

Composite Fuselage Technologies for Next Generation Commercial Aircraft

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Abstract

The global commercial fleet includes 35,550 aircraft, with 30,300 active and 5,250 inactive. Single-aisle families comprise nearly 60% of this total amount ref. to Jun 2025 data. Estimates predict 38.9 million flights and 5.2% passenger growth for 2025. Long-term forecasts suggest demand for over 40,000 new aircraft over the next 20 years, effectively doubling today's global fleet.

Commercial aviation ranks among the safest public transport modes due to rigorous regulations and technological progress. Airbus remains committed to "*Safety First*" as a core value, ensuring the highest safety standards across all operations while pioneering sustainable aerospace for a safe and united world.

OEMs evaluate global trends to engineer technologies that satisfy future demand. To optimize passenger experience, airline value, and production rates, requirements are refined while prioritizing safety. For next-generation single-aisle aircraft, two tendencies may be assumed:

- Monthly delivery targets 80+ units.
- Composite materials in primary and secondary airframe structure will play a significant role

Achieving future goals within a competitive environment requires addressing various drivers, e. g. higher production rates than today. This significant increase over current composite production necessitates a step change in design, manufacturing, and high-rate industrial systems.

Commercial aviation history reveals a steady rise in composite usage, culminating in major structures like the Airbus A350XWB's 32m wing covers and fuselage, where composites now achieved 53% of total structural weight.

This paper examines technologies for high-rate composite manufacturing and processing in future commercial aircraft, leveraging past experience to explore new methods. Two primary examples are detailed:

- Discontinuous fibre reinforced composites and press forming technology improving sustainability through waste reduction using end-of-spool material, e. g. from Automated Tape Laying (ATL) and/ or Automated Fibre Placement (AFP)
- Large scale thermoplastic composite fuselage technologies investigated in the European funded CleanSky2 program "Multifunctional Fuselage Demonstrator / MFFD"

Keywords: commercial aviation, next generation aircraft, fuselage, high rate, composites

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1. Introduction

A Statistical Analysis of Commercial Aircraft Accidents 1958-2025 [4] says *" … our industry has achieved huge improvements in safety, especially over the last two decades. It also underlines the significant contribution technology has made in ensuring that taking a flight in a commercial jet aircraft is a low-risk activity. … "* which leads to *"In 2025, all aircraft generations had a combined rate of 0.09 fatal accidents per million flight cycles."*

Airbus "*pioneers sustainable aerospace for a safe and united world*," aiming to design and deliver innovative solutions that create a cleaner, better-connected, and more prosperous society. The company organizes its operational tasks across three core business units:

- Commercial Aircraft: Designs, manufactures, and supports a comprehensive family of large passenger and freight aircraft.
- Helicopters: Delivers a highly versatile portfolio of civil and military vertical flight solutions for global operators.
- Defence and Space: Focuses on safeguarding national sovereignty and exploring frontiers through military transport aircraft, advanced cybersecurity, and Earth observation satellites.

"The number one priority of Airbus is the continued safe transport of everyone and everything that flies aboard an Airbus product" [4, 5].

1.1 Commercial aviation today

According to the International Air Transport Association (IATA), the total global commercial fleet stands at 35,550 aircraft. Within this current status, the operational capacity is split between 30,300 active units and 5,250 aircraft held in storage due to maintenance, age, capacity management, and other reasons [1]. For the year 2025, the aviation industry predicted a total of 38.9 million flights globally. This figure marks a tremendous milestone in aviation history, representing an immense growth trajectory compared to the historical development of 37.3 million flights in 2024 and the deep pandemic lows of 16.9 million flights recorded in 2020. Narrow-body or single-aisle aircraft families dominate air transportation. They account for over 60% of total commercial aircraft deliveries globally [2].

1.2 Global Market Forecast

The forecast for 2025–2044 indicates that the global commercial aircraft fleet is expected to nearly double, driven e. g. by continued traffic growth, improving affordability, and strong economic factors [3]:

- **Traffic Growth**: Air traffic is expected to maintain a 3.6% Compound Annual Growth Rate (CAGR).
- **Fleet Demand**: 43,420 new deliveries are projected, growing the total fleet from 24,730 to 49,210 aircraft by 2044.
- **Replacement Cycle**: Older aircraft will be replaced by 44% of new deliveries.
- **Economic Drivers**: Growth is supported by World GDP (+2.5% CAGR), trade (+2.6% CAGR), and a 1.5 billion person increase in the middle class.
- **Regional Shift**: Asia and the Middle East lead growth.

