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COMPOSITE BODY CONSTRUCTION OPTIMIZATION AND TECHNOLOGICAL DESIGN OF AN ELECTRICALLY POWERED RACE CAR

The paper discusses the ways of structural optimization of composite automotive bodies, such as in race cars using electric and hybrid power sources. To reach these goals we were using CFD aerodynamic design check. Taking into account all the above mentioned issues, the integrated 3D-CAD race bolide body model prototype was designed, based on the concept of NACA profiles used in surface positive and negative curvatures generation to ensure better air overflow, stability, drag coefficient, downforce etc. The result of the integrated 3D-CAD race bolide body model is also presented as a real scale composite automotive body. This paper also discusses technological methods as well as problems and stages of real-life designing (from mould to ready composite part). The results can be useful for such consideration and on such issues as production and development of complex shape composite bodies, using readily obtainable and justified by cost-effectiveness materials and software.

Keywords: aerodynamics, automotive, composite, parts technology

1. Introduction

In modern automotive industry, designing all kinds of vehicles is not anymore imaginable without using 3D-CAD processing software [1]. The processes that are involved in modern car production in almost 70 percent consist of computer aided processes (Fig. 1).

In this paper we are taking into account processes that are more commonly associated with project race car (bolide) construction. In the race car industry one of the main aspects that regulates the prospective outlook are legislation boundaries. In our case, these are IET Formula 24 and 24+ Technical and Sporting Regulations [2]. The goal is to ensure bolide longest endurance among competitors

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during up to 2 hour race using 12 volt batteries [3]. To do this, we can use knowledge and practices in 3D designing, as it will be shown later in this paper.

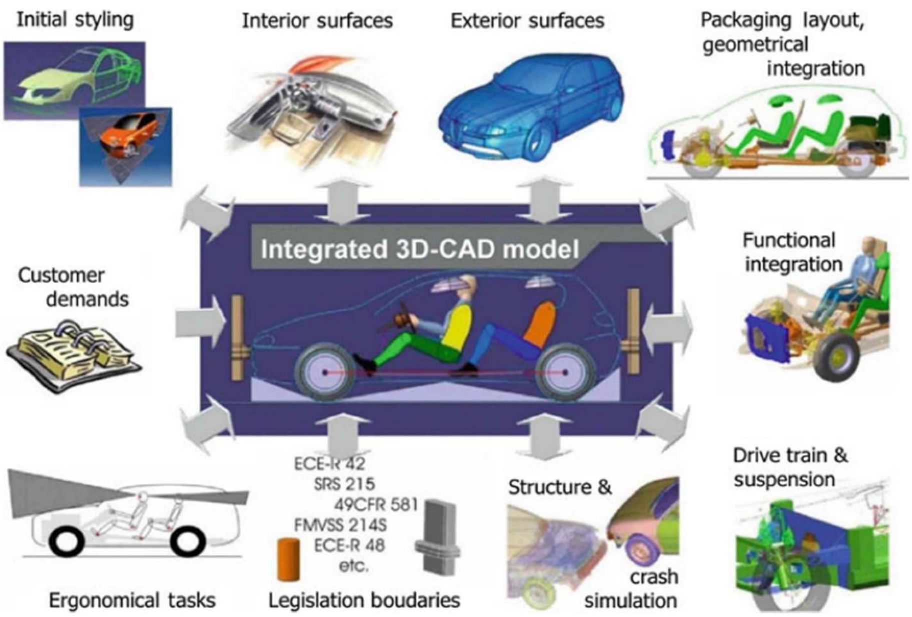

Fig. 1. The visualization of interrelation processes of 3D-CAD integration into automotive design state

Novelty of this work is determined by the alternative use of composite material cost effective combination in comparison with common face sheet construction of epoxy/carbon high cost fabrication methods, mentioned in literature [4] relevant chapter. The main goal was to create outer composite automotive sheet body, using economically efficient combination of fiberglass, carbon and hybrid and polyester resin in specific construction. For this reason the final product consists 90% of fiberglass lightweight 160 g/m^2 2 layers and 450 sandwich fiberglass mat core sandwich. Other 10% were used to improve stiffness and strength and impact resistance of the structure, like driver casing, using unidirectional carbon 280 g/m^2, and front part nose, using impact resistant carbon/kevlar (hybrid). As the reinforcement/matrix, low cost polyester resin was choosed. The cost efficiency of material and technology used in this work is numerically proven.

