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HOT AIR DECONTAMINATION OF THE C-141 AIRCRAFT TECHNOLOGY DEVELOPMENT PROGRAM

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14. ABSTRACT
Hot Air Decontamination (HAD) is a process involving the elevation of temperatures, which accelerates the removal of chemical agents from materials without affecting their integrity. A preliminary feasibility study identified a relevant evaporation model. Results from this study formulated a two-phased technology development and testing effort. This program characterized evaporation of chemical agents from representative aircraft materials, and developed and demonstrated the effectiveness of a Hot Air System (HAS) to elevate and maintain surface temperatures and air velocities of the cargo area of a military aircraft, the C-141 Starlifter. Field thermal data indicated that an average temperature of 150.1 °F ± 4.3 °F and an average air velocity of 3.5 ft/sec was achieved and maintained on aircraft cargo bay surfaces. To characterize the evaporative effects of agents on representative materials, laboratory tests, which involved coupon and evaporative studies were conducted. These studies characterized agent evaporation at realistic conditions and correlated these results with simulants. Analytical data from the laboratory suggested that hot air (150 °F) provides a 2-log reduction of surface contamination (1 g/m^2) for mustard, thickened mustard, and VX agents when exposing contaminated materials for 3, 4, and 20 hr, respectively. Coupon studies further validated the laboratory results.

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PREFACE

The work described in this report was authorized under Project No. 30603384BP0. The work was started in July 2003 and completed in January 2004.

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Acknowledgments

The U.S. Army Soldier and Biological Command* provided program oversight, coupon material fabrication, technical support, and funding for this project.

The Battelle Eastern Science and Technology (BEST) Center conducted Hot Air System and test fixture design, field engineering, procurement, operations management, and technical and program management. The Battelle's Hazardous Materials Research Center (HMRC), conducted simulant and agent sampling procedures and analysis for both the laboratory and field operations.

CooperHeat, MQS provided design and field engineering, procurement, construction, installation, and operation of the HAS for field operations including instrumentation, control, and monitoring support.

The Program Manager (PM) for the C-141 Special Programs Office (SPO) provided the field test site. The PM also reviewed and approved test and safety plans and procedures used during field operations, and served as a technical resource for aircraft specifications and requirements.

The Aerospace Maintenance and Regeneration Center provided site support including escorts, facility resources (fuel, wood shop, vehicles, and equipment), and safety oversight.

*Now known as the U.S. Army Research, Development and Engineering Command.

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HOT AIR DECONTAMINATION
OF THE C-141 AIRCRAFT TECHNOLOGY DEVELOPMENT PROGRAM

1. INTRODUCTION

The Joint Service Sensitive Equipment Decontamination (JSSED) program charter is to develop sensitive equipment and vehicle/aircraft interior decontami-nation systems. The JSSED Technology Working Group in 2002 published the Analysis of Alternatives (AoA) Report for the technology segments Blocks-II/III,* which includes vehicle, ship and aircraft interiors. The AoA is an evaluation of current commercial technologies considered suitable for chemical and biological decontamination of sensitive interior surfaces and associated on-board components.** None of the technologies evaluated could be considered technically mature enough to transition into an acquisition program. However, several technologies did survive the critical technical and cost-effectiveness evaluation. Neither the thermal desorption nor the application of temperature to accelerate the release of contamination through natural evaporation scored relatively high chiefly due to its non-invasive effects on surfaces. As a result, a basic integration development program was initiated through the U.S. Army Edgewood Chemical and Biological Center (ECBC), Aberdeen Proving Ground, Maryland.

The objective of this program is to determine whether hot air is a viable approach for decontaminating the interiors of aircraft exposed to CW agents. The aircraft selected for testing was a decommissioned Air Force C-141B Starlifter located on an open airfield at the Aerospace Maintenance and Regeneration Center (AMARC) on the Davis-Monthan Air Force Base (Tucson, AZ).

Other objectives of the field and laboratory studies were to:

- Generate data for the hot air process using a thoroughly instrumented system. Use this data to evaluate system requirements, performance, and meteorological effects during operation.

- Develop data collection and analysis techniques and protocols for use in field and laboratory studies (e.g., agent and simulant dosing and extraction methods).

The laboratory testing included over 400 samples, seven representative materials, and three exposure times to characterize evaporation of HD, thickened HD, and VX agents from coupons. The field testing included approximately 100 samples, over 200 dynamic temperature sampling points, seven representative materials, and fourteen system trials over varied meteorological conditions to develop system requirements and demonstrate the performance of a Hot Air System (HAS).

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*Baig, Imran A., et al., *Literature Search and Feasibility Study on Thermal Desorption for Decontaminating the Interiors of Combat Vehicles*. Battelle Eastern Science and Technology Center, unpublished data, September 2003.

**Mueller, Mark, *Analysis of Alternatives (AoA) Report: Joint Service Sensitive Equipment Decontamination (JSSED) Development Blocks II and III*, unpublished data, March 2003.

1.1 Background/Prior Research.

Results from a literature search indicated that a number of past studies were conducted on decontamination of aircraft interiors involving thermal evaporation. However, most of these programs studied process and surface temperatures above 200 °F, which are incompatible with current military aircraft equipment specifications. In addition, previous research neglected consideration of a convective heat transfer analysis. This analysis was significant and relevant for optimal system development and performance. The temperature storage limit of aircraft components is 160 °F due to sensitive items such as electrical circuitry; moreover, fuselage circuitry has the ability to withstand a maximum operating temperature limit of 140 °F. Because little experimental data is available on agent evaporation rates at these temperatures, several evaporation models were reviewed to predict the time required to evaporate chemical agents at varying temperatures. Dr. Kenneth Chinn's model for estimating agent evaporation was selected.* The estimate of evaporation of chemical agent using Dr. Chinn's model is dependent on variables such as droplet size, wind speed, volatility, and purity. Evaporative model results and the detailed system analysis provided confidence to proceed with the experimentation phases of the program. In addition to the variables noted by Dr. Chinn, other parameters are included that are related to the aircraft interior surfaces and evaporative loss. Correlations between chemical agent, surrogate agent, and surface material are part of the test matrix.

1.2 Program Technical Approach.

The technical approach of this program involved a feasibility study and a two-phased technology development and testing effort (Figure 1). The feasibility study consisted of three consecutive components, which were a literature search, data analysis, and modeling. Recommendations from the feasibility study and system analysis mitigated the technical risks involved with the two-phased development and testing effort.

