EPA/600/R-07/025
March 2007

Demonstration Evaluation of Biodegradable Degreaser

by

Battelle
Columbus, Ohio 43201

Contract No. 68-C-00-185
Task Order 0026

Task Order Manager

David Ferguson
National Risk Management Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

DISCLAIMER

The work reported in this document is funded by the U.S. Environmental Protection Agency (EPA) under Task Order (TO) 0026 of Contract No. 68-C-00-185 to Battelle. It has been subjected to the Agency's peer and administrative reviews and has been approved for publication as an EPA document. Any opinions expressed in this paper are those of the author(s) and do not, necessarily, reflect the official positions and policies of the EPA. Any mention of products or trade names does not constitute recommendation for use by the EPA.

FOREWORD

The U.S. Environmental Protection Agency (EPA 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 yto support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Sally Gutierrez, Director
National Risk Management Research Laboratory

ABSTRACT

The objective of this project was to evaluate a bio-based parts-degreasing fluid called Eagle Kleen™ manufactured by Hydra-Tone Chemicals, Inc. (HTCI). Performance tests of this methyl-ester/surfactant, ready-to-use, micro-emulsion degreaser indicated that it was effective in removing oil and grease contamination from bare metal and painted surfaces, and its degreasing power is similar to alkaline and solvent cleaners. The project included the preparation of the Quality Assurance Project Plan (QAPP) and conducting the following three Tasks: 1 – Laboratory Testing, 2 – Site Testing (conducted at the Vehicle Shop at Robins Air Force Base [AFB], the Gas Turbine Engine [GTE] Shop at Hill AFB, and an equipment supplier), and 3 – Engineering Cost Assessment.

CONTENTS

FIGURES

TABLES

ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
ASTM	American Society for Testing and Materials
CPVC	chloropolyvinylchloride
CFR	Code of Federal Regulations
DOT	Department of Transportation
ECA	Engineering Cost Assessment
EPA	(United States) Environmental Protection Agency
ESOH	Environmental, Safety, and Occupational Health
HDPE	high-density polyethylene
HTCI	Hydra-Tone Chemicals, Inc.
IVD	Ion Vapor Deposited
IWTP	industrial wastewater treatment plant
LD_{50}	lethal dose at which 50% of the species does not survive
MSDS	Material Safety Data Sheet(s)
NESHAP	National Emission Standards for Hazardous Air Pollutants
NRMRL	National Risk Management Research Laboratory
NPV	net present value
PPE	personal protective equipment
ppm	parts per million
PVC	polyvinylchloride
QAPP	Quality Assurance Project Plan
QA/QC	quality assurance/quality control
QPL	qualified product list
RTU	ready-to-use
SARA	Superfund Amendment and Reauthorization Act
SMI	Scientific Materials International, Inc.
TOM	Task Order Manager
USAF	United States Air Force
UN	United Nations
VOC	volatile organic compound

EXECUTIVE SUMMARY

The objective of this project was to evaluate a bio-based parts-degreasing fluid called Eagle Kleen™ manufactured by Hydra-Tone Chemicals, Inc. (HTCI). Performance tests of this methyl-ester/surfactant, ready-to-use, micro-emulsion degreaser indicated that it was effective in removing oil and grease contamination from bare metal and painted surfaces, and its degreasing power is similar to alkaline and solvent cleaners. The project included the preparation of the Quality Assurance Project Plan (QAPP) and conducting the following three Tasks: 1 – Laboratory Testing, 2 – Site Testing (conducted at the Vehicle Shop at Robins Air Force Base [AFB], the Gas Turbine Engine [GTE] Shop at Hill AFB, and an equipment supplier), and 3 – Engineering Cost Assessment.

Analytical Testing. In this task, the non-hazardous, non-flammable, non-corrosive degreaser was assessed against a military specification (MIL-PRF-87937D) for water dilutable aerospace cleaning compounds. It met biodegradable, flash point, cleaning performance, residue, and cold stability requirements, as well as a series of metal and painted surface corrosion tests. It was found acceptable for sealants, rubber, and insulated wire, as well as hydrogen embrittlement. This ability to meet the hydrogen embrittlement requirement is a significant achievement that sets it apart from most aqueous cleaners. Unfortunately, it was found to craze acrylics and polycarbonates. It also could not pass the heat stability tests designed for water dilutable cleaners, which is a test not totally appropriate for a ready-to-use formulation such as Eagle Kleen™. The fluid was found suitable for full-scale demonstration trials where simple degreasing of metal and/or painted surfaces was required. Independent material compatibility testing indicates that Eagle Kleen™ is a powerful degreaser and, in some cases, could dissolve polymeric materials used for gloves, seals, gaskets, tank construction plastics, and certain materials used for tubing and hoses. However, acceptable alternatives for these items are commonly available, such as neoprene gloves, Viton or Teflon gaskets and seals, and high-density polyethylene (HDPE) tanks and containers.

HTCI describes Eagle Kleen™ as "non-toxic." However, limited aquatic toxicity testing, as part of the MIL-PRF-87937D evaluation, indicated that Eagle Kleen™ was toxic to some aquatic life forms even at low concentrations. Additional toxicity tests, where Eagle Kleen™ was evaluated against a typical solvent and a typical alkaline cleaner, indicated that all three were toxic to aquatic life forms at typical use concentrations.

Site Testing. Full-scale demonstration trials were held at Robins AFB and at Hill AFB. Brief tests were also conducted at Ransohoff, Inc., an immersion parts washer manufacturer. Details of those demonstrations are summarized below.

Robins AFB. The Robins AFB vehicle shop demonstration included side-by-side testing of 3-inch-diameter steel wheel bearings cleaning with the shop's regular solvent, Safety Kleen PRF 680 Type II hydrocarbon degreaser, and with Eagle Kleen III™ degreaser. The initial assessment, using actual wheel bearings removed from base vehicles for routine maintenance, showed that there was little or no difference in the appearance of the cleaned parts, regardless of the degreaser used. The following characteristics were noted for Eagle Kleen™:

- In general, the level of cleaning was adequate, but on an individual part basis, the performance was either equal to or slightly inferior to the hydrocarbon degreaser.

- Cleaning times using Eagle Kleen™ were approximately 50% longer for a part of similar size, shape, and type of contamination than using Safety Kleen.

- The degreaser had an odor that was objectionable to some operators.
- Parts felt dramatically more slippery in gloved hands, until the parts were rinsed with water.

The Vehicle Shop manager indicated that Eagle Kleen™ may not be cost-effective due to the longer cleaning time that was required. For Eagle Kleen™ to be economically attractive, its base cost, handling cost, and disposal costs would have to be lower, and/or its lifetime would have to be much longer than that of a traditional solvent.

Hill AFB. The demonstration at the Hill AFB GTE shop included side-by-side testing of a variety of GTE parts cleaned in the shop's automated RAMCO system. The shop used hot alkaline cleaning (Turco 6849), water rinsing, and drying operations. Many of the parts that were degreased at the GTE shop had heavy carbon contamination. All had some degree of oil and/or grease contamination too. The initial assessment showed that Eagle Kleen™ was less effective than Turco 6849. The following characteristics were noted for Eagle Kleen™:

- The operators reported that Turco 6849 removed the oil, grease, and carbon deposits; in contrast, Eagle Kleen™ removed most of the oil and grease, but was not effective at removing heavy carbon contamination.
- Test results indicated that operating Eagle Kleen™ at an elevated temperature (90-120°F) did not significantly improve performance; however, the change in temperature dramatically increased complaints related to odor.
- The two-week testing schedule was stopped after three days due to these issues.

Ransohoff. Tests at the Ransohoff, Inc. company in Cincinnati, OH included testing of selected, condemned GTE parts cleaned using the Ransohoff, Inc. ultrasonics-enhanced system. A few of the parts showed some carbon contamination, and had some degree of oil contamination. The initial assessment showed that a 5% solution of Eagle Kleen™ with ultrasonics was extremely effective at removing the carbon deposits. The following characteristics were noted for Eagle Kleen™:

- A dilute solution of Eagle Kleen III can be used in an ultrasonically enhanced parts washer to remove a substantial portion of carbon deposited on typical GTE shop parts.
- Cleaning appeared good, but was not complete. A longer immersion time or hand cleaning might be required for complete carbon removal.
- The solution was not effective at removing grease/heavy oils.
- The Eagle Kleen III odor was detectable but not overpowering, even with the top off of the cleaning unit. It is anticipated that the odor problem would be reduced if the top is open for only a few minutes per hour. However, some type of ventilation would be required in most applications.

Engineering Cost Assessment. The assessment indicated that the installation of a new ultrasonic cleaning bath and the use of Eagle Kleen III results in an attractive payback of <3.3 years depending on the cost for handling, treatment and disposal of the spent alkaline cleaner and spent rinse.

1.0 PROJECT DESCRIPTION

1.1 General Overview

The purpose of this Task Order was to evaluate Hydra-Tone Chemicals, Inc.'s (HTCI's) Eagle Kleen™ biodegradable degreaser as a potential substitute for conventional alkaline cleaners and hydrocarbon cleaning solvents. Battelle conducted the evaluation under contract agreement with the National Risk Management Research Laboratory (NRMRL) of the United States Environmental Protection Agency (EPA). The approach of the NRMRL is to work with industry to provide technical and economic information about new technologies for potential users so that they can achieve voluntary reductions in the use and release of hazardous substances. The intent of EPA's approach is to encourage the use of less-polluting substances in industrial operations.