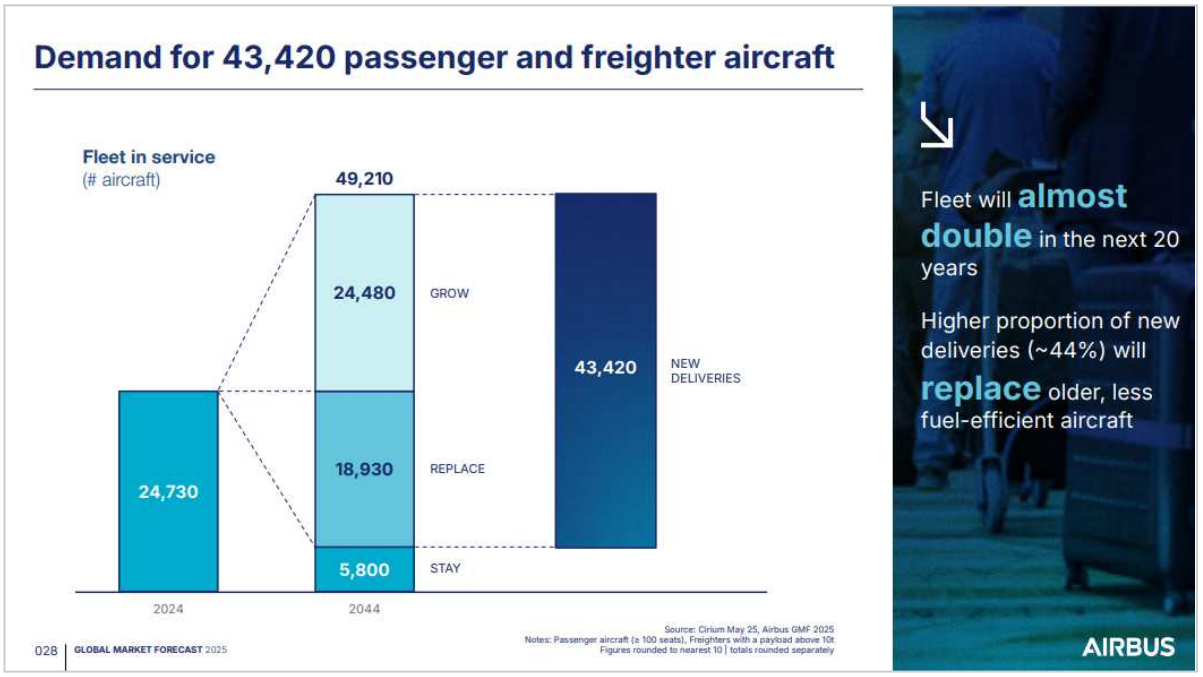


Figure 1 – Demand of passenger & freighter aircraft [3]

Single Aisle aircraft dominate the new delivery forecast, making up the vast majority of future commercial demand.

- **Volume:** Single-aisle jets represent about 79% of new deliveries, totaling approximately 34,250 aircraft through 2044.
- **Demand Breakdown:** This requirement includes 19,290 units for expansion and 14,960 for replacement.
- **Regional Dominance:** Single-aisle demand remains dominant globally, typically making up 81% to 92% of passenger aircraft needs across most major regions.



Figure 2 – Demand of new passenger single aisle aircraft [3]

In summary, the commercial fleet is projected to double over 20 years, with the single-aisle market remaining dominant.

2. Key developments and needs

This section outlines key developments impacting the industry. It first reviews Airbus' core technology fields for next-generation single-aisle aircraft. Following this, it examines specific topics, including the evolution of Carbon Fibre Reinforced Polymers (CFRP) and environmental initiatives ranging from fuel burn reduction to the HIGH5+ program, describing essential elements of the operational ecosystem.

2.1 Core technologies for next generation single aisle aircraft

Core technological fields for Airbus' Research & Technology have been outlined to show areas of focus, as discussed at the Airbus Summit in Toulouse on Mar 24-25 2025 [6, 7]:

- **Propulsion**: Focuses on energy efficiency via disruptive Ultra-High Bypass Ratio (UHBR) and Open Fan designs to cut fuel use and CO2 emissions.
- **Wing and Aerodynamics**: Optimizes efficiency through high aspect ratios that increase wingspan in flight while ensuring gate compatibility.
- **Electrification and Hybridisation**: Increases the use of hybrid-electric power and next-gen batteries for taxiing and onboard systems, targeting a 5% CO2 reduction.
- **Fuselage, Materials, and Systems**: Researches lightweight thermoset, thermoplastic, and bio-based composites to enhance performance, efficiency, and circularity.
- **System Evolution**: Develops a connected platform for shared computing and automation, serving as the aircraft "brain" to improve safety and maintenance.

2.2 Evolution of composite materials in Airbus' primary aircraft structures

Airbus has spent 50 years evolving its use of composite technology, prioritizing weight reduction, design flexibility, and lower maintenance due to fatigue and corrosion resistance. This steady progress in integrating Carbon Fibre Reinforced Polymer (CFRP) into airframe structures is illustrated by the increasing structural weight percentage over time [8, 23]

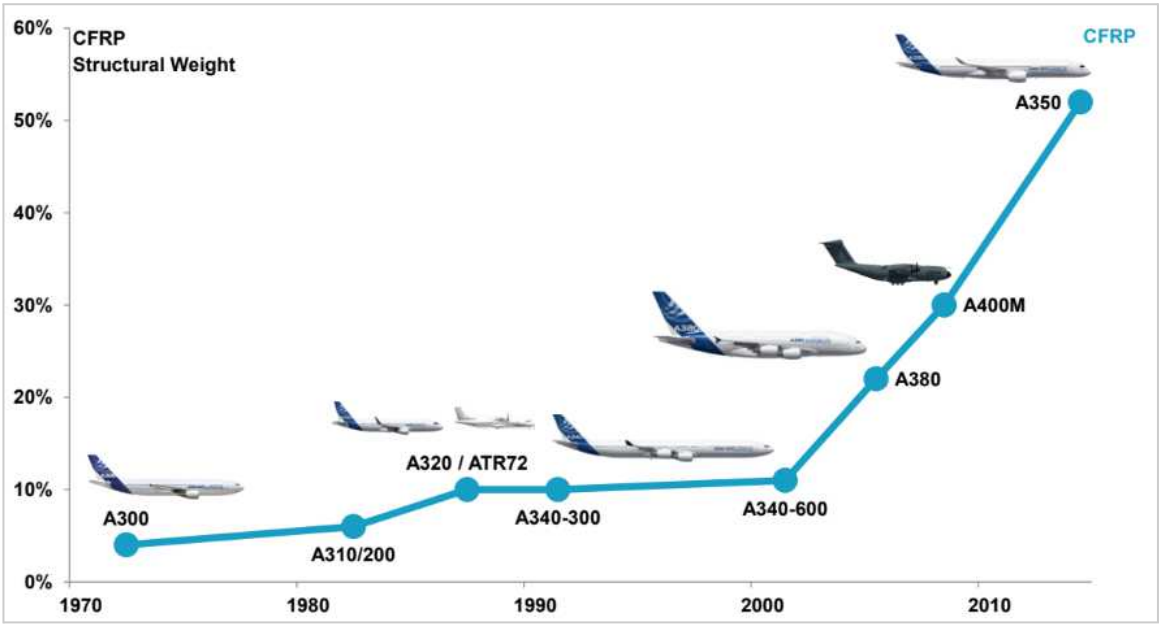


Figure 3 – Airbus' composite evolution

Since the 1970s, Airbus has expanded composite usage from small A300 components like spoilers and rudders to full A310-300 vertical tail planes in the early 1980s. Key milestones include the A320's 1988 composite horizontal tail plane, the A340-600's 2002 composite rear fuselage, and the A380's 2005 CFRP center wing box. The A400M introduced all-composite wing skins in 2009, leading to the A350XWB in 2014, which features a majority-composite airframe (53%) including fuselage panels and wing structures.
This incremental CFRP integration, continuously enriched by in-service feedback, has established the current state-of-the-art in design and manufacturing, providing a solid foundation for future developments..
CFRP is expected to be vital for future aircraft, though a specific program and material decisions are still pending.

