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Andrzej BAIER, Julia NOJEK*

Institute of Engineering Processes Automation and Integrated Manufacturing Systems, Faculty of Mechanical Engineering, Silesian University of Technology, Gliwice, Poland
* julia.nojek@gmail.com

POSSIBLE APPLICATION OF ARTIFICIAL SHARK SKIN AS SURFACE REDUCTING AERODYNAMIC DRAG

Abstract: In this paper the possibility of using artificial shark skin in order to improve aerodynamics of Silesian Greenpower race car is considered. Strong evidences, that this synthetic product should be applied on the surface of the Greenpowers car sheathing are presented.

1. Introduction

Aerodynamics of vehicles is one of the most important areas in their design - appropriate selection of parameters allows to reduce air resistance and thus significantly increase the speed and economics of travel. This area is part of the fluid mechanic, which also includes hydrodynamics. These two issues, aerodynamics and hydrodynamics vary from each other with environment where the research is carried. Air has lower viscosity in comparison to liquid and it is about 64 times less viscous than water, but aqueous media are not as compressible as air [1].

Despite occurring differences aerodynamic drag can be described by the following equation:

$$R = \frac{1}{2}\rho C A v^2, \tag{1}$$

where: R – aerodynamic drag, ρ - density of the medium, C – coefficient depending on the shape of the object, A – sectional area of the body, v - speed of the body relative to the medium.

Based on the equation (1) which can be used either in aerodynamics and in hydrodynamics it was decided to show common parts of this two areas and their application [1,2].

The signs of this law can be seen in animal kingdom, especially in water environment. A lot of animals possess features allowing them to swim faster. And it is not only the streamline shape of their bodies, but also scales or denticles, which are characteristic for sharks.

Shark skin is not smooth like for example dolphins' one but covered with structures similar to small teeth placed all over them (Fig.1.). That structure of scales permit these animals to reduce the viscosity of water by breaking up water vortices that would otherwise create drag. This attribute of this predatory fish is used in different areas – Speedo Fastskin is one of the best examples. It is product from Speedo, company manufacturing swim accessories, which takes advantages of shark skin and covers the surface of suit with small v-shaped channels being the projection of animal denticles. This shows the possibilities of recreating such structures – one can see difference between real and artificial shark skin in Fig.1. and Fig.2., respectively [5,6,7].

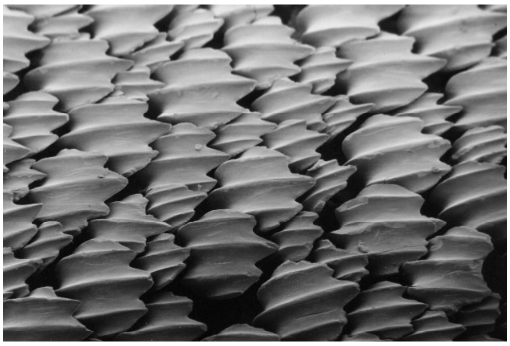

Fig.1. Magnified shark skin [3]

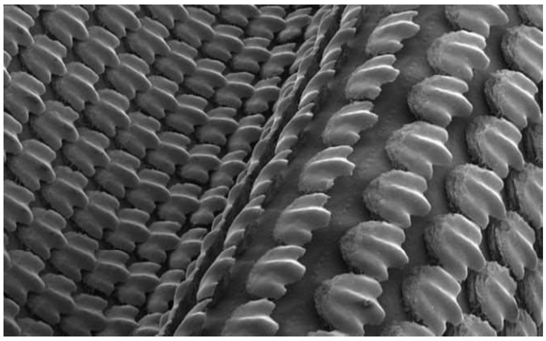

Fig.2. Close up of synthetic shark skin [4]

2. Results of simulations of synthetic shark skin and Greenpower race car

Synthetic shark skin (Fig.2.) manufactured with multimaterial 3D printing has been tested using different parameters.

In the following two tables are shown received results presenting the dependence of static drag force and drag reduction percentage on channel flow speed, Reynolds number and S+; also power consumption and costs of transport of synthetic shark skin and smooth membranes under various motion programs [4].

