AeroStrategy

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Material Wealth

The Growing Use Of Composites Is Ending The 80-Year Reign Of Metallic Aircraft

The aerospace composites market will quadruple by 2026

Fast forward through the last 80 years of aircraft history and you'll see biplanes morph into monoplanes, mechanical components replaced by electronics, and propellers turn into jets. It's a story of stunning technological success, with one improvement swiftly following another. Yet, over eight decades, one thing remained the same. Airframes, engines, and countless critical parts were all made of metal. Since the late 1920s, the history of aviation, from steel and aluminium alloys to superalloys and titanium, has been an Age of Metal.

But, much as the Bronze Age superseded the Stone Age, an era of new materials is coming. For of all the many marvels the aerospace industry can look forward to – from advanced electronic systems to the integration of sophisticated diagnostics and prognostics – some of the most fundamental changes will result from the growing use of composite materials. A new generation of high-composite aircraft designs promises to

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The 10-40% weight savings from composites is particularly important in an environment with high fuel prices and tighter emissions standards

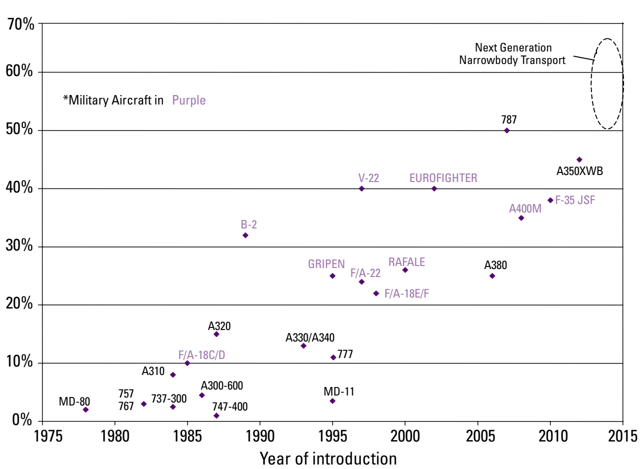
dramatically accelerate the growth of a market currently valued at more than $7 billion. The Age of Composites is dawning.

This historic shift will create ripples throughout the industry and the aviation supply chain. New materials demand new skills, new equipment, new practices, and new expectations. This AeroStrategy Commentary describes the size and scope of the composites revolution to come – including our view on the outlook over the next 20-years. It also explains the forces driving this transformation and explores its many repercussions, some readily predictable and others surprising.

Shifting into High-Composite Gear: Why Now?

Composite materials, as the name implies, consist of two or more materials that are fused into one and that together possess properties different from any of its constituents. It is fitting, then, that the reason the composites revolution has taken off is a compound of the product's unusual physical characteristics *and* recent technological developments that have altered its production economics.

Figure 1: Aircraft Composite Content (% of structural weight)



Source: Teal Group, Boeing, Airbus, Composite Market Reports

The advantages of composites in aircraft design are high strength-to-weight ratio (specific strength), excellent fatigue endurance, corrosion resistance, generally good impact resistance, and malleability that permit them to be tailored to design requirements. Composites also facilitate a lower parts count because the number of subassemblies and fasteners can be reduced. In all, a switch from metal to composites can shave 10-40% off the weight and 15–30% from the design cost of a structure. Weight savings are particularly important in a market environment characterized by high fuel prices and the prospect of ever-more stringent aircraft emissions standards. On the other hand, composites also have notable disadvantages, including poor compressive properties, the requirement for non-destructive inspection techniques, and relatively high fabrication costs.

The most common aerospace composites are fiber-reinforced plastics such as carbon fiber /epoxy resin. Other common types include sandwich structures and fiber metal laminates. The resin generally determines the temperature tolerance of a composite material while the fiber dictates its strength. Epoxy is the resin most often used in aerospace applications. The most common fiber is carbon, which is used extensively in structural components to leverage its high specific strength. Interiors and radomes typically use less expensive glass fiber.

