Eliminating CFC-113 and Methyl Chloroform in Aircraft Maintenance Procedures

Final

Developed for the Thai Airways/ Government of Thailand/ U.S. EPA Solvent Elimination Project

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ELIMINATING CFC-113 AND METHYL CHLOROFORM IN AIRCRAFT MAINTENANCE PROCEDURES

by

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FOREWORD

Thai Airways International, the Government of Thailand, the International Cooperative for Ozone Layer Protection (ICOLP), and the U.S. Environmental Protection Agency (EPA) have agreed to cooperate to phase out the use of ozone-depleting substances in aircraft maintenance solvent cleaning applications. The project is undertaken as part of the World Bank Global Solvents Project under the Multilateral Fund of the Montreal Protocol. This manual has been developed as part of this program. It will prove useful to other airlines because aircraft maintenance procedures apply to all airlines, regardless of location or size. The manual has been prepared by an international committee of experts from the airline and aerospace industries, the environmental agencies of Sweden and the United States, and the United States Air Force. Committee members represent both developed and developing countries.

The manual describes a step-by-step approach for characterizing the use of ozone-depleting solvents and identifying and evaluating alternatives. It is a "how-to" document which describes all of the steps necessary to successfully phase out the use of CFC-113 and methyl chloroform (MCF) in aircraft maintenance applications. Many of the alternatives described are currently in use at major airlines around the world. The manual addresses major maintenance cleaning applications and gives brief descriptions of the commercially available alternatives to CFC-113 and MCF. The manual provides sufficient technical information on the solvent alternatives to enable users to gather more detailed information on their alternatives of choice. A list of equipment and materials vendors is provided.

The manual's major findings remove misconceptions prevalent at many airlines. These findings are:

- Airlines can use any alternatives which meet aircraft standards without the explicit approval of the original equipment manufacturer (OEM) -- At least two of the three large manufacturers of commercial jet aircraft have published and distributed performance-based standards recommended for use by airlines. Alternatives which meet these standards can be used without approval of the OEM.

- The OEM will provide the names of alternatives for some but not all applications of CFC-113 and MCF -- Several OEMs have explicitly stated that they are not actively qualifying solvent alternatives, and that this responsibility lies with the airline. There are, however, a few exceptions to this rule.

- CFC-113 and MCF have been unnecessarily used in many cleaning applications -- These solvents have been used for many years in applications for which they were never intended. Reductions in consumption of more than 50 percent have been reported as the result of eliminating use of CFC-113 and MCF in unnecessary applications.

Airlines have chosen to identify and test solvent alternatives on their own rather than wait for more direct involvement from the OEMs. Lufthansa and SAS have virtually eliminated their use of CFC-113 and MCF through this proactive approach. Others are well on their way towards significantly reducing their consumption. This manual documents these successful phaseouts.

The Montreal Protocol

The 1987 Montreal Protocol on Substances that Deplete the Ozone Layer and subsequent 1990 and 1992 amendments and adjustments control the production and consumption of ozone-depleting chemicals. As a result of the most recent meetings in Copenhagen in November 1992, two such chemicals, chlorofluorocarbon 1,1,2-trichloro-1,2,2-trifluoroethane (commonly referred to as CFC-113) and 1,1,1-trichloroethane (commonly referred to as methyl chloroform or MCF), will be completely phased out in developed countries by the year 1996, and by 2010 and 2015, respectively, in developing countries. In addition, the 1992 amendments include a freeze and reduction schedule for hydrochlorofluorocarbons (HCFCs), with a phaseout in developed countries by the year 2030.

Exhibit 1 lists the countries that are Parties to the Montreal Protocol as of May 1993. In addition, many companies worldwide have corporate policies to expedite the phaseout of ozone depleting chemicals. Exhibit 2 presents the corporate policies on CFC-113 reduction for some of these companies.

In addition to providing regulatory schedules for the phaseout of ozone-depleting chemicals, the Montreal Protocol established a fund that will finance the incremental costs of phasing out ozone-depleting substances by eligible developing countries that are Party to the Protocol. Eligible countries are those with an annual consumption of CFCs and MCF of less than 0.3 kg per person.

Exhibit 1

PARTIES TO THE MONTREAL PROTOCOL

Algeria
Antigua and Barbuda
Argentina
Australia
Austria
Bahamas
Bahrain
Bangladesh
Barbados
Belarus
Belgium
Botswana
Brazil
Brunei Darussalam
Bulgaria
Burkina Faso
Cameroon
Canada
Central African Republic
Chile
China
Congo
Costa Rica
Cote d'Ivoire
Croatia
Cuba
Cyprus
Czech Republic
Denmark
Dominica
Ecuador
Egypt
El Salvador
EEC
Fiji
Finland
France
Gambia
Germany
Ghana
Greece
Grenada
Guatemala
Guinea
Hungary
Iceland
India
Indonesia
Iran
Ireland
Israel
Italy
Jamaica
Japan
Jordan
Kenya
Kiribati
Kuwait
Lebanon
Libyan Arab Jamahiriya
Liechtenstein
Luxembourg
Malawi
Malaysia
Maldives
Malta
Marshall Islands
Mauritius
Mexico
Monaco
Morocco
Netherlands
New Zealand
Nicaragua
Niger
Nigeria
Norway
Pakistan
Panama
Papua New Guinea
Paraguay
Peru
Philippines
Poland
Portugal
Romania
Republic of Korea
Russian Federation
St. Kitts and Nevis
Samoa
Saudi Arabia
Senegal
Seychelles
Singapore
Slovakia
Slovenia
South Africa
Spain
Sri Lanka
Sudan
Swaziland
Sweden
Switzerland
Syrian Arab Republic
Tanzania
Thailand
Togo
Trinidad & Tobago
Tunisia
Turkey
Uganda
Ukraine
United Arab Emirates
United Kingdom
United States
Uruguay
Uzbekistan
Venezuela
Yugoslavia
Zambia
Zimbabwe

Date: May, 1993

Exhibit 2

OZONE-DEPLETING SOLVENT CORPORATE PHASEOUT DATES

Successful Phaseout:

A-dec
ADC Telecommunications
Advanced Micro Devices
Alcatel Network Systems
Apple Computer
Applied Magnetics
Aishin Seiki
Alps Electric
AT&T
Cadillac Gage
Calsonic
Canon
Corbin Russwin Hardware
Casio Computer
Chip Supply
Clarion
Compaq Computers
Conner Peripherals
Commins Engine
Diatek
Fuji Photo Film
Fujitsu
Harris Semiconductors
Hewlett Packard
IBM
ITT Cannon
Japan Aviation Electronics
Kilovac
Kyocera
Mabuchi Motor
Matsushita
MDM
Minebea
Minolta Camera
Mitsui High-tech
Motorola
Murata Erie N.A.
Murata Manufacturing
National Semiconductor
NEC
Nihon Dempa Kogyo
Nissan
Northern Telecom
NRC
Iki Electric
Omron
OTC/SPX
Pacific Scientific EKD
Ricoh
Rohm
Sanyo MEG
Sanyo Energy
Seagate Technology
Seiko Epson
Seiko-sha
Sharp
Shin-etsu Polymer
SMC
Sony
Stanley Electric
Sun Microsystems
Symmons Industries
Talley Defense Systems
Thomson Consumer Electronics
3M
Toshiba
Toshiba Display Devices
Toyota Motor
Unisia JECCS
Yokogawa Electric

Future Phaseout:

Citizen Watch -- 12/93
Funac -- 12/93
Hitachi -- 12/93
Hitachi Metals -- 12/93
Isuzu Motors -- 1993
Kohyo Seiko -- 12/93
Mitsubishi Electric -- 12/93
Mitsubishi Heavy Industry -- 12/94
Mitsubishi Motors -- 8/93
NHK Spring -- 12/93
Nissan Diesel Motor -- 1994
NSK -- 12/93
Olympus Optical -- 12/93
Sumitomo Electric -- 12/93
Sumitomo Special Metals -- 12/93
Suzuki Motor -- 1994
Taiyo Yuden -- 12/93
Victor Japan -- 11/93
Yamaha -- 12/93
Zexel -- 8/93

International Phaseout Schedules

Several countries have passed legislation to phase out CFC-113 and methyl chloroform (MCF) earlier than target dates set by the Montreal Protocol in an effort to slow ongoing depletion of the stratospheric ozone layer. These policies are summarized below.

Canada

Environment Canada, the federal environmental agency responsible for environmental protection in Canada, has proposed a reduction program that is more stringent than the Montreal Protocol. Environment Canada has also announced a series of target dates for the phaseout of CFCs in specific end uses. For solvent cleaning applications, such as metal and precision cleaning, it mandates a phaseout of CFC-113 by the end of 1994. Under the proposed schedule, production, imports, and exports of CFCs are to be eliminated by January 1, 1996, with a 75 percent reduction by January 1, 1994. For carbon tetrachloride, the phaseout date is January 1, 1995 -- one year earlier than that mandated by the Montreal Protocol. Halons are proposed to be eliminated by January 1, 1994. Production, imports, and exports of methyl chloroform will be halted by January 1, 1996, with interim reductions of 50 percent by January 1, 1994, and 85 percent by January 1, 1995.

European Community

Under the Single European Act of 1987, the twelve members of the European Community (EC) are subject to environmental directives. The members of the EC are Belgium, Denmark, Germany, France, Greece, Great Britain, Ireland, Italy, Luxembourg, the Netherlands, Portugal, and Spain. Council Regulation number 594/91 of March 4, 1991 provides regulatory provisions for the production of substances that deplete the ozone layer. The EC phaseout schedule for CFC-113 production is more stringent than the Montreal Protocol. It calls for an 85 percent reduction of CFC-113 by January 1, 1994 and a complete phaseout by January 1, 1995. For MCF, the production phaseout schedule calls for a 50 percent cut in production by January 1, 1994 and a complete phaseout by January 1, 1996. While all members must abide by these dates, Council Regulation number 3322/88 of October 31, 1988 states that EC members may take even more extensive measures to protect the ozone layer.

European Free Trade Agreement Countries

The European Free Trade Agreement (EFTA) countries, Austria, Finland, Iceland, Norway, Sweden, and Switzerland, have each adopted measures to completely phase out fully halogenated ozone-depleting compounds. Austria, Finland, Norway, and Sweden will completely phase out their use of CFC-113 in all applications by January 1, 1995. Sweden also plans an aggressive phaseout date of 1995 for MCF. In addition, some of the EFTA countries have sector-specific interim phaseout dates for certain solvent uses. Austria is planning to phase out CFC-113 in a number of solvent cleaning applications by January 1, 1994. Norway and Sweden already eliminated their use of CFC-113 in all applications except textile dry cleaning on July 1, 1991 and January 1, 1991, respectively.

Japan

On May 13, 1992, the Ministry of International Trade and Industry of Japan requested its 72 Industrial Associations to phase out CFC and methyl chloroform usage by the end of 1995.

United States

The U.S. Clean Air Act (CAA), as amended in 1990, contains several provisions pertaining to stratospheric ozone protection. These ozone-depleting substances are defined as Class I and Class II substances. Class I substances include all fully halogenated CFCs, three halons, MCF, and carbon tetrachloride. Class II substances are defined to include 33 hydrochlorofluorocarbons (HCFCs). The sections of the CAA that are of importance to users of this manual are discussed below.

- ***Section 112: National Emission Standards for Hazardous Air Pollutants***

  This section of the CAA requires the EPA to develop emissions standards for 189 chemical compounds listed as hazardous air pollutants (HAPs). The list of HAPs includes the chlorinated solvents as well as many organic solvents likely to be used in aircraft maintenance.

- ***Section 604 and Section 605: Phaseout of Production and Consumption of Class I and Class II Substances.***

  The U.S. EPA is currently accelerating this phaseout schedule in response to former President George Bush's call for a more rapid phaseout and the recent amendments made to the Protocol in Copenhagen.

- ***Section 610: Nonessential Products Containing Chlorofluorocarbons***

  This provision directs EPA to promulgate regulations that prohibit the sale or distribution of certain "nonessential" products that release Class I and Class II substances during manufacture, use, storage, or disposal.

- ***Section 611: Labeling***

  This section of the CAA directed EPA to promulgate regulations requiring the labeling of products that contain or were manufactured with Class I and Class II substances and containers of these substances. Containers in which Class I and Class II substances are stored must also be labeled. The label will read "Warning: Contains or manufactured with [*insert name of substance*], a substance which harms public health and environment by destroying ozone in the upper atmosphere". The label must clearly identify the ODS by chemical name for easy recognition by average consumers, and must be placed so that it is clearly legible and conspicuous. This regulation took effect on May 15, 1993.

  No later than January 1, 2015, products containing or manufactured with a Class II substance must be labeled.

- ***Section 612: Safe Alternatives Policy***

  Section 612 establishes a framework for evaluating the overall environmental and human health impact of current and future alternatives to ozone-depleting solvents. Such regulation ensures that ozone-depleting substances will be replaced by substitutes that reduce overall risks to human health and the environment.

As an incentive to reduce the production and consumption of ozone-depleting substances in the U.S., Congress placed an excise tax on ozone-depleting chemicals manufactured or imported for use in the United States. This tax provides a further incentive to use alternatives and substitutes to CFC-113 and MCF. The tax amounts are based on each chemical's ozone depleting potential. These taxes have recently been increased as a part of the U.S. Congress' comprehensive energy bill of 1992.

Calendar Year	Tax Amount Per Pound	
	CFC-113	MCF
1991	$1.096	$0.137
1992	$1.336	$0.167
1993	$2.68	$0.211
1994	$3.48	$0.435
1995	$4.28	$0.535

Cooperative Efforts

Japan

The recent Japanese Ozone Layer Protection Act gives the Ministry of International Trade and Industry (MITI) the authorization to promulgate ordinances governing the use of ozone-depleting compounds. MITI and the Environmental Agency have established the "Guidelines for Discharge Reduction and Use Rationalization." Based upon these guidelines, various government agencies provide administrative guidance and advice to the industries under their respective jurisdictions. Specifically, MITI is working with the Japan Industrial Conference for Ozone Layer Protection (JICOP) to prepare a series of manuals which provide technical information on alternatives to CFC-113 and MCF. The manuals prepared are:

- Manual for Phasing-Out 1,1,1-Trichloroethane;
- Manual for reduction in the Use of Ozone-Depleting Substances.

MITI also encourages industry to reduce consumption of ozone-depleting compounds through economic measures such as tax incentives to promote the use of equipment to recover and reuse solvents.

Sweden

There are two major cooperative efforts within the Government/Industry/Research Institution sectors targeting the phaseout of ODSs and chlorinated solvents:

- The TRE-project (Technology for Clean Electronics); and

- The AMY-project (Cleaning of Metallic surfaces).

In addition, direct support is being provided to industry for industrial scale introduction of new technologies. These are, to name a few, closed looped systems, microbiological cleaning systems, ion exchange technologies, electrochemical cleaning systems, vacuum evaporation systems, reverse osmosis, and alternative solvent-based systems.