2. Materials and equipment

Definite bolide required basic materials are presented as examples in Fig. 2. The selection of required materials and equipment aided to plan the budget and effectiveness of the project. Effectiveness is the main criterion to present not only the profitability, but it also let us clearly understand which method of designing is more useful and qualitative. The problem is that there is no actual information in different sources about how to measure effectiveness of a technological method. In our case the only way to do it was the real time experience using current materials and equipment selection. In result we got relative, but reliable technological method results based on experience, which can be used as a starting point for next similar projects to avoid organizational mistakes and prospective stage obstacles, described further.

Fig. 2. Basic equipment required, set № 4 of 4: 1 – measuring equipment, 2 – resin mixing cup 50 l 8 bar, 3 – mechanical connections for bolide parts, 4 – chemical protective gloves, 5 – latex gloves, 6 – protective glasses, protective clothes and clean wipes, 7 – heating fan, 8 – rivet gun, 9 – pliers, 10 – manual screwdriver, 11 – dust particle protective mask FFP1 type and Moldex® type chemical, 12 – pneumatic grinding machine and basic attachments, 13 – pneumatic grinding machine specific round cutting abrasive for steel, 14 – pneumatic elliptical grinding machine, 15 – electric jig saw, 16 – standard blades for jig saw, 17 – abrasive blades for jig saw

To evaluate total effectiveness of the production process or overall equipment effectiveness [5] and to get numerical result we were using the total effectiveness evaluation procedure, for the coefficient of total equipment effectiveness E_{OEE}:

$$E_{OEE} = \frac{R_{numerical}}{S_{\cos t}} \tag{1}$$

where: $R_{numerical}$ – some numerically expressed value we got after completing production process (includes quality, time etc.),

$S_{\cos t}$ – cash investment amount into project.

Total effectiveness of the production process can be described numerically by the equation (4) in percentages, if we multiply by 100 formulae (1). The formulae (1) result give us clear evidence of the used equipment effectiveness in accordance with the invested amount of budget using current bolide building technological method. The results of the current method compared with other known one are presented further.

3. 3D-CAD design of the bolide

Utilizing CAD drawings as a modelling tool is one of the most popular engineering methods. Still, however, designers suffer from inconsistency of software and are vastly limited by possibilities of standard computing power of typical hardware. To get actual calculations CAD drawings were reverse engineered from dimensionless surfaces, surfaces recreated as overlapping, knitted and filled to obtain structure similar to what was expected to obtain in real-life production, with the main goal of keeping the outside shell as close to the design intent as possible. A similar algorithm of behavior can be used in the case of 3D scanning as shown in Fig. 3. The only difference is in preparing parasolid elements to feed SolidWorks Flow Simulation add-in. In our case we scanned first the prototype of bolide using 3D smart SCAN C2 2MP scanner to obtain a cloud of points (around 17 million points) that later was rebuild into the .stl format and subsequently into parasolid in GeoMagic Design. Modelling in GeoMagic was partially similar to what was done to the theoretical model in Solid Works, as we created volumes, from them cross sections, and we used scanned body contours as guidelines for the loft.

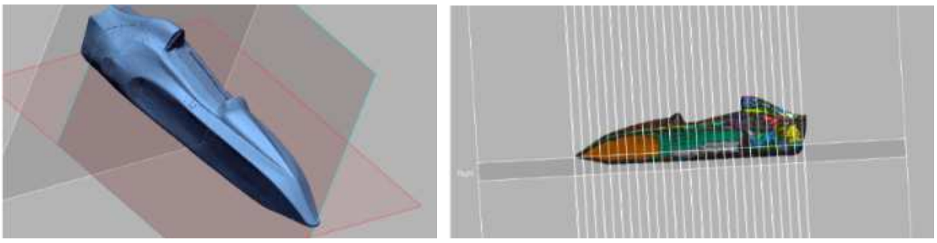

Fig. 3. States of creating solid body after 3D scanning (closed surfaces and parasolid creation)

We can install such air control surface devices (Fig. 4) to make research concerning Venturi effect [6] study etc., that appears under the body and ends at the diffuser zone, as well as to study other common factors like laminar air flow, Reynolds number [7] etc. For these kind of experiments we can use airflow simulation software. However, it requires much greater financial, time, intellectual work demands, as well as much greater computational processing powers and resources.

