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The crucial role of **composites** in next-generation aircraft design

A white paper written by Counterpoint Market Intelligence in collaboration with Hexcel Corporation

EXECUTIVE SUMMARY

With global aviation projected to grow significantly over the coming decades, the industry requires technologies that can lower carbon emissions and improve aircraft fuel efficiency. Composite materials, already transformative in modern aircraft like the Airbus A350 and Boeing 787, will play a key role in the pathway to net zero. This white paper explores how composites offer a compelling combination of high strength, low weight and adaptability to aircraft designers. These properties allow engineers to balance the underlying trade-offs between aerodynamic performance and lightweight structures – resulting in substantial fuel reduction versus metallic designs. Leveraging composite technologies will be key for aerospace manufacturers to deliver the next generation of aircraft designs capable of significantly reduced fuel consumption and carbon emissions.

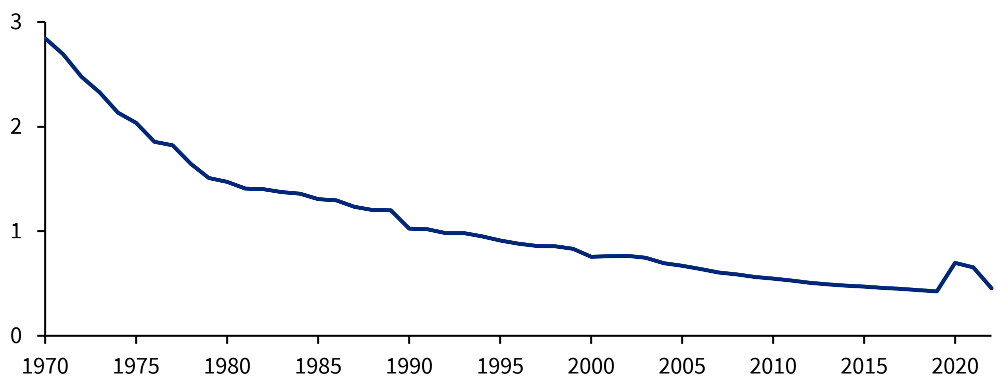
Composite materials
The Airbus A350 wing makes extensive use of composite materials

AIRCRAFT FUEL EFFICIENCY

Industry trends will require more fuel-efficient aircraft – and composites are a key enabler

Since the advent of commercial jet travel in the 1950s, the aerospace industry has made remarkable strides in fuel efficiency. Modern aircraft consume far less fuel – and therefore produce far fewer carbon emissions – per passenger-mile than early jet airliners. The chart below displays the carbon emissions per passenger-mile from 1970 to 2022, showing a substantial decrease.

Aviation industry fuel efficiency[1, 2]
Pounds of CO_2 per revenue-passenger-mile



To meet the industry's decarbonization objectives, the industry will need to continue to make progress in reducing aircraft fuel consumption. The International Civil Aviation Organization (ICAO) forecasts air travel to grow at 4% annually from 2023 until 2050.[3] Without further improvements in fuel efficiency, emissions for the sector will continue to grow. Other innovations, such as sustainable aviation fuel (SAF) or alternative propulsion technology, can assist in getting to net zero, but the high cost of SAF and the long timeline for new propulsion technology present a challenge for the industry. Reducing the amount of fuel consumed in the first place using existing technologies is a critical step. In addition, fuel often comprises the largest single expense for an airline (a quarter to a third of an airline's operating expenses[4]), and reducing fuel consumption is vital for airline operations and profitability.