HTCI introduced Eagle Kleen™ as an environmentally friendly degreasing agent, designed to provide the same degreasing effect as conventional alkaline cleaners and non-chlorinated cleaning solvents used in immersion tanks and spray washers. HTCI's product literature indicates that Eagle Kleen™ is completely biodegradable, non-hazardous, non-flammable, non-toxic, non-corrosive, and safe-to-use. Eagle Kleen™ is a naturally derived product based on seed oil. It is a ready-to-use (RTU) liquid degreaser designed with a special methyl-ester micro-emulsion formulation. This unique solvent technology is intended to be used for the removal of grease, cutting fluids, motor and transmission oils, hydraulic fluids, and other surface contaminants. Eagle Kleen™ has a flash point greater than 200˚F (93˚C) and is considered non-flammable. Eagle Kleen does not contain Superfund Amendment and Reauthorization Act (SARA) 313-listed extremely hazardous substances or California Proposition 65 components. HTCI recommends that Eagle Kleen™ should be used at temperatures above 50˚F (10˚C) to provide adequate parts cleaning.

1.2 Goals

The goal of this NRMRL project is to validate the cleaning efficiency and economics of using HTCI's Eagle Kleen™ biodegradable degreaser as an alternative to (and potential substitute for) hydrocarbon-solvent degreasers and heated alkaline immersion cleaners. Such degreasers have been introduced in the parts cleaning industry as replacements for organic solvents, most of which are ozone-depleting substances and/or are targeted for reduced usage by EPA's 33/50 program (EPA, 1999).

Data were tracked on cleaning efficiency, bath performance, cleaning time, and working conditions when using each fluid. By comparing these data, the suitability of Eagle Kleen™ as a replacement fluid in these applications was assessed. The following three general issues were addressed:

1. The proposed new technology/methodology must be effective in performing the process function that it is intended to replace.

2. There must be a significant, measurable reduction in the quantity of waste hazard (pollutant) produced and in the level of hazard produced.

3. The economics of the alternative technology must be quantified and compared to the economics of the existing technology.

The consideration of each issue is critical to recommending the new technology as a feasible alternative to the existing technology. The site testing task was designed to address items 1 and 2, and gather information to evaluate item 3.

1.3 Demonstration/Report Organization.

The Battelle Program Manager for this project was Dr. Bruce Alleman. Dr. Alleman was responsible for all technical requirements and was supported by Dr. Bruce Sass who served as the Battelle Task Order Leader. Dr. Sass maintained regular telephone communication with the U.S. EPA Task Order Manager (TOM), Mr. David Ferguson. Ms. Sara Kuczek was responsible for preparing the QAPP, supervising the laboratory effort (Task 1), and data reporting. Mr. Nick Conkle was responsible for Site Testing (Task 2) and the Engineering Cost Assessment (Task 3). The Field Evaluation Integration (Task 4) was eliminated. Ms. Betsy Cutie was the Battelle QA Officer who monitored project performance with regard to the QAPP.

This report is organized in the following sections:

1. Task 1: Analytical Testing
2. Task 2: Site Testing
3. Task 3: Economic Cost Assessment
4. Conclusions
5. References
6. Appendices.

2.0 TASK 1 – ANALYTICAL TESTING

Prior to laboratory testing, Battelle consulted stakeholders at Robins Air Force Base (AFB) and Hill AFB to discuss immersion and spray degreaser requirements for military parts cleaning. The purpose of these discussions was to gain approval and learn about cleaning and materials compatibility requirements that could be used as criteria with which to measure the performance of the different cleaning materials and methods, and to form a direct way of comparing conventional cleaners with Eagle Kleen™. The appropriate cleaning and materials compatibility requirements are contained in MIL-PRF-87937D ("Performance Specification: Cleaning Compound, Aerospace Equipment"). It is attached as Appendix A. The purpose of Task 1 was to demonstrate Eagle Kleen's™ ability to meet the criteria listed in MIL-PRF-87937D. Testing was to proceed at Hill AFB only if Eagle Kleen™ was comparable to or surpassed the specification standards or requirements. No specific prequalification testing was required at Robins AFB's Vehicle Shop, but the corrosion testing results along with the other analytical tests provided by this specification provided valuable information.

Degreasers used by the United States Air Force (USAF) must conform to MIL-PRF-87937D and, in some cases, MIL-C-29602 or MIL-PRF-85570 to comply with the Process Orders and Technical Orders dictating repair and maintenance of F-15, F-16, C-5, C-17, C-130, and C-141 aircraft component parts. To facilitate the timely completion of this study, Battelle tested Eagle Kleen's™ performance on all requirements outlined in MIL-PRF-87937D with the exception of long-term storage stability. Due to the scheduling of the demonstration, this was not required because the material was not stored for longer than a few months. To meet MIL-PRF-87937D, Battelle completed the material qualification requirements tests listed for Type IV cleaners. Battelle managed the subcontracted analytical tests, performed quality assurance (QA)/quality control (QC) assessments, and performed pre-testing (QA/QC of sample) in its laboratories. Cleaning efficiency testing was part of the MIL-PRF-87937D series of tests, as described in Section 4.5.21 in MIL-PRF-87937D. Some qualifying cleaning tests were performed by Battelle prior to the on-site demonstration at Robins AFB in order to assess efficiency prior to final results being available from the certification testing. Table 1 provides details on the MIL-PRF 87937D testing performed by Scientific Materials International, Inc. (SMI).

The collection of test coupons/materials and conduct of laboratory testing required 2 months for each formulation tested. Per SMI's instructions, 3 gallons, supplied in plastic containers meeting DOT UN 1H1 as required by 49 CFR 178, were required to test per MIL-PRF-87937D. (Note: It is possible that Eagle Kleen™ could qualify as a Type II degreaser, a Water Dilutable Cleaning Compound, but it was felt that it would be appropriate to test it as a Type IV degreaser for these applications.)

Table 1. Subcontractor for MIL-PRF-87937D Testing

Laboratory	Address	Certifications
Scientific Materials International, Inc. (SMI)	12219 SW 131 Avenue Miami, Florida 33186-6401 Contact: Pat Viani (305) 971-7047	"Internationally recognized as an authorized facility by airframe and engine manufacturers throughout the world, including the U.S. Air Force and U.S. Navy." www.smiinc.com "We adhere to standard laboratory practices and utilize certified standards for our meters and instruments where applicable. We have military inspections which authorize our laboratory to perform testing of aerospace maintenance chemicals in accordance with military standards." Patricia Viani in an email to Sara Kuczek dated 20 February 2004.

The sample of material was to be collected from HTCI's readily available stock of Eagle Kleen™ to assure that a valid subset of the material was obtained and was not specialized for this test. Due to early failures, HTCI was required to alter Eagle Kleen's™ formulation and specialized batches were tested. This process of change is detailed later in the report. All material tested was sent to Battelle for quality assurance/
quality control (QA/QC) prior to sending the material on to SMI for certification.

By performing QA/QC on the sample at Battelle prior to shipment to SMI, it was possible to ensure that the product submitted for certification fell within the acceptable production ranges and appearances. When the product failed these tests, an additional sample was requested from HTCI that met the specifications prior to commencement of testing.

Per MIL-PRF-87937D, the tests described in performance specification were conducted (see Table 2). HTCI supplied data on the flash point, pH, toxicity, constituents, appearance, volatile organic compounds (VOCs), drying point, and total immersion corrosion. These data were used for comparison when evaluating the results from the SMI testing of MIL-PRF-87937D, but after the necessary formulation adjustments, it was found that the data previously supplied by HTCI were not reflective of the current formulation. HTCI certified that the composition of Eagle Kleen™ met the non-testable requirements (i.e., workmanship) outlined in MIL-PRF-87937D.

2.1 Initial Laboratory Evaluation

A laboratory experiment was conducted to test the original formulation of Eagle Kleen™ (designated Eagle Kleen I) for effectiveness as a degreasing agent. Contaminated bearings that were to be discarded were obtained through Robins AFB Vehicle Shop contacts.

Three contaminated wheel bearings (two ~3 inches in diameter and one ~2.5 inches in diameter) were obtained. One was placed in a beaker and submersed in Eagle Kleen™ for approximately 25 minutes. During that time there was little change to the solution color. Some grease may have been loosened in the inner bearings, but no apparent degreasing was observed (see Figure 1).

Because the part was not satisfactorily degreased by immersion, it was sprayed with virgin Eagle Kleen™ for 5 minutes at a very low rate (130 mL/min); this had some minor cleaning effect. The part was mechanically agitated by hand in the solution, which resulted in additional cleaning. The part then was sprayed with water and wiped with a paper towel, which left yellow to brown deposits on the towel. There was evidence of heavy grease deposits on the back side of the wheel bearing. After cleaning, the solution looked yellow.

The wheel bearing surface remained slippery and the cleaning results did not look impressive. The dried part was allowed to sit in a hood on a clean paper towel for later observation. Upon returning, the part had no rust, but was still very slippery due to either the residual grease or Eagle Kleen™ on the part.

A second wheel bearing initially was sprayed with virgin Eagle Kleen™ at a low flowrate, but this activity showed little grease removal. The part still showed evidence of grease deposits on the back side and the surface was slippery. It was determined that the part had not been cleaned adequately, so the bearing was returned to the cleaning solution and re-inspected after 30 minutes of soaking. After mechanically agitating the bearing in the bath, spraying with water, and drying with a paper towel, the part looked significantly better and nearly all the grease deposits were gone (see Figure 2). The surface was not slippery and in general the cleaning looked acceptable. The part was re-dipped in Eagle Kleen™, rinsed in water, and allowed to sit on a paper towel for an hour and then observed; there appeared to be some evidence of spot rusting.