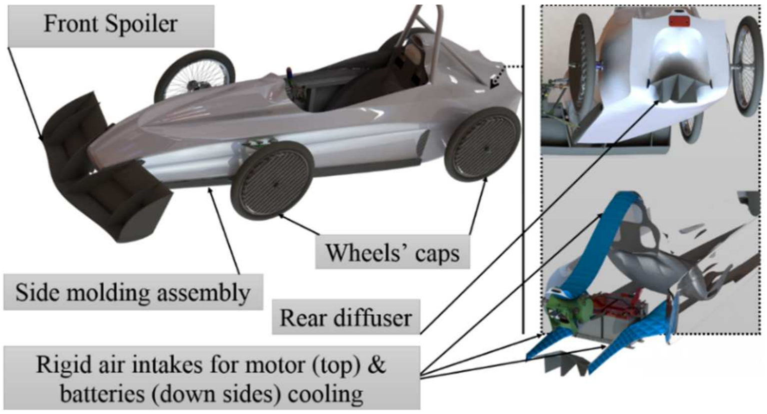

Fig. 4. Probabilistic aerodynamical set of air control surface devices in the case of further bolide modifications

4. Specific bolide composite body building technology

As a designing idea to make the overall body construction look like the Naca 4412 profile (Fig. 5) coordinate data [8] were used. The 3D designing allowed us not only design the complex shapes, but also to count the initial material needed with good accuracy. The production of specific mould consists of 5 main stages:

- gluing two sides of the mould and covering the area of the required body part shape boundaries,
- applying industrial transparent foil on two side tape covered areas,
- waxing foil covered areas for better mould to ready part further release,
- laminating composite material directly on to preliminary prepared surface,
- releasing body parts.

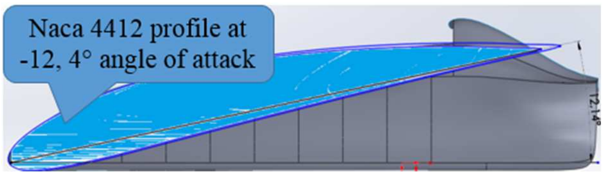

Fig. 5. 1st version body design

We used this method, in view of effectiveness, because surface perfect finishing is not required in comparison with a method like vacuum infusion. Surface can be not very smooth because the tension of industrial transparent foil and adequate tape installation prevents excessive air bubbles and delamination.

Before the lamination process, we performed the preliminary analysis of the future construction and took into account the directions of forces acting during the object (bolide) exploitation. Since the lay-up fibre orientation straightly affects mechanical properties of laminate or future construction, it is obvious to orient most layers to the direction of load to be carried. We were using a balanced laminate fibre orientation map everywhere in bolide body construction laminates following the guide routes (fibre orientation directions) by the scheme of 0°, +45°, –45°, and 90° degrees directions, as mentioned earlier a quasi-isotropic laminate [9].

We used custom designed fasteners sets as the method of composite body parts connection in a specific case (Fig. 6), using glue connection, rivets, custom duraluminium. Each set of fasteners accomplished their own task during exploitation. For example the rubber inside coating clamps would ensure soft and good grip connection with stainless frame, as well as provide absorption of vibrations and momentum shocks, during the ride on rough road surfaces. Tangent mounted clamps were providing tangential position of surfaces at the point of bolide body parts edge connection areas. Also we prepared a carbon frame to add additional stiffness to the middle bolide body part, as well as its 50 mm elongation around perimeter, which was providing connection and easier installing with front and rear parts. We used special vinyl ester based bonding paste to provide best connection between the carbon polyester frame and polyester body laminates, accordingly to this product technical specification and abilities [10].

