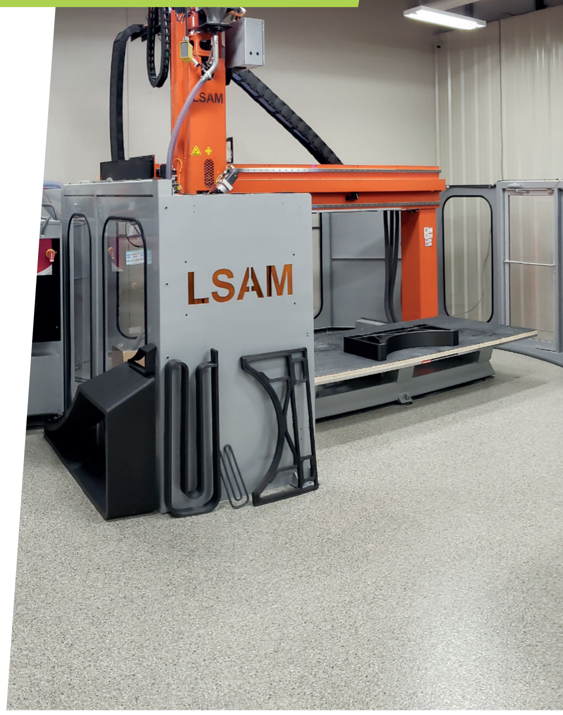
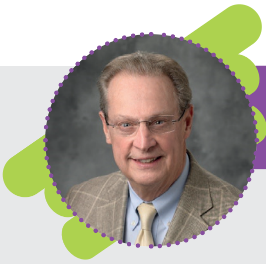


Creating the world's largest 3D-printed structure

Dr R. Byron Pipes, of the **Composites Manufacturing and Simulation Centre** at **Purdue University** in the US, forms part of a team that was involved in the development and installation of the world's largest 3D-printed structure – located within the US National Football League's Las Vegas Raiders' Allegiant Stadium.



Dr R. Byron Pipes

John L. Bray Distinguished Professor of Engineering, Composites Manufacturing and Simulation Centre (CMSC), Schools of Aeronautics and Astronautics, Chemical Engineering and Materials Engineering, Neil Armstrong Hall of Engineering, Purdue University, USA

Field of research
Advanced Composites

Research project
Engineering the world's largest 3D-printed structure, the National Football League's (NFL's) Las Vegas Raiders' stadium torch

Funders
US Department of Energy (DOE), US National Science Foundation (NSF), Boeing, Saab, other global industry players

TALK LIKE AN ...

ADVANCED COMPOSITES ENGINEER

3D printing — the construction of a three-dimensional object from a CAD model or a digital 3D model

Anisotropic — a physics term describing something that changes in property depending on the direction in which it is measured

Carbon fibre-reinforced polycarbonate composite — a material that is ideal as a structural component with high strength and stiffness-to-weight, excellent surface quality and dimensional stability

Compressive stress — a stress that causes a structure to lose its shape or become crushed

Digital twin — a real-time virtual representation of a real-world physical system or process that serves as the indistinguishable digital counterpart of it for practical purposes

Extrusion deposition — in 3D printing, where material is melted, driven through a nozzle, deposited layer-by-layer and compacted to ribbon form

Large scale additive manufacturing — a production process where a 3D printer creates large workpieces and finishes them through router machining

