

Nestled between the 767 and the 747 in terms of size, the Boeing 777 is the world's largest twin-engine airplane. It was initially conceived as an enlarged version of the 767, but it grew to 85% of the 747 in actual size, and sports a wingspan of nearly 200 feet and a fuselage approximately 11 feet in diameter. Its passenger seating and range combination put it in a unique niche that has allowed development of a generation of stretch and range variants.

To enable such a large twin-engine airplane, Boeing had to achieve significant reductions in structural weight while maintaining overall affordability. This was made possible by the development of breakthrough materials.

The 777 Program enabled the maturation of a large number of materials that were under development in the mid- to late-1980s. Materials that were transitioned into production included new advanced 7000 and 2000 series aluminum alloys, damage-tolerant composites, and advanced titanium alloys. These materials as well as non-structural materials advances enabled a reduction in weight of over 5800 pounds.

The aluminum airplane

From a structural-weight standpoint, the 777 is primarily an aluminum airplane. Seventy percent of the overall structure is aluminum, including the wing box and fuselage. Of course, the aluminum alloys are not the garden-variety aerospace materials of the past. These are engineered alloys offering improved strength, toughness, and corrosion resistance.

Despite the predominance of aluminum, the 777 does contain significantly more composite materials by weight than earlier Boeing aircraft. The vertical fin, horizontal stabilizers, and passenger-floor beams utilize a Boeing/supplier developed toughened, damage-resistant carbon fiber epoxy resin system.

Titanium alloy improvements are critical in combating the galvanic potential difference between aluminum and Carbon Fiber Reinforced Plastic (CFRP), and titanium alloys are



The Boeing 777

The development of the Boeing 777 was made possible by the development of breakthrough materials that allowed reductions in structural weight while maintaining affordability.

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used extensively in interface areas. In addition, titanium replaced many steel components in the landing gear and engine strut area in an effort to reduce weight and improve corrosion resistance.

Although structural materials receive the most attention, it is important to note that the 777 also paved the way for a wide variety of non-structural advanced materials. Significant material applications included the introduction of improved passenger windows, and dust covers more resistant to the environment and more able to withstand wear and tear. More-durable materials were also developed and implemented for insulation blankets, interior paints, decorative inks, cargo floors, and cargo liners. Furthermore, many of these improved materials also generated significant weight savings.

Alloy developments

During the waning days of the mid-1980s, a frustrated Boeing and its aluminum suppliers shut down massive efforts to develop aluminum-lithium alloys. As a result of this experience, Boeing initiated a process with these suppliers in which alloys

were first studied on paper. Suppliers were asked to propose various 'what if' alloys for major structural applications. These 'what if' alloys were evaluated for benefit and affordability. This unique approach allowed promising alloys to be identified early on and, unlike their aluminum-lithium counterparts, these alloys were robust to price and property changes during development.

The 'what if' process focused on advanced alloys for wing and fuselage applications. For the wing, Boeing identified a general need for higher-strength alloys with good toughness and improved corrosion resistance – relatively standard targets. However, in the case of the fuselage, Boeing had just completed a rigorous review of fatigue and corrosion issues in its fleet of aging airplanes. This effort brought into focus the need for advances in toughness, fatigue crack growth resistance, and corrosion resistance.



The Boeing 777-300ER's new semi-levered landing gear system has performed flawlessly during the flight-test program. The unique gear, which is manufactured by Goodrich Corp., allows the airplane to rotate early by shifting the center of rotation from the main axle to aft axle of the three-axle landing gear truck. As the airplane rotates, the nose is allowed to rise higher earlier.



As a result of this innovative process, Boeing and Alcoa were able to generate and bring to market a number of breakthrough alloys and heat treatments. The advanced fuselage alloy 2524 yielded significant improvements in the design properties associated with fuselage skin durability. To further address fleet corrosion issues, 777 designers worked diligently to maintain the clad surface on the interior of the airplane, particularly in the moisture-laden bilge area.

This material breakthrough was

married with advancements in 7000 series alloy heat treatment (T77511 – retrogression re-age), which allowed higher-strength 7150 materials for fuselage extruded stringers. The result was a structure that is tougher, stronger, and more corrosion-resistant than earlier designs.

