Sealant Removal from an A-10 Thunderbolt Center Wing Fuel Tank Using a Portable Hand-Held Nd:YAG Laser System

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Summary

The authors describe a system for removing sealant from an A-10 Thunderbolt center wing fuel tank using a portable hand-held Nd:YAG laser. This laser technology was demonstrated in the confined space of an A-10 center wing fuel tank. The results indicate that portable 200- and 500-watt-rated systems remove the sealant around a fastener in less than a minute or ½ minute, respectively. The laser system included a 100-foot flexible umbilical hose from the laser power source and the purge air system to the work-head and video display at the target area. A 400-cfm waste-collection and filtration system removes ablated debris and sealant vapors, maintains good visibility, and eliminates any chance for fire. The incentive for deploying this laser technology is cost savings and quality of maintenance.

Introduction

More than 350 A-10 Thunderbolt aircraft (Warthogs) are in service with the U.S. Air Force, Air Combat Command, the U.S. Air Force Reserve, and the Air National Guard (Figure 1). The maneuverability of these aircraft at low speed and at low altitude (below 1,000 feet) allows accurate and effective targeting and weapon delivery over all types of terrain. Such maneuverability in close-range targeting situations also leads to structural stress.

Figure 1. *A-10 Thunderbolt ready for action*

Periodically, center wing tanks require inspection for structural defects. The A-10 center wing tanks have sealant (e.g., Military Specification 8802-Polisulfide) covering fastener areas to eliminate fuel leakage (Figure 2).

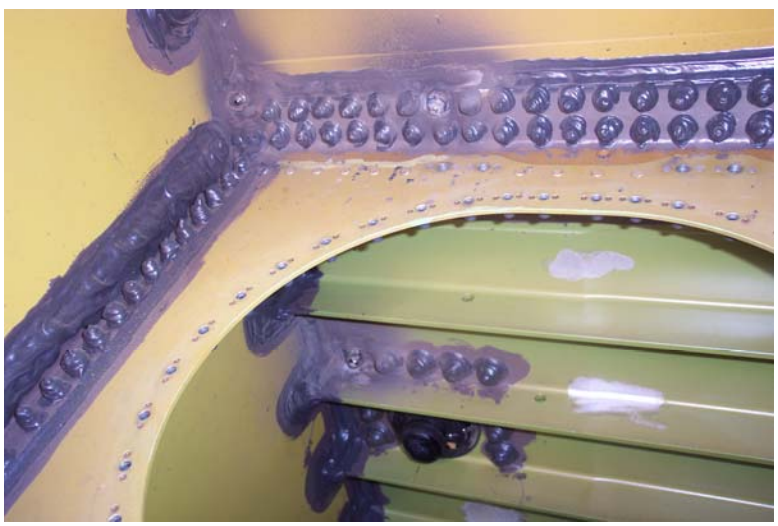

Figure 2. *Sealant covering fasteners in the center wing tank*

When fuel tanks leak or when critical non-destructive examinations or repair of these areas is necessary, the traditional method is to remove sealant manually by mechanical means (scraping). This method is time-consuming and tedious due to the irregular geometries of the fastener regions. The confined space makes the task even more difficult. Incomplete cleaning is highly likely and mechanical scraping can also damage the structure if adequate care is not taken (Figure 3). Each A-10 has eight cells like those shown in Figures 2 and 3 in the center wing tank, and each cell has about 600 sealant-covered fasteners.

Figure 3. *Example of results of mechanical (scraping) to remove sealant*

A portable laser system offers an alternative sealant removal capability for confined space applications with irregular geometrical surfaces. General Lasertronics Corporation (GLC) in San Jose, California, has developed a system that appears to meet these requirements. Prior to recommending the technology be deployed, testing was conducted at GLC facilities on a retired center wing tank (Figure 4) using a Neodymium-doped Yttrium-Aluminum-Garnet (Nd: YAG) laser system. The Nd:YAG laser delivers a beam at a 1064-nanometer wavelength and can be Q-switched to pulse at a desired frequency. At the selected Q-switch frequency, the power of short laser pulses is increased by a factor of about 1000 over the average delivered power level. Extremely high power of short pulses allows the sealant to be removed without delivering heat to the material not removed. Final-stage optics in the hand-held tool rapidly scan the pulsed laser beam over the target area at a rate to ensure that the beam cannot dwell in one location independent of the operator motion.

The purpose of the testing was to determine if this laser technology had the potential to improve current sealant removal technology. The objectives were to show feasibility to meet these five requirements:

- a portable laser that can remove sealant more economically than current methods
- a hand-held delivery system that is capable of removing all sealant in the center wing section without causing any apparent substrate damage to 2024 T3 or 7075-T6 aluminum alloys
- a hand-held delivery system that is easy and safe to use

- a system that has reasonable reliability so that it would be operational for long periods of time without maintenance

- a process that does not cause fires while removing sealant.