Table 2. Analytical Testing Per MIL-PRF-87937D

Specification	Title		Test Method
MIL-PRF-87937D, Section 3.4	Compositional Assurance	Non-volatile Residue	Test described in MIL-PRF-87937D, Section 4.5.1
		pH	Test described in MIL-PRF-87937D, Section 4.5.3, ASTM E 70
		IR	Test described in MIL-PRF-87937D, Section 4.8.2
MIL-PRF-87937D, Section 3.5	Chemical Properties	Insoluble Matter	Test described in MIL-PRF-87937D, Section 4.5.2
		Flash Point	Test described in MIL-PRF-87937D, Section 4.5.7, ASTM D 56
		Emulsion	Test described in MIL-PRF-87937D, Section 4.5.8
		Wet Tape Adhesion	Test described in MIL-PRF-87937D, Section 4.5.27
		Cleaning Efficiency	Test described in MIL-PRF-87937D, Section 4.5.21
		Residue Rinsibility	Test described in MIL-PRF-87937D, Section 4.5.4
MIL-PRF-87937D, Section 3.6	Physical Properties	Heat Stability	Test described in MIL-PRF-87937D, Section 4.5.5
		Cold Stability	Test described in MIL-PRF-87937D, Section 4.5.6
MIL-PRF-87937D, Section 3.7	Effect on Metals	Hydrogen Embrittlement (Cadmium and Ion Vapor Deposited [IVD] Plated Bars)	Test described in MIL-PRF-87937D, Section 4.5.9, ASTM F 519
		Total Immersion Corrosion	Test described in MIL-PRF-87937D, Section 4.5.10, ASTM F 483
		Low-Embrittling Cadmium	Test described in MIL-PRF-87937D, Section 4.5.11, ASTM F 1111
		Effects on Unpainted Metals	Test described in MIL-PRF-87937D, Section 4.5.12, ASTM F 485
		Sandwich Corrosion	Test described in MIL-PRF-87937D, Section 4.5.16, ASTM F 1110
		Wet Tape Adhesion	Test described in MIL-PRF-87937D, Section 4.5.27
MIL-PRF-87937D, Section 3.8	Effect on Painted Surfaces		Test described in MIL-PRF-87937D, Section 4.5.13, ASTM F 502
MIL-PRF-87937D, Section 3.9	Stress crazing of MIL-PRF-5425 and MIL-PRF-25690 (Type A and C) acrylic plastics		Test described in MIL-PRF-87937D, Section 4.5.14, ASTM F 484
MIL-PRF-87937D, Section 3.10	Stress crazing of polycarbonate plastics		Test described in MIL-PRF-87937D, Section 4.5.15, ASTM F 484
MIL-PRF-87937D, Section 3.11[b]	Long term storage		**Test skipped.** Test described in MIL-PRF-87937D, Section 4.5.17, ASTM F 1104
MIL-PRF-87937D, Section 3.12	Hot dip galvanizing corrosion		Test described in MIL-PRF-87937D, Section 4.5.18, ASTM F 483

Table 2. Analytical Testing Per MIL-PRF-87937D (Continued)

Specification	Title	Test Method
MIL-PRF-87937D, Section 3.13	Workmanship	Certified by manufacturer
MIL-PRF-87937D, Section 3.14	Effect on polysulfide sealants	Test described in MIL-PRF-87937D, Section 4.5.19, ASTM D 2240
MIL-PRF-87937D, Section 3.15	Rubber compatibility	Test described in MIL-PRF-87937D, Section 4.5.20, ASTM D 2240
MIL-PRF-87937D, Section 3.16	Effect on polyimide insulated wire	Test described in MIL-PRF-87937D, Section 4.5.26
MIL-PRF-87937D, Section 3.3	Toxicity	Percent survival will be recorded for *Pimephales promelas* and *Ceriodaphnia dubia* at 1, 10, 50, and 100 ppm concentrations
MIL-PRF-87937D, Section 3.3.4	Biodegradability	Test described in MIL-PRF-87937D, Section 4.5.22, 40 CFR, Part 796.3100

(a) All listed analytical tests must be passed in order for the on-site demonstration to proceed. Due to this, all tests are considered critical in this phase of the program.

(b) Long-term storage was not tested.

Figure 1. Bearing Inspection after Initial Immersion

Figure 2. Bearing after Final Cleaning

At this stage, it appeared that Eagle Kleen™ would degrease a part effectively enough for a mechanic to determine if it had a major defect that would require replacement. It also appeared that the part would be clean enough for repacking with grease for reinstallation. It was determined that this cleaning ability was suitable for site testing to commence at Robins AFB, but because spot rusting was observed, the demonstration was delayed until corrosion data were obtained.

2.2 Analytical Laboratory Testing – Eagle Kleen I

After the initial laboratory evaluation, the original formulation (i.e., Eagle Kleen I) was submitted to SMI for MIL-PRF-87937D testing. However, there was not an exact category match for testing the fluid. Eagle Kleen™ solution is intended to replace dilutable fluids, but is supplied as a "ready-to-use" fluid not a water-dilutable concentrate. Therefore, it was determined to test it as a "Type IV – Heavy Duty Water-Dilutable Cleaning Compound" but to test it as ready-to-use (non-diluted) fluid when certain tests called for the dilution of the test material. The fluid was submitted on July 14, 2004 and test results were reported on September 20, 2004. Table 3 summarizes the results. The full results are included in Appendix B.

Eagle Kleen I did not pass MIL-PRF-87937D requirements. Specifically, it failed the heat stability and several metal corrosion tests. Because the material is intended to be used at room temperature, the team determined that failing the heat stability tests was not a reason to reformulate and retest alone, but that without passing the corrosion tests, the demonstrations could not proceed at either proposed location.

Table 3. Eagle Kleen I Analytical Test Results per MIL-PRF-87937D

MIL-PRF-87937D Section Number	Test Name	Results
3.3	Toxicity	Informational[a]
3.3.4	Biodegradability	Conforms
3.4	Compositional assurance	Informational
3.5	Chemical properties	
3.5.1	Chemical Requirements	
	Insoluble matter	Conforms
	Flash point	Conforms
	Emulsion characteristics	Conforms[b]
	Wet adhesion tape test	Conforms[b]
	% Cleaning efficiency	Conforms[b]
	Terpene hydrocarbons	Not applicable
3.5.2	Residue rinsibility	Conforms[b]
3.6	Physical properties	
3.6.1	Heat stability	Does not conform
3.6.2	Cold stability	Conforms
3.6.3	Rheology	
3.6.3.1	Consistency	Not applicable
3.6.3.2	Sprayability	Not applicable
3.7	Effect on metals	
3.7.1	Hydrogen embrittlement	Does not conform[b]
3.7.2	Total immersion corrosion	Does not conform[b]
3.7.3	Low-embrittling cadmium plate corrosion	Does not conform[b]
3.7.4	Effects on unpainted metal surfaces	Conforms[b]
3.7.5	Sandwich corrosion	Does not conform[b]
3.7.6	Wet adhesion tape test	Conforms[b]
3.8	Effect on painted surfaces	Conforms[b]
3.9	Stress crazing of MIL-PRF-5425 and MIL – PRF-25690 (Type A and C) acrylic plastics	Conforms[b][c]
3.10	Stress crazing of polycarbonate plastic	Conforms[b][c]
3.11	Long-term storage stability	Not performed
3.12	Hot dip galvanizing corrosion	Conforms[b]
3.13	Workmanship	Was "certified" by manufacturer to conform with requirements
3.14	Effect on polysulfide sealants	Conforms[b]
3.15	Rubber compatibility	Conforms[b]
3.16	Effect on polyimide insulated wire	Conforms[b]

(a) Toxicity data is reported, but not as the widely accepted LD_{50} values. Additional toxicity testing was conducted.
(b) Test performed using "as received" solution (ready-to-use) instead of dilution required by specification. Results were not considered for qualified product listing (QPL).
(c) Because of the high surfactant content of Eagle Kleen™, it should craze most stressed transparent plastics when subjected to extended exposure. Passing of these tests was unexpected and could not be duplicated in subsequent tests.

2.3 Analytical Laboratory Testing – Eagle Kleen II

HTCI, along with their manufacturing partner, decided to reformulate the Eagle Kleen I degreaser by adding a corrosion-controlling agent, and designated the resulting new formulation Eagle Kleen II. After HTCI submitted a sample of the newly revised formulation, Battelle performed QA/QC tests in addition to an additional cleaning test. It then was decided by the evaluation team that, in order to reduce testing time and conserve funds, only the tests that failed the initial analytical testing at SMI would be run on Eagle Kleen II. If all passed, the full set of tests would be continued. The sample was submitted to SMI on September 10, 2004 and the results report was received on September 30, 2004. Results are summarized in Table 4. The SMI Report is included in Appendix C.

Table 4. Eagle Kleen II Analytical Test Results per MIL-PRF-87937D

MIL-PRF-87937D Section Number	Test Name	Results[a]
3.7	Effect on metals	
3.7.1	Hydrogen embrittlement	Conforms
3.7.2	Total immersion corrosion	Does not conform
3.7.3	Low-embrittling cadmium plate corrosion	Does not conform
3.7.5	Sandwich corrosion	Conforms

(a) Test performed using "as received" solution (ready-to-use) instead of dilution required by specification. Results were not considered for QPL listing.

Although this reformulation was an improvement over Eagle Kleen I, Eagle Kleen II continued to fail some of the required tests. Of great significance, however, was the ability of this degreaser to pass the hydrogen embrittlement test. Most, if not all, near neutral pH aqueous cleaners fail this test. The ability of the reformulated fluid to not embrittle high-strength steels made the degreaser unique and opened the door for use in many aerospace applications.

2.4 Analytical Laboratory Testing – Eagle Kleen III

HTCI and their manufacturing partner decided to reformulate again, creating Eagle Kleen III using a different concentration of an alternative corrosion agent. After QA/QC testing by Battelle, a sample was submitted to SMI for testing. Initial testing at HTCI's manufacturing partner and by Battelle indicated that this formulation should pass the tests that were not passed by Eagle Kleen II. Therefore, the entire testing sequence at SMI was initiated. SMI received the sample of Eagle Kleen III on December 1, 2004 and the results report was issued on March 7, 2005. Results are summarized in Table 5. The SMI Report is included in Appendix D.

