Advanced Aircraft Maintenance Systems: An Automated Closed-Cycle Dry Stripping Technology for Transport Size Aircraft


SUMMARY

CAE's closed-cycle automated depaint process, in combination with secondary closed-cycle manual support systems, will be able to depaint an entire aircraft using the Starch Media Dry Stripping (SMDS) Process. This will be accomplished in existing aircraft maintenance or paint hangars. The Starch Media process is capable of removing coatings selectively or completely from commercial and military aircraft. While effective on today's coating systems, the starch media process can be potentially improved through selecting and/or modifying both the media and the coatings used on aircraft.

The CAE paint removal technology consists of a selection of end-effectors designed to accomplish the stripping process. The majority of the aircraft will be stripped with an automated end-effector, and "smaller, difficult to access" areas will be stripped with closed-cycle manual units. Components removed from the aircraft can be stripped in a separate blastroom sized to accommodate parts as large as flight controls. This blastroom can be designed to utilize either a manual (hand-held) stripping methodology or can be upgraded to include automated equipment.

The manual hand-held process will use specially designed end-effectors to deal with small on-aircraft areas. These stand-alone units will not require the large processing equipment (PET) used for the automated system.

The Automated Closed-Cycle System for transport aircraft is comprised of a 4-axis robotic arm and end-effector mounted on a 12-foot beam. This important area of the total system is common to all carrier options. The travel beam provides lateral translation movement for the robotic arm/end-effector and is supported by a Travel Beam Positioner (TBP). The six-foot 3-DOF robotic arm mounted to the travel beam provides vertical movement of the end-effector and allows the compliant end-effector to align itself normal to the aircraft surface. The Travel Beam Positioner is mounted on a mobile platform (Mobile Carrier) which moves laterally along the side of the aircraft via rails.

There are several carrier options to choose from depending upon available hangar area, workload, and makeup of aircraft type.

End-Effector

The end-effector contains two blasting nozzles and a vacuum recovery duct. The two blasting nozzles deliver the stripping media and the vacuum hose recovers the used media and paint. Sensors on the end-effector confirm surface contact with the aircraft and the end-effector will be compliant to compensate for curved surfaces. A computer vision system, using cameras and sensors mounted on the end-effector, monitors the effectiveness of the stripping process inside the blast enclosure.

Four pneumatic actuators are mounted on the blast enclosure. These actuators provide passive compliance of the end-effector to the aircraft surface. These actuators allow for three additional degrees of freedom (roll, pitch, and heave) of the end-effector. End of stroke sensors are attached to the pneumatic cylinders. When these sensors detect that the actuators are fully compressed, the robotic arm reacts accordingly.

The Blast-Enclosure housing is fabricated from aluminum. The blast enclosure is composed of:

(i) Viewing Window: This window is used by the vision camera and lighting.
(ii) Deflector plate: This retractable plate is used to deflect the starch media particles away from the aircraft surface during the step-down of the end-effector/robotic arm, or in case of interruption of the end-effector translation.
(iii) Brushes: Used to prevent the media and the paint from escaping to the environment.
(iv) Casters: Used with force feedback sensors to minimize friction.

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Letters to the Editor

Jack Champaigne,
Editor of Aircraft Paint Stripping News

Dear Readers:

We started this newsletter in 1996 with high hopes that it would be an excellent vehicle for sharing information with the aircraft paint stripping community. We followed a format that is very successful for our shot peening newsletter. And while we have received favorable feedback from readers and support from advertisers, it has not been enough to sustain our efforts to produce Aircraft Paint Stripping News.

However, all hope is not dead. We will make our final evaluation after the DOD Conference (see us at the Electronics Inc. booth). We could certainly be persuaded to continue publication with enough input from readers.

NOW is the time to send letters, submit articles and place advertising!

Best Regards,
Jack Champaigne

Things don't look good for this newsletter.

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The purpose of the recovery duct is to capture the wheat starch media and paint particles within the blast enclosure during stripping. The recovered particles are then conveyed back to the Process Equipment Trailer (PET) where the media is reclassified and the fine dust is extracted.

In order to stop blasting into the end-effector without stopping the blasting process, a nozzle bypass valve is installed just before the nozzle. This valve will operate when repositioning the travel-beam or if containment is lost at the end-effector.

Lighting is an extremely important part of the computer vision system. Correct lighting enables proper image acquisition and processing by the vision system and ensures process repeatability.

Positioning, Collision Avoidance, and Safety Sensors

Initial positioning of the end-effector on the aircraft will be assisted with proximity sensors. As the end-effector approaches the surface, these sensors measure the distance between the end-effector plate and the aircraft. The robotic arm controller uses the output of these sensors to correct the alignment between the end-effector and the stripping surface.

Infra-red transmitters will be used on the end-effector to detect obstacles rising from the aircraft surface which block the stripping path. Proximity sensors will be used on the travel beam and mobile carrier to safeguard against collision with the aircraft when repositioning the travel beam or mobile carrier. Force sensors on the end-effector castors will monitor the force exerted on the aircraft. A pneumatic sensor inside the end-effector enclosure will instantaneously detect if vacuum is lost.