Phase I of the development and testing effort was conducted in two steps. Step 1 involved system development and performance characterization testing. Step 2 involved the evaporative field-testing. The purpose of Step 1 was to develop and establish system requirements and procedures for achieving optimal performance of a HAS in the field. The purpose of Step 2 was to remobilize the HAS, confirm its previous performance, and validate laboratory results by conducting simulant efficacy testing using contaminated coupons left inside the aircraft during heat cycles.

The Phase II laboratory testing effort involved the collection and analysis of representative coupons, which were contaminated with chemical agents and simulants. These coupons were exposed to hot air conditions observed in Step 1. Phase II established correlations between agent and simulant evaporative data and provided preliminary data on the chemical agent removal efficacy associated with the HAS conditions.

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*Baig, Imran A., et al., *Literature Search and Feasibility Study on Thermal Desorption for Decontaminating the Interiors of Combat Vehicles.* Battelle Eastern Science and Technology Center, unpublished data, September 2003.

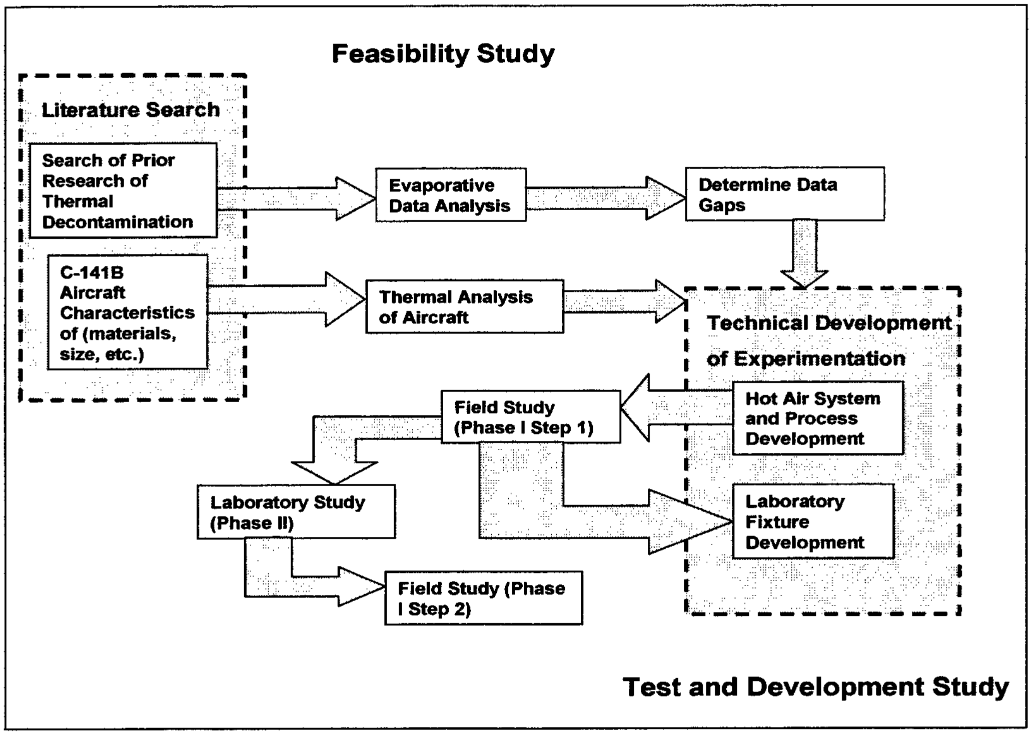

Figure 1. Technical Approach Flow Diagram

1.3 Program Assumptions.

The following assumptions were developed to maintain a reasonable and focused scope considering technical, budgetary, and scheduling constraints.

- The decontamination envelope in the aircraft consisted of all interior fuselage surfaces except the cockpit and unpressurized aft fuselage area, which is to the rear of the pressure door. This fuselage area is defined as the area between the crew door wall, the pressure door, and below the top edge (8' above the aluminum decking) of the fiberglass panels.

- A surface contamination level of 1 g/m^2 was used to represent contamination due to a transfer hazard from contaminated cargo or personnel entering an aircraft cargo area.

- Because aircraft configurations and materials vary from one aircraft to the next, system performance (e.g., heat-up times, temperature distribution) may not be directly related to other vehicles.

- HAS performance and the analytical data collected in this program are for the conditions of these testing efforts only and may not be valid for different environmental conditions, process durations, temperatures, or materials.

2. HAS OVERVIEW

2.1 HAS and Process Description.

The HAS is designed to decontaminate the interior cargo areas of aircraft. Hot burner exhaust air is directed into a mixing chamber and is then carried through a distribution duct into the aircraft. The HAS volatilizes chemical contamination on surfaces by distributing hot air into the fuselage, which elevates the surface temperatures of aircraft or aircraft cargo materials. The fuselage is maintained under positive pressure by two high velocity blowers; one blower directs air to the burner and the other blower mixes outside air with the burner exhaust that enters the mixing chamber. Once entering the aircraft, exhaust air and off-gas are controlled through plywood damper interfaces sealed to the crew doors at the rear of the aircraft. All equipment, instrumentation, and controls were designed for maximum safety and environmental protection.

Figure 2 shows a schematic of the HAS process. Figures 3 through 6 are photographs of the C-141, HAS, and associated process equipment. A brief description of each follows below.

- **Burner** is a multi-million BTU capacity, forced, direct propane-fired burner consisting of high velocity blower assemblies, a multi-million BTU gas train, and an electric propane vaporizer.

- **Mixing chamber** is located immediately downstream of the burner to facilitate cooling and temperature control of the burner exhaust air entering the aircraft.

- **Distribution system** consists of a cylindrical inlet duct, interfaced to the exit side of the mixing chamber. This duct feeds a rugged, adjustable, "breadboard" distribution duct located within the aircraft.

- **Generators** power the blowers, gas vaporizer, and control system.

- **Control system** includes a data acquisition unit (DAU) fed by type K thermocouples, junction boxes, and extension wires. The DAU allows control, monitoring, and data collection necessary for the operation of the HAS.

Technicians monitor operation of the HAS from a control trailer that houses the DAU. Pressure and temperature are monitored periodically to ensure safe and efficient operation of the HAS. In addition, the DAU is a record-keeping system that maintains electronic and hardcopy records. The burner output, controlled by an electronic valve within the gas train, regulates process air temperatures. The process air, which is the temperature of the turbulent air distributed within the aircraft, and maximum surface temperatures provides feedback for control of the system.