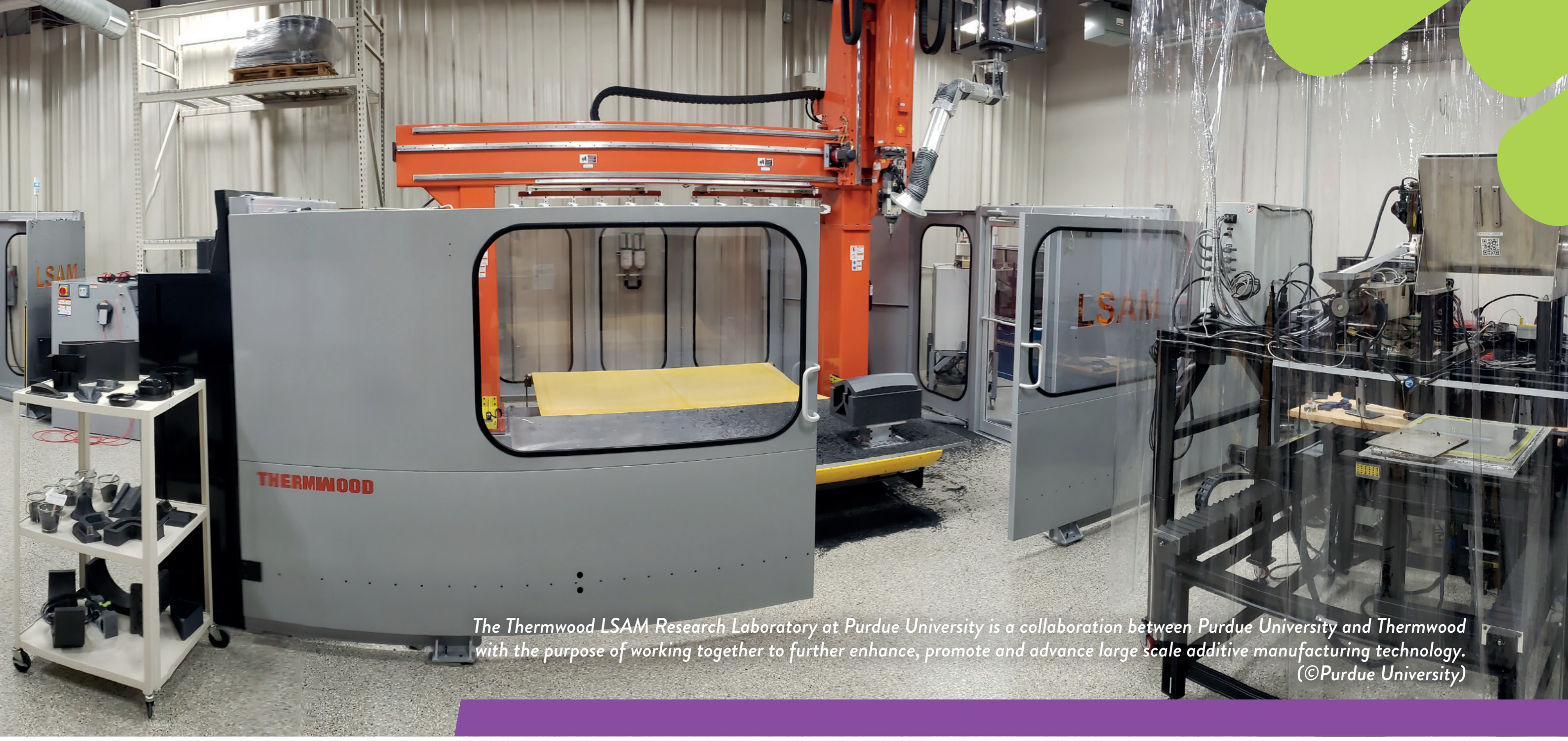
The National Football League (NFL) is the most popular and successful sport in the US and is proving to be increasingly popular globally. Given the NFL's prominence and the prestige of its players, it is not surprising that the NFL teams are often in the news. What might surprise you is that one team, the Las Vegas Raiders, can now make the unusual claim of being the proud owners of the world's largest 3D-printed structure, one that was built as a homage to Al Davis, an American football legend who served as head coach and general manager of the Las Vegas Raiders.

In early 2022, the Al Davis memorial – the Las Vegas Raiders' stadium torch – was installed at the Raiders' home, the Allegiant Stadium. This 93-feet tall 3D-printed structure is the tallest that has ever been created, anywhere in the world, and is testament to the sheer scale of the NFL and the esteem that Al Davis is held in – and nowhere seems more apt as a home than larger-than-life Las Vegas! The stadium torch is an impressive structure, but how much work goes in to installing such a feature? It is one thing to commission the world's largest 3D-printed structure, but entirely another to build it in a way that works. And this is where Dr R. Byron Pipes comes in.

