EQUIPMENT ALTERNATIVES FOR PRECISION CLEANING IN THE AEROSPACE INDUSTRY

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Ken Marts is currently the technical lead for CFC Replacement Programs and responsible for the implementation of a program to reduce the usage of CFC 113 at Martin Marietta by more than 95% by 1993. Ken earned BS and MS Engineering degrees from the Colorado School of Mines and an ME degree from the University of Colorado.

John Howard is a Manufacturing Operations Manager at MMAG. John is the lead for CFC Replacement Programs and is also responsible for the previously mentioned CFC 113 reduction program. John has more than thirty years experience in cleaning, assembly, and test operations of space launch vehicle and spacecraft systems. This included cleanroom design and operation as well as the design and use of CFC 113, alcohol, and water final cleaning systems.

ABSTRACT

Precision cleaning of aerospace components and assemblies at Martin Marietta Astronautics Group (Denver, CO) entails a two-step cleaning process. Precleaning in an aqueous cleaner enhanced with ultrasonic agitation followed by an isopropyl alcohol (IPA) spray used to meet the required cleanliness levels (reference Table 1). This process was developed to replace the use of ozone depleting CFC 113 and trichloroethane for precision cleaning as well as meeting several other life cycle requirements including, safety and environmental considerations, hardware configuration, and producibility (reference Table 2).

Two IPA spray systems are operational (one manually operated and a second larger automated system). Cleaning results to date using the developed process and IPA cleaning system indicate excellent performance in meeting the cleaning requirements and system life cycle requirements. The results obtained to date cleaning perfluoropolyether lubricated bearings, printed circuit boards, typical propulsion components, and ground hardware (swivel fittings, tees, etc.) contaminated with hydrocarbon, silicone, and perfluoropolyether based lubricants are reported herein.

TABLE 1 Propulsion Components and Cleanliness Requirements

Component	Cleanliness Requirement (MIL-STD-1246)
Tubing/Fittings	100A
Valves/Filters	150A
Pressure Transducer	150A
Tanks	150A
internal Components	100A
Engine Modules	100A
Special Components	**25A**

TABLE 2 Alternative System Requirements

ITEM	REQUIREMENT
Cleanliness Level	NVR< 1.0 mg/ft^2 Particulate: 5-15u
Hardware Configuration	Components, Assemblies Flat/Curved Surfaces Entrapped Areas
Safety Considerations	Flammability Personnel Protection
Environmental Considerations	VOC's Spent Cleaning Material
Contamination Monitoring	Particulate NVR

Construction and operation of the alcohol spray equipment is discussed as well as cleaning results obtained using the equipment. Air flow, ‘volatile organic compound (VOC) recovery methods, distillation, and safety concerns are also discussed.

PRECISION CLEANING OF AEROSPACE HARDWARE AT MARTIN MARIETTA

In the past, precision cleaning of spacecraft components has been by ultrasonic immersion in CFC 113 followed by a low pressure CFC 113 or alcohol spray rinse. Medium and large object precision cleaning was accomplished by spray rinsing CFC 113 over a large object ultrasonic cleaner located in a Class 100,000 clean room. Small details and assemblies were precision cleaned with CFC 113 or isopropyl alcohol on a Class 100 laminar flow bench which exhausts to the outside. Filtering of the CFC 113/alcohol (isopropyl) was accomplished using a series of membrane filters and an 0.8 micron filter at the nozzle. These operations were performed in an open spray booth.

Final cleaning of medium and large assemblies is much more difficult and typically accomplished by flow through of CFC 113 or alcohol followed by gaseous nitrogen purges for up to 8 hours. Use of a vacuum drying oven to assist drying was also occasionally used. Cleanliness verification for particulate and non-volatile residue (NVR) was made prior to drying. The purpose of this 'cleaning scenario is to precision clean the hardware at a low assembly level such that high precision cleanliness levels can still be met for the end product.

The current cleaning process consists of an ultrasonic aqueous degreaser preclean, followed by water rinse and gaseous nitrogen purge (for drying) and finally an isopropyl alcohol (IPA) spray rinse for final cleaning. The use of CFC 113 and other ozone depleting substances in the cleaning processes have been totally eliminated. This process is illustrated in Figure 1 and described in more detail in the next section.