Composites first appeared in performance-oriented military aircraft, notably fighter and attack planes that traditionally require high thrust-to-weight ratios and, more recently, stealth. Early adopters of significant content included the F/A-18 C/D, AV-8B II, and B2 Spirit, the latter to achieve a low radar signature. Composites typically comprise 20–50% of the aircraft structure for modern fighters such as the F22, F35 Joint Strike Fighter, Rafale, and Eurofighter (Figure 1). Many of these aircraft also have engines that integrate composites into their gas path. These composites are made with high-temperature resins (bismaleimide or polyamide), making them tolerant of temperatures hundreds of degrees above the 225° F limit of the epoxy resins typically used for airframe structures.

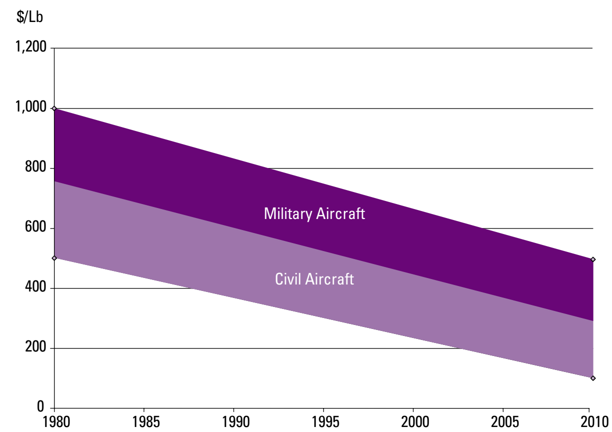
The military also makes extensive use of composites in its rotary wing aircraft, in both rotor blades and aerostructures, principally for weight savings. The V22 is more than 40% composite. Military transport aircraft, by contrast, have been largely metallic. The C17 is 8% composite, the C130J just 2%. This will change in 2010 when the Airbus Military Company A400M transport enters service, as its design features an all-composite wing and an overall composite content equivalent to 35% of the aircraft's empty weight.

Less adventurous than its military brethren, the air transport sector has nonetheless been markedly increasing composite usage over the last few decades. Aircraft designs of the 1970s and early 1980s made sparing use of composites in radomes, wing-to-body fairings, interior structures, and control surfaces, accounting for just 1–3% of the aircraft structural weight. But as the composites industry matured and costs began to decrease, commercial applications began to appear in a wide range of products, from automobiles to sporting goods as well as commercial aircraft. Airbus ushered in a new generation of aircraft with the A320 in the late 1980s – later matched by Boeing with its B777 – that increased the proportion of composites to 10–15% of structural weight.

If aerospace composite usage is headed skyward, credit can go to recent advances in technologies and processes, including automated tape lay-up (ATL) machines, fiber placement, resin transfer molding (RTM), and resin film infusion (RFI) that have lowered production costs. Structures that cost $500/lb to fabricate in the early 1990s are now much less expensive – some as low as $125 - 150/lb. (Figure 2). Not surprisingly, the latest designs make far freer use of composite materials. Nearly one-fourth of the massive Airbus A380, now set for introduction later this year, will be made of composites. Its upper fuselage will in part consist of the hybrid composite/metallic structure known as GLARE. All told, the A380 will carry 66,000 pounds of structural composites.

Using the same yardstick, the half-composite Boeing B787 will be twice as revolutionary. The aircraft features an all-composite fuselage and heavy deployment of composites throughout the wing, nacelle, and interior. These applications, coupled with greater use of titanium and aluminium-lithium, will significantly reduce the aircraft's weight, accounting for a large part of its 15–20% fuel consumption advantage over earlier generation wide body aircraft. Spurred in part by the B787's innovations, the recently announced Airbus A350XWB reportedly has a composite penetration of 45%.

Figure 2: Aerospace Composite Production Costs



Source: AeroStrategy, Composite Market Reports

These next-generation wide body aircraft are only part of the reason the aerospace composites industry is poised to reach new heights. Airbus and Boeing are now hinting they will considerably expand composites usage in the narrow body aircraft that will eventually replace the popular B737 and A320 models over the next decade. This would dramatically accelerate the composite revolution and amplify its impact on the aerospace supply chain, as narrow body aircraft currently account for 70% of the global air transport fleet.

Even business aircraft designs, which have traditionally been conservative about composites integration, are beginning to change. Raytheon leveraged its technology and experience from the ill-fated Starship

Composite fabrication costs are considerably lower than a decade ago

GEnx

program to integrate composite fuselages into its recent Premier and Hawker 4000 designs. Gulfstream introduced high-temperature bismaleimide (BMI) thrust reversers in its G450. And Dassault developed a composite empennage for its new Falcon 7X aircraft.

