APPENDIX F

CONTRACT SUMMARY REPORT

CONTRACT SUMMARY REPORT

CDRL A006, DI-S-3591/A

for

Semi-Automation and Industrialization of a Pressurized Water Coatings Removal System

1.0 INTRODUCTION

1.1 Objective

The objective of this program was to prototype a semi-automated pressurized water coatings removal system designed to meet the following goals for depaint C-130 and C-141B aircraft at Robins AFB:

Production Throughput	Less than 28 hours of stripping time for a C-130 aircraft, less than 38 hours of stripping time for a C-141B
Scheduled Maintenance	Less than 1 hour per 100 hours
Unscheduled Maintenance	Less than 1 hour per day (based on 16 hr/day)

1.2 Scope

The scope of this effort was:

(a) to conceptualize the manipulator system and all the other items needed for an industrialized semi-automated pressurized water coatings removal system
(b) to construct a prototype system
(c) to conduct functional and durability tests to demonstrate the utility, reliability and maintainability of the prototype system
(d) to install the prototype system into Building 50 at Robins AFB and train operators for follow-on demonstration
(e) to prepare a facilitization plan for the future production depainting system
(f) to prepare drawings, manuals, and other documents to aid technology transfer. As envisioned, the future production depainting facility at Robins AFB will include the prototype system described herein plus two replicates.

2.0 TECHNICAL DISCUSSION

This report presents a brief summary of the technical approach and the results obtained. Details are provided in the reports listed as references.

2.1 Technical Approach

A rigorous focus on R&M issues guided each step of the design and development process, from the early layouts through to decisions regarding replacement parts and assemblies. This attention to detail, together with the involvement of end-users in each step of the design process, led to the development of a production-ready prototype system. Specifically, Battelle's approach[1] was to:

- Define the system requirements[2] and concept selection criteria
- Conduct a trade study to down-select the "best" system concept[3]
- Design an integrated prototype system and perform R&M analysis[4]
- Procure and fabricate prototype system components
- Prepare a facilitization plan for the future depainting system[5]
- Conduct functional tests[6,7] and limited durability tests[8,9]
- Prepare drawings and parts lists sufficient for procurement of replicates[10]
- Prepare Operator's Manuals and Training Manuals[11] to aid technology transfer
- Prototype the system at Robins AFB, conduct verification tests[12,13], and train staff.

2.2 System Overview

The selected concept (Figure 1) is a fully-integrated mobile depainting system that uses high-pressure water to semi-automatically remove protective coatings from C-130 and C-141 aircraft without the expense and complexity of an abrasive media, and without the need for chemical softeners. The system includes a manipulator-mounted nozzle, a water pressurization system, a process control system, collision avoidance features, and an effluent collection and water recycling system. A single operator controls the manipulator positioning and initializes the coatings removal process. This operator can halt the system at any time and is expected to modulate the traverse rate based on visual monitoring of the coatings removal process.

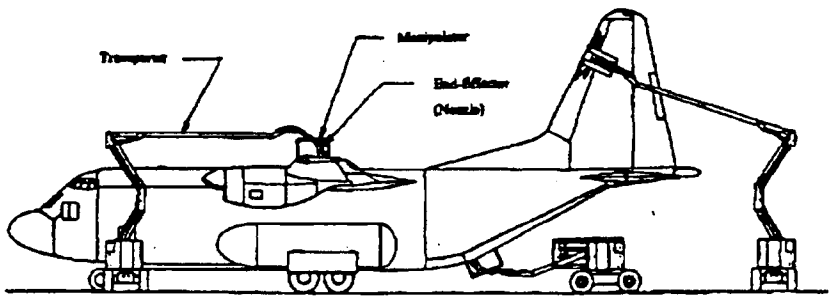

Figure 1. Prototype System Schematic

This system features a rotating high-pressure water nozzle that was previously qualified for use on USAF aircraft, and an effluent recovery system and a water reclamation system that were developed for use on a Navy ship hull coatings removal system.[14] The prototype was designed and constructed by Waterjet Systems, Inc., under a subcontract agreement with Battelle