2.3 Sustainability and environmental impact

The global framework and its breakdown into the OEM industrial system will be analyzed to highlight approach consistency.

2.3.1 Global perspective

Per the Air Transport Action Group's (ATAG) Waypoint 2050 roadmaps, the global aviation industry has committed to reach net-zero carbon emissions by 2050 across four primary sectors [10]:

- **Technology**: Rapidly deploying fuel-efficient, next-gen aircraft and propulsion, including small electric aircraft by 2030 and hydrogen-powered commercial flight by 2045.
- **Operations**: Saving fuel through modernized Air Traffic Management and optimized flight/airport efficiencies.
- **Sustainable Aviation Fuel (SAF)**: As the main decarbonization lever, production must scale to 430–500 million tonnes annually by 2050.
- **Market Measures**: Utilizing ICAO's CORSIA in the near term while accelerating high-quality carbon removals for residual emissions.

Airbus commercial aircraft technologies significantly contribute to meeting sustainability and environmental targets such as e. g.

- **Efficiency: Modern** aircraft, including the A220 and A320neo, improve fuel efficiency and CO2 emissions by up to 25% over previous models. Industry-wide, fuel burn per passenger seat mile has dropped 82% in 50 years [9].

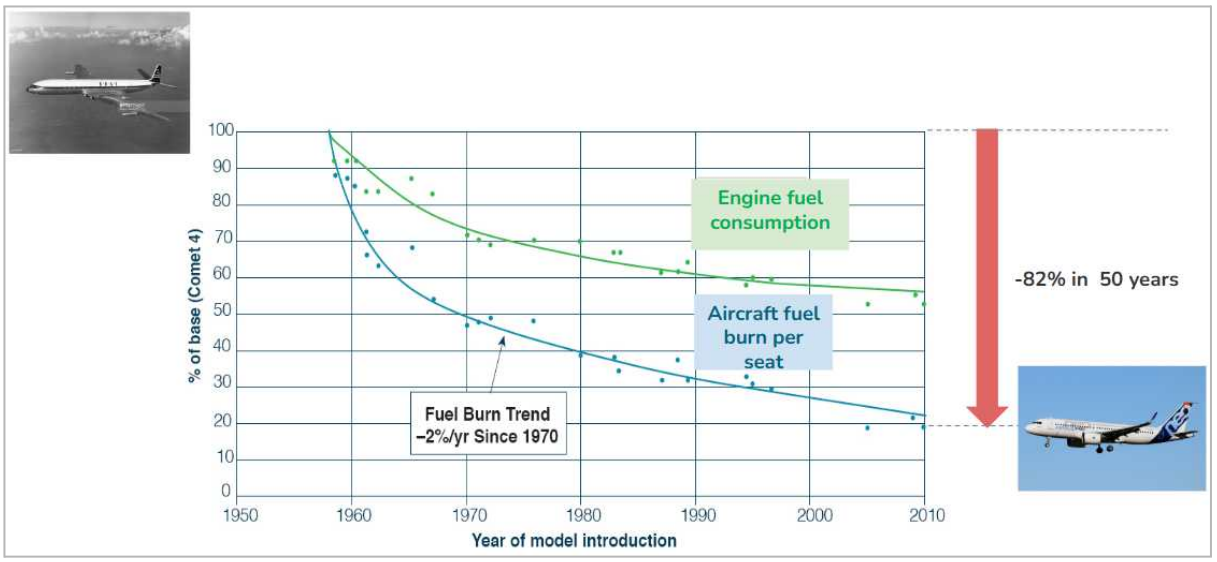


Figure 4 – History of commercial aircraft fuel burn per seat mile

- **Decarbonisation Commitments:** Airbus targets 100% SAF capability by 2030 and net-zero carbon emissions by 2050 as illustrated below.

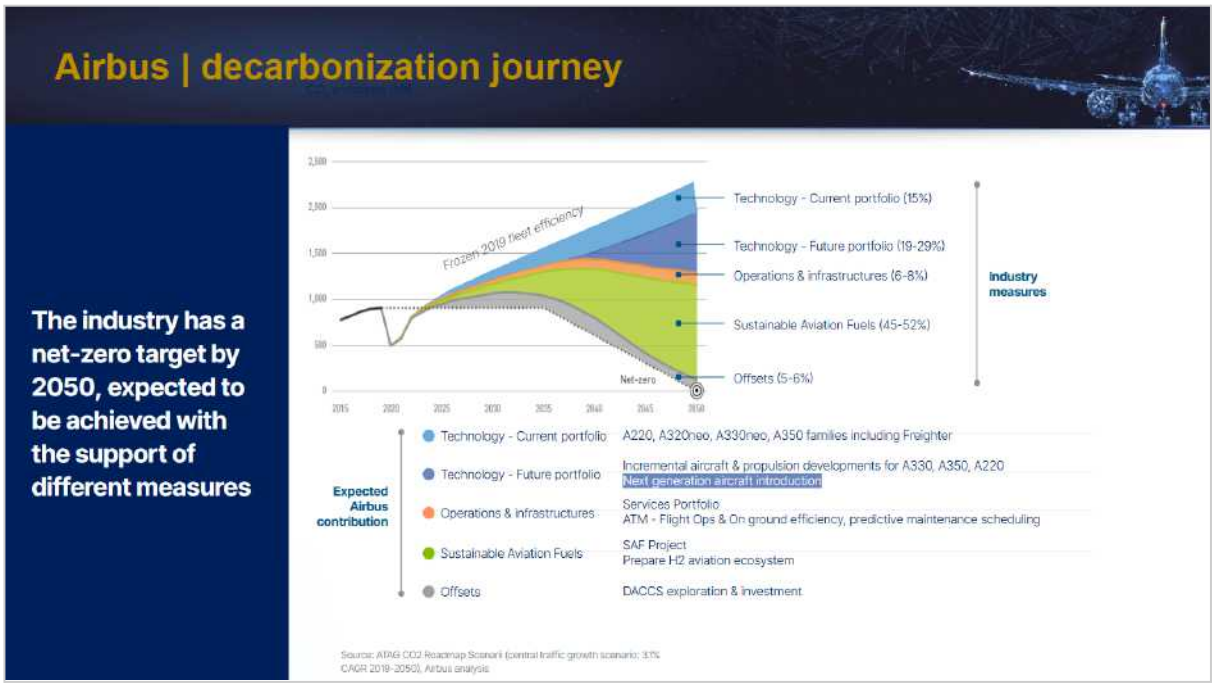


Figure 5 – Decarbonization journey [11]

In summary, Airbus committed to the global aviation industry's 2050 net-zero targets and various initiatives have been implemented impacting the current and future portfolio.