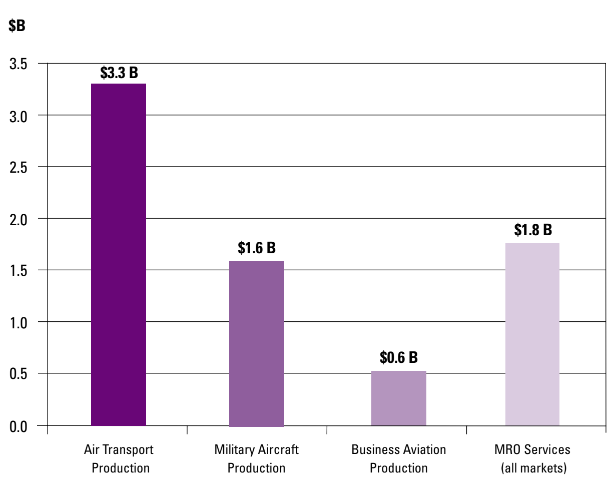
Increased impetus also comes from modern engine designs. Like the airframe segment, the military market pioneered the integration of composites into engine designs including the TF34, F100, F110, F404, F414, and T700. More recently, two Pratt & Whitney engines, the F119 and F135, as well as the Eurojet EJ200, will integrate even higher levels of composites to cope with the unique demands of new generation fighter aircraft. In the commercial market, GE led the way by making the GE90's fan blades out of composites.

The aerospace composites market is currently worth $7.3 billion

Its new engine, the GEnx, goes farther, introducing a composite front fan case to complement its proven composite fan technology. As a result, aggregate composite usage per engine will exceed 1,500 lbs – 13% of total engine weight. This is more than twice the composite usage in a GE90 engine.

Limiting the penetration of composites in engine design are the harsh temperature extremes in aeroengines, which often exceed the resin service temperatures. This means that most near-term applications will be in the "cold section" of the engine.

Figure 3: Aerospace Composite Market. Total = $7.3B



Source: AeroStrategy
Note: excludes UAVs

Market Magnitude: Foreseeing Double

The market for aerospace composites, encompassing both production and maintenance, repair, and overhaul (MRO) services (Figure 3), is, by AeroStrategy estimates, worth $7.3 billion in 2006. Production of finished composite components and structures for new aircraft, mostly carbon fiber reinforced plastics (CFRP), accounts for three-quarters of the market, or $5.5 billion.

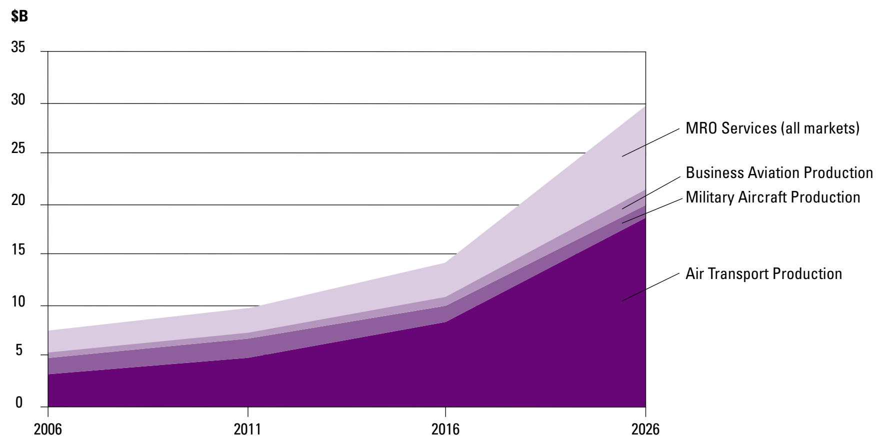
The air transport production (OEM) sector, which provides equipment to the world's airlines and cargo operators, accounts for $3.3 billion of this total. The next largest segment, military aircraft, is valued at $1.6 billion. In this market, the higher penetration of composites in fighters is offset by the small size of both the fighter fleet and the aircraft themselves when compared to air transport. Finally, $600 million of composites are integrated in business aircraft (including civil helicopters), a value that reflects lower penetration and smaller aerostructures.

