Boeing has developed tools, information, and training to help airlines repair the 787's composite structure and surfaces.

Making Composite Repairs to the 787

The 787 Dreamliner offers a number of operational benefits due to the airframe comprising approximately half (by weight) carbon fiber reinforced plastic and other composites. As airlines add the 787 to their fleets, they are increasingly interested in repair methods for the airplane's composite structure. Boeing offers information to enable airlines to make effective repairs to many different types of damage — often without taking the airplane out of service.

By Arne Lewis, Associate Technical Fellow, Commercial Aviation Services, 787 Service Engineering

The 787's composite structure has airframe maintenance costs that are 30 percent lower than any comparable airplane. This is largely due to its absence of corrosion and fatigue, the two primary drivers for repair and maintenance of the airplane structure. The 787 also weighs, on average, less than more conventional aluminum designs, resulting in greater fuel efficiency. The combination of these two factors made the choice for a composite airframe very appealing to designers and airlines.

This article will help the reader understand why composites were chosen for the 787 and what Boeing is doing to help the repair community transition to repairing composites.

THE EVOLUTION OF COMPOSITES IN COMMERCIAL AVIATION

Aluminum structures have been a mainstay in commercial airplane design for many years. While the evolution of aluminum designs has improved the strength-to-weight ratio, the industry has been seeking double-digit performance improvements in fuel efficiency for new airplanes. Composites, combined with system improvements, have helped provide the path to such improvements.

A composite is a combination of two or more materials (reinforcing elements, fillers, and composite matrix binder) differing in form or composition on a macro scale. The constituents retain their identities: While they act in concert, they do not dissolve or merge completely into one another.

Composites also offer strength-to-weight ratios that enable lighter weight structures that allow the airplane design to feature items such as larger windows and lower altitude pressures in the cabin. In addition, a composite airplane structure has inherent resistance to fatigue damage and corrosion.

Composites are not new to commercial aviation. In fact, composites have been used in airframe structures since the 1950s, and their use has been increasing

Figure 1: The aftbody sections of the 787 Dreamliner are created using an advanced carbon fiber placement technology

As pictured here, an automated fiber placement (AFP) machine in Boeing's South Carolina facility lays carbon fiber tape using precise patterns and layers to maximize the strength of the barrel.

steadily over the last 45 years. Composite structures on commercial airplanes (see fig. 1) can be all fiberglass layers, all carbon layers, a mixture of the two (often referred to as hybrid parts), or cured with honeycomb core (see fig. 2). Over time, tougher composite materials and enhanced, robust designs have been developed and are being used for primary structure on both the 777 and the 787.

USE OF COMPOSITES ON THE BOEING DREAMLINER

In developing the 787, Boeing determined the most effective use of composites by evaluating every element of the airplane's structure for function, load carrying capability, and durability. This evaluation resulted in composite materials being used extensively on the 787 airframe, making these materials dominant in areas that are traditionally aluminum (see fig. 3).

Many studies, tests, and demonstrations were performed to validate the strength and impact resistance of the composite material, particularly in comparison to aluminum structures. Additionally, in conjunction with airline partners, many damage scenarios were reviewed and the time and effort required to repair each type of damage were evaluated.

The damage scenarios and impact testing provided necessary information to assure areas prone to damage were strengthened and designed to enable repairs if damaged.

Due to its use of toughened carbon materials, solid laminate composite structure is inherently very durable. Tests have shown the 787 fuselage can resist damage that would easily occur in an aluminum fuselage.