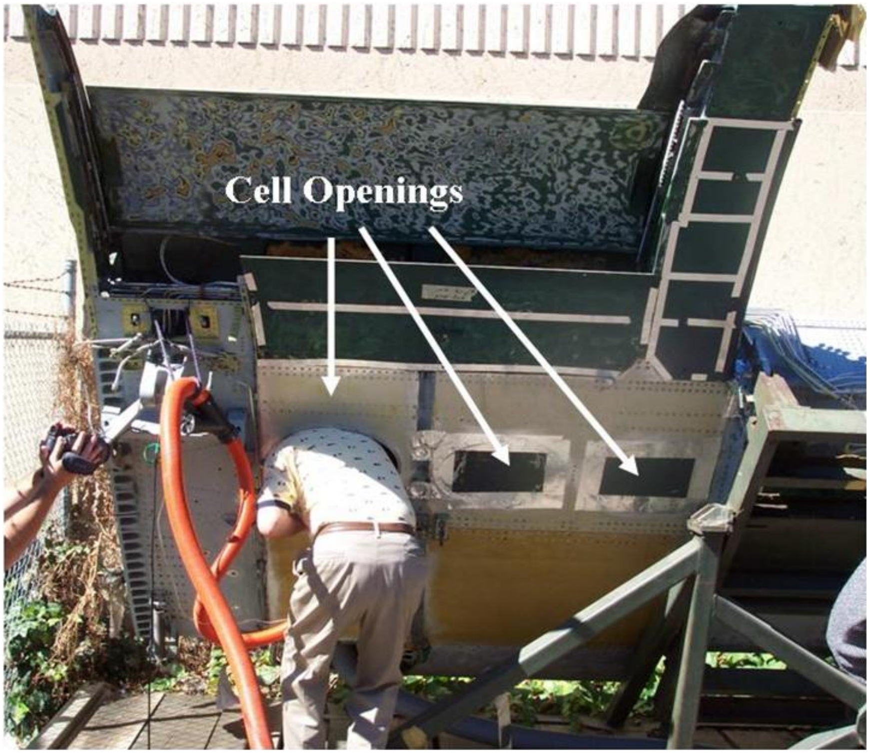

Figure 4. *Port half of the retired center wing tank showing fuel cell openings are barely large enough for an operator*

<u>Equipment and Instrumentation Used</u>

For this confined space application, a tool developed by GLC, based on a patent that GLC filed under AF SBIR Topic No. 98-270, was modified to fit within an end-effector configuration that is 2.6 inches in diameter and 8 inches in length. The tool contains the beam-scanning mechanism and optics to focus the beam onto the user-selected surface location in a two-dimensional spiral scan pattern. The pattern was selected to avoid substrate damage and to ensure complete and systematic coating removal (Figure 5).

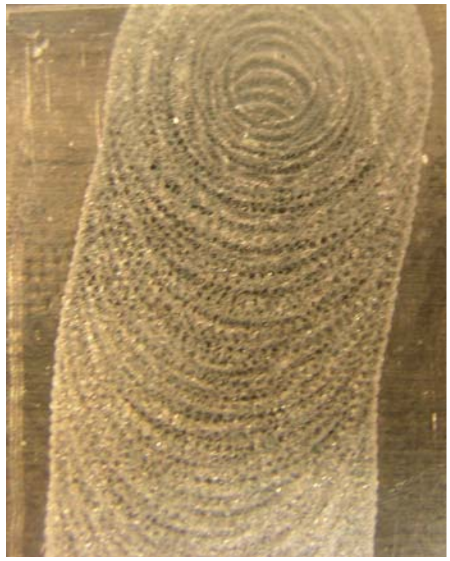

Figure 5. *Typical spiral scan used*

In addition, the tool carries a miniature camera that provides a video feed to a head-mounted display (Figure 6).

Figure 6. *Operator uses video display if line-of-sight obstructions exist*

While wearing the display unit, the operator can see a surface spot where the laser is removing material even if line-of-sight obstructions exist in the wing tank. The end effector, its aperture, the video camera, and the optical fiber umbilical hose are shown in Figure 7.

***Figure** 7. GLC confined space tool for laser coating removal*

Air is blown at a rate of approximately 25 cfm through the umbilical hose (orange hose in Figures 4, 6, and 7), through the tool, and out the laser beam aperture. The air provides cooling for the optics, electronics, and mechanical components in the tool as well as protects the optics from intrusion by sealant particles from the ablating surface. Additionally, the air reduces the concentration of combustible vapors during sealant removal to a point well below the Lower Flammability Limit (LFL). The umbilical length was approximately 100 feet, so the laser and air blower can be located a significant distance from the aircraft (Figure 4).

