Component ARMS

A Waterjet Coating Removal System for Aircraft & Missile Components and Small Vehicles

UNITED TECHNOLOGIES PRATT & WHITNEY

WATERJET SYSTEMS, INC.
6000 TECHNOLOGY DRIVE
BLDG 6 • P. O. BOX 070019
HUNTSVILLE AL 35807-7019

This document is the property of Waterjet Systems, Inc. (WJS), a wholly owned subsidiary of United Technologies Corporation, and is delivered to the recipient on the express condition that it not be disclosed, reproduced in whole or in part, or used for any purpose other than evaluation of the data contained herein. If, however, a contract is awarded to WJS as a result of or in connection with the submission of this document, the recipient shall have the right to duplicate, use or disclose the data contained herein to the extent provided in the resulting contract. This restriction does not limit the recipient’s right to use information obtained from another source without restriction.
## CONTENTS

1.0 THE WATERJET PROCESS AND THE COMPONENT ARMS™ ........... 1
  1.1 Waterjet Systems, Inc................................................................. 5
  1.2 A Typical Component ARMS™ ................................................. 7
  1.3 Cost Effectiveness .................................................................. 9
  1.4 Ongoing Research and Development ...................................... 10

2.0 SYSTEM SPECIFICATIONS ....................................................... 11
  2.1 Robot Subsystem .................................................................. 11
  2.2 End Effectors ......................................................................... 14
  2.3 Water System ......................................................................... 15
    2.3.1 High Pressure Pump ....................................................... 15
    2.3.3 Chiller ............................................................................ 16
    2.3.4 Water Reclamation Unit ................................................... 17
  2.4 Workcell Enclosure ............................................................... 18
  2.5 Electrical Subsystem ............................................................. 18
  2.6 Operator’s Graphic Workstation ............................................ 19
  2.7 Safety and Fail-Safe Operations ............................................. 19
  2.8 Acceptance Tests ................................................................. 20
  2.9 Training ................................................................................ 20
  2.10 On-Site Setup and System Startup ....................................... 21
  2.11 Warranty and Service .......................................................... 21
  2.12 Documentation ..................................................................... 21
  2.13 Facility Requirements .......................................................... 22
  2.14 Options ................................................................................ 22
    2.14.1 Service Options .............................................................. 22
    2.14.2 Quick-Change Tooling Package ...................................... 23
    2.14.3 Additional End Effectors and Nozzles ............................ 23
    2.14.4 Closed-Loop Ventilation ............................................... 23
    2.14.5 Spare Parts Package ....................................................... 24
    2.14.6 Installation .................................................................... 24

3.0 PROJECT SCHEDULE................................................................. 25

STANDARD WARRANTY

EXPANDED WARRANTY

PREVENTIVE MAINTENANCE RIDER
1.0 THE WATERJET PROCESS AND THE COMPONENT ARMS

In today’s demanding and competitive component refurbishment industry, new technologies are needed to replace existing methods that are either too costly to continue or being totally banned or restricted by environmental regulations. One alternative that has recently emerged from the U.S. space program as a leading candidate is ultrahigh-pressure waterjet. Some call today’s waterjet systems the “machine tools of the next century.”

With recently developed ultrahigh-pressure water pumps and precision nozzles, the waterjet process has been refined for precision industrial applications such as cutting, cleaning, degreasing, debonding, decoating and depainting. A typical waterjet system includes a high pressure water pump, a robot for precise manipulation, and an “end effector” with a waterjet nozzle designed for precise application of the waterjet energy.

The waterjet process has inherent advantages over conventional technologies such as machining, vapor degreasing, grit blasting and chemical baths, including:
- Closed loop system:
  - No toxic effluent.
  - No toxic vapors.
  - No dry particulates.
- Significantly reduced chemicals and toxic waste.
- Low manpower requirements.
- High throughput potential.
- Quick return on investment.
- Automated processing of complex geometries.

This document describes a Component ARMS™ (Automated Robotic Maintenance System) for precision removal of structural adhesives, thermal-spray coatings, paint, primer and grease from aluminum, titanium and steel aircraft and missile components. The system can also clean or depaint small vehicles, such as Humvees, armored personnel carriers, tanks, light aircraft, and a wide variety of other operational and maintenance hardware, including storage canisters and assembly-line carriers.
Specific aircraft and missile components that can be processed include:

- Missile wings
- Wing frame epoxies
- Over-wing fairings.
- Equipment bay doors.
- Loading bay doors.
- Engine bay doors.
- Horizontal stabilizers.
- Thrust augmenters.
- Thrust reversers.
- Rudders.
- Flaps.
- Slats.

The Component ARMS described herein is an enclosed waterjet workcell, of variable size, containing one or more 6-axis heavy-duty industrial robots, either fixed or on servo-tracks, for rapid decoating of small and large aircraft and missile components, small vehicles or other hardware. A turntable can also be installed at the end of the servo-track to allow processing of small components.