2.3.2 Environmental footprint

Targeted delivery rates of 80+ single-aisle aircraft monthly present significant industrial and sustainability challenges. While aviation environmental efforts traditionally focused on flight operations, increasing production requires addressing the industrial footprint. This includes direct factory emissions (scope 1), indirect energy use (scope 2), and upstream and downstream value chain emissions (scope 3) [13]. To reduce its environmental impact, Airbus launched the "high5+" initiative. This strategy aims to substantially decrease the global industrial footprint by 2030, using 2015 as a baseline [12].



Figure 6 – Airbus high5+ targets

Aligned with the SBTi pathway, Airbus aims to reduce absolute scope 1 and 2 emissions by 63% by 2030 through its high5+ program, which targets energy, water, Volatile Organic Compounds (VOCs), waste, and greenhouse gases. Delivering 80+ next-generation single-aisle aircraft monthly while meeting these environmental targets will be a challenge for traditional manufacturing and assembly technologies.

Composite materials for future primary aircraft structures must significantly surpass current serial production standards in key areas, including:

- Energy usage: e, g. thermosets require frozen storage and lengthy, energy-intensive autoclave curing, which impacts scope 1 emissions at higher production rates.
- Material waste: e. g. Automated Tape Laying (ATL) and Automated Fibre Placement (AFP) processes inevitably produce scrap and end-of-spool waste, as achieving 100% material utilization is impossible.

Production facilities must further develop from linear "take-make-waste" models to eco-efficient, circular systems.

This paper explores concepts and alternative materials that targets weight reduction, leading to lower operational emissions, and supporting sustainability at the same time.

Discontinuous fibre technologies reduce waste by repurposing high-value production scrap for other applications, e. g. secondary loaded parts.

The Multifunctional Fuselage Demonstrator (MFFD) explores thermoplastic composites for primary

structures, providing an energy-efficient, high-rate alternative for parts manufacture and assembly processes through welding technologies that may improve environmental footprints.

3. Discontinuous Fibre Technologies

Airbus' composite evolution shows that continuous unidirectional (UD) CFRP tape enabled composites to reach 53% of the A350XWB's structural weight.
Discontinuous Fibre Technologies (DFT) complement high-performance UD composites by offering a bridge to isotropic metallic or polymer materials. Out-of-autoclave processes, such as compression or injection moulding, achieve cycle times in minutes, a method already established in the automotive sector for high rate manufacturing.
DFT utilizes discontinuous fibres usually in the shape of chips or granules allowing the material to flow to a certain extent during processing. Standard semi-finished products include Sheet Moulding Compound (SMC) and Bulk Moulding Compound (BMC).

3.1 DFT applications for Airbus commercial aircraft

DFT offers a high-rate production alternative for next-generation aircraft, particularly for small, complex parts currently made from aluminium or titanium. Replacing aluminium with composites eliminates galvanic corrosion risks in a CFRP environment, while substituting titanium can reduce costs and supply chain risks.
Use cases include secondary structures like window frames, fittings, and cleats. Standardizing these parts improves the business case by building families.
A bottom-up approach during early design is helpful to maximize aircraft-level benefits and establish common certification and qualification standards.

3.2 DFT contribution to sustainability

The amount of material procured is always higher than in final components. The buy-to-fly (BtF) ratio quantifies this difference, representing the ratio of procured material to that in the finished part. Since BtF is always less than 1, maximizing this ratio is crucial for the business case.
Modern composite manufacturing inevitably produces "waste," such as end-of-spool material from AFP processes. This high-quality scrap can be repurposed into different forms (SMC, BMC, etc.) for secondary structures via press forming or injection moulding. Reusing this material increases the effective buy-to-fly ratio and supports the high5+ target of reducing waste and raw material consumption by 20%.
For sure, processing must account for distinct material characteristics, as e. g. thermoset and thermoplastic systems require different solutions.
Subsequent chapters use the "r-" prefix (e.g., r-DFT, r-SMC, r-BMC) to denote re-used material.

3.3 DFT applications

The following chapters outline strategies and examples for expanding DFT use in future applications.

3.3.1 Re-used Sheet Moulding Compound (r-SMC) for commercial aircraft

In this paragraph, the focus is on thermoset based SMC. In general, this technology allows the near-net-shape manufacturing of complex CFRP parts in an efficient one-shot compression moulding process. Short cycle times and the limited required post-processing effort, e. g. for trimming, makes SMC an important technology brick for a future high rate manufacturing of CRFP parts.
The SMC technology has a long history in the electrical industry e.g. for cabinets and in the

automotive industry. As a low-cost manufacturing technology the market is dominated by glass-fibre reinforced materials [14]. However, in recent years many material suppliers have developed high performance materials based on carbon fibres and epoxy resin systems making SMC technology appropriate for secondary loaded structural applications in commercial aircrafts.

Re-use SMC (r-SMC) approach from end-of-spool material

As an alternative to commercially available off-the-shelf SMC material, a proposal is presented for the re-use of CFRP waste in the form of an SMC style semi-finished product which is called r-SMC.

The manufacture of composite structures - specifically large structures like e. g. A350XWB fuselage or wing parts - results in measurable amounts of composite waste in the plants which will increase with, on the one side, higher production rates in the current portfolio, and, on the other side, even more with CFRP in entirely new programs such as a next generation aircraft. For better understanding of the main focus, different types of waste as shown in the picture below.