The prototype system was installed at Robins AFB in May, 1998 following several weeks of system validation testing at Waterjet Systems' facility. Demonstrations on a C-130 aircraft (Figures 2 through 4) indicated that this system can strip polysufide coatings at a rate of 312 ft^2/hr

(5.2 ft^2/min), and can be repositioned for the next stripping operation within 7 minutes (on average). The process leaves the aircraft surface clean and dry (Figure 5). The dimensions of the manipulator were intended to allow the semi-automated system to access more than 60-percent of the surface on C-130 and C-141B aircraft. However, the recent validation tests indicate that this goal has not been realized. The two additional mobile units will need to have smaller manipulators (e.g., 9 ft^2/patch) so that the fully-implemented coatings removal system will be able to strip 7,000 ft^2 from C-130 aircraft. This change increases the C-130 processing time from 30 hours/aircraft (target value) to 33 hours/aircraft for polysulfide coatings, and to 38 hours/aircraft for the more difficult epoxy coatings.

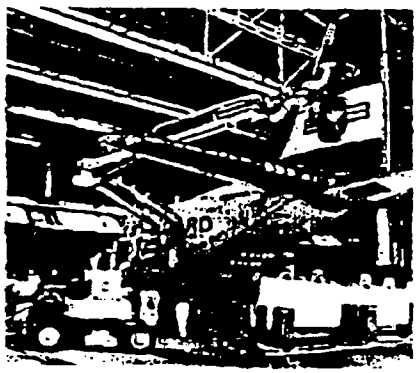

Figure 2. Prototype Ready to Depaint Vertical Stabilizer

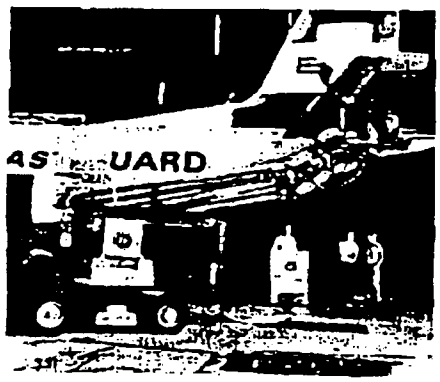

Figure 3. Prototype System Depainting Horizontal Stabilizer

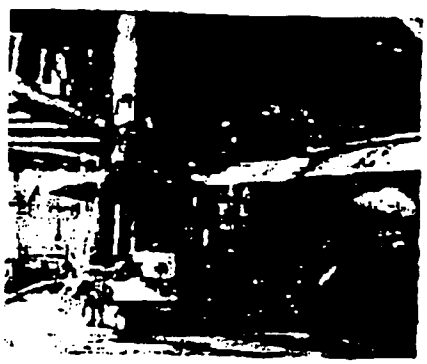

Figure 4. Prototype System Depainting Wing

Figure 5. Depainted Surface of Fuselage

The prototype system requires two operators – one to position the manipulator and one to operate the remotely located process equipment: the high-pressure water pump, the effluent collection system elements, and the water reclamation system. However, only four operators would be necessary to operate the three systems of this type that are necessary to achieve WR-ALC's

production throughput goals. When fully implemented, the semi-automated systems have the potential to reduce the labor costs per aircraft by as much as 40-percent compared to present methods.

The only hazardous waste materials generated by this process – paint chips and residue – are automatically captured and deposited into a 55-gallon drum for easy disposal. Operators and maintenance staff quickly became proficient at using the system. Operators see the virtues of this method that does not require manual nozzle manipulations, cumbersome protective clothing, or any clean up of the hangar floor

2.3 System Elements

The semi-automated coatings removal system hardware consists of an end-effector subsystem, a manipulator assembly, a mobile transporter, a remote operator control panel, a high-pressure water pump, an effluent collection system, and a water reclamation system. Software controls the end-effector motion and stripping process parameters. Landing controller software automatically slows all motions and normalizes the manipulator as the foot-pads approach the aircraft's surface. The collision avoidance sensors and software help to prevent unwanted contact with aircraft features. Additional descriptions of these functional elements are provided below.