MAINTAINABILITY: A KEY 787 DESIGN REQUIREMENT

The ability of airlines to maintain the 787 was a key consideration during its development. The airplane's structure was designed for robustness in an in-service environment. Maintenance and repair

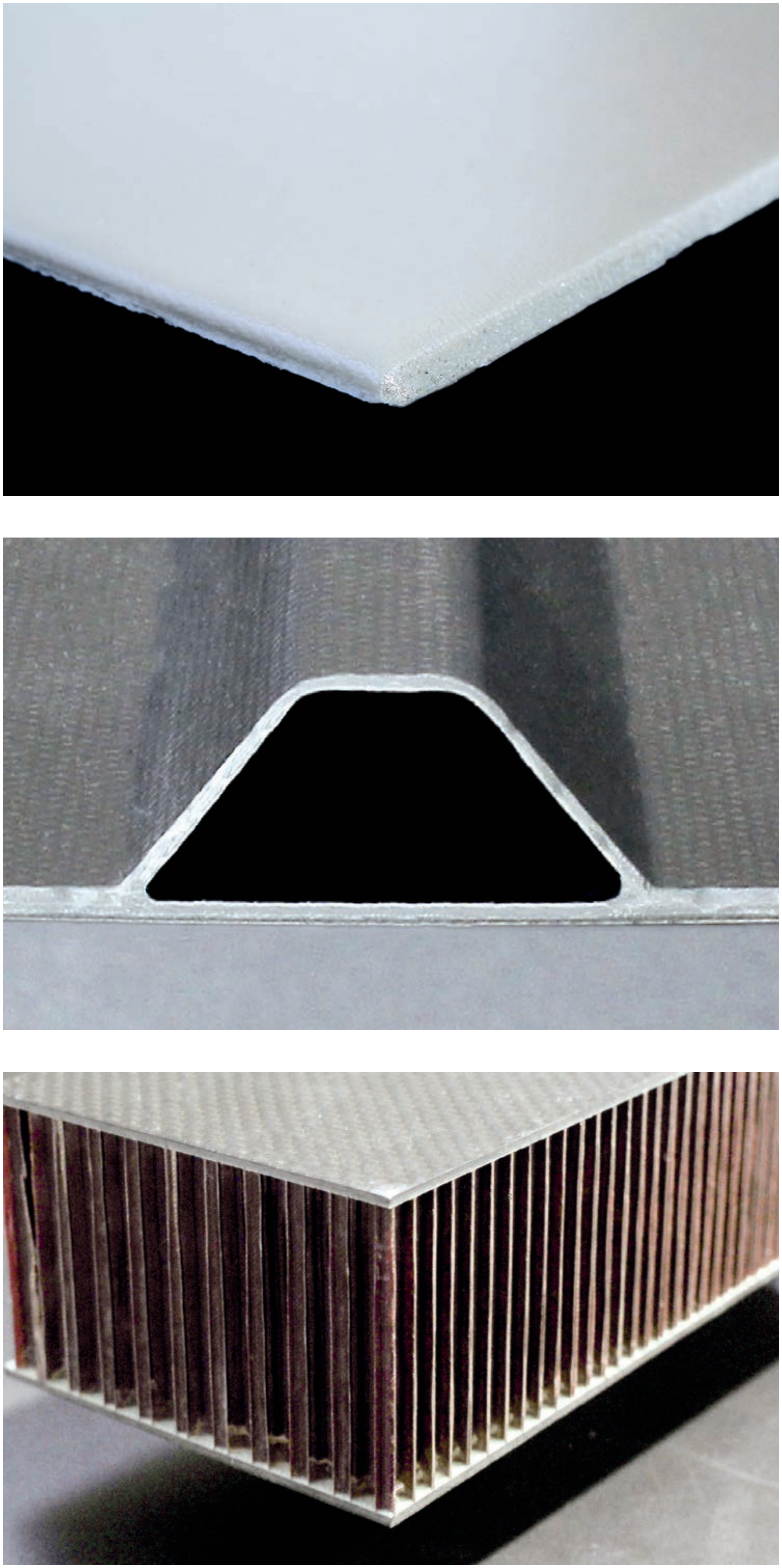


Figure 2: Types of composites

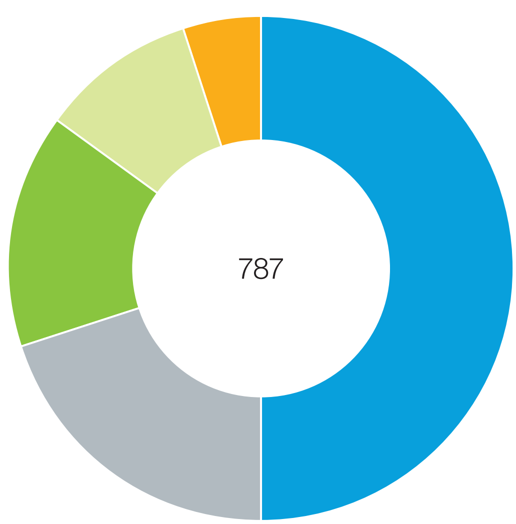
Composites on commercial airplanes include fiberglass solid laminates (top), carbon solid laminates (center), or cured with a honeycomb core (bottom).

Figure 3: Composites on the 787

Composites comprise more than 50 percent of the 787 airframe.

Materials

■ Carbon laminate ■ Carbon sandwich ■ Other composites ■ Aluminum ■ Titanium ■ Titanium/Steel/Aluminum

