

Advances in the automated pulsed waterjet stripping system (APWSS)

J. Bonnell, F. Cuneo, J. Duguay and C. Thibideau
Vector Aerospace, Engine Services-Atlantic, Canada

Abstract

After extensive development work and collaboration with several sub-contractors, VLN Technologies installed a totally integrated automated pulsed waterjet stripping system (APWSS) at the MRO (maintenance, repair and overhaul) facility at Vector Aerospace in January 2009. Since then several improvements have been made to render the system more ergonomic and more efficient. In this paper brief background and the improvements incorporated in to the system are described, including some results on stripping coatings from typical aircraft components.

1 INTRODUCTION

Vector Aerospace is a Designated Overhaul Facility (DOF) in maintenance, repair and overhaul (MRO) services for fixed wing and rotary wing aircraft operators around the globe (1). Vector is committed to being the benchmark against which maintenance, repair and overhaul businesses are measured. Vector Aerospace Engine Services - Atlantic is a fully-authorized Pratt & Whitney Canada (PWC) Distributor & Designated Overhaul Facility (DDOF) for the PT6A & JT15D engine series, as well as a PWC Designated Overhaul Facility (DOF) for the PW100 engine series.

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 (Fig. 1) 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. For example, thermal barrier coating (TBC) from typical parts, an example of which is illustrated in Fig. 2, is normally removed in the chemical tanks. This process takes 20-26 hours, including the time for prep work and finishing work. The project was initiated assuming that the FPWJ (*forced pulsed waterjet*) technique will substantially improve the restoration process. The mandate of the collaborative project between VLN and Vector Aerospace was to design, manufacture, test, debug and install APWSS to effectively strip, without damage to the substrate material, the following coatings:

- Aluminized Epoxy Enamel
- SermeTel Type “W”
- Plasma sprayed Thermal Barrier Coating (TBC)
- Tungsten Carbide HVOF

Prior to designing and manufacturing the APWSS, extensive testing was conducted on stripping these coatings in the laboratory at VLN Tech. All tests were conducted at pressures ≤ 103 -MPa (Fig. 3). The results from this initial laboratory work confirmed that these coatings can be effectively removed at pressures of the order of 69-MPa. In

addition to these tests, extensive work was conducted on the simulation of the kinematics of the robot arm to access all areas of the aircraft parts. Based on the simulation work (Fig. 4), special nozzle configurations were designed and fabricated to reach all areas of the parts, keeping appropriate standoff distances for effective stripping without damaging the part (Fig. 5). Following these promising results contract was given to VLN to design, manufacture and install the APWSS at Vector Aerospace Atlantic. The statement of work (SOW) dictated that the APWSS meets all the criteria stipulated by aerospace regulatory agencies, more particularly in this case, Pratt and Whitney. Generally, these criteria are: safety of the aircraft components after stripping, user friendly operation of the APWSS, environmental considerations, etc.

2 BACKGROUND

In this paper no description is given on the basics of FPWJ. Extensive details are given by Vijay and his co-workers (2). Details of the APWSS are reported by Tieu, et al (1). For the sake of clarity highlights from their publication is listed below.

The 3-D virtual view of the APWSS is illustrated in Fig. 6. It consists of:

- A sealed booth (4 X 2 X 4-m) where a ceiling-mounted Kawasaki robot performs the FPWJ nozzle articulation.
- A drain on the floor, which drains the waste water with the coating particles into a pit at the back of the booth with the sump pump.
- A filtration system to filter the waste water which is discharged into a collection tank. The water to the pump is supplied from the tank.
- Jetstream high-pressure pump rated to deliver 44.7-litre/min of water at 103.5-MPa. It is equipped with a booster pump at the inlet and is controlled by a variable frequency drive (VFD) for smooth operation (1).
- An exhaust/ventilation system to direct the mist of water to atmosphere. A baffled filter is installed to trap the entrained particles.
- **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 Fig. 7 production information is communicated to the CCS through the touch screen interface (HMI – Human Machine Interface). Here the operator can select the parts to be processed, view alarm information, view production status, control devices manually, enter predefined part recipes and enter system control parameters.