> ICAO forecasts air travel to grow **4%** annually to 2050

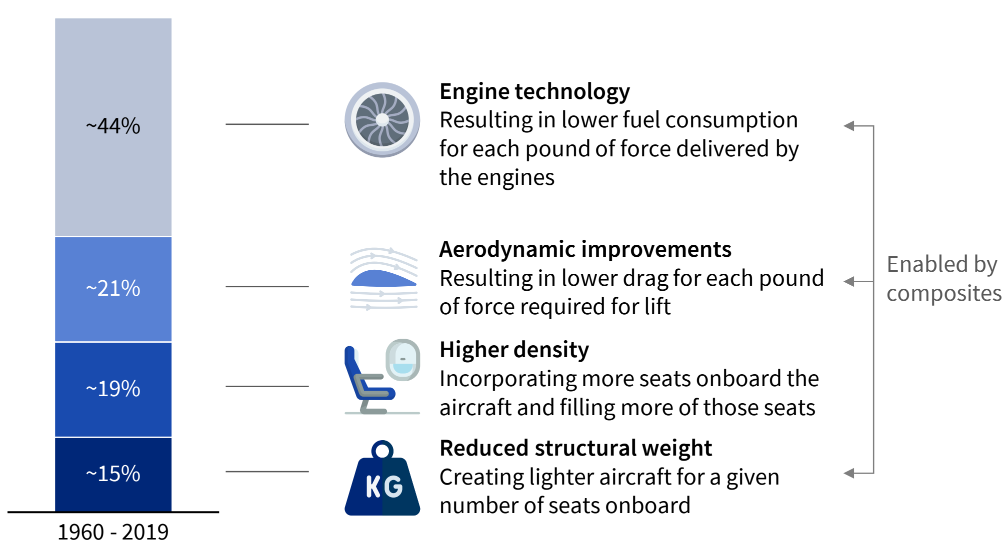
Historically, aircraft manufacturers have improved fuel efficiency (in terms of fuel per passenger-mile) through four major levers: improved engine technology, higher density of seats and passengers, aerodynamic improvements, and lowering structural weight. A 2022 study examined the contributions of these levers to fuel savings over time, as shown in the chart at the bottom of the page. [5] To date, much of the improvement in the current fleet has come from engine technology. Seating and passenger density have also been major contributors, particularly during the expansion of low-cost carriers in the early 2000s. Using a different methodology, an analysis by McKinsey found that nearly half of fuel efficiency savings between 2005 and 2019 were due to seat density and passenger load factors rather than aircraft improvements.[6]

Aerodynamic performance and structural weight took a leap forward with the introduction of the Airbus A380 and then the Boeing 787 and Airbus A350. The A380 introduced carbon fiber composites in the central wing structure. Boeing's 787 features both a composite wing and fuselage, incorporating composites into 50% of the aircraft structure.[7] Airbus followed a similar path with the A350, with composites accounting for 53% of the aircraft's structural weight.[8] This follows a wider trend of aircraft programs incorporating more composites than earlier designs. Airbus's A220 features a composite wing and as does Boeing's 777X.

Although structural weight has played a smaller role so far, this is likely to change in the future. Passenger densities are approaching a natural limit. Pushing the boundaries of engine technologies will require major design changes, such as open rotor systems, which will take time to develop and certify. Therefore, to continue the trajectory of fuel savings, aerodynamics improvements and reduced structural weight are set to become even more important in next-generation programs than we have seen historically. For aircraft designers, composites play a critical role by enabling both aerodynamic improvements and reducing structural weight – a trade-off that we explore in the next section.

Sources of aircraft fuel efficiency[5]

Relative contribution to aircraft efficiency improvements between 1960 and 2019



OPTIMIZING WEIGHT AND DRAG

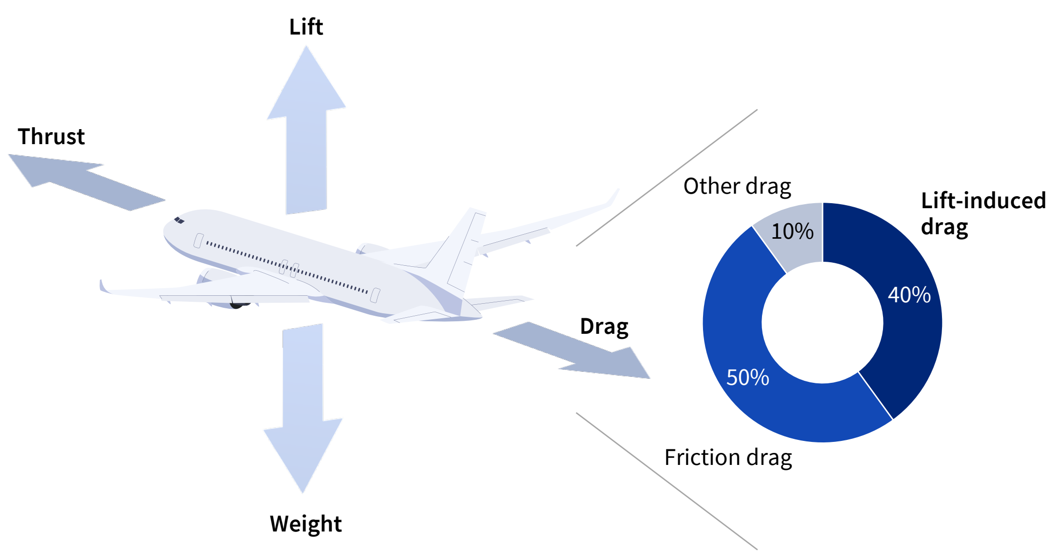
Weight and drag have inherent trade-offs in aircraft wing design