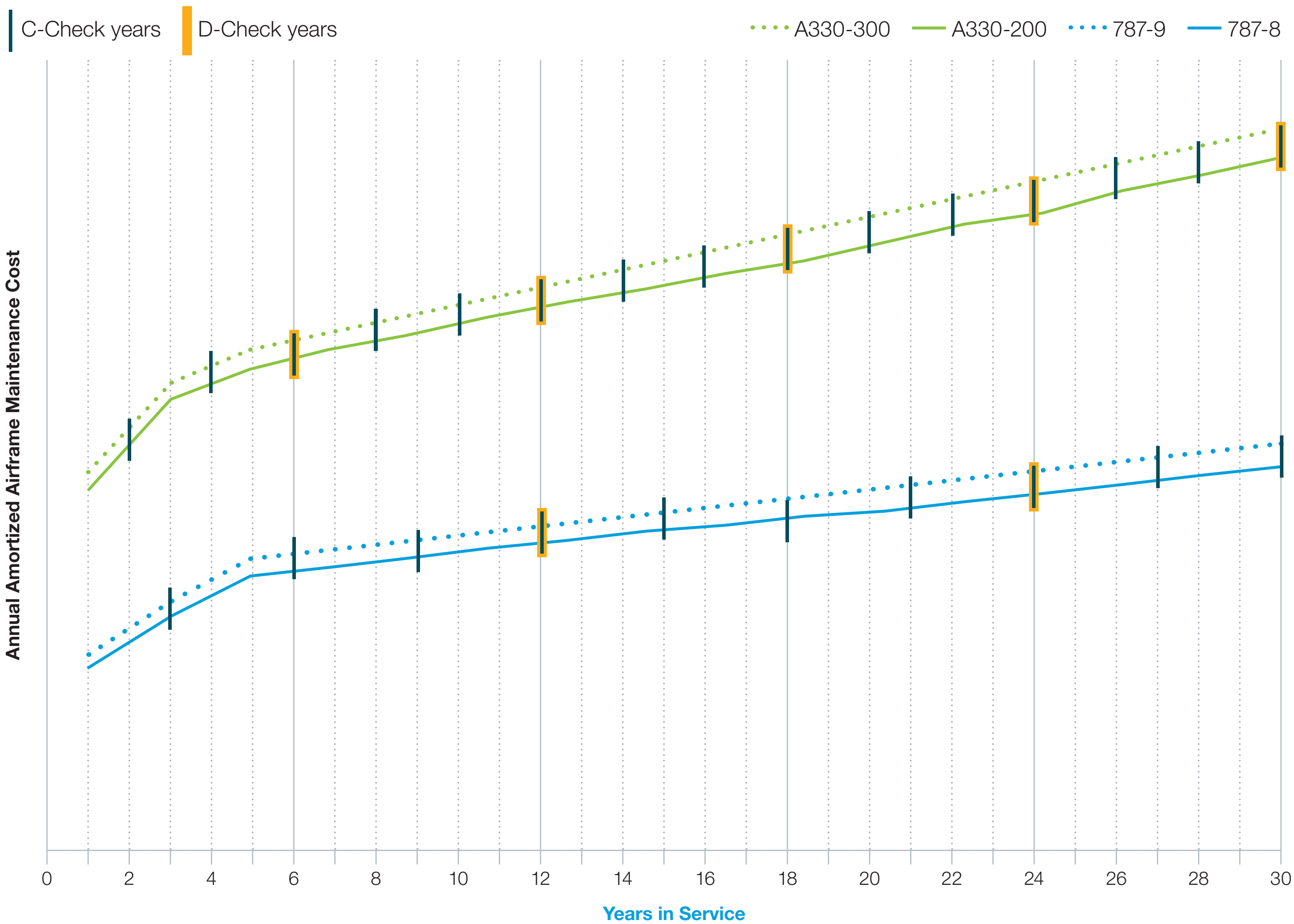


Materials by weight

■ Composite ■ Aluminum ■ Titanium ■ Steel ■ Miscellaneous

Figure 4: 787 maintenance cost reductions

In addition to longer intervals between scheduled maintenance checks, the 787 reduces labor hours by approximately 20 percent on a per-check basis. Total scheduled labor hours are reduced by approximately 60 percent over the life of the airplane. These reductions in required scheduled maintenance are a significant contributor to the 787's overall 30 percent airframe and systems maintenance cost reduction target.



considerations were inherent in the design. Boeing developed inspection equipment and techniques to support unplanned maintenance, such as airplane-on-ground events.

The 787 program had a maintenance cost reduction target of approximately 30 percent (see fig. 4). More than 100 design requirements and objectives were related to repair and maintenance.

Operators' in-service experience has demonstrated the robustness of the 787's composite structure. For example, one operator reported that hangar scaffolding came in contact with one of its 787s. The discrepant area was inspected fully and found not to have any type of delaminations or damage. The airline also reported that this type of force applied to an aluminum fuselage would have caused damage that would have taken the airplane out of service for several days.

NEW REPAIR INSTRUCTIONS IN THE 787 STRUCTURAL REPAIR MANUAL (SRM)

Successful repairs to composite structure require the repair technician to strictly follow detailed and accurate repair instructions. For quality enhancement, the 787 SRM builds upon the established composite repair techniques and materials that Boeing successfully developed for the 777. Since the 787 has extensive composite structure, more than 20 new sections were added to 787 SRM chapter 51 to explain repair processes and procedures for:

- Pre-impregnated repairs (both original cure temperature and reduced temperature cure) use material that has been frozen, thawed, and then cured with heat.
- Wet layup repairs use dry fabric that is impregnated with resin.
- Bolted repairs for common architecture elements, including the skin-stringer, frame, and shear tie. This repair uses sheet metal (aluminum, titanium, or steel/corrosion-resistant stainless steel) bolted onto the structure. The repair can be flush with the airplane skin or, in

Figure 5: New inspection techniques

Maintenance personnel can first use a ramp damage checker (left and center) and, if necessary, the wheel probe (right) to quickly assess the condition of laminate and sandwich structures on the 787.

some cases, might protrude into the airstream.

- Quick composite repairs (see "Special kit enables airlines to make quick composite repairs" on page 12).

The new sections in the SRM address clean environments for bonding repairs on the airplane, better ply compaction methods to reduce porosity, drying solid laminate, and performing heat surveys to assure proper heat distribution during the repair cure. Most of the repairs in the 787 SRM use tools and equipment that have been used to repair legacy airplane composite components and have been available on the market for many years. One exception is the use of a double vacuum bag debulk (DVD) system, a newer process that is implemented for several 787 repairs. The 787 SRM describes how technicians can construct a DVD box from simple lumber materials.