Figure 7 – Waste types in a typical automated manufacturing process for a composite part [15]

On the one hand, cured CFRP waste usually results from mechanical post-processing, like trimming and cut-outs or, in the worst case, scrapped parts which are difficult to be re-used without intensive chemical processing. On the other hand, uncured prepreg waste may come from cut-offs or scrap plies during the lay-up and is usually disorderly disposed of. This type of waste is not well suited for further prepreg re-use. However, in Automated Fibre Placement (AFP) and Automated Tape Laying (ATL) processes due to process-related reasons, spools are discharged with some prepreg tape material left on them. This so-called end-of-spool material is a particularly valuable form of CFRP waste due to the fact that it is still on a spool in pristine condition and, usually, well within its worklife.

Let's assume only 2% of procured prepreg material may end up as end-of-spool waste. At first, this single figure doesn't sound like a very big amount. But the overall amount is significant if large parts are considered such as big 32m long A350 wing covers or higher rate single aisle vertical tail plane shells.

The re-use SMC technology aims at utilizing this high quality waste by transforming the end-of-spool prepreg to an SMC type, defined semi-finished product for the near-net shape manufacturing of aircraft composite parts. This approach contributes to significantly reducing

CFRP waste in the plant to meet high5+ targets and, therefore, improving the overall buy-to-fly ratio of prepregs procured. The r-SMC technology approach can be applied to various materials and formats and may improve the business case because available high quality “waste” is used instead of buying virgin SMC material.

r-SMC production

In this paragraph, the production of r-SMC is described in more detail step by step along the process chain as shown in the picture below.

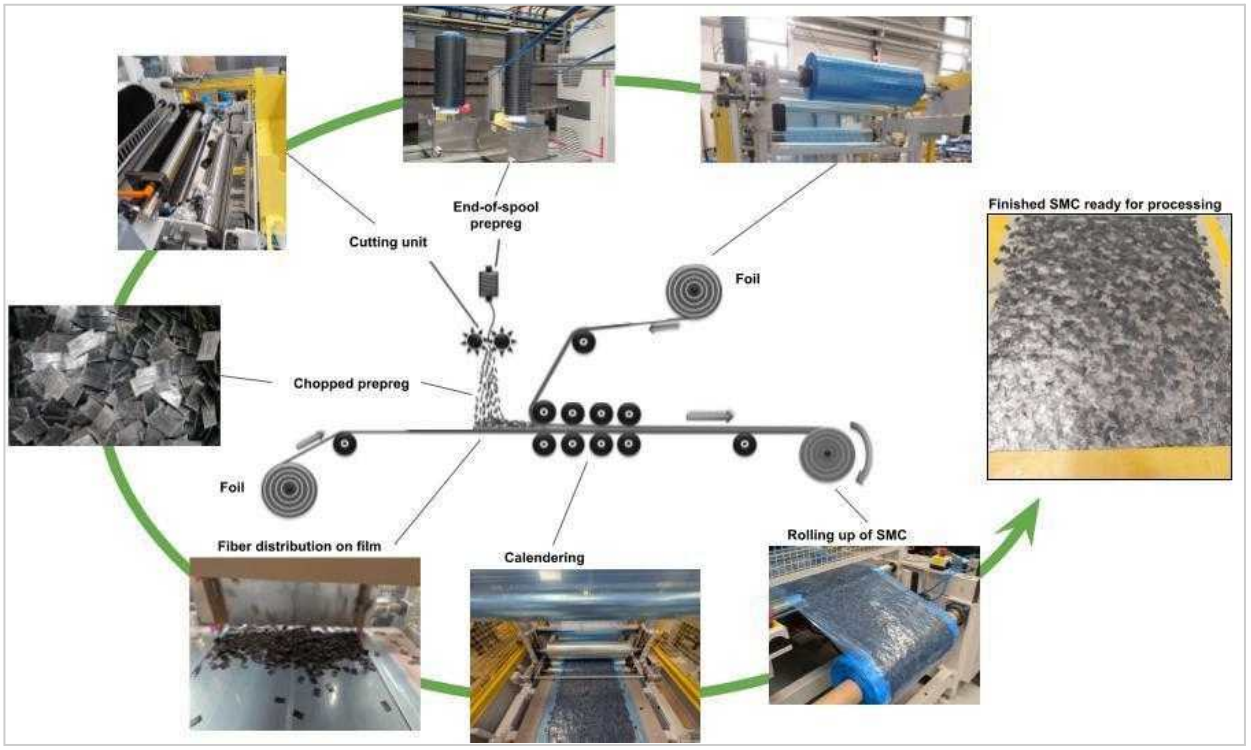


Figure 8 –Process chain for the production of re-use SMC

The input is high-quality end-of-spool slit tape prepreg which is spliced and rewinded to enable a provision of enough tape material in an adequate length of several hundreds of meters to ensure continuous r-SMC production.

The slit tape is inserted into a cutting unit which cuts it into chips with a defined chip length. The chips are randomly distributed on a carrier foil. Depending on the demand, a variation of the chip length as well as of the chip width is possible. A second foil is placed on top of the material, so that the SMC semi finished material is enfolded in between. Afterwards, two rolls preconsolidate the material. The tackiness of the prepreg material makes easy handling possible. This r-SMC sheet material is produced in a width of 500mm and rolled up as endless material, ready for further processing like preform cutting and part production via compression moulding.

Challenges

State-of-the-art, commercially available SMC materials are produced out of dry fibres randomly distributed on a resin film and subsequently impregnated by calendaring rolls. The cutting of prepregs is more challenging compared to the cutting for dry fibres only. Therefore, a thorough concept assessment has been performed to determine the most promising cutting concept for such materials. Cutting of prepreg implicates that resin residues contaminate the knives/ blades which has an impact on the cutting process continuity. Furthermore, processing temperature

strongly affects the service life of the knives.
For the r-SMC, there are several parameters which should be kept within strictly defined boundary conditions to ensure a constant and predictable material performance. Inline monitoring of a random fibre orientation is realized through photogrammetry. This ensures to achieve an in-plane quasiisotropic material behavior. The areal weight and a constant thickness of the SMC sheet can be controlled by the cutting speed and the conveyor speed of the carrier foil. Furthermore several measures were implemented to optimize the areal weight.
As epoxy based thermoset prepreg material has a defined shelf life at room temperature, the “material out” time is tracked and recorded for every incoming material to ensure processing within defined requirements. This procedure is well known and has been adapted from the series production of CFRP parts for commercial aircrafts.