Again, because the material is intended to be used at room temperature, the team determined that failing the heat stability tests alone was not a reason to reformulate and retest. However, the corrosion testing passed and the fluid continued to meet the hydrogen embrittlement requirements, the changes to the formulation appeared to cause stress crazing failures on the acrylic and polycarbonate plastics. To confirm that the correct results were obtained, these tests were performed once more. Eagle Kleen III did not pass these repeat tests.

After consulting with the demonstration team, including representatives from Robins AFB and Hill AFB, it was determined that the parts that were processed in each of their shops did not require much, if any, processing of plastics, and the demonstrations could commence without passing these two tests.

Table 5. Eagle Kleen III Analytical Test Results per MIL-PRF-87937D

MIL-PRF-87937D Section Number	Test Name	Results
3.3	Toxicity	Informational[(a)]
3.3.4	Biodegradability	Conforms
3.4	Compositional assurance	Informational
3.5	Chemical properties	
3.5.1	Chemical Requirements	
	Insoluble matter	Conforms
	Flash point	Conforms
	Emulsion characteristics	Conforms[(b)]
	Wet adhesion tape test	Conforms[(b)]
	% Cleaning efficiency	Conforms[(b)]
	Terpene hydrocarbons	Not applicable
3.5.2	Residue rinsibility	Conforms[(b)]
3.6	Physical properties	
3.6.1	Heat stability	Does not conform
3.6.2	Cold stability	Conforms
3.6.3	Rheology	
3.6.3.1	Consistency	Not applicable
3.6.3.2	Sprayability	Not applicable
3.7	Effect on metals	
3.7.1	Hydrogen embrittlement	Conforms[(b)]
3.7.2	Total immersion corrosion	Conforms[(b)]
3.7.3	Low-embrittling cadmium plate corrosion	Conforms[(b)]
3.7.4	Effects on unpainted metal surfaces	Conforms[(b)]
3.7.5	Sandwich corrosion	Conforms[(b)]
3.7.6	Wet adhesion tape test	Conforms[(b)]
3.8	Effect on painted surfaces	Conforms[(b)]
3.9	Stress crazing of MIL-PRF-5425 and MIL – PRF-25690 (Type A and C) acrylic plastics	Does not conform[(b, c)]
3.10	Stress crazing of polycarbonate plastic	Does not conform[(b, c)]
3.11	Long-term storage stability	Not performed
3.12	Hot dip galvanizing corrosion	Conforms[(b)]
3.13	Workmanship	Was “certified” by manufacturer to conform with requirements
3.14	Effect on polysulfide sealants	Conforms[(b)]
3.15	Rubber compatibility	Conforms[(b)]
3.16	Effect on polyimide insulated wire	Conforms[(b)]

(a) Toxicity data is reported, but not as the widely accepted LD_{50} values. Additional toxicity testing was conducted.
(b) Test performed using “as received” solution (ready-to-use) instead of dilution required by specification. Results were not considered for QPL listing.
(c) Because of the high surfactant content of Eagle Kleen™, it should craze most stressed transparent plastics when subjected to extended exposure.

2.5 Analytical Laboratory Testing – Eagle Kleen III, Vapor Pressure

During laboratory evaluation of the Eagle Kleen™ formulations, it was noted that the odor from the fluid was strong, even at room temperature. In addition, the evaluation team wanted to confirm that the fluid was low to non-volatile, in order to avoid engineering control requirements and confirm that Eagle Kleen™ was below the 7-mm Hg limit set under the Aerospace National Environmental Standards for Hazardous Air Pollutants (NESHAP). The Air Force defines an aqueous cleaner as having greater than 80% water. As Eagle Kleen™ does not meet this criterion, it would be subject to the NESHAP restrictions.

SMI was contracted to perform the "Test Method for Vapor Pressure of Petroleum Products (Reid Method)", ASTM D 323. This test was performed on the same fluid lot of Eagle Kleen III used for the analytical testing described in Section 2.0, and the results are shown in Table 6. The Reid Vapor Pressure of the fluid was determined to be less that 0.2 mm Hg at 20°C, which is less than the 7-mm Hg limit. Therefore, Eagle Kleen™ was exempt from any VOC regulations set by the Air Force, and testing could proceed. The SMI test report on vapor pressure is included as Appendix E.

Table 6. Reid Vapor Pressure Results for Eagle Kleen III

Sample	Reid Vapor Pressure
Eagle Kleen III	<0.2 mm Hg at 20 °C

2.6 Material Compatibility Evaluation

While conducting the Robins AFB demonstration, it was determined that Eagle Kleen™ is not suitable for use with or on certain types of polymers. A scrub brush used during the hand cleaning at the Vehicle shop was left to lay in approximately ½-inch of Eagle Kleen III degreaser over the weekend. Upon return to the shop the following week, employees found that the scrub brush had "melted" (see Figure 3 for the "before" photograph and Figure 4 for the "after" photograph).

At this point, Russ Markesbery of HTCI supplied the team with a list of materials that should be compatible with Eagle Kleen™. This list was not comprehensive and additional testing was deemed necessary. Testing at Battelle found that the handle was composed of either a copolymer of polystyrene and methylene (copoly[styrene-methylene]) or a copolymer of styrene and polyethylene. Although the spectrum more closely matched the first copolymer listed, the second is a much more widely available material. Because this fluid would be used in conjunction with seals, hoses, pumps, and various personal protective equipment (PPE), Battelle completed a short, non-comprehensive study of material compatibility. Materials that may be used with, or cleaned by, this fluid were chosen for this study. Results are detailed in Table 7.

After reviewing this study, it became apparent that if Eagle Kleen™ were to be used in a large-scale setting, care would need to be taken to ensure the materials of construction for the equipment used in conjunction with the fluid were compatible with Eagle Kleen™. In addition, the facility would need to stress the importance of using the appropriate PPE for this task and set up a stringent replacement schedule of said PPE. However, from the preliminary compatibility testing performed, it appears that acceptable alternatives, such as neoprene gloves, Viton or Teflon gaskets and seals, and high-density polyethylene (HDPE) tanks and containers are readily available.

Figure 3. Handle Before Exposure to Eagle Kleen III

Figure 4. Handle After Exposure to Eagle Kleen III

Table 7. Material Compatibility Analysis Results

Materials	Disclosed by HTCI after Brush Incident as being Incompatible	Incompatible After an Hour of Exposure	Incompatible After 3 Weeks' of Exposure	Initial Testing Did Not Result in Signs of Incompatibility
Vinyl-acrylics	X			
PVC	X			
Tygon	X			
Polycarbonate	X			
SBR Rubber Sheet		X		
Neoprene		X[(a)]		
Viton		X[(a)]		
Buna-N		X		
EDPM		X		
PVC/Tygon		X		
Polyurethane			X	
Silicone			X	
Polycarbonate				X
Polyethylene (including HDpe0				X
CPVC			X	
Nylon				X
Phenolic				X
Fiberglass				X
Polyester				X
Polypropylene				X
PTFE (i.e., Teflon)				X
Delrin				X

(a) Minor discoloration of solution after one hour exposure but no evidence of performance deterioration.

2.7 Analytical Laboratory Toxicity Testing – Eagle Kleen III

The toxicity test run as part of the initial MIL-PRF-87937D screening indicated that Eagle Kleen™ may not be as "non-toxic" as originally indicated by the manufacturer. Specifically, after 24 hours at only 10 ppm, no fathead minnows remained alive in the Eagle Kleen solution (see Tables 8 and 9). This indicated that Eagle Kleen™ has some toxicity even at low levels.

A data search was conducted to determine the toxicity in relation to this information, but no results were found that were in a comparable format. Therefore, to make a fair comparison, LC_{50} data were collected for Eagle Kleen III and for the other cleaners used in this study, Safety Kleen PRF 680 Type II (hydrocarbon solvent) and Turco 6849 (alkaline cleaner). In general, LC_{50} values below 1,000 mg/L indicate a toxic substance; and, as noted in Table 10, all three cleaners have low LC_{50} figures, meaning they are toxic to aquatic life; see Appendix F for details.

2.8 Conclusions

After the third reformulation, it was determined that although Eagle Kleen™ still did not pass all laboratory certification tests specified in MIL-PRF-87937D, it passed all except (1) stress crazing of acrylic plastics and polycarbonate plastics, and (2) heat stability. These results were deemed sufficient by the evaluation team, Robins AFB, and Hill AFB to proceed with the demonstrations. In order to actually certify Eagle Kleen™, a new category of degreaser must be added to MIL-PRF-87937D or another specification written for it because it did not fall into an established category.

Table 8. 96-Hour *Pimephales promelas* Bioassay

Percentage of Fathead minnows (*Pimephales promelas*) Surviving			
Concentration	**After 24 Hours**	**After 48 hours**	**After 96 Hours**
1 ppm	100	100	100
10 ppm	0	0	0
50 ppm	0	0	0
100 ppm	0	0	0

Table 9. 48-Hour *Ceriodaphnia dubia* Bioassay

Percentage of Water Fleas Cladoceran (*Ceriodaphnia dubia*) Surviving		
Concentration	**After 24 Hours**	**After 48 hours**
1 ppm	90	50
10 ppm	50	20
50 ppm	0	0
100 ppm	0	0

Table 10. Aquatic Toxicity as Measured by Lethal Concentrations

Fluid	**LC_{50}, 48-hr *Daphnia magna* (mg/L)**	**LC_{50}, 96-hr *Pimephales promelas* (mg/L)**
Eagle Kleen III (100%)	25	30
Safety Kleen PRF 680 Type II (100%); hydrocarbon solvent	125	>70,000[a]
Turco 6849 (20%), alkaline cleaner	150	225
Turco Rust Bloc (4%), anti-rusting compound	79,200	33,500

(a) The lighter-than water solvent floated on the surface, and this may have biased the results.

