flows							
Construction Year	1						
Operating Year		1	2	3	4	5	6
Revenues		\$0	\$0	\$0	\$0	\$0	\$0
+ Operating Savings		\$79,674	\$83,658	\$87,840	\$92,232	\$96,844	\$101,686
Net Revenues		\$79,674	\$83,658	\$87,840	\$92,232	\$96,844	\$101,686
- Depreciation		\$64,471	\$46,051	\$32,893	\$32,235	\$32,235	\$17,762
Taxable Income		\$15,203	\$37,607	\$54,947	\$59,997	\$64,609	\$83,924
- Income Tax		\$0	\$0	\$0	\$0	\$0	\$0
Profit after Tax		\$15,203	\$37,607	\$54,947	\$59,997	\$64,609	\$83,924
+ Depreciation		\$64,471	\$46,051	\$32,893	\$32,235	\$32,235	\$17,762
After-Tax Cash Flow		\$79,674	\$83,658	\$87,840	\$92,232	\$96,844	\$101,686
Cash Flow for ROI	(\$226,668)	\$79,674	\$83,658	\$87,840	\$92,232	\$96,844	\$101,686
Net Present Value	(\$226,668)	(\$157,386)	(\$94,129)	(\$36,373)	\$16,362	\$64,510	\$108,472
Return on Investment		-64.85%	-19.18%	5.22%	18.43%	26.05%	30.70%

SECTION 5 QUALITY ASSURANCE

A Quality Assurance Project Plan (QAPjP) had been prepared and approved by the U.S. EPA before on-site testing began (Chen, 1991). The QAPjP contains a detailed description of the experimental design and specific quality assurance objectives. The QAPjP also includes analytical procedures and calibration, as well as methods for internal quality control checks, performance and system audits, and corrective action. Discussion pertinent to quality assurance is provided in Sections 5.1 and 5.2.

5.1 QUALITY ASSURANCE OBJECTIVES

The four quantitative data quality indicators, i.e., precision, accuracy, method detection limit (MDL) and completeness, for the various measurements required for this study have been set at levels shown in Table 3-2. Precision for most of the measurements is estimated by calculating relative percent difference (RPD) of laboratory duplicates. Precision for pH is estimated by calculating the pH limit for duplicates. Accuracy for most of the measurements is estimated using percent recovery of laboratory matrix spikes. For pH measurements, bias is determined by analysis of standard reference materials. Completeness is presented as the percentage of valid data over the total number of measurements.

The MDLs for ICP are 0.005, 0.007, 0.003, 0.017, 0.001, 0.005, and 0.003 mg/L for Cd, Cr, Cu, Pb, Mn, Ni, and Zn, respectively. The MDLs for TSS and oil and grease are 10 and 0.5 mg/L, respectively. The sensitivity for pH measurement is < 0.1 pH unit. The MDLs for airborne metal particulates are 0.001 mg/filter for Cd, 0.005 mg/filter for Cr, Cu and pb, and 0.009 mg/filter for Zn. All of these are within the limits set in Table 3-2.

In addition to the four data quality indicators, ICP calibration verification and ICP interference check were also performed for the total and leachable metal analyses in the laboratory. These data are included in Appendix C.

The data quality indicators calculation does not apply to the anodized surface damage test and the noise exposure test. Anodized surface damage was generally qualitative; therefore, quantitatively assessing precision and accuracy did not apply. The precision and accuracy of the sound-level meter and dosimeter are manufacturer-specified.

No independent on-site audits were performed during on-site testing and laboratory analyses. However, the Battelle Study Leader and QA Officer reviewed the analytical data for compliance with the QA objectives after completion of laboratory testing.

5.1.1 Precision

Precision quantifies the repeatability of a given measurement. The RPDs for TSS and metals measurements are calculated by equation (1) and presented in Table 5-1:

$$\text{RPD (\%)} = \frac{|(\text{Regular}) - (\text{Duplicate})|}{(\text{Regular} + \text{Duplicate})/2} \times 100\% \quad (1)$$

As shown in Table 5-1, the RPDs range from -12.9% to 14.3% for TSS and all metal measurements (including total and leachable metals in liquid and/or solid wastes). The RPDs are well within the limits (i.e., $\pm 25\%$) specified in the QAPjP. The RPD for oil and grease measurements (1.2%, see Table 5-2) is calculated according to equations (2) and (3):

$$\text{RPD (\%)} = \frac{|C_1 + C_2|}{(C_1 + C_2)/2} \times 100\% \quad (2)$$

$$\text{where } C_x = (\text{Spiked Sample})_x - (\text{Regular Sample})_x \quad x = 1, 2 \quad (3)$$