United States

The U.S. Environmental Protection Agency (EPA) has been working with industry to disseminate information on technically feasible, cost effective, and environmentally sound alternatives to ozone-depleting substances. As part of this effort, the U.S. EPA is working with the International Cooperative for Ozone Layer Protection (ICOLP) to prepare a series of manuals to provide technical information on alternatives to CFC-113 and MCF. Additional information about ICOLP can be found in Appendix A. The manuals are based on actual industrial experiences that will serve as a guide to users of CFC-113 and MCF worldwide. These manuals will be updated periodically as technical developments occur.

The manuals in the series are:

- Conservation and Recycling Practices for CFC-113 and Methyl Chloroform.

- Aqueous and Semi-Aqueous Alternatives to CFC-113 and Methyl Chloroform Cleaning of Printed Circuit Board Assemblies.

- Alternatives for CFC-113 and Methyl Chloroform in Metal Cleaning.

- Eliminating CFC-113 and Methyl Chloroform in Precision Cleaning Operations.

- No-Clean Soldering to Eliminate CFC-113 and Methyl Chloroform Cleaning of Printed Circuit Board Assemblies.

- Eliminating CFC-113 and Methyl Chloroform in Aircraft Maintenance Procedures.

* * * * * * *

This particular manual provides those in an organization involved in aircraft maintenance with a simply-structured program to help eliminate the use of CFC-113 and/or MCF. It presents alternative processes which can be used in aircraft cleaning, most of which are approved by major aircraft and engine manufacturers. Many are currently in use at airlines around the world. The goal of the manual is to:

- Warn users of CFC-113 and methyl chloroform of the impending halt in production and the consequences to their operations;

- Identify the currently available and emerging alternatives for CFC-113 and methyl chloroform;

- Provide an overview of the tasks which are required to successfully implement an alternative process or chemical;

- Provide an overview of the environmental, health, safety, and other factors associated with alternatives and the benefits achievable from the phaseout of CFC-113 and methyl chloroform;

- Present detailed case studies on the actual industrial applications of these technologies to:

  -- Identify unresolved problems in eliminating CFC-113 and methyl chloroform; and

  -- Describe the equipment configuration of a typical maintenance facility after it has eliminated its use of CFC-113 and methyl chloroform.

This manual will benefit all users of CFC-113 and MCF in the aircraft maintenance industry. Ultimately, however, the success of a CFC-113 and MCF elimination strategy will depend upon how effectively reduction and elimination programs are organized. Experience has also shown that a strong education and training program for workers using new processes results in greater efficiency and a smooth transition away from CFC-113 and MCF. The development and implementation of alternatives to CFC-113 and MCF for aircraft cleaning present a demanding challenge for most organizations. The rewards for success are the contribution to global environmental protection and an increase in industrial efficiency.

STRUCTURE OF THE MANUAL

This manual is divided into the following sections:

- **EXISTING CLEANING PROCESS CHARACTERIZATION**

This section presents the initial steps a facility must take in order to reduce and eliminate CFC-113 and MCF usage in cleaning procedures. It emphasizes the importance of being familiar with the different aspects of the cleaning processes.

- **INTRODUCTION TO CLEANING IN AIRCRAFT MAINTENANCE PROCEDURES**

This section introduces the maintenance procedures which usually require cleaning, summarizes the types of cleaning which have been traditionally used, and presents a number of cleaning operations which apply to specific areas of aircraft and engine maintenance.

- **METHODOLOGY FOR SELECTING AN ALTERNATIVE PROCESS**

This section discusses various organizational, policy, technical, economic, and environment, health, and safety issues that should be considered when selecting a cleaning process.

- **QUALIFICATION TESTING OF ALTERNATIVE CLEANING PROCESSES AND MATERIALS**

This section discusses the importance of performing an aircraft or engine manufacturer's required tests of an alternative cleaning chemical or process and presents guidelines for conducting these tests.

- **INTRODUCTION TO ALTERNATIVE CHEMICALS AND PROCESSES**

This section describes the operational principles and outlines the advantages and disadvantages of several alternative technologies, including aqueous cleaning, semi-aqueous cleaning, aliphatic hydrocarbons, chlorinated solvents, other organic solvents, etc.

- **SUMMARY OF CLEANING APPLICATIONS**

This section presents summary sheets for a number of general aircraft cleaning procedures. These procedures are grouped into three categories: exterior surface cleaning, assembly cleaning, and component cleaning. It describes how CFC-113 and methyl chloroform may currently be used, the possible alternatives, relevant specifications, and associated environmental impacts.

- **USE OF CFC-113 AND METHYL CHLOROFORM IN SPECIALIZED FORMULATIONS**

This section presents information on how CFC-113 and methyl chloroform are used in additional applications, including non-cleaning applications.

- **CASE STUDIES OF SUCCESSFUL IMPLEMENTATION OF ALTERNATIVE PROCESSES**

This section provides examples of industrial applications of alternative technologies in aircraft cleaning.

EXISTING CLEANING PROCESS CHARACTERIZATION

The first step in reducing and eventually eliminating the use of CFC-113 and MCF in aircraft maintenance cleaning is designating a multidisciplinary team to coordinate the effort. Team members should represent various shops within the maintenance facility, including electronics, instrumentation, engine, hydraulics, landing gear, plating, painting, and cleaning. The team should also include representatives from plant engineering, environmental control, occupational health and safety, quality control, and purchasing, if possible.

In order for the team to develop an effective program, it must first acquire a good overall knowledge of existing cleaning processes within its facility and the systems in which they are performed. This knowledge will help the team to identify and prioritize the cleaning operations to which it must direct its attention. Once these operations are identified, the team can analyze the processes to reduce CFC-113/MCF usage and determine cleaning requirements so that an optimal alternative may be selected for each application.

Acquiring an adequate knowledge of the maintenance facility can be accomplished by conducting a facility-wide study using surveys. These surveys should be distributed to shop foremen for completion. If possible, the team should visit each shop to observe existing procedures, interview operators, and collect substrate and soil samples for laboratory tests. The study should include a flow chart of each manufacturing or maintenance process as well as tabular summaries of soils, substrates, and part geometry. Conducting the survey will allow the team to establish contacts and develop rapport with the individuals who will ultimately be affected by the process change. The cooperation and input of these individuals is essential to the success of the phaseout program.

After the study has been completed, the team should be able to characterize the different cleaning operations around the maintenance facility. The following sections suggest typical questions the team should be able to answer about existing cleaning processes, disposal practices, the substrates being cleaned, and the soils being removed.

Analyzing Existing Cleaning Methods

In order to reduce and eliminate the use of CFC-113 and MCF in aircraft maintenance cleaning, the team must identify and analyze all of the processes that use these substances. Questions the team should be able to answer include:

- What maintenance processes incorporate CFC-113 and MCF?
- What quantity of CFC-113 and MCF is used in each process?
- Where do CFC-113 and MCF losses occur?
- Where does the cleaning take place in the facility?
- What percentage of time are the cleaning machines in use?
- How many parts are cleaned per day per machine?

Exhibit 3

CFC-113 AND METHYL CHLOROFORM USAGE PROFILE

SHOP NAME & LOCATION: ____

NAME OF CONTACT IN SHOP: ______________________________________

A. PROCESS IDENTIFICATION

Aircraft Parts Cleaned (e.g. fuselage, engine components, seats -- be as specific as possible):

____

Current Cleaning Method (e.g. open-top vapor degreasing, conveyorized vapor degreasing, cold cleaning, dip tank, hand-wipe, aerosol, etc.):

____

Number of Cleaning Machines in Shop Which Use CFC-113 or MCF:

____

Controls on Cleaning Equipment (e.g. covers, extended freeboard, cooling coils, etc.):

____

Other Uses (e.g., carriers, drying):

____

Substrates Typically Cleaned:

____

____

Soils Typically Removed (e.g., dirt, carbon deposits, grease) (attach MSDS for the soil if available):

____

____

Standards to be met (e.g., AMS, military, etc.):

____

____

B. PRODUCTS USED

Generic Name of Solvent (circle one; use one survey for each chemical):

CFC-113 **MCF (1,1,1-trichloroethane)**

Trade Name of Solvent (e.g. Daiflon 113, Freon TF, Chlorothene SM, Triethane) (see Appendix C for additional tradenames):

____

Manufacturer (e.g. Daikin, DuPont, Dow, PPG) (see Appendix C for additional manufacturers):

____

C. USE HISTORY

Quantity Purchased and Used Yearly; specify units (e.g. liters, gallons):

	PURCHASED (quantity of solvent purchased or requisitioned by this shop for cleaning)	USED (quantity of solvent consumed in this shop for cleaning)
1989		
1990		
1991		
1992		

D. CFC-113 AND MCF DISPOSAL PRACTICES

	1989	1990	1991	1992
Quantity shipped out as waste for disposal (specify units):				
Disposal costs:				
Quantity shipped out for recycling (specify units):				
Cost of recycling:				
Quantity recycled on site (specify units):				
Quantity lost to the environment[1] (through leakage, spillage, testing, dragout, evaporation, etc.) (specify units)				

[1] This quantity can be calculated as follows: Quantity Lost = Quantity Purchased - Quantity shipped out as waste.

An effective way to collect such information is through a written survey. Exhibit 3 shows an example of a survey that can be used to characterize CFC-113 and MCF usage in all aspects of the facility's operations.

The information gathered using surveys and other means can be stored in an electronic database for future use. The creation of such a comprehensive database will allow the team to monitor progress and to pinpoint areas in the facility where consumption of ODSs remains high. Facilities may choose to design the tracking system themselves, hire a firm to create a custom system, or purchase an existing system from another facility. At least one European airline has created such a system which it offers for sale to other facilities.

Through familiarizing itself with current usage patterns, the team will not only know which cleaning operations can utilize currently available alternative cleaning methods, but also which operations can reduce their use of CFC-113 and MCF until another method becomes available.

For example, when the maintenance facility of one large airline became aware of the environmental problems caused by CFC-113 and MCF, it examined its cleaning processes to determine where reduction and elimination could occur. It identified areas where it could make the greatest reduction with the least amount of difficulty. In one situation, it discovered that the instrumentation shop was cleaning small parts by running them under MCF dispensed by a faucet. This faucet mechanism resulted in a great deal of MCF being wasted. The company decided to switch the cleaning operation to an MCF aerosol spray. Although it will still need to be eliminated, this new cleaning method provided a much more controlled use of the solvent, thus greatly reducing the shop's consumption of ODSs.

If several similar cleaning operations exist throughout the maintenance facility, the team may choose to consolidate some of them into a central location. This could also allow for more efficient use of the cleaning materials and facilities.

If the team finds that CFC-113 and MCF losses are fairly high, they may suggest ways to curb the loss, such as using covers on vapor degreasers and using wipe cloths and storage bags to save spilled CFC-113/MCF. Taking such measures will help the maintenance facility to reduce its use of ozone depleting substances until an alternative, ODS-free method is chosen.

Analyzing Solvent Disposal Procedures

In addition to analyzing the cleaning processes, the team should also analyze the facility's disposal practices. Being familiar with disposal practices will aid the team in further reducing CFC-113 and MCF usage. Questions the team should be able to answer include:

- How is CFC-113 and MCF reclaimed/disposed of after use?
- How often is the CFC-113 and MCF replaced in degreasing processes?

The team should ensure that the used CFC-113 and MCF is being treated and disposed of safely. An evaluation of disposal techniques will allow the team to investigate whether these solvents can be used for longer periods of time prior to disposal, thus further reducing the facility's usage of CFC-113 and MCF. In addition, the team will be able to evaluate the possibility of using spent solvent in subsequent cleaning operations where pure solvent is not needed.

Characterizing the Substrate

When studies are conducted regarding alternative cleaning methods, it is critical that the team is familiar with the substrates being cleaned in each operation. Often, cleaning processes that are effective on one substrate cannot be used on another substrate, even if the soil is identical. Questions that the team should consider include:

- What material/substrate is being cleaned?
- What degree of cleanliness is required?
- What is the surface finish required?
- What coatings are on the surface?
- What is the size and geometric configuration of the part? Is there solvent entrapment potential associated with the part? How rough is the surface of the part?
- To what level of assembly has the part been dismantled?

As the team learns more about the substrates that are being cleaned, they will become aware of the properties that they must look for and the choices that they will be limited to in choosing a new cleaning chemical or process.

For example, one material that requires special attention is titanium (and its alloys). It can be sensitive to attack (e.g., stress corrosion cracking) by residual chlorinated and fluorinated solvents, particularly if subjected to processes at temperatures greater than 662°F (350°C). It can also be vulnerable to a reduction in fatigue strength if subject to dry abrasive blasting. The team should be familiar with the parts of the aircraft that contain this metal. Another material which may warrant special attention is beryllium, a product often used in guidance systems.

Composite materials in aircraft also require special attention. Composite materials are widely used in the construction secondary structure and flight control surfaces, where high strength and stiffness and low density are required. For example, graphite/epoxy is often used to make the rudder, elevators, spoilers, and ailerons. Kevlar is found in cargo linings, outboard stowage bins and center supports, nacelle strut and thrust reverser fairings, and various other components. Kevlar/graphite is used in the construction of cowl components, main landing gear doors, fixed tie panels, tips, wing to body fairings, and other important parts.

Parts with excessive porosity, parts that have severely rough surfaces, parts that have permanent overlapping joints, parts with blind holes, honeycomb core structures, and tubing can retain cleaning solution, which may cause corrosion. Care must be taken to thoroughly dry these parts after cleaning.

Special care is also required during cleaning prior to nondestructive testing procedures such as penetrant inspection. In order to conduct an accurate penetrant inspection test, the product surface must be completely free of residual surface contamination. The presence of cleaner residue or other contaminants may shield flaws in the structure and prevent the inspection fluid from penetrating surface flaws or cracks. Therefore, care must be exercised to ensure that the cleaning method employed results in a sufficiently clean surface prior to inspection.

Honeycomb structures in airplane parts such as the nose radome require even greater caution when cleaning. Cleaning occurs prior to bonding to ensure maximum bond strength and integrity. Alkaline and aqueous cleaning methods must be applied with great care because at flight altitudes, any remaining vestiges of moisture in the honeycomb structures may freeze, possibly causing the structure to crack.

During aircraft maintenance, components of the airplane are disassembled into varying levels of disassembly for cleaning, inspection, and repair. Knowledge of the level of disassembly is important because it may help the team in choosing a new cleaning process that does not use CFC-113 or MCF. For example, a structure may be disassembled to subassembly level and cleaned using vapor degreasing. However, if the part were further dismantled to a component level, thus reducing its geometric complexity, the cleaning process may be switched to aqueous or alkaline cleaning without any impact on cleaning effectiveness.

Characterizing the Soils

Another important step in characterizing existing cleaning processes is identifying the soils to be removed. To gain familiarity with the wide variety of soils cleaned in normal aircraft maintenance, the team should evaluate the soils being cleaned in each operation individually. This can be accomplished in part by asking the following questions for every cleaning operation being evaluated:

- What type of soils are being removed?
- Where are the soils coming from?
- What are the performance conditions around the substrate and soil (heat, cold, high stress)?
- Why is the soil being removed (overhaul, inspection, repair)?