2.3.1 End-Effector Subsystem

The end-effector subsystem includes a 6-inch-wide (15 cm) rotating nozzle element surrounded by an effluent-recovery shroud and surface compliance and collision-avoidance features. The Even-Energy™ nozzle contains 29 laser-drilled industrial-sapphire orifices of varying sizes that are placed to provide an even energy distribution. This nozzle has been approved for use on USAF aircraft wherever the metal thickness is 0.032-inch or greater. The nozzle body does not wear out from water flow; the orifices are the only consumables. Individual orifices can be replaced quickly using standard tools.

2.3.2 Manipulator Assembly

The manipulator assembly provides the interface between the aircraft surface and the end-effector (Figure 6). Once the three soft contact points of the prototype manipulator are positioned against the aircraft, the end-effector automatically strips a maximum area of 65 by 45 inches (165 by 114-cm) in a raster pattern using CNC-type drives and path controls. The manipulator includes collision-avoidance sensors and laser guide beams to aid alignment with previously stripped areas. The legs of the manipulators have soft load-sensing pads that limit the force applied to the aircraft surface to 20 lb/in^2 and a vacuum system that helps hold the pads securely against the aircraft during the stripping process.

2.3.3 Mobile Transporter

The transporter is a commercial off-the-shelf lift system selected based upon utility and R&M considerations. The transporter has an articulating boom with a load and reach capacity suitable for this application. Its maximum working height of 45 ft (13.7 m) is capable of accessing tail elements of C-130 and C-141B aircraft. The transporter's horizontal reach of 22 ft (6.7 m) at a height of 21 ft (6.4 m) above the floor allows the system to reach the tops of the wings and fuselage. All process hoses and cables are routed along the boom. The transporter uses electrical power via an umbilical cord.

2.3.4 Remote Operator Control Panel

The control console (Figure 7) allows the operator to control the transporter, manipulator, landing controller, end-effector traverse rate, high-pressure water pump, and water reclamation system. The control panel is mounted on a roll-around cart so that the operator can easily position it — on the hanger floor or on a man-lift — for the greatest visibility.

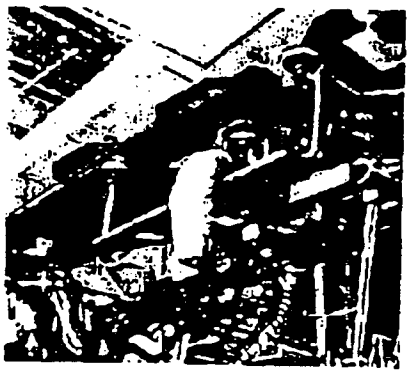

Figure 6. Manipulator and End-Effector

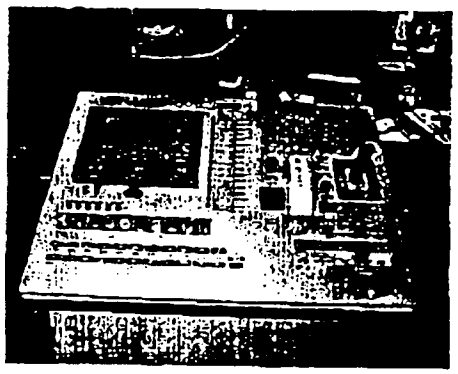

Figure 7. Remote Operator Control Console

2.3.5 High-Pressure Water Pump

A high-pressure, dual-intensifier, hydraulic water pump is located remotely in a stationary utility trailer (Figure 8). This pump supplies water to the nozzle at pressures ranging from 15,000 to 30,000 psi at a nominal flow rate of 5 gallons/minute. The intensifiers are designed to be easily accessible for maintenance and repair. The hydraulic system includes an integral full-flow filtration system, hydraulic reservoir, and pressure gages.