From initial laboratory evaluations, Eagle Kleen™ did appear to degrease, but did not seem to degrease quickly or by immersion alone. From previous experiments, it did not immediately appear to be a significant improvement over traditional degreasers. Site demonstrations at Hill AFB and Robins AFB were conducted to gauge its actual cleaning ability and cost effectiveness.

Areas of improvement and development still remain. Eagle Kleen™ does not appear to be compatible with all materials used in the construction of hoses, pumps, seals, and gaskets. Eagle Kleen™ is a powerful degreaser and, in some cases, could dissolve polymeric materials used for gloves, seals, gaskets, tank construction plastics and certain materials used for tubing and hoses. But, acceptable alternatives for these items are commonly available, such as neoprene gloves, Viton or Teflon gaskets and seals, and HDPE tanks and containers.

Limited aquatic toxicity testing with 100% Eagle Kleen III, as part of the MIL-PRF-87937D evaluation, indicated that Eagle Kleen™ was toxic to some aquatic life forms even at low concentrations. Additional toxicity tests, where Eagle Kleen™ was compared to a typical solvent and a typical alkaline cleaner, indicated that all three were toxic to aquatic life forms at typical use concentrations.

3.0 TASK 2 – SITE TESTING

3.1 Background

The Task 2 site demonstration took place at two primary locations: the Vehicle Shop of Robins AFB, located at the Warner Robins Air Logistics Center of the U.S. Air Force; and the gas turbine engine (GTE) Shop at Hill AFB, located at the Ogden Air Logistics Center. Two parts washers were used at each demonstration location. One was filled with the conventional cleaner and operated at standard conditions, and the other was filled with Eagle Kleen™. By running two parts washers simultaneously, side-by-side results were obtained allowing a direct comparison of cleaning performance.

The tests included cleaning approximately the same type and number of parts, having a similar degree of contamination, through each bath under real world conditions. Cleaning fluids from the parts washers, and where applicable the rinse tanks, were sampled on a daily basis. At the Vehicle Shop the parts were restricted to wheel bearings. In the GTE Shop a variety of parts, representative of normal parts processed is the shop were evaluated. A limited number of condemned parts were used for off-site follow-on testing (see Section 3.4).

Operating parameters, such as cleaning efficiency and bath life, were evaluated. A qualitative cleaning evaluation score was assigned to each run for the conventional treatment and for Eagle Kleen™. In Table 11, scores in red (1 and 2) were ranked as “unacceptable” cleaning, whereas those in green (3, 4, and 5) indicated as acceptable. Critical measurements are listed in Table 12. Also, observations on bath cleanliness were made, and the pH was measured for the aqueous cleaner and rinse waters.

Table 11. Cleaning Score Description

Score	Grease Contamination Level After cleaning
1	Still very dirty
2	Not cleaned well; a lot of contamination still remains
3	Definitely contaminant present
4	Maybe some contaminant present, but fairly cleaned
5	Perfectly clean

Table 12. Critical Measurements for Site Testing

Critical Measurements	Qualitative/ Quantitative	Measurement Time Basis
Number of parts cleaned	Quantitative	At time of degreasing
Number of parts needing reprocessing	Quantitative	At time of degreasing
Fluid efficiency	Qualitative	At time of degreasing, daily, and weekly
Bath condition	Qualitative	Daily and weekly
Fluid addition and replacement	Qualitative	As needed
Cost of fluid	Quantitative	Once during project
Visual observation of bath sample for cleanliness	Qualitative	Weekly

3.2 Robins AFB Testing

The Vehicle Shop at Robins AFB processed a high throughput of 3-inch-diameter steel wheel bearings, which were degreased using a traditional hydrocarbon-based solvent in a parts washer. This demonstration study was structured for side-by-side testing of parts cleaning with the shop's regular solvent and with Eagle Kleen™ degreaser. This allowed the evaluation team, which consisted of personnel from Robins AFB and Battelle, to compare the performance of both fluids under controlled conditions. Information was tracked on cleaning efficiency, bath life (longevity), time for cleaning, and other noticeable effects that would be of concern to shop staff. By comparing these data, the suitability of Eagle Kleen™ as a replacement fluid in this application was assessed.

During the first week of testing (March 28-31, 2005), several different vehicle-shop mechanics were asked to assess the performance of both Eagle Kleen™ and Safety Kleen™ (PRF 680 Type II hydrocarbon degreaser) using three conventional parts washers set up for the demonstration (a parts washer and an aqueous rinse washer were used for Eagle Kleen™, and a single parts washer was used for Safety Kleen™), see Figures 5 and 6.

The initial assessment used actual wheel bearings removed from base vehicles for routine maintenance. Photographs of the bearings before and after cleaning with Eagle Kleen™ (Figure 7) showed that the degreaser was effective at removing grease and oil. However, this study also showed that there was little or no difference in the appearance of the cleaned parts, regardless of the degreaser used.

After conducting the side-by-side tests, the following characteristics were noted for Eagle Kleen™:

- In general, the level of cleaning was adequate, but on an individual part basis, the performance was either equal to or slightly inferior to the hydrocarbon degreaser;

- Cleaning times were approximately 50% longer for a part of similar size, shape, and type of contamination than using Safety Kleen;

- Eagle Kleen™ had an odor that was objectionable to some operators;

- Parts felt more slippery in gloved hands, until the parts were rinsed with water.

The Vehicle Shop manager indicated that he was interested in the potential degreasing ability of Eagle Kleen™, but that the product may not be cost-effective due to the longer cleaning time that was required (he was quoted as saying "time is money"). For Eagle Kleen™ to be economically attractive, according to the manager, its base cost, handling cost, and disposal costs would have to be lower, and/or its lifetime would have to be much longer than that of a traditional solvent.

HTCI, the supplier of Eagle Kleen™, stated that the degreaser could solubilize grease and oil up to 23% of its weight (e.g., 23 lb of grease or oil could be solubilized in 100 lb of Eagle Kleen™). This ratio of contaminant to degreaser would be equivalent to cleaning hundreds, or even thousands, of parts, making a true part-by-part test of this claim impractical in the time period allocated for the demonstration. To overcome these constraints, an accelerated contamination protocol was used, where both cleaning baths were contaminated with heavy grease and heavy-duty motor oil, and testing was done to determine cleaning effectiveness. Some of the same parts were contaminated and cleaned several times as part of the assessment. This portion of the demonstration was conducted during the week of April 18-22, 2005.

Figure 5. Degreaser and Rinse Tanks for Eagle Kleen™ and Safety Kleen™ Bath

Figure 6. Wheel Bearings Being Degreased with Eagle Kleen™

Figure 7. Wheel Bearings Before (left) and After (right) Degreasing with Eagle Kleen™

To rank the cleaning efficiency of the two degreasing fluids, the scoring system noted in Table 11 was employed. After cleaning each set of bearings, the cleaning performance was assessed and assigned a score. Before testing began, the team decided that if a part received an overall score below 3.0, the operator would need to perform additional cleaning for the part to be acceptable. After cleaning more than 1,000 equivalent parts, cleaning scores ranged from 4.0, when the degreasers were fresh, to 2.5. In general, both degreasers were effective in removing heavy oils, transmission and hydraulic fluids, regular lubricating oils, and grease. In general, it was found that Eagle Kleen™ has the ability to degrease a large number of parts and, under normal use, would tend to have a very long bath life. However, the hydrocarbon degreaser (Safety Kleen™) degreased a similar number of contaminated parts, and therefore also can be said to have performed well in this study. Based on results of the side-by-side comparison, it was concluded that Eagle Kleen™ would not have a longer life than the traditional solvent degreaser (see Figure 8).

At the conclusion of the testing program, the Vehicle Shop expressed interest in continuing to use Eagle Kleen™ and moved the three parts washers to a different building (Building 148) where the shop maintained powered equipment, such as portable generators and tug trucks. Testing was not supervised at the same level as was done in the Vehicle Shop. A preliminary assessment, based on a limited number of tests, indicated that the mechanics in this area did not find the degreaser suitable for this equipment. They cited longer degreasing times as the main deficiency in Eagle Kleen™ and noted that the degreaser's odor was a potential concern to shop staff.

A formal request for an Environmental Impact Analysis of Eagle Kleen™ was submitted to the Robins AFB Environmental Management Department. The approval criteria included environmentally friendliness and cost-effectiveness as compared to the current solvent degreaser. The application assumed that rinse water containing Eagle Kleen™ (drag-out) and dissolved contaminants could be discharged to the Robins AFB industrial wastewater treatment plant (IWTP). Discharge of spent Eagle Kleen™ to the IWTP appears to be impractical and probably not allowed by the base. This would require the spent Eagle Kleen™, like the spent hydrocarbon degreaser, to be drummed for off-site disposal. Approval for use at Robins AFB was not received.

A cost comparison between Eagle Kleen™ and the traditional solvent degreaser was not performed due to the longer cleaning time, odor issues, and the unfavorable review by the Building 148 shop.