Demand for MRO services of composite structures and components is sizable – $1.8 billion – and growing, yet is often overlooked. Key activities in this segment include repair of thrust reversers, radomes, nacelles, flight control surfaces, structural components, helicopter blades, fairings, and aircraft interiors.

So much for the present. What of the future? AeroStrategy foresees that the introduction of new high-composite content air transport aircraft, combined with MRO demand growth, will lead to a near doubling of the aerospace composites market. This market is anticipated to reach $14 billion within a decade, a compound annual growth rate of nearly 7%. The air transport OEM sector will be the source of much of this growth, as it is expected to expand at a sizzling annual rate of 9.5%.

Beyond ten years, how big can the composites market get? AeroStrategy has prepared a bottom-up, data-driven prediction that extends to 2026. But first, a word of caution. Nobel-prize winner Niels Bohr, inventor of the "planetary" model of the atom, once said, "Prediction is very difficult, especially about the future." He might have added: the farther out you look, the fuzzier it gets. Yet AeroStrategy is willing to venture that in the 2016-2026 timeframe, the market for aerospace composites may double yet again to $30 billion. This figure assumes that future air transport aircraft, including the much anticipated B737 and A320 replacements, integrate composites at an even higher rate, mainly by bringing them into their primary structures. This estimate also assumes that the composites penetration of business aircraft will rise significantly. Granted this, the trend is clear (Figure 4): over the next two decades, air transport production will drive overall market growth followed by composite MRO services.

Figure 4: Aerospace Composite Market Forecast ($B) 2006-2026



Source: AeroStrategy.
Notes: excludes UAVs, figures in 2006 dollars

From Metal-Bending to Chain-Challenging: Supplier Dynamics

The robust growth of composites will increasingly reshape the aerospace supply chain as it shifts from the "metal bending" paradigm that has been in place since the introduction of metallic monoplanes in the 1920s. But how? Consider a simplified aerospace production supply chain (Figure 5) that includes four principal participants:

- Aircraft and engine OEMs responsible for system integration and final assembly
- Tier I suppliers of major assemblies and aerostructures that sell directly to OEMs
- Tier II suppliers that produce sub-assemblies, parts, and components sold to Tier I suppliers and upstream OEMs
- Raw material suppliers of fiber, resin, prepreg, and metals

How will each fare? The primary customers, aircraft OEMs, appear to be pursuing a strategy derived from the automotive industry: focus on final assembly and systems integration and cut back on internal aerostructures and production capability. In practice this means relying on a select group of Tier I suppliers to provide design and supply chain management while limiting interaction with Tier II suppliers. OEMs are essentially shifting commercial and technology risk to their supply chain partners. A good recent example is Boeing's divestiture of its Wichita and Tulsa fuselage production facilities (now Spirit Aerosystems). In consequence, the market available to aerostructures firms will grow faster than overall aerospace production.

Tier I suppliers are already busy consolidating and bulking up as they take on the integration and supply chain management activities aircraft OEMs are abandoning. This new breed of Tier I suppliers must acquire sufficient size and breadth to allow them to make the requisite investments to remain competitive – investments in composites technology and capital equipment such as large autoclaves and automatic tape laying equipment.

OEMs are shifting commercial and technology risk to their supply chain partners

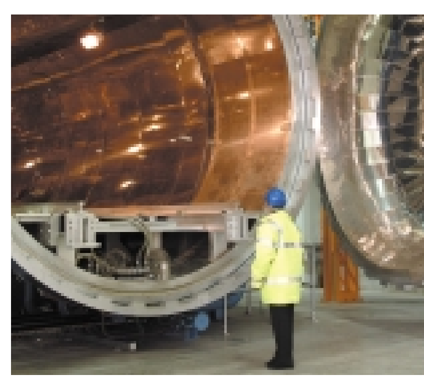
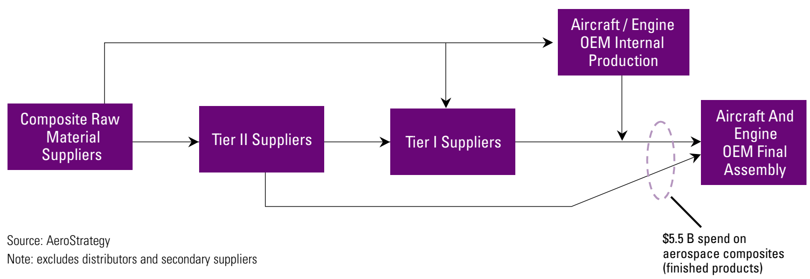