The use of CFC-113 or MCF in cleaning is often a precursor to further processing, such as inspection and repair. Typical soils found on aircraft include:

- ***Organic liquids and oils*** such as formulated hydraulic fluid, lubricants, oil base rust preventatives, etc.
- ***Semi-solid*** soils such as viscous oils, greases, heavy rust preventives, etc.
- ***Solids*** such as mud, salts, carbonized oils, oxides, corrosion products, etc.

Usually, the longer the soil remains on the substrate, and the higher the temperature to which the part has been exposed, the more difficult the soil becomes to remove. The sooner the part is cleaned after contamination, the easier it will be to remove the soil.

Proper and thorough identification of the soils, their sources, and their properties will enable the team to more accurately identify the requirements for the new cleaning process.

INTRODUCTION TO CLEANING IN AIRCRAFT MAINTENANCE PROCEDURES

Chlorofluorocarbon 113 (CFC-113) and methyl chloroform (MCF) have been used for many solvent cleaning applications. These solvents exhibit good solvency for a wide variety of organic contaminants and are noncorrosive to the metals being cleaned. They have low heats of vaporization and high vapor pressures that are beneficial in vapor cleaning processes and allow evaporative drying of cleaned parts. Additionally, these solvents are non-flammable, have low toxicity, and remain chemically stable when properly formulated with adequate stabilizers.

Cleaning is an essential process in the production, maintenance, and repair of commercial and military aircraft. As a surface preparation process, cleaning removes contaminants and prepares parts for subsequent operations such as inspection, repair, bonding, coating, and testing. Cleaning is used in the maintenance of a wide variety of aircraft parts and fixtures. Generally speaking, the cleaning which is performed in maintaining aircraft can be grouped into three categories: metal cleaning, electronics cleaning, and precision cleaning.

Metal cleaning is defined as the removal of oil, grease, and other contaminants from metal parts during manufacture, maintenance, or repair procedures. In maintenance procedures, aircraft assemblies are often inspected, removed, disassembled, cleaned, repaired if necessary, reassembled, and reattached to the aircraft. Examples of aircraft assemblies on which CFC-113 and MCF have been used in metal cleaning operations include landing gear, and control surfaces.

Electronics cleaning usually refers to the removal of flux residues which remain after soldering operations are completed. Large-scale electronics cleaning is often performed in continuous cleaning equipment, while smaller operations are carried out by hand using an aerosol cleaner or solvent on a swab. In aircraft maintenance procedures, the primary example of an area in which electronics cleaning is required is the avionics of an aircraft. These operations usually consist of rework performance by hand and thus require only small-scale cleaning operations.

Precision cleaning is either metal cleaning or electronics cleaning (although it is usually used in reference to metal cleaning operations) which is characterized by the need for an extremely high level of cleanliness. Examples of equipment in aircraft which require precision cleaning include gyroscopes and other components of guidance systems. In systems such as these, contaminant particles one micron or less in size could result in a system failure.

Solvent cleaning may be divided into two types: cold cleaning and vapor degreasing. Cold cleaning is usually accomplished with solvents at, or slightly above, room temperature. In cold cleaning, parts are cleaned by being immersed and soaked, sprayed, or wiped with the solvent.

The majority of solvent cleaning in aircraft maintenance has traditionally been performed by vapor degreasing. In this process, the solvent is heated to its boiling point and the solvent vapor is used to remove contaminants. A basic vapor degreaser consists of a steel tank (with or without a cover) that has a heat source at the bottom to boil the solvent and cooling coils near the upper section to condense the vapors.

Heat, introduced into the reservoir, boils the solvent and generates hot solvent vapor which displaces the lighter air and forms a vapor zone above the boiling solvent up to the cooling zone. The hot vapor is condensed when it reaches the cooling zone by condensing coils or a water jacket, thus maintaining a fixed vapor level and creating a thermal balance. The hot vapor condenses on the cool part suspended in the vapor zone causing the solvent to dissolve or displace the contaminants or soils.

Vapor degreasing is, in most applications, more advantageous than cold cleaning. This is due to the fact that the solvent bath in a vapor degreasing process is less contaminated over time than a similar bath in a cold cleaning operation. Although the boiling solvent contains the contaminants from previously cleaned parts, these usually boil at higher temperatures than the solvent, resulting in the formation of essentially pure solvent vapors. In addition, the high temperature of vapor cleaning aids in wax and heavy grease removal as well as significantly reducing or eliminating drying time for the cleaned parts.

The impending phaseout of ozone-depleting substances has led the aircraft maintenance industry to undertake an extensive search for alternative cleaners and cleaning processes which will replace the use of CFC-113 and MCF. In some cases, these alternatives can make use of existing vapor degreasing equipment, but in the majority of cases, new technologies are being implemented. This manual will describe technologies which are currently being used successfully in aircraft maintenance cleaning operations, and will summarize alternatives which apply to the most frequent maintenance cleaning operations.

Eight general cleaning applications which apply to specific areas of aircraft maintenance are discussed in this manual. Specifically, the areas covered are:

- Aircraft exterior surface cleaning
- Landing gear cleaning
- Cleaning of engines or engine modules
- Cleaning of flight control surfaces
- Electrical equipment cleaning
- Cleaning of hydraulic lines
- Cleaning of aircraft seat covers and draperies
- Cleaning prior to subsequent operations.

The remainder of this section provides a brief description of each of these application areas.

Aircraft Exterior Surface Cleaning

Exterior surface cleaning refers primarily to the cleaning of the aircraft fuselage. Through frequent cleaning of the aircraft's exterior, a wide variety of everyday soils will be removed. Typical soils include traffic dirt, oxidation deposits, and exhaust deposits. The removal of these contaminants is vital to ensure the prevention of corrosion on uncoated surfaces.

While removal of soils is necessary to ensure safe aircraft operation, a large portion of the exterior surface cleaning performed is for cosmetic reasons only. Cleaning and subsequent polishing will give the aircraft fuselage a shine which should be aesthetically pleasing to passengers. In addition by maintaining a clean aircraft, the total weight of the aircraft will be reduced and less fuel will be used in normal operations.

Landing Gear Cleaning

The landing gear on a typical commercial aircraft consists of main gear and nose gear. Both the main gear and the nose gear consist of a number of components. These include, but are not limited to: doors, extension and retraction systems, wheels, brakes, steering system, and a position/warning system. Typical landing gear assemblies are shown in Exhibit 4.

Cleaning of landing gear assemblies can be performed on the aircraft in the case of standard maintenance work, or off the aircraft for complete overhaul procedures.

Cleaning of Engines or Engine Modules

Engine cleaning in aircraft maintenance procedures is complex and often involves breaking down assembled engines into modules for work. An example of a typical jet engine and its component modules is shown in Exhibit 5. Cleaning of

ex 4

ex 5

engines is necessary in order to allow for accurate inspection of individual modules. In engine cleaning operations, workers must be careful to accurately identify all of the materials being cleaned, since certain metals cannot be cleaned using all methods. These metals include titanium, titanium alloys, and aluminum alloys, all of which are frequently found in aircraft engines.

Cleaning procedures for engines and engine modules can be loosely grouped into three categories -- aqueous alkaline cleaning, solvent cleaning, and media blasting. These techniques will be described in detail in a later section of this manual.

Cleaning of Flight Control Surfaces

Flight control surfaces are those parts of the aircraft structure which influence aerodynamics and which control operational variables such as speed altitude, and direction. Flight controls found on a typical aircraft are shown in Exhibit 6 and include: ailerons, elevators, rudder, speedbrakes, horizontal stabilizer, leading-edge slats, and trailing-edge flaps.

All flight control surfaces are smooth, and can be cleaned either on the aircraft or after being removed. Special consideration must be given to those flight controls which are comprised of composite materials. These controls vary from aircraft to aircraft. For instance on the Boeing 767 aircraft, the spoilers, ailerons, rudder, and elevators are composed of graphite and epoxy. In addition to the surfaces themselves, the hydraulic lines which are vital to the operation of the various flight controls also require cleaning.

Electrical Equipment Cleaning

Aircraft avionics often require cleaning after maintenance operations before they can be reinstalled in the aircraft. The majority of the maintenance work performed on electrical equipment is manual soldering rework. As in original production, flux residues must be removed from avionics after touch-up soldering work has been completed in order to ensure that residues do not interfere with the proper functioning of the equipment.

Cleaning of Hydraulic Lines

Hydraulic lines in aircraft carry hydraulic fluid to the flight control surfaces so that free movement of the flight controls is maintained. During scheduled maintenance, hydraulic lines are removed and inner and outer surfaces are cleaned. This has traditionally been accomplished using MCF vapor degreasing and ambient temperature immersion. In addition, during maintenance, a number of activities may occur which would result in the spillage of hydraulic fluid on the outside of the lines. These activities include addition of hydraulic fluid and maintenance on the pumps which move the fluid through the lines. Prior to reassembling the aircraft, any spilled hydraulic fluid must be cleaned off the hydraulic lines. This has traditionally been accomplished using a wipe or spray technique and MCF.

Cleaning of Aircraft Seat Covers and Draperies

As a part of regular aircraft maintenance, seat covers and draperies are removed from an aircraft and cleaned. A drycleaning process is used to remove dirt and other soils from the fabrics. While many drycleaning operations currently use perchloroethylene, a nonozone-depleting chlorinated solvent, as the cleaning agent, some may use CFC-113. In these processes, it is necessary to eliminate the use of CFC-113.

Cleaning Prior to Subsequent Operations

Cleaning of surfaces on components or assemblies prior to performing a subsequent operation is

ex 6

often vital to the integrity of that operation. For example, cleanliness prior to fluorescent penetrant inspection (FPI) (to confirm the condition/air-worthiness of the component) will rely on there being no residual contaminants prior to or during the FPI procedures. Similarly, the integrity of repair processes used to re-establish service capability of components will depend on achieving the requisite cleanliness standard for the subsequent process. This manual will provide alternatives to the use of CFC-113 and methyl chloroform in five such cleaning applications:

- Cleaning Prior to Coating
- Cleaning Prior to Adhesive Bonding
- Cleaning Prior to Nondestructive Testing
- Cleaning Prior to Reassembly
- Cleaning Prior to Welding

METHODOLOGY FOR SELECTING AN ALTERNATIVE CLEANING PROCESS

In developing and selecting an alternative chemical or process for use in aircraft maintenance cleaning processes, a wide variety of criteria should be considered. These criteria can be broadly grouped into the following categories:

- Organizational
- Policy and Regulatory
- Technical
- Economic
- Environment, Health, and Safety

Organizational

The most important aspect of a corporate phaseout of ozone depleting substances (ODSs) is the commitment of the corporate management to such a program. Without such a commitment, a facility will be hard-pressed to successfully complete its phaseout. Important considerations which pertain to the corporate organization include:

- ***Compatibility with other corporate goals***. Corporate policy might disallow the use of particular solvents if the company is sensitive to public opinion. This would result from a corporate policy in which the opinions of the general public are to be considered in all decision-making.

- ***Compatibility with corporate environmental policy***. Some alternatives generate other forms of emissions, effluents, or wastes that are also the subject of corporate environmental goals.

- ***Feasibility given existing organizational structure***. Environmental concerns may already be the responsibility of a particular task force within the company. Some companies have made environmental performance a criterion for evaluating managerial performance.

- ***Willingness to provide capital***. Corporate management must be willing to make capital investments in new equipment in order to facilitate a phaseout of ODSs. They should understand that a capital outlay at the present time may result in significant cost savings in future years.

Policy and Regulatory

Any potential alternative chemical or process must be evaluated as to its compliance with a variety of government regulations and laws. At the very least, alternatives must comply with the mandates of the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer and its subsequent amendments. In addition, alternatives must meet with federal and local regulations which apply in the country in which the alternative is to be implemented. In the United States for example, alternatives must be evaluated in regards to several sections of the Clean Air Act Amendments of 1990, as well as strict regulations on emissions of volatile organic compounds (VOCs) in some metropolitan areas.

Technical

The technical feasibility of an alternative process must be evaluated on a case-by-case basis and is dependent on a number of important considerations. While these considerations will vary from facility to facility depending on location and function, a number of these considerations are universal in their applicability. Important criteria to consider when evaluating an alternative cleaning process for its technical adequacy include the following:

- Cleaning ability
- Compliance to specifications
- Material compatibility
- Effect on subsequent processes
- Process control
- Throughput of the cleaning process
- New process installation
- Floor space requirements
- Operating and maintenance require-ments.

Cleaning Ability

The degree of cleanliness required when cleaning a part varies from industry to industry and from process to process. In some metal cleaning applications, cleanliness requirements are less stringent in terms of measurable residue while in industries where critical components are being cleaned, requirements may be more stringent. Meeting cleanliness standards in the aerospace industry may require the removal of all contaminants. The high performance coatings and adhesives used on jet aircraft require, for example, a high degree of surface cleanliness to insure the integrity of the coatings.

The successful removal of contamination from a surface is not a property of the solvent alone, but a combined relationship of the cleaner, the substrate, the soils, and the cleaning conditions. Characteristics of the cleaner or solvent which greatly affect its cleaning ability include wetting, capillary action, detergency, solubility, and emulsification.

Several standard tests can be used to determine the cleaning ability of an alternative chemical or process. Some of these tests can be run on the shop floor (visuals, tissue paper, water break, and acid copper test), whereas other tests would have to be performed in a laboratory. Realizing that many aircraft maintenance facilities have limited, if any, laboratory facilities, the shop-floor tests become more important. Ultimately, the most important question to ask regarding any cleaning process is, "Will the part pass inspection?"

- ***Visual Examination.*** This test is useful only for visible contamination, but it can be done in a production/plant environment.
- ***Tissue Paper Test***. The cleaned surface is rubbed with white tissue paper and the tissue is observed for discoloration. This test is simple and can be done in the production/plant environment.
- ***Water Break***. If the last clean rinse forms a continuous water film on the part as it is removed, the surface can be considered clean.
- ***Acid Copper Test***. A ferrous panel is immersed in a copper sulfate solution. On clean surface areas, copper will be deposited by chemical activity, forming a strong adherent, semi-bright coating that is spot free.
- ***Atomizer Test***. Water mist is applied to a clean dry surface with an atomizer. The cleanliness is determined by the value of the advancing contact angle.
- ***Contact Angle of Water Drop***. A drop of water is placed on the test surface; the contact angle is then measured either photographically or by a contact angle goniometer. Although this is an accurate method of determining relative surface cleanliness, it can only be used under laboratory conditions. In addition, the presence of a surfactant on the test surface may result in a false reading.
- ***Kerosene Viewing of Water Break***. The test panel is withdrawn from water and is immediately submerged in a transparent container of kerosene that is lighted from the bottom. Water breaks are displaced by kerosene.
- ***Radioactive Tracer***. A radioactive soiling compound is applied to the test piece, and the residual radioactivity is measured after cleaning. This is the most sensitive of the quantitative tests now available. Use standard precautions when working with radioactive materials.
- ***Elemental Analysis***. A surface carbon determination is one of the most accurate methods of identifying small amounts of organic residues such as oils

remaining after the cleaning of metal parts. A test part is introduced into an electric resistance furnace and carbon dioxide is introduced at 958°F (500°C). Measurements are taken using a non-dispersive infrared analyzer (wave length = 4240 nm). The sensitivity is 0.01 mg/m^2 and the accuracy is 0.5 percent carbon content.

