

# **Automotive and Aerospace Technology Smart Composite Materials which use Piezoelectric Discs and Fiber Bragg Gratings (FBGs)**

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## **Abstract**

A vehicle's weight plays a vital role in its fuel efficiency. For instance, reducing the gross vehicle weight by ten percent can enhance an automobile's fuel economy by approximately eight percent. This correlation is a key factor behind the growing integration of carbon fiber into structural and non-structural components of commercial vehicles. With an anticipated compound annual growth rate (CAGR) of 11% from 2014 to 2019, the adoption of carbon fiber has been increasing. Its application not only improves fuel efficiency for petroleum-powered vehicles but also boosts the driving range of electric vehicles. Another noteworthy trend in the automotive industry is the rising adoption of monocoque structures. A monocoque is a design approach used in vehicles, aircraft, seacraft, and spacecraft in which the frame and exterior skin are unified into a single structure. This innovative construction significantly reduces weight by eliminating the need for separate frame and skin components. The industry is leaning toward the use of carbon fiber monocoques due to their lightweight properties, despite their major

drawback: high costs. These costs primarily stem from both the initial manufacturing process and subsequent repairs. The introduction of advanced technology aimed at minimizing these costs could accelerate the adoption of carbon fiber monocoques across various sectors. A promising approach involves embedding guided wave-based systems for composite cure monitoring into monocoques—using piezoelectric discs and fiber Bragg gratings (FBGs). The initiative aims to implement this cutting-edge solution into Formula One car monocoques first, with a broader vision to eventually transition the technology into commercial vehicles. By addressing the industry's current need to lower long-term costs associated with carbon fiber, this innovation has the potential to gain a competitive edge before similar solutions emerge. The proposed Modular CFRP Sensing System (MCSS) satisfies dual objectives: reducing manufacturing costs while simplifying repair processes for carbon fiber monocoques. This system supports real-time cure monitoring during production and continuous in-situ monitoring throughout the lifespan of the monocoque. In the event of damage, quick identification is made possible, facilitating efficient repairs using modular replacement components. This combination of ease of damage detection and reduced maintenance costs addresses key challenges linked to carbon fiber applications, making them more economically viable for widespread use. [1], [2], [3].

This technology holds significant potential for the aeronautical and automotive industries. Carbon fiber reinforced polymer composites, like the one in question, are already widely deployed in planes and cars, with both markets experiencing consistent year-over-year growth. These industries are perpetually seeking ways to enhance their operations, emphasizing innovations that not only make vehicles safer but also increase their reliability. With this advanced technology implemented in cars and aircraft, users would gain immediate insights into which components have sustained damage or require repairs. This capability could drastically reduce maintenance costs—a factor of critical importance, particularly in the cost-sensitive airline industry. The primary strategy for introducing this innovation to the market involves horizontally integrating it within the carbon fiber sector. By positioning it as an essential feature in high-performance carbon fiber components, the technology could become a standard in the industry. As a startup, this approach appears to be the most practical, given the existing demand for large-scale manufacturing of such components. By maintaining a focus solely on covering basic experimental costs, we can offload the more capital-intensive manufacturing processes to established companies. This model allows for seamless integration

into the market while minimizing initial investment costs, paving the way for this transformative technology to become a staple in its target sector. [1-50]

**Keywords:** Automotive Technology, Aerospace Technology, Automobile, Plane, Mechanical Engineering, Composite Material, Material Science, Modular CFRP Sensing System (MCSS), Carbon Fiber Reinforced Polymer (CFRP), Energy Transfer, Thermodynamics, Piezoelectric Discs, Fiber Bragg Gratings (FBGs), Engine Control Unit (ECU)

