# Exterior Decorative Coatings Improvements on Commercial Airplanes

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Commercial aviation is a highly competitive industry for both the OEM (Original Equipment Manufacturer) and the airlines. The exterior coatings on airplanes are increasingly being used for branding and marketing by the airlines, in addition to the protective function they must provide the airframe from extreme environmental conditions. This paper covers the fundamental environmental and performance requirements of the exterior decorative coating system, the processes and materials used to paint these airplanes, current improvements and future goals. Special emphasis will be given to investigation and solution to the paint adhesion issue known in aerospace as "rivet rash".

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Commercial aerospace is a truly worldwide industry that has evolved into a duopoly of Boeing and Airbus for the supply of large aircraft to an increasingly complex market on the airline side. For the airlines, the effects of the deregulation that began in the 1980's, and continuing with this year's Open Skies agreement for Europe and North America, has caused a major shift in the economics of the airline industry. In this market driven by low fares and low operating costs, branding has played an increasing role in airline's efforts to attract and keep customers. The most striking way to differentiate an airline's image is the exterior decorative paint.

The exterior coatings perform both a decorative and protective role. This paper will focus on the Boeing system for aluminum airplanes, where the corrosion protection begins with clad aluminum. This clad finish provides a primary level of corrosion protection that allows for an unpainted finish such as that used by American Airlines.

For painted exterior designs, called the livery, the following process steps are performed. It is noteworthy that all of the preparation and painting of the airplane is a manual process. The exterior aluminum clad skins are received in the paint hangar with an alkaline removable temporary protective coating (TPC). The TPC is removed with a thickened alkaline cleaning solution and rinsed with copious amounts of water. The next step is to clean the surface with a combination of solvent and alkaline cleaners to remove any residual protective coating and other contaminates that end up on the skin from upstream manufacturing processes, such as drilling lubrication or sealant splatters. Once the skin is chemically clean, a de-oxidation step is performed by either manually wet power abrading with abrasive pads or by applying an acid cleaner. This is followed by application of a conversion coating to enhance the adhesion of the primer. A solvent borne corrosion inhibiting epoxy primer is then followed by a polyurethane topcoat.

This basic process has been used since the 1960's. While there had been some incremental changes in the process through the 70's and 80's, the most dramatic driver for change came with the creation of Aerospace specific environmental regulations in the United States. The Aerospace National Emission Standards for Hazardous Air Pollutants (ANESHAP) were implemented in September 1998. These regulations included changes in solvent cleaning, spray gun cleaning, paint stripping, and the use of low VOC (Volatile Organic Compound) primers and topcoats. The ANESHAP regulations required primers and topcoats to meet VOC limits of 350 and 420 grams VOC/liter, respectively.

## Performance and Environmental Requirements

Corrosion and substrate protection are the fundamental rolls of finishes on airplanes. For Boeing airplanes, the primary corrosion protection for the exterior fuselage is the aluminum cladding bonded to the surface of the particular alloy. The corrosion protection provided by this thin layer of cladding is why Boeing airplanes can remain unpainted (polished). However protective coating is always required for composite structures to protect the resin from UV degradation. Coated metal parts require a corrosion inhibiting primer that contains hexavalent chrome.

The coatings on the exterior must withstand one of the most demanding environments of any coating. The finish is subjected to thousands of thermal cycles ranging from +160º to -60º F, intense UV exposure at high altitudes, aerodynamic and erosion forces up to 600 mph, and contact with fuel, oils, and hydraulic fluid. The phosphate ester fire resistant hydraulic fluids are particularly aggressive and would cause automotive topcoats to bubble in less than a day, yet the aerospace finish system is expected to last up to eight years, depending on each airline's maintenance schedule.

## Rivet Rash

The selective loss of paint adhesion on aluminum rivets, shown in Figure 1, is known in the aerospace industry as "rivet rash". This condition has existed to varying degrees since the beginning of the jet aircraft age. It is such a common condition that there is a good chance that every reader has boarded an airplane with rivet rash and never given it a thought. But rivet rash started to appear earlier and more severe after the change to ANESHAP compliant coatings.