Precision limit for pH is estimated using the following equation (4):

$$\text{Precision Limit} = \text{pH (Regular Sample)} - \text{pH (Duplicate Sample)} \quad (4)$$

The precision limit is -0.005 and 0 pH unit for the two wastewaters analyzed (see Table 5-3), which, again, are within the limit specified (i.e., ± 0.1 pH unit). The RPDs for airborne metals measurements were not calculated because all analyzed data were beneath the method detection limits.

TABLE 5-1. PRECISION OF TSS AND METALS MEASUREMENTS

Sample Matrix	Sample Number	Parameter	Concentration Unit	Regular Sample	Duplicate Sample	RPD (%) ^a		Lab ^c Blank
						Actual	QA Objective	
Wastewater in vat	LWV-2-TSS/pH	TSS	mg/L	251	255	1.6	±25	< 10
	LWV-1-M	Cd ^b	mg/L	0.0317	0.0345	8.5	±25	< 0.0050
	LWV-1-M	Cu ^b	mg/L	8.2010	8.4670	3.2	±25	< 0.0070
	LWV-1-M	Cu ^b	mg/L	1.2700	1.2280	3.4	±25	< 0.0030-0.0051
	LWV-1-M	Pb ^b	mg/L	1.4740	1.5420	4.5	±25	< 0.0170
	LWV-1-M	Mn ^b	mg/L	0.0224	0.0220	1.8	±25	< 0.0010
	LWV-1-M	Ni ^b	mg/L	0.0066	0.0061	7.9	±25	< 0.0050
	LWV-1-M	Zn ^b	mg/L	6.2320	6.4760	3.8	±25	< 0.0030-0.0075
Wastewater in rotoclon separator	LWDC-2-pH/TSS	TSS	mg/L	< 10	< 10	N/A ^c	±25	< 10
	LWDC-1	Cd ^b	mg/L	0.0050	0.0050	0	±25	< 0.0050
	LWDC-1	Cu ^b	mg/L	0.3440	0.3480	1.2	±25	< 0.0070
	LWDC-1	Cu ^b	mg/L	0.0609	0.0629	3.2	±25	< 0.0030-0.0051
	LWDC-1	Pb ^b	mg/L	0.0333	0.0379	12.9	±25	< 0.00170
	LWDC-1	Mn ^b	mg/L	0.0060	0.0063	4.9	±25	< 0.0010
	LWDC-1	Ni ^b	mg/L	0.0156	0.0156	0	±25	< 0.0050
	LWDC-1	Zn ^b	mg/L	0.4996	0.5100	2.1	±25	< 0.0030-0.0075
Solids in vat	SWV-2	Cd ^b	mg/kg	1.6792	1.6509	1.7	±25	< 0.0050
	SWV-2	Cu ^b	mg/kg	141.8868	143.7736	1.3	±25	< 0.0070
	SWV-2	Cu ^b	mg/kg	24.9623	25.0094	0.2	±25	< 0.0030-0.0051
	SWV-2	Pb ^b	mg/kg	44.3208	44.2358	0.2	±25	< 0.0170
	SWV-2	Mn ^b	mg/kg	1.3396	1.3396	0	±25	< 0.0010
	SWV-2	Ni ^b	mg/kg	0.5660	0.6132	8.0	±25	< 0.0050
	SWV-2	Zn ^b	mg/kg	281.7925	286.0377	1.5	±25	< 0.0030-0.0075
	SWV-2	Cd ^d	mg/L	0.0360	0.0371	3.0	±25	< 0.0050
Solids in vat (TCLP)	SWV-2	Cu ^d	mg/L	2.7990	3.0370	8.2	±25	< 0.0070
	SWV-2	Cu ^d	mg/L	0.5182	0.5738	10.4	±25	< 0.0030-0.0051
	SWV-2	Pb ^d	mg/L	0.4951	0.5423	9.1	±25	< 0.0170
	SWV-2	Mn ^d	mg/L	0.0074	0.0083	11.5	±25	< 0.0010
	SWV-2	Ni ^d	mg/L	0.0060	0.0052	14.3	±25	< 0.0050
	SWV-2	Zn ^d	mg/L	4.8070	5.2060	8.0	±25	< 0.0030-0.0075
	SWV-2	Cd ^d	mg/L	0.0360	0.0371	3.0	±25	< 0.0050
	SWV-2	Cu ^d	mg/L	2.7990	3.0370	8.2	±25	< 0.0070

^a RPD (%) = Relative percent difference (%) = $\frac{(\text{Regular}) - (\text{Duplicate})}{(\text{Regular} + \text{Duplicate})/2} \times 100\%$ ^b Total metal.^c Concentration units: mg/L.^d Leachable metal.^e Analyte in regular or duplicate sample under detection limit.