Computer Vision System (CVS)

The travel speed and position of the end-effector will automatically be adjusted in real-time to maintain optimum strip rate and proper blast trace overlap by using computer-vision based technology.

The CVS will be used for three real-time motion control tasks:
1. Step-down at end of each trace
2. Overlap control during end-effector travel
3. Travel-speed adjustment

The operator can easily set and adjust the translation-speed of the end-effector/arm to obtain the desired stripping result. This is accomplished by referring to the video image of the stripping action inside the blast-enclosure.

Using a joy-stick control, the operator can regulate the travel speed as is done with cruise control for an automobile. In order to “calibrate” the CVS to the actual color contrast required, the operator will perform this task at the beginning of the automated stripping action. Calibration is effected on the actual paint system of the aircraft. The operator will also monitor and control the translation speed when the task at hand is too complex for the CVS.

Fortunately, the simpler situations typically represent the majority of the aircraft surface allowing the CVS and automation controls to function.
New Flat CAE Nozzle

Successful nozzle development at CAE has created a major breakthrough for dry stripping technology. The industry standard Venturi-type nozzles have been the industry benchmark for years. However, these round Venturi nozzles do not provide optimum efficiency for media blasting, especially with light abrasives at low pressures. Through the use of advanced Computational Fluid Dynamics (CFD) software and the full time dedication of a CAE Engineer, we have produced a new flat nozzle that maximizes paint removal efficiency. When used in an automated application where linear travel speed is constant, a single flat nozzle produces strip rates of 2.0 - 3.0 ft/min. for complete finish removal, and in excess of 3.0 ft/min. when selectively stripping both Mil-spec and commercial paint systems. This increased productivity is achieved without increasing the mechanical effects of the starch media process. Investigations have also demonstrated the benefits of higher media flow rates, namely increased productivity and reduced mechanical effects of substrate materials.

CAE is finalizing its design and selection of materials for nozzles used with automated application. CAE continues to investigate how this new design can be modified to produce more efficient nozzles for manual hand-held applications.

Automated System Description

Robotic Arm

The robotic arm is a four degree-of-freedom manipulator (1 translational and 3 revolute). The translational joint allows for horizontal movement on the travel beam. The three revolute joints allow for movement of the arm on a vertical plane perpendicular to the travel beam.

The travel beam is a truss structure. The main purpose for the beam is to provide precise horizontal travel for the robotic arm's paint-stripping process.

The arm's shoulder section allows for left/right movement along the travel beam. This section of the arm contains power drives for horizontal movement, and rotational movement of the upper arm.

In the upper arm, two brushless DC motors provide rotational movement of the upper arm itself, and rotation of the wrist through a pulley system.

The forearm section is approximately 3.75 feet long, and is connected to the joint of the arm's wrist.

Mobile Carrier Options

As stated previously, there are several carrier options to choose from. Selection will be driven by the available working space around the aircraft and confines of the hanger, the anticipated workload, and the variety of aircraft involved.

High Elevation and Low Elevation Mobile Carriers are floor-standing structural frames that support the Travel Beam Positioner (TBP). The Mobile Carrier is self-propelled and rests on heavy duty wheels. Four retractable stabilizers are deployed to immobilize the mobile carrier prior to stripping.

In order to accommodate various customer requirements and to offer the most efficient solution, CAE has designed a selection of Mobile Carriers. Fixed, hangar specific carrier options are also available.

The Mobile Carriers options are grouped as follows:
3. Adjustable “High Elevation” Mobile Carrier for both wide and narrow-body aircraft.
4. “Low Elevation” Carrier for under-wing and lower fuselage areas.
5. “Man-Lift” Carrier for both narrow and wide body aircraft high elevation areas.

Depending upon the makeup of the workload, a user would select the appropriate Carrier Group that best accommodates the aircraft involved. The end-effector/robotic arm and travel beam assembly is interchangeable with all Mobile Carriers. If the workload and aircraft type change, a new Carrier type can always be added.

High-Elevation Mobile Carrier

This option is used to strip the majority of the upper surface of the aircraft. As previously shown this carrier currently comes in three versions: two with “fixed elevations” and one with an “adjustable elevation”. These different carrier configurations serve as the “platform” for the three DOF Travel Beam Positioner.

The Travel Beam Positioner supports the travel beam, robotic arm, and end-effector through two parallel retracting/extending support beams. These beams rotate in the vertical plane. The TBP will automatically reposition on the main rail of the Mobile Carrier. Video cameras will be located at each end of the travel beam and on the arm's shoulder.

Low Elevation Mobile Carrier

This low-profile carrier is used to strip under the wings and lower areas of the aircraft. The travel beam, robotic arm and end-effector are mounted on a low-profile carriage which provides height adjustment. The low-profile carriage is in turn mounted on a carrier rail similar to the one used on the High Elevation Mobile Carrier.