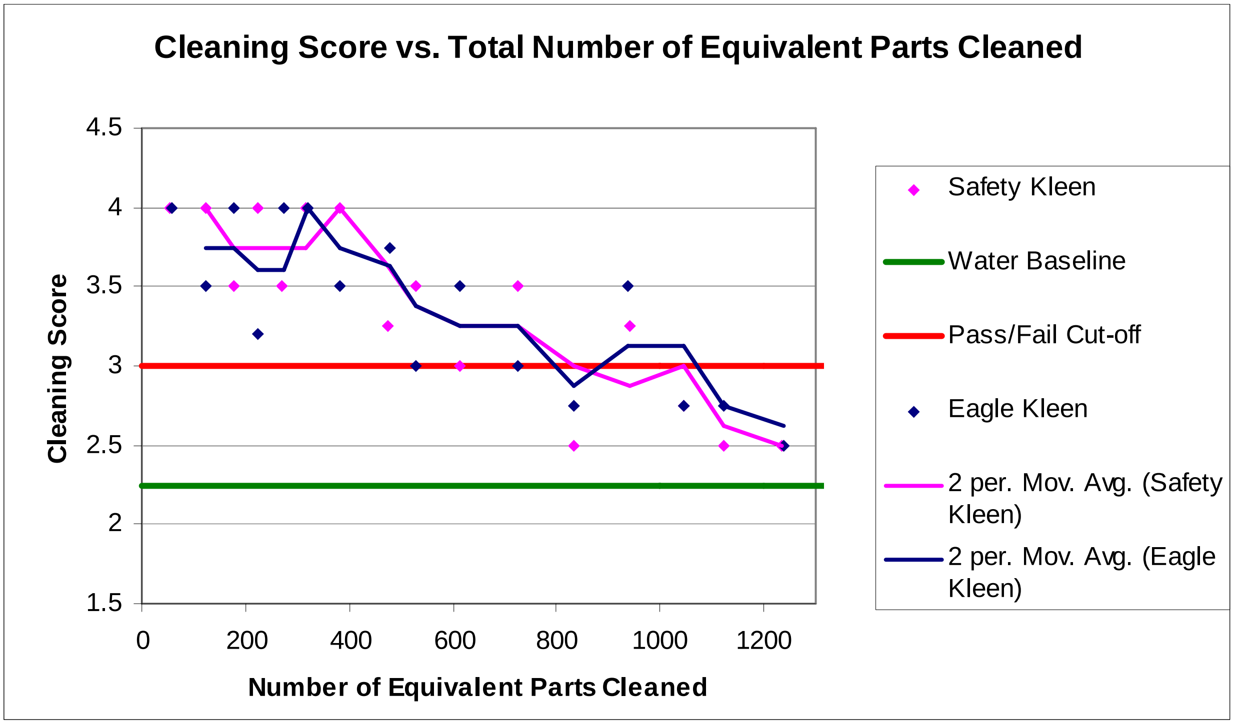

Figure 8. Cleaning Score for Equivalent Number of Parts Cleaned Using the Two Degreasers

3.3 Hill AFB Testing

The evaluation at Hill AFB was conducted for one week, over the period September 12-16, 2005. The GTE shop degreases parts on a routine basis and installed an automated RAMCO system for degreasing, rinsing, and drying operations (see Figure 9). The shop's RAMCO degreasing system was used for testing two types of degreasers. The normal cleaning tank was filled with Turco 6849 (prepared by diluting 10 gallons of Turco 6849 to approximately 65 gallons of water). Another tank was filled with Eagle Kleen™, which was prepared without dilution (see Figure 10).

Both tanks initially were heated to 145°F. However, the optimum temperature for Eagle Kleen™ was not known, so the bath temperature for Eagle Kleen™ was controlled at approximately 90°F in an initial series of tests and 120°F in a second series. Results indicated increasing the temperature did not significantly improve performance; however, the change in temperature dramatically increased complaints related to odor. A flow diagram illustrating the cleaning process during the demonstration is shown in Figure 11.

Many of the parts that were degreased in the GTE shop had heavy carbon contamination. All had some degree of oil contamination and some also had grease contamination. During the evaluation, parts were processed in the same manner as in normal operations. Similar types of parts with comparable levels of contamination were placed into steel baskets and prepared for cleaning. Each basket of parts was inserted into a cleaning tank for approximately 60 minutes, with mild agitation by circulating fluid. Ultrasonic energy was applied for approximately one minute in the Turco 6849 bath. No ultrasonic energy was used in the Eagle Kleen™ bath or its rinse tank. After the cleaning step, the baskets were transferred to a rinse tank for 30 minutes, and then dried for 30 minutes in air heated to 240°F.

Figure 9. RAMCO Cleaning Line at Hill AFB GTE Shop

Figure 10. Eagle Kleen™ Degreaser Bath

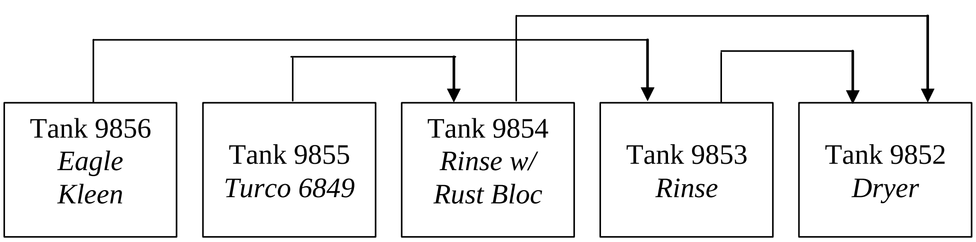

Figure 11. Process Flow Diagram for Cleaning in the Hill AFB Gas Turbine Engine Shop

The number of baskets processed through each bath was recorded and the shop work load was divided equally between the two degreasers. Cleaning times were staggered to allow use of only one dryer. After drying, the parts were allowed to cool and were examined side by side. Several cleaning operators in the GTE Shop were asked to evaluate the performance of Eagle Kleen™ against Turco 6849. The operators reported that Turco 6849 removed the oil and grease, and nearly all the carbon deposits. In contrast, Eagle Kleen™ removed part of the oil and grease, but was not effective at removing heavy carbon contamination. A comparison of heavily-carbon contaminated parts, after cleaning with the two degreasers, is shown in Figure 12.

Figure 12. Example of Air Inlet Housing Prior to Cleaning (left), After Degreasing with Turco 6849 (center), and After Degreasing with Eagle Kleen™ (right)

In general, tests at the GTE shop revealed the following about Eagle Kleen™:

- Removal of oil and grease tended to be equal to or slightly inferior to Turco 6849 degreaser for lightly soiled parts.
- Eagle Kleen™ was not effective at cleaning carbon-contaminated parts.
- Parts cleaned using Eagle Kleen™ required more manual cleaning than Turco 6849 after the 30-minute degreasing step for all types of contamination.
- The strong odor of Eagle Kleen™ was objectionable to the operators. Operation without a ventilation system caused some operators to complain of headaches, irritation of mucous membranes, and light headedness.

After each basket of parts was processed, the cleanliness of each part was ranked on a scale from 0 to 5, taking into account the appearance and feel (greasy/clean) (see Figure 13). Depending on the number of parts requiring reprocessing, the scores were reduced accordingly (see Figure 14). Parts that were degreased with Eagle Kleen™ required reprocessing on a consistent basis. In total, it was concluded based on these test results that Turco 6849 outperformed Eagle Kleen™.

Due to the odor issue and Eagle Kleen™'s ineffectiveness at cleaning heavy carbon-contaminated parts, the degreasing team decided to suspend the demonstration at the close of the first week (September 16, 2005). Better ventilation, or respirators, would be required for future use of Eagle Kleen™ in this operation.