TABLE 5-2. PRECISION AND ACCURACY OF OIL AND GREASE MEASUREMENTS

Sample Number	Regular Sample (mg/L)	Spike Added (mg/L)	Recovery (%) ^a		RPD (%) ^b		
			Spiked Sample (mg/L)	Actual	QA Objective	Actual	QA Objective
LWV-OG-MS	30.7	10	38.7	80	75 - 125	1.2	±25
LWV-3-OG	58.0	10	66.1	81	75 - 125		<0.5

^a Recovery (%) = $\frac{(\text{Spiked Sample}) - (\text{Regular Sample})}{(\text{Spike Added})} \times 100\%$

^b RPD (%) = $\frac{C_1 - C_2}{C_1 + C_2} \times 100\%$, where $C_x = (\text{Spiked Sample})_x - (\text{Regular Sample})_x$ and $x = 1, 2$

TABLE 5-3. PRECISION OF pH MEASUREMENTS^a

Sample Matrix	Sample Number	Regular Sample	Duplicate Sample	Precision Limit ^b		Lab Blank
				Actual	QA Objective	
Wastewater in vat	LWV-2-TSS/pH	8.365	8.370	-0.005	±0.1	7.011
Wastewater in rotoclon separator	LWDC-2 - pH/TSS	8.219	8.219	0	±0.1	7.011

^a The bias of pH measurements has been determined using a standard reference electrolyte solution.

^b Precision limit for pH = pH (Regular Sample) - pH (Duplicate Sample).

Because only duplicate observations were made during analyses, RPDs, rather than RSDs, became the appropriate estimators of precision and, therefore, were used for the above calculations.

5.1.2 Accuracy

Accuracy refers to the percentage of a known amount of analyte recovered from a given matrix. Percent recoveries for metals (including total, leachable, and airborne) and oil and grease measurements are estimated by equation (5) and presented in Tables 5-2, 5-4, and 5-5:

$$\text{Recovery (\%)} = \frac{(\text{Spiked Sample}) - (\text{Regular Sample})}{(\text{Spike Added})} \times 100\% \quad (5)$$

All data in these tables are within the limits specified. The bias of pH measurements has been determined using a standard reference electrolyte solution.

5.1.3 Completeness

Completeness refers to the percentage of valid data received from actual testing done in the laboratory. Completeness is calculated as follows:

$$\text{Completeness} = \frac{\text{Number of Measurements Judged Valid}}{\text{Total Number of Measurements}} \times 100\% \quad (6)$$

Completeness for all measurements is 100%.

5.2 LIMITATIONS AND QUALIFICATIONS

Based on the above quality assurance data, the results from the laboratory analyses provide a good basis for drawing conclusions about waste reduction and pollution prevention.

