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Paper

DESIGN, MANUFACTURE AND INSTALLATION OF APWSS

(AUTOMATED PULSED WATERJET STRIPPING SYSTEM)

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ABSTRACT

Starting from an extensive laboratory study, a totally automated and integrated pulsed waterjet stripping system was installed at Vector Aerospace in Canada. The function of the APWSS (***A***utomated ***P***ulsed ***W***aterjet ***S***tripping ***S***ystem) is to strip thermal barrier coating (TBC) and a variety of other hard coatings from aircraft engines and other complicated parts. The system is currently undergoing thorough testing for reliability, reproducibility and other requirements for stripping.

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1. INTRODUCTION

This collaborative project between VLN Tech and Vector Aerospace to design, develop, manufacture and install an automated pulsed waterjet stripping system (APWSS) was based on the encouraging results obtained in the extensive investigations carried out by Vijay and co-workers (Refs. 1, 2, 3, 4 and 5). For example Figure 1 (Ref. 5) illustrates some of the myriad of aircraft components that are coated with a variety of hard metallic {for instance, HVOF (tungsten-carbide-chromium-cobalt)} and non-metallic coatings (epoxy). In fact, as discussed in detail by Tieu, Yan and Vijay (Ref. 2), HVOF appears to be a coating of the future, replacing chrome (hexavalent chrome has proven to be carcinogenic) currently used extensively in the aerospace industry. As is clear from Figure 1, all of these coatings, including chrome (Ref. 3), were removed quite readily with the forced pulsed waterjet (FPWJ) at pressures ranging from 34.5 to 90-MPa to bare metal finish without damage to the substrate (see also Ref. 4). Since the project was extensive, in this paper only highlights of the APWSS are described. No details of the FPWJ technique are given herein as these are explained at length in the references cited and also in Ref. 6.

2. MANDATE (STATEMENT OF WORK)

Vector Aerospace is a Designated Overhaul Facility (DOF) for Pratt and Whitney Canada for several engine models. As a DOF, major overhaul and repair work takes place on the entire engine. One of the processes currently employed in the restoration process is the stripping of gas turbine engine coatings. The current techniques used involve the use of abrasive chemicals and media blasting. Both processes have been found to be time consuming and costly when the whole process, including the disposal of waste is taken into account. The project was initiated assuming that the FPWJ technique will substantially improve the restoration process. The mandate of the collaborative project was to design, manufacture, test, debug and install APWSS to effectively strip, without damage to the substrate material, the following coatings:

- Aluminized Epoxy Enamel
- Sermel tel type "W"
- Plasma sprayed Thermal Barrier Coating (TBC)
- Tungsten Carbide HVOF

The purpose of the Statement of Work (SOW) was to ensure that the APWSS meets all the criteria (safety of the aircraft components after stripping, user friendly operation of the APWSS, environmental considerations, etc) stipulated by aerospace regulatory agencies, more particularly in this case, Pratt and Whitney.

3. SYSTEM REQUIREMENTS (FIGURES 2 & 3)

As depicted in Figure 2, which was used in the early design stages, the requirement was to manufacture a versatile and self-contained system capable of handling aircraft parts of varying geometries and sizes. As illustrated in the conceptual design (Figure 2), the mandate was to provide a simple set-up and operation. The APWSS must consist of:

- An encapsulated system whereby a ceiling-mounted robot encased in sealed booth performs the FPWJ articulation.
- The booth must allow for the capture of the stripped coating materials and the recirculation of filtered water.
- The stripping process must be repeatable to ensure quality.
- The turntable and the carriage must handle repair articles (mostly cylindrical in shape) varying in diameter and height from 0.02 to 1.2-m (0.8 to 48-in) and 0.5 to 70-kg (1.1 to 154-lb_m) with internal and external coatings.
- The APWSS must not exceed 4 X 4 X 4-m (13 X 13 X 13-ft) in dimensions such that the internal space of the booth must allow two technicians to load the parts and perform required maintenance operations. It must fit in a room of 5.48 X 22 X 35-m (18 X 22 X 35-ft) dimensions (see Figure 3).
- The operative noise levels outside the booth must comply with OSHA 85-db (A) requirement.
- Power supply: 575-VAC volts
- Water treatment: The filtration and recirculation system must meet the environmental regulations (that is, waste material must be collected separately, etc). The system must only require a small amount of make-up water to compensate for the evaporative losses. Due to the high levels of calcium and magnesium at the location of installation, water softener must be used in water treatment. The treatment system must also include provisions for inhibiting growth of bacteria and rust.
- A turntable controlled as the 7^{th} axis robot must be included for component positioning during stripping. The turntable must withstand the impact forces of the FPWJ and also the weight of the heavy part (80-kg). The table must have variable rotational speeds from 0.25 to 50-RPM and, must have the facility for 22^o motorized tilt. Outriggers must be provided to the turntable surface to provide support for large parts.
- The control of the APWSS must be performed by a single human-machine interface (HMI) system, consisting of two modes of operation: a teaching and an operative mode. In the ‘teach’ mode, a technician will set up the operational parameters and robotic paths for each part to be processed, which will be saved in a database and linked to a part number, with the picture of the part displayed on the HMI monitor screen. In the operative mode, the technician will perform the stripping procedure by simply entering a part number. A constant real-time monitoring must be incorporated to allow the technician to view all pertinent parameters while the stripping process is in progress. Any malfunctions of the system or warnings must be reported through the HMI together with the steps to rectify the fault. A complete or partial shut down of the APWSS or, any of its subsystems must be incorporated into the ***Central Control System*** (CCS). A series of emergency steps must be provided to stop the system under abnormal conditions or harm the personnel.

Figure 2 shows all the sub-systems of APWSS which were selected and designed to meet all the requirements stated above. Figure 3 shows the plan view of the layout of APWSS in the room at Vector Aerospace. All sub-systems were thoroughly tested (pre-installation approval tests) and debugged before delivery for installation at Vector Aerospace. A description of some of the sub-systems is given in the following section.

4. INSTALLATION

The APWSS was installed at Vector Aerospace in February/March 2009. Figure 4 illustrates the installation showing the booth, carriage with the turntable, high pressure pump and the HMI monitor. The specifications of some of the main components are given below.

Kawsaki Robot (Model FS60L): As depicted in Figure 5, the robot was mounted on the ceiling of the booth. The 6-axis robotic manipulator is rated for a payload of 60-kg (132-lb_m). Other specifications of this model can be found on the Kawasaki website. The robotic arm could be programmed to move from its home position, depicted in Figure 6, to move smoothly both inside and outside of the parts to be processed (see also Figure 13).

High Pressure Pump: The pump is a Jetstream pump rated to deliver 44.7-litre/min (11.8-usgpm) at 103.5-MPa (15-kpsi). It was equipped with a booster pump at the inlet and was controlled by a variable frequency drive (VFD). The function of the VFD is briefly discussed below.

Pressure at the nozzle (basically pump pressure) is set by the rotational speed of the motor of the pump. The fine adjustment of this speed is achieved by the VFD, which powers the high pressure pump's inverter duty motor. The command reference set point is communicated to the VFD using a high speed serial communication protocol. The same communication channel is also used to monitor the VFD status and report any faults back to the operator. The actual pressure is measured with a high pressure sensor whose value is communicated back to the CCS in real time. This pressure reading is then compared to the set point value as commanded by the CCS. Using a closed loop proportional-integral-derivative (PID) control, the motor speed is adjusted by the CCS to compensate for the difference between the set point and actual current pressure. The response characteristics of the PID are system dependant and optimized to ensure efficient and accurate control (± 1% of setpoint).

As part of the control algorithm, the theoretical nozzle pressure is calculated in real time based on the current pump speed and the pump and nozzle characteristics. Any deviation between the theoretical pressure and the actual pressure which is greater than the allowed tolerance will alarm the operator of a potential problem. Reasons for a potential problem include: incorrect nozzle installed, worn or plugged nozzle, pinched or burst hose, high pressure pump issues or sensor issues.