For aircraft designers, weight and aerodynamic performance form a complex balancing act. These two factors are closely connected through the relationship between lift and drag. When an aircraft is in steady, level flight, the forces acting upon it—lift, weight, thrust, and drag—are balanced. The wings must generate enough lift to balance the aircraft's weight, while the engines must produce sufficient thrust to overcome aerodynamic drag. The greater the drag on the aircraft, the more thrust required from the engines, leading to greater fuel consumption and increased carbon emissions.

Approximately **40%** of an aircraft's drag in cruise relates to the weight of the aircraft

The drag on an aircraft comes from several sources. The ratio of these sources changes as the aircraft burns fuel, but typically about half of the drag experienced in flight is created by friction between the air and surfaces of the aircraft. Around 40% of drag is lift-induced drag, caused by high-pressure air from beneath the wing spilling around the tips to the low-pressure area above.[9] This flow creates swirling air that acts like a brake, slowing the aircraft down.

Drag composition of a typical single-aisle aircraft[9]
Percentage of total drag acting on the aircraft in cruise



In this way, the weight of the aircraft has a direct effect on the carbon emissions. A heavier aircraft requires more lift → creates more lift-induced drag → demands more thrust from the engines → consumes more fuel to produce that thrust → produces greater carbon emissions through higher fuel consumption. Aircraft do not just feel this effect during takeoff, but rather for every mile that the aircraft flies. This relationship can have a compounding effect – if the aircraft needs more fuel to carry the extra weight, that fuel will also incur a drag penalty, requiring even more fuel.

Aircraft designers can reduce lift-induced drag in two primary ways:

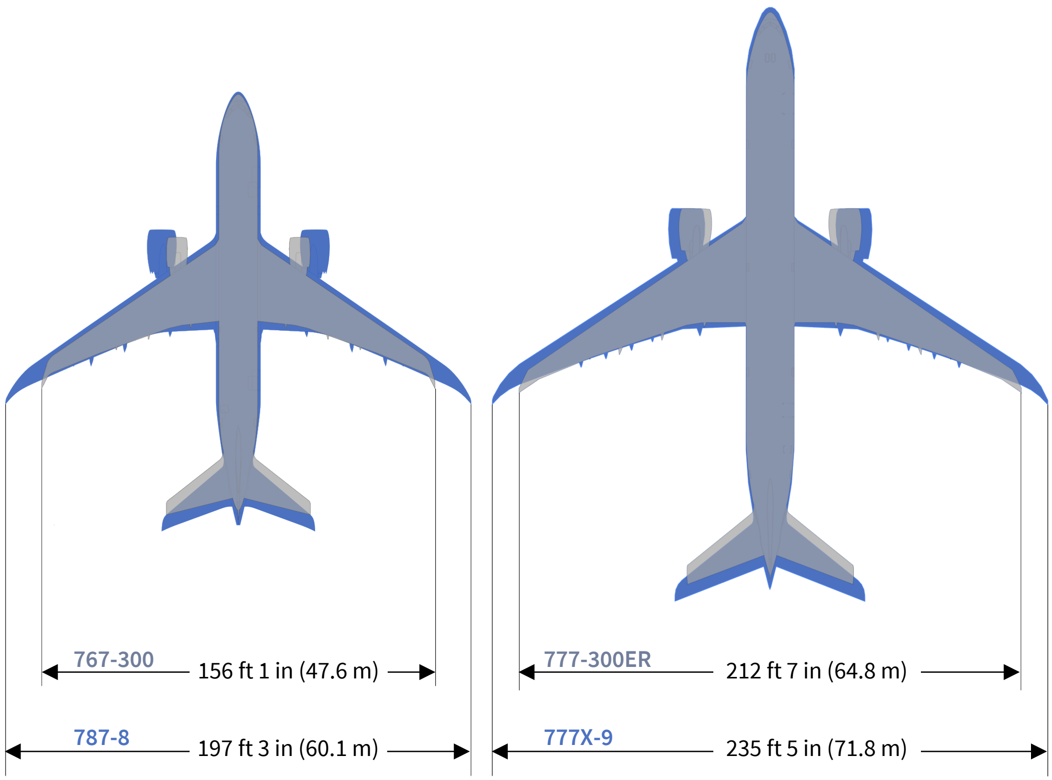
Lowering the weight of the aircraft
By reducing the mass that must be lifted, an airline can reduce fuel burn. Even relatively small changes in aircraft weight can add up to large impacts. In 2014, for example, American Airlines replaced 5 lb (2.3 kg) flight attendant manuals with 1.2 lb (0.5 kg) tablets and saved the airline an estimated $650,000 per year in fuel.[10] In the same way, using lighter weight materials in the aircraft design reduces induced drag and improves efficiency.