TABLE 5-4. ACCURACY OF METALS MEASUREMENTS

Sample Matrix	Sample Number	Metal	Concentration Unit	Regular Sample	Spike Added	Spiked Sample	Recovery (%) ^a		Lab Blank
							Actual	QA Objective	
Wastewater in vat	LWV-1-M	Cd ^b	mg/L	0.0317	1.000	0.9831	95.1	75-125	<0.0050
		Cr ^b	mg/L	8.2000	1.000	9.1210	92.0	75-125	<0.0070
		Cu ^b	mg/L	1.2700	1.000	2.1650	89.5	75-125	<0.0030-0.0051
		Pb ^b	mg/L	1.4740	1.000	2.4950	102.1	75-125	<0.0170
		Mn ^b	mg/L	0.0224	1.000	0.8604	83.8	75-125	<0.0010
		Ni ^b	mg/L	0.0066	1.000	0.8581	85.2	75-125	<0.0050
		Zn ^b	mg/L	6.2320	1.000	7.3310	109.9	75-125	<0.0030-0.0075
Wastewater in rotoclon separator	LWCDC-1	Cd ^b	mg/L	0.0050	0.500	0.5138	102.8	75-125	<0.0050
		Cr ^b	mg/L	0.3440	0.500	0.8765	106.5	75-125	<0.0070
		Cu ^b	mg/L	0.0609	0.500	0.5974	107.3	75-125	<0.0030-0.0051
		Pb ^b	mg/L	0.0333	0.500	0.5506	103.5	75-125	<0.0170
		Mn ^b	mg/L	0.0060	0.500	0.5115	101.1	75-125	<0.0010
		Ni ^b	mg/L	0.0156	0.500	0.4918	95.2	75-125	<0.0050
		Zn ^b	mg/L	0.5000	0.500	1.0570	111.5	75-125	<0.0030-0.0075
Solids in vat	SWV-2	Cd ^b	mg/kg	1.6792	93.46	91.3551	96.0	75-125	<0.0050
		Cr ^b	mg/kg	141.8868	93.46	232.0561	96.5	75-125	<0.0069
		Cu ^b	mg/kg	24.9623	93.46	116.0748	97.5	75-125	<0.0013
		Pb ^b	mg/kg	44.3208	93.46	132.9907	94.9	75-125	<0.0170
		Mn ^b	mg/kg	1.3396	93.46	89.3925	94.2	75-125	<0.0002
		Ni ^b	mg/kg	0.5660	93.46	86.4486	91.9	75-125	<0.0050
		Zn ^b	mg/kg	281.7925	93.46	370.5607	95.0	75-125	<0.0019
Solids in vat	SWV-2	Cd ^c	mg/L	0.0360	0.500	0.5158	96.0	75-125	<0.0050
		Cr ^c	mg/L	2.7990	0.500	3.3290	106.0	75-125	<0.0070
		Cu ^c	mg/L	0.5182	0.500	1.0100	98.4	75-125	<0.0030-0.0051
		Pb ^c	mg/L	0.4951	0.500	0.9415	89.3	75-125	<0.0170
		Mn ^c	mg/L	0.0074	0.500	0.4671	91.9	75-125	<0.0010
		Ni ^c	mg/L	0.0060	0.500	0.4459	88.0	75-125	<0.0050
		Zn ^c	mg/L	4.8070	0.500	5.3190	102.4	75-125	<0.0030-0.0075

^a Recovery (%) = $\frac{(\text{Spiked Sample}) - (\text{Regular Sample})}{(\text{Spike Added})} \times 100\%$

^b Total metal.

^c Leachable metal.

TABLE 5-5. ACCURACY OF AIRBORNE METALS MEASUREMENTS

Sample Number	Metal	Recovery (%) ^a		Method Recovery (%) ^b
		Actual	QA Objective	
Metal 5147- Background	Cd	100.00	75 - 125	95.54
	Cr	98.06	75 - 125	94.55
	Cu	96.70	75 - 125	93.73
	Pb	99.21	75 - 125	99.90
	Zn	99.52	75 - 125	85.53
Metal 5148- Primary	Cd	100.00	75 - 125	95.54
	Cr	100.00	75 - 125	94.55
	Cu	99.53	75 - 125	93.73
	Pb	98.42	75 - 125	99.90
	Zn	98.55	75 - 125	85.53
Metal 5149- Replicate	Cd	102.04	75 - 125	96.46
	Cr	103.79	75 - 125	93.70
	Cu	103.81	75 - 125	93.93
	Pb	103.65	75 - 125	95.02
	Zn	103.47	75 - 125	92.60
Metal 5150- Replicate	Cd	101.03	75 - 125	95.50
	Cr	102.90	75 - 125	93.89
	Cu	104.29	75 - 125	94.09
	Pb	101.18	75 - 125	95.68
	Zn	105.31	75 - 125	88.97
Metal 5151- Field Blk 1	Cd	102.04	75 - 125	96.46
	Cr	87.68	75 - 125	93.70
	Cu	96.19	75 - 125	93.93
	Pb	103.04	75 - 125	95.02
	Zn	105.45	75 - 125	92.60
Metal 5152- Field Blk 2	Cd	101.00	75 - 125	95.54
	Cr	100.97	75 - 125	94.55
	Cu	100.47	75 - 125	93.73
	Pb	98.22	75 - 125	99.90
	Zn	100.00	75 - 125	85.53

TABLE 5-5. ACCURACY OF AIRBORNE METALS MEASUREMENTS (Continued)