ASSESSING DAMAGE ON THE 787

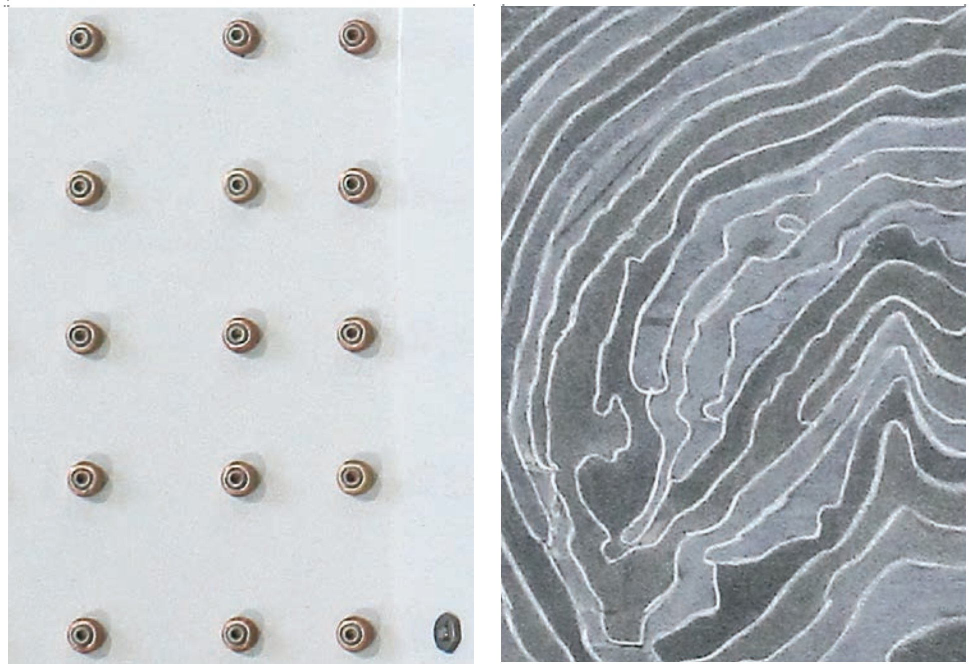
Damage to composite structure can manifest itself differently than in aluminum structures. Because aluminum usually dents or tears, damage is typically visible. In contrast, composites will show rub marks or a small dent. If there is enough energy transferred, a delamination of plies may occur. When the delamination is critical, it will be visible on the exterior side and/or on the interior side of the fuselage. Because of this different manifestation of damage, the aircraft maintenance manual (AMM) addresses specific conditions and inspections that need to be accomplished.

The development of the 787 also included the creation of a simplified inspection device to aid maintenance personnel in assessing the extent of damage. The inspection device, called the ramp damage checker, was developed specifically for the ramp technician. For additional damage characterization and more in-depth inspections, a wheel probe was developed to speed and simplify the assessment of laminate and sandwich structures (see fig. 5). Heat damage can be detected using instrumented inspection

Figure 6: Repair method considerations

Airlines have the option of bolted or bonded repairs. Each approach has its advantages.

	BOLTED REPAIR	BONDED REPAIR
Benefits	■ Faster processing time. ■ No risk of heat damage. ■ Repair material not sensitive.	■ No protruding parts. ■ Lightweight. ■ Category A (permanent repair).
Other Considerations	■ Heavier. ■ Hole drilling must be done with care and caution. ■ Repairs may be Category B (require inspections).	■ Slower processing time. ■ Risk of heat damage and porosity. ■ Material is time, temperature, and moisture sensitive.



methods as outlined in the nondestructive inspection manual.

Please note that any significant impact or damage needs to be inspected per the instructions in the 787 SRM and/or the 787 AMM, chapter 5.

ADVANCED REPAIR TECHNOLOGIES

Boeing has extensive experience supporting composite structures in service. In addition, Boeing participates actively in forums such as the SAE-sponsored Commercial Aircraft Composite Repair Committee to gain and share knowledge about composite repairs.

The repair technologies Boeing has developed for the 787 build upon the success of 777 composite repairs. Numerous repair tests were made based on repairs described in the SRM to validate repair capabilities. Repair tests included static and fatigue (including accidental damage and environment effects), tension, compression, and combined loads.