The system includes specialized end effectors and several nozzles designed to apply the waterjet energy uniformly across the stripping path. The unique design of these nozzles optimizes the rate of adhesive or coating removal while virtually eliminating the potential for surface/substrate damage.

The entire system can be mounted on a subfloor to contain water, allow for filtration of all adhesive or coating residue, and provide for reclamation and reuse of all process water. The only waste product is the coating residue filtered from the process water by the water reclamation unit supplied with the system.

Using a Component ARMS™ (without a servo-track), we have been working with several military maintenance agencies on the removal of rubber and adhesives from military hardware. For example, on our first test run, we stripped the hard rubber from a new armored vehicle tread in less than 4 minutes.
With the same system (again, in our first attempt), we stripped a variety of adhesive resins from aircraft panels at removal rates in excess of 100 square feet per hour. We are currently working on optimizing process parameters and nozzle designs for these specific military maintenance jobs.

Based on our own operational experience with robotic systems, we designed the Component ARMS™ to meet the four most important demands of a schedule-driven operator: durability, reliability, maintainability and safety. Then we added an important feature for those with a vision of the future: modularity, for maximum operational flexibility and growth.

With our modular design, a Component ARMS™ can be customized to meet both current and future needs. For example, the original workcell size and door locations can be customized. At any time, walls can be extended and servo-track added for even longer parts, a turntable can be added for processing small components, or two different pumps can be integrated for both high-pressure/low-flow stripping of tenacious coatings and low-pressure/high-flow stripping of paints and primers.

The system can also be readily integrated into existing or future assembly-line process controls through its 8-axis robot controller, which is expandable to 12 axes.

These factors combine to make our Component ARMS™ the most flexible and expandable system for waterjet processing. But there are several other features that add even more value to our ARMS™ technology.
• **Innovative Nozzle Technology** - Our nozzle technology is unique; it is based on 15 years of directly related research on waterjet physics, development of operational systems, and operation of those systems in a schedule-intensive environment. The key to combining optimal processing speed with no substrate damage is the uniform transfer of waterjet energy across the stripping path. Our computerized methodology for achieving these objectives in the design of our nozzles is so unique and innovative that we have a patent pending on the design process.

• **Proven, Dextrous Robot** - The 6-axis pedestal robot in our Component ARMS™ has proved its durability in the automotive industry, with a mean time between failure (MTBF) of 48 months. It is also inherently superior to other robots in accessing lips, overhangs and rims of typical complex-geometry components. With its &axis controller (expandable to 12 axes), the operator can control turntable, servo-tracks or other process equipment to take on increasingly difficult cleaning and decoating jobs.

• **Heavy-Duty Payload Capability** - The robot in the Component ARMS™ can accurately manipulate a heavier payload, up to 264 pounds, than most other robots. To get the most out of a component refurbishing workcell, the robot must be able to accurately manipulate some rather sophisticated and heavy (60-pound) end effectors, in addition to neutralizing the backthrust from the high pressure water stream. Operating at 55,000 psi and 3 gallons per minute, for example, the backthrust alone is greater than 35 pounds. These considerations demand a sturdy, heavy-duty robot.
1.1 Waterjet Systems, Inc.
Waterjet Systems, Inc. (WJS) is a subsidiary of United Technologies Corporation (UTC), 16th largest U.S. corporation, and is operated by Pratt & Whitney (P&W), the worlds leading producer of jet engines.

The heritage of WJS is our 15 years of experience as part of UTC/USBI Co., working on NASA’s Space Shuttle Program. We refined waterjet technology to a high level of precision for NASA, then developed robotic systems and processes to remove insulation and paint from the non-motor segments of NASA’s solid rocket booster (SRB). This experience became the foundation on which we have built Waterjet Systems, Inc.

Besides the Component ARMS™, we are developing a growing list of similar products for a variety of special applications, including:

- Engine ARMS™, for decoating jet engine components.
- Aircraft ARMS™, for depainting large aircraft.
- Ship ARMS™, for depainting and defouling ships.
- Structure ARMS™, for depainting steel bridges (and capturing lead-based paint).

We delivered our first Engine ARMS™ to Delta Air Lines in July 1992; it is now in operation at their Atlanta maintenance base. Other Engine ARMS™ are in operation or being assembled for Pratt & Whitney plants in Berwick, Maine; Columbus, Georgia; East Hartford, Connecticut; and the Kennedy Space Center for USBI to refurbish additional Shuttle booster components.