Sample Number	Metal	Recovery (%) ^a		Method Recovery (%) ^b
		Actual	QA Objective	
Metal 5153- Primary	Cd	99.00	75 - 125	95.54
	Cr	98.54	75 - 125	94.55
	Cu	98.11	75 - 125	93.73
	Pb	100.20	75 - 125	99.90
	Zn	99.03	75 - 125	85.53
Metal 5154- Replicate	Cd	96.94	75 - 125	96.46
	Cr	99.05	75 - 125	93.70
	Cu	97.62	75 - 125	93.93
	Pb	98.99	75 - 125	95.02
	Zn	97.52	75 - 125	92.60
Metal 5155- Replicate	Cd	101.03	75 - 125	95.50
	Cr	100.00	75 - 125	93.89
	Cu	98.10	75 - 125	94.09
	Pb	101.38	75 - 125	95.68
	Zn	100.97	75 - 125	88.97
Metal 5156- Field Blk 1	Cd	107.14	75 - 125	96.46
	Cr	102.37	75 - 125	93.70
	Cu	102.86	75 - 125	93.93
	Pb	108.92	75 - 125	95.02
	Zn	110.89	75 - 125	92.60
Metal 5157- Field Blk 2	Cd	98.00	75 - 125	95.54
	Cr	98.06	75 - 125	94.55
	Cu	96.70	75 - 125	93.73
	Pb	97.83	75 - 125	99.90
	Zn	98.07	75 - 125	85.53

^a Recovery (%) = $\frac{(\text{Spiked Sample}) - (\text{Regular Sample})}{(\text{Spike Added})} \times 100\%$

Matrix spikes were accomplished by spiking a known aliquot of metals of interest into the digested solution.

^b Method Recovery (%) = $\frac{(\text{Method Standard}) - (\text{Method Blank})}{(\text{Pipet Standard})} \times 100\%$

Most of the data for the economic analysis were obtained from NASA/JSC and the vendor's management. Several assumptions made for the economic analysis have been discussed in Section 4. Informed assumptions were made only when hard data were absent. These assumptions are site-specific, and readers are encouraged to adjust them to their own cases.

SECTION 6

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APPENDIX A

**METHOD OF ASSESSING
ANODIZED SURFACE DAMAGE**

SPECIAL METHOD OF ASSESSING ANODIZED SURFACE DAMAGE

1. Scope
 - 1.1 This is a special method for testing under the Waste Reduction Innovative Technology Evaluation (WRITE) Program to estimate anodized surface damage on aircraft wheels.
2. Summary of Method
 - 2.1 This method measures the incidental damage that wheels endure when their paint is stripped via bicarbonate of soda blasting.
3. Significance and Use
 - 3.1 To a limited extent, this method assesses the effectiveness of stripping paint with bicarbonate of soda.
 - 3.2 This is a preliminary scoping test for use in the WRITE project evaluation of replacing conventional chemical stripper with bicarbonate of soda stripping.
4. Terminology
 - 4.1 NDI — Nondestructive inspection. This is a method used to inspect unpainted aircraft parts for fatigue cracks and other signs of damage.
 - 4.2 Standoff distance — Distance from the nozzle to the surface to be stripped.
5. Apparatus
 - 5.1 Two rear wheels from a T-38 aircraft.
 - 5.2 One ARMEX™/ACCUSTRIP™ sodium bicarbonate blast system, Model 16W.
 - 5.3 One camera with a close-range lens.
 - 5.4 Almigrip-brand polyurethane primer and topcoat.
 - 5.5 Miscellaneous equipment for painting.
6. Procedures
 - 6.1 Clean two rear wheels from a T-38 aircraft, using NASA standard procedures.
 - 6.2 Prepare the blast system for operation (see manufacturer instructions). Media flow rate should be 1-4 lb/min at 40-60 psi pressure with a water flow rate of 0.5 gal/min.
 - 6.3 Hold the blast nozzle at a standoff distance of 12 to 24 inches and an impingement angle of 30 degrees. Completely strip the paint from one wheel.
 - 6.4 Photograph the stripped wheel with a camera equipped with a close-range lens. Distance from camera to wheel should be between 6 and 12 inches.

- 6.5 A team of three experienced NDI technicians should examine the wheel and provide the data required in the data sheet (see Figure A-1).
- 6.6 Repaint the wheel, applying polyurethane primer and topcoat. Allow at least 12 hours drying time.
- 6.7 Repeat steps 6.2 through 6.4.
- 6.8 The same NDI technicians from step 6.5 should again examine the same wheel and record the data in the data sheet.
- 6.9 Repeat steps 6.2 through 6.8 for the second wheel.