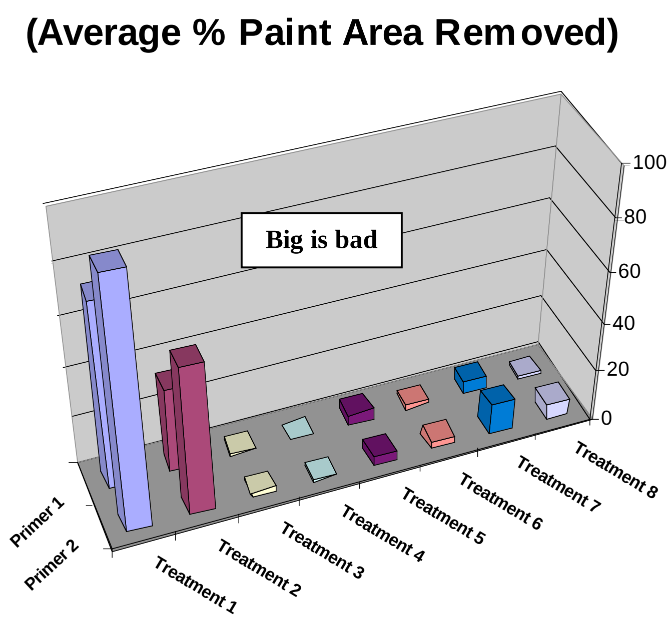
Figure 1- Severe "Rivet Rash" by flight deck window.

Customer feedback and fleet surveys prompted Boeing to initiate an investigation to more fully understand the root cause of the rivet rash. The study focused on the primer adhesion to the fasteners in comparison to the clad aluminum skin. Boeing investigated not only the paint hangar processes, but also the rivet manufacturing process and the mechanical, chemical, and aging life cycle of the rivets prior to reaching the paint hangar.

This investigation was quite extensive and this paper will not cover the details of that effort. However, the key finding of this investigation was that the conversion coat applied to the raw rivets at the manufacturer became detrimental to adhesion of primer as it aged. Figure 2 shows the impact of primer adhesion on aged and fresh conversion coated rivets and alternative finishing processes (burnishing and abrading of the rivet head only to remove the conversion coat).

While an obvious conclusion would be to not apply the conversion coating at the rivet manufacturer, issues surrounding compatibility with multiple specifications, both military and commercial users, supply chain processes, and other factors made this unfeasible.




| Treatment | Condition of original conversion coating | Abrade prior to hangar conversion coat? |
|---|---|---|
| 1 | Aged (months) | No |
| 2 | Aged (months) | Yes |
| 3 | Fresh | No |
| 4 | Fresh | Yes |
| 5 | 48 hours | No |
| 6 | 48 hours | Yes |
| 7 | Burnished | No |
| 8 | Burnished | Yes |

Figure 2 - The adhesion of primers based on the surface treatment following the rivet manufacturing processes.

A solution that avoided most of the issues above was the addition of an extra conversion coating to promote adhesion. Boeing and our rivet manufacturer, Allfast Fastening Systems, developed a process that added a sol-gel coating to the rivets while the initial conversion coating was not aged.


Figure 3 - Standard rivet finish.

Rivets were installed in test foils for the Boeing Whirling Arm Rain Erosion test, which subjects foils to simulated rain at high speed. A decorative paint system was applied to the foils and the adhesion to the rivets was noted. Figures 3 and 4 show a dramatic improvement in adhesion provided by the sol-gel coating.


Figure 4 - Sol-gel rivet finish.

The benefit of the sol-gel technology for promoting primer adhesion on rivets that are prepared with different cleaning processes (defined in Figure 5) and primers are shown in Figures 6 and 7.

| Treatment | Abrade? | Solvent? | Acid Clean? | Conversion Coating Type? |
|---|---|---|---|---|
| 1 | No | No | No | Type 1 |
| 2 | Yes | No | No | Type 1 |
| 3 | No | Yes | No | Type 1 |
| 4 | No | No | Yes | Type 1 |
| 5 | No | No | Yes | Type 1 |
| 6 | No | No | No | Type 2 |
| 7 | Yes | No | No | Type 2 |

Figure 5 – Sample of rivet head surface treatments prior to priming.

(% Paint Area Removed)