To run the system an operator simply needs to call up a recipe which has been previously stored in the central database. This recipe includes operating variables which have been optimized for a particular part and stored in the central database. This recipe includes the processing pressure required for an efficient coating removal. Several confirmation screens are presented to the operator to ensure that the proper part and nozzle have been installed. These screens include pictures of the part and nozzle for ease of use and designed to reduce the chances of an operator error.

Filtration and Recirculation System: This system is illustrated in Figure 8. The booth was designed in such a way that the waste water drained into a pit adjacent to the rear wall. The sump pump in the pit was capable of pumping 79.5-liter/min (21-usgpm) of waste water into the filtration system above the tank. In order to meet the requirements of makeup water, etc., a float valve was installed in the tank to monitor the water level. Water to the high pressure pump was fed from the tank.

Exhaust/Ventilation: The exhaust duct from the booth to the fan is shown in Figure 9. The fan was rated for 56.6-m^3/min (2,000-ft^3/min) and a baffled filter was installed upstream of the fan to exhaust clean air into the atmosphere.

Central Control System (CCS): As stated in the mandate, APWSS is fully automated allowing the operator to select a part from a predefined listing and begin the stripping process with a simple press of a button. The CCS monitors all sub-systems and prompts the operator to clear faults as they occur. It also prompts the operator to initialize the sub-systems as required to run in auto mode. If any mandatory conditions are not met, the stripping process shuts down and informs the operator about the deficiencies. Key process parameters are trended and provide a 1-hour history which can be reviewed to ensure proper processing. The production system is made up of several sub-systems all of which are managed by the CCS. As illustrated in Figures 10, 11 and 12, production information is communicated to the CCS through the touch screen interface (HMI). Here the operator can select parts to be processed, view alarm information, view production status, control devices manually, enter predefined part recipes and enter system control parameters.

The main sub-systems are: Holding Tank and Filter, High Pressure Pump, Ultrasonic Generator (for producing FPWJ), Booth Enclosure and Robot. In normal production mode, all of these sub-systems are controlled by the CCS. It is possible to monitor each sub-system individually for trouble shooting and process checking purposes. This individual monitoring is only available to maintenance personnel who have the understanding of how the various subsystems interact with each other.

Although the robot start/stop action is controlled by the CCS, its motion is controlled by the '***teach pendant***' of robot controller (Figure 10) and the corresponding part program. Every part must have a robot program assigned to it. Up to 256 parts can be pre-configured and up to 256 robot motion programs can be defined. It is possible to use the same robot motion program for several parts with similar geometries and process requirements. The robot motion program also controls the water and ultrasonic generator by triggering the corresponding output in the motion command.

Two levels of security are provided. The lowest level (operator) only allows part selection and process start/stop control. The highest level (maintenance) allows recipe creation, system parameter setup and manual control. A brief description of the procedures is given below.

<u>System Navigation</u>: As shown in the close-up view (Figure 12), the screen layout is divided into two areas. One set for operators and another for maintenance. While the "**Operator Screen**" displays, ***production***, ***trends*** and ***alarms***, the "**Maintenance Screen**" displays, ***production***, ***trends***, ***alarms***, ***manual control***, ***recipe management*** and ***system parameters***. Navigation to each screen is achieved by pressing the corresponding ***Goto*** button. The sequence of operations is:

- **Powering up the system:** This step basically involves such operations as, "make sure that the booth doors are closed and all E-stop buttons reset, check that there is sufficient water in the holding tank," etc.
- **Processing a part:** This step requires that all sub-systems have been powered up, all faults have been cleared and all devices are in standby mode. If all conditions are met, then the stripping process will start. If not, pressing the "***CANCEL***" at any step will stop the process.
- **Stopping the System:** Once a part has been processed, the robot returns to the home position (Figure 6), high pressure pump turns off and the system remains in standby mode waiting for the next start cycle. In emergency, pressing the E-stop button on the robot controller will stop its motion and depressurizes the system and, pressing the E-stop button on the HMI monitor (Figure 11) shuts down the entire system.