We are also fabricating an Aircraft ARMS for the U.S. military in a manufacturing technology (MANTECH) program called Large Aircraft Robotic Paint Stripping (LARPS) under Contract F33615-91-C-5708. The LARPS System is scheduled for installation at Tinker AFB, Oklahoma, in late 1994, with operations beginning in early 1995. It will be operated by the Oklahoma City Air Logistics Center (OC-ALC) for automated, robotic depainting of B-1, B-52, KC-135 and E-3A aircraft.
Our work on the LARPS program provides the foundation for our Component ARMS™. For LARPS, we conducted an extensive process optimization study on both Al 2024-T3 and Al 7075-T6 that included evaluation of:

- Surface roughness.
- Fatigue life.
- Cyclic stress.
- Residual stress.
- Substrate damage.
- Coating removal rates.
- Fatigue crack growth.
- Water intrusion and sealant integrity.
- Corrosion.
- Repaintability.
- Spot weld integrity.

These tests demonstrated the most important aspect of the ARMS technology: that high pressure waterjet is a totally acceptable, and environmentally sound, process for removing paint from sensitive military aircraft fuselage structure. These tests were the first ever conducted on aircraft structure with this alternative depainting process.

A second important aspect of the ARMS technology is its ability to selectively strip coatings in layers, if desired (e.g., removing a topcoat but leaving the primer). Selective coating removal is a unique feature of our high pressure water-jet technology; our nozzle design makes energy transfer uniform, and the process has inherent parameters for precision control, such as:

- Nozzle standoff distance.
- Nozzle attack angle.
- Nozzle traverse rate (or dwell time).
- Nozzle rotation speed.
- Water pressure.
1.2 A Typical Component ARMS™
A typical Component ARMS™ workcell includes:
- Workcell enclosure with loading doors, observation window, ventilation system, overhead crane, and subfloor for drainage.
- 6-DOF pedestal robot mounted on a servo-track.
- Robot controller with operator's workstation.
- Component turntable.
- Water pump, 57,000 psi, 3 gpm flow rate.
- Closed-loop water filtration and reclamation system.
The simplest configuration is a single, fixed robot capable of reaching all areas of a component within its operating envelope. A more sophisticated configuration could include two robots, operating on parallel servo-tracks, capable of rapid processing of large, elongated aircraft components, fuselages or vehicles. A cell could also incorporate a small turntable at one end to provide dual use capability: large components and small ones, both of which could be processed simultaneously.

The size of the workcell is set by the size of the components to be processed. The number of robots and their mobility within the cell are determined by the size and shape of the components and the throughput requirements. If desired, the workcell can be integrated into existing assembly-line operations for on-line cleaning, degreasing and decoating, such as cleaning car carriers of paint.

The entire workcell can be mounted on a subfloor so all water and coating residue can be filtered and the water recycled for reuse. The subfloor design also precludes the need for major facility modifications and permits easy relocation of the workcell should that become necessary.

The only waste product of the system is the adhesive or other coating residue removed. A water reclamation subsystem provides total closed-loop capture and filtering of coating residue, and reuse of the process water.

Operation of the robot within the workcell is controlled by a single operator at the robot controller located outside the workcell.

All software to operate the system is included. Component process programs can be developed by WJS or by operator personnel using the robot’s teach pendant.
Three nozzles are also included with the system. Each nozzle consists of a nozzle body and several laser-drilled, sapphire orifices arranged in the most efficient pattern by our proprietary computer program. We have a patent pending on the design methodology.

Essentially, the spatial orientation and size of each orifice in the nozzle body are designed to work together to apply the waterjet energy uniformly across the stripping path. This unique design is the key to optimizing the stripping rate while preventing damage to the substrate surface.

The nozzle body is made to last “forever;” only the nozzle orifices are consumable, lasting up to 400 operational hours. Orifices are replaceable with an Allen wrench; nozzle bodies can be quickly replaced on the end effector with common adjustable wrenches.

1.3 Cost Effectiveness

The three most important and enduring characteristics of ARMS hardware are environmental soundness, productivity and cost effectiveness. One Component ARMS™ can replace machining, grit blasting and chemical baths, saving the operator 80-90% in labor, throughput time and environmental compliance costs. More specifically, one Component ARMS™ can:

- Reduce decoating times from 80-90%.
- Remove less substrate material.
- Expose surface stress cracks (rather than mask them as with machining).
- Eliminate toxic gases and dry particulate.
- Contain and dramatically reduce toxic effluents.

We have also demonstrated a level of precision not possible with other methods; we have stripped some multilayered coatings one layer at a time. We have also proved the process on the toughest of coatings, including the 4-mil-thick chemical-agent-resistant coating on military “Humvees,” plasma-sprayed bond coats, and epoxy/resin composites.

We have found that a typical payback period for a Component ARMS™ is one year or less.
1.4 Ongoing Research and Development

Our research on waterjet refurbishment takes place in Huntsville, Alabama, in our modern Automation and Coatings Facility (ACF), a 10,000 square foot facility with several robotic workcells for R&D and production. We perform waterjet processing with pedestal and gantry robots, high pressure pumps, and WJS-developed end effectors and water-recovery system.