- ***Fluorescent Dye***. An oil soluble fluorescent dye is mixed with an oily soiling material and applied to the test panels. After the panels are cleaned, the retained soil is visible under ultraviolet or black light. Note that some cleaners may selectively remove tracer or fluorescent dyes.

- ***Gravimetric***. The test panels are weighed before and after cleaning. The sensitivity of the method depends upon the sensitivity of the balance and the size of the panel.

- ***Oil Spot***. A drop of solvent is used to degrease an area the size of the drop. The drop is picked up with a pipette and evaporated on ground glass. An evaporation ring indicates contamina-tion.

- ***Particulate Contamination***. A thin film of polyvinyl chloride is pressed against the test surface, heated to 240°F (115°C), and cooled. It is then carefully stripped from the surface and examined under the microscope. The particulate contaminants will be embedded in the vinyl sheet.

- ***Particle Removal Test***. Particle removal can be tested by artificially contaminating surfaces with known particles of various sizes down to and below the size of interest for removal. Precision particles from submicron to tens of microns in size can be obtained. Nephelometric methods and membrane filtration methods such as ASTM-F24 are useful low-cost techniques for evaluating general cleaning.

- ***Chemical Analysis***. Surface cleanliness can be evaluated and surface contaminants identified and quantified by using a number of analytical chemical techniques. The techniques most often used are Auger electron spectroscopy (AES), secondary ion mass spectroscopy (SIMS), x-ray photo-electron spectroscopy (XPS), and microscopic Fourier-Transform infrared spectroscopy (micro FT-IR).

- ***Optical Monitoring and Polarized Light Microscopy***. Visual inspection using microscopy is relatively inexpensive and gives fast results.

- ***End Use Tests.*** These tests can be conducted to examine the effect of cleaning on subsequent process steps such as the application of protective coating (some of these are discussed later in this section).

Compliance to Specifications

Standards and specifications often complicate the search for alternative chemicals or processes by requiring the use of a specific cleaner or solvent for a specific cleaning application. This is a particularly important consideration in the maintenance of military aircraft.

In instances where cleaning requirements are governed by military or other specifications, it is necessary to either verify compliance by using the indicated cleaners or solvents only, or renegotiate existing specifications before switching to alternative technologies. Types of specifications which apply directly to aircraft maintenance procedures include military specifications (milspecs), SAE/AMS (Society of Automotive Engineers/Aircraft Maintenance Standards) specifications, and ASTM (American Society for Testing and Materials) standards.

Material Compatibility

In the selection of an alternative process, material compatibility is as important as the cleaning ability of the cleaner itself. Issues to be considered include: the possibility for corrosion or chemical attack of metals, plastics, composites, and other sensitive materials; swelling or deformation of elastomers; and damage to coatings or adhesives present on the surface. In the aircraft industry, compatibility of materials is extremely important when dealing with surfaces of titanium alloys, high temperature superalloys, and/or composite materials.

Compatibility can be evaluated by performing a number of tests including:

- Stress corrosion (ASTM-G38) cracking (SCC) of parts can occur when susceptible materials (from which the parts are made) are corrosion sensitized during cleaning and are subsequently aged in a tension stress application, possibly with variations in temperature. In general SCC tests are run by subjecting a test specimen of the same composition and heat treatment as the part, to a constant tension stress load after being exposed to the corrosive medium. A number of ASTM test methods specify complete test details for specimen configuration and stress loading. See TM-01-69 MACE standard "Laboratory Corrosion Testing of Metals for the Process Industry."

- Total immersion corrosion (ASTM 483) testing evaluates the general corrosive attack of a cleaner which can cause unacceptable dimensional changes in a metal surface. A number of specifications describe variations on this test (MIL-C-87936, ASTM F483). Metal cleaners for aluminum and aluminum alloys can be evaluated in accordance with ASTM D930. Cleaners for all other metals can be evaluated using ASTM D1280. For example, the test can be conducted by completely immersing a tared specimen into the test solution so that there is no air/solution interface. The specimen is allowed to sit undisturbed for 24 hours after which it is removed, rinsed, dried, and reweighed. Corrosion is measured as weight loss or gain. The amount of allowable loss should be predetermined depending on the kind of material and use, but should be restricted to a few milligrams.

- Sandwich corrosion (ASTM F1110) testing measures the corrosivity of a cleaner confined between faying surfaces and periodically exposed to specified temperature and humidity conditions.

- Hydrogen embrittlement (ASTM F519-77) testing is conducted to determine if cleaners will adversely affect high strength steel. Testing can be conducted in accordance with ASTM F519, using both cadmium plated and unplated Type 1A steel specimens. The specimens are subjected to 75 percent of their ultimate tensile strength while immersed in the test solution. The specimens must not break for a minimum of 150 hours.

Effect on Subsequent Processes

Since cleaning is an integral part of manufacturing processes, it is critical to examine cleaning effectiveness and the effect of cleaners on subsequent manufacturing steps. The manufacturing steps in aircraft maintenance before which cleaning is usually considered necessary include:

- ***Inspection***. Visual inspections may be numerous, making speed and ease of part handling very important. Parts are cleaned to meet customer requirements and have to be inspected to identify any defects.

- ***Assembly***. Assembly requires that parts be free from inorganic and organic contaminants. The cleaning process should leave the parts clean and dry, ready for assembly, and/or subsequent finishing.

- ***Further Metal Working or Treatment***. In many instances, parts must be prepared for subsequent operations such as welding, heat treating, or further machining. Cleaning between steps allows the operator to start each new step with clean, dry parts. Before heat treatment, all traces of processing oils should be removed from the surfaces; their presence causes smoking, nonuniform hardening, and heat treatment discoloration on certain metals. Through heat treatment, residual contaminants can cause intergranular attack, and therefore the loss of fatigue strength, or stress corrosion mechanisms.

- ***Machining***. By starting a machining operation with a clean surface, the chance of carrying imperfect parts through to other operations is minimized. Cutting oils used during machining give best results when applied to clean surfaces.

- ***Application of Protective Coatings***. Cleaning is used extensively before and after the application of protective and/or decorative finishes. For example, surfaces cleaned before painting, enameling, or lacquering, give better adhesion of finishes. Similarly, cleaning is used to remove large amounts of oil contamination, prior to electroplating and passivation of ferrous metal alloys, and anodizing and chemical conversion coating of aluminum.

Potential residues remaining after cleaning with an alternative product or process must be evaluated for their compatibility with subsequent processes. This is especially important in cleaning prior to nondestructive testing (NDT) inspection.

Process Control

Process control is part of a quality assurance program. Being satisfied with a process is vital to a successful program. One example of good process control is checking cleaner solution composition on a routine basis. Maintaining proper solution concentration by making small, frequent additions is much more effective than making a few large additions. The proper automated chemical dispensing equipment, which can be activated by a timer or by conductivity of the solution, is a good method for control.

Throughput of the Cleaning Process

Although most of the cleaning processes associated with aircraft maintenance are not continuous processes, throughput can be an important parameter. For example, adhesion of finishes can be affected by moisture remaining on a surface to be coated. The rapid drying time associated with solvent cleaning provides an advantage in speeding up production processes. For batch cleaning processes, this factor may not be critical. Some alternative processes may require slower throughput for optimized operations along with special drying stages.

New Process Installation

The ease with which a solvent cleaning process using CFC-113 or MCF can be converted to or replaced by an alternative cleaning process will have a direct bearing on the choice of alternative. Issues associated with the installation of the new process include facility preparation, production/ service downtime, user awareness/education, qualification testing, and transition between the two processes. In some cases, wastewater treatment facilities may be required.

Floor Space Requirements

Equipment must be compatible with the plan and space constraints of the facility's manufacturing floor. A new process might require rearranging subsequent processes to optimize the floor plan. In many cases, alternatives take up more space than solvent cleaning processes. For example, compared to a single vapor degreaser, most aqueous cleaning processes include a minimum of two wash/rinse tanks and a drying device. The result often is an increase in the amount of floor space required. However, some cabinet spray washers are designed to wash, rinse, and dry in the same cabinet, thereby minimizing the need for multiple tanks. Rearranging existing equipment or installing a new process may also affect environmental permitting requirements.

Operating and Maintenance Requirements

Each new process may require a modification or rewriting of standard operating and maintenance procedures. In these cases, not only will there be the need to develop and test the new procedures, but special operator training may be needed to familiarize operators with the proper procedures associated with the new cleaning technologies.

Due to the fact that process parameters are likely to require more close control when substituting an alternative process, maintenance of process equipment on a regular basis is critical.

In some alternative processes, as the concentration of soils in the cleaning solution increases, parts may leave the cleaning solution with unacceptable amounts of residual soil. Regular monitoring, control of solutions, the use of filtration, and adequate post-rinsing/washing procedures must be considered.

Economic

Process economics is a key factor in the selection of alternative processes. Initial costs associated with an alternative process include capital costs of equipment, possible costs associated with waste treatment/handling equipment and costs for permit changes for new construction or new operating procedures. In addition, operating cost equations include material, labor, maintenance, and utility costs. Cost estimates for an alternative process can be developed through preliminary process design.

One simple approach is to calculate net present value (NPV) based on the discount rate and period of investment the company uses. The NPV is calculated as follows, where (n) is the number of years, and (i) is the discount rate.

$$NPV = Cost_{ø} + Cost_1/(1+i) + Cost_2/(1+i)^2 + ... + Cost_n/(l+i)^n$$

While traditional economic considerations such as rate of return and payback period are important, the CFC-113 and MCF reduction program can be justified on a basis of environmental protection and solvent supply reliability. It is important to recognize that the price of CFC-113 and

MCF will rise rapidly as the supplies are reduced and taxes are imposed. Because of the considerable difference in ozone-depleting potential, the price increases of CFC-113 and MCF will vary. Include the cost savings resulting from savings in solvent consumption in all cost calculations. Many of the alternative processes can be much less expensive than the current CFC and MCF processes being used.

Environment, Health, and Safety

Important environment, health, and safety issues to consider when evaluating an alternative cleaning process include:

- ***Compatibility with appropriate federal and local regulations***. Local regulations on ozone-depleting chemicals, VOCs, and waste effluent can be more stringent than their federal counterparts. For example, some areas have strict laws regulating the use of VOCs, while others have very few controls. In addition, there are often additional regulatory requirements which accompany the phaseout of ozone-depleting substances. For example, in addition to the phaseout requirements under the Clean Air Act in the United States, there are a number of provisions either in effect or which will go into effect over the next few years that will also impact the selection of alternatives. These provisions include Section 610: Nonessential Products Containing Chlorofluorocarbons, Section 611: Labeling, and Section 612: Safe Alternatives Policy. These and other provisions must be considered before selecting alternatives. In Europe, "Best available technology (BAT)" guidelines have been developed in order to control VOC emissions from solvent cleaning processes. These guidelines outline recommended equipment design and operating practices for use in cold cleaning, vapor degreasing, and "in-line" cleaning. The guidelines also address treatment and disposal of waste materials from solvent cleaning operations. This includes not only spent solvent, but contaminants such as solids and oils as well.

- ***Compatibility with regulatory trends.*** Since new environmental policy is emphasizing pollution prevention and risk reduction, it is prudent to move to cleaner products and processes that are less polluting, less energy-intensive, less toxic, and less dependent on raw materials.

- ***Public perceptions***. Legislation such as "right-to-know" laws has provided the public in many countries with more information about the chemicals used by specific plants and their associated risks. Public information has made plants more accountable to the concerns of neighboring communities.

- ***Potential of alternatives for ozone depletion and global warming***. Each potential alternative must be evaluated for its contribution to ozone depletion as well as global warming. In most cases, it will be considered unacceptable to replace a high ozone depletor with a nonozone-depleting substance that has a high global warming potential. The focus during the phaseout of ozone-depleting substances should be on finding substitutes which do not contribute significantly to other environmental problems.

- ***Energy efficiency***. The energy efficiency of an alternative cleaning process will have direct impacts on both the cost of maintaining a process as well as on the environment via global warming concerns.

- ***Effects on waste stream***. Some alternative cleaning processes will result in an increase in the amount of waste generated, while others will either decrease waste or produce a different type of waste. In any case, the phaseout of CFC-113 and MCF in cleaning operations will reduce or eliminate the need to dispose of spent solvent. However, processes such as aqueous cleaning, which are likely to be widely used in aircraft maintenance, will result in large amounts of wastewater which may need to be treated before being discharged to a POTW.

- ***Toxicity and Worker Safety***. Alternatives should minimize occupational exposure to hazardous chemicals where possible. Personal Exposure Limits (PELs) such as those determined by the Occupational Safety and Health Administration (OSHA) in the U.S. should be considered before selecting alternatives. Personal protective equipment, such as gloves, safety glasses, and shop aprons, should be reviewed for compatibility with alternative cleaners. Work procedures and practices should be reviewed and modified to accommodate the properties of the alternative cleaner. A toxicologist should also be consulted if the cleaner or cleaning process is new to the facility.

- ***Flammability***. Fire and explosion hazards are very important considerations. In some instances, changes in a material or process will require the review of fire protection engineers and insurance carriers . Flammability should be evaluated and adequate fire control measures should be implemented before switching to a cleaning process which involves potentially flammable substances.

* * * * *

In order to speed the process of evaluating potential alternatives, several large airlines in the United States have developed standardized forms to gather information on alternatives. On these forms, vendors of alternatives provide information including the following:

- chemical type
- chemical composition
- physical properties
- usage instructions
- customer approvals
- results of standard industry tests (ASTM, Douglas, Boeing)
- effects on aircraft materials
- health impacts
- safety procedures, and
- regulated contents.

For at least one of the airlines, an alternative will not be considered if the chemical data sheet is not completed in its entirety. At Continental Airlines, the completed datasheet is reviewed by representatives from engineering, safety, and environmental programs. If all approve the use of the product, it is then brought in for testing. The full "Chemical Qualification Sheet" used by Continental is presented in Appendix D.

QUALIFICATION TESTING OF ALTERNATIVE CLEANING PROCESSES AND MATERIALS

As mentioned in the previous section, there are a number of important items to consider in evaluating the acceptability of an alternative chemical or process. Perhaps the most important criteria in selecting an alternative is the qualification testing required by the aircraft manufacturers. This testing is vital to insure the safety of the aircraft and to avoid the possibility of future warranty and/or liability problems.

In many cases, the maintenance manuals for an aircraft will specify the exact type of cleaner to be used in a specific process. For instance, the Boeing 747 Maintenance Manual calls for the use of a mild alkaline cleaner in order to clean the exterior surface of the aircraft. While this does indicate that the specified cleaner or cleaning method is approved for use on the aircraft, it does not mean that the specified cleaner is the only acceptable product. Herein lies the opportunity for airlines to begin using alternative materials and processes.