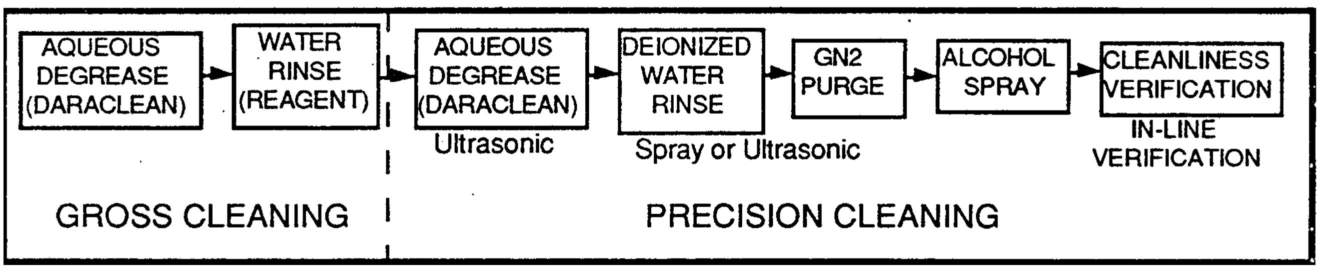

FIGURE 1 Current Precision Cleaning Method

Precision Cleaning Processes

Aqueous Based Cleaning

Aqueous cleaners are finding increased usage for gross cleaning of items. Work at Martin Marietta has shown that in most cases an aqueous cleaner, at an operating temperature of approximately 60°C (140°F) is a better soil remover than the ozone depleting 1,1,1, Trichloroethane used in a vapor degrease process[1]. This method was demonstrated using an immersion technique.

An aqueous cleaner is being used as a precleaner for precision cleaning applications; to replace CFC 113 vapor degreasing, for gross cleaning of detail parts, components, and assemblies where no entrapped areas are present. The aqueous cleaner is being used in an ultrasonic tank and heated to 60 to 71°C (140 to 160°F). Continuous filtering is used to remove particulate and skimmers are in use to remove excess molecular contaminants. The spent cleaner will be processed through Martin Marietta's water treatment plant.

Alcohol: Specific issues

Isopropyl alcohol in an enclosed booth is used to pressure spray the alcohol onto and through the hardware being cleaned. The use of IPA introduced several issues addressed in design of the precision cleaning system. These issues are discussed in an earlier article* and are as follows:

1. Flammability

2. Alcohol vapors
3. Alcohol reuse
4. Alcohol loss
5. Alcohol bath life

ALCOHOL SPRAY SYSTEM FEATURES

The alcohol spray system is a total encompassing cleaning facility incorporating a safety control module (to address safety issues related to the use of alcohol), filtering subsystems to filter the alcohol, nitrogen, and air prior to entry into the chamber, an air exhaust subsystem to exhaust the air to the atmosphere (including alcohol vapor recovery/treatment), and an alcohol distillation subsystem. Each of these subsystems is described in more detail below. Figure 2 illustrates the spray chamber and the computer control console.

The spray chamber is fabricated from stainless steel and utilizes two glove ports for handling hardware and has a translucent metallized polycarbonate window viewport. The polycarbonate is metallized using an electrically conductive coating. This coating is in turn grounded to the structure through surface contact. The entire cleaning system is also grounded to a central facility ground. A spray nozzle attachment is used to apply alcohol at pressures up to 100 psi to the hardware being cleaned. A catch tank for used alcohol is located at the bottom of the spray chamber prior to the alcohol being filtered for reuse and transferred to the alcohol storage tank.

A distillation capability will be present to recycle “contaminated” alcohol and’ replace the alcohol supply tanks with “refined alcohol. This process eliminates molecular and contamination and moisture buildup in the processing alcohol.

Safety Features

The spray chamber system utilizes numerous features to address the hazardous conditions which can be present when alcohol is utilized. These features are incorporated into a safety control panel and details were reported in an earlier paper (reference 2).

Air Supply/Ventilation

The ventilation subsystem (vapor exhaust) is designed to meet NFPA standards for flammable liquids applications and provides 150 cfm face equivalent velocity. Air exhaust is accomplished through an overhead blower system which evacuates the chamber and provides five air changes per minute. This air flow also meets safety criteria for removal of alcohol fumes and to exhaust them.

Filtering Requirement

Precision cleaning of components for removal of NVR and particulate requires fine filtration of both the air supplied to the spray chamber as well as the alcohol supplied to the cleaning gun. Air is supplied to the spray chamber through HEPA filters providing approximately Class 100 air to the workpiece surface being cleaned.