We have removed a wide variety of coatings with water alone. To date, we have decoated a large selection of turbine engine components; we are approved by P&W, General Electric and Rolls-Royce for waterjet stripping of selected gas turbine engine parts.

We have also cleaned, stripped and polished hundreds of other items, from the mundane to the exotic. Included among these are an Army Humvee and Battle Tank engine components, Tomahawk wing surfaces and airframe epoxy, a truck door, television screen glass panels, polyester thread spinnerets, and many other hard-to-clean items - some of which the customer had determined were "too difficult and not cost effective to refurbish."

It does not take much imagination to see the high pressure waterjet process and our ARMS™ technology as not only the machine tool of the next century, but also the tool that gives life to very dirty but long-forgotten engine, airframe and transmission components.
2.0 SYSTEM SPECIFICATIONS

Our Component ARMS™ consists of a robot subsystem (robot with protective shroud, servo-track, and controller with operator’s workstation), a turntable, process equipment (high pressure pump, pump controller, water reclamation system and chiller), a robot end effector with waterjet nozzles, and a workcell enclosure (modular, variable size). All required safety features, component programming, training and product support are also included.

2.1 Robot Subsystem

The robot subsystem consists of the robot (mechanical unit), controller, servo-track and protective shroud.

2.1.1 Robot (Mechanical Unit)

The robot is a high-precision 6-DOF articulated arm, electric servo-driven, industrial robot. All six axes of motion are controlled simultaneously. The wrist has been designed to operate in a water environment. It has a mean time between failure (MTBF) of 48 months.

2.1.1.1 Work Envelope

Maximum reach is 95 inches, with a vertical travel distance of up to 105.7 inches and 300° of base rotation. With a servo-track, the work envelope expands laterally with the length of the servo-track.

2.1.1.2 Payload

Maximum robot payload is 264 pounds, based on a load center 9.45 inches from the faceplate.

2.1.1.3 Speed

Maximum linear speed of the end effector is 40 inches per second (ips).

2.1.1.4 Repeatability

The end effector position repeatability is ±0.020-inch. This is a worst-case design specification based on the robot moving at maximum speed (40 ips) and carrying the maximum payload (264 pounds). Since our typical end effector weighs under 60 pounds and typical robot speed is 4 ips, actual repeatability is normally better than the design specification.
2.1.1.5 Robot Water Protection System
The water protection system for the robot consists of a heavy-duty, waterproof shroud that allows free movement of the robot arm. The shroud is designed to inhibit corrosion, rusting and contamination of the robot in a severe debris and moisture environment.

2.1.1.6 Drives
The drive trains incorporate AC servomotors and RV speed reducers and are easily and separately replaceable for maintenance. Each axis motor is capable of fast acceleration and deceleration, providing precision positioning and long service life. All six axes use electromechanical brakes at the motors with absolute encoder feedback. Limit switches and hard stops are provided at all travel limits. Software limits exist before the hard stops and are user-definable.

2.1.2 Robot Controller
The robot controller and its system software are capable of controlling the robot mechanical unit, the servo-track, a turntable, and the workcell processing equipment. The operating system has full programming, editing and self-diagnostic capabilities. Two RS-232 serial communication ports and a built-in modular input/output (I/O) system are included. Operator commands are input through either the onboard monitor and keyboard or an attached teach pendant. The controller is enclosed in a freestanding cabinet and is capable of operating from 32-122°F (0-50°C) and 5-95 percent relative humidity. Basic features of the controller include:
-8-axis control unit (expandable to 12)
-2 MB CMOS RAM Data memory
-1.5 MB RAM
-KAREL V2.2 software
-3-1/2 inch floppy disk drive
-Teach pendant
-User transformer with duplex receptacle
-Power input 460 VAC, 3-phase, 60-Hz
-Modular I/O unit
-DI module, 2 included; DO module, 1 included
-DA module, 1 included; AD module, 1 included
-Genius module, 1 included
-Serial communications software
2.1.3 Turntable
A turntable, controlled as the 7th axis of the robot controller, is included for component positioning during processing.

A 60-inch diameter, 3/4-inch thick tooling plate, with 1000-pound capacity (at 6-inch center of gravity) is standard. The turntable can be programmed to rotate at variable speeds from 0 to 4.5 rpm or index a specified number of degrees (e.g., 90, 120, 180, etc.) with a precision of 1 degree.

An adjustable part fixture is standard. Outriggers can be attached to the turntable surface if future parts exceed the turntable’s 60-inch-diameter.

2.1.4 Servo-Track
A servo-track is incorporated to provide linear motion for the robot within the enclosed workcell. Movement of a robot along the track is controlled as the 8th axis of the robot controller to permit completely integrated operation.
2.2 End Effectors
We designed our end effectors to remove the widest variety of coatings. End effectors are attached to a common robot interface plate at the end of the robot arm.