In general, initiating a program to select alternatives, as well as the actual evaluation and selection process, is entirely the responsibility of each individual airline. While the aircraft and engine manufacturers do provide some guidance for performing product evaluations, most do not actively test and approve new cleaning materials and processes. Both Douglas Aircraft and the Boeing Corporation have stated this policy clearly in guidance documents distributed to all customers.

The Douglas Aircraft Company's Customer Service Document (CSD) #1 states that "Douglas will not test and approve maintenance chemicals for use on operational jet aircraft, as was done originally. The responsibility for approval of aircraft maintenance chemicals for use on Douglas manufactured aircraft is with the operator." Similarly, the Boeing Company's document D6-17487, which contains testing guidelines for alternatives, states that "the Boeing Company will not perform the tests described [in this document] for the airlines nor will the Boeing Company act as an intermediary between vendors and airlines. . . . The final selection of materials rests with the user." The full text of the Douglas and Boeing documents can be found in Appendices E and F, respectively.

In these documents, Boeing and Douglas have specified the testing procedures to be carried out in approving alternative cleaning chemicals and processes. For each manufacturer, a specific set of tests are required for each alternative chemical or process. The tests to be performed are dependent on the type of cleaner being evaluated, as summarized in Exhibits 7a and 7b.

Boeing gives step-by-step instructions for carrying out each of the required tests, while Douglas cites standard test methods approved by the American Society for Testing and Materials (ASTM). Both manufacturers give explicit details identifying materials to be used in the tests.

Both Boeing and Douglas stress that the selection of a substitute is the decision of the individual airline. Test results need not be submitted to the aircraft manufacturer for formal approval.

Exhibit 7a

QUALIFICATION TESTS RECOMMENDED BY BOEING

Certification Tests	Manual, Alkaline and Emulsion Cleaners and Liquid Waxes	Acid Brighteners and Corrosion Removers	Paint Strippers	Carbon Removers	Airplane and Facility Deicers	Toilet Flushing Fluids
Sandwich Corrosion Test	X		X[1]	X	X	X
Immersion Corrosion Test			X[1]	X		
Acrylic Crazing Test	X	X		X	X	
Polycarbonate Crazing Test						X
Elastomer Degradation Tests						X
Tape Adhesion Tests						X
Paint Softening Tests	X	X		X	X	X
Hydrogen Embrittlement Test	X		X	X	X	

[1] Materials meeting MIL-R-25134 need not be tested for corrosion.

Exhibit 7b

QUALIFICATION TESTS RECOMMENDED BY DOUGLAS

Qualification Test	I General Purpose Cleaner	II Carbon Exhaust Remover	III Paint Remover	IV Deoxidizer/Brightener	V Polishes	VI Deicing Compounds
Effects on Painted Surface	X	X	-	-	-	X
Residue	X	X	-	-	X	X
Sandwich Corrosion	X	X	X	X[1]	X	X
Stress Crazing of Acrylic Plastic	X	-	-	X	X	X
Immersion Corrosion, Aluminum	X	X	X	X	X	X
Hydrogen Embrittlement	X	X	X	-	X	X
Cadmium Removal	X	X	X	-	-	X

[1] Test chemical conversion coated aluminum only (P/W 7452876-7, -11, -15), slight etching of the aluminum surface is acceptable.

REVIEW OF EXISTING PROGRAM

The following sequence of activities should be performed to develop a maintenance cleaning program that eliminates the use of CFC-113 and MCF:

- Determine where and why CFC-113 and methyl chloroform are consumed in aircraft maintenance cleaning operations;
- Characterize existing cleaning processes. This activity will help reveal how cleaning integrates with other manufacturing processes and determine whether cleaning is necessary;
- Characterize current solvent material and process control methods, operating procedures and disposal practices and determine the sources of any solvent losses. This step will help identify "housekeeping" measures to reduce solvent consumption at little or no net cost to the facility;
- Characterize the substrate materials being cleaned. This step includes identifying the type and geometry of materials being cleaned;
- Characterize the soils and their sources;
- Establish criteria that must be considered before selecting an alternative cleaning process. These criteria include organizational, policy, technical, economic, environment, health, and safety issues; and
- Evaluate and perform qualification testing of alternative chemicals and processes. These tests will be required to gain aircraft and engine manufacturers' approval of the alternatives.

These steps will provide a better understanding of cleaning needs, allow for the elimination and/or consolidation of certain cleaning operations, and develop a systematic procedure for selecting an alternative cleaning process. With this understanding, the next section describes some major alternative processes to solvent cleaning using CFC-113 and methyl chloroform.

ALTERNATIVE MATERIALS AND PROCESSES

Alternative cleaning materials and processes and alternative solvents to eliminate CFC-113 and MCF are now available for standard aircraft maintenance practices. The choice of an alternative depends on a variety of factors, including the cleanliness required and economic, technical, health, safety, and environmental issues.

It may also be possible to reduce and/or eliminate deposition of soils which require cleaning, allowing the use of a less aggressive cleaning method. Therefore, the conversion to an alternative cleaning process may be made simpler by evaluating the ability to reduce contamination.

The following sections describe the major advantages, disadvantages, and key process details associated with the most promising alternatives.

These technologies should be evaluated on a case-by-case basis. A list of vendors and references at the end of this manual may be a useful source of additional information. The following alternatives are addressed in this manual:

"Good Housekeeping" Practices

Alternative Cleaning Processes:

- Aqueous
- Semi-Aqueous

Alternative Solvents:

- Aliphatic Hydrocarbons
- Chlorinated Solvents
- Organic Solvents
- Hydrochlorofluorocarbons (for essential applications)

Other Cleaning Techniques:

- Perfluorocarbons
- Supercritical Carbon Dioxide
- Media Blasting

"GOOD HOUSEKEEPING" PRACTICES

As previously mentioned, one of the primary components of a successful phaseout strategy is the identification of uses of the solvent to be eliminated. An accurate picture of solvent usage will allow the phaseout team to focus its efforts on those areas where large quantities of solvent are used and where alternatives are readily available. This solvent use characterization can also be used to decrease consumption immediately through the classification of uses as either legitimate and improper uses.

Many of the aircraft maintenance applications in which CFC-113 and MCF are being used in a facility are neither necessary nor intended uses. When these substances were introduced to the facility years ago, they were intended for specific applications. However, their excellent cleaning ability, coupled with the availability of these solvents, has often resulted in their abuse.

One method of significantly reducing a facility's usage of CFC-113, and especially MCF, is the implementation of "good housekeeping" measures. These measures should be designed to limit use of these substances to applications for which they are intended, and to eliminate their use in other convenience applications. The first step in this "good housekeeping" procedure is the identification of all uses of the solvents.

Use of CFC-113 and MCF should be evaluated using surveys, shop inspections, and whatever additional means are necessary. The resulting data should be cataloged so that it can be compared with future data. Computerizing the cataloging system may make tracking usage patterns easier in the long run.

Once the survey of current uses is completed, the solvent substitution team should evaluate each of the uses to determine whether or not the solvent being used was intended for use in that application. In cases where it is decided that the solvent was not meant to be used in a specific application, this usage should be eliminated immediately and replaced with the originally intended solvent or cleaning process. Investigations should also be conducted to learn how CFC-113 or MCF came to be used for the unintended application. The results of this investigation should help to prevent the same problem from occurring in other applications or with other chemicals.

After the cataloging system is in place, arrangements can be made to monitor and log all future purchases and dispersements of CFC-113, MCF, and all other solvents. Airlines using an approach such as this have had substantial success in controlling their consumption not only of ozone-depleting solvents, but of other solvents as well, thereby experiencing significant cost savings. One major airline in Europe has reported a reduction in CFC-113 and MCF usage of more than 50 percent through "good housekeeping" measures alone.

AQUEOUS CLEANING

Aqueous cleaners use water as the primary solvent. They often incorporate surfactants and builders with special additives such as pH buffers, corrosion inhibitors, saponifiers, emulsifiers, deflocculants, complexing agents, antifoaming agents, and other materials. These ingredients can be formulated, blended, and concentrated in varying degrees to accommodate the user's cleaning needs. Exhibit 8 presents an overview of the advantages and disadvantages of aqueous cleaning.

Since the discovery that CFC-113 and MCF were contributing to depletion of ozone in the stratosphere, many aircraft maintenance facilities have switched to alternative cleaning processes. Many of the cleaning procedures which previously used CFC-113 and methyl chloroform can and have been satisfactorily converted to aqueous cleaning.

In order to implement an aqueous cleaning process, there are several factors to consider. These include the cleaning ability of the cleaning solution, the compatibility with aircraft materials, the equipment needed to conduct the cleaning operations, and worker safety. The optimum selection of chemistry and equipment will dictate the efficiency of the overall cleaning process.

Process Chemistry

Aqueous cleaners are made up of three basic components: (1) the builders which make up the largest portion of the cleaner and create stable soil emulsions once soils are removed from a surface, (2) the organic and inorganic additives which promote cleaning and cleaner stability, and (3) the surfactants and wetting agents which are the key constituents and remove or displace soils from surfaces and initiate the emulsification process. As noted earlier, aqueous cleaners can be tailored to meet specialized cleaning needs.

Builders are the alkaline salts in aqueous cleaners. They are usually a blend selected from the following groups: alkali metal orthophosphates and condensed phosphates, alkali metal hydroxides, silicates, carbonates, bicarbonates, and borates. A blend of two or more of these builders is typical in most aqueous cleaners.

Although phosphates are the best overall builders, discharge of cleaning solutions containing phosphates is often subject to environmental regulations, thereby limiting their use. Chelating agents such as the sodium salt of ethylenediamine tetra acetic acid (EDTA) and gluconates can be used instead of phosphates. Silicates are sometimes difficult to rinse and may cause trouble in subsequent plating operations if not completely removed. They may also cause fouling in process equipment such as filters and pumps. Hydroxides are effective on difficult soils. They saponify effectively because of their high pH. Carbonates are an inexpensive alkaline source but are less effective builders than the phosphates.

Additives can be either organic or inorganic compounds and provide additional cleaning or surface modifications. Glycols, glycol ethers, chelating agents, and polyvalent metal salts, are common additives.

Surfactants are organic compounds that provide detergency, emulsification, and wetting in alkaline cleaners. Surfactants are unique because of their characteristic chemical structure. They have two distinct structural components attached together as a single molecule. The hydrophobic half has little attraction for the solvent (water) and is insoluble. The other half is hydrophilic and is polar, having a strong attraction for the solvent (water) which carries the molecule into solution. Their unique chemical structure provides high affinity for surface adsorption. Surfactants are classified as anionic, cationic, nonionic, and zwitterionic (amphoteric). Their use reduces the surface tension of water,

Exhibit 8

AQUEOUS CLEANING

ADVANTAGES

Aqueous cleaning has several advantages over organic solvent cleaning.

- Safety -- Aqueous systems have fewer worker safety problems compared to many solvents. They are not flammable or explosive. Consult material safety data sheets for information on health and safety.
- Cleaning -- Aqueous systems can be designed to clean particles and films better than solvents.
- Flexibility -- Aqueous systems have multiple degrees-of-freedom in process design, formulation and concentration. This freedom helps aqueous cleaning provide superior cleaning for a wider variety of contamination.
- Removal of Inorganic or Polar Soils -- Aqueous cleaning is particularly good for cleaning inorganic or polar materials. Many machine shops are using water-based lubricants and coolants to replace oil-based lubricants for environmental and other reasons. Water-based lubricants are well suited to aqueous cleaning processes.
- Oil and Grease Removal -- Organic films, oils, and greases can be effectively removed by aqueous chemistry.
- Multiple Cleaning Mechanism -- Aqueous cleaning functions by several mechanisms rather than just dissolution. These include saponification (chemical reaction), displacement, emulsification, dispersion, and others. Particles are effectively removed by surface activity coupled with the application of mechanical energy.
- Ultrasonics Applicability -- Ultrasonics are much more effective in water-based solvents than in CFC-113 or MCF solvents.
- Material and Waste Disposal Cost -- Aqueous cleaning solutions are generally less expensive than solvents and, when properly handled, will reduce waste disposal costs.

DISADVANTAGES

Depending upon the specific cleaning application there are also disadvantages.

- Cleaning Difficulty -- Parts with blind holes, small crevices, tubing, and honeycomb structures may be difficult to clean and/or dry, and may require process optimization.
- Process Control -- Solvent cleaning is a very forgiving process. To be effective, aqueous processes require careful engineering and control.
- Rinsing -- Some aqueous cleaner residues, particularly from surfactants, can be difficult to rinse. Trace residues may be detrimental for some applications and materials. Special caution should be taken for parts requiring subsequent vacuum deposition, liquid oxygen contact, etc. Rinsing can be improved using DI water or alcohol rinse.
- Drying -- It may be difficult to dry tubing and certain part geometries with crevices and blind holes. Drying equipment is often required.
- Floor Space -- In some instances aqueous cleaning equipment may require more floor space.
- Capital Cost -- In some cases, new facilities will need to be constructed.
- Material Compatibility -- Corrosion of metals or delayed environmental stress cracking of certain polymers may occur.
- Water -- In some applications high purity water is needed. Pure water can be expensive.
- Energy Consumption -- Energy consumption may be higher than solvent cleaning if applications require heated rinse and drying stages.
- Wastewater Disposal -- In some instances, wastewater may require treatment prior to discharge.

allowing it to penetrate into tightly spaced areas where water could not otherwise reach.

The use of a nonfoaming cleaner is extremely important in alkaline cleaning applications performed using a spray technique.

Nonionic surfactant is generally the only type of surfactant that results in minimum foaming and provides good detergency. Therefore, it is often used in spray applications. All types of surfactants can be used for immersion cleaning, although cationic surfactants are rarely used.

Process Equipment

Typical aqueous cleaning equipment can be classified in two general categories: in-line and batch. In-line equipment is generally highly automated and allows for continuous processing of the product being cleaned. Batch cleaning requires that operators load and unload the cleaning equipment after each cycle is completed. Given equal cleaning cycle times, in-line cleaners allow for a significantly higher throughput than batch cleaners.

The in-line and batch equipment can be further classified according to the method by which the cleaner is applied to the part to be cleaned. The three basic methods of aqueous cleaning are immersion, spray, and ultrasonic. Exhibit 9 presents an overview of the advantages and disadvantages of these three types of equipment.

Immersion equipment cleans by immersing parts in an aqueous solution and using agitation or heat to displace and float away contaminants. Agitation can be either mechanical or ultrasonic.

Spray equipment cleans parts with a solution sprayed at medium-to-high pressure. Spray pressure can vary from as low as 2 psi to 400 psi or more. In general, higher spray pressure is more effective in removing soil from metal surfaces. Aqueous cleaners which are specifically designed for spray application are prepared with low foaming detergents.