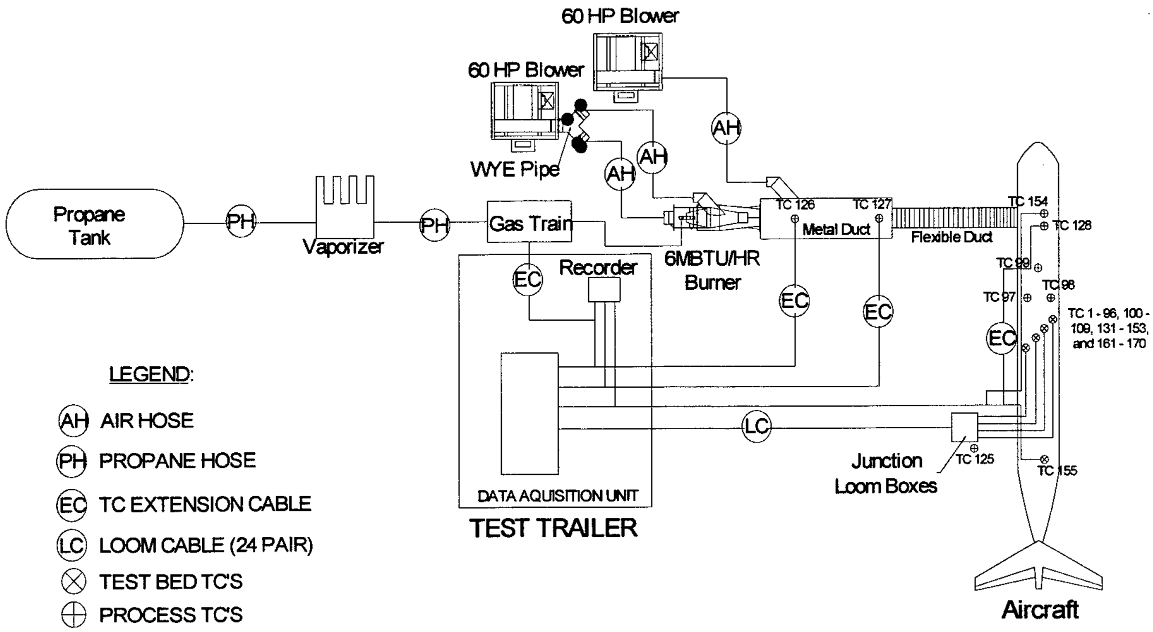

Figure 2. Schematic of the Hot Air Decontamination System Installed on a C-141

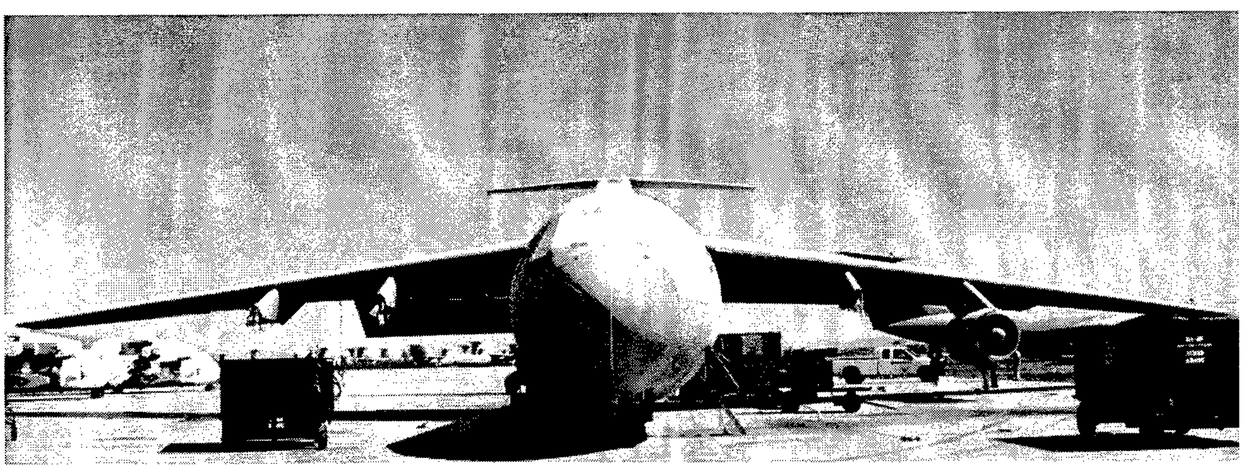

Figure 3. Frontal View of the C-141B Starlifter Test Aircraft Located on a Test Pad Davis-Monthan Air Force Base

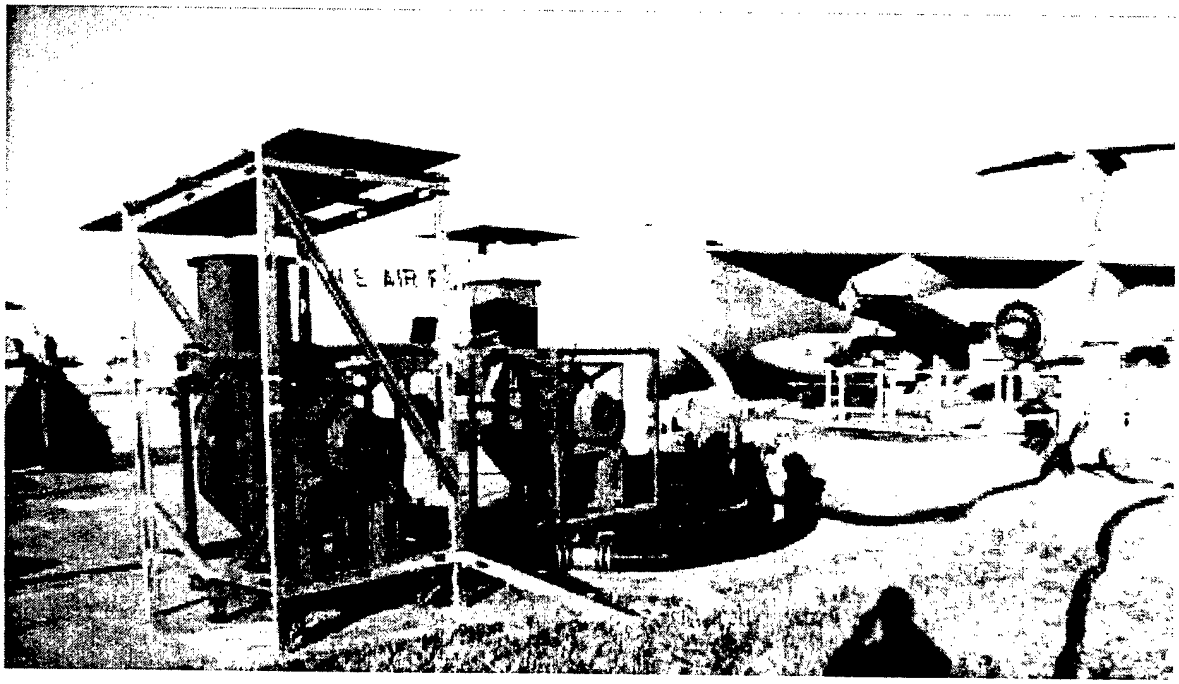

Figure 4. Tandem High Velocity Blower Assemblies Connected to the HAS Mixing Chamber