Practicalities

Dimensional Innovations (DI), a Kansas-based design, technology and fabrication firm, was tasked with building the 3D-printed torch structure. To achieve this, it used a large-scale additive manufacturing solution that was developed by Thermwood Corporation. When designing the torch, the aesthetic concerns were given precedence – it was a case of working backwards in many ways, where the desired appearance of the torch was decided on before experts were drafted in to determine the feasibility and practicalities of such an undertaking.

Collaborating with structural engineers, Byron and his team, based in the Composites Manufacturing and Simulation Centre at Purdue University, were tasked with studying the behaviour of the structure under different environmental stresses, such as wind, as well as the internal stress of its own weight. It was their responsibility to make the idea of this monumental structure a safe and practical reality.



The Thermwood LSAM Research Laboratory at Purdue University is a collaboration between Purdue University and Thermwood with the purpose of working together to further enhance, promote and advance large scale additive manufacturing technology. (©Purdue University)

Modelling

Byron and the team employed a technique whereby a 'digital twin' of the structure was created. "A digital twin of a structural geometry such as the Las Vegas Raiders' torch is developed by constructing a model of the structure that includes the anisotropic material properties of the printed system, as well as the multiple joining elements," explains Byron. "The torch geometry was achieved by first printing smaller elements of the structure and then joining them into ring geometries that were assembled together to create the beautiful form of the torch." The digital twin – based on real-time data – allowed the team to produce an overall structure that was fit for purpose, as well as aesthetically pleasing.

Safety

As befits a memorial in a sporting environment, the Al Davis Memorial Torch is an impressive and awe-inspiring sight; it aims to inspire fans and celebrate sporting endeavour. Like any football match where victory looks easy for the dominant team, it also looks elegant and effortless. Except, of course, no football match is effortless, and no structure, especially the world's largest 3D-printed structure, is without its challenges. The team knew the torch would look good, but would it be safe?

To ensure its safety during the construction phase and once in place in the stadium, the team modelled how the structure would 'behave' in different adverse circumstances. The stress of the structure's self-weight and wind loading were modelled, and its deformations and internal stress state were used to predict the torch's safety. The buckling instability – the changing shape – of the structure due to compressive stresses was also examined. To doubly ensure safety, a conventional space frame structure was constructed inside the torch to provide for additional constraints to excessive deformation in adverse circumstances.

Material

Carbon fibre-reinforced polycarbonate composite was decided upon as the ideal material for this ambitious 3D printing project because it possesses a combination of 'printability' characteristics and structural performance properties. "Printing rates of 500 pounds per hour required adequate flow characteristics, while structural performance was assured by the carbon fibre fraction of the composite," explains Byron. "The torch was constructed of 225 3D-printed blocks, each weighing approximately 350 lbs. Over 100,000 lbs of raw material were used to print the blocks."

Large-scale

You might have done 3D printing in school or even have your own 3D printer at home and, if so, you will be familiar with the layer-by-layer process 3D printing uses. However, you are unlikely to be familiar with the scale of 3D printing that the memorial torch project involved. The large-scale additive manufacturing the project used is based on extrusion deposition, where solid pellets of the carbon fibre-reinforced polycarbonate are melted and, printed out' of the machine in a 'ribbon'. By using this method, three-dimensional geometries can be created in the layering process that is typical of additive manufacturing, with printing rates of up to 500 lbs per hour. Hobbyists and students in schools use much smaller printers, which use a solid filament that is melted and then deposited but does not transform the filament to the ribbon form. In addition, the systems you might be familiar with print at much lower rates of grams per hour.