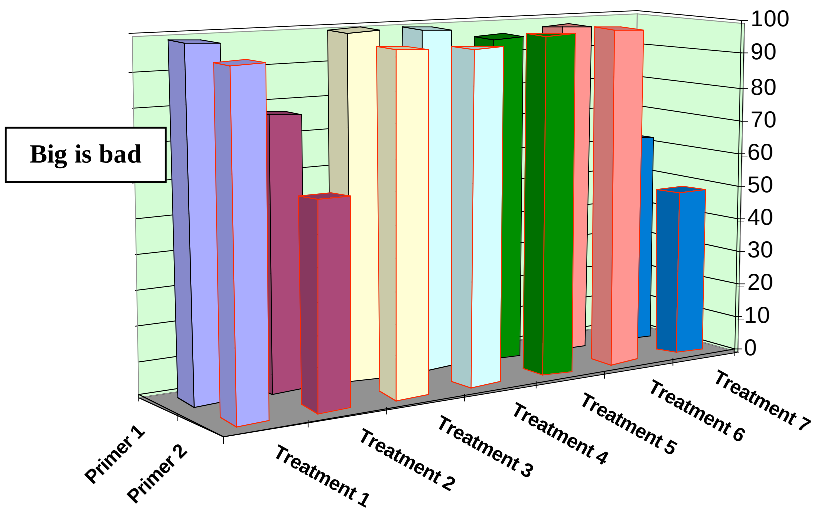



Figure 6 - The effect of the standard aged rivet finish as painted in production.

(% Paint Area Removed)

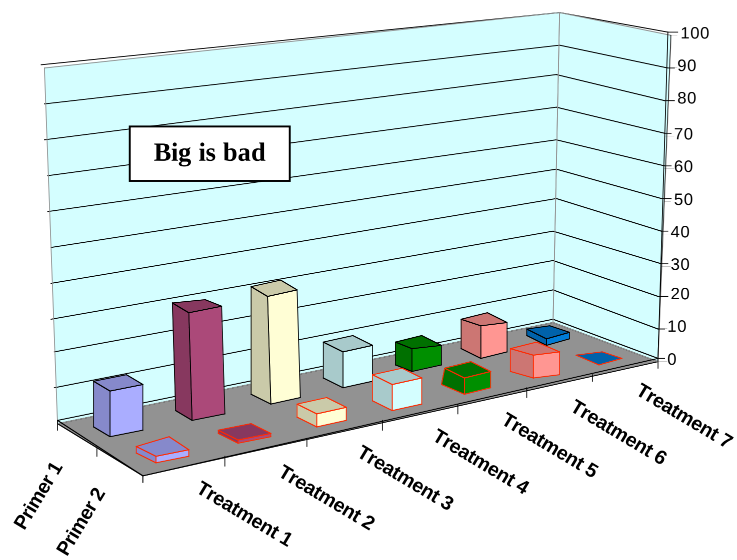



Figure 7 -The effect of the rivet new sol-gel finish as painted in production.

The new sol-gel finish was implemented in early 2003 on all aluminum fasteners produced by Allfast, the sole supplier to Boeing and our parts suppliers. Since the clear sol-gel coated rivets are not visibly different from the non-sol-gel, the main tool to identify them is by the packing as shown in Figure 7.


Figure 8 - Standard one Pound bag of aluminum rivets with sol-gel noted on packaging.

Given the large number of suppliers and parts that receive rivets, Boeing focused the initial use of the sol-gel coated rivets on the high erosion front section of the fuselage, known as the 41 section, where the occurrence of rivet rash is most severe. By 2004 the conversion of the 41 section to all sol-gel coated rivets was complete for all Boeing models.

**Plan – Act – Assess: Verifying the results**

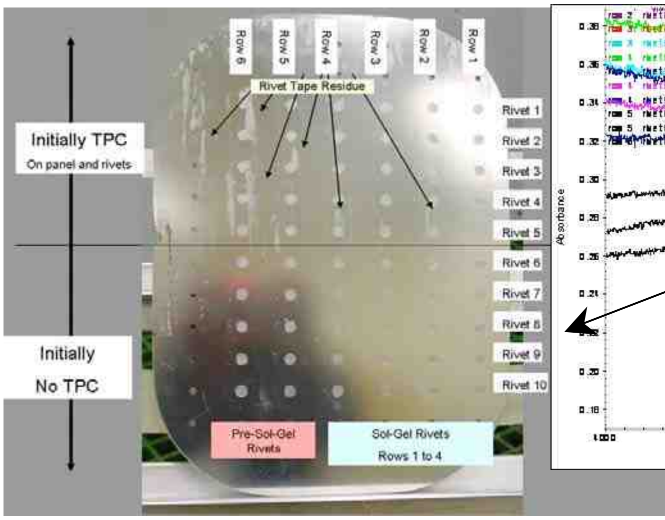
The year following the implementation of the new rivet coating, Boeing surveyed the performance on various models operating in Europe, Asia, and North America. The results were encouraging as the onset and occurrence of rivet rash was significantly lower than prior to the sol-gel coating, but it was not completely eliminated (see Figures 9 and 10).

Figure 9 - Rivet rash on a Boeing 777 painted prior to sol-gel rivet conversion after 18 months in-service.