We provide one 90° end effector and up to three different nozzles with the system, depending on the application. We also provide one spare nozzle body and four sets of spare orifices. The nozzle body does not wear out from water flow; the orifices in the body are the only consumables.

Nozzle orifices are laser-drilled, industrial sapphires manufactured with a large variety of diameters to produce effective flow parameters. Nozzle orifices are easily changed with an Allen wrench; the nozzle body is easily removed with common adjustable wrenches.

A quick-change tooling package is available as an option if decoating tasks demand a variety of end effectors or if a dual-pump system is selected. Additional end effectors and spare nozzles are also available as options.
An auxiliary hydraulic power unit (HPU) is supplied with the system to rotate the nozzle. It supplies hydraulic fluid to a hydraulic motor in the end effector, which drives a high pressure water (HPW) swivel through a belt-and-pulley mechanism. The HPU provides rpm control via an interface with the robot controller; the process program sets the nozzle rotation rate for a particular component (with a specified range), monitors actual nozzle rpm, and shuts down the system if nozzle rotation is out of range.

2.3 Water System
Process equipment includes the ultrahigh pressure waterjett pump, water reclamation system and chiller.

2.3.1 High Pressure Pump
An ultrahigh-pressure, dual intensifier water pump supplies water to the end effector at the required high pressure and volume for the stripping operation. It is self-contained and ideally suited to the task of stripping especially tough coatings such as aerospace adhesives, epoxies, rubber, composites and plasma-spray. It is capable of supplying water to the robot at pressures up 57,000 psi and flow rates up to 3 gpm.

A hydraulic system drives plunger-type intensifiers as part of a closed-loop system. The intensifiers are designed for accessibility for maintenance and repair. The hydraulic system includes an integral full-flow filtration system (5 microns or less), hydraulic reservoir, and pressure gauges. The system’s electric motors operate on 460-VAC, 3-phase, 60-Hz power.

All pressure lines and fittings are ultrahigh pressure tubing burst-rated at 90,000 psi. Operating noise has been reduced to a maximum of 85 dbA near the pump.
Several optional, complementary pumps are also available for lower-pressure, higher-flow stripping processes, such as paint removal. One ideal unit for dual-pump operations provides high pressure water up to 36,000 psi with a continuous flow rate of 6 gpm. It is specifically designed for paint stripping, cleaning and degreasing applications. For a dual-pump system, plumbing is provided for rapid switching from one pump to the other.

A programmable logic controller (PLC) with modular I/O system is provided with the pump for remote pump operation by the robot controller through a Genius communication network. The pump can also be manually operated through a digital control station on the pump face. An automatic system protection feature is provided to monitor critical pump functions and shut down the unit if abnormal parameters are detected. The pump system also includes a built-in, low-voltage, soft-start, Wye-Delta starting system with an automatic pressure-bleed.

2.3.2 Chiller
A closed-loop recirculating air-cooled chiller is provided to cool the hydraulic fluid operating the pump’s dual intensifiers and assure maximum performance of the pumping system.
2.3.3 Water Reclamation Unit

A water reclamation unit is provided to allow reuse of the water by the high pressure pump. A sump pump first directs the water to a centrifugal separator which removes a majority of the particulates. The water from the centrifugal separator is then directed through a 20-micron filter and into a 300 gallon raw water tank; the level within this tank is kept constant with the addition of plant-supplied potable water to compensate for evaporative losses. The raw water is pumped through a series of filters, an oil separator, and an ozone generator before being deposited into a 200 gallon clearwell tank. The water in the clearwell tank is then passed through deionization tanks and three banks of filters down to 0.45-micron for reuse by the system's high pressure water pump.
2.4 Workcell Enclosure
The workcell enclosure is of modular design for custom fitting to a specific operator's needs. All enclosures provide a soundproof and waterproof barrier around the robot, meeting the current OSHA 85 db(A) sound-level requirement. One or more viewing windows (43 x 31 inches) can be located wherever convenient for the operator. A personnel access door is also included. Component loading doors are customized for the specific application, including manual loading doors. Optional enclosures can be provided to isolate the operator's control station, the pump or other process equipment, if desired.

2.4.1 Subfloor
A raised water channeling subfloor with sump pump can be supplied with the waterjet cell, if desired. The subfloor eliminates the need to modify a facility for water drainage; it also makes the entire workcell self-contained and easily moveable from one location to another, if necessary.

2.4.2 Monorail and Air Hoist
A ceiling-mounted monorail and an air hoist are supplied for handling large and heavy parts. The monorail and the hoist are each rated for 1/2-ton (1,000 pounds).