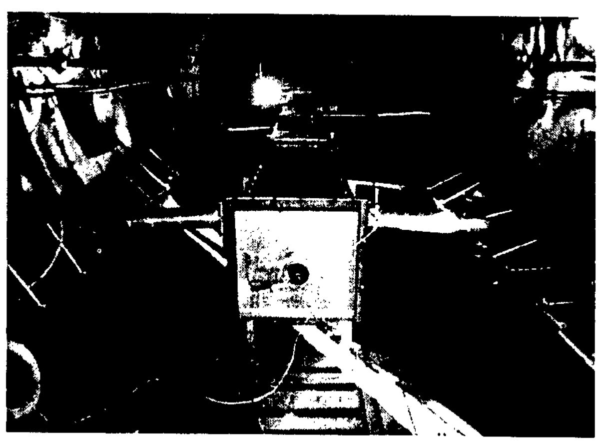

Figure 5. View from the Crew Deck of the Interior Hot Air Distribution Duct

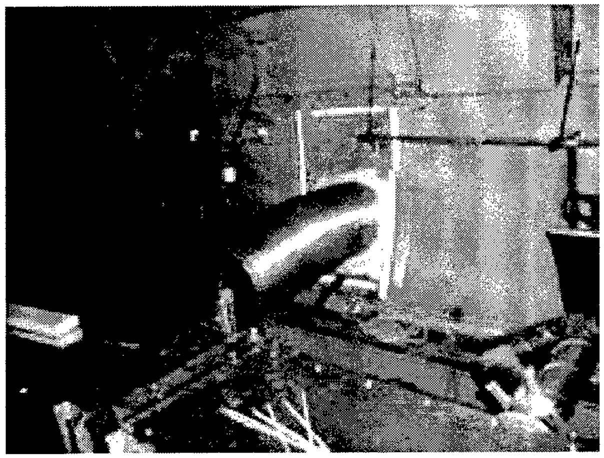

Figure 6. Interior View of the Interface Between the Interior Distribution Duct and the Flexible Supply Duct

2.2 HAS Development and Operation.

The Phase I field development and testing effort was conducted in two steps. Step 1 was conducted from 8 - 17 April 2003, and focused on developing an optimized system and establishing system parameters. Step 2 was conducted 27 – 31 July 2003 to remobilize the optimized system and validate, in the field, the evaporative results from Phase II. Thermocouples provided dynamic surface and process temperature information. An air velocity probe characterized air profiles at surface locations within the cargo bay during system operation. Throughout the testing, consumption rates of propane gas, diesel fuel, and electricity were tracked. HAS operating and support material expenses and direct labor costs were used to estimate indirect life cycle costs of hot air as an approach for future applications.

Monitoring surface and process temperatures during the heat cycle was critical in the system optimization process. Early in the test effort, optimization cycles began at lower threshold temperatures. In subsequent tests, temperatures were increased until optimal system and process parameters and procedures were developed. The system and process achieved steady-state surface temperature conditions below but near the maximum allowable temperature of 160 °F. Air velocity data collected for each system configuration were used to optimize the velocities within the fuselage. By adjusting the ducting (damper settings, direction of flow, location and number of orifices, etc.), a uniform velocity distribution was achieved throughout the cargo area.

Airflow was critical to balancing and maintaining the convective heat transfer needed to achieve optimal performance. An average temperature of 150 °F was maintained for test durations of over 24 hr for all surfaces measured. The thermocouple data provided temperature profiles of the interior surfaces of the aircraft fuselage. Furthermore, temperatures were monitored from the DAU system thermocouples to control operating conditions.

There were approximately 200 thermocouples used to measure temperature. Approximately 180 sensors (Figure 7) represented a distribution of interior surfaces, while approximately 20 thermocouples were used to measure process temperatures. Surface temperature measurements included aluminum decking, fiberglass interior panels, painted aluminum, exposed doorframe structures, painted aluminum cabinets, seat webbing, resin cloth insulation, wiring surfaces, and miscellaneous sensitive equipment. Process temperature measurements included ambient air, process air temperatures, outside aircraft skin, high and low sides of the mixing chamber, and the inlet duct.

Process control was achieved by monitoring thermocouple readings and adjusting the burner valve settings accordingly. Electronic readings were monitored on a computer display in real-time, while hardcopy readings were monitored in 5-min intervals. From experience gained in early trials, specific thermocouples were identified as achieving higher than average temperatures during heat cycles. These locations were elevated to near the threshold temperature, which provided a temperature measurement ceiling. The valve feeding the burner was adjusted electronically to raise or lower these higher thermocouple readings. Burner valve adjustments maintained control of the higher temperature readings within a few degrees under the threshold. Burner adjustments averaged 5 or 6/hr depending on changes to the meteorological and environmental conditions such as sunrise, sunset, wind, visibility, outside temperature, and rain, etc.