Process waste is evacuated from the cell through a separate umbilical hose with an approximate flow rate of 400 cfm. The evacuated air is filtered and collected in a storage tank. This capability removes ablated debris, sealant vapors, and helps maintain good visibility while eliminating the chance for combustion (fire) in the cell.

The tests on the A-10 center wing tank cells were conducted at two laser power levels. The first power level was a 200-watt (rated) Nd:YAG lamp-pumped, Q-switched US Laser Corporation 406Q laser, operating at 13 kHz using a 24-kW power source. This laser delivered about 160 watts (average) to the surface. The second power level was a 500-watt (rated) Nd:YAG diode-pumped, Q-switched Cutting Edge Optronics (a Northrop-Grumman subsidiary) laser operated at 10 kHz using a 16-kW power source. This laser delivers about 375 watts (average).

<u>Results</u>

The portable 200- and 500-watt laser systems were used on the fuel tank region of the retired A-10 Thunderbolt's center wing section. The laser beam effectively removed the sealant. The sealant (~ 1/8 inch thick) on a given nut fastener (~ 0.8 in.^{2}) and the surrounding area (equivalent fastener) were removed in less than a minute with the 200-watt system and in less than ½ minute with the 500-watt system.(Figure 8). Complete sealant removal from a larger area is shown in Figure 9. The results from this demonstration extrapolate to removing all of the sealant from one cell (1/8 of the entire center wing tank) within 10 hours of continuous operation for the 200-watt system and within 5 hours for the 500-watt system.

Ease of use was demonstrated by inexperienced observers taking part in removing sealant with little difficulty. Effectiveness depended on maintaining the ±¼-inch focus length of the laser beam, which improved significantly in a short period of time for each operator. Depth of field at the laser beam focal plane was sufficient so that the operator could maintain performance while moving the tool across, over, and around the target areas.

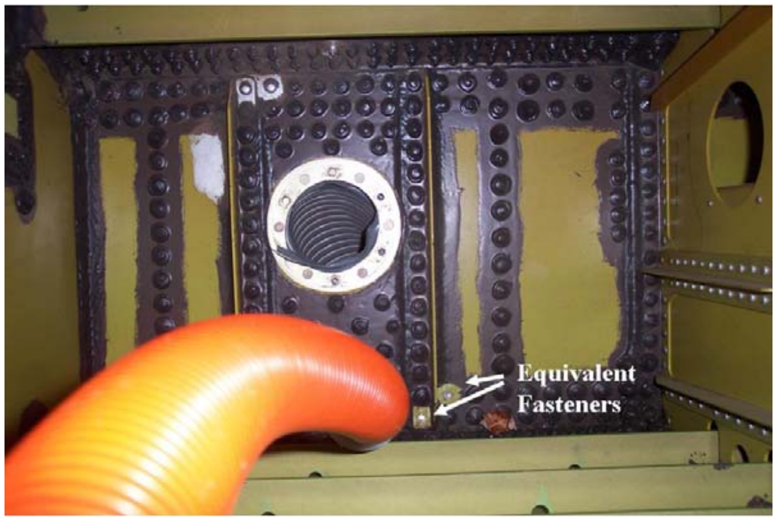

Figure 8. *Sealant stripped from two fasteners to right of umbilical*

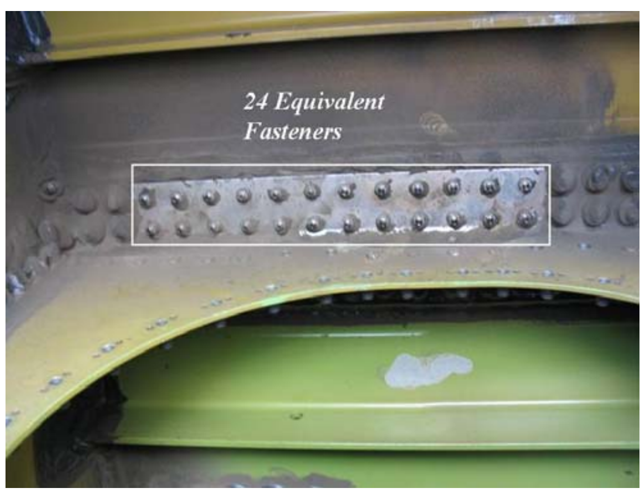

Figure 9. *Sealant completely removed from a larger area (same area as shown in Figure 2).*

The hand-held, end-effector tool and umbilical hose were sufficiently sized and flexible to access all areas within the eight fuel cells of the center wing section. Airflow from the end-effector dispersed sealant so that visibility of the target areas was always good, either by direct view or through the head-mounted video display. Thus visibility had no impact on trigger time. Trigger time was greater than 75% as the operator moved from one target area to another and could be much higher with practice. It appeared an operator could address all areas of the eight fuel cells without supplemental equipment or robotics.