The spray design should be able to reach all part surfaces by mechanically manipulating the part or the spray nozzles. Although spray cleaning is effective on a wide variety of parts, some part configurations may be difficult to clean using currently available spray technology.

A high pressure spray is an effective final rinse step. Pressures may range from 100 psi in noncritical applications to 500 - 2000 psi in critical applications. Optimization of nozzle design such as spray pattern, drop size and formation, pressure/velocity, and volume have a major impact on effectiveness. A final spray is much cleaner than an immersion rinse, since the water spray contacting the part can be highly pure and filtered.

Ultrasonic cleaning equipment works well with water-based processes. Because the cavitation efficiency is higher for water than for CFC-113 and MCF, the removal of particles from surfaces is usually more effective in aqueous versus organic solvent media. Process design requires caution to insure that cavitation erosion of part surfaces is not a problem. Certain part geometries are also sensitive to ultrasonic agitation.

It is important to optimize system operations when using ultrasonic systems. Since good ultrasonic cleaners have few standing waves, reflection from the surface and the walls is an important consideration. The number of parts and their orientation to walls, fixtures, and other parts will impact cleaning performance. The fixturing should be low mass, low surface energy, and nonabsorbing cavitation resistant material such as a stainless steel wire frame. Avoid using plastics for fixtures because of leaching and absorption of sonic energy.

Both ultrasonic and spray equipment can be used together to great advantage, especially in rinsing. Low pressure (40-80 psi) spray at relatively high volumes is good for initial rinsing. It is critical to keep the part wet at all times prior to final drying. A secondary immersion-ultrasonic rinse is especially useful for parts with complex geometry or blind holes.

In some instances final rinsing with DI water or an alcohol, such as isopropanol, can remove residues and prevent water spots.

Exhibit 9

AQUEOUS CLEANING PROCESS EQUIPMENT

	IMMERSION WITH ULTRASONIC AGITATION	IMMERSION WITH MECHANICAL AGITATION	SPRAY WASHER
ADVANTAGES	High level of cleanliness; cleans complex parts/ configurations Can be automated Usable with parts on trays Low maintenance May be performed at ambient temperature	Cleans complex parts and configurations Will flush out chips Simple to operate Usable with parts on trays Can use existing vapor degreasing equipment with some modifications.	High level of cleanliness Inexpensive Will flush out chips Simple to operate High volume Spray unit may be portable
DISADVANTAGES	High cost Requires rinse water for some applications Requires new basket design Limits part size and tank volumes May require separate dryer	Requires rinse water for some applications Harder to automate Requires proper part orientation and/or changes while in solution May require separate dryer	Requires rinse water for some applications Not effective in cleaning complex parts May require separate dryer

Process Details

Aqueous cleaning in aircraft maintenance procedures is currently performed using both large- and small-scale immersion and spray cleaning techniques. Many products are cleaned individually due to their large size, although some batch cleaning does take place. In addition to immersion and spray equipment, aqueous cleaning in aircraft maintenance is performed by manual wiping or scrubbing.

The aqueous cleaning procedure used in aircraft maintenance consists of three general process steps:

- Wash Stage
- Rinse Stage
- Dry Stage

The following is a description of the stages which make up the aqueous cleaning process.

Wash Stage. The wash stage in an aqueous cleaning process refers to the application of a water-based cleaner, often mixed with detergents and surfactants. In aircraft maintenance procedures, the method of cleaner application is primarily dependent on the part or surface being cleaned.

Relatively small assemblies which have been removed from the aircraft can be immersed in a tank which contains the cleaning agent. Often this solution will be heated to improve cleaning. Parts which are too large for immersion tanks may be cleaned using a spray washer. If immersion tanks are used, contamination build-up in the cleaning solution must be monitored. When the level of contamination becomes too high, the cleaner should be treated and reused or disposed of.

Surfaces which are cleaned without removal from the aircraft include the fuselage and flight control surfaces. These are usually cleaned manually by wiping, brushing, or low-pressure spray.

In the manual wipe process, the cleaner is applied to the surface using a cloth wipe or a small mop which has been soaked in the cleaner. In the low-pressure spray technique, the cleaner is applied with a small, portable spray gun. In most cases, manual wiping is substantially more time consuming than immersion and spray washing techniques.

Rinse Stage. The rinse stage of aqueous cleaning removes all of the cleaning solution applied during the wash stage from the part being cleaned. As the cleaner is removed, all of the contaminants which have been displaced and/or solubilized are also removed from the part. The rinse is often performed using water with no additives or, in some cases, deionized water. However, rinse aids are sometimes added to water to cause the water to form a sheet rather than "bead up." This sheeting action reduces water spots and aids in quicker, more uniform drying.

The rinse processes in aircraft maintenance are identical to those employed in the wash stage - immersion, spray, or wipe. In any case, the result should be a clean surface. In some cases, several rinse stages are required.

Dry Stage. The dry stage is a vital part of any aqueous cleaning process. In aircraft maintenance cleaning, special attention must be paid to ensure that all water is removed from parts before reassembly. A failure to remove water can result in the water freezing when the aircraft reaches high altitudes. This freezing can in turn cause excessive stress on the aircraft, possibly resulting in cracking.

There are five drying methods currently employed with aqueous cleaning in the aircraft industry. The first is the use of a drying oven. These units evaporate excess water through the application of heat and can accommodate a wide variety of parts. Ovens can only be used for parts which have been removed from the body of the aircraft. The second drying option is a manual wipe with a dry cloth or mop to absorb the excess water from the clean part. This method will not be adequate for parts with small crevices and/or closely spaced components since a cloth or mop may not be able to fit within the small spaces in which water may be trapped. A third method for the removal of excess water is forced air drying. In this method, hot air is blown onto the cleaned part to force water off the part. Applications where the air is blown at an angle of approximately 45° are known as air knives. A fourth method for drying parts after cleaning is the use of dewatering oils. These oils, when placed on a cleaned surface, displace moisture and provide a thin film preservative on the part. As an alternative to these four drying methods, some aircraft maintenance facilities choose to let the cleaned parts dry in air. Given enough drying time, all residual water should evaporate, leaving a clean, dry part. This time, however, can be quite lengthy and may slow the repair or overhaul process. In addition, air drying increases the risk of corrosion and may leave residual salts from evaporation on the component.

Other Process Details

There are at least three additional process details which will influence a facility's decision regarding the feasibility of aqueous cleaning.

Removal of Cleaning Fluids. Care should be taken to prevent cleaning fluids from becoming trapped in holes and capillary spaces. Low surface tension cleaners sometimes penetrate spaces and are not easily displaced by a higher surface tension, pure water rinse. Penetration into small spaces is a function of both surface tension and capillary forces.

Wastewater Issues. One of the major drawbacks associated with the use of aqueous cleaning is the fact that wastewater treatment may be required prior to discharging spent cleaner and rinse water. In some applications the cleaning bath is changed infrequently and a relatively low volume of wastewater is discharged. In others, the water can be evaporated to leave only a small volume of concentrated waste for recycling. Due to the size of most maintenance facilities, and the large number of parts to be cleaned, extensive use of aqueous cleaning could result in substantial wastewater treatment needs. The wastewater treatment process must also account for the wide variety of soils cleaned from aircraft surfaces and assemblies. Facilities considering a switch to aqueous cleaning should consult with their local water authorities to determine the need for pre-treatment of wastewater prior to discharge.

Water Recycling. Recycling or regeneration of the cleaner/detergent solution is feasible and should be considered. This can be accomplished using a combination of oil skimming techniques, coalescing separators, and ultrafiltration (e.g., ceramic membranes). Vendors of aqueous cleaners sometimes pick-up spent cleaner from customers, recycle it, and re-sell it.

SEMI-AQUEOUS CLEANING

Semi-aqueous cleaning involves the use of a nonwater-based cleaner with a water rinse. It is applicable to electronics, metal, and precision cleaning processes, although it is most frequently used in metal cleaning. Semi-aqueous cleaners can consist of a wide variety of chemical constituents. Examples of semi-aqueous cleaning formulations are hydrocarbon/surfactant mixtures, alcohol blends, terpenes, and petroleum distillates. Semi-aqueous cleaning is used in many aircraft maintenance facilities, though not to the extent of aqueous cleaning.

The advantages of semi-aqueous cleaning solutions include the following:

- Good cleaning ability; typically superior to aqueous cleaning for heavy grease, tar, waxes, and hard-to-remove soils;
- Compatible with most metals and plastics;
- Suppressed vapor pressure (especially if used in emulsified form);
- Non-alkalinity of process prevents etching of metals, thus helping to keep metals out of the waste stream and minimizing potential adverse impact to the substrate;
- Reduced evaporative loss;
- Potential decrease in solvent purchase cost;
- A rust inhibitor can be included in the formulation to protect parts from rusting.

Drawbacks associated with the use of semi-aqueous cleaning processes include:

- Rinsability problems; thus residues may remain on the part;
- Disposal of spent solvent after water recycling may increase costs;
- Flammability concerns, particularly if a concentrated cleaner is used in a spray application. However, the flammability issue can be solved with proper equipment design;
- Some cleaners have objectionable odors;
- Some of the cleaners are VOCs;
- Drying equipment may be required in some applications;
- Some cleaners can auto-oxidize in the presence of air. One example of such a cleaner is d-limonene (a terpene hydrocarbon isomer). This can be reduced using an antioxidant additive;
- Some constituents pose potential exposure risks to workers. For example, ethylene glycol methyl ether has displayed evidence of potential risk in laboratory animals.

Process Equipment

The equipment normally used in a typical semi-aqueous cleaning process is similar to that used in aqueous applications: immersion equipment, spray equipment, and cloths/mops for manual cleaning. Manual cleaning, however, is not extensively practiced in the aircraft maintenance industry using semi-aqueous cleaners.

While equipment which has been designed specifically for use with concentrated semi-aqueous cleaners is available, some vapor degreasing units can be modified to become an immersion wash tank. However, a rinse tank will also usually be required.

Immersion equipment is still the simplest method of cleaning parts and/or assemblies which can be removed from the aircraft. The primary distinction from aqueous immersion cleaning is that, due to the high solvency of hydrocarbon/surfactant blends, less mechanical energy may be required to achieve a satisfactory level of cleanliness. However, to achieve a higher level of cleanliness, agitation must be added to the process, either mechanically or with ultrasonics, or the cleaning solution must be heated.

As with aqueous cleaning, a mechanical spray can improve the cleaning performance of the semi-aqueous cleaning solution. It is important to note that, if a spray is used with a concentrated hydrocarbon/surfactant blend, the atomized solution is prone to combustion and special care must be taken to prevent fire risks. One such prevention measure is the use of a nitrogen blanket which displaces oxygen from the spray chamber, thereby reducing fire risk.

One semi-aqueous cleaning option, called "spray-under immersion," combines both immersion and spray cleaning techniques. In this equipment, high pressure spray nozzles are placed below the surface of the liquid. This prevents the formation of atomized solution and decreases flammability. Mechanical agitation, workpiece movement, and at properly designed ultrasonic agitation may also be used.

Process Details

Just as the equipment used in semi-aqueous cleaning processes is similar to that used in aqueous cleaning, so too are the cleaning stages. The semi-aqueous cleaning process consists of a wash stage, a rinse stage, and a dry stage.

There are two primary differences between the aqueous and semi-aqueous cleaning processes. The first is the cleaner which is used in the wash stage. As mentioned, rather than the simple detergent and water mixture used in aqueous cleaning, semi-aqueous processes make use of any one of a number of cleaning agents, including hydrocarbons, alcohols, and terpenes.

The second difference lies in the addition of a second wash stage after the initial wash in the cleaner. In many cases, the initial cleaning stage may be followed by an emulsion wash stage.

In the wash step, the cleaner is applied to the part being cleaned with some form of mechanical energy. However, due to the fact that semi-aqueous cleaners generally have higher solvency power than aqueous cleaners, less mechanical energy is usually needed to achieve an acceptable level of cleanliness.

Low flash point hydrocarbon/surfactant cleaners are generally not heated; however, some are slightly warmed when the cleaner is used in a diluted form. High flash point hydrocarbon/ surfactant cleaners may be heated to within 20-30°F (-7 - -1°C) of their flash point to remove difficult soils. Cleaners that are ignitable should not be used in vapor or spray cleaning without an inert atmosphere or other protective equipment. In addition, application methods that avoid misting, such as spray-under immersion or ultrasonics, should be used.

Many semi-aqueous processes include an emulsion stage after the initial wash and before the rinse stage. In this stage, the part is immersed in an emulsion which further cleans the part and helps to remove soils from the part's surface. This step results in less contamination of the rinsewater, making recycling of the rinsewater easier than it would be otherwise. The emulsion cleaner is sent to a decanter where the soils are removed from the cleaner. The cleaner can then be reused in the emulsion wash.

A rinse with clean water removes the residues left by the wash step(s). The rinse step is necessary when concentrated cleaners are used because of their low volatility (which prevent them from evaporating from the parts cleaned in the wash stage). However, the rinse step may not be necessary when a dilute hydrocarbon emulsion is used, provided the level of cleanliness needed does not require removal of the residue from the wash stage. In some instances, a fast evaporating alcohol is used as a final rinse step. The rinse step may also serve as a finishing process and, in some instances, is used to apply rust inhibitors to the parts.

The drying step serves the same function as in aqueous cleaning. The removal of excess water from the part prepares it for further processing, prevents it from rusting, and reduces the possibility of cracks forming in the aircraft due to frozen water. The same types of drying methods used in aqueous cleaning -- heat, forced air, manual wipe, dewatering oils, ambient air drying -- are also used in semi-aqueous processes.

Another similarity between aqueous and semi-aqueous processes is the possible need for wastewater treatment. In order to avoid processing excessive quantities of wastewater, some maintenance facilities may choose to recycle their spent cleaners. Some currently available semi-aqueous cleaners can be easily separated from the rinse water. This allows the rinse water to be recycled or reused. The waste cleaner can then be burned as fuel.

ALIPHATIC HYDROCARBONS

There is a wide range of aliphatic hydrocarbon solvents that can be used in aircraft maintenance cleaning (see Exhibit 10). At the present time, many aircraft manufacturers recommend the use of several of these solvents in cleaning applications detailed in maintenance manuals. The current use of these solvents in routine aircraft maintenance is widespread.

Petroleum fractions, commonly known as mineral spirits or kerosene, are used extensively in maintenance cleaning (e.g., auto repair). These substances are derived from the distillation of petroleum. They are used in single-stage cleaning operations in open-top equipment using ambient air drying. Synthetic aliphatic hydrocarbons, which offer closer control of composition, odor, boiling range, evaporation rate, etc., are employed in OEM cleaning processes as well as in maintenance operations.

The advantages of aliphatic hydrocarbon cleaners include:

- Superior cleaning ability for a wide variety of soils, especially heavy grease, tar, waxes and hard to remove soils. This makes them especially useful in aircraft cleaning where a variety of lubricants and grime are removed from surfaces. Low surface tension allows good penetration into areas with closely spaced parts or components.

- Compatible (non-corrosive) with most rubbers, plastics and metals.