FIGURE A-1. ANODIZED SURFACE DAMAGE DATA SHEET

Date: _____ Time: _____ Operator: _____
Wheel number: _____ Run number (circle): _____ One Two
Media flow rate: _____ Nozzle pressure: _____ Water flow rate: _____
Stripping time: _____

1. Is there any surface damage? Yes ☐ No ☐

2. If yes, is it anodized surface damage? Yes ☐ No ☐

Describe other damages: _____

3. Is the anodized surface damage due primarily to mechanical wear? Yes ☐ No ☐

Describe location, appearance, etc.: _____

ARMEX™ blasting? Yes ☐ No ☐

Describe location, appearance, etc.: _____

Other causes? Yes ☐ No ☐

Describe causes, location, appearance, etc.: _____

4. If this is a second run, do you notice any differences between this and the previous inspection? Yes ☐ No ☐

If yes, describe it: _____

ADDITIONAL COMMENTS: _____

APPENDIX B

THE EFFECTS OF ARMEX[®]/ACCUSTRIP SYSTEM[™] ON FATIGUE CRACKS IN ALCLAD TEST PANELS

THE EFFECTS OF THE ARMEX®/ACCUSTRIP™ SYSTEM ON FATIGUE CRACKS IN ALCLAD AIRCRAFT ALUMINUM

During the introduction of the Armex/Accustrip process as an alternate method of paint removal for the Aviation Industry, questions arose concerning effects of the process on fatigue cracks in alclad aluminum. The Aviation Industry has recently begun routinely stripping airframes and inspecting for fatigue cracks in the skin of the aircraft. The concern was that the Armex/Accustrip system may deform the alclad coating and fill in or mask the cracks.

In order to investigate these concerns, sixteen panels of A12024 T3 Alclad (.032") were prepared according to ASTM E647 using a Krouse 5-KIP, DDS fatigue machine. The cracks induced were roughly 1/4-3/8" long and all but invisible to the naked eye. The cracks were photographed using a Scanning Electron Microscope at 100X. Eight of the panels were then prepared and painted with mil. spec. epoxy primer and polyurethane topcoat. The panels were photographed after conversion coating was applied and it was noted that the conversion coating application partially filled in the cracks. The panels were then blasted with Armex Blast Media at 50, 60, 70, and 80 psi nozzle pressure using a 60 deg. blast angle, 12" stand off, and 3 #/min media flow. Two panels were blasted at each pressure setting. The next phase of the test was a dye penetrant examination of the panels as per mil. spec. 410. In all cases the cracks were readily identified under ultraviolet light and photographed. One panel, blasted at 80 psi, did show some distortion at the end of the crack. More importantly, eddy current inspection identified each crack readily.

In conclusion, the findings of this test are that the Armex/Accustrip system does not impede conventional methods of fatigue crack detection. It should be noted that even though the application of the chromate conversion coating with scotchbrite did partially mask the crack from visual detection the crack was still located using eddy current inspection.

I would like to thank the Quality Assurance people at NASA's Ellington Field and Northrup Worldwide Aviation Services Inc. for their assistance in the preparation of the panels and Bell Evaluation Labs for their assistance in the inspection of the panels.

Tim Williams
Project Technician
CDS Group
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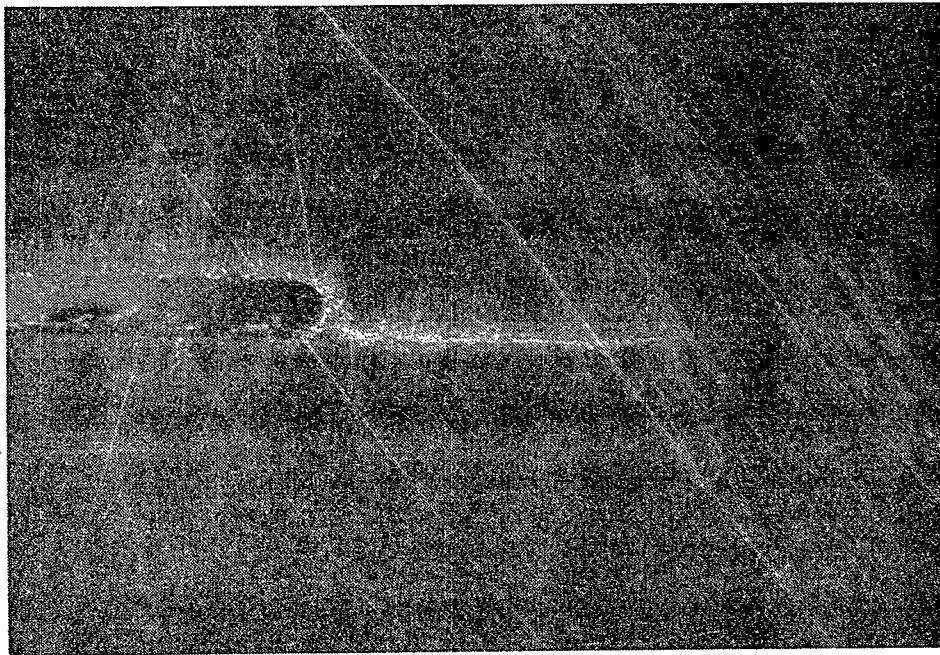