Figure 5: Aerospace Composite Manufacturing Supply Chain

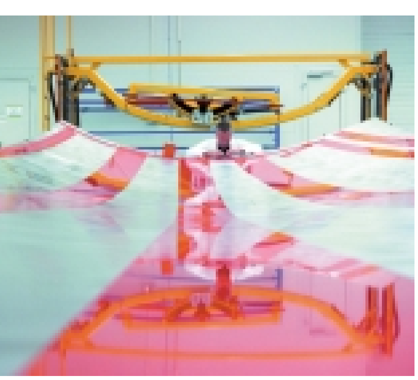


Source: AeroStrategy
Note: excludes distributors and secondary suppliers

AeroStrategy believes that there are 20 to 25 Tier I suppliers with aerostructures revenue in excess of several hundred million dollars. Some of the better known are, in North America, Goodrich, NORDAM, Spirit Aerosystems, and Vought; in Europe, Aircelle, Alenia, and GKN; and in Japan, Fuji Heavy Industries, Kawasaki Heavy Industries, and Mitsubishi Heavy Industries.

Most Tier II firms will be challenged to develop composites capabilities or face a diminishing market

Consolidation among Tier I suppliers is being accompanied by globalization, again, to enhance competitiveness. Alenia and Vought recently created a joint venture, Global Aeronautica, which will produce more than 60% of the composite B787 fuselage. Global Aeronautica broke ground on an integration facility in South Carolina that will join subassemblies produced in Italy and the U.S. Two other Tier I suppliers, Goodrich and NORDAM, recently completed major expansions of nacelle/thrust reverser MRO facilities in Singapore and Europe, respectively. British firm GKN recently acquired Stellex Aerostructures in the U.S. And Spirit Aerosystems acquired BAE Systems' aerostructures business unit, creating a significant European presence for what was formerly a Boeing cost center.



The other end of the supply chain is anchored by a concentrated group of raw materials suppliers. Just four – Cytec, Hexcel, Toray, and Toho Tenax – control approximately 80% of a $1.5 billion-plus market for aerospace composite raw materials. The upsurge in composites demand in aerospace and other industries has been so great that production capacity (notably for carbon fiber) has been tested. In a sure sign that they know this is not a temporary shortage, suppliers are adding capacity. Hexcel recently broke ground on a new carbon fiber facility in Spain, with plans to expand total capacity by 50% by 2008. Toray intends to increase its global carbon fiber capacity 44% by 2007, from 20 to 28.8 million pounds per year. And in late 2006, Cytec will revive and modernize a mothballed carbon fiber facility in the U.S. Even so, carbon fiber will likely remain in short supply through the end of the decade as demand escalates for both aerospace and non-aerospace applications. This could create opportunities for new market entrants or possibly permit smaller aerospace suppliers like Mitsubishi Rayon, SGL, and Zoltek to grow.

Non-composite raw materials suppliers are also affected. Titanium is in short supply, in part, because it does not produce galvanic corrosion when mated with composite components, an issue for some aluminium alloys. The B787 will incorporate 15% titanium by weight – far higher than prior commercial aircraft designs. The comparable figure for the F-35 Joint Strike Fighter is even higher – 20%. Another supplier group, aluminium suppliers, are scrambling to produce lighter, more effective alloys to limit encroachment of composites.

Wedged between consolidating Tier I suppliers and a handful of raw material providers are a vast number of Tier II aerostructures, subassembly, and parts suppliers, with, for the most part, revenues of under $100 million. Hundreds and possibly thousands of Tier II suppliers face significant challenges in a composite-oriented environment, including:

- *Shifting distribution channels.* Many Tier II suppliers were built on small contracts with aircraft and engine OEMs. But their distribution channels are shifting to Tier I companies, upsetting long-standing business relationships.
- *New technologies.* Most Tier II firms, to the extent that they focus on metallic structures, will be challenged to develop composites capabilities or face a diminishing market.
- *New competition.* A wave of new Tier II suppliers is originating in low-cost regions, such as East Asia and Eastern Europe, often as part of a national strategy to expand aerospace participation.
- *Demographics.* Owners nearing retirement age established many Tier II firms. Some firms will retire when their owners do.