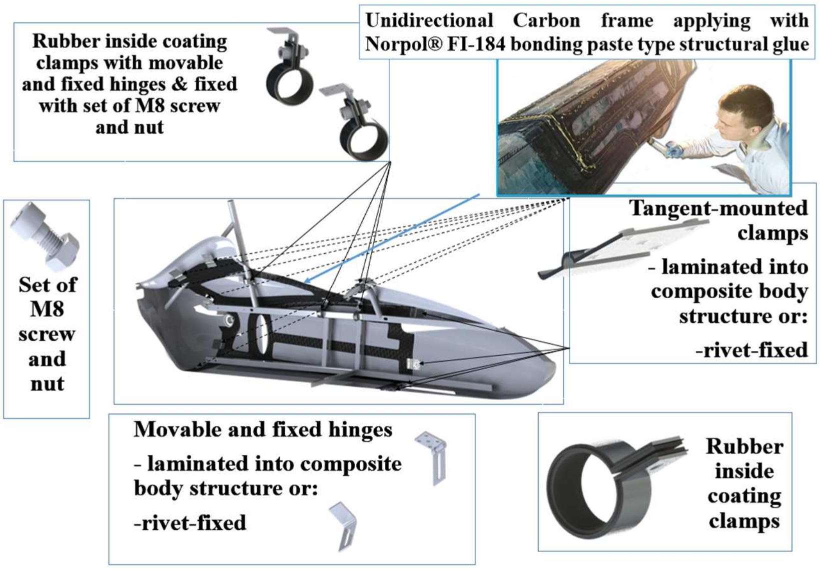

Fig. 6. Bolide body parts custom connection using sets of purpose-oriented fasteners

5. Research methodology and results analysis

Taking into account methodologies used in bolide body construction production we can mention the technology of mould making using 3D to 2D as well as the composite fabric fibre orientation method and the method of composite body parts connection. Values of aerodynamical drag ratio for bolide are obtained using finite volumes method calculation. The computational fluid dynamics module of SolidWorks 2017 software, called Fluid Simulation, was used. Surfaces were knitted and filled to obtain a structure similar to what was expected in further production, and finally solid bodies were formed. On this stage real thickness of bolide shell was ignored and the body was assumed as rigid one when subjected to incoming airflow with speed below 20 m/s. Only then bodies were meshed (Fig. 7). Considering crudeness of tests approximate of 283 226 cells total and 64 360 fluid cells containing solids were used, approximation (up to 1 mm^2) of frontal area found as 316746 mm^2. With ambient pressure at 101325 Pa, temperature 293.2 K and incoming, along main axis of bolide, airflow of 20 m/s calculations were held.

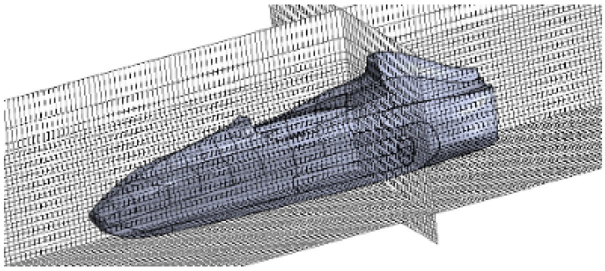

Fig. 7. Global mesh as seen in SolidWorks Flow Simulation with 280k fluid cells

Streamlines and cut plots are used to determine the shape of airflow around bolides body. Understanding of fluid behavior is crucial to determine whether simplified calculated methods are sufficient to predict real force acting on surfaces.

To integrate the aerodynamical coefficient of resistance (drag coefficient) into the flow simulation analysis and to get drag equation goal we were using the drag equation procedure, for the coefficient of drag C_d:

$$C_d = \frac{F_d}{\frac{1}{2}\rho V^2 A} \tag{2}$$

where: F_d – drag force constituent in the direction of the flow velocity,
ρ – density of the ambient environment,
V – velocity of flow in relation to the object,
A – cross reference area.

The drag coefficient is obtained as the so-called equation goal where drag equation procedure is written in.

Speed isolines on cut plots along the main bolide axis are used to visualise fluid flow, especially around parts suspected for being possible obstacles for smooth transition. The visualisation above, shown in Fig. 8 and Fig. 9, allowed to show that such a problem exists with windshield, due to its shape acting effectively as an aerodynamic break.

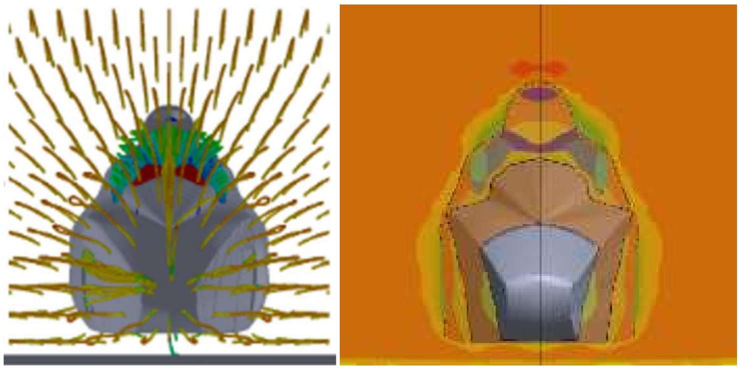

Fig. 8. Flow speed from the front side (on left streamlines, on right cut plots)