2.4.3 Mist Collector and Ventilation Unit
A mist collector and ventilation unit is provided with the enclosure. The standard unit includes three types of filters: two 4-inch impingers, two 1-inch aluminum mesh filters, and two 90% V-bags. The first two filters are cleanable aluminum, and the V-bag is disposable. The V-bag is rated per ASHRAE Test 52/76. The mist collector can be open- or closed-loop; the closed-loop version is optional and eliminates the need for outside venting.
2.5 Electrical Subsystem
Electrical equipment includes all required motor starters or safety disconnect switches, enclosure lighting panel, two flashing beacons and door safety interlocks for the enclosure, and required cables and cable tray between the major components. Also included is a power distribution panel to allow a single-point power hookup during installation. If we install the system, we include all electrical wiring between the power distribution panel and the major components.

2.6 Operator’s Graphic Workstation
A user-friendly graphic workstation for the operator can be selected as an option. It does not require any special programming skills to operate. With this workstation, all automatic and rework operations of the workcell are controlled from the menu-driven workstation, with the robot controller used for manual robot and teaching functions.

Specifications for the workstation are as follows:
- 14” color CRT & VGA resolution graphics.
- Embedded 80286 processor, 128 MB screen memory.
- Screen security with password protection.
- 35 built-in data entry and 20 function keys.
- 2 RS-232C and 1 printer port.
- Designed for harsh (factory) environment.

2.7 Safety and Fail-Safe Operations
We designed the Engine ARMS™ with inherent safety features. Personnel and environmental safety systems for the workcell include warning signs, lights and workcell access door interlocks, which prohibit robot automatic functions when personnel are in the cell. Our systems meet OSHA 29CFR 1910-212 Al, ANSI RIA-R15.06-1986, and Pratt & Whitney MES 9000 series specifications.

The robot has emergency stops, limit switches and hard stops to safely set travel limits, while the robot controller has user-defined software limits (soft stops) that provide further safety protection; the soft stops are designed to activate before the hard stops. The pump is soundproofed, and the pump controller monitors critical
functions that will shut down the unit if abnormal parameters are detected. The end effector has a sensor to detect overloads (such as bumping a part), and a sensor to monitor nozzle rotation and shut the system down if over- or under-rotation are detected.

2.8 Acceptance Tests
Acceptance tests can be performed in our facility and again at the operator's facility after installation and startup, using components supplied by the operator. Typical acceptance tests include:
- Robot Testing:
  - Individual axis motion
  - Combined axis motion
  - Tool orientation ability
  - Servotrack operation.
  - Turntable movement.
  - Emergency stop verification.
- Process Testing (coating removal demonstration).

2.9 Training
A training program is provided, typically including:
- A video overview.
- Hands-on, modular training sessions with customer operators and maintenance personnel, generally consisting of:
  - Two weeks on system operations.
  - One week on pump operation and maintenance
  - One week on robot maintenance.
- Loose-leaf manuals for easy updates and annotation.
- Factory-trained operators as instructors.
- Trouble-shooting scenarios.
- Various training aids.
2.10 **On-Site Setup and System Startup**

Three weeks of on-site setup and system startup supervision is provided. Installation and facility modifications are normally performed by the operator.

2.11 **Warranty and Service**

Our Standard Warranty cover the system for 12 months from date of shipment. (See copy of Standard Warranty attached.) An Expanded Warranty and Preventive Maintenance Rider with enhanced service options are available. The warranties and rider can be extended beyond their normal one-year periods.

Our Field Service Department (FSD) coordinates all service-related activities at the operator’s installation, such as maintenance service and repair parts, during the one-year warranty period. A FSD representative is assigned to the customer’s installation and serves as the focal point and expeditor for all service requirements. We maintain an inventory of system spare parts and coordinate frequently with its subsystem manufacturers to maintain proper inventories.

2.12 **Documentation**

Final design documents are provided for the robot, workcell enclosure, and all support processing equipment. Two copies of system documentation are supplied, including, but not limited to, the following:

- Drawings.
  - System Layout.
  - Mechanical.
  - Electrical.
  - Plumbing.
- Interface I/O.
- Equipment manufacturer’s documentation.
- Spare parts list.
2.13 Facility Requirements
Utility requirements to be provided by the user are listed below. The enclosure subfloor, pump, water reclamation, chiller and mist collector do not require any floor modification except for equipment anchors.

All wiring and conduit installation between the power distribution panel and individual device panels is considered part of user installation, unless we install the system.

Plant potable water is required for makeup only. The user must route a 1/2-inch supply line (3-5 gpm) to the raw water tank; we supply the on-off valve. Chilled water for the high pressure water pump is not required since a chiller is included with the base system.