2.3.6 Effluent Collection System

The effluent collected within the end-effector shroud is conveyed to a stationary utility trailer via an 8-inch diameter hose. A "dri-prime" pump removes the material from the bottom chamber of the vacuum and deposits it into a vibratory liquid/solid separator. The separator acts as a "shaker," removing about 95-percent of the solid material (Figure 9). The liquid is then pumped into a micro-separator, which is the first stage of the water reclamation unit. The micro-separator uses centrifugal force to remove all materials that are heavier than water. The water is then passed through a coalescing tank (to remove oils and film), and successively through an ozone generator, charcoal filter, micro-filters, and, finally, a deionization system that assures that the water Recycled to the pump is Grade A deionized water.

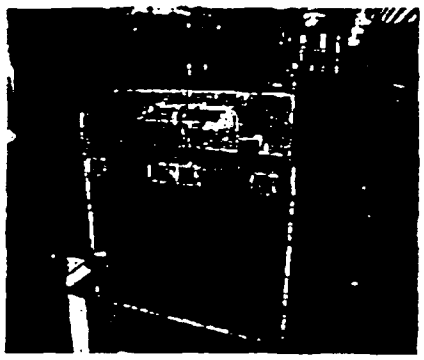

Figure 8. High Pressure Water Pump

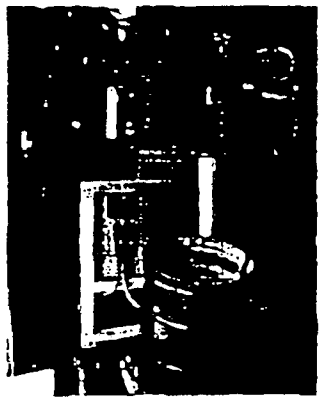

Figure 9. Effluent Collection System

2.3.7 Water Reclamation System

A modular water reclamation unit filters and conditions the recycled process water and returns it to the pump. About 30 to 50 gallons of water evaporate each day and must be replaced with fresh water.

2.3.8 Process Control Software

The Process Control Software is designed to control the motion of the end-effector along a predetermined path within the manipulator and to control the nozzle stripping sequence. The manipulator X, Y, and Z axes are also controlled by this software. The operator interfaces with the process controller via the remote control console that includes a Station Operator Terminal (SOT). The software allows the operator to monitor and control program sequencing, process speeds, and manual positioning.

2.3.9 Landing Controller Software

The Landing Controller Software is designed to control the landing sequence of the manipulator onto the surface of the aircraft. During the landing sequence, the software controls the approach speed, normalizes the three legs of the manipulator, and limits the loads on the aircraft surface.

The Landing Controller Display provides the operator with information about the position of the manipulator in relation to the boom and the stripping surface target area. The display features controls that allow the operator to enable or disable the automatic landing controls. The landing sequence consists of four modes: the initial approach, final approach, contact, and landing.

2.3.10 Collision Avoidance System

The system is equipped with several sensors to halt the system motions and to alert the operator of a "collision" event. The boom elements have protective light beams. The manipulator legs have ultrasonic sensors and touch sensors. The end-effector has touch sensors around its perimeter.

3.0 CONCLUSIONS

The primary conclusions drawn from this work are:

1. The results of the off-site tests and the recent demonstrations on C-130 aircraft at Robins AFB show that the prototype semi-automated coatings removal system satisfies the original design goals except for the target production rates. Coatings removal on 7,000 ft^2 of a C-130 is expected to take 33 hours/aircraft for polysulfide coatings and 38 hours/aircraft for epoxy coatings compared to a target value of 30 hours/aircraft.

2. Strip rates exceeding 312 ft^2/hr (5.2 ft^2/min) completely removed the coatings from several areas of the C-130 aircraft with polysulfide coatings and left the surfaces clean and dry.

3. The initial feedback from operators, production managers, and maintenance staff at WR-ALC was very positive. The benefits offered by the prototype system — environmentally, economically, and ergonomically — were recognized and appreciated.