Boeing's research and in-service experience have demonstrated repairs for all areas of composite structures using bonded repairs, bolted repairs, or a hybrid comprising bonding with a bolted substructure (see fig. 6). There are various factors an airline needs to consider when choosing which type of repair to make. The SRM only allows you to choose the repair method that restores ultimate load carrying capabilities and meets the operational needs of the airline. The airline needs to factor in:

- Which repair method will get the airplane back into revenue service the soonest.
- Repair environment (weather condition, hangar availability).
- Repair material availability.
- How much weight will be added to the airplane.
- How much aerodynamic drag will be added to the airplane.

When damage is determined to be minor, quick repairs to the composite surface can be accomplished in about an hour using a prepackaged time-limited

Special kit enables airlines to make quick composite repairs

Because ramp rash and other minor mishaps are a fact of life for a commercial airplane, Boeing has developed a quick way to repair composite materials. Previously, the most common way to fix composite skin damage involved moving the airplane to a maintenance hangar and using sophisticated cure controllers and heater mats to cure epoxy resins and adhesives in place. In contrast, the 787 Quick Composite Repair (QCR) kit allows minor damage to be repaired at the gate, quickly and with no electricity.

To create the kit, Boeing's research team narrowed 150 candidate adhesives down to 10, evaluating them in laboratory tests during a four-year period. The adhesives were subjected to extreme hot and cold thermal conditions and tested for their shelf life, curing temperatures, and bond strength, among other parameters.

The QCR kit includes sanding disks, gloves, lint-free wipes, vacuum bag film, structural patches, anti-caul foil patches, heat pack, and adhesives.

The areas of the airplane where Quick Composite Repairs can be used and application instructions are provided in the 787-8 and 787-9 SRMs. QCR kits can be obtained through Boeing Material Services.

composite repair kit. (See "Special kit enables airlines to make quick composite repairs" above.)

Regardless of which method is selected, all 787 SRM repairs are structurally acceptable when applied as directed in the SRM.

SPECIAL DAMAGE CASES

Because of the uniqueness of the 787 composite structure, many repair questions from operators have centered on two specific types of damage: lightning strikes and large area damage.

Lightning strikes. Studies have shown that the airplane surface shapes are the determining factor for lightning strike attachment. (See *AERO*, second-quarter 2012.) While lightning strike damage can occur to composite structures, the damage is often minimal and repairable with a time-limited repair. The damage must first be inspected for size and depth. Once the size and depth are known, the airline will need to review the SRM for allowable damage limits and decide on the proper course of action. There have been many instances where the lightning damage can be sealed with resin or aluminum foil tape as a temporary repair and service can resume immediately until the airplane can be put into maintenance at a more convenient time. If the damage is larger than allowable damage limits, most damage can be repaired using wet layup methods that have been used in the aviation industry for many years.

Large area damage. This type of damage is generally considered to be an area of approximately 3 feet by 3 feet (1 meter by 1 meter) or larger. Damage of that size and larger is repaired using a pre-cured panel bolted in place with splicing straps and doublers. This method has been successfully performed in-service on 787 fuselage

It is important that airlines receiving 787s review their capabilities, knowledge, repair processes, repair materials, and training to ensure they are prepared for repair. Because of the increased use of composites on the 787, Boeing has developed a suite of composite structure repair classes specifically for the 787.

structures. In cases where the fuselage was damaged through the thickness, the Boeing airplane-on-ground team was dispatched and successfully performed permanent bonded and bolted repairs.

BOEING STRUCTURES REPAIR TRAINING

It is important that airlines receiving 787s review their capabilities, knowledge, repair processes, repair materials, and training to ensure they are prepared for repair. Because of the increased use of composites on the 787, Boeing has developed a suite of composite structure repair classes specifically for the 787. These classes include:

- Line and Base Mechanics course. Standard Air Transport Association (ATA) 104 level 3 course.
- Technicians course. Designed for mechanics who perform composite repairs on a daily basis.
- Engineers course. For engineers who design the repairs for the technicians.
- Inspectors course. Designed for line, base, and back shop inspections.

SUMMARY

Boeing has developed unique tools, information, and training to help airlines make repairs to the 787's composite structure and surfaces. These tools enable airlines to make effective repairs to many different types of damage, in many cases without leaving the gate.