The same technological breakthroughs that enabled application of 7150 alloys on the fuselage, were also incorporated into wing alloy 'what if' studies. These studies identified a candidate alloy that had a particularly unique combination of properties, pricing, and corrosion resistance: 7055-T7751. This alloy provides a nearly 10% gain in strength, with higher toughness and significantly improved corrosion resistance.

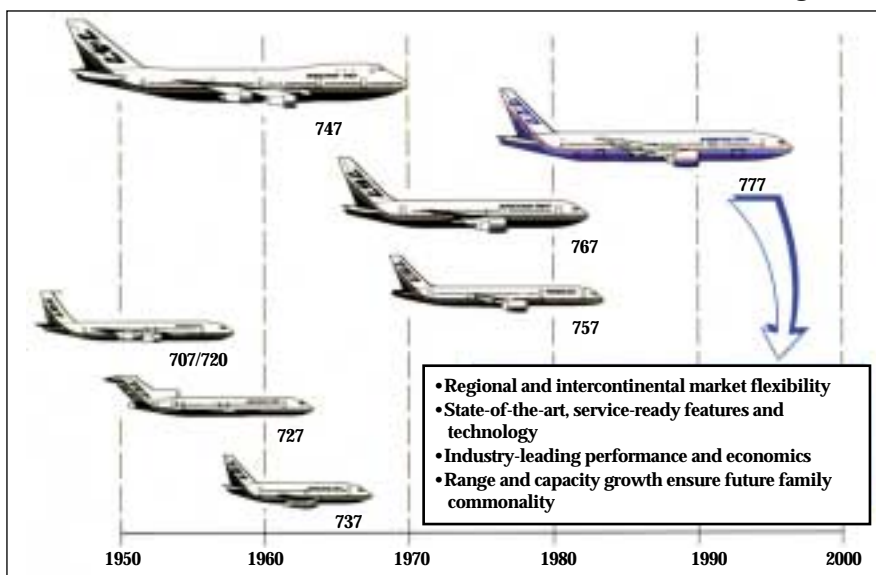
Toughened carbon fiber epoxy

Efforts to develop an improved carbon fiber epoxy resin system date back to the early- to mid-1980s. These efforts also originated with Boeing's in-service fleet experience. Since the production of the 757 and 767, airline customers have had to contend with thin-gage composite structures in a wide number of applications. Complaints about this material's sensitivity to impact damage and the difficulty of repair were many.

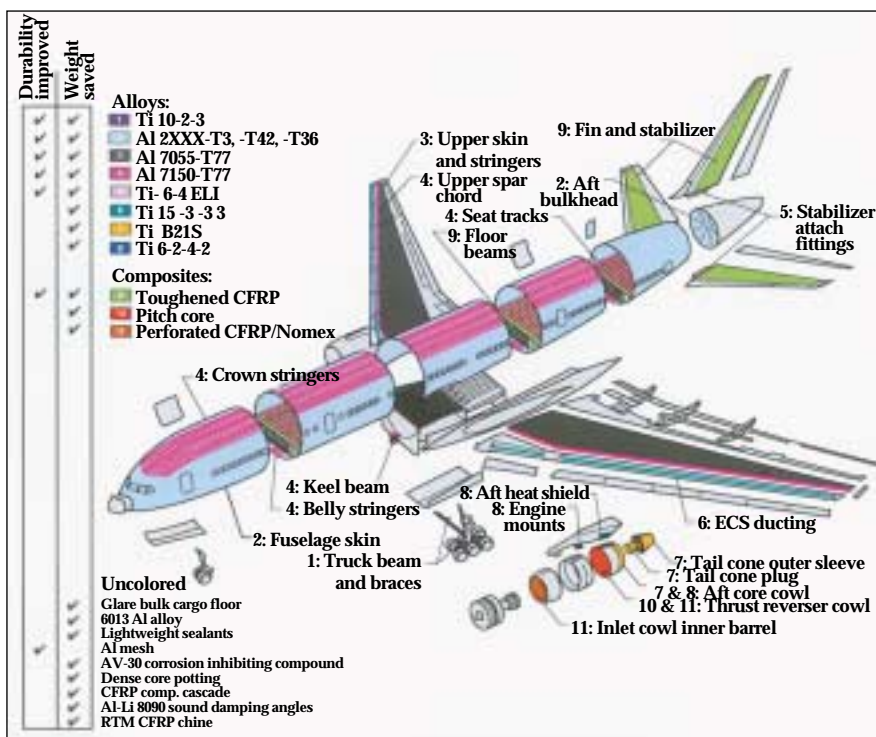
In response to these complaints, Boeing initiated and led a significant effort to develop a toughened epoxy matrix that would be more resistant to damage. Supplier efforts were repeatedly thwarted by the negative impact of toughening agents on hot/wet compression strength.