Optimizing the wing design
Engineers can optimize features of the wing to lower induced drag. One option is to use a longer, slender wing. For a fixed wing area, a longer wingspan can reduce induced drag because it allows the wing to generate lift more efficiently. However, this is not without trade-offs; a longer wing typically comes with increased weight. The challenge for designers is to strike the right balance, ensuring that any additional weight does not negate the aerodynamic benefits.

Composite materials are highly beneficial to aerospace designs as they allow aircraft designers to achieve a more optimal wing design without the weight penalties that would be seen with metals.

Two examples on the next page help illustrate how manufacturers are incorporating these longer, thinner wings into their design. Boeing's 767-300 and 787-8 aircraft have similar fuselage lengths and passenger capacities. The former is a largely metallic design that entered service in 1982, while the latter features a composites wing and fuselage and entered service in 2011. The 787's composite wing extends 41 feet (12.5 meters) further than the 767's metallic wing, thereby lowering the drag on the aircraft.

Comparison of wing designs
Composites enable wider wingspans, which reduces lift-induced drag



Similarly, Boeing's upcoming 777X series features a composite wing compared to metallic wings of earlier generations of the 777 aircraft. The 777X features a long, thin wing that improves aerodynamic efficiency. Despite being slightly larger than prior generations, the 777X needs a less powerful engine, reflecting the lower thrust required with these aerodynamic changes. The benefits of this wing are so critical to the design, that the aircraft features folding wingtips to ensure the aircraft can use the same airport facilities as earlier 777 generations.

Airbus has taken a similar approach. The company's A350 and A220 aircraft both feature long, thin, composite wings that improve aerodynamic performance. The next section details the properties of composites that allow designers to incorporate these improvements in aerodynamics into modern aircraft.

PROPERTIES OF COMPOSITE MATERIALS

Composites offer high strength and stiffness which can be tailored to the design

Composites are a combination of two or more materials with different properties. The combination of these components results in a material with unique characteristics. The composites used on aircraft are typically composed of fibers made from carbon or glass, combined with a polymer matrix resin.

These composites differ from traditional metallic materials like aluminum, steel, and titanium in several key characteristics that are particularly advantageous for aircraft design:

High Strength-to-Weight Ratio
Composites, such as carbon fiber reinforced polymers, offer the strength needed to withstand high aerodynamic and structural loads at a relatively low weight. This characteristic is crucial for long, thin wing designs where the use of metal would require adding more material to make them strong enough, resulting in heavier wings.

High Stiffness-to-Weight Ratio
Not only must an aircraft's wings be strong, but they also need to be stiff enough to prevent aeroelastic phenomena like flutter, which can compromise safety and performance. Composites deliver the necessary stiffness without the weight penalties associated with metals.

Tailorable Properties
Composites can be engineered so that their strength and stiffness are optimized in specific directions. This "tailorability" means that material can be placed exactly where it is needed to counteract expected loads, without incurring unnecessary weight or cost from over-engineering areas that do not require such high performance.