The alcohol filtering subsystem filters inlet alcohol supplied to the spray gun/nozzles and outlet alcohol from the spray chamber’s small alcohol return tank. Particulate, but not molecular contamination is filtered using this subsystem. Filter sizes used are dependent on the final hardware cleanliness desired.

VOC TREATMENT:

To comply with air standards in several municipalities, alcohol vapors may need to be treated to lower the volatile organic compound (VOC) release into the atmosphere. The current measured release is approximately 300 ppm. The use of catalytic incineration is expected to reduce this by 98 to 99 percent for a net release not to exceed 10 ppm, or less than one pound release of alcohol per day. This assumes a normal 8 hour work shift per day of operation. **VOC** treatment was not a concern in the current application, and has not been incorporated into the operational system.

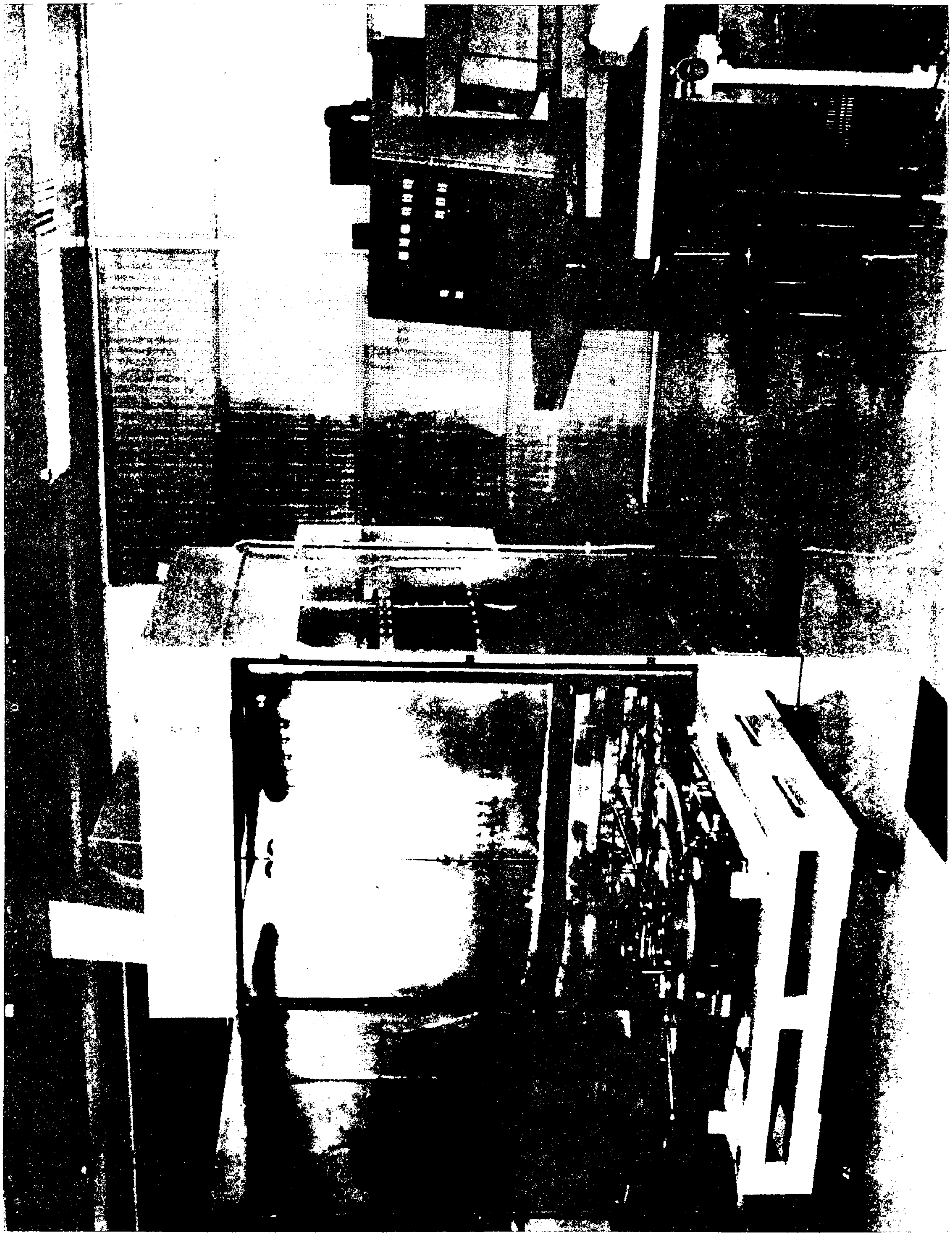

FIGURE 2 Alcohol Spray Chamber Configuration (Automated system) Illustrating Both Spray Chamber and Computer Control Console