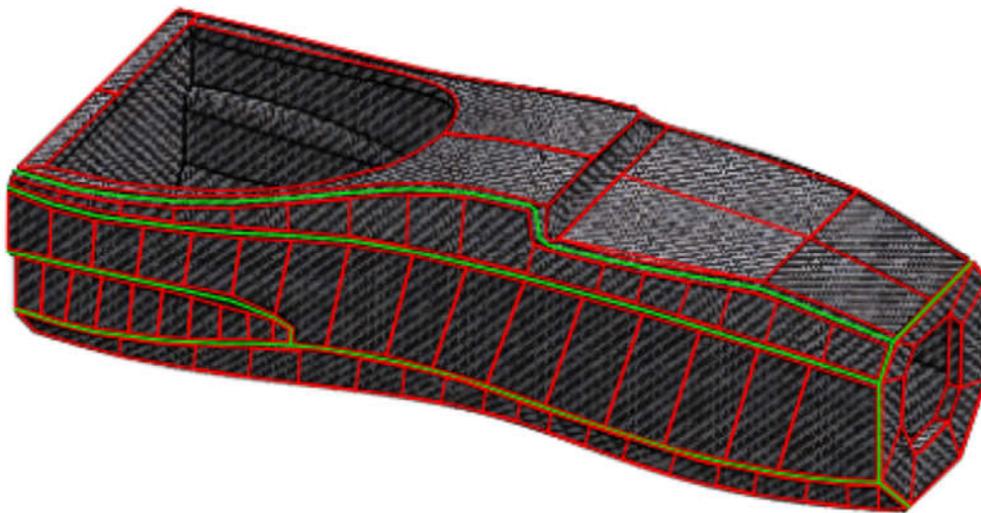
## **Introduction**

Carbon Fiber Reinforced Polymer (CFRP) represents a significant material advancement, and the proposed innovative spinoff seeks to integrate a guided wave-based system for the cure monitoring of composites within Formula One car monocoques. This system leverages piezoelectric discs and fiber Bragg gratings (FBGs), ultimately aiming to adapt this technology for broader applications in commercial vehicles. By addressing the present need to lower long-term costs associated with carbon fiber, this technology has the potential to penetrate the market ahead of substantial competition. The Modular CFRP Sensing System (MCSS) offers a dual benefit of reducing both manufacturing and maintenance expenses for carbon fiber monocoques. It achieves this by enabling efficient cure monitoring during initial production as well as real-time in-situ condition monitoring across the monocoque's lifecycle. In cases of damage, repairs can be seamlessly executed using existing techniques with modular components, providing a rapid and cost-effective solution. By streamlining damage detection and repair processes, this approach addresses two primary factors driving high carbon fiber expenses. This advanced technology holds promising implications for the aeronautical and automotive industries, both of which already employ carbon fiber reinforced polymer composites and are experiencing consistent growth. These sectors continuously prioritize innovations that enhance safety and reliability while improving operational efficiency. With MCSS implementation, planes and cars could instantly identify damaged or repair-needy components, substantially reducing maintenance costs—a particularly valued benefit for industries like aviation. To ensure successful market introduction, the primary strategy revolves around horizontal integration within the carbon fiber industry. Positioning this system as an essential component for high-precision carbon fiber parts would establish its necessity in advanced manufacturing processes. As a startup, prioritizing this strategy allows for

streamlined entry into the market. By focusing on covering initial experimental costs and partnering with established manufacturers to shoulder large-scale production, the cost burden is minimized while ensuring effective market penetration. The result would be a transformative shift in carbon fiber technology adoption, making high-performance solutions more accessible and cost-efficient across multiple industries. [1-50]

### **Material, Method, Discussion**

Figure 1 illustrates the overall functionality of the technology. During the manufacturing process, optical sensing fibers are integrated into the composite layers of a carbon monocoque in a specific pattern. These fibers connect to a central communications bus, with the inputs and outputs of the sensing elements visible in the figure as a red box and green lines, respectively. The communications bus can subsequently be connected to an engine control unit (ECU) or a standard computer. This setup enables real-time monitoring of the curing process during factory production. Once the vehicle is operational, the condition of the monocoque can be assessed by connecting the ECU or a maintenance computer. The modular design of the sensing units allows individual sections of the monocoque to be replaced without compromising the system's sensing capabilities. Currently, no other technology offers embedded curing and life-cycle monitoring specifically for carbon fiber monocoques, let alone integrates a modular system that enhances adaptability and functionality. [1-50]