In normal production mode, the CCS also controls the holding tank, filter, high pressure pump, ultrasonic generator (for producing FPWJ), booth enclosure and the robot, which are the sub-systems of the APWSS. 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 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.

- **System Navigation:** As shown in Fig. 7, 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 powering all sub-systems, clearing all faults and to ensure that 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 (shown in Fig. 10), high pressure pump is turned 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 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). If the UG malfunctions for any reason, the "**Reset UG**" button will light up, warning the operator to take remedial action.

3 DEFICIENCIES AND IMPROVEMENTS

Deficiencies: At the time of installation, there were several shortcomings in the APWSS. This was essentially due to the deadlines set for delivery. The major deficiencies were: turntable, leakage of water from the booth, doors, windows and insulation materials in the booth resulting in high levels of sound and the exhaust system.

Improvements: These are listed below.

- **Main Booth:** The original booth (enclosure) was replaced with high quality assemblies from Eckel Industries (Fig. 8). The main reasons for replacement were: to eliminate leakage, increase sound attenuation and aesthetics. The new Eckel booth consists of 101.6-mm thick walls (upgraded from the original 76.2-mm thick walls), stainless steel interior surface with excellent acoustic insulation materials in the interspaces between the walls. Brackets and mounting points were also provided to accommodate the mist eliminator and Robotrax cable carrier. As is clear from Fig. 8, the booth now satisfies all the requirements specified in the original SOW (including, aesthetics).
- **Pump Enclosure:** Apart from the noise of waterjet, high pressure pump and the associated VFD generate significant unpleasant sound levels. In order to minimize these sound levels, a high quality acoustic booth was constructed to enclose these units. A general view of the enclosure can be seen in Fig. 8 with the close-up views in Fig. 9. The construction is modular so that it can be easily dismantled for maintenance or repair of the pump. There are three access doors (Fig. 9) with sufficient space in the enclosure to facilitate maintenance operations. In order to prevent high temperatures, the booth also incorporates an air intake/exhaust fan. The combination of main and the pump booths has reduced the noise level by 10 to 15-dB.
- **Interior of the Main Booth:** The interior of the main booth is shown in Fig. 10. The home position of the robotic arm with the nozzle assembly and the turntable for holding the part to be stripped can be clearly seen. Although not visible, a robotrax cable carrier, constructed with plastic and stainless steel hardware, was installed to prevent the high-pressure hose and the coaxial cable in order to keep them above the recommended minimum bend radii. The cable carrier also serves the purpose of preventing interference of hoses with the movement of robotic arm. Another improvement is to control the precise motion of the robot. By downloading a linear speed function called, "Direct Speed," it has been possible to key in very specific translation speeds in increments of 0.1-mm/s. This is quite critical to optimize the parameters for stripping without damaging the part. The default method of commanding speed was to set the speed from 0 to 9, with each number corresponding to a preset translation speed.
- **Exhaust System and the Mist Eliminator:** The mist eliminator and the refinished exhaust system are illustrated respectively in Figs. 11 and 12. When the system was installed, there was significant leakage between exhaust sections, as well as at the exhaust fan frame/exterior wall interface. The problem was addressed by extending the ductwork all the way through the exterior wall and installing appropriate gaskets between sections. Other parts which contributed to significant noise while the fan was running were all removed from the system.

As mentioned above the excess leakage was also due to excessive moisture running through to exhaust duct. A mist eliminator, which decreases the amount of large water droplets, was installed in the main booth (Fig. 11). The combination of the mist eliminator and the improved exhaust system has completely eliminated the leak issue. Furthermore, the reduction in moisture exhausted through the system has prevented the louvers from freezing at sub-zero temperatures in the winter.