The table on the next page shows select properties of carbon fiber compared to common aerospace metals. Properties are shown for a particular grade of fiber (Hexcel's HexTow® IM7) and those same fibers when combined with a resin matrix into a unidirectional (UD) tape. Material selection depends upon a range of factors beyond those shown here, but the table illustrates the high performance of carbon fibers along these dimensions. These properties make composites indispensable for modern wing design. The ability to create longer, thinner wings without a corresponding increase in weight not only improves aerodynamic efficiency but also directly translates to fuel savings. In the examples shown above, the 787 improved fuel efficiency by about 25% compared to the 767,[11] and the 777X is projected to deliver 10-15% better fuel efficiency than the 777-300ER.[12] Both aircraft also feature updated engines which contribute to these improvements, yet aerodynamics and lightweight composite structures are instrumental to the efficiency gains.

Academic studies can also give a sense of the benefits of composites over metallic designs. An optimization study from the University of Michigan compared metal versus composite wings and found the composite wings to be 30-40% lighter resulting in 5-8% fuel savings.[13] Similarly, a NASA study on next-generation single-aisle aircraft estimates that a new aircraft program could see a 7% improvement in aerodynamic efficiency and a 9% improvement in the empty weight of the aircraft using the latest composite technology in the wing and fuselage.[14] Combined, the study estimated a 7% savings in fuel consumption. For a typical single-aisle aircraft, that equates to approximately 275 gallons (1,041 liters) of fuel[4] or $600 in cost for each hour the aircraft operates.[15]

Properties of common aerospace materials
Strength-to-weight and stiffness to weight relative to aluminum 2024-T4

Material	Density	Strength-to-weight	Stiffness-to-weight
Carbon fiber – IM7	**0.6x**	**18.9x**	**5.9x**
UD tape – IM7	**0.6x**	**9.4x**	**3.8x**
Titanium – Ti-6Al-4V	1.6x	1.3x	1.0x
Aluminum 7075-T6	1.0x	1.2x	1.0x
Aluminum 2024-T4	1.0x	1.0x	1.0x
Steel – 4340	2.8x	0.8x	1.0x

Over the life of the aircraft, these improvements have a large effect. Using the average 2019 block hours and fuel burn for large narrowbody (single-aisle) aircraft from MIT's Airline Data Project[4], this equates to 6 million gallons of fuel savings over an assumed 25-year lifespan of the aircraft. As each pound of fuel generates over three pounds of CO_2 emissions, this results in 60,000 tons of reduced CO_2 emissions per aircraft. To give a sense of scale, 60,000 tons of CO_2 is the same amount of emissions 1,500 medium passenger vehicles produce over their lifetime.[16]

Fuel savings from composites in one aircraft could be equivalent to removing

1,500

passenger vehicles from the road

It is not only the wings that benefit from composite technology. Aircraft designers have increasingly applied composites to vertical and horizontal stabilizers, nacelles, fuselages (as seen in the Boeing 787 and Airbus A350), and engine components such as fan blades and casings. In these applications, the primary advantage remains weight reduction. However, unlike wing components, many of these areas do not enjoy the added aerodynamic benefits, and designers must also carefully evaluate if composites are the best material for the application. In these decisions, secondary benefits such as better fatigue resistance and corrosion resistance form an important consideration, as composites can also lower the maintenance costs through their longer lifespan. For example, of the 700 Boeing 787s that have undergone routine maintenance checks, none have shown evidence of airframe fatigue. [7]