4.0 RECOMMENDATIONS

Battelle recommends that WR-ALC initiate a program to monitor the performance of the prototype system during the next several months of production use. Data on scheduled maintenance, unscheduled maintenance, production rates, and operator experience should be collected. This will provide a basis for determining the desirability of making any modifications to enhance the design of the prototype unit prior to proceeding with the procurement of additional units to complete the production facility requirement.

5.0 REFERENCES

The following are the reference documents for this test report:

1. Hall, R. L., *Program Plan*, CDRL A001, Department of the Air Force Contract No. F09603-95-D-0180-0002 Modification-02 dated 01 May 1997, report prepared by Battelle for Warner Robins Air Logistics Center, 07 October 1996.

2. Hall, R. L., *System Requirements*, CDRL A002, Department of the Air Force Contract No. F09603-95-D-0180-0002 Modification-02 dated 01 May 1997, report

prepared by Battelle for Warner Robins Air Logistics Center, 15 January 1996.

3. Hall, R. L., *Preliminary Design Review*, CDRL A002, Department of the Air Force Contract No. F09603-95-D-0180-0002 Modification-02 dated 01 May 1997, report prepared by Battelle for Warner Robins Air Logistics Center, 22 July 1996.

4. Hall, R. L., *Critical Design Review*, CDRL A002, Department of the Air Force Contract No. F09603-95-D-0180-0002 Modification-02 dated 01 May 1997, report prepared by Battelle for Warner Robins Air Logistics Center, 29 May 1997.

5. Hall, R. L., *Overall Facilitization Plan*, Department of the Air Force Contract No. F09603-95-D-0180-0002 Modification-02 dated 01 May 1997, report prepared by Battelle for Warner Robins Air Logistics Center, 14 November 1997.

6. Hall, R. L., *Acceptance Test Plan*, CDRL A003, Department of the Air Force Contract No. F09603-95-D-0180-0002 Modification-02 dated 01 May 1997, report prepared by Battelle for Warner Robins Air Logistics Center, 13 August 1997.

7. Hall, R. L., *Acceptance Test Report*, CDRL A005, Department of the Air Force Contract No. F09603-95-D-0180-0002 Modification-02 dated 01 May 1997, report prepared by Battelle for Warner Robins Air Logistics Center, 26 February 1998.

8. Hall, R. L., *Reliability and Maintainability Test Plan*, CDRL A003, Department of the Air Force Contract No. F09603-95-D-0180-0002 Modification-02 dated 01 May 1997, report prepared by Battelle for Warner Robins Air Logistics Center, 12 August 1997.

9. Hall, R. L., *Reliability and Maintainability Test Report*, CDRL A005, Department of the Air Force Contract No. F09603-95-D-0180-0002 Modification-02 dated 01 May 1997, report prepared by Battelle for Warner Robins Air Logistics Center, 14 May 1998.

10. Hall, R. L., *Revised Drawings and Parts Lists*, CDRL A005, Department of the Air Force Contract No. F09603-95-D-0180-0002 Modification-02 dated 01 May 1997, report prepared by Battelle for Warner Robins Air Logistics Center, 29 May 1998.

11. Hall, R. L., *Final Design Review*, CDRL A002, Department of the Air Force Contract No. F09603-95-D-0180-0002 Modification-02 dated 01 May 1997, report prepared by Battelle for Warner Robins Air Logistics Center, 01 June 1998.

12. Hall, R. L., *Verification Test Plan*, CDRL A003, Department of the Air Force Contract No. F09603-95-D-0180-0002 Modification-02 dated 01 May 1997, report prepared by Battelle for Warner Robins Air Logistics Center, 02 April 1998.

13. Hall, R. L., *Verification Test Report*, CDRL A005, Department of the Air Force Contract No. F09603-95-D-0180-0002 Modification-02 dated 01 May 1997, report prepared by Battelle for Warner Robins Air Logistics Center, 01 June 1998.

14. J. Williams and R. M. Rice, *Navy High-Pressure Waterjet Closed-Loop Paint Stripping System*, Journal of Ship Production, Vol. 12, No. 1, February, 1996, pp. 59-66.