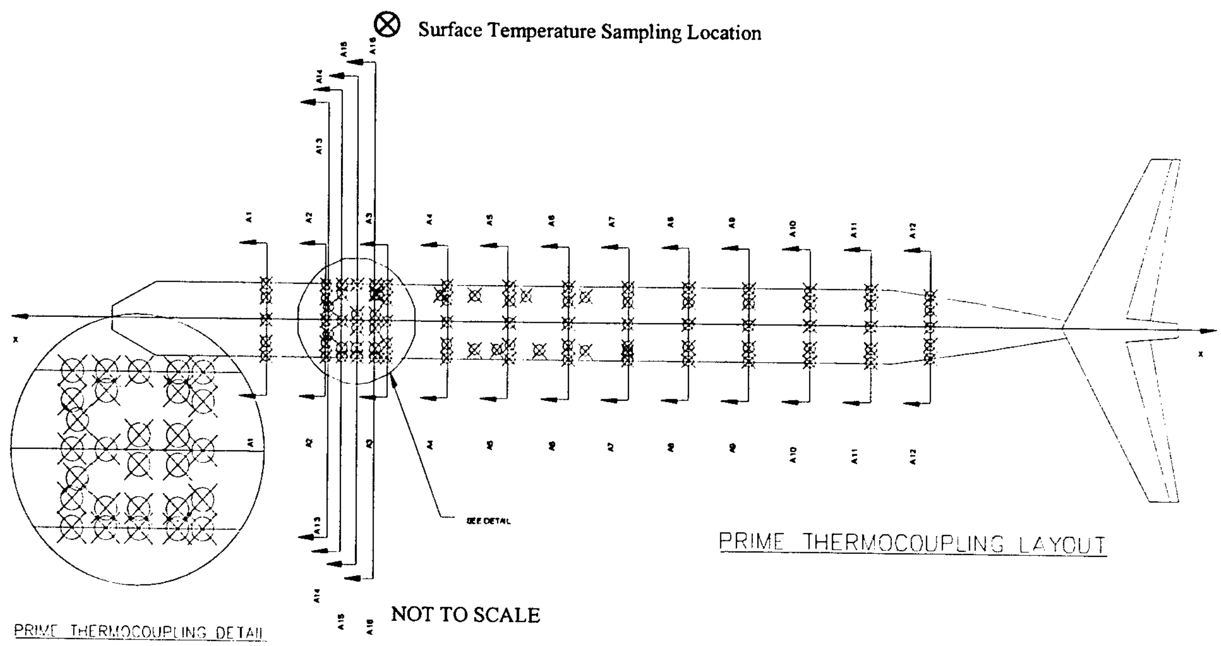

Figure 7. Schematic of the Thermocouple Locations in the C-141B Used During Field Testing

3. COUPON TESTING PROCEDURES

3.1 Laboratory Testing with Agents and Simulants.

The laboratory testing was conducted to measure the agent and simulant evaporation with exposure to forced hot air. In addition, a correlation was established between chemical agent and chemical agent simulants. Three chemical agents and corresponding simulants were selected for testing, including HD and methyl salicylate (MeS), thickened HD and thickened methyl salicylate (tMeS), and VX and diethyl sebacate (DeS). Seven aircraft materials were evaluated, including bare aluminum (Al 2024), polyimide (Kapton), butyl-coated insulated cloth (Boeing product), nylon cloth (MIL-C-7219), clear polycarbonate, Chemical Agent Resistant Coating (CARC) (MIL-C-53039A), and U.S. Air Force Topcoat (AF Topcoat) (MIL-PRF-85285C).

The test coupons were contaminated at a nominal density of 1 g/m^2 using a single 1-µL drop on a 10 cm^2 coupon. The chemicals were allowed to soak into the materials for 60 min prior to initiation of the forced hot air flow. Each coupon was then exposed to a flow of hot air (3.5 ft/sec, 150 °F) for selected times. The evaporation was measured by extracting the residual chemical agent or simulant from the test coupons in hexane.

3.2 Simulant Field Testing.

Simulant testing was performed in conjunction with Phase II testing using the simulants MeS, tMeS, and DeS on all seven material types. The test coupons were contaminated at a nominal density of 1 g/m^2 using a single 1µL drop on a 10 cm^2 coupon. The simulants were allowed to soak into the materials for 60 min prior to initiation of the hot air decontamination of the aircraft. The coupons contaminated with MeS and tMeS were in the aircraft for 4 hr of hot air decontamination. The coupons contaminated with DeS were in the aircraft for 20 hr of hot air decontamination.

4. FIELD TESTING

4.1 HAS Performance Results.

Temperature monitoring and collection was conducted as an indicator of the HAS performance. Figures 8 through 10 present data from two field trials, Tests 11 and 12. Test 11 results provide operational data during ideal summer conditions. The average surface temperature achieved was 150.1 °F ± 4.3 °F with an average air velocity of 3.5 ft/sec. The time to reach steady-state temperature was determined as 1.5 hr. This represents best case system performance considering the beneficial meteorological environment (higher ambient temperature, lower ambient wind velocity, and radiant sunlight conditions) that provides lower heat losses at surfaces during heat-up.

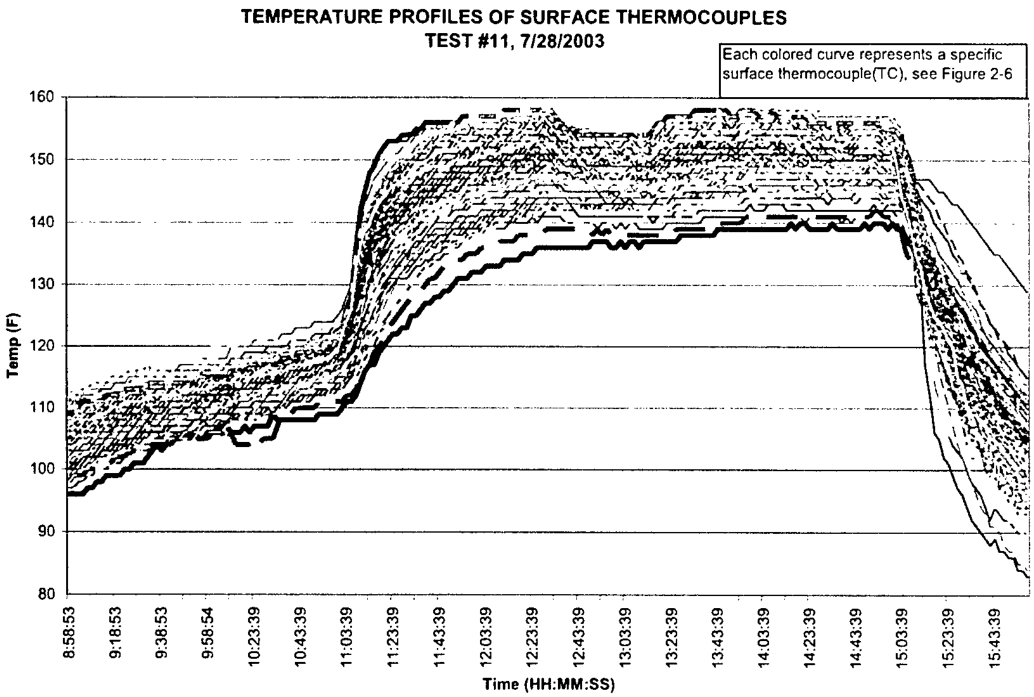

Figure 8. Temperature Profile Graph for a 4-Hour Heating Trial (Test 11) Results from all of the internal thermocouples are shown.