The most important requirement is to ensure that the APWSS functions in the "***pulse on***" mode, otherwise the jet will be continuous (CWJ) and the hard coatings will not be stripped. However, in the "CWJ" mode, the machine can be used to strip soft coatings or, pre-washing the parts. The displays on the HMI screen show the status of ultrasonic generator (UG) which produces the pulses (FPWJ). The display of the magnitude of the UG power level on the HMI screen is a simple diagnostic tool for the operator. If the UG malfunctions for any reason, the "***Reset UG***" button will light up, warning the operator to take remedial action.

5. TESTING THE APWSS AFTER INSTALLATION

The installation was completed in February/March of this year. A series of tests has been conducted to ensure that it is functioning as planned. Figure 13 shows some of the TBC coated aircraft engine parts used in the testing program. The most important observations are:

- FPWJ removes the TBC quite readily at pressures ≤ 69-MPa (10-kpsi) and hydraulic powers of ≤ 30-kW (40-hp).
- Robotic arm with the specially designed (acoustically tuned) nozzle (Figure 6) reaches all parts of the complicated parts (Figure 13).
- Productivity (that is, the time taken to strip a complete part) is far superior compared to the chemical dipping and media blasting techniques currently used at the DOF. For example, the part displayed in the third photograph of Figure 13 was stripped in less than 6-minutes compared to about 15 to 20-hours taken by the chemical dipping process.
- The surface finish is considered to be excellent.
- As the APWSS uses only soft tap water and the moisture is filtered before exhausting to the atmosphere, the stripping process is totally environmentally friendly.
- The smooth running of the system with an elaborate CCS is safe and operator friendly.

6. CONCLUSIONS

It took just about a year to design, manufacture and install the APWSS at Vector Aerospace. Although further tests are in progress (basically to seek certification), the most important conclusion is: FPWJ works and is a highly viable tool for removing a variety of coatings used in the aircraft and aerospace industries.

7. ACKNOWLEDGMENTS

The successful completion of this collaborative project would have been impossible without the encouraging and continuing support from Mr. Mark Booth, VP Process & Repair Services, Vector Aerospace. It is hard to list all the names of individuals who have contributed to the success of this project in various ways. However, the authors are grateful to:

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Mr. Bruce Sharpe, President, Liquid Laser Systems, who took every possible step to deliver the high pressure pump meeting all the requirements.

8. REFERENCES

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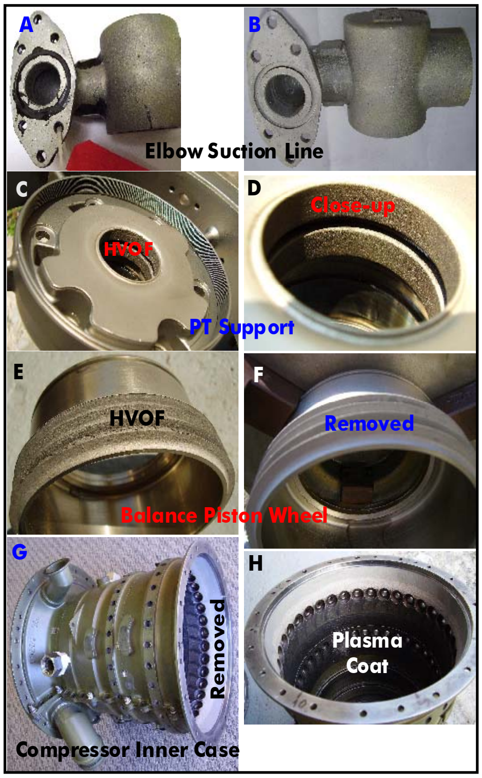

Figure 1. Removing several types of coatings/sealants from a variety of aircraft parts.