**Figure 1:** Formula One-inspired carbon fiber reinforced polymer monocoque featuring MCSS technology.

The implementation of technology in carbon fiber monocoques has the potential to transform this market segment entirely. It would enable real-time life-cycle monitoring of vehicles, reducing the need for unnecessary repairs. At present, the testing of curing processes and life-cycle assessments requires dedicated equipment and highly trained technicians. This new approach would render both obsolete. A practical example of the challenges with existing carbon fiber monocoques is evident in the case of the Lamborghini Aventador. When damaged, the vehicle must first be transported to a specialized facility. There, a technician uses ultrasound to analyze the monocoque, and the collected data is sent to Italy for further analysis. Finally, experts are dispatched to perform the repair. Despite this being a costly and complex process, it remains more economical than replacing the monocoque entirely. However, for vehicles with a lower initial cost, such repairs would often be financially unfeasible. By integrating embedded sensors within the car, several steps in this intricate process could be eliminated, significantly reducing maintenance costs while streamlining vehicle care. [4]

## **Conclusion**

The target market for this technology includes Formula One (F1) and, eventually, commercial vehicles. Both sectors stand to benefit significantly from its implementation. Formula One, known for being on the cutting edge of automotive innovation, is the world's most-watched annual sporting series and represents the pinnacle of performance road racing. As reported by Statista, Formula One continues to achieve record-breaking revenue figures, surpassing two billion dollars in 2019 with an estimated total turnover exceeding four billion. Additionally, the sport supports a workforce of approximately 50,000 people across more than 30 countries. [5], [6]

The Formula One industry is currently grappling with several challenges, notably the effects of the Coronavirus pandemic, which has heavily disrupted the race calendar. To address this, a potential solution under development involves teams competing in their home countries on newly constructed circuits to minimize travel requirements. Another significant issue revolves around the accessibility of the sport for teams. Formula One is working on new regulations aimed at making participation more affordable, including the consideration of shared components like monocoques. This approach could help reduce costs while maintaining competitive fairness. On top of these measures, Formula One remains committed to enhancing

safety standards within the industry. Employing Carbon Fiber Reinforced Polymer Monocoques equipped with in-situ monitoring capabilities could not only improve safety but also result in substantial cost efficiency. The idea of sharing monocoques among teams stems from the dual objectives of cost reduction and safety enhancement. Currently, the production of monocoques costs at least \$1.2 million per season, posing a significant financial hurdle for new teams seeking entry into the sport. [7],[8]

There are currently ten competitive teams in Formula 1, attracting approximately 471 million viewers as of 2019. These teams are under constant pressure to outpace their rivals by consistently enhancing their cars, driving continuous advancements in technology. Notably, innovations from Formula 1 often find their way into commercial markets. This trend became particularly evident in 2014 when F1 regulations reduced engine sizes from 2.4 liters to 1.6 liters, a capacity comparable to that of a Ford Fiesta. While decreasing engine size typically leads to reduced power, this change spurred the development of innovative new systems. [9],[10]

The current state of technology presents a significant opportunity to penetrate a relatively undeveloped market brimming with potential for expansion. Broadly, this market can be categorized into three primary sectors: aerospace, automotive, and nautical industries. Each of these sectors already utilizes various types of carbon fiber-reinforced polymer (CFRP) monocoque designs, all of which share a common demand for integrated sensing technologies. This innovation has the potential to transform both the aerospace and automotive industries. Carbon fiber-reinforced polymer composites are already widely used in aircraft and vehicles, both of which are experiencing steady and consistent market growth. These industries are continuously seeking advancements that not only enhance safety but also improve overall reliability. With the integration of this technology, vehicles on the road and planes in the sky would provide real-time insights into damaged or repair-needing components, enabling immediate identification of maintenance requirements. This capability could significantly reduce overall maintenance expenditures, a benefit highly valued by the airline industry. The proposed strategy for introducing this technology involves horizontal integration within the carbon fiber sector, aiming to make it an indispensable feature of high-performance carbon fiber components. As a startup, this approach aligns well with current market dynamics, which demand large-scale production of these advanced components. By focusing primarily on covering the initial costs associated with experimentation while outsourcing large-scale manufacturing to established companies, the business can effectively minimize overhead costs.