Figure B-1. Alclad panel (#7 of 8) prior to painting.

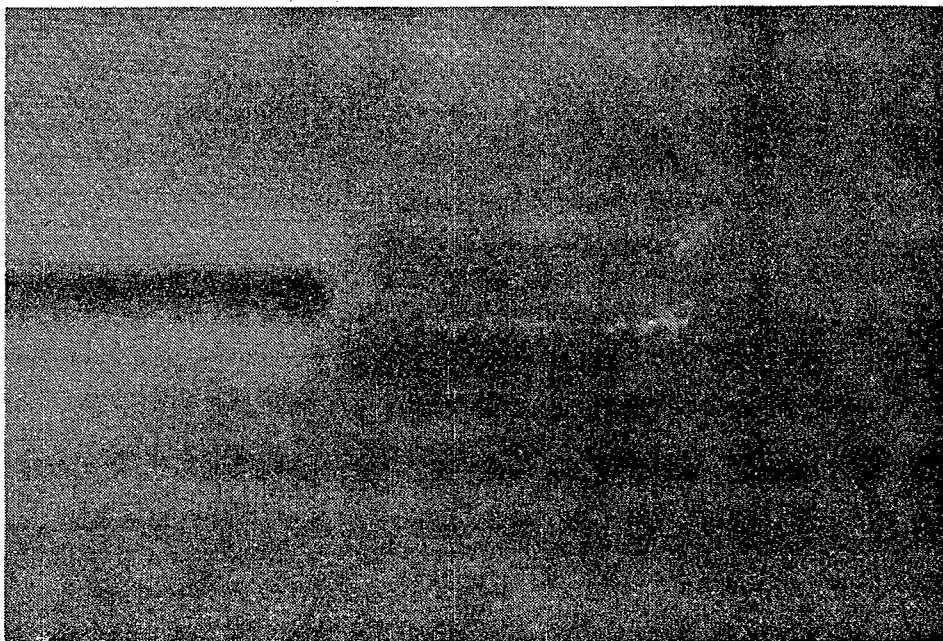


Figure B-2. Painted Alclad panel (#7 of 8).