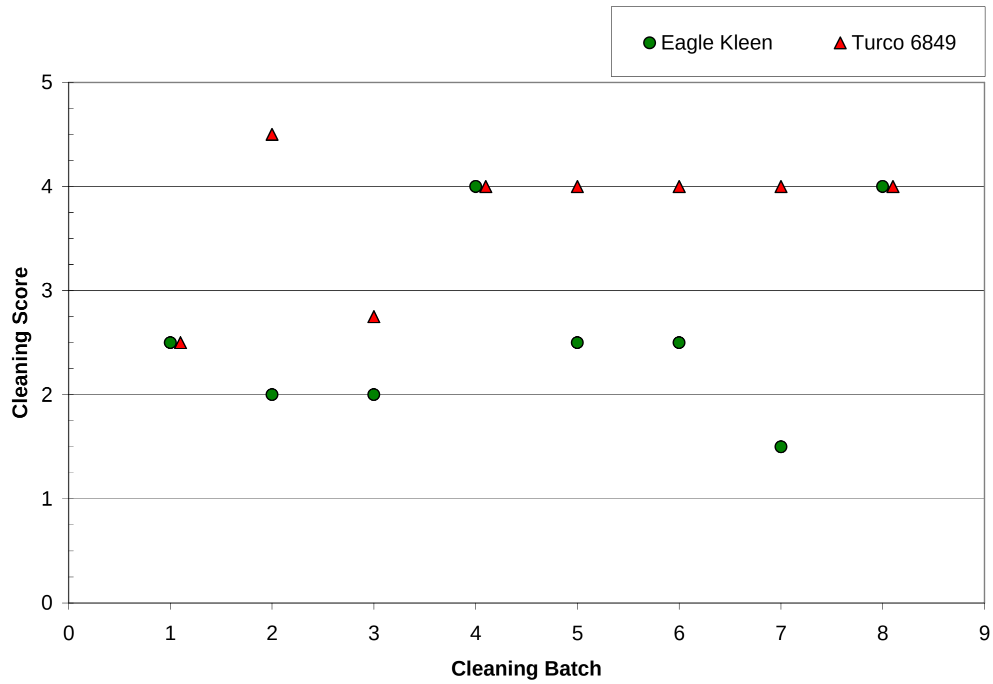

Figure 13. Overall Cleaning Score

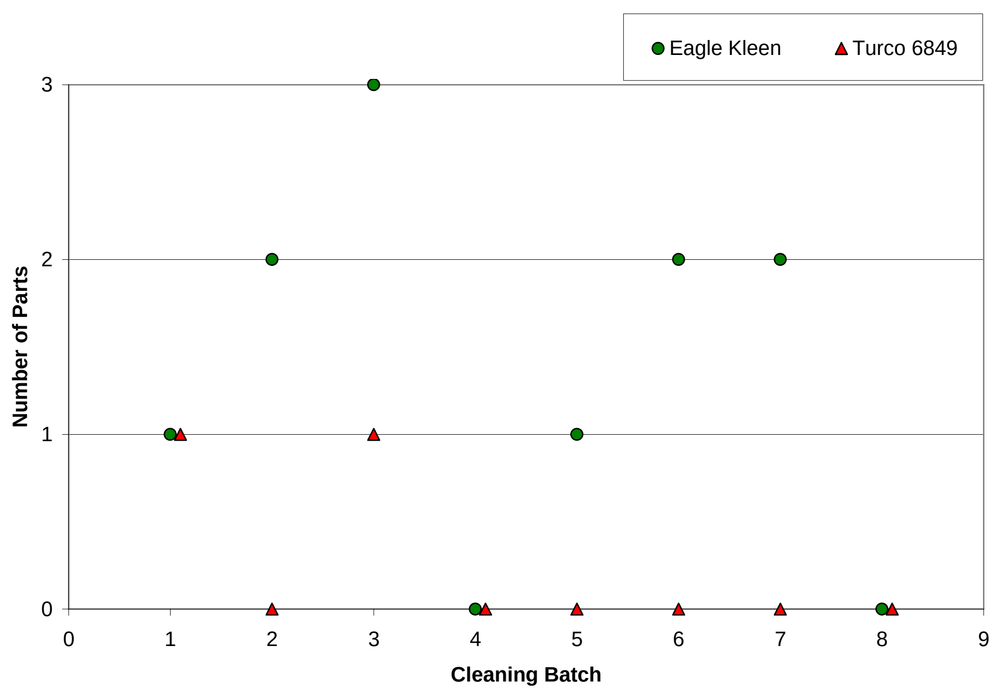

Figure 14. Parts Requiring Reprocessing

After the suspension of Eagle Kleen™ operations for the main degreasing area in the GTE shop, the cleaning engineer indicated that the shop may be interested in considering Eagle Kleen™ for non-carbon contaminated cleaning applications. He requested a quote form Hydra-Tone for a three-step cleaning system to replace a PD-680 solvent cleaning application. HTCI and the shop engineer independently pursued this option.

Additionally, the Plating Shop at Hill AFB expressed interested in considering Eagle Kleen™ for replacing certain alkaline cleaning baths. The SMI materials compatibility data (per MIL PRF 87937D) indicated that the fluid should be compatible with these application needs. The plating shop also explored this option with HTCI.

The tests in a standard parts washer, without ultrasonic energy, indicated that Eagle Kleen™ was effective in removing oil and grease but not for removing heavy carbon deposits.

Subsequent tests in November 2005 and March 2006 indicated that such carbon deposits could be removed when a diluted solution (5% Eagle Kleen™ and 95% water) were used in an appropriate cleaning bath.

After these tests, the cleaning engineer in the GTE Shop expressed renewed interest. A major driving force was economics. The conventional alkaline cleaner contains chelating agents. Because of the chelating agent's deleterious affect on metals precipitation at the Hill AFB IWTP plant, the IWTP staff required that all degreaser solutions and rinse water be drummed, and transported to their site for specialized treatment. The expense of pursuing this path made a non-chelating agent degreaser especially attractive, so an Engineering Cost Assessment was performed (see Section 4.0).

3.4 Ransohoff Testing

Once primary site demonstration testing was done, additional testing was conducted at Ransohoff, Inc., a manufacturer of parts cleaners, located in Cincinnati, OH, to determine whether a diluted solution of Eagle Kleen III in an ultrasonic-enhanced parts washer could remove carbon deposits and/or oil and grease from parts. First, on November 2, 2005, a series of cleaning tests were performed on condemned parts obtained from Hill AFB using a 100% solution of Eagle Kleen III. The tests were run using an unagitated 5.6-gal Ransohoff HT-1212 heated tank operated at 25 kHz with a 600-watt density. Initially, the results indicated showed poor de-carbonizing. However, after dilution to 5% and operation at 120ºF, good (in some cases dramatic) carbon removal was achieved with immersion times ranging form 5 to 15 minutes.

Then, on March 14, 2006, tests were conducted on parts obtained from Hill AFB to gather additional data operated at similar conditions. The parts were too large to fit in the small lab unit, so an available "Grease Monkey" CLASSIC 3523 Blackstone~Ney unit (sold by Ransohoff, Inc.) was adapted for the tests (see Figure 15). The unit dimensions were 35 inches long, 23 inches wide, and 13 inches deep, with built-in 40 kHz transducers, and was operated at 25 kHz and a 2000-watt density. However, operation at a more aggressive frequency (25 kHz) was desired, so two portable, rectangular transducers were inserted into the unit. The unit was filled with distilled with 120ºF water, and two gallons of Eagle Kleen III were added and allowed to warm up (see Figure 16). Results with 5% Eagle Kleen™ at 120ºF and 15 minutes immersion times indicated dramatic removal of encrusted grease and carbon for some parts; however, the dilute Eagle Kleen™ solution was not effective at removing oils and grease.

Figure 15. "Grease Monkey" CLASSIC 3523 Blackstone~Ney Parts Washer

Figure 16. Parts Washer after Eagle Kleen™ Added

In an attempt to allow a better evaluation of the effectiveness of Eagle Kleen™ a fan assembly along with a different part (some type of housing) were submerged and suspended over the solution (see Figure 17). The fan assembly after 15 minutes showed a dramatic removal of the black coating. On the front, there is a clear demarcation of where the fan was immersed in the cleaner, and in this area the surface looks very clean (see Figure 18). The area cleaned is free of the black deposit. Another view, showing the dramatic cleaning achieved, is shown in Figure 19. On the rear side, where the fins are observed, it shows the surface substantially cleaned, but not totally (see Figure 20). This photo also shows an area that was not submerged, and is still completely covered with the dark brown/black substance.

Figure 17. Parts Partially Suspended in Cleaning Bath

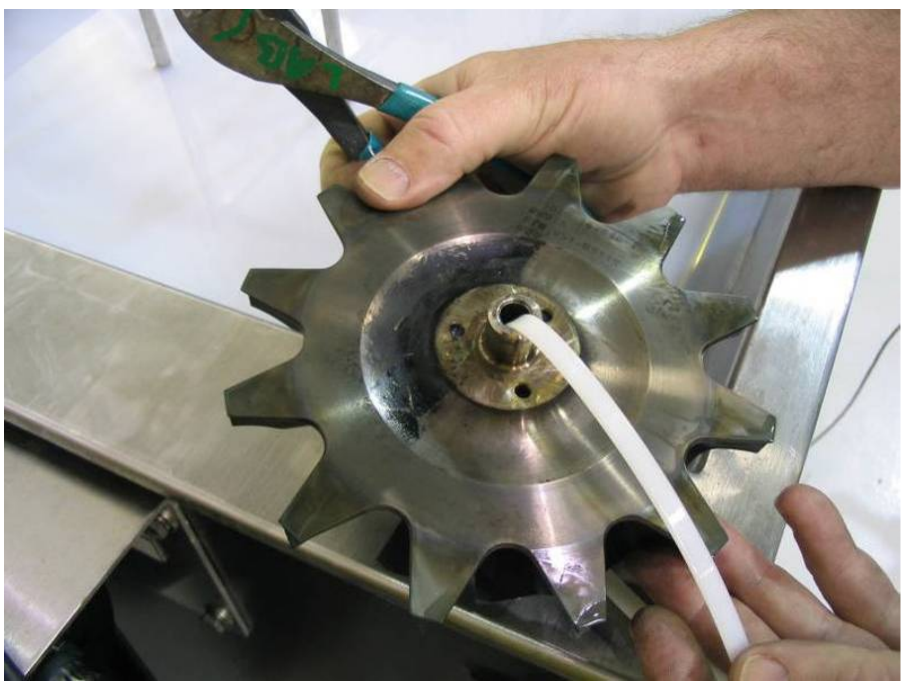

Figure 18. Top View of Fan Assembly After Cleaning

Figure 19. Front View of Fan Assembly after Cleaning

Figure 20. Rear View of Fan Assembly

In general, tests at the Ransohoff facility included the following:

- A dilute solution of Eagle Kleen III can be used in an ultrasonically enhanced parts washer to remove a substantial portion of carbon deposited on typical GTE parts.
- Cleaning appeared good, but was not complete. A longer immersion time or hand cleaning might be required for complete carbon removal.
- The solution was not effective in removing grease/heavy oils.
- Eagle Kleen III odor was detectable, but not overpowering even with the top off the cleaning unit. Odor when the top was open only a few minutes per hours would be less. However, some type of ventilation would probably be required in many applications.

A tank arrangement for Hill AFB GTE-parts cleaning was devised based on the test results. It consisted of the five-step degreasing and carbon removal set up presented in Table 13. Russ Markesbery indicated that he had proposed a similar tank configuration to Jeff Powell at Hill AFB. Photos of the Agisonic AG-30 are provided on Figures 21 and 22.

Table 13. Aqueous Cleaning Tank Operating Conditions

Step	Aqueous Concentration	Temperature (ºF)	Duration (minutes)	Other
1	100% Eagle Kleen III	120	30 – 60	Expect bath life: 4 to 8 weeks
2[(a)]	5% Eagle Kleen III in Water	120	15	Ultrasonics
3	4% Rust Bloc in Water[(b)]	150	30	
4	Water	150	30	
5	Dryer	200	60	

(a) All other units could employ the existing RAMCO line cleaning tanks. The ultrasonics would be conducted in a new 80-gallon, Blackstone~Ney Agisonic AG-30 agitated, parts cleaner.

(b) Rust Bloc may not be needed, but because Hill AFB is comfortable with its use, it was included in this process configuration.

Figure 21. Agisonic AG-30 Shown from Front
(Note: the lid is set off to the right of the tank)

Figure 22. Agisonic AG-30 Looking Down into Basket
(Note: the tray is in the parts-loading position)

4.0 TASK 3 – ENGINEERING COST ASSESSMENT

Task 3 is an Engineering Cost Assessment (ECA) designed to evaluate the functional, financial, and Environmental, Safety, and Occupational Health (ESOH) performance of Eagle Kleen™ based on information obtained at Hill AFB. The calculations were made using degreaser costs from Hill AFB and HTCI, equipment costs from Ransohoff Inc., and engineering estimates. (Because the Eagle Kleen™ degreaser was not found to be an acceptable replacement for the hydrocarbon solvent degreaser, no ECA was prepared for Robins AFB.)