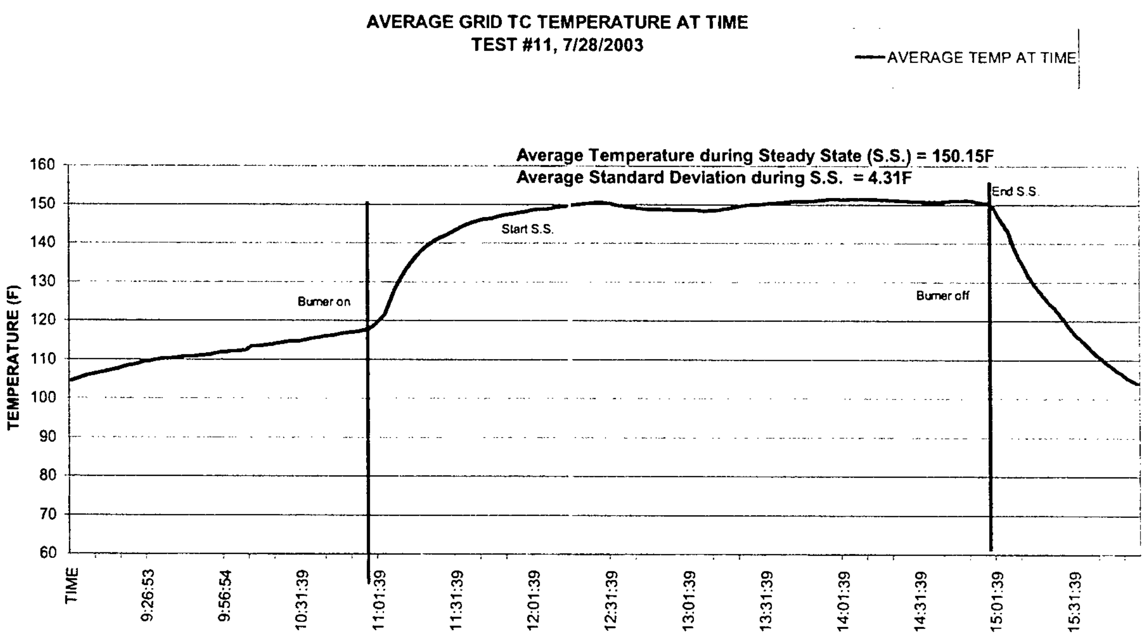

Figure 9. Average Temperature Profile Graph for a 4-Hour Heating Trial (Test 11) The average grid temperature is determined from the individual thermocouples shown in Figure 8.

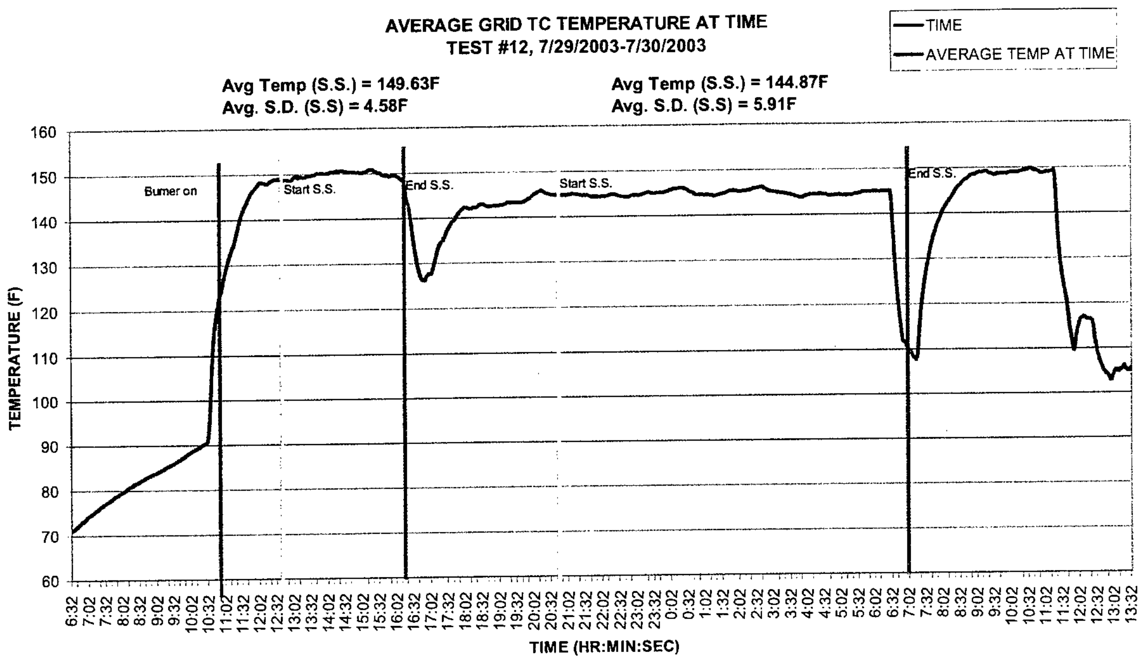

Figure 10. Average Temperature Profile Graph for a 20-Hour Heating/Coupon Efficacy Trial (Test 12). The average grid temperature was determined from the individual thermocouples shown in Figure 8.

Consequently, Test 12 represents system performance during non-ideal conditions (heavy rain, high winds, lower temperatures, cloud cover, and night conditions). In the initial phases of this trial, steady-state conditions mirror Test 11 performance with the average temperature calculated at 149.6 °F ± 4.6 °F. At 10 hr into Test 12, a severe storm swept through the test bed and brought heavy rain, lower ambient temperatures, and high winds. After an initial drop in temperature, the system regained steady-state performance within 3.5 hr, but at a lower average temperature and slightly higher standard deviation, 144.8 °F ± 5.9 °F. Heat losses are higher during non-ideal conditions; consequently, a lower average temperature and more variability is expected. This follows theoretical estimations from the thermal analysis conducted in development of the system design.