Teamwork

Innovative projects such as this always rely on team effort and the combination of a huge range of skills and expertise. The Purdue University team was led by Sergii Kravchenko, a post-doctoral research assistant, who bought his expertise in aeronautics, astronautics, advanced composites and structural mechanics to the project. Dr Kravchenko is now Assistant Professor of Materials Engineering at the University of British Columbia in Canada.

Despite the novelty of this particular project, the work involved can be considered typical of the research and development projects undertaken by Byron's team in the Composites Manufacturing and Simulation Centre at Purdue University. "It must be pointed out that my team is generally geared towards studying the manufacture and performance of automotive and aerospace products where weight saving is desired," explains Byron. "However, the tools, methods, skills and knowledge we employed in our work on the torch were very similar, despite the difference in project focus."

Potential

These are exciting times for Byron and the team, with much work on the horizon. "Future projects include the establishment of an industrial consortium to support the further development of extrusion deposition additive manufacturing. New material forms will be created by adding continuous fibre to the discontinuous fibre composite form of conventional extrusion deposition additive manufacturing," explains Byron. "In so doing, the structural performance properties of the additive manufactured structure will facilitate wider application of large-scale additive manufacturing."

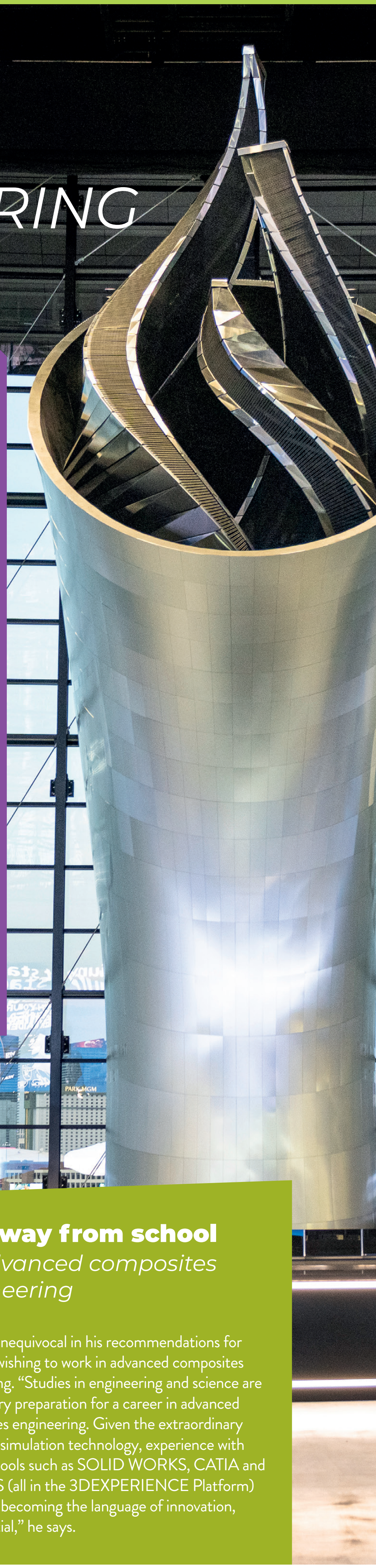
The potential for large scale 3D printing is wide open. "The future applications of large scale, extrusion deposition additive manufacturing will be limited only by the imagination and creative characteristics of future engineers," says Byron. "I am confident that this is just the beginning of an exciting period of engineering creativity."

The Al Davis Memorial Torch in numbers

Al Davis is an American football legend who served as head coach and general manager of the Las Vegas Raiders. The torch designed to commemorate his contribution to the sport and his team is the world's largest 3D-printed structure. These numbers help contextualise just how enormous the structure is:

- 93 feet tall
- Composed of 226 3D-printed subcomponents
- Also composed of 5,580 printed layers of material
- Weighs 101,228 pounds (46,000 kilograms)
- Upper 60% of the torch is clad in 1,148 unique aluminium panels

ABOUT *ADVANCED COMPOSITES ENGINEERING*



We tend to think of advances in digital technologies in terms of the new phones, laptops and screens in front of us, but digital transformation permeates many different fields – and engineering is no different. It is anticipated that advanced composites engineering (as well as other fields within engineering) will undergo rapid changes and developments in the near future. "The digital systems model and the digital twin enable partners to integrate their decision making in a shared process that speeds product development and ensures decision traceability over the product life," explains Byron. "The digital twin of the manufacturing process is a primary focus right now, because of its ability to both capture unique manufacturing details and help assess changes in product performance and operational and maintenance needs across the product lifecycle."