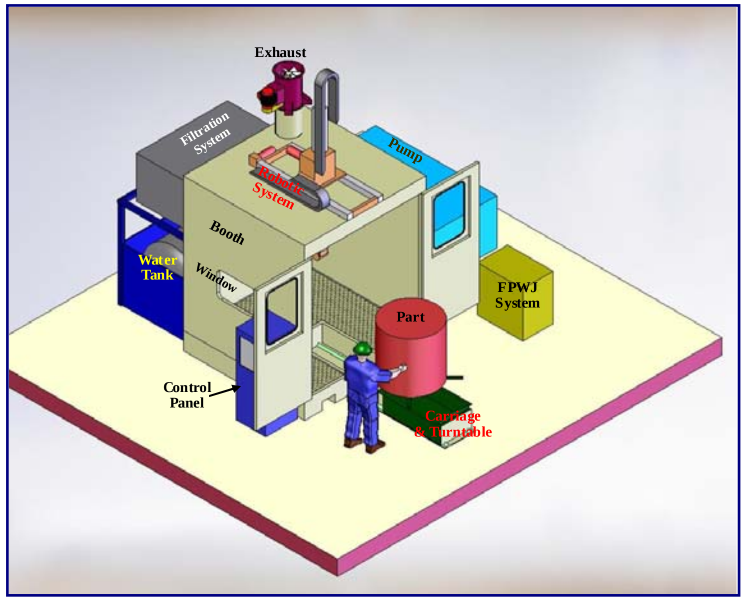

Figure 2. Conceptual (virtual) views of the APWSS used during the development stage.

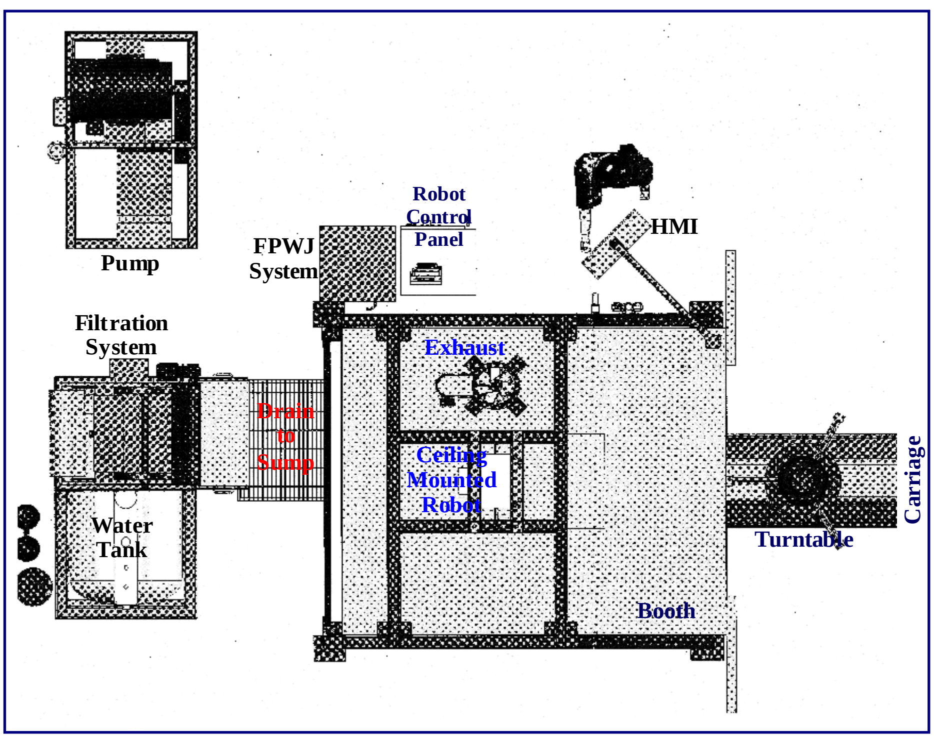

Figure 3. Plan view of the layout of the APWSS at Vector Aerospace.