4.2 Coupon Testing Results.

Coupon extractions for HD, MeS, tHD, and tMeS were below detection limits after 1 hr of hot air decontamination for the bare aluminum, Kapton, AF topcoat, and nylon cloth. The data is shown in Tables 1 and 2, and the corresponding plot in Figure 11. Additionally, the data show a good correlation between HD/MeS and tHD/tMeS (data not shown).

Table 1. Percent of HD/MeS Remaining after Hot Air Decontamination

MATERIAL	*AGENT/ SIMULANT*	*AFTER 1-HR AMBIENT*	*HOT AIR DECON TIME*		
			1 HR	2 HR	3 HR
ALUMINUM	HD	95.7%	0.5%	0.5%	0.5%
	MES	96.4%	0.5%	0.5%	0.5%
CARC	HD	Not tested	16.3%	3.9%	4.6%
	MES	Not tested	6.7%	3.7%	2.0%
INSULATED CLOTH	HD	96.9%	11.9%	1.3%	0.5%
	MES	75.0%	11.9%	0.8%	0.5%
KAPTON	HD	101.6%	0.5%	0.5%	0.5%
	MES	76.0%	0.5%	0.5%	0.5%
POLYCARBONATE	HD	96.2%	8.8%	2.5%	1.0%
	MES	74.0%	11.9%	4.3%	1.9%
AF TOPCOAT	HD	87.6%	0.5%	0.5%	0.5%
	MES	11.0%	0.6%	0.6%	0.6%
WEBBING	HD	10.6%	0.5%	0.5%	0.5%
	MES	13.7%	0.7%	0.7%	0.7%

Table 2. Percent of tHD/tMeS Remaining after Hot Air Decontamination

MATERIAL	*AGENT/ SIMULANT*	*AFTER 1-HR AMBIENT*	*HOT AIR DECON TIME*		
			1 HR	2 HR	3 HR
ALUMINUM	tHD	66.5%	0.5%	0.5%	0.5%
	tMES	57.9%	0.6%	0.6%	0.6%
CARC	tHD	Not tested	0.8%	0.5%	0.5%
	tMES	Not tested	2.1%	2.2%	1.8%
INSULATED CLOTH	tHD	78.9%	7.4%	0.6%	0.6%
	tMES	73.4%	10.3%	1.1%	1.2%
KAPTON	tHD	75.8%	0.5%	0.5%	0.5%
	tMES	58.6%	0.6%	0.6%	0.6%
POLYCARBONATE	tHD	87.6%	7.7%	1.3%	0.6%
	tMES	62.2%	11.8%	5.9%	2.2%
AF TOPCOAT	tHD	72.2%	0.5%	0.5%	0.5%
	tMES	54.2%	0.6%	0.6%	0.6%
WEBBING	tHD	35.2%	0.5%	0.5%	0.5%
	tMES	41.1%	0.7%	0.7%	0.7%

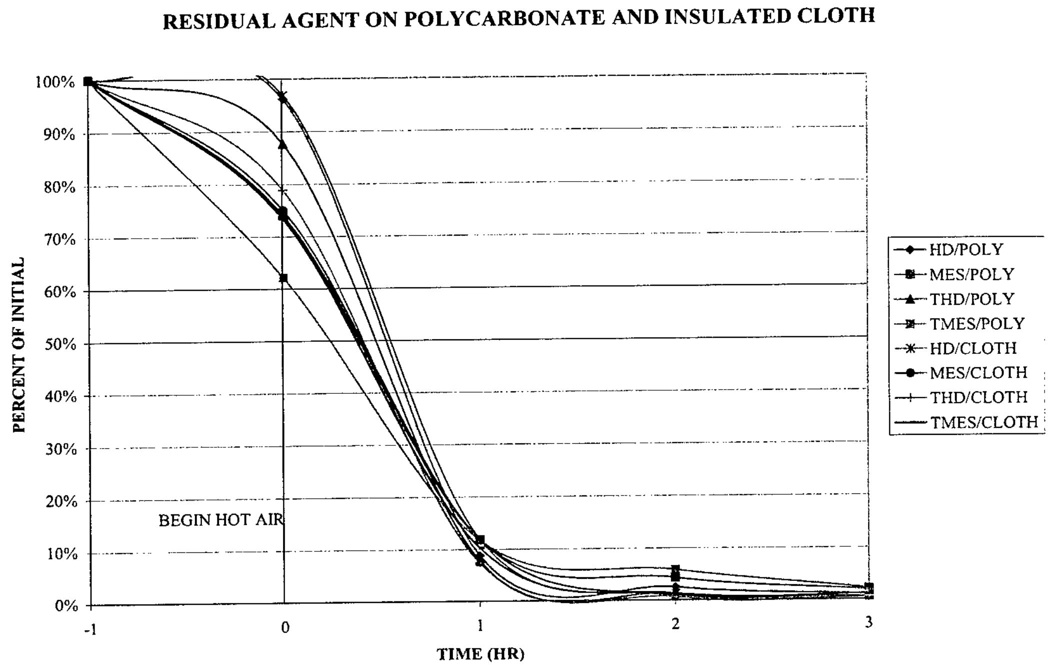

Figure 11. Residual HD, Mes, and tMeS on Polycarbonate and Insulated Cloth

The residual agent/simulant extracted from the coupons during laboratory testing was averaged for the replicates and normalized to the percent of agent/simulant applied. The detection limit of the test ranged from 0.5% to 0.7% of the amount of agent/simulant applied. The residual VX/DeS on the test materials after hot air decontamination are shown in Table 3 and corresponding Figure 12.