Tier II companies will undergo churn and consolidation as a result – even in today's benign aerospace environment. The eventual fallout could be considerable.

Somewhat surprisingly, the composites revolution will change not only what producers do but *where*. While new composite production processes, such as automated tape laying and resin transfer molding, are more capital intensive, and thus require significant investment, they also promise to slash both production times and labor requirements. This means the aerostructures market may split into two geographically distinct factions. The manufacture of advanced composite structures will move to clusters where advanced technology companies and highly skilled composite workers reside, while metallic aerostructures production will likely migrate to low labor cost regions. Instances of composite production clusters can already be seen in Germany, Italy, Japan, Spain, the U.K., and the U.S.

MRO Supply Chain

The composites revolution also has similarly profound implications for the MRO supply chain.

First, operators will surely get some relief via the lower cost of operating and maintaining composite designs. But they will just as certainly be challenged to find the people and the organizations equipped to do the necessary work.

The integration of composites into the primary structure of the aircraft means that composite maintenance skills, including use of non-destructive inspection (NDI) equipment, will need to be upgraded significantly across the board. Regrettably, many schools and maintenance training curricula are not currently up to the job of training technicians to cope with high composite aircraft. This means MRO organizations must develop supplemental training programs themselves or purchase them to close the gap. Engineering skills must also be adapted and the MRO knowledge base for composite primary structures must be rapidly expanded. High composite content aircraft will undoubtedly present new, unforeseen maintenance challenges. This was certainly the case for early-generation metallic aircraft.

The composites revolution has profound implications for the MRO supply chain

Repair of composite primary structures calls for new types of capital investment. Companies now without advanced non-destructive testing equipment or large autoclaves must obtain them if they wish to compete. This hurdle raises a question for operators and smaller independent MROs: do they want to invest in maintenance capability for new generation aircraft or not? The result may be two tiers of composite MROs. On one side are those that focus on traditional secondary structures, such as fairing and control surfaces; on the other are those prepared to tackle the unique challenges of the primary structure.

Finally, high-composite aircraft will drive fundamental changes in aircraft maintenance programs. Boeing contends that, as a result of its composite primary structure, the B787 will require 14 fewer line checks, two fewer C-checks, and one less 4C check than the A330. In addition, the target interval for line maintenance checks on the B787 is once every 1,000 hours, 400 greater than the interval for the B777. High-composite engines may also benefit from greater reliability and more relaxed inspection. Consider that, amazingly, just three GE90 composite fan blades have been removed from service in eleven years. Operators may well see their overall maintenance expenditures decline on a unit basis, even as the market for composite MRO services expands.

Conclusion

The aerospace industry has always been at the leading edge of technology development for advanced materials. In the 1920s and 1930s, it created lightweight aluminium alloys that ushered in the age of metallic aircraft. In the 1950s and 1960s, it developed superalloys to cope with the severe demands of jet engines and spacecraft. And in the 1970s and 1980s, it pioneered the use of advanced composites for military aircraft.

Once viewed as a desirable but expensive option for aircraft designs, composites have come of age largely due to economic factors. With production costs continuing to fall and fuel prices continuing to rise, they are increasingly viewed as the *best value* rather than simply the *most advanced* design alternative.

To be sure, metals will not disappear from aircraft designs anytime soon, and will remain the dominant material in aeroengines, components, and certain aircraft structures for the foreseeable future. But increasingly metals will be the *exception* in future aircraft designs rather than the *rule*. Metals will be used when a composite won't suffice rather than the other way around.

The implications of this transformation, which will unfold over the next several decades, are profound. Operators, suppliers, investors and governments must take stock of what the composites revolution will mean, and prepare accordingly. Indeed, the Age of Composites is arriving.

AeroStrategy is a management consulting firm, specializing in strategy and market analysis for the aviation and aerospace industries. We value your feedback and welcome your letters and comments on any aspect of this AeroStrategy commentary.

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