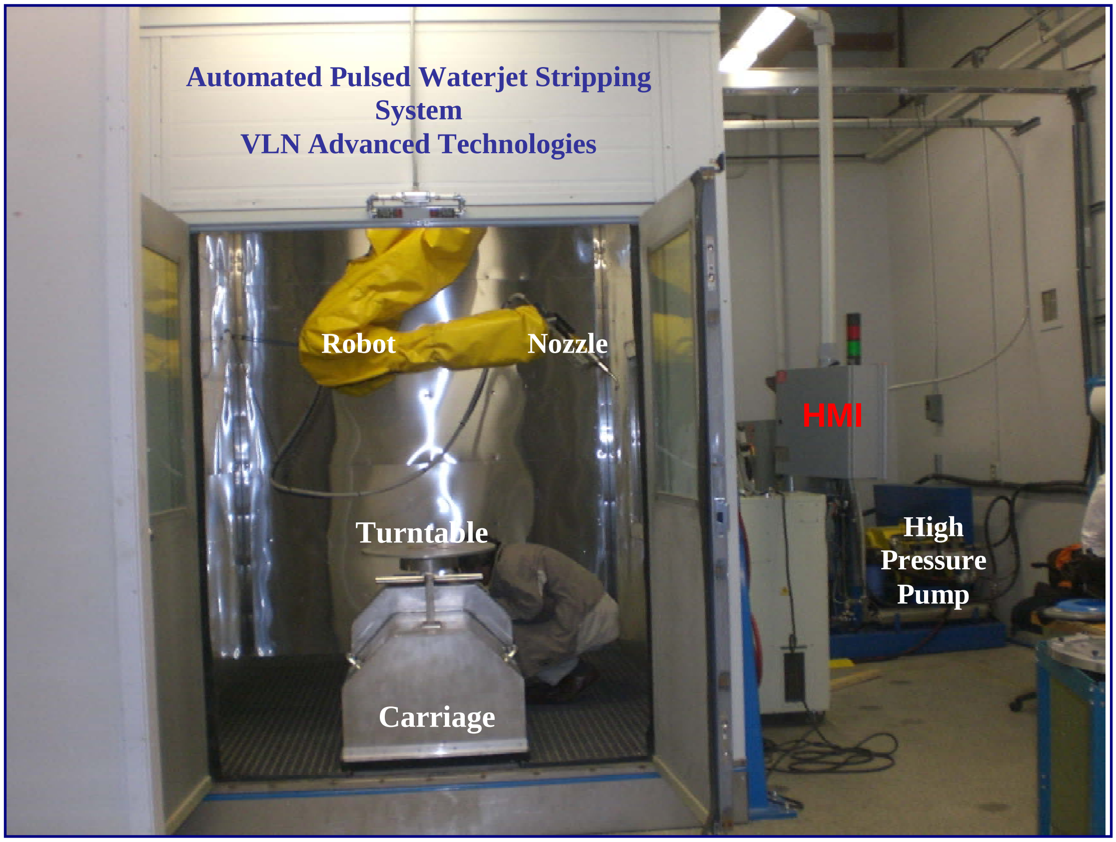

Figure 4. A general view of the APWSS installed at Vector Aerospace.

Figure 5. A close-up view of the Kawasaki robot mounted on the ceiling of the booth

Figure 6. FPWJ nozzle assembly mounted on the robotic arm.

Figure 7. A general view of the Jetstream pump controlled by the VFD.

Figure 9. Close-up view of the exhaust duct from the booth.

Figure 11. Close-up view of the HMI monitor.

Figure 8. A general view of the water filtration system mounted over the tank.

Figure 10. General view of the HMI and robot control box located near the window of the booth.