Outlook
Increasing production rates of the current commercial aircraft portfolio and new CFRP applications, e. g. in a next generation aircraft will result in an increase of available high quality end-of-spool material “waste” which may be used for further secondary parts production.
As proposed, already qualified materials are used for r-SMC and r-BMC production which are transferred into different shapes and forms. Therefore, time-consuming and expensive qualification efforts are significantly reduced compared to new, unqualified material.
To keep it easy and simple, the most efficient way to operate such a machine is to install it near the production area where end-of-spool material will be available. This lean approach drastically reduces the efforts for material transport and logistics and simplifies the administrative processes for material handling and tracking within the plant.
Besides the processing of thermoset material the machine is capable of processing thermoplastic slit tape, too. Additional thermoplastic DFT routes have been successfully explored. In addition it is worth mentioning that the machine can be used for producing both r-SMC as well as r-BMC.
This approach has been developed and shared in the Airbus group resulting in other business units exploring further use cases in parallel as discussed below.

3.3.2 Helicopter use cases in special equipment

The helicopter industry, particularly in the domain of specialized equipment, presents unique challenges and opportunities for the implementation of sustainable material practices. Discontinuous Fibre Technology (DFT) derived from recycled materials (r-DFT) is considered as a high-performance, cost-effective, and environmentally conscious solution for structural components. A special use case is the usage of r-DFT in external equipment such as hoists (similar to chapter 3.1 for Airbus commercial aircraft) .
The bearing hole support is a safety component for external hoists, given the significant dynamic loads and environmental exposure they face. Maintaining stringent material properties is essential for both operational longevity and safety, particularly to support these bearing holes. The conventional design utilized a metallic structure with bolted local reinforcement.



Figure 8 – External Helicopter Hoist with attachment boom

The utilization of r-DFT was determined as the optimal choice based on its ability to satisfy key performance criteria, including suitability for complex geometries, precise thermal compatibility, and the effective elimination of corrosion pathways.
The reliance on virgin material is eliminated, thereby enhancing the sustainability contribution. This benefit is maintained even with lower helicopter production rates, as the salvaged material is sourced from alternative aircraft programs.
A high-bearing-load-capable, thick-walled component (t > 20 mm) with a highly complex geometry is pre-manufactured. This component is intended for subsequent integration into the primary structural load-carrying element in a second process step.
The solution has undergone successful testing and certification, demonstrating acceptable performance across the entire defined test campaign. This validated package is now available to customers. The design and stress teams are responsible for the solution's specification and acceptance, respectively.
This approach not only supports the circular economy but also delivers a technical advantage through the elimination of corrosion risks while maintaining identical thermal properties for structural integrity.
Future work will focus on expanding the application of r-DFT in other high-load, non-primary structure applications for all local reinforcements in aerospace business.

3.4 DFT wrap up

Discontinuous Fibre Technologies bridge the gap between high performance unidirectional, continuous CFRP structures and polymer or metallic isotropic parts, usually smaller sized and secondary loaded.
Key benefits include reduced galvanic corrosion in CFRP environments and support for high5+ targets by repurposing manufacturing waste. Reusing high-quality scrap for SMC/BMC materials increases the buy-to-fly ratio.
This initiative is a collaborative effort across Airbus Commercial and Helicopters business units.

4. Multifunctional Fuselage Demonstrator (MFFD)

The Multifunctional Fuselage Demonstrator (MFFD) is the world’s largest thermoplastic composite research fuselage section, measuring 8 meters long and 4 meters in diameter. Initiated under the European CleanSky 2 framework, it aims to develop technologies for weight reduction, economic competitiveness, and improved sustainability through reduced emissions and recycling potential.

Utilizing thermoplastic composites similar to Toray CETEX® TC 1255 LM/PAEK, the MFFD offers advantages such as room-temperature storage and the elimination of clean room requirements for processing. A key feature is the use of welding technologies for assembly, which reduces weight by avoiding rivets and enables cleaner shop floor processes and new assembly sequencing.
The program sought to prove if large-scale thermoplastic structures could be manufactured at a 1:1 scale. Consequently, a typical commercial fuselage section was chosen as an R&T platform to demonstrate competing technologies in a realistic environment, maximizing learning for partners involved.
The Airbus-led program integrated structure, cabin, and systems from the early design phase. It focused on a two-half-shell concept (upper and lower) to support parallel assembly and production rates of 70-100 aircraft per month. This design also incorporates pre-equipped modules.

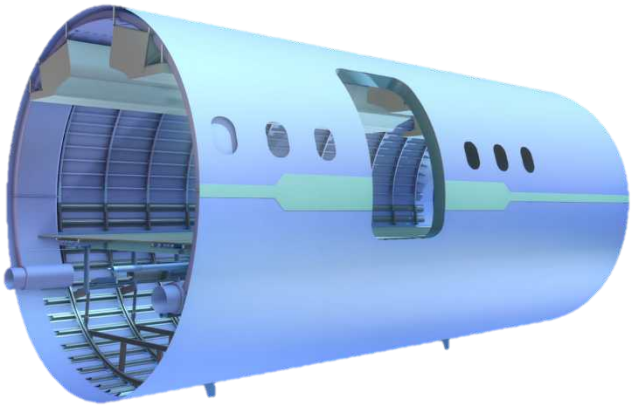


Figure 9 – Design of the Multifunctional Fuselage Demonstrator/ MFFD

4.1 MFFD key achievements

Key outcomes are highlighted through partner contributions, showcasing the consortium's collective effort in driving the MFFD program to success. [16]

4.1.1 Elementary Parts and Sub-Structures

Aernnova concentrated on maturing structural components:

- Cargo Door Surrounding Structure: Tooling design, manufacturing, and welding.
- Upper Shell Stringers: Developed 8m length Z cross-section stringers using continuous compression molding.
- Tapered Butt Straps: Manufactured flat, tapered straps essential for joining the semi-fuselage shells.
- Co-consolidated Fuselage Panel: Completed the full process from material characterization and sizing to structural testing, providing evidence that in-situ co-consolidation meets static strength requirements.

Airbus Aerostructures and Premium AEROTEC collaborated to create a robust thermoplastic integral frame manufacturing concept, prioritizing shorter cycles and reduced assembly through integral design. Produced via Automated Fibre Placement and press forming with heated steel molds, 28 frames were delivered to be integrated in the MFFD upper skin.