Fortunately for Boeing, Toray had been working diligently on a resin system that involved a toughening interlayer. The resulting system set a new standard for toughness and strength in composite material technology. Impact test results demonstrated to the airlines that this new system also suffered significantly less damage, and that such damage could be repaired in a manner similar to repair of existing aluminum structures.

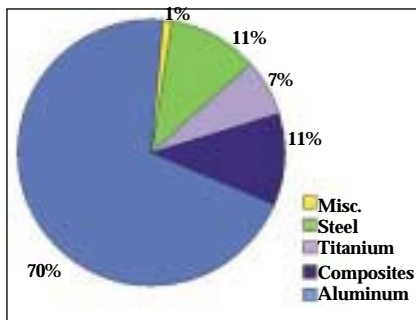
This breakthrough in CFRP toughness was optimized to enable Continuous Tape Laying Machines (CTLTM) to fabricate structures, resulting in reduced manufacturing costs. The new toughened matrix CFRP is used for the main box cover panels and the main box spars. The main torque box cover panel consists of an integrally



Boeing aircraft and the years they were introduced into service.



Breakout of advanced materials on the 777.



Aluminum alloys and other advanced materials by weight on the Boeing 777.

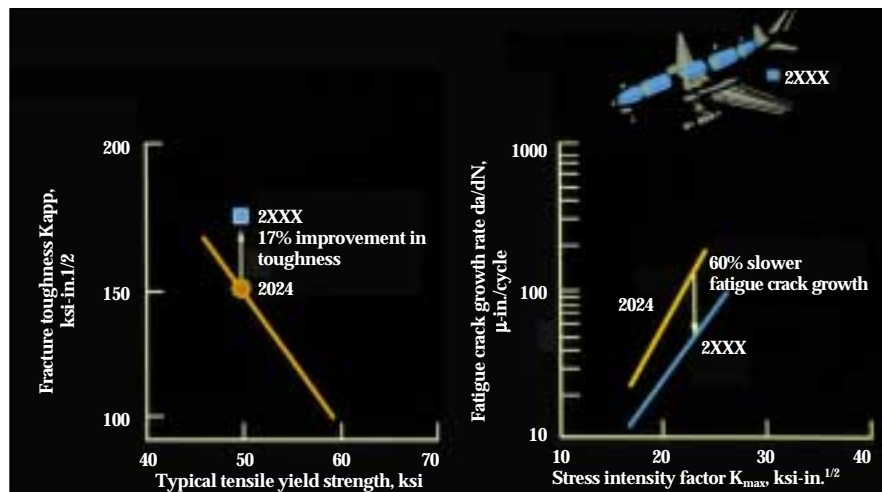
stiffened skin with I-section stiffeners at a constant spacing. The basic skin ply lay-ups are quite simple, with doublers inserted as pre-kitted units. This approach permits the panels to be laid up by the CTLM, resulting in significant cost reductions. To achieve accurate part control, the stiffeners are pre-cured and co-bonded to the skin panel during the panel cure cycle.