- They employ no water and can therefore clean water-sensitive parts.

- Low odor and low toxicity grades are available.

Exhibit 10

PROPERTIES OF ALIPHATIC SOLVENTS

PRODUCT	Lb./Gal. 60°F	Sp. Gr. 60°/60°F	Boiling Range °F	Fl. Pt. °F TCC	Evap. Rate[1]
Mineral Spirits	6.37	0.764	305-395	105	0.1
Odorless Mineral Spirits	6.33	0.760	350-395	128	0.1
Stoddard Solvent	6.47	0.796	320-369	107	0.2
140 Solvent	6.54	0.786	360-410	140	0.1
C10/C11 Isoparaffin	6.25	0.750	320-340	107	0.3
C13 N-Paraffin	6.35	0.760	320-340	200	0.1
C10 Cycloparaffin	6.75	0.810	330-360	105	0.2
Kerosene	6.60	0.790	330-495	130	-

[1] n-Butyl Acetate=1

Note: Fl. Pt. = Flash Point; Sp. Gr. = Specific Gravity

- Some products are available with flash points greater than 200°F.
- Reduced evaporative loss.
- No wastewater is produced.
- Waste streams from those products with flash points greater than 140°F may be classified as nonhazardous.
- Synthetic aliphatic hydrocarbons are not regulated as hazardous air pollutants under the Clean Air Act.
- Recyclable by distillation. High stability and recovery.

The disadvantages include:

- Flammability concerns. However, these concerns can be mitigated with proper equipment design.
- Slower drying times than CFC-113 and MCF.
- VOC control may be required.
- Some grades have low Occupational Exposure Limits.
- Odors may cause some worker discomfort.

The steps in a typical aliphatic hydrocarbon cleaning process are analogous to those for aqueous or semi-aqueous processes. Equipment designs for use with aliphatic hydrocarbons are modified aqueous equipment designs, primarily to account for flammability and VOC concerns.

The major steps in the cleaning process are typically:

- Wash steps (1 to 3 stages depending on degree of cleaning needed) with an aliphatic hydrocarbon cleaner;
- Drying step, often using forced air;
- VOC emission control by destruction or recovery from solvent laden air, if required; and
- Waste solvent recovery and/or disposal.

The wash steps involve liquid-phase cleaning at temperatures sufficiently below the flash point of the fluid. Ultrasonics or other agitation processes such as immersion spraying can be used to augment cleaning action. Spraying or misting processes, where fine droplets are formed, should be employed only in an inert environment or with equipment with other protection against ignition conditions. This protection is required because fine droplets can ignite at temperatures below bulk fluid flash point.

Fluids with flash points near 104°F (40°C) should be operated in unheated equipment, at ambient temperatures. For higher flash points, hot clean-ing can be employed to boost cleaning action. For systems with good temperature control (indepen-dent temperature sensors, cutouts, level indicators, etc.), a safety margin of 59°F (15°C) between the fluid flash point and the cleaning temperature is recommended. Obviously, use of a high flash point solvent will greatly reduce the risk of fire. For systems with poor temperature control, a larger margin should be employed.

Each wash step should be followed by a drain period, preferably with parts rotation, to minimize solvent dragout from stage to stage.

In multistage processes, fluid from one bath is periodically transferred to the preceding bath as its soil level builds up. Fresh solvent is added only to the final bath to ensure the highest cleanliness of parts, and spent solvent is removed only from the first stage.

The drying step normally uses forced air, which may be heated. If the dryer is not operating at 59°F (15°C) below the flash point of the fluid, sufficient air flow should be provided so that the effluent air composition is well below the Lower Explosive Limit of the system.

Where required, the VOC recovery step is an important part of the cleaning process. Depending on the solvent chosen, either carbon adsorption or condensation are the best technologies for capturing solvent vapors from spent drying air. Numerous vendors market this type of recovery equipment. In some cases, however, the VOC concentration in the air may be too low to facilitate recovery and catalytic incineration may be required to destroy the VOCs.

In the waste recovery area, the best reclamation technology for these products is usually filtration and distillation. One of the advantages of some of the aliphatic hydrocarbon solvents with few impurities and narrow distillation range is that the recovery in distillation is high. Should some disposal of residual solvent be necessary, fuel substitution or incineration are good routes.

OTHER CHLORINATED SOLVENTS

One of the most appealing substitutes for CFC-113 and MCF in terms of process details is the use of another chlorinated solvent which does not contribute to ozone-depletion. The solvents normally used in cleaning applications are trichloroethylene, perchloroethylene, and methylene chloride. While these substances are ideal due to the fact that they are used in vapor degreasing applications, as are CFC-113 and MCF, they may have significant health and environmental impacts which, if not properly addressed, make their use less attractive.

These three cleaning solvents have undergone extensive testing in recent years for safety, health, and environmental impacts. As a result of this testing, two of the solvents -- trichloroethylene and perchloroethylene -- have been classified as VOCs and hazardous air pollutants in the U.S. (although the U.S. EPA has recently proposed that perchloroethylene be exempted from regulation as a VOC). This classification has significant implications for their use in the U.S. since it requires that emissions control measures be employed and extensive records be kept when using these solvents.

In addition to these environmental impacts, two of the nonozone-depleting chlorinated solvents have been shown to be carcinogenic to animals in extensive toxicity testing. This discovery has prompted the International Agency for Research on Cancer to classify both perchloroethylene and methylene chloride as "possibly carcinogenic to humans." In addition, many governments have set very low permissible worker exposure limits for all three chlorinated solvents. The U.S. Occupational Safety and Health Administration (OSHA) has set worker exposure limits at 100 parts per million (ppm) for perchloroethylene and trichloroethylene, and 500 ppm for methylene chloride. A proposal has been submitted to lower the permissible exposure limit (PEL) for methylene chloride to 25 ppm.

Chlorinated solvents are subject to hazardous waste regulations in some areas, including the U.S. where they are covered under the Resource Conservation and Recovery Act (RCRA). Users of these solvents must be aware of and comply with all regulations governing use, storage, and disposal of these materials.

Despite the many possible environmental and safety effects associated with the use of chlorinated solvents, they are feasible substitutes for CFC-113 and methyl chloroform in aircraft maintenance cleaning provided adequate control measures are used. These controls must include use in a tight vapor degreaser which is equipped with a cover, increased freeboard, and freeboard chillers. The controls will help to limit emissions of the solvent vapor. These controls are similar to those described and diagramed in the discussion of HCFCs. Exhibit 11 summarizes the solvent properties of these other chlorinated solvents.

Dry cleaning operations are one application in which chlorinated solvents are being widely substituted for CFC-113. Perchloroethylene has been used for years in commercial dry cleaning operations and is now being adopted by airlines for use on seat covers and draperies. New state-of-the-art cleaning equipment has been developed which limits emissions while recovering and reusing the perchloroethylene cleaner. One major airline in the United States has moved away from synthetic materials to more wool and leather in order to be able to use perchloroethylene for dry cleaning. However, perchloroethylene does not clean leather very well and CFC-113 is still needed in some cases. Due to the significant difference between the cost of perchloroethylene and CFC-113, this airline has experienced a large savings by switching to perchloroethylene. After an initial capital investment of $860,000 for new equipment and facilities work, the airline's average monthly solvent cost dropped from $90,000 to $9,000. Thus, the equipment paid for itself in just under 11 months. This savings was realized while processing over 160,000 lbs. of dry cleaning per month.

Exhibit 11

PROPERTIES OF CHLORINATED SOLVENTS

Physical Properties	CFC-113	MCF	Trichloro-ethylene	Perchloro-ethylene	Methylene Chloride
Ozone Depleting Potential	0.8	0.12	0	0	0
Chemical Formula	CCl_2FCClF_2	CH_3CCl_3	$CHClCCl_2$	CCl_2CCl_2	CH_2Cl_2
Molecular Weight	187.38	133.5	131.4	165.9	84.9
Boiling Point (°C)	47.6	73.8	87	121	4.0
Density (g/cm^3)	1.56	1.34	1.46	1.62	1.33
Surface Tension (dyne/cm)	17.3	25.4	29.3	31.3	N/A
Kauri Butanol Value	31	124	130	91	132
U.S. OSHA PEL 8 hr. TWA (ppm)	1000	350[a]	100	100	500
Flash Point (°C)	None	None	None	None	None

[a] Obtained from HSIA White Paper 1989.

Source: UNEP 1991.

OTHER ORGANIC SOLVENTS

The solvent cleaning industry has used a wide range of other organic solvents for electronics, metal, and precision cleaning. Some of the solvents commonly used, include ketones, alcohols, ethers, and esters. These solvents can be used in either a heated state or at room temperature in a dip tank, or in hand-wipe operations. Due to the fact that most are flammable, these types of organic solvents are most often used at room temperature in a process commonly known as cold cleaning. In aircraft maintenance procedures, organic solvents are often excellent candidates for use as a wipe solvent in manual cleaning.

The ketones form a group of very powerful solvents (see Exhibit 12). In particular, acetone (dimethyl ketone) and methyl ethyl ketone (MEK) are good solvents for polymers and adhesives. Both are recommended extensively in aircraft manufacturer maintenance manuals. In addition, acetone is an efficient dewatering agent. However, their flammability (note that acetone has a flash point of 0°F) and incompatibility with many structural polymers (e.g., stress cracking of polyether sulphone, polyether ketone, and polycarbonate) means that they should only be used with care and in small quantities. It is important to note that MEK is often classified as a hazardous air pollutant, as it is in the U.S. Even so, it is the single most widely used hazardous air pollutant in aerospace applications, with a consumption in the U.S. of approximately 3,965,000 pounds per year.

Alcohols such as ethanol and isopropanol, and several glycol ethers are used alone and in blends in a number of applications. These solvents are chosen for their high polarity and for their effective solvent power. The alcohols have a range of flash points and extreme care must be exercised while using the lower flash point alcohols (see Exhibit 13).

A relatively new type of organic solvent cleaning used in the aircraft maintenance industry employs a special vapor degreaser designed for use with alcohols. One class of such equipment uses an alcohol vapor zone to clean the parts, and has a perfluorocarbon vapor blanket above the alcohol. This blanket effectively reduces the flammability risk associated with the heated alcohol. Perfluorocarbons are discussed later in this section. The second class of alcohol vapor degreasing equipment does not make use of an inerting agent such as perfluorocarbons. In these systems, there are numerous safety devices built into the equipment, including air monitors, automatic sprinkler systems, and automatic shutoff capabilities. Nevertheless, when using this equipment, workers must exercise extreme caution to reduce the risk of explosion.

Esters, such as dibasic esters and aliphatic mono esters, have good solvent properties. They offer good cleaning for a variety of grimes and soils. Most of these materials are readily soluble in alcohols, ketones, ethers, and hydrocarbons, but are only slightly soluble in water. Dibasic esters generally have a high flash point and low vapor pressure. They are only slightly soluble in high paraffinic hydrocarbons. Dibasic esters are so low in vapor pressure that a residual film may remain on a surface after application, thereby necessitating a water rinse stage. Aliphatic esters, generally acetates, range in formula from ethyl acetate to tridecyl acetate. The higher grades (hexyl acetate and heavier) are commonly used in degreasing. They fall into the combustible or non-combustible flash point range. They have acceptable compatibility with most polymers. These esters can be dried from a surface by forced air drying with no residual film.

As with chlorinated solvents, many of the organic solvents are toxic and have low worker exposure

Exhibit 12

PROPERTIES OF KETONES

KETONES	Formula	Mol. Wt.	lbs per gal	B.P. °F	F.P. °F	Evap Rate CCl_4 =100	Coefficient of Expansion Per °F	Surface Tension @ 68°F Dynes/cm
ACETONE	CH_3COCH_3	58.08	6.58	132-134	-138.6	139	0.00080	23.7
METHYL ETHYL KETONE	$CH_3COC_2H_5$	72.10	6.71	174-177	-123.5	97	0.00076	24.6
DIETHYL KETONE	$C_2H_5COC_2H_5$	86.13	6.80	212-219	-43.5	-	0.00069	24.8
METHYL n-PROPYL KETONE	$CH_3COC_3H_7$	86.13	6.72	214-225	-108.0	66	0.00062	25.2
CYCLOHEXANONE	$(CH_2)_5CO$	98.14	7.88	266-343	-49.0	12	0.00051	-
METHYL ISOBUTYL KETONE	$(CH_3)_2CHCH_2COCH_3$	100.16	6.68	234-244	-120.5	47	0.00063	22.7
METHYL n-BUTYL KETONE	$CH_3COC_4H_9$	100.16	6.83	237-279	-70.4	32	0.00055	25.5
METHYL CYCLOHEXANONE (Mixed Isomers)	$(CH_3)C_5H_9C0$	112.17	7.67	237-343	-	7	0.00042	-
ACETONYL ACETONE	$CH_3COC_2H_4COCH_3$	114.14	8.10	365-383	15.8	-	0.00052	39.6
DIISOPROPYL KETONE	$(CH_3)_2CHCOCH(CH_3)_2$	114.18	6.73	237-261	-	-	-	-
METHYL n-AMYL KETONE	$CH_3(CH_2)_4COCH_3$	114.18	6.81	297-309	-31.9	15	0.00057	-
DIACETONE	$(CH_3)_2C(OH)CH_2COCH_3$	116.16	7.82	266-356	-65.2	4	0.00055	29.8

KETONES	Formula	Sol % by Wt. @ 68°F		Flash Pt (TCC) °F	Flammable Limits % by Volume in Air		Toxicity MAC in ppm	Spec. Heat Liq. @ 68°F Btu/(lb)(°F)	Latent Heat @ B.P. Btu/lb
		In Water	O' Water		Lower	Upper			
ACETONE	CH_3COCH_3	∞	∞	0	2.6	12.8	1000	0.51	224
METHYL ETHYL KETONE	$CH_3COC_2H_5$	26.8	11.8	28	1.8	11.5	250	0.53	191
DIETHYL KETONE	$C_2H_5COC_2H_5$	$3.4^{104°F}$	4.6	55	-	-	250	0.56	163
METHYL n-PROPYL KETONE	$CH_3COC_3H_7$	4.3	3.3	45	1.6	8.2	200	-	180
CYCLOHEXANONE	$(CH_2)_5CO$	2.3	8.0	145	1.1	-	100	0.49	-
METHYL ISOBUTYL KETONE	$(CH_3)_2CHCH_2COCH_3$	2.0	1.8	64	1.4	7.5	100	0.55	148
METHYL n-BUTYL KETONE	$CH_3COC_4H_9$	$3.4^{77°F}$	$3.7^{77°F}$	73	1.2	8.0	100	0.55	148
METHYL CYCLOHEXANONE (Mixed Isomers)	$(CH_3)C_5H_9C0$	0.2	3.0	118	-	-	100	$0.44^{58°F}$	-
ACETONYL ACETONE	$CH_3COC_2H_4COCH_3$	∞	∞	174	-	-	-	-	-
DIISOPROPYL KETONE	$(CH_3)_2CHCOCH(CH_3)_2$	0.6	-	75	-	-	-	-	-
METHYL n-AMYL KETONE	$CH_3(CH_2)_4COCH_3$	0.4	1.5	120	-	-	100	-	149
DIACETONE	$(CH_3)_2C(OH)CH_2COCH_3$	∞	∞	48	-	-	50	$0.50^{58°F}$	200

Source: DuPont Company, Handbook of Standards for Solvents

Exhibit 13

PROPERTIES OF ALCOHOLS

CHEMICAL	Lb./Gal. 60°F	Sp. Gr. 20°/20°C	Boiling Range °F	Fl. Pt. °F TCC	Evap. Rate[1]
Methanol	6.60	0.792	147-149	54	3.5
Ethanol, Prop. Anhydrous	6.65	0.799	165-176	49	1.8
Ethanol, Spec. Industrial Anhydrous	6.65	0.795	167-178	50	1.8
Isopropanol, Anhydrous	6.55	0.786	179-182	53	1.7
n-Propanol	6.71	0.806	205-208	74	1.0
2-Butanol	6.73	0.809	207-215	72	0.9
Isobutanol	6.68	0.803	225-228	85	0.6
n-Butanol	6.75	0.811	241-245	97	0.5
Amyl Alcohol (primary)	6.79	0.815	261-282	120	0.3
Methyl Amyl Alcohol	6.72	0.808	266-271	103	0.3
Cyclohexanol	7.89	0.949	320-325	142	0.05
2-Ethylhexanol	6.94	0.834	360-367	164	0.01
Texanol	7.90	0.950	471-477	248[2]	0.002

1 n-Butyl Acetate=1
2 C.O.C.