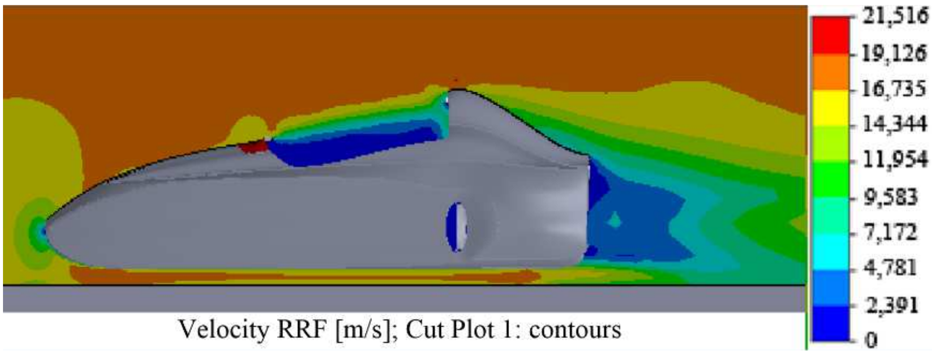

Fig. 9. Flow behavior along the main axis

Comparative analysis of specific technological building methods is represented in Fig. 10 and Fig. 11. According to Fig. 10 data analysis the most expenses are in the method using 3D mould printing and then vacuum bagging. It's for the reason of high 3D material amount and glue (to connect 3D printed surface parts) cost. TEME factor is the highest for this method, but it's a relative value because it's calculated proportionally to TEU, by the relation to calculate specific effectiveness of each unit equipment, using the formulae of maximal one unit effectiveness (MOUE):

$$MOUE = \frac{TEME}{TEU} \tag{3}$$

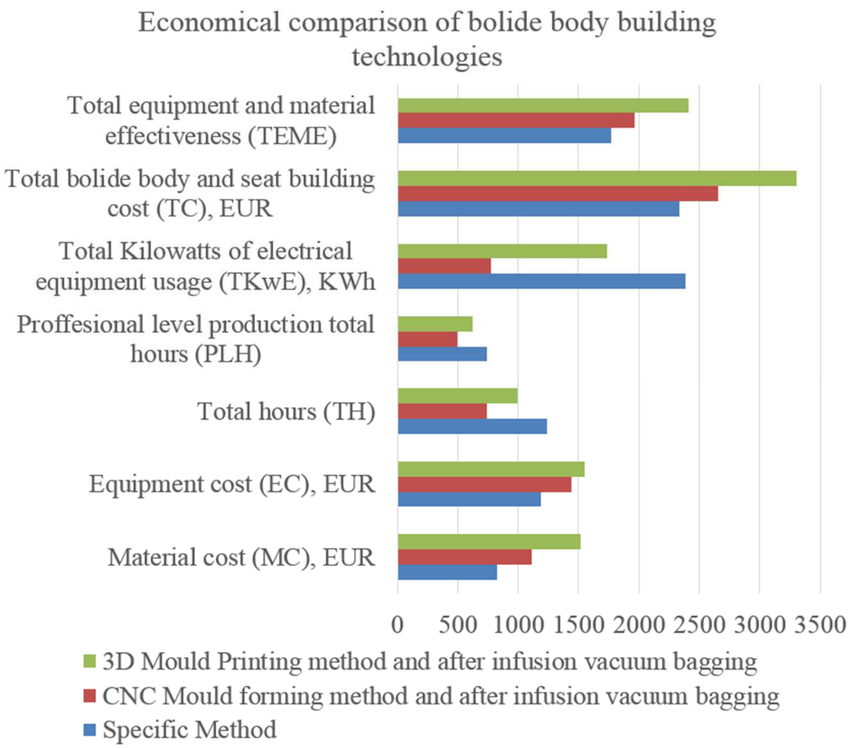

Fig. 10. Economic comparison analysis histogram of technological building methods