What other aspects of advanced composites engineering will be improved by technological developments?

Additive manufacturing will soon provide individualised products at manufacturing costs now only achieved by large-scale, automated production. Replacement parts will also be able to be produced onsite before long, without the need to stock inventory – it means we will live in a world where parts will be created as and when required, thereby minimising waste. "Major corporations have already installed systems that demonstrate a dramatic positive impact on both cost and time-to-build for critical industrial components, such as very large production moulds, tools and fixtures," explains Byron. "The future potential and benefits of this emerging technology could be highly significant to creating and maintaining a competitive advantage for major US industries worldwide."

What research opportunities will be open to the next generation of advanced composites engineers?

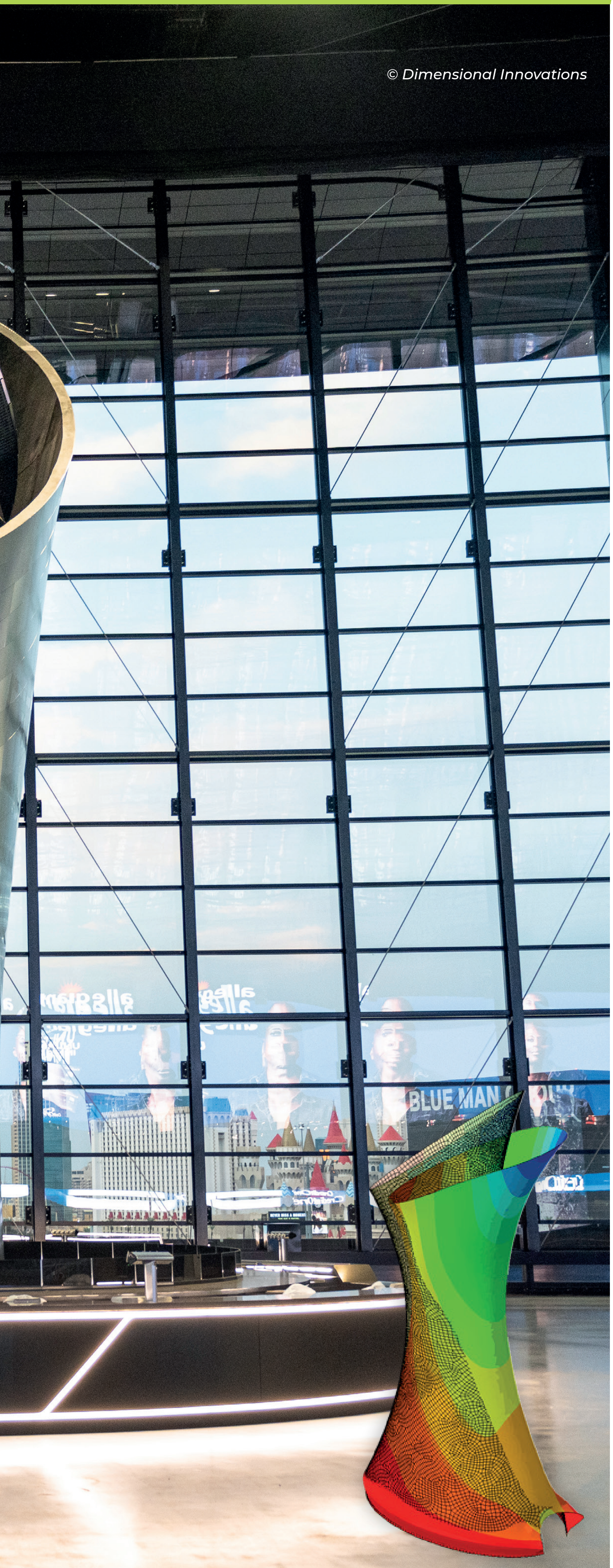
Byron expects that his primary interest in the future will be manufacturing research in advanced composites. "Manufacturability is the primary economic factor in determining product success," he says. "As long as this remains the case – and I expect it will for some time yet –, it will provide great rewards to society. It is also the primary barrier to application in many needed products, and I expect the next generation of engineers will be focused on this alongside researchers like myself."