Source: Southwest Chemical Company, Solvent Properties Reference Manual limits. Prior to implementing such products, the review of an occupational health professional may be necessary to ensure that the products are being used in a safe manner. All possible efforts should be made to protect workers from prolonged exposure to toxic chemicals.

With many of the organic solvent alternatives to CFC-113 and MCF, there may be problems with odor. Even though volatility and airborne concentrations may be reduced, the relatively strong odors of some of these solvents may build. Without adequate ventilation and possibly masks for workers, these odors may reach a level which would cause discomfort for workers. Therefore, care should be taken to reduce the odor build-up in any location.

Other issues to consider in evaluating organic solvents as CFC-113 and MCF substitutes include VOC emissions and waste disposal. In many locations, most of the organic solvents will be considered VOCs and emissions control is likely to be required. In addition, in many cases, the spent solvent will be considered hazardous waste. It may, therefore, require special handling and disposal practices.

HYDROCHLOROFLUOROCARBONS FOR ESSENTIAL APPLICATIONS

Faced with the phaseout of CFC-113 and MCF, some users of these solvents looked toward several HCFCs (e.g., HCFC-225ca, HCFC-225cb, HCFC-141b, and HCFC-123) as possible substitutes. Exhibit 14 presents physical properties of these chemicals. They are highly desirable due to their good cleaning performance, and their similarity in application method to CFC-113 and MCF.

However, due to their environmental and health impacts, the use of these substances in solvent cleaning applications will be severely limited. At the present time, the only HCFCs which could be used in aircraft maintenance procedures are HCFC-141b and HCFC-225cb. This is due to the toxicity concerns associated with HCFC-123 and HCFC-225ca based on testing performed by the Program for Alternative Fluorocarbon Toxicity Testing (PAFT).

Exhibit 14

PHYSICAL PROPERTIES OF HCFCs AND OTHER SOLVENT BLENDS

	CFC-113	MCF	HCFC-225ca	HCFC-225cb	HCFC-141b
Chemical Formula	CCl_2FCClF_2	CH_3CCl_3	$CF_3CF_2CHCl_2$	$CClF_2CF_2CHClF$	CH_3CFCl_2
Ozone Depleting 0.11 Potential	0.8	0.1	~0.05	~0.05	
Boiling Point (°C)	47.6	73.9	51.1	56.1	32.1
Viscosity (cps) @ 25°C	0.68	0.79	0.59	0.61	0.43
Surface Tension (dyne/cm)	17.3	25.56	16.3	17.7	18.4
Kauri-Butanol Value	31	124	34	30	76
Flash Point °C	None	None	None	None	None
Toxicity	Low	Low	Underway	Underway	Near Completion

Therefore, these substances are no longer being recommended for use in solvent cleaning applications, where workers will be exposed to the chemicals for long periods of time. In addition, two major manufacturers have withdrawn all of their HCFC-123 formulations previously marketed for solvent cleaning applications. HCFC-141b is currently available and is manufactured by a few companies for use in solvent cleaning applications. Previous formulations included mixtures with HCFC-123 and methanol, but current formulations have dropped the use of HCFC-123. The major drawback associated with the use of HCFC-141b is its relatively high ODP of 0.11. This is only slightly below the ODP of MCF (0.12), a product which HCFC-141b is to be replacing. This similarity in ODP has limited the extent to which HCFC-141b can replace CFC-113 and MCF, since it is generally seen as an unacceptable substitute for MCF. In the U.S., for example, the EPA is likely to ban the use of HCFC-141b as a substitute for MCF in solvent cleaning applications. All of these factors make HCFC-141b an unlikely substitute for MCF in aircraft maintenance cleaning operations.

At the present time, it appears HCFC-225 is a good substitute for both CFC-113 and MCF in general metal and precision cleaning. It is similar to CFC-113 in its chemical and physical properties, and can form azeotropes with alcohols. It is also compatible with most plastics, elastomers, and metals. HCFC-225 can be used as a CFC-113 replacement, where other alternatives do not exist, with relatively few changes in equipment or process operations. Its ability to replace MCF, however, will be limited because the solvency of HCFC-225 is low compared with that of MCF. At present, an HCFC-225 plant has been commissioned which will have a capacity to produce 2,000 MT per year of HCFC-225 (as a mixture of 45 percent HCFC-225ca and 55 percent HCFC-225cb). It is expected that this product will be available in significant quantities in 1994.

As a means of addressing the ODP of HCFCs, the Parties to the Montreal Protocol developed a phaseout schedule for HCFCs at their November 1992 meeting in Copenhagen. Under the new amendment, HCFC consumption must be frozen at the base level by 1996; be cut by 90 percent from the base level by 2015; be cut by 99.5 percent by 2020; and be cut by 100 percent by 2030. The base level is equal to 3.1 percent of 1989 CFC consumption plus 100 percent of 1989 HCFC consumption. This phaseout is prompting many potential users of HCFCs to switch directly to other alternatives.

If HCFCs must be used, it is important to consider the process design changes which may be required in order to reduce emissions. For example, conventional degreasers require modification to extend freeboards and lower condenser temperatures. In addition, provisions such as superheated-vapor drying or increased dwell times in freeboard are desirable to reduce dragout losses and can be incorporated into the design.

The high volatility of HCFC cleaning solutions require special equipment design criteria. In addition, the economic use of HCFCs may require special emission control features for vapor degreasers (see Exhibit 15, 16, and 17). These include:

- Automated work transport facilities;
- Hoods and/or automated covers on top entry machines;
- Facilities for work handling that minimize solvent entrapment;
- Facilities for superheated vapor drying;
- Freeboard deepened to width ratios of 1.0 to 2.0;
- Main condenser operating at 45° to 55°F (7° to 13°C);
- Secondary condenser operating at -30° to -20°F (-34° to -29°C);
- Dehumidification condenser operating at -30 to -20°F (-34° to -29°C)(optional);
- Seals and gaskets of chemically compatible materials;
- Stainless steel construction;

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- Welded piping containing a minimum of flanged joints;

- A gasketed water separator or refrigerated desiccant dryer for methanol blends;

- A cool room to work in is recommended;

- Controlled exhaust from refrigeration unit to prevent excessive heat from reaching the separator chambers.

Material compatibility is another important consideration. Certain blends may require compatibility testing with titanium, magnesium, zinc and other metals. In addition, the solvent blends have shown some adverse effects with plastics such as ABS, acrylic, and Hi-Impact Styrene. Like metals, plastics need to be tested on an individual basis.

Other Cleaning Techniques

In addition to the more common alternative cleaning procedures described in the previous sections, there are several additional processes which can be used to a lesser extent in aircraft maintenance cleaning. These techniques include the following:

- Perfluorocarbons
- Supercritical carbon dioxide
- Media blasting techniques

Each of these procedures has strict limitations associated with its use.

Perfluorocarbons

Perfluorocarbons (PFCs) are a group of compounds in which all of the hydrogen atoms of a hydrocarbon are replaced with fluorine atoms. They are characterized by extreme stability, low toxicity, nonflammability, and zero ozone-depletion potential. The wide range of boiling points available for PFCs makes them very versatile. One manufacturer notes that six PFC compounds have boiling points ranging from 84° to 320°F (29° to 160°C).

A major disadvantage associated with the use of PFCs is their extremely high global warming potential. Due to their stability, atmospheric lifetimes for some PFCs have been estimated to be greater than 500 years, perhaps reaching as high as 3,000 years. Thus, it is possible that by widely substituting PFCs for CFC-113 and MCF, users might be trading one environmental problem for another. This tradeoff has prompted the governments of several developed countries to severely restrict, or consider restricting, the use of PFCs in solvent cleaning. Both the U.S. and Sweden have indicated that they intend to limit use of PFCs to essential uses only, or ban their use altogether in some applications.

A second major disadvantage associated with the use of PFCs is their extremely high cost. The high cost is due to the complex manufacturing processes which are carried out to produce these synthetic compounds. In late 1990, a typical low- to mid-range boiling point PFC cost US$90 per kilogram.

PFCs have proven to be effective in precision cleaning applications such as the cleaning of high accuracy gyroscopes. All current high density flotation fluids are soluble in PFCs and can therefore be used for flushing filled assemblies. In addition, high pressure spraying with PFCs is an extremely effective method of particle removal. The excellent stability of PFCs makes them compatible with all gyroscope construction materials, including beryllium. Due to their global warming potential and extremely high cost, any equipment in which PFCs are used will need to be tightly sealed to avoid large losses of the compounds.

Supercritical Carbon Dioxide

The use of supercritical carbon dioxide in precision cleaning applications is a relatively new alternative to CFC-113 and MCF cleaning. It has been proven effective in removing a wide variety of oils, including silicones, damping fluids, machining oils, and lubricating oils, from assemblies in aircraft maintenance. Supercritical carbon dioxide is especially useful in applications where aqueous and semi-aqueous cleaners are unable to penetrate small crevices and pores in assemblies. Excessive cleaning may result in damage to plastic parts. Therefore, time, pressure, and temperature must be monitored during the cleaning process.

The supercritical carbon dioxide cleaning process was tested by a major manufacturer on inertial guidance systems in 1981, and is currently being further developed through a U.S. Air Force program. Testing has shown that the process is as effective as CFC-113 in removing fill fluids from gyroscope housings prior to rebuild. The supercritical carbon dioxide cleaning process is being developed to focus on small parts as well as low-throughput of high value parts, and equipment costs will range from US$50,000 to US$250,000, depending on the application.

Media Blasting Techniques

The technique of blasting a surface with a given media in order to dislodge contaminants is fairly common in aircraft maintenance procedures. This technique is generally applicable only to smooth surfaces, and is used primarily to remove scale, corrosion, oxidation, and carbon deposits. It relies on the use of very high-pressure spray of a given media which, when it contacts the surface to be cleaned, dislodges the soils on the surface, resulting in a clean product. Blasting is most often used on aircraft engine parts, and can be divided into two general types of processes -- dry abrasive blasting, and wet abrasive blasting.

The media used in the blasting procedures is dependent upon the product being cleaned and the blasting technique employed. For dry abrasive blasting, there are a large number of media which are recommended and/or currently used by aircraft maintenance engineers. These include:

- Sand
- Plastic beads
- Glass beads
- Nut shells and rice hulls
- Fruit pits
- Wheat starch

Dry abrasive blasting using wheat starch as the media is currently undergoing testing at two large airlines in the United States. Regardless of the media used in dry abrasive blasting, the material being cleaned must be able to withstand extreme pressures and should have a breaking strength of at least 210,000 pounds per square inch (1450 MPa). In addition, care must be taken to prevent explosions.

Another consideration associated with most dry abrasive blasting is the amount of waste generated by the procedure. The overall quantity and type of waste will depend on the size of the parts being cleaned and the media being used in the blasting process. One large military facility in the United States reports producing approximately 600,000 lbs. of waste in a single year.

Wet abrasive blasting is used primarily for surface cleaning prior to painting and is similar to dry abrasive blasting with the exception that a liquid is used in a high-pressure spray in the place of one of the dry media previously mentioned. There are two types of wet abrasive blasting, fine and medium. This classification refers to the spray which is applied, determining whether a fine atomized spray is delivered, or a less fine spray is used. Surfaces to be cleaned using wet abrasive blasting must be able to withstand the same pressures as those cleaned with dry abrasive blasting. Typical media used in wet abrasive blasting are water and sodium bicarbonate/water mixtures. Care must be taken to ensure that wet abrasive blasting is not used on parts which may be vulnerable to corrosion.

For small-scale operations, the blasting operation is carried out in a blasting booth which is equipped with a number of safety devices including air-extraction systems, soundproofing, and dust catchers. In addition, operators inside the booth wear safety gear, gloves, breathing masks, and protective clothes. While some blasting procedures are carried out with the operator inside the booth, others have the operator standing outside and using gloves which are built into the side of the booth.

Wet abrasive blasting is also being used successfully in large-scale applications, although the use in these cases is primarily for stripping paint. One military facility in the U.S. has recently constructed a new facility in which it can strip paint from an entire aircraft using a sodium bicarbonate/water slurry. A similar facility has recently been built in Germany, where paint is removed from aircraft using a water/alcohol spray.

Several precautions must be taken when using any type of blasting. Blasting should not be used as a cleaning method for parts which will later be subject to fluorescent dye testing, as the blast residue may cover small cracks in the surface. Another issue is recontamination of clean surfaces. Whenever possible, a different booth and spray device should be used for each material being cleaned (e.g., alloyed steel, titanium parts, etc.). This will ensure that no cross-contamination of parts will occur. In addition, when cleaning titanium surfaces using dry abrasive blasting, booths should be cleaned frequently. This will reduce the risk of fire which could come with the accumulation of fine particles of titanium or its alloys.

Recently, a new form of blasting has been developed for use in a variety of applications, including aircraft cleaning procedures. It is similar to the dry abrasive blasting techniques previously described, but uses carbon dioxide (CO_2) pellets as the blasting media. While the cleaning technique -- use of a high pressure blasting gun -- is the same, the process itself is not abrasive.

The CO_2 pellet blasting system converts liquid CO_2 into dry ice pellets. These pellets are then propelled through a blast nozzle by high velocity air and the hard pellets strike the surface to be cleaned. When the pellets first reach the surface, they penetrate the contaminant and hit the surface itself. At this point the pellet "ruptures" and the kinetic energy forces the CO_2 to be released along the surface being cleaned. This force then dislodges the contaminant from behind, removing it from the surface. Exhibit 18 illustrates this process.

Ex 18