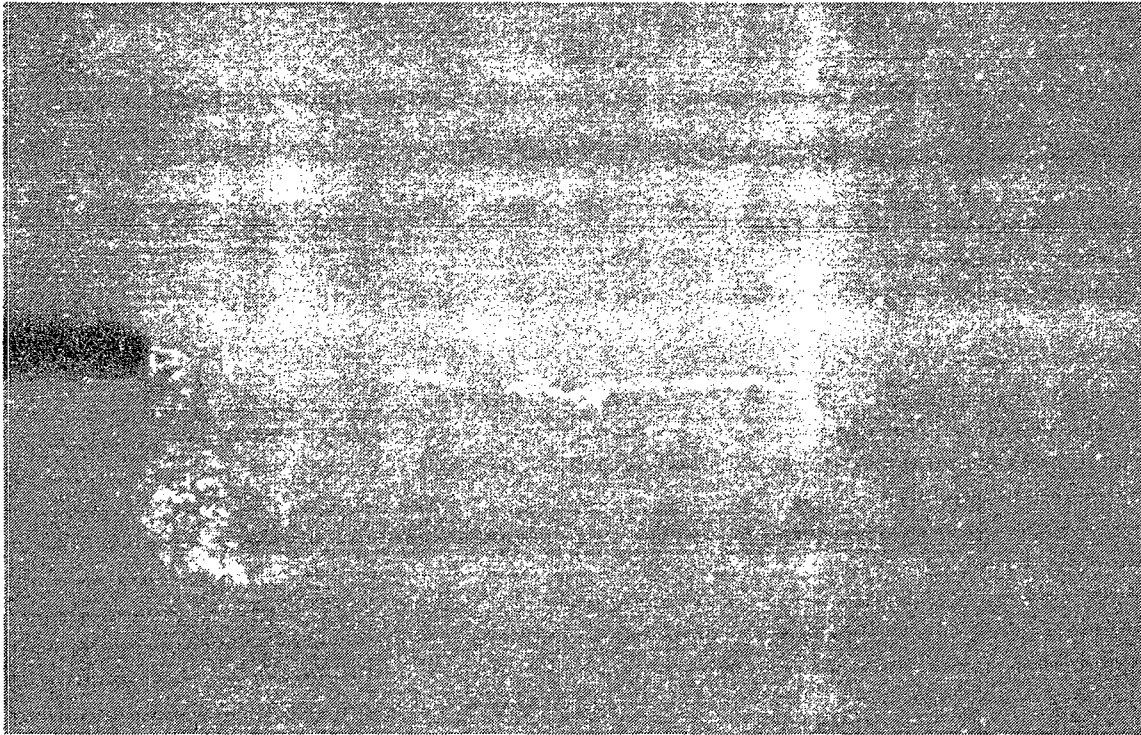


Figure B-3. Alclad panel (#7 of 8) after blasting with ARMEX® blast media at 80 psi.

APPENDIX C

ICP CALIBRATION VERIFICATION AND ICP INTERFERENCE CHECK

TABLE C-1. ICP CALIBRATION VERIFICATION^a

Metal	True (mg/L)	Initial Calibration			Continuing Calibration				
		Actual (mg/L)	R ^b (%)	Actual (mg/L)	R ^b (%)	Actual (mg/L)	R ^b (%)	Actual (mg/L)	R ^b (%)
Cd	0.5000	0.5230	104.6	0.5068	101.4	0.4917	98.3	0.4979	99.6
Cr	0.5000	0.4975	99.5	0.4993	99.9	0.4866	97.3	0.4800	96.0
Cu	0.5000	0.5136	102.7	0.5148	103.0	0.4925	98.5	0.4757	95.1
Pb	0.5000	0.5186	103.7	0.5008	100.2	0.4897	97.9	0.4998	100.0
Mn	0.5000	0.5056	101.1	0.4961	99.2	0.4777	95.5	0.4707	94.1
Ni	0.5000	0.4955	99.1	0.4824	96.5	0.4735	94.7	0.4723	94.5
Zn	0.5000	0.5146	102.9	0.5070	101.4	0.4932	98.6	0.4920	98.4

^a Continuing calibration check was carried out every 10 samples after initial calibration.

$$^b R (\%) = \frac{\text{Actual}}{\text{True}} \times 100\%$$

TABLE C-2. ICP INTERFERENCE CHECK^a

Metal	True (mg/L)	Initial Check		Final Check	
		Actual (mg/L)	Recovery ^b (%)	Actual (mg/L)	Recovery (%)
Al	500.0000	488.7000	97.7	471.3000	94.3
Ba	0.5000	0.4858	97.2	0.4607	92.1
Be	0.5000	0.4794	95.9	0.4601	92.0
Cd	1.0000	0.9083	90.8	0.8901	89.0
Ca	500.0000	498.5000	99.7	494.2000	98.8
Cr	0.500	0.4712	94.2	0.4765	95.3
Co	0.500	0.4432	88.6	0.4375	87.5
Cu	0.500	0.4676	93.5	0.4456	89.1
Fe	200.000	179.5000	89.8	179.7000	89.8
Pb	1.0000	0.9893	98.9	1.0450	104.5
Mg	500.0000	486.7000	97.3	478.2000	95.6
Mn	0.5000	0.4339	86.8	0.4259	85.2
Ni	1.0000	0.8704	87.0	0.8685	86.8
Ag	1.0000	0.9721	97.2	0.9825	98.2
V	0.5000	0.4883	97.7	0.4884	97.7
Zn	1.0000	0.9372	93.7	0.9270	92.7

^a Interference check was carried out before and after sample analyses.

^b Recovery (%) = $\frac{\text{Actual}}{\text{True}} \times 100\%$