Titanium alloys

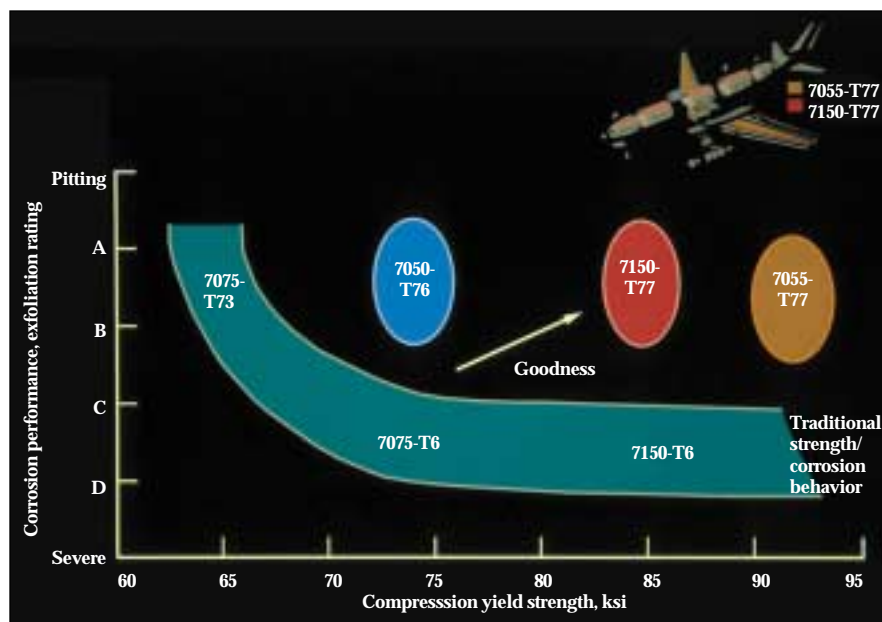
Titanium applications have increased with each major commercial airplane introduction. In the case of the 777, the use of titanium was expanded into previous CFRP structure areas to minimize the risk of galvanic corrosion that is present with aluminum. For this application, beta-annealed Ti-6Al-4V ELI (Extra Low Interstitial) was introduced into the commercial fleet, and it provides the maximum damage tolerance properties for titanium alloys.

Titanium was also selected for landing gear components. The single largest titanium application, and perhaps the biggest challenge, was applying Ti 10-2-3 to the main landing gear truck beam. This application challenged Boeing's metallurgists to develop tight process controls for welding the three pieces that made up this component. (Note: As part of a subsequent cost reduction effort, Boeing ultimately converted the three forgings to a single forging.) The resulting truck beam saved substantial weight and also resulted in a design without the typical corrosion and paint damage risks associated with high-strength steel landing gear components.

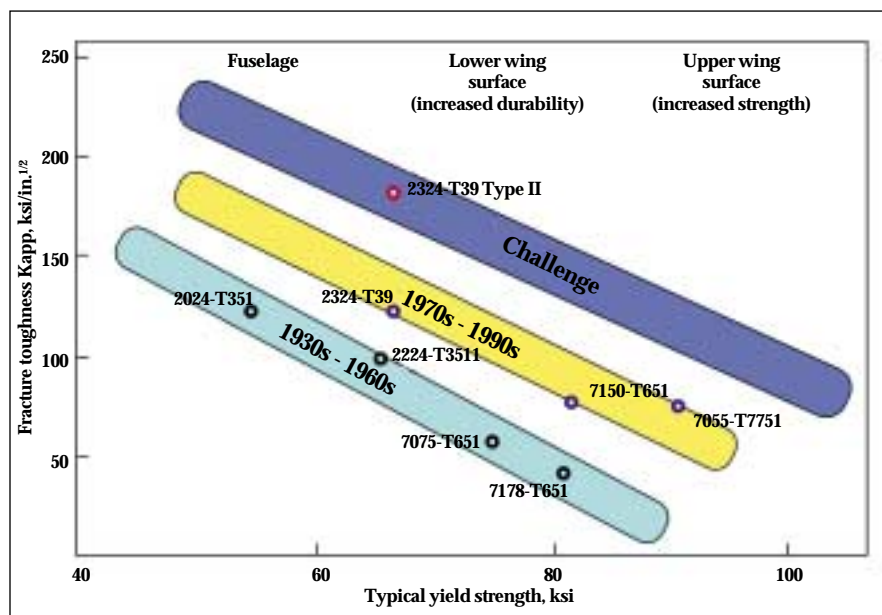
Titanium alloy developments in the early- to mid-1980s were pushed into new product forms and applications for the 777 as well. While earlier Boeing airplanes included titanium for landing-gear springs and high-



Toughened 2000 series aluminum alloy properties. This alloy is for the body skin.



Advances in 7000 series corrosion-resistant aluminum alloys.



Advanced aluminum alloys with higher toughness and improved corrosion resistance.



temperature environmental control ducting, these alloys had several performance and in-service shortcomings. During the design of the 777, Boeing's metallurgists worked closely with parts manufacturers to upgrade to Ti 15-3-3-3 for both clock-type springs and ducting.

Another major step forward was the selection of Beta-21S titanium for the engine plug and nozzle hot structure, normally fabricated of nickel-base alloys. Beta-21S, developed for its high resistance to oxidation, resulted in significant weight reduction for this exhaust component.