Figure 10 – Integral frames ready for assembly

4.1.2 Upper MFFD Module

The MFFD upper shell featured advanced manufacturing at DLR-ZLP in Augsburg, where 141 kg of UD tape was placed via AFP with in-situ consolidation for the skin. Quality was monitored by an inline Tape Placement Sensor. Assembly involved automated ultrasonic spot and robot-based continuous welding for 44 stringers. Additionally, 730 resistance welds integrated frames using a custom weld bridge, while a robot-cobot system precisely welded 300 cleats [17,18].



Figure 11 – MFFD upper shell section, upside down as manufactured

The single-piece upper MFFD module, comprising the skin, stringers, and integral frames, was successfully delivered to the Fraunhofer major component assembly facility in Stade.

4.1.3 Lower MFFD Module

The STUNNING consortium (GKN Fokker, NLR, TUD, SAMXL, Diehl Aviation) built the MFFD Lower Shell Module. NLR manufactured the skin via laser AFP and autoclave consolidation, while Xelis supplied Omega stringers. GKN Fokker handled key component production and conduction welding for sub-assemblies and floor grid connections.

Final assembly occurred at SAMXL. SAMXL and TUD collaborated to ultrasonically spot-weld short fibre injected clips and frame sub-assemblies to the skin-stringer assembly. Systems and floor beam integration has been successfully completed as well. The completed, pre-equipped MFFD lower module is shown below.



Figure 12 – MFFD lower shell module as delivered, pre-equipped with systems

The MFFD lower shell, comprising structural components and system dummies, was delivered as a single module for major component assembly.

4.1.4 Major Component Assembly (MCA)

The final MFFD upper and lower fuselage module joining occurred at Fraunhofer in Stade, Germany. This automated assembly, using hexapods and laser trackers, evaluated two longitudinal joint designs and welding methods [20, 21]:

- Butt Strap Joint: Fraunhofer used CO2 laser welding for the primary seam, adding matrix material via a gap-filling end effector.
- Overlap Joint: WELDER partners proved a high-productivity ultrasonic welding method.

To withstand high welding loads, a rigid tooling system with internal positioners was utilized. Following the shell joining process, resistance welding was employed to link the upper and lower frames via frame couplings.



Figure 13 – MFFD Major Component Assembly facility at Fraunhofer

MFFD was successfully delivered to ZAL in Hamburg for final integration and validation to conclude the program.

4.1.5 Cargo door system

Saab managed the Cargo Door system, investigating metallic and composite doors using flexible assembly jigs and additive thermoplastic tooling. Key technical achievements included a CFRP cargo door as well as an electromechanical actuation system for lifting, latching, and locking [16]. This system was subsequently installed in the MFFD, as illustrated below.



Figure 14 – Cargo door installed in MFFD

4.1.6 MFFD successful completion

A roll-out event was held on Jul 3rd 2024 at Hamburg's ZAL Center of Applied Aeronautical Research to present the first and largest thermoplastic composite fuselage demonstrator for commercial aircraft. Key stakeholders and funding authorities celebrated the successful delivery of the MFFD, highlighting its importance for the European ecosystem within the CleanSky2 framework.

The final MFFD configuration, including an access platform for further R&T activities like cabin installation, is shown below.



Figure 15 – MFFD, final set-up @ ZAL, Hamburg, Germany

4.1.7 MFFD wrap-up

The European MFFD consortium matured over 40 technology bricks, delivering a 1:1 scale fuselage section. This achievement provided partners with a deep understanding of thermoplastic design, manufacturing, and joining techniques, effectively bridging the technical expertise gap for large-scale thermoplastic structures.

The Airbus web story "Fantastic Thermoplastics" [22] details the program's motivation and the CleanSky2 consortium's role. The project's success was capped by winning the 2026 JEC Innovation Award for "Aerospace Parts," recognizing the consortium's outstanding achievement.



Figure 16 – CleanSky2 “Multifunctional Fuselage Demonstrator/ MFFD”

Acknowledgement

MFFD has received funding from the Clean Sky 2 Joint Undertaking (JU) under grant agreement No 945583. The JU receives support from the European Union’s Horizon 2020 research and innovation programme and the Clean Sky 2 JU members other than the Union.

5. Scope beyond

A comprehensive overview about Thermoplastics State-of-the-Art and development axis including overmoulding, stamping and welding can be found in [23]. The following section highlights two dedicated examples with focus on re-use without fibre degradation and further developments in in-situ consolidation.

5.1 Recycling A380 secondary structure for A320 NEO

Airbus, Daher, Toray, and Tarmac Aerosave are collaborating on a circular strategy to reuse thermoplastic composites. High-performance Cetex TC1100 pylon covers from retired A380s are being repurposed into new A320 structural components. By maintaining continuous fibres and avoiding degradation from grinding, this project advances recycling technology and extends material lifecycles. The process involves removing paint and cutting new geometries from existing covers to provide a "2nd life" for aerospace materials [24].