NEXT-GENERATION AIRCRAFT DESIGN

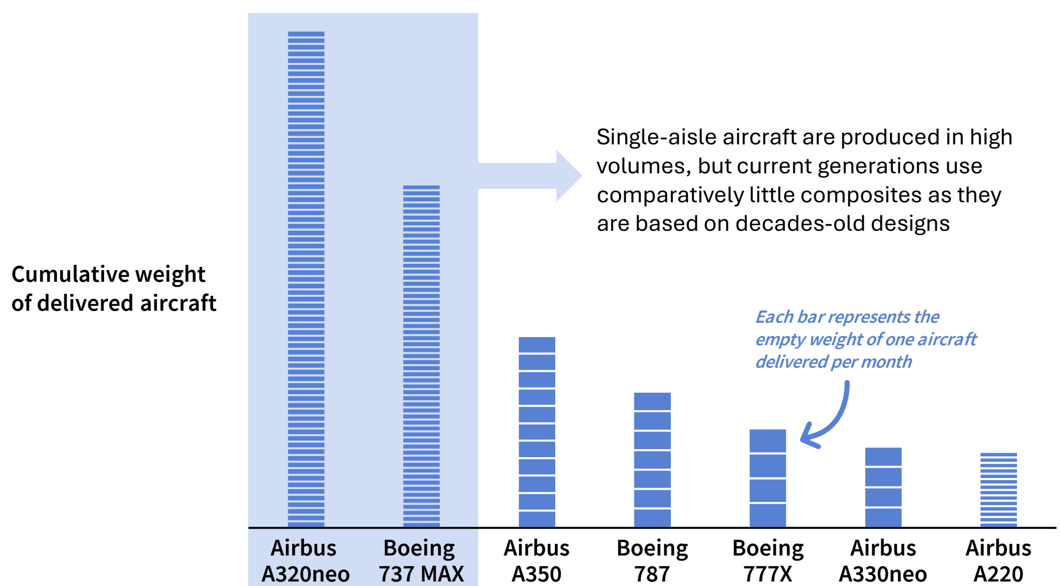
Advanced concepts rely on advanced materials to enable these designs

As the aerospace industry strives toward net zero emissions, the role of composites in aircraft design is set to expand further. In the chart below, each stacked bar in the chart represents the empty weight of one aircraft, and the number of bars represents the number of aircraft produced each month based on manufacturer forecasts. Boeing and Airbus's current single aisle aircraft have the highest production rates in the industry. These aircraft are based on decades-old designs that use far fewer composite materials than more recent programs. Incorporating more composites into the next-generation designs of these aircraft remains one of the largest opportunities for improving fuel efficiency in the industry.

The industry is actively looking towards how to increase composite usage in these designs. Airbus's Wing of Tomorrow program is a collaborative initiative focusing on lightweight materials, improved aerodynamics and automated manufacturing. Similarly, Airbus's Multifunctional Fuselage Demonstrator (MFFD) is a research initiative focusing on improving aircraft fuselage design. The goal is to integrate advanced composite materials, modular structures, and multifunctional components. [17]

Opportunity in single-aisle aircraft

Cumulative empty weight of aircraft delivered based on forecast monthly average deliveries in 2027



	Airbus A320neo	Boeing 737 MAX	Airbus A350	Boeing 787	Boeing 777X	Airbus A330neo	Airbus A220
Aircraft type	Single-aisle	Single-aisle	Twin-aisle	Twin-aisle	Twin-aisle	Twin-aisle	Single-aisle
Percent composites in aerostructures	15%	15%	53%	50%	30%	13%	46%

Advanced concepts

JetZero's all-composite blended wing body design further reduces aerodynamic drag

Speaking about the next-generation single-aisle at the company's 2025 summit, Airbus's Karim Mokkadem stated "everything will go towards longer, narrower and thin wings to increase the lift and to reduce the drag. At the same time, those wings will be made of new material – lighter material, composite material."

Advanced aerodynamic design concepts also make substantial use of composite materials. Research by NASA and other organizations into high-aspect ratio and ultra-high aspect ratio wings looks to push the boundaries of wing technology further to reduce induced drag. [19]

More revolutionary designs smoothly blend the wing and fuselage of the aircraft into a single form. Several manufacturers have explored this "blended wing body" , such as NASA and Boeing's X-48 demonstrator. JetZero, an aviation start-up, aims to bring a 250-passenger version to market. Their design relies on composites materials [20] to provide both the structural strength and as well as the flexibility in production to create these smooth, intricate shapes.

Despite the performance benefits, the initial cost of composite materials can be higher than metals and certain manufacturing processes can take longer. Composites often outperform metals when considering the full lifecycle costs – with the initial higher price of the materials offset by savings in service from fuel and maintenance – but these trade-offs are complex decisions for designers. Innovation continues to find ways of more cost-effectively producing composites components at higher rates.

Composites are no longer merely an advantage but a necessity in achieving future aviation efficiency and sustainability targets. By enabling designers to optimize aircraft structures for both reduced weight and enhanced aerodynamics, composites provide measurable emissions reductions and improved operating economics. The impact of composites is already being seen in modern aircraft designs and is set to become increasingly important in the future.

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