<table>
<thead>
<tr>
<th>Compressed Air</th>
<th>80-100 psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potable Water</td>
<td>3-5 gpm@ 55 psi</td>
</tr>
<tr>
<td>Power - Total Service</td>
<td>460 VAC, 350A, 3Ø,60 Hz</td>
</tr>
<tr>
<td>Water Pump</td>
<td>460 VAC, 180A, 3Ø,60 Hz</td>
</tr>
<tr>
<td>Robot Controller</td>
<td>460 VAC, 30A, 3Ø,60 Hz</td>
</tr>
<tr>
<td>Water Reclamation</td>
<td>460 VAC, 20A, 3Ø,60 Hz</td>
</tr>
<tr>
<td>Mist Collector</td>
<td>460 VAC, 15A, 3Ø,60 Hz</td>
</tr>
<tr>
<td>Chiller</td>
<td>460 VAC, 20A, 3Ø,60 Hz</td>
</tr>
<tr>
<td>Water Protection</td>
<td>460 VAC, 15A, 3Ø,60 Hz</td>
</tr>
<tr>
<td>Aux. Hydraulic Unit</td>
<td>460 VAC, 15A, 3Ø,60 Hz</td>
</tr>
<tr>
<td>Enclosure Lighting</td>
<td>115 VAC, 20A, 1Ø,60 Hz</td>
</tr>
<tr>
<td>Environmental</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>32°F to 122°F</td>
</tr>
<tr>
<td>Humidity</td>
<td>5% to 95% RH</td>
</tr>
<tr>
<td>Floor Space (Overall)</td>
<td>Variable and Adaptable</td>
</tr>
</tbody>
</table>

2.14 Options

2.14.1 Service Options

2.14.1.1 Expanded Warranty
An Expanded Warranty is available to cover all warranty service costs. (See attached copy for details.)
2.14.1.2 **Preventive Maintenance Rider**
A Preventive Maintenance Rider is available to provide a service option in which we perform a series of preventive maintenance tasks, mechanical inspections, software diagnostics and report generation on a quarterly basis. (See attached copy for details.)

2.14.2 **Quick-Change Tooling Package**
A quick-change tooling package is available. It includes required hardware and software for a dual end-effector system: 1 robot tooling adaptor, 2 end-effector tooling adaptors, 2 end-effector holding fixtures, required robot I/O modules and software, and a junction box and cabling wired to the quick-change rack.

2.14.3 **Additional End Effectors and Nozzles**
The following end effectors and nozzle designs are available, with or without quick-change tooling capability:

A. 90° spare or modified length.
B. 180° orientation
C. 135° orientation
D. Nozzles
   - 0.375-inch dia. 2 orifices
   - 0.50-inch dia. 4 orifices
   - 0.75-inch dia. 5 orifices
   - 1.5-inch dia. 5 orifices
   - 2.0-inch dia. 8 orifices
   - 2.0-inch dia. 4 orifices

2.14.4 **Closed-Loop Ventilation**
The mist collector supplied with the system includes filters to remove the coating particulates from the exhaust air and vent the air safely out the top of the unit directly into the plant. However, if desired, optional ductwork to redirect the exhaust air back into the workcell enclosure can be provided. Additional air processing can be included in this option, such as a dehumidifier or an air conditioner to lower the exhausted air temperature.
2.14.5 Spare Parts Package
A 90-day supply of consumables is included (fuses, filters, gaskets, etc.). A full set of initial system spares is available as an option (spare parts for the robot, pump, water reclamation, chiller, mist collector and end-effector subsystems).

2.14.6 Installation
We can quote installation of the system as an option; this includes all labor and material for complete installation of the system. The user must provide single-source power, pneumatic/air, water drops within 20 feet of the system tie-in points. Installation supervision and startup are provided with each system.
3.0 PROJECT SCHEDULE

A typical delivery schedule is shown below. Delivery is usually dependent on the availability of certain long-lead items; however, accelerated delivery is possible, depending on the number of systems in assembly and integration at WJS facilities at the time of order.

<table>
<thead>
<tr>
<th>TASK</th>
<th>MONTHS AFTER ATP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Authority to Proceed (ATP)</td>
<td></td>
</tr>
<tr>
<td>Long-Lead Procurement</td>
<td></td>
</tr>
<tr>
<td>Facility Design &amp; Integration</td>
<td></td>
</tr>
<tr>
<td>Fabrication</td>
<td></td>
</tr>
<tr>
<td>Shipment to Customer</td>
<td></td>
</tr>
<tr>
<td>Installation</td>
<td></td>
</tr>
<tr>
<td>Acceptance Testing</td>
<td></td>
</tr>
<tr>
<td>Training</td>
<td></td>
</tr>
<tr>
<td>Robot Maintenance</td>
<td></td>
</tr>
<tr>
<td>Robot &amp; Pump Ops</td>
<td></td>
</tr>
</tbody>
</table>

Use or disclosure of data contained on this sheet is subject to the restriction on the title page of this document.
Waterjet Systems, Inc., a subsidiary of the United Technologies Corporation, warrants to the Buyer all parts of its manufacture furnished under this agreement to be free from defects in material and workmanship for a period of one year from the Effective Date, which shall be the date of shipment to the Buyer.