The baseline ESOH and cost data for the conventional, alkaline immersion degreaser were collected by Battelle engineers during the Hill AFB demonstration task. Operating costs (labor, materials, energy) for industrial processes were difficult to collect, and were assumed to be the same for the conventional and Eagle Kleen™ degreasers.

Similarly, environmental treatment costs associated with a small operation or a process within a larger industrial facility also were difficult to obtain; engineering estimates were used to estimate wastewater collection, handling, and treatment for the conventional degreaser. (Note: the alkaline cleaner contains chelating agents and requires special collection and treatment, whereas the chelating-agent free Eagle Kleen™ can be discharged directly to the IWTP.)

Most industrial facilities track environmental costs at an aggregate level and rarely for a specific operation. The safety and occupational health profile of Eagle Kleen™ indicated ventilation was required to provide a similar profile as the alkaline cleaner. The ESOH evaluation included review of the material and safety data sheets (MSDS) and the physical and chemical properties of the degreasers. The assessment of their workplace impacts, based on aquatic toxicity, corrosivity, inhalation, skin contact, and flammability during operating conditions of the cleaning process, indicated similar impact should be expected once ventilation was installed.

The ECA included a list of assumptions, and appropriate extrapolations are documented for data gaps from the baseline data collection process. The assumptions were based on direct interviews with the shop floor workers and supervisors.

The ECA assumes that three of the four cleaning tanks, and the dryer, from the RAMCO system will be utilized in the new system. Only one new unit and ventilation for the two cleaning tanks, are included in the capitol costs estimate. The assessment also includes a payback period for transitioning from conventional degreasers to Eagle Kleen™.

The assessment factors are noted in Table 14. The cost for handling, treatment and disposal of the spent alkaline cleaner and spent rinse could not be determined and was estimated. Because this cost was a major contributor to the positive cash flow projected, this value should be determined. A sensitivity analysis was performed varying the drummed waste handling and disposal fee (see Table 15). Even with a relatively conservative $100/drum handling fee, the payback is only 3.2 years. Under the base case, where a rate of $150/drum was assumed, the payback is 2.2 years.

Table 14. ECA Assessment Factors

No.	Item	Information
1	Project Title	Replacement of Alkaline Cleaner with Chelating Agent-Free Biobased Cleaner
2	Project Description	This effort will qualify a new cleaning tank and alternative degreaser in the GTE shop. Implementation will improve degreasing and carbon removal performance, reduce waste generation, eliminate the discharge of chelating agents to the IWTP, and lower operating costs. Project duration is one-year and will start with the requirements definition phase that will include a 1-week on-site technology verification task that will help develop the design package for the new degreaser system. A new degreasing tank with an improved ultrasonic generator will be integrated into the existing RAMCO small-parts degrease line in the GTE shop. The equipment, installation in Building 238 at Hill AFB, training, and performance evaluation will be completed during FY07.
3	Justification	This project could provide significant reductions in waste generation: 21K gal/yr. of wastewater would be avoided. Also chemical and water usage would be reduced: 1100 gal/yr. of Turco 6849 alkaline cleaner, and 21K gal/yr. of fresh water. Waste-waters from the current operations contain chelating agents and require transport to the IWTP in carboys and special treatment. Substitution with Eagle Kleen III degreaser would eliminate the special handing requirements allowing the rinse water to be discharged directly to the industrial sewer. This will reduce handling labor and paperwork while ensuring un-interrupted metals precipitation in the IWTP. Additionally, the longer service life possible with Eagle Kleen™ will allow less frequent cleaning of the tanks, labor cost savings, and reduce degreaser chemical requirements and costs. Drivers: TRI, performance, and cost reduction.
4	Current Process Description	Small GTE parts are subjected to 1 hour of degreasing in two stages (30 minutes each) of hot degreasing (145ºF) using Turco 6849 alkaline cleaner. Each part is hand cleaned after the first stage. The parts are then rinsed for 1 hour in two hot (145ºF) aqueous rinse tanks (30 minutes each) fortified with Rustbloc rust inhibitor. The degreased parts are then sent to a dryer. In the current degreasing and rinsing operations, significant quantities of alkaline cleaner and inhibitor are consumed. Turco 6849 contains several compounds listed as hazardous materials.
5	Implementation Project Description and Budget	Total Project Cost: $200K Requirements Definition & Design Package: $15K Technology Verification (1 week) using Rented Equipment (on actual parts): $40K Technology Transfer: $100K (based on $68K of equipment and $22K for installation) Technology Validation 1-month (cleaning performance): $45K. Description of tasks: • The design package and specifications will be developed as part of the Requirements definition phase of the task. A test plan will be produced for 1-week onsite technology verification on serviceable parts. The results will help develop the design package for a full scale unit to be installed in the GTE shop. The 1-week technology verification will demonstrate the effectiveness of the integrated degreasing equipment and solvent. • Technology Transfer includes the purchase and installation of a new ultrasonic parts-cleaner, reconfiguration of the existing RAMCO cleaning and rinse tanks, and the addition of a ventilation system. It also includes training and integration of the new unit into the shop-floor cleaning operations. • Technology Validation will follow the operation of the equipment to ensure it is meeting the cleaning specifications. It will include a final report outlining the system performance.

Table 14. ECA Assessment Factors (Continued)

No.	Item	Information
6	Costs and Savings*	Current Annual Environmental Costs (~31K gal/yr. wastewater treated @ $15/Kgal; 570 drums/yr of drummed waste @ $150/drum) = $86K New Annual Environmental Costs (~10K gal/yr. wastewater treated @ $15/Kgal; 18 drums/yr of drummed waste @ $150/drum) = $3K Annual Environmental Savings = $83K Current Annual Operational Costs (29 Kgal/yr process makeup water @ $1.16/Kgal, 1100 gal Turco 6849 @ $13.75/gal, 8 gal of Rustbloc @ $17.40/gal) = $15,300 + solvent remaking time (4 hrs/week @$100/hr over 52 weeks/year) = $20,800 for a total of $36K. New Annual Operational Costs (8 Kgal/yr process makeup water @ $1.16/Kgal, 2300 gal Eagle Kleen III @ $9.98/gal, and 8 gal of Rustbloc @ $17.40/gal) = $23,100 + solvent remaking time (4 hrs every 4 weeks @ $100/hr over 52 weeks/yr) = $5,200 for a total of $28K Annual Operational Cost Savings = $8K Total Investment = $200K Total Savings = $83K + $8K = $91K/year Payback = Total Project Cost ($200K)/Savings ($91K) = 2.2 years Note: If Equipment is not needed, then payback is immediate

Table 15. ECA Sensitivity Analysis

Costs of Wastewater Handling and Treatment ($/drum)	Savings ($K/year)	Payback Period (years)
100	63	3.2
150	91	2.2
200	118	1.7
250	146	1.4

5.0 CONCLUSIONS AND RECOMENDATIONS

5.1 Conclusions

Based on the laboratory evaluation, field testing, and engineering cost assessment, the following conclusions were drawn:

1. Concentrated Eagle Kleen™:
    - The concentrated degreaser passed substantially all the MIL-PRF 87937D requirements for water dilatable degreasers, including physical property, corrosion, and the all-important hydrogen embrittlement test. However, it failed the heat stability and stressed-plastics crazing requirements, preventing it from being listed on the qualified fluids list.
    - In cleaning applications that do not involve acrylic or polycarbonates, the fluid may be used on a case-by-case basis. Eagle Kleen™ is a very aggressive degreaser and can dissolve certain plastics and elastomers. Attention must be paid to proper selection of construction material and PPE.
    - The fluid after degreasing leaves a slimy, slippery surface that must be rinsed with water.
    - The fluid can effectively remove oil and grease, but without ultrasonic energy is not effective at removing heavy carbon contamination.
    - The degreaser has a noticeable odor that some operators found offensive. Operation at elevated temperature (120ºF) dramatically increased complaints related to odor.
    - Ventilation during use is required.

2. Dilute Eagle Kleen™:
    - A dilute solution of Eagle Kleen III can be used in an ultrasonically enhanced parts washer to remove a substantial portion of carbon deposited on typical GTE parts. Cleaning appeared good, but was not complete. A longer immersion time or hand cleaning might be required for complete carbon removal.
    - The solution was not effective in removing grease/heavy oils.
    - The dilute degreaser in not slippery.
    - The odor of the dilute solution was detectable, but less severe an issues as with concentrated Eagle Kleen™.
    - Ventilation during use is required.

3. The economic cost assessment indicated a payback of 2.7 years with a positive NPV, indicating there are economic benefits to be gained when using Eagle Kleen™.

5.2 Recommendations

1. The degreaser should be evaluated in a real-world test using a suitable ultrasonically enhanced parts washer equipped with a suitable ventilation system. If cleaning results are verified, the degreaser should be considered for implementation.
2. The cost of handling, treatment, and disposal of spent alkaline cleaner and spent rinse should be verified, and the costs/savings/payback projections should be re-examined for specific applications.

6.0 REFERENCES

Anonymous. 1997. MIL-PRF-87937D “Cleaning Compound, Aerospace Equipment” (See Appendix A for a full copy.)

Tam, T.M., et al. 1993. “Evaluation Performance Test Methods for Aqueous Cleaner,” Plating and Shop Finishing, December, pp. 58-62.

Cohen, L. E. 1987. “How Clean is Your “Clean” Metal Surface?,” Plating and Surface Finishing, November, pp. 58- 61.

U. S. EPA. 1999. EPA-745-R-99-004, “33/50 Program The Final Record,” March, p. 2.