4 MEASUREMENT OF SOUND LEVELS

The sound level outside the booth with the original installation was well above 85-dB stipulated by OSHA (Occupational Safety & Health Administration, USA). After

incorporating all the improvements described above, sound level measurements were taken using Radioshack Sound Level Meter (Model 33-2055, range: 50 to 126-dB, accuracy: ± 2 -dB, display response: fast & slow). The measurements were taken with the operator at the HMI monitor (see Fig. 6), approximately 1.5-m from the main enclosure window and also 0.9 to 1.2-m in front of the main enclosure (booth) doors (see Fig. 8). The measurements at various operating pressures (for orifice diameter of 1.6-mm) are listed below.

Table 1. Summary of sound levels.

Pressure (MPa)	45	48	55	62	69
Sound Level (dB)	79-84	80-84	80-85	81-87	82-87

The maximum value (in the range listed above) was the level of sound when the nozzle-robot assembly was at the home position (≈ 10 -s). The minimum value was during the period when the part was stripped, that is, when the FPWJ was inside the part, the noise was reduced. Therefore, the improvements of the APWSS did indeed reduce the noise to the levels specified by OSHA.

5 REMOVAL OF SEVERAL COATINGS WITH THE APWSS

The following substrates and coatings have been thoroughly tested on the APWSS and the optimal parameters have been determined.

- Thermal Barrier Coating (TBC) on Inconel 625 (AMS-5387).
- Araldite surface sealant/epoxy primer/aluminized epoxy enamel on magnesium alloy (AMS-4377).
- SermeTel type “W” on 410 Stainless Steel (AMS-6359).
- HVOF (WC-Co-Cr) on 4340 alloy steel (AMS 6415).
- Plasma Sprayed Coatings (Various types) on Inconel 625 (AMS-5387).

Thermal Barrier Coating (TBC)

Thermal Barrier coating was removed at pressures as low as 38-MPa using multiple passes. However, the optimum removal rate was observed to occur at 103.5-MPa with the 1.575-mm orifice. Substrate thickness is of primary concern when determining the appropriate setting of pressure.

As mentioned earlier, TBC is normally removed in chemical strip tanks and may take 20 – 26 hours to complete. With the FPWJ, turn-around-time (TAT) has been reduced to 2-3 hours. Currently, attempts are in progress to further improve these times by varying operating and orifice configurational parameters. Since only clean water is used for stripping, environmental hazards posed by chemicals have been eliminated.

Araldite Surface Sealant/Epoxy Primer/Aluminized Epoxy Enamel

Several configurations proved successful with this coating/substrate combination. Pressures varying from 41.4-MPa (1.575-mm orifice) to 69-MPa (1.372-mm orifice) were used, including twin-orifice (each orifice 1.016-mm in diameter) rotating nozzle. The removal rate achieved with the 1.575-mm orifice was found to be better than the

rotating nozzle. This is attributed to the inefficiency of the rotating nozzle (due to complex flow paths inside the nozzle).

SermeTel type “W”

SermeTel type “W” was successfully removed using 1.372-mm orifice at 69-MPa or, the twin rotating nozzle mentioned above. Once again the stripping rate achieved with the single-orifice nozzle was better.

HVOF (WC-Co-Cr)

HVOF was removed quite effectively without damage of the substrate materials of the parts with the single-orifice (1.372-mm) at pressures from 69 to 103.5-MPa. The removal rate increased only by 15% when the pressure was increased from 69 to 103.5-MPa. However, as the effective standoff distance increases significantly with the pressure, stripping at higher pressures would be advantageous where long standoff distance is important (for example, locations of the parts which are difficult to access at short standoff distances).

Plasma Sprayed Coatings (Various)

Testing is in progress to optimize the parameters of the APWSS on various parts with complex geometries with plasma sprayed coatings. Normally, repairing a circular (round) plasma sprayed part involves removing the plasma by machining. However, due to imperfection in the parts (for instance, irregularity in the roundness), often it can be difficult to remove all plasma coating without removing some parent material. The APWSS can actually salvage parts due to its ability to strip all plasma while leaving the substrate undamaged, resulting in considerable cost savings. Figure 14 illustrates one of the typical plasma coated aircraft parts effectively stripped with the APWSS.

Furthermore, as with other coatings, plasma coated parts can be stripped much faster with the APWSS compared with conventional machining. While setting up in the conventional machining operations can take a significant amount of time (depending on the part and repair scheme), the APWSS setup is as simple as mounting the part to a base fixture.