Table 3. Percent of VX/DeS Remaining after Hot Air Decontamination

MATERIAL	*AGENT/ SIMULANT*	*AFTER 1-HR AMBIENT*	*HOT AIR DECON TIME*		
			4 HR	8 HR	20 HR
ALUMINUM	VX	91.9%	1.4%	1.0%	0.7%
	DeS	82.7%	4.7%	0.9%	0.6%
CARC	VX	Not tested	10.8%	1.4%	0.7%
	DeS	Not tested	28.6%	15.0%	6.6%
INSULATED CLOTH	VX	95.6%	50.6%	29.5%	5.8%
	DeS	77.9%	64.8%	58.3%	25.5%
KAPTON	VX	88.9%	1.0%	0.7%	0.7%
	DeS	82.9%	42.1%	8.5%	0.6%
POLYCARBONATE	VX	106.3%	11.9%	3.2%	0.7%
	DeS	84.4%	46.8%	26.9%	5.3%
AF TOPCOAT	VX	86.1%	12.3%	0.9%	1.4%
	DeS	94.0%	9.0%	3.1%	1.0%
WEBBING	VX	90.0%	0.8%	0.8%	0.8%
	DeS	65.8%	2.1%	0.8%	0.7%

RESIDUAL AGENT ON POLYCARBONATE AND INSULATED CLOTH

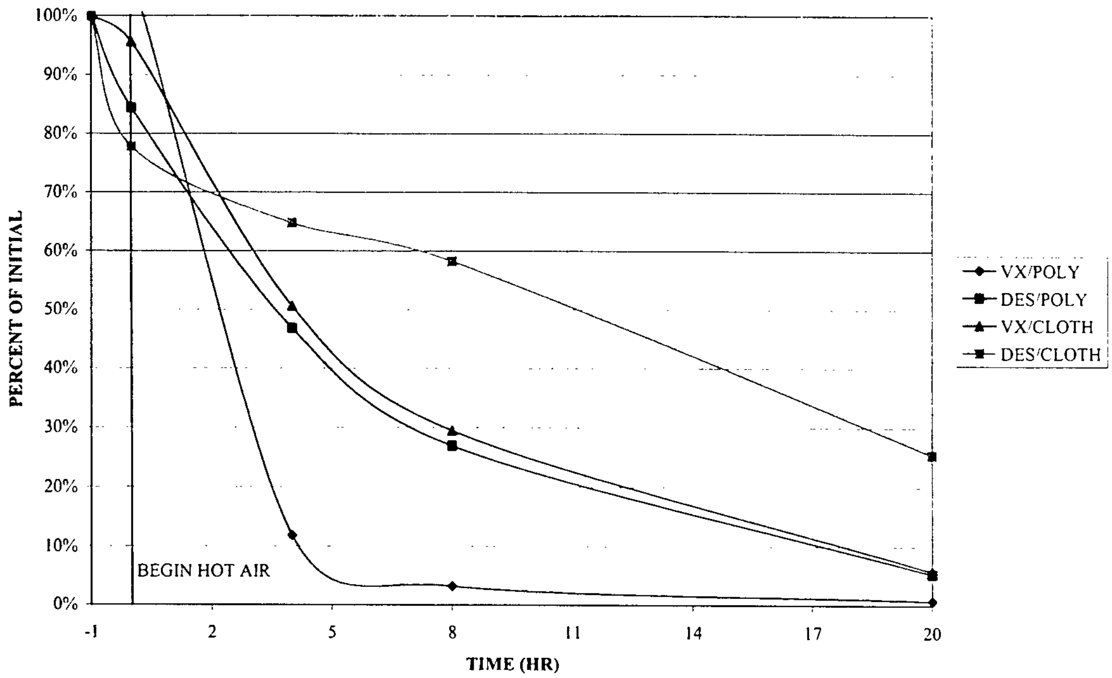

Figure 12. Residual VX and DeS on Polycarbonate and Insulated Cloth

As expected, differences in agent evaporation rates exist between some of the materials tested. It appears that for VX, the insulated cloth, followed by the AF topcoat, are the more difficult of the surfaces to decontaminate using hot air at the temperatures applied during this testing. For the other surfaces tested, the amount of agent remaining after 20 hr of laboratory scale hot air decontamination is at or below the limits of laboratory detection. The laboratory coupon data also show a good correlation between VX/DeS for aluminum, kapton, AF topcoat, and nylon webbing, but a relatively poor correlation for the CARC, insulated cloth, and polycarbonate.

Table 4 shows a comparison of the laboratory and field test coupon results. Except for insulated cloth and polycarbonate, it appears that the HAS effectively removed the simulants from the coupons during the field trials. Laboratory results appear to confirm the relative difficulty of removing DeS from insulated cloth and polycarbonate.

Table 4. Comparison of Laboratory and Field Trial Coupon Testing Results

MATERIAL	*LAB MeS*	*FIELD MeS*	*LAB tMeS*	*FIELD tMeS*	*LAB DeS*	*FIELD DeS*
	3-HR	4-HR	3-HR	4-HR	20-HR	20-HR
ALUMINUM	<0.5%	<0.5%	0.6%	<0.5%	0.6%	<0.5%
CARC	2.0%	<0.5%	1.8%	<0.5%	6.6%	<0.5%
INSULATED CLOTH	<0.5%	<0.5%	1.2%	<0.5%	25.5%	9.5%
KAPTON	<0.5%	<0.5%	0.6%	<0.5%	0.6%	<0.5%
POLYCARBONATE	1.9%	3.4%	2.2%	2.7%	5.3%	29.8%
AF TOPCOAT	0.6%	<0.5%	0.6%	<0.5%	1.0%	<0.5%
WEBBING	0.7%	Not tested	0.7%	Not tested	0.7%	<0.5%

5. CONCLUSIONS

The trial application of a Hot Air System (HAS) on the cargo area of a C-141 Starlifter showed promising results. Using a conservatively designed HAS system composed of readily available components, the target surface temperatures in this area were achieved with a reasonable amount of variability caused by known factors such as the thermal properties of materials, thermal pathways, changes in ambient conditions, and air flow patterns. With an average airflow of approximately 3.5 m/s and an average temperature of 150 °F for 4 hr, coupon studies within the aircraft showed a reduction of methyl salicylate (MeS) and thickened methyl salicylate (tMeS) to below detection limits on all sample aircraft materials except for polycarbonate. When the decontamination time was increased to 20 hr, the polycarbonate and insulated cloth coupons dosed with diethyl sebacate were still contaminated with the simulant. The retarded evaporation rates of the simulants from these materials were also seen in corresponding laboratory coupon evaluations. The lab studies indicated that the agents demonstrated similar material interactions but to a lesser extent than the simulants.

Based on these findings, the efficacy of using hot air decontamination for removal of chemical agents is sound for the studied C-141 system. The coupon data indicates that decontamination times in excess of a day may be necessary to meet the challenge of VX. Because airflow distribution is critical for effective decontamination, the air distribution system will need to be modified to apply this technique to other aircraft designs. Furthermore, differences in the materials of construction and airframe design may require different airflow strategies to achieve target surface temperatures. In addition, the study showed a significant interaction of outside environmental conditions on the performance of the HAS. The present study was accomplished during summer conditions. It would be beneficial to repeat the above evaluation in winter conditions to define limitations of the system design to this relevant environment.