Figure 10 - Minimal rivet rash on a Boeing 777 painted after sol-gel rivet conversion after 14 months in-service.

Further laboratory testing found that sol-gel coated rivets made in-process contamination a significant issue. Testing the new sol-gel coated rivets in skin panel cutouts revealed the TPC removal process allowed TPC residue to be deposited on the rivet surface and interfere with the primer adhesion. The properties of sol-gel that promoted adhesion with the primer also bonded well with the TPC resin. A test carried out to verify the impact of TPC contamination is presented in Figures 11a and 11b.



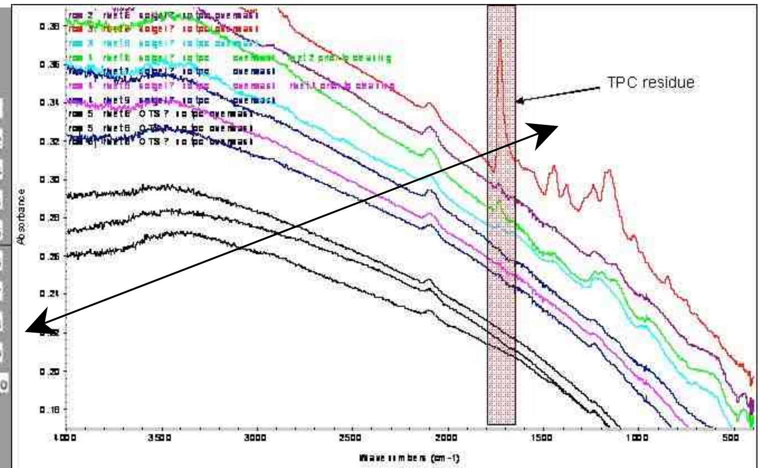




Figure 11b - FT/IR showing TPC residue.

Figure 11a - Riveted test panel evaluating the impact of TPC residue.

The in-service data showed a negative impact on the 41 section only. The areas aft of the high erosion zone remained free of rivet rash based on the most recent survey data. To address the high erosion areas, Boeing added an additional manual abrasion cleaning step to the surface preparation on section 41.

## Closing the Gap on Adhesion Loss: Primers and Conversion Coating

While the additional abrasion cleaning process provided the adhesion improvement for the airlines, we were concerned about the negative ergonomic impact on our workforce, as well as the inherent variability of a manual process. In 2005 independent projects, on primer and conversion coating, began yielding results that could further improve the adhesion of the exterior coatings.

The primer project found high solids primers from our two decorative coatings suppliers appeared to offer higher adhesion values than the currently used high solids primer. Scale-up of the primers progressed to a point that production trial airplanes were successfully painted in early 2006. Both these primers were added to the exterior paint specification and production has converted to these primers by mid-2007. A recent inspection of one of the airplanes, after over 4,000 flight hours, found no paint loss on any rivets.

In 2006 Boeing also tested two non-chromated conversion coatings, one of which was a commercialized version of the Boeing patented sol-gel. While both conversion coats met the environmental chrome reduction goals, the sol-gel product, when tested for rivet adhesion, produced superior paint adhesion when compared to the other non-chrome conversion coat.  A full scale test was performed on a flight test airplane for the Boeing 777-200LR program.  Two airplanes were part of the flight test program, so the conventional chromated conversion coating was used on one airplane and the sol-gel product on the second.  After almost a year in test, the sol-gel treated airplane had no rivet rash, while the conventional coating showed 11 rivets with adhesion loss.

The full scale airplane test also provided an additional important test with the chemical stripping required prior to repainting the airplane in the airline customer's livery.  The paint applied to sol-gel conversion coat, while requiring slightly more time to strip, was completely and successfully removed with a peroxide activated, benzyl alcohol paint stripper commonly used today for environmental compliance (see Figure 12).

Figure 12 - Paint stripping sequence and complete coating removal from the sol-gel treated metal surface.

**Conclusions and Future Directions**

The performance of these improvements will not be fully known until after two to three years of in-service operation, although the initial results are very encouraging. Airlines are already experiencing a significant reduction in rivet rash and the improvements implemented in 2007 should complete the efforts to eliminate rivet rash. The knowledge gained by this effort has been incorporated into the requirements for future material evaluation.

In addition, new material evaluations continue. At the top of the priority list are new materials that make all our processes more robust and stable, as well as efforts to eliminate chrome from our primers and other environmental improvements. Almost every paint hangar process has an improvement effort at the idea stage, completing feasibility, or ready to implement. On top of all these projects on existing models, the era of the all composite airplane, the Boeing 787, is about to begin.

But that's another story.

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