Should any equipment or material prove defective, Waterjet Systems, Inc., at its option, will (1) replace the defective parts! (2) authorize the equipment to be returned for repair, or (3) authorize repairs to be made at the Buyer’s facility. Defective parts will be repaired or replaced without charge, but removal and installation of parts are to be made at Buyer’s expense. Waterjet Systems, Inc. will, on a “best efforts” basis, make repairs or supply replacement parts within twenty-four (24) hours of notification.

This warranty does not cover consumable items, part failures or equipment malfunctions due to normal wear and tear, accident, abuse or failure to maintain the equipment in accordance with Waterjet Systems, Inc. specifications. All software is warranted to operate as described provided the Buyer (1) does not, without written authorization, modify the software in any way, and (2) uses the software in accordance with instructions supplied.

This warranty is conditioned upon Waterjet Systems, Inc. being notified in writing by the Buyer within seven (7) days after discovery of any defects, the return of defective articles to Waterjet Systems, Inc. (transportation charges prepaid by the purchaser), and subsequent examination by Waterjet Systems, Inc. of such articles to ensure that the defect or failure was not caused by negligence, misuse, improper maintenance or installation, accident, or unauthorized repair or alteration. Designated equipment not suitable for return because of size or weight can, however, be repaired under warranty on site, at the discretion of Waterjet Systems, Inc.

Accessories or equipment furnished by Waterjet Systems, Inc. but manufactured by others shall carry the warranty of the manufacturer as conveyed to Waterjet Systems, Inc., which shall be passed on to the Buyer.

This Standard Warranty can be renewed on an annual basis for up to ten (10) years by direct purchase through Waterjet Systems, Inc.

This Standard Warranty covers the original Buyer only. It is not assignable or transferrable without the expressed, written permission of Waterjet Systems, Inc.
Waterjet Systems, Inc., a subsidiary of the United Technologies Corporation, warrants to the Buyer all parts of its manufacture furnished under this agreement to be free from defects in material and workmanship for a period of one year from the Effective Date, which shall be the date of shipment to the Buyer.

Should any equipment or material prove defective, Waterjet Systems, Inc, at its option, will (1) repair or replace the defective parts with all labor, travel and material costs borne by Waterjet Systems, Inc., or (2) authorize repair or replacement to be made by the Buyer in his facility with Waterjet Systems, Inc. responsible for labor costs incurred by the Buyer. Waterjet Systems, Inc. will, on a “best efforts” basis, make repairs or supply replacement parts within twenty-four (24) hours of notification.

This warranty does not cover consumable items or part failures or equipment malfunctions due to normal wear and tear, accident, abuse or failure to maintain the equipment in accordance with Waterjet Systems, Inc. specifications. All software is warranted to operate as described provided the Buyer (1) does not, without written authorization, modify the software in any way, and (2) uses the software in accordance with instructions supplied.

Waterjet Systems, Inc reserves the right to ensure that a defect or failure has not been caused by negligence, misuse, improper maintenance or installation, accident, or unauthorized repair or alteration. If any of these conditions are found to have caused the defect or failure, the Buyer shall bear the cost of all repair parts.

This Expanded Warranty can be renewed on an annual basis for up to ten (10) years by direct purchase through Waterjet Systems, Inc.

This Expanded Warranty covers the original Buyer only. It is not assignable or transferrable without the expressed, written permission of Waterjet Systems, Inc.
Waterjet Systems, Inc., a subsidiary of the United Technologies Corporation, shall provide the Buyer a quarterly preventive maintenance service for all equipment purchased from Waterjet Systems, Inc. This service shall be over and above the provisions of the Standard or Expanded Warranties and shall include the on-site visit of experienced Waterjet Systems, Inc. Field Service Representatives, who will perform the following services every ninety (90) days:

1- Conduct a complete examination of all system components for signs of wear, deterioration, corrosion, reduced performance, or out-of-specification condition. All parts found to be defective from other than normal wear and tear shall be repaired or replaced, as necessary. All fluid levels and lubricants shall be checked for age and level and shall be replaced or refilled, as appropriate.

2- Wash down and clean all system components of dirt, grime and residual coating debris.

3- Ensure full compliance with all current Service Bulletins. Any component requiring service or modification shall be modified, replaced or adjusted, as necessary.

4- Review Buyer’s maintenance log for the equipment to ensure that all problems encountered during the previous quarter are addressed and corrected. Water-jet Systems, Inc. shall prepare a quarterly report on the results of the inspection, with specific recommendations to ensure continued, trouble-free operation of the equipment.

5- Review software upgrades that have occurred after the installed version and advise Buyer of the differences, if any, the new software would make in the Purchaser’s operations.

This Preventive Maintenance Rider shall begin on the Effective Date and continue for one calendar year.