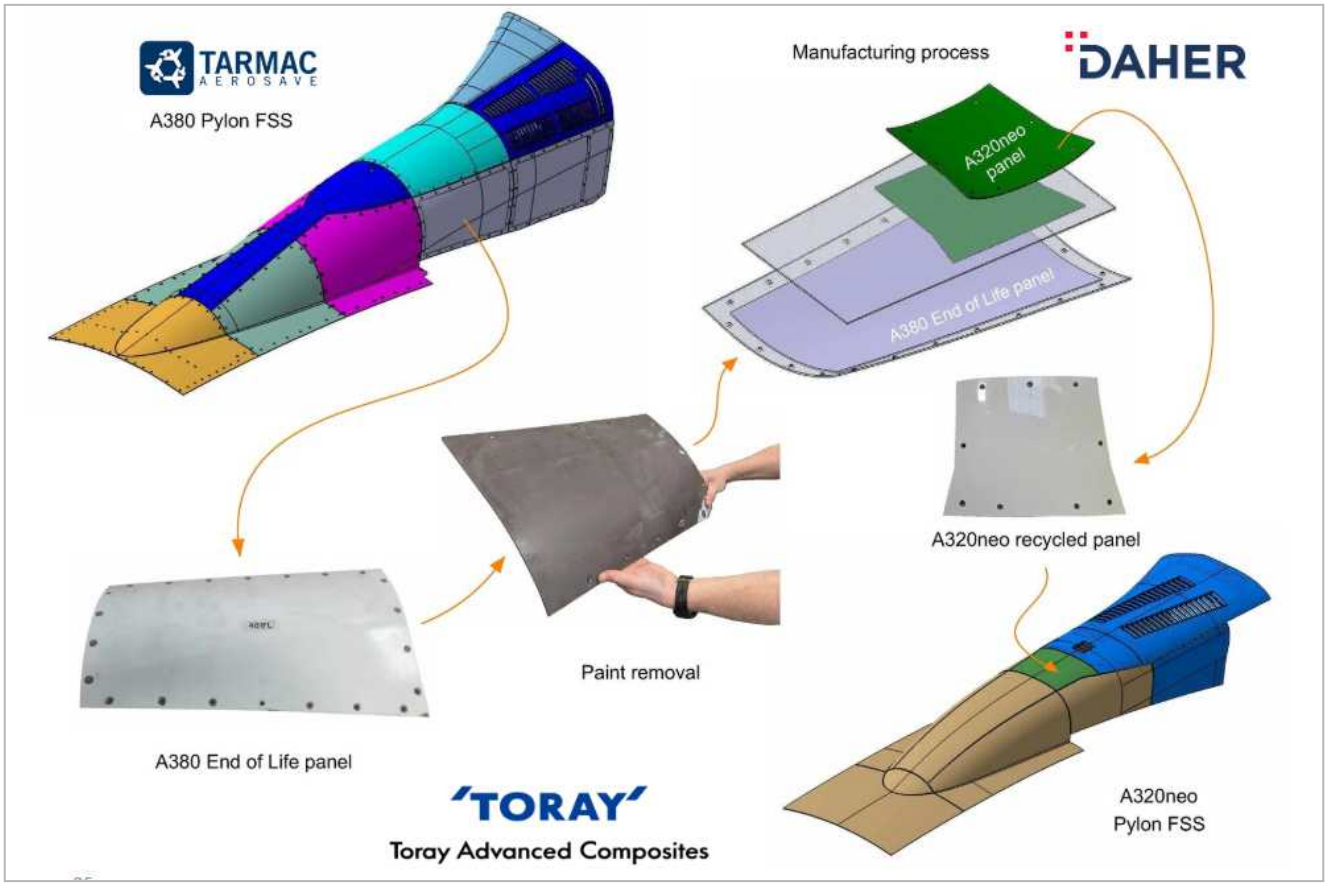


Figure 17 – Recycling A380 secondary structure for A320 NEO

The project's exceptional quality was recognized with the 2026 JEC Innovation Award in the "Circularity & Recycling" category [25].

5.2 In-situ consolidation

The CS2 MFFD program explored in-situ consolidation, a concept further matured by the HERWINGT consortium in CleanAviation. This initiative focuses on ultra-high-performance wings for next-generation Hybrid-Electric Regional aircraft. GKN Aerospace developed a lower wing skin using Laser Automated Fibre Placement with Toray TC-1225 LM-PAEK thermoplastic at GKN Fokker in Hoogeveen. This technology facilitates weight savings and part integration for moderately complex shapes and closed contours, though lay-up rates remain an area for potential improvement [25].

The “Integrated stiffened In-situ consolidated skin” has been presented to the public at the Innovation planet area during the JEC Composites Show 2026 [26].

This demonstrates how joint consortium platforms catalyze new applications. Specifically, in-situ consolidation concepts from the CleanSky2 fuselage skin inspired wing cover developments in CleanAviation.

6. Conclusions

Airbus is dedicated to *pioneering sustainable aerospace for a safe and united world*. Single-aisle models currently comprise over 60% of the 35,550-strong global fleet. With traffic growing at 3.6%, the fleet is expected to nearly double by 2044, requiring 43,420 new deliveries—79% of which will be single-aisle jets. To meet this demand sustainably, Airbus is developing next-generation technologies, e. g. in propulsion, aerodynamics, and electrification as well as investigating alternative material concepts and industrial systems for parts production and assembly. These innovations align with the industry's 2050 net-zero goal and Airbus' "high5+" initiative, which targets a 63% industrial CO2 reduction by 2030.

Discontinuous Fibre Technologies (DFT) bridge the gap between high-strength continuous fibres and isotropic metallic or polymer materials. Using out-of-autoclave processes like compression molding, DFT enables high-rate production of complex secondary loaded parts offering a cost-effective, corrosion-resistant alternative to metals. A major sustainability benefit is the repurposing of high-quality uncured "waste"—specifically end-of-spool material from ATL and AFP—into semi-finished products like r-SMC and r-BMC. This improves the buy-to-fly ratio and supports "high5+" waste reduction targets. The r-SMC process transforms prepreg tape into randomly distributed chips to create quasi-isotropic sheets for near-net-shape manufacturing. By using qualified materials, this approach reduces qualification costs and has the potential to be deployed to other composite plants.

The **Multifunctional Fuselage Demonstrator (MFFD)** is the world's largest thermoplastic composite research fuselage, developed under the European CleanSky2 framework to enhance aircraft weight, competitiveness, and sustainability. Utilizing LM-PAEK composites and advanced welding, the project eliminated traditional riveting for cleaner, parallel sub-assembly and joining of upper and lower modules. This approach supports high production rates of 70–100 aircraft monthly. Achievements include maturing 40 technology bricks, such as integral frames and continuous stringers, alongside innovative processes like in-situ consolidation and automated joining via thermoplastic welding technology.

Additional composite initiatives emphasize circularity and advanced thermoplastic processing. One effort repurposed retired A380 pylon covers into A320 structural components, preserving fibre integrity. Furthermore, an in-situ consolidation for ultra-high-performance wing covers on future Hybrid-Electric Regional aircraft has been developed in CleanAviation.

Regardless of the architecture or the specific technologies and material systems chosen in the future, this paper explores some composite technology opportunities for the next generation of commercial aircraft. It is anticipated that forthcoming platforms will necessitate widespread composite integration within both primary and secondary structures. Consequently, the development of industrial systems and materials capable of supporting high-rate production will be essential.

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