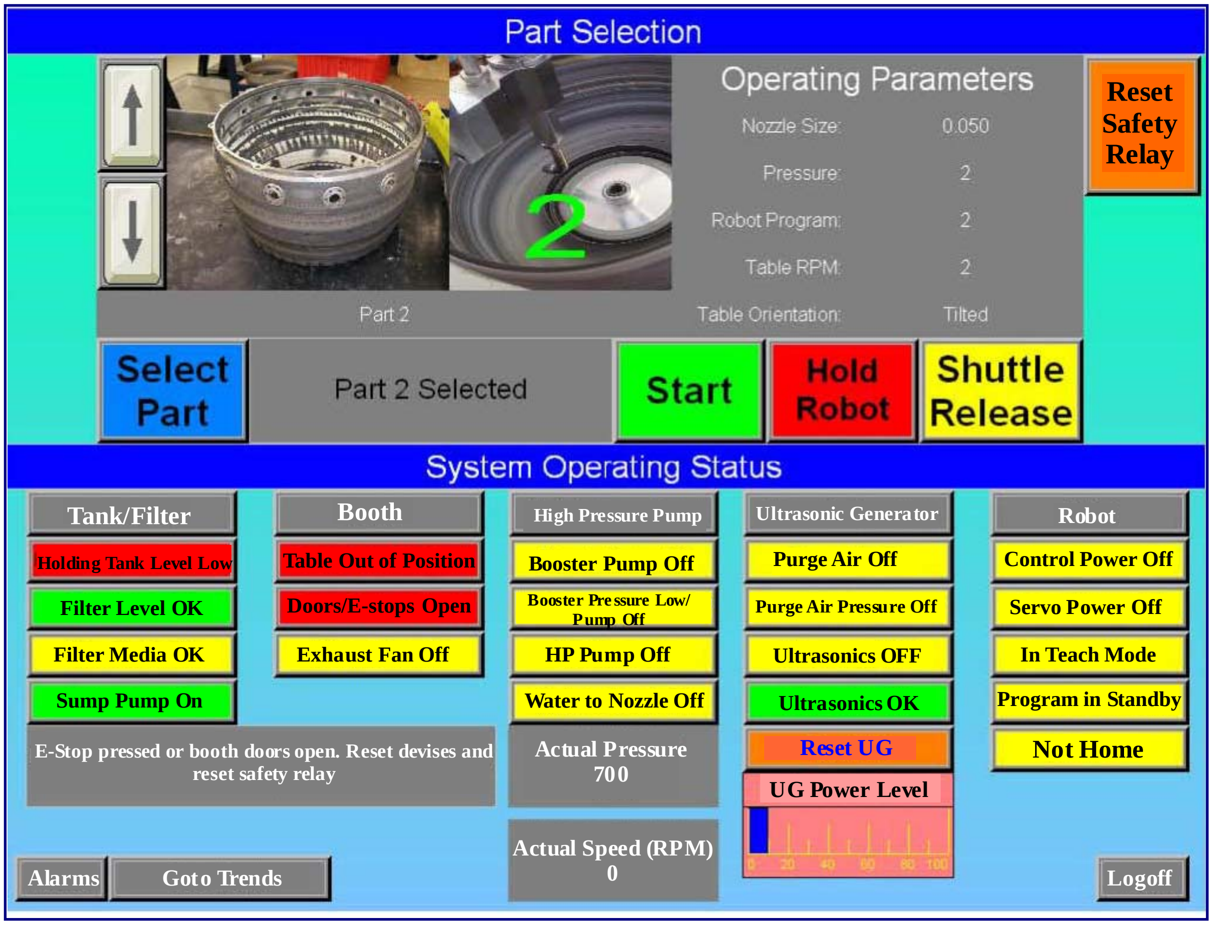

Figure 12. A close-up view of the HMI screen.

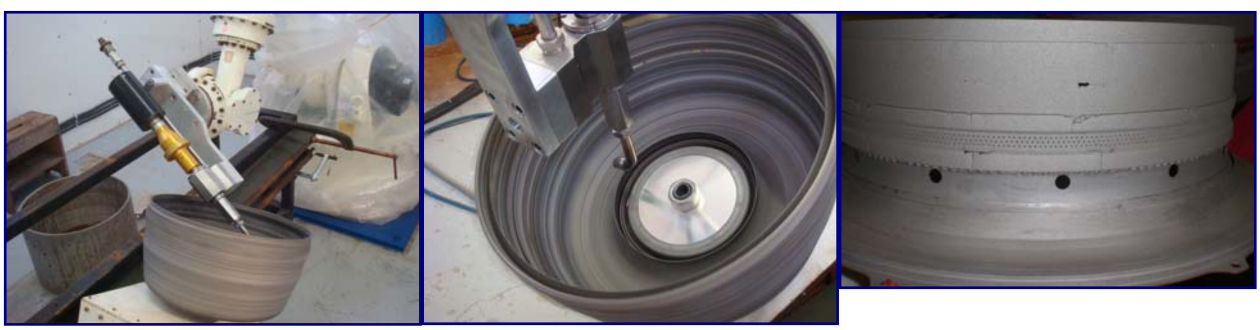

Figure. 13. Stripping of a variety of aircraft parts with the specially designed FPWJ nozzles. The third photograph shows a close-up view of the part from which TBC coating was removed.