Explore careers in *advanced composites engineering*

- Learn more about what a composites engineer does: **www.engre.co/blogs/articles/what-is-a-composite-engineer**
- Byron recommends looking at the American Society of Composites website: **www.asc-composites.org**
- The Composites Manufacturing and Simulation Centre (**www.purdue.edu/cmsc**) hosts its own online composites community resource, known as the Composites Design and Manufacturing HUB (**www.cdmhub.org**), which was launched as an exciting and informative educational tool for budding engineers.
- According to **www.raise.me**, the average salary for composites engineers in the US is between $86,000 and $93,000, although this is dependent on experience: **www.raise.me/careers/architecture-and-engineering/materials-engineers/composites-engineers**

Pathway from school to *advanced composites engineering*

Byron is unequivocal in his recommendations for students wishing to work in advanced composites engineering. "Studies in engineering and science are the primary preparation for a career in advanced composites engineering. Given the extraordinary growth in simulation technology, experience with software tools such as SOLID WORKS, CATIA and ABAQUS (all in the 3DEXPERIENCE Platform) which are becoming the language of innovation, are essential," he says.



Digital twin of the Las Vegas Raiders' Torch

Q&A

Meet Byron

What were your interests when you were growing up?

Engineering and creativity have always been linked in my mind and, early on, my interests were in architecture, where 'form follows function' while simultaneously creating beauty. Perhaps the earliest manifestation of my interest in engineering occurred when I saw a sign in a General Motors dealership advertising the Soap Box Derby race for boys aged 12-15. The race required the boy (girls joined the race in the 1970s) to build his own car while following a few specific directions and goals. The Soap Box Derby organisation supplied a steering wheel, four wheels and two axles (purchase price $25, circa 1953), but the rest was up to the boy.

Wow! How did you go about building the car?

My father helped me access a large-scale band saw to make the curved cuts required for the aerodynamic shape of the car. Our neighbourhood appliance store owner agreed to supply the $25 in exchange for painting the 'Brown Brothers Appliances' name on the side of the car. Constructed largely of plywood, my car was designed as a ribbed structure with a thin skin of ¼ inch plywood and sheet metal. It was painted dark green with the tiger shark of the Flying Tigers P-52 (a World War 2 plane) on the nose of the car for aesthetic advantage. The learning experience in creating an engineered system to meet a set of specifications revealed just what technical creativity could be, and I was hooked!

Who or what inspired you to pursue advanced composites engineering?

I have always advised my students upon graduation to look for a position where significant and continued learning must occur, where exciting new ideas are being developed. I took my own advice in 1969 when I joined the Composite Structures Group at a major aerospace conglomerate, General Dynamics. Composed largely of doctoral graduates in engineering, the team was challenged by the US Air Force to develop advanced composites to provide weight savings for fuel efficiency and performance gains for military aircraft. In a few short years, all future aircraft — commercial and defence — would contain components constructed of composite materials, and, indeed, stealth technology would demand that the aircraft be made entirely of composites.

What are your proudest career achievements, so far?

In 1987, I was elected to the US National Academy of Engineering and in 2018, the University of Edinburgh, in the UK, awarded me the honorary degree of Doctor *honoris causa*, which remain my proudest moments to date.

What are your ambitions for the future?

Doing more of the same creative scholarship in composite materials manufacturing!