This strategy allows for seamless horizontal integration into the industry, ensuring cost efficiency while embedding the innovative technology within key market segments. [1-50]

## **BIOGRAPHY OF AUTHOR:**

### **Asst. Prof. Dr. Dipl.-Ing. Emin Taner ELMAS**



Asst.Prof. Dr. Emin Taner ELMAS is a Mechanical Engineer having degrees of B.Sc., M.Sc., Ph.D., and was born in Sivas in 1974. He completed his doctorate at Ege University, Graduate School of Natural and Applied Sciences, Mechanical Engineering Department, Thermodynamics Science Branch, and his master's degree at Dokuz Eylül University, Mechanical Engineering Department, Energy Science Branch. He also completed his undergraduate education at Hacettepe University, ZEF, Mechanical Engineering Department and graduated from the faculty with honors in 1995 and became a mechanical engineer. He was awarded a non-refundable scholarship by the Turkish Chamber of Mechanical Engineers in his 4<sup>th</sup> year because he was the most successful student during his first 3 classes study at the faculty. He graduated from İzmir Atatürk High School in 1991.

Asst. Prof. Dr. ELMAS has completed his military service as a NATO Officer in Bosnia and Herzegovina. He was a “Reserved Officer” as a “2<sup>nd</sup> Lieutenant” as an “English-Turkish Interpreter”. He was also a “Guard Commander” and served in Sarajevo, Camp Butmir within the SFOR task force of NATO. He has been awarded with 2 (two) NATO Medals and Turkish Armed Forces Service Certificate of Pride (Bosnia & Herzegovina).

In addition to his academic duties at universities, he has worked as an engineer and manager in various industrial institutions, organizations and companies; He has served as Construction Site Manager, Project Manager, Management Representative, Quality Manager, Production Manager, Energy Manager, CSO-CTO, CBDO, Factory Manager, Deputy General Manager and General Manager.

Asst. Prof. Dr. Elmas is Department Head and is an Assistant Professor of Automotive Technology at the Department of Motor Vehicles and Transportation Technologies at Vocational School of Higher Education for Technical Sciences at IGDİR UNIVERSITY, Turkey. He is also an Assistant Professor of Bioengineering & BioSciences at the same university. He has nearly 30 years of total experience in academia and in industry.

He has served as a scientific referee and panelist for ASME, TUBITAK and many scientific institutions, organizations and universities, including NASA.

“Mechanical Engineering, Energy Transfer, Thermodynamics, Fluid Mechanics, Heat Transfer, Higher Mathematics, Evaporation, Heat Pipes, Space Sciences, Automotive, Bioengineering, Medical Engineering Applications, Neuroengineering, Medical Technique” are his academic and scientific fields of study; “Heating-Ventilation Air Conditioning Applications, Pressure Vessels, Heat Exchangers, Energy Efficiency, Steam Boilers, Power Plants, Cogeneration, Water Purification, Water Treatment, Industrial Equipment and Machinery, Welding Manufacturing, Sheet Metal Forming, Machining” are his industrial experience fields.

Asst. Prof. Dr. Emin Taner ELMAS is also a musician, saz (baglama) virtuoso player and ney (Nay, Turkish Reed Flute) performer. He plays also cümbüş instrument and performs darbuka rhythm instrument. He has a YouTube Music Channel (Emin Taner ELMAS) which includes some of his sound recordings of him playing the saz-baglama and blowing the ney. He composed the poem written by the great poet Âşık Veysel ŞATIROĞLU under the name of “Raşit Bey” in memory of his father Judge (Hâkim) Raşit ELMAS as “Raşit Bey Türküsü”, wrote it down, notated and published it as an academic article and broadcasted this song on his own music channel. He wrote the poems entitled “Canım Babam” and “Geldim Babam” which he wrote also in memory of his father and published in an academic literature journal, and composed instrumental musics for these poems. He also composed an instrumental song called “Annem Annem Türküsü” and gave it to his mother, Lawyer Tuna ELMAS, as a gift on Mother’s Day, 11.05.2025. He also has a poem titled "Ney and Neyzen." He also wrote and presented a poem titled "Esra Kardeşim" to his sister, Esra ELMAS, an archaeologist and

English teacher. He has published books including "Saz-Bağlama Tuning System Method" ("Saz- Bağlama Akort Sistemi Metodu") and "Ney and Neyzen; Ney's Pitches, Frets, Sound Stages, Octaves, Structure, Performance, Ney Maintenance and Basic Music Theory" (Ney ve Neyzen; Ney'de Perdeler, Ses Devreleri, Oktavlar, Yapısı, İcrası, Ney Bakımı ile Temel Musiki Nazariyatı). He continues his artistic studies by writing various articles, books, poetry, lyrics and also realizing musical composition and repertoire works.

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