All the stripping work has been conducted on parts fabricated with Inconel-625. APWSS has been found to be quite powerful to remove any coating. However, geometry of the parts dictates setting of appropriate operating parameters for stripping the coatings without damage.

6 CONCLUSIONS

After initial installation in January 2009, significant improvements were incorporated into the APWSS. The main conclusions from the work reported in this paper are:

- The improvements have contributed significantly to the ergonomics of the system.
- The noise levels have been reduced to meet the OSHA requirements.
- Several types of thermal spray coatings (metallic & non-metallic) from the aircraft parts have been successfully removed without damaging the substrates and good

surface finish for re-coating. Operating pressures are within the range of 50 to 69-MPa.

- APWSS uses filtered and recycled water and therefore there is no loss of water (except for moisture).
- APWSS is user and environmentally friendly system.

7 ACKNOWLEDGEMENTS

The authors are highly thankful to:

Mr. B. Daniels, W. Bloom, A. Tieu, M. Vijay and W. Yan from VLN Advanced Technologies, Ottawa, Ontario, Canada.

Mr. M. Booth, General Manager, Vector Aerospace, Africa.

Mr. B. Jesulaitis, B. Colwill and B. Strongman, Vector Aerospace Engine Services-Atlantic, Summerside, PEI, Canada.

Mr. M.R. Berezowsky and his associates at Automated Jetting Systems, Mississauga, Ontario, Canada.

Mr. Bruce Sharpe, Liquid Laser Jetting Systems, Concord, Ontario, Canada.

Mr. B. Rochelle, Kawasaki Robotics USA, Inc., Wixom, MI, USA.

Mr. A. Rafiei, Eckel Industries of Canada, Morrisburg, Ontario, Canada.

8 REFERENCES

1. Tieu, A., W.Yan, B. Daniels, M. Vijay, F.M. Cuneo and M.R. Berezowsky, "Design, manufacture and installation of APWSS (Automated Pulsed Waterjet Stripping System)," Paper
2. Vijay, M.M, "Fundamentals and applications of cavitating and forced pulsed waterjet techniques," Revised Technical Note, January 2010. VLN Tech., Ottawa, Canada (can be obtained by request: mvijay@vln-tech.com).



Fig. 1. General views of the chemical stripping facility. (A) Overall view, (B) close-up view.



Fig. 2. A typical engine component processed with chemical solutions.



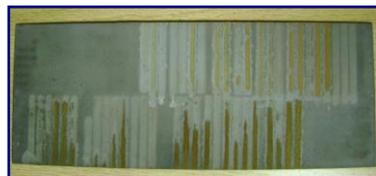
Araldite/epoxy on magnesium alloy



Sermetel on 410 stainless steel



TBC/Bond on inconel-625



WC-Co-Cr HVOF on 4340 steel

Fig. 3. Initial stripping tests conducted on several substrates to optimize the operating parameters without damaging the substrates.