DEMONSTRATION PROGRAM:

Test Objectives

A demonstration test of the operational system was recently completed. The objectives of the test program were:

1) Assess cleaning capability comparisons between CFC 113 and the aqueous cleaner/IPA process.
2) Assess cleaning capability of aqueous cleaner/IPA process versus other cleaning modifications to clean bearings and populated, printed circuit boards.

The test program demonstrated the capability of the alcohol spray system to meet its intended requirements.

Test Approach

The demonstration program was broken into several phases in order to adequately address the previously mentioned objectives.

Phase A: Several aerospace components were cleaned to precision cleanliness levels and recontaminated with typical shop and cleanroom contaminants including machining lubricants, hydrocarbon lubricants, perfluorinated lubricants, and dust. These components included several thrust and ball bearings, several simulated mechanism gears, propellant tubing (0.5 and 0.75 inch diameter (12.5 and 19.0 mm respectively), several pieces of a simulated propellant management device with faying surfaces and a tightly meshed stainless steel screen cloth (325 by 2300 mesh per linear inch), populated printed circuit boards, and ground launch support hardware. Table 3 lists the components cleaned and their respective contaminants.

These components were then cleaned using the following process (except as modified by the descriptions in the individual program phases):

*1. Preclean in aqueous cleaner (ultrasonic) maintained at 130° to 150°F for 10 to 20 minutes.
2. Rinse using filtered deionized water for 10 minutes. Spray and ultrasonic followed by spray water rinses were used on separate sets of test samples.
3. Gaseous nitrogen purge for 1 to 2 minutes or until water is no longer visible on surfaces.
4. Obtain NVR rinse samples for particulate, NVR, and water content analysis.
5. Isopropyl alcohol spray for 10 to 20 minutes followed by gaseous nitrogen purge.
6. Obtain NVR rinse sample for contamination (molecular and particulate) analysis.

* Some' mechanical agitation and brushing was required for components lubricated with the perfluoropolyether Braycote 601 lubricant. In addition, ultrasonic agitation was not used for the populated printed circuit boards or bearings.

Phase 8: The bearings cleaned followed the same process outlined above in steps 1 thru 6 except ultrasonic agitation of the bearings-was not used. Mechanical brushing during precleaning in the aqueous cleaner was required due to the tenacity of the Braycote lubricant used. This lubricant is widely used in spacecraft mechanisms and is a perfluoropolyether based lubricant. CFC 113 is one of the few cleaners found to readily clean surfaces lubricated with this lubricant. The aqueous cleaner used with mechanical agitation was found to adequately remove the lubricant from these bearing surfaces. The bearings were standard caged ball bearings with a phenolic retainer and were approximately 2.0 inch in diameter by 0.75 inch width. The requirements for this cleaning were to remove the lubricant for vacuum impregnation of the phenolic cages with Bray 815Z oil prior to relubrication.

Phase C: The printed circuit boards (PCB) cleaned were populated with standard electrical components including surface mount devices and plated thru-hole (PTH). The boards had been populated and soldered in a manual bench-top operation (an RMA flux was used). Cleanliness requirements for these boards was to pass an Omegameter test for ionic resistivity. This test method establishes the amount of surface ionic contaminant present on a PCB assembly. The higher the resistivity value obtained, the cleaner the board surface. A threshold resistivity equivalent to 10 µgrams of NaCl per square inch of board surface was established based on space flight requirements for the same test. A cleaning time of 30 to 60 seconds in IPA only was used. Additional information on the PCB's can be obtained from the authors ((303) 977-8374).

Test Results

Results from these tests revealed the following:

PHASE A: System Cleaning Capability

Precleaning of the test samples in the aqueous cleaner removed the largest bulk of the molecular contaminants and final cleaning in the alcohol spray removed the remainder. In several cases, cleanliness levels of MIL-STD-1246 100A were achieved after aqueous cleaning and prior to alcohol cleaning. Cleanliness levels of 25A to 50A were not uncommon after alcohol cleaning. The only problem encountered was in the removal of perfluorinated polyether lubricants (Bray 601 in particular). Cleaning of hardware with this contaminant required additional soak/rinse periods and mechanical agitation while in the aqueous cleaner along with brushing for removal of the lubricant. CFC 113 has been readily used in the past for removal of perfluorinated polyether lubricants.