Eye protection that blocks the laser wavelength light appears to be the only necessary safety precaution for the operator and observers. Operating at a single wavelength (1064 nanometers) allows the use of clear eyeglasses that filter the laser light without hampering an operator's visibility. Operational protocol is available to safely use this equipment in a depot setting.

While total time durations of the tests at the 200- and 500-watt power levels were only about 1 hour each, there were no reliability issues with the current design during these or subsequent testing. Proprietary features of the optical fiber components minimize the thermal stress on the fiber. Long-term reliability data for these systems are primarily anecdotal. For example, General Lasertronics has conducted numerous demonstrations of the 200-watt system since 2000 without laser-induced damage. Cumulative operating time was at least 1,000 hours. Also, a recent long-term project provided approximately 1,500 hours of near-continuous operation without optical fiber failure. The 500-watt system is newer, so less reliability experience exists. The optical fiber components for the 500-watt system are configured, however, to operate at the same thermal conditions as the 200-watt system. It may be expected that the life of the fiber-optics would be at least 3,000 hours before requiring replacement. Laser diodes are warranted for 10,000 hours of operation.

<u>Potential Life-Cycle Cost Savings Using Laser Sealant Removal Technology.</u> How much time it takes to remove sealant with the current mechanical scraping technology depends on the operator. It is assumed that the laser technology is more consistent and much faster as well as safer for the airplane. The demonstrated speed of sealant removal was <½ minute/fastener and <1 minute/fastener for the 500- and 200-watt systems, respectively. Which power level is deployed will depend entirely on desired throughput versus the difference in hardware cost (~ $1000/watt). All other cost factors such as implementing procedures and addressing safety issues would be the same for either power level.

<u>Substrate Damage.</u> The question of whether substrate damage can occur from this laser-stripping process was not addressed directly by this work. The question has been answered, however, by an investigation conducted by R.L. Cargill and J.A. Maasberg, both of San Jose, California. The initial phase of the investigation ("Metallurgical Analysis of Laser Sealant Removal from B737 Fuselage Panels") was presented to the Federal Aviation Administration in Seattle, Washington, on January 20, 2006, by Aerospace Laser Services, Inc., a subsidiary of Aria International Corporation, which funded the project.

The subject investigation focused on metallurgical analysis of laser-stripped 2024-T3 Alclad aluminum panels from an exemplar B737 aircraft. This aluminum alloy is similar to the material in the A-10 center wing fuel tank. The Cargill/Maasberg investigation included real-time measurements of temperature transients at various depths from the application surface. The data showed that the maximum laser process temperatures were insufficient to cause metallurgical changes. This conclusion was verified with cross-sectional microhardness measurements, metallographic analysis, and residual stress measurements.

Subsequently, a formal high-cycle fatigue test program was undertaken in order to qualify the laser process in conformance with SAE Aerospace Standard MA4872. This test protocol required the test articles to be primed, painted, and laser-stripped five times before the fatigue test coupons were machined from the 0.032-inch-thick 2024-T3 panels. This thickness is required under the rigorous "Priority 1" criteria in the SAE Standard. A detailed statistical analysis of the fatigue test data confirmed that the laser process has no impact on the fatigue life of 2024-T3 aluminum. All of the test data were presented by Cargill in a final report submitted to the FAA on June 21, 2006. Pursuant to this submittal, Aerospace Laser Services, Inc. was granted the only Alternate Method of Compliance (AMOC) and FAA approval for the use of a laser-stripping process on commercial jet aircraft that is in effect as of this date.

Conclusions

The results from this demonstration and the other work discussed here indicate that this laser technology met all five technical feasibility requirements:

- This technology is expected to be more economical than currently deployed technologies because it reduces labor intensity and secondary damage to the structure.
- The Cargill/Maasberg investigation of 2024-T3 Alclad aluminum with the same 500-watt-rated laser system used in this work showed no substrate damage or adverse effect on materials properties.
- The hand-held delivery system was easy and safe to use with appropriate eye protection.
- This system is reliable and no significant maintenance issues were identified.
- The engineered system reduces the concentration of combustible vapors during sealant removal and eliminates the chance for combustion (fire) in the cell.

Besides meeting these technical requirements, this system demonstrated flexibility for working in confined space, and the video display worked well, overcoming line-of-sight obstructions. We believe this laser system is suitable for deployment for A-10 Thunderbolt Depot Maintenance.