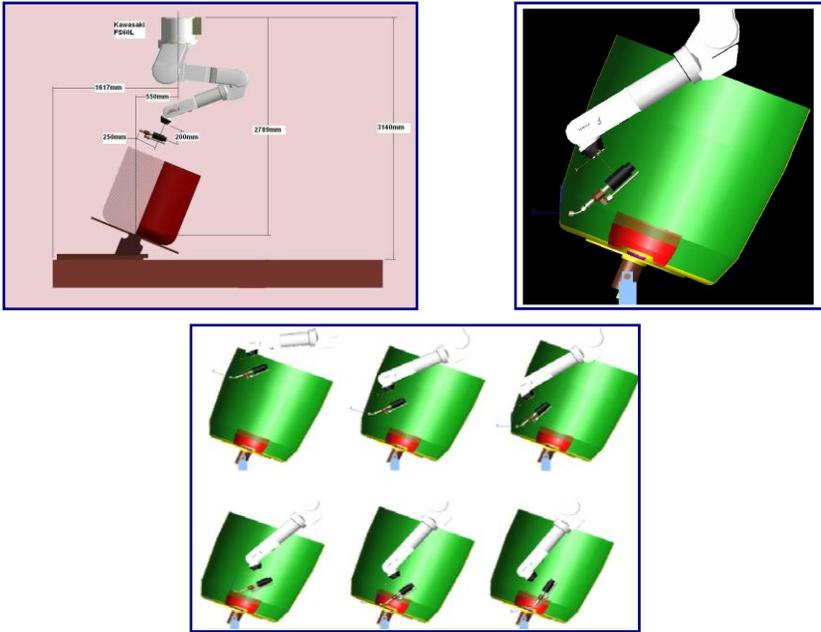


Fig. 4. Simulation studies conducted on the kinematics of the robotic arm to strip several critical areas without damaging the expensive parts.



Fig. 5. Programming the robot (based on simulation studies) to strip critical areas (from top to the bottom) of one of the engine components without damage.

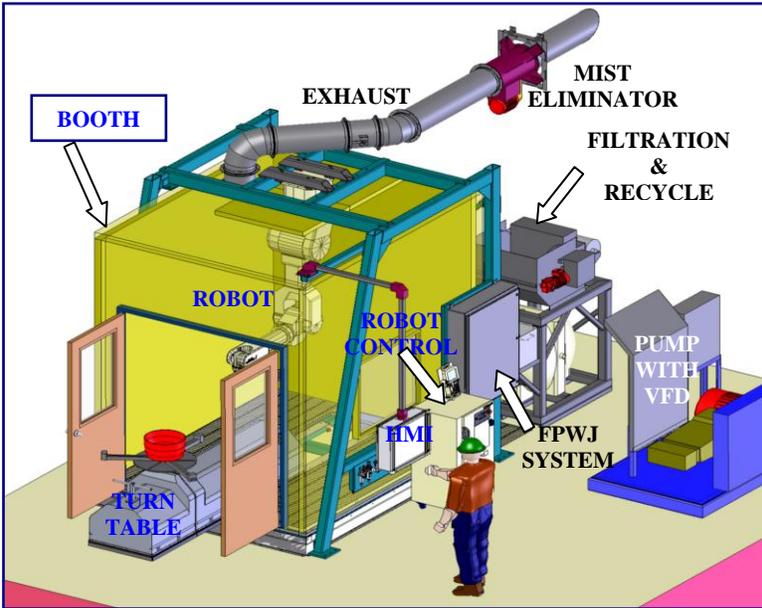


Fig. 6. Conceptual design and layout of the APWSS based on extensive computer simulations.

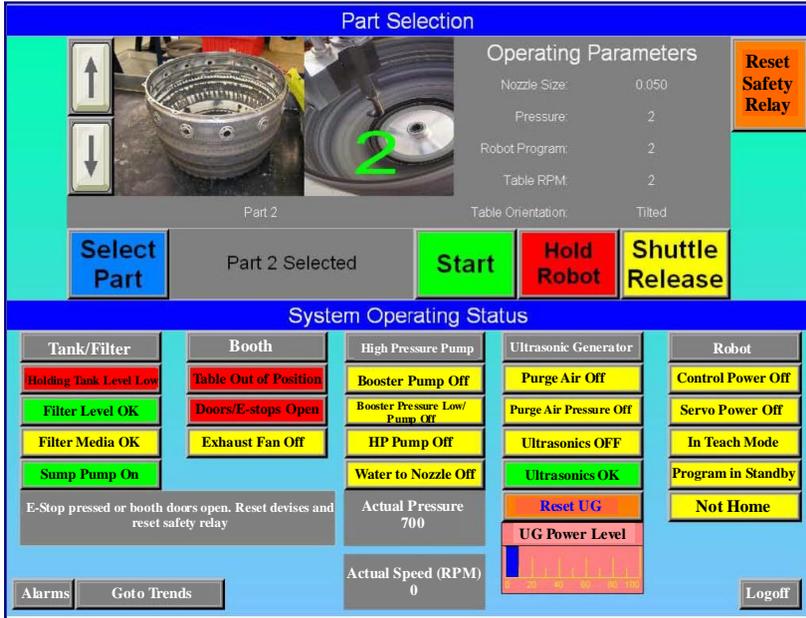


Fig. 7. A close-up view of the HMI (human-machine-interaction) screen (1).