Non-structural materials

In the interest of creating a preferred airplane, Boeing's materials engineers concentrated on every detail, and identified the potential for breakthroughs in some less obvious areas, for example:

By filling traditional sealants with micro-balloons, over 300 pounds of weight was eliminated while keeping the same basic properties.

Through detailed analyses and tests, Boeing confirmed that an entire coat of paint could be eliminated from the lower portion of the fuselage interior. Amazingly, while this change eliminated over 250 pounds of weight, the primary driving force behind its incorporation was improved paint adhesion

and better corrosion resistance.

These changes typify the innovative thinking that enabled the development of a preferred airplane in terms of cost, weight, and affordability.

Boeing 777 to 7E7

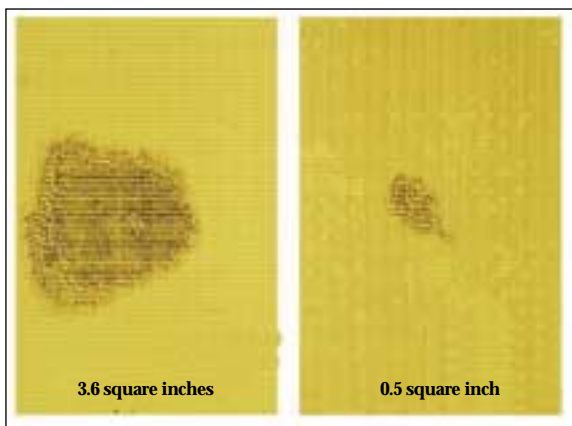
The 777 represented a breakthrough in materials applications for commercial aircraft. The introduction of this airplane was well-timed to drive a number of critical advances in materials technologies to maturity, with the end result being implementation. The rate of incorporation for these advances onto the 777 is remarkable, and reflects the high degree of alignment in research work over the five years preceding the design effort. This research was clearly focused on fleet concerns raised by airlines, and the deliberate development of enhanced performance materials that were cost-effective.

Just as the 777 was a breakthrough in terms of materials applications, the 7E7 promises to provide an even greater opportunity for innovation, both in technical advances and in the creation of the cooperative process needed to develop these technologies with our global partners.

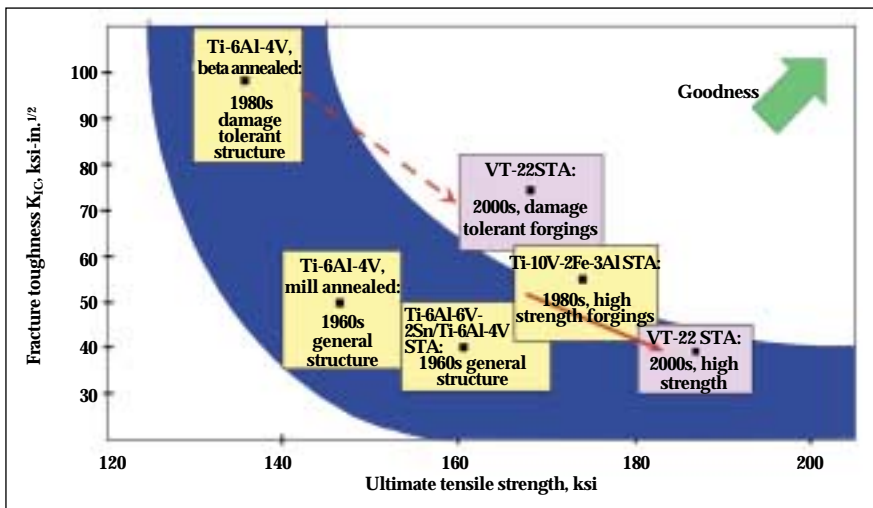
To compete against products that are based on many of the same material technologies found on the 777, the 7E7 engineers must consider further technology breakthroughs and expand the application of advanced technologies beyond the current norm.

Fortunately, materials development in the last five years has been promising. Today, confidence has increased in composites as a primary structure, based on 777 successes. Encouraging progress has been made in aluminum, steel and titanium technologies. Finally, understanding the need for environmentally responsible processes has also grown. Many technologies are now maturing in this area and offer an opportunity to design and produce an airplane that is not only cost and performance preferred, but more environmentally friendly than airplanes of the past.

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Comparative composite material damage resistance. After a 270 in.-lb impact, the conventional composite material on the left shows much more damage than the new 777 advanced composite material on the right.



Titanium alloy development has progressed in both strength and toughness.