Man-Lift Support System

This carrier is yet another way to place the automated system next to the aircraft. The robotic arm assembly can be transferred to this structure from either the High or Low Elevation Carriers so that one Automated End-Effector could be used to strip all major areas of the aircraft if desired.

Process and Support Systems

Process Equipment Trailer

The Process Equipment Trailer (PET) stores, delivers and recovers the starch media. This media “processing center” filters out paint and manages reusable media to insure that cleanliness and appropriate media size is maintained.

At nozzle operating pressures of 30 - 40 psi, approximately 10% of the media is consumed with each blast cycle. The PET and the end-effector form a closed-loop system for paint removal. The PET starch media delivery system consists of a hopper for media...
storage, and controls for regulating blasting pressure and media flow rate. The recovery system comprises a vacuum pump, media and paint filters and separators. As the media is used, the size of the starch media particles can be maintained at an optimal level with the regular automatic addition of new media. The process equipment is mounted on a towable trailer. Compressors and a refrigerant air-dryer are either mounted on a separate trailer or dry air is supplied from the facility.

Mobile Operator Station
The operator control cabin is situated on a vehicle capable of towing the PET around the aircraft. The operator's cabin contains monitors and operational controls for the PET, arm/end-effector and the selected carrier.

Typical System Operation
The following outlines how a typical system operation would proceed.
1. The Mobile Carrier is located next to the aircraft by the operating crew to begin stripping of station #1.
2. The end-effector is located at a “start-point” by the operator.
3. The operator initiates the stripping program. Lateral movement of the end-effector across the surface removes paint completely or selectively depending upon travel speed.
4. The Computer Vision System monitors the stripping action and controls the stripping activity by adjusting the end-effector travel speed.
5. At the end of each lateral pass, the system automatically “steps-down” for a subsequent horizontal pass.
6. Upon completion of station #1, the system will automatically move to the next station via the Travel Beam Positioner (TBP). The same activity is repeated at station #2 and so on.
7. Upon completion of all areas within reach of the Mobile Carrier, the operator, with ground crew assistance, moves the carrier to the next area of the aircraft to be stripped.
8. Once all upper areas of the aircraft are stripped with the High Elevation Mobile Carrier, the PET is connected to the Low Elevation Carrier System to complete remaining areas (note this equipment interchange is needed only if one PET/MOS is used).
9. If multiple PET/MOS vehicles are used, this would allow both low and high carrier systems to function concurrently.

Concurrent Activities
1. With this “closed-cycle/dust-free” process, masking is kept to a minimum.
2. Planning will allow masking activity to take place concurrently with the depaint task, minimizing strip cycle time and aircraft downtime.
3. De-masking of stripped areas can also take place during the stripping activity.
4. Other maintenance activities may also be conducted on the aircraft while the stripping activity takes place.

Manual Depaint (Touch-up)
1. Small, difficult to access areas, will be stripped using manual, closed-cycle/dust-free systems. Currently these systems are hand-held but we are working on semi-automated or ergonomically assisted support systems.
2. Areas to be stripped manually are easily identifiable and can be stripped before, during or after the automated stripping activity takes place.
3. Although these systems will be closed-cycle and dust-free, they will provide significantly lower strip rates versus the automated system.
4. It is anticipated that approximately 10% of the aircraft, on average, will require manual closed-cycle stripping.

Recap of CAE’s SMDS Process Improvements

Media Particle Size Control
Proper starch media size management has lead to increases in paint stripping efficiency. Paint removal rates improved significantly once an optimum media mix was determined. Maintaining the proper mix is easily obtained by automatically adding new starch media to recovered working media.

Media Regulation Valves
Stable, non-surging media flow is essential for the optimized use of Starch Media Dry Stripping (SMDS). Properly engineered media flow regulating devices are now available from several manufacturers. These flow valves provide an obvious benefit to the overall process, particularly when automated application is involved.

Nozzle Development
As previously outlined, new flat nozzle development has increased strip rates up to 300% over conventional round nozzles. This achievement, combined with proper media mix and media flow has raised the SMDS process to new levels.

Automated Closed-Cycle (Dust-Free) Depaint System
CAE Electronics has invested significant time, energy and resources to establish a viable depaint system for transport-sized aircraft. We continue to move forward with our development and anticipate expanding the technology into other areas of aircraft maintenance and inspection. CAE’s ability to provide a platform for advanced “end-effector tools” for application on transport size aircraft opens up new opportunities. A selection of end-effectors for other maintenance tasks is currently being reviewed and, when appropriate, will be incorporated into our automation program.

A linguistics professor was lecturing to his class one day. “In English,” he said, “A double negative forms a positive. In some languages, though, such as Russian, a double negative is still a negative. However, there is no language wherein a double positive can form a negative?”

A voice from the back of the room piped up, “Yeah, right.”