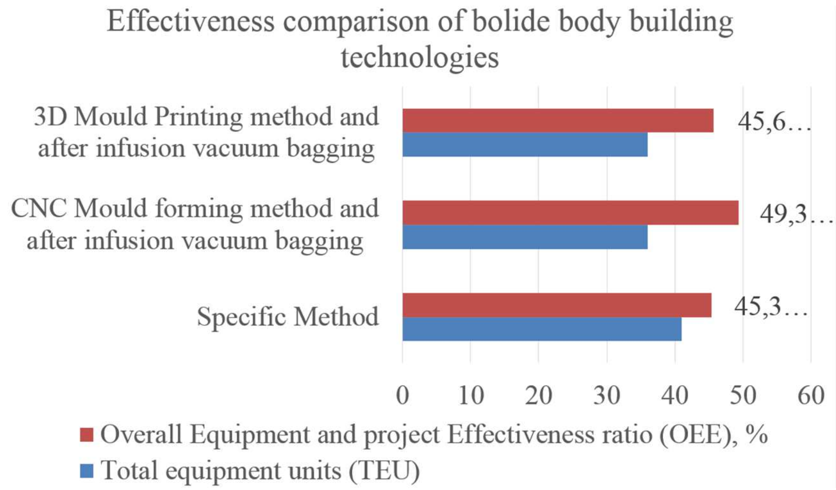

Fig. 11. Effectiveness comparative analysis histogram

The TEME actually never can reach TC or amount 100%, because all equipment cannot be working without faults, including human factor. More demonstrative parameter is overall equipment and project effectiveness ratio (OOE), represented in Fig. 11. It includes all the mentioned parameters, by relation, using the formulae of overall equipment and project effectiveness:

$$\mathrm{OEE} = \frac{\mathrm{TEME} \cdot \mathrm{PLH}}{\mathrm{TC} \cdot \mathrm{TH}} \cdot 100\% \tag{4}$$

where: $\frac{\mathrm{PLH}}{\mathrm{TH}}$ – is professional level production total level hours 2-to-1 ratio to total real working hours.

The highest OOE is assigned to the CNC mould forming method and further vacuum bagging (Fig. 11). That is obvious and proven by the attached calculations of this work.

Other explanations are ideal symmetry and linear airflow, as well as ignoring induced drag which may lead to the increase of total C_d to more believable values around 0,19-0,20 (Tab. 1).

Table 1. Comparison of some production and concept cars drag coefficient [11]

Drag coefficient value	Model name	Year of production
0.19	Alfa Romeo B.A.T. 7 Concept	1954
0.19	General Motors Ultralite	1992
0.1768	***KUT Bolide***	***2018***
0.17	Pininfarina Fiat 124 concept (Morelli shape)	1978

6. Conclusions

The results, experience and knowledge gained while writing this publication, prove the necessity of planning and organization of work to put into effect such methods of composite parts production. This attitude provides us with predictable vision of future projects and results which can be obtained and analysed further.

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METODY OPTYMALIZACJI KONSTRUKCJI KAROSERII KOMPOZYTOWEJ ORAZ PROJEKT TECHNOLOGII DLA SAMOCHODÓW Z SILNIKIEM ELEKTRYCZNYM

S t r e s z c z e n i e

W artykule omówiono sposoby optymalizacji strukturalnej kompozytowych nadwozi samochodowych, takich jak samochody wyścigowe wykorzystujące elektryczne i hybrydowe źródeł energii. Aby osiągnąć te cele, korzystano z kontroli aerodynamicznej projektu CFD. Opracowano zintegrowany prototyp modelu nadwozia typu 3D-CAD oparty na koncepcji profili NACA, stosowany w generowaniu dodatnich i ujemnych krzywizn powierzchni, aby zapewnić lepsze parametry: stabilność, współczynnik oporu, siłę docisku itd. Rezultat zintegrowanego modelu nadwozia typu 3D-CAD z nadwoziem wyścigowym jest także prezentowany jako nadwozie kompozytowe w skali rzeczywistej. W artykule omówiono również metody technologiczne oraz problemy i etapy projektowania rzeczywistego (od formy do gotowej części kompozytowej). Uzyskane wyniki mogą być przydatne do produkcji złożonych brył kompozytowych, przy użyciu łatwo dostępnych i opłacalnych materiałów oraz oprogramowania.

Słowa kluczowe: aerodynamika, motoryzacja, kompozyt, technologia części

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