During this testing phase, water pickup/concentration in the alcohol bath was also assessed. Most hardware is processed directly from the water rinse bath area to the alcohol spray area (after GN2 dry) and some moisture may still be present on the hardware. This moisture is then transferred to the alcohol bath. Testing indicated the water pickup by the alcohol bath was minimal and the water content of the alcohol bath did not exceed the maximum water content requirement after the week-long test program (approximately 24 hours of operation during that period). This is also a good indication that the GN2 purge was effective in moisture removal from the hardware surfaces being cleaned.

The conclusion drawn from this phase of testing was that cleanliness levels which had been met using the previous CFC 113 process are attainable and can often be improved using the aqueous cleaner/IPA cleaning process.

PHASE B: Bearing Cleaning

The bearings were cleaned to remove visible evidence of Braycote grease. No evidence of corrosion was noted after exposure to the aqueous degreaser or the subsequent water rinse (the bearings were made using 52100 steel). Cleanliness levels were not required nor measured. The majority of the lubricant was removed during the aqueous degreasing operation so as to not 'contaminate the IPA spray system bath. The resultant surface was left free of the Braycote grease for subsequent vacuum impregnation with oil and relubrication.

PHASE C: PCB Cleaning

The PCB cleaning results indicated the acceptability for flux and contaminant removal from board surfaces provided the boards are not exposed to high elevated temperatures or left for prolonged periods of time after repair solder operations prior to cleaning. Table 3 gives the results of the PCB Omegameter testing after cleaning the PCB 's with alcohol. In all cases, board cleanliness met the 10.0 µgrams NaCl per square inch of board area. The IPA system was successful in removing the RMA flux to acceptable levels compared with cleanliness results obtained using 1,1,1 trichloroethane.

TABLE 3 PCB Cleaning Results After IPA Spray Cleaning

Board Number	Cleanliness Level	Comments
47	20.0 µgrams NaCl/in^2	No IPA cleaning, Baseline sample only
1	0.0 µgrams NaCl/in^2	10.0 µgrams NaCl/in^2 max rqmt.
2	0.0 µgrams NaCl/in^2	10.0 µgrams NaCl/in^2 max rqmt.
3	0.0 µgrams NaCl/in^2	10.0 µgrams NaCl/in^2 max rqmt.
32	0.0 µgrams NaCl/in^2	10.0 µgrams NaCl/in^2 max rqmt.
33	0.0 µgrams NaCl/in^2	10.0 µgrams NaCl/in^2 max rqmt.

CONCLUSIONS

An aqueous precleaner and alcohol spray cleaning system were implemented to replace CFC 113 and/or 1,1,1 trichloroethane vapor degrease and CFC 113 spray rinse final clean. The demonstration program verified that this cleaning system meets all requirements of cleanliness (MIL-STD-1246 level 100A minimum, cleaner/hardware compatibility, and capability for all desired hardware configurations), safety (personnel and equipment; i.e. flammability and VOC), and environmental (VOC release and spent alcohol use) requirements. The environmental requirements being met are those specific to the metropolitan Denver, Colorado area, but could be refined for use of the system elsewhere. All data gathered indicates isopropyl alcohol can successfully be used to replace CFC 113 for precision cleaning aerospace hardware. Use of alcohol spray systems for precision cleaning in other industries is also feasible. Derivatives of the cleaning system for these other industries and with other cleaning materials may also prove successful. Use of alcohol for cleaning requires incorporation of special design features to address the inherent hazards while using a potentially hazardous material.

The process used (aqueous cleaner followed by IPA spray) was shown to effectively clean numerous contaminants (hydrocarbon, silicone, and perfluorinated lubricant systems) from hardware surfaces to meet final cleanliness requirements.

REFERENCES

1. Snyder, J. T.; Aqueous Degreasing: A Viable Alternative To Vapor Degreasing; Martin Marietta Astronautics Group Report; and private conversations

2. Marts, K. and Howard, J.; CFC Alternative Cleaning Systems: Alternative Processing Techniques and Their Effectiveness In Precision Cleaning; Journal of The Institute of Environmental Sciences; V. 34 (5); Sept/Oct 1991