Fig. 8. A general view of the new booth with well insulated walls.



Fig. 9. Close-up views of the pump enclosure. (A) Access door for VFD and control box, (B) Access door for accumulator and other accessories.



Fig. 10. Interior view of the booth manufactured with stainless steel, acoustic materials and double-pane windows to abate noise levels when the system is in operation.

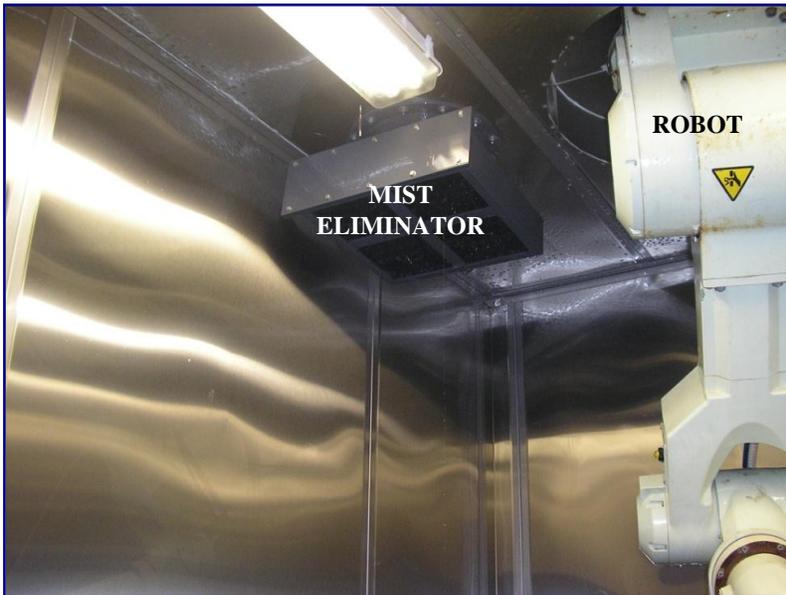


Fig. 11. View of the interior showing the mist eliminator mounted on the ceiling leading to the exhaust system.

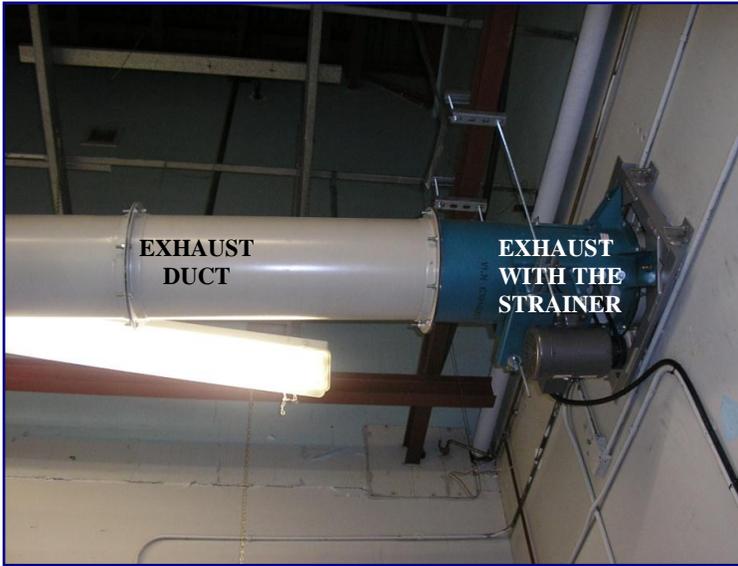


Fig. 12. Exhaust duct from the mist eliminator in the



Fig. 13. One of the several engine parts stripped in the APWSS at pressures ≈ 69 -MPa.



Fig. 14. Plasma sprayed part. (A) Prior to stripping and (B) stripped with the APWSS.