Tab. 1. Dependence of static drag force and drag reduction percentage on channel flow speed, Reynolds number and S+[4]

Water tank flow speed (m s^{-1})	Re_{ch} ($\times10^3$)	Re_c ($\times10^3$)	Turbulent $S+$	Drag force: Synthetic shark skin (mN)	Smooth membrane (mN)	Drag reduction (%)
0.129	32.31	9.94	5.61	7.59±0.42	8.31±0.19	8.72
0.194	48.47	14.95	8.09	19.26±0.48	20.02±0.46	3.79
0.258	64.63	19.88	10.46	36.26±0.55	37.46±0.37	3.20
0.323	80.78	24.89	12.80	58.84±0.60	60.16±0.71	2.19
0.387	96.94	29.83	15.07	89.88±1.55	86.58±0.31	−3.81
0.452	113.09	34.83	17.33	129.72±1.40	119.93±0.37	−8.16
0.517	129.25	39.85	19.55	178.0±1.22	159.5±1.21	−11.60
0.581	145.41	44.77	21.72	241.58±2.86	209.90±0.59	−15.09

For definitions of channel Reynolds number (Re_{ch}), chord Reynolds number (Re_c) and turbulent $S+$, see Materials and methods.
Static drag force data consist of eight water tank flow speed points taken between 0.129 and 0.581 m s^{-1} at increments of 0.065 m s^{-1}. Negative drag reduction values in the last column indicate that the shark skin membrane had enhanced drag relative to the smooth model. Drag force measurements are the means of N=5 replicate trials; error values are ±1 s.e.m.

Tables shown above prove that using shark skin denticles like structure coating can lead to reduction of the drag up to 15% and at the same time to reduction of the costs of transport. With such results it can be established that covering places on race car sheathing particularly vulnerable to aerodynamic drag could improve the reduction of drag force.

Taking findings below (Fig.3., Fig.4.) of the Silesian Greenpower race car ANSYS simulation it can be shown that there are areas placed on the car which generate higher aerodynamic drag.

Tab. 2. Power consumption and cost of transport of synthetic skin and smooth membranes under various motion programs[4]

	Total power (mW)		COT ($J\,m^{-1}\,kg^{-1}$)			
Motion program	Shark skin	Smooth	Shark skin	Smooth	Power reduction (%)	COT reduction (%)
f=1 Hz, *h*=±1 cm	9.23±0.22	9.75±0.16	1.22±0.03	1.26±0.02	5.54	3.18
f=1 Hz, *h*=±2.5 cm	89.4±0.38	88.3±0.49	5.08±0.02	5.25±0.03	−1.24	3.26
f=1.5 Hz, *h*=±1 cm	39.3±0.27	39.15±0.36	2.64±0.02	2.81±0.03	−0.38	5.87
f=2.5 Hz, *h*=±1 cm	114.28±0.49	121.05±1.55	5.40±0.02	5.64±0.07	5.60	3.14
f=1 Hz, *h*=±1.5 cm, θ=10 deg	17.57±0.09	17.67±0.10	1.17±0.01	1.235±0.01	0.57	5.11
f=1 Hz, *h*=±1.5 cm, θ=30 deg	77.93±0.50	76.88±0.82	6.48±0.04	6.39±0.07	−1.37	−1.40

COT, cost of transport; *f*, frequency; *h*, heave; θ, pitch.
Total power (heave power + pitch power, per flapping cycle), and COT data are shown. All power and COT results are the mean of *N*=5 replicate trials for each measurement; error values are ±1 s.e.m.

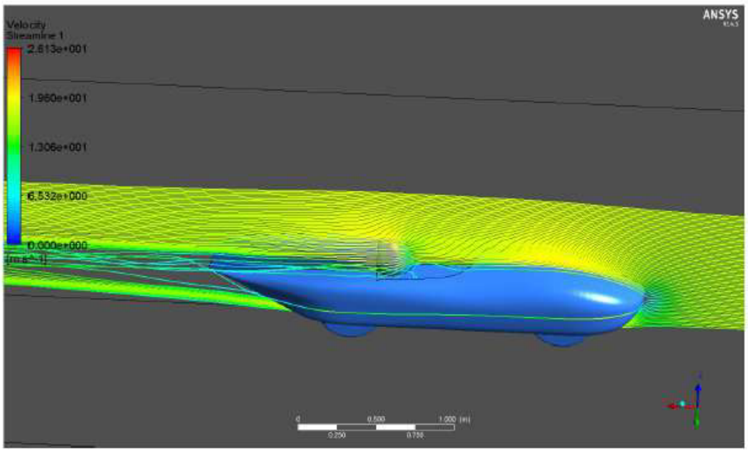

Fig.3. The course of streams of air around the race car SG2013[8]

In Fig.3. air streams around the rear of the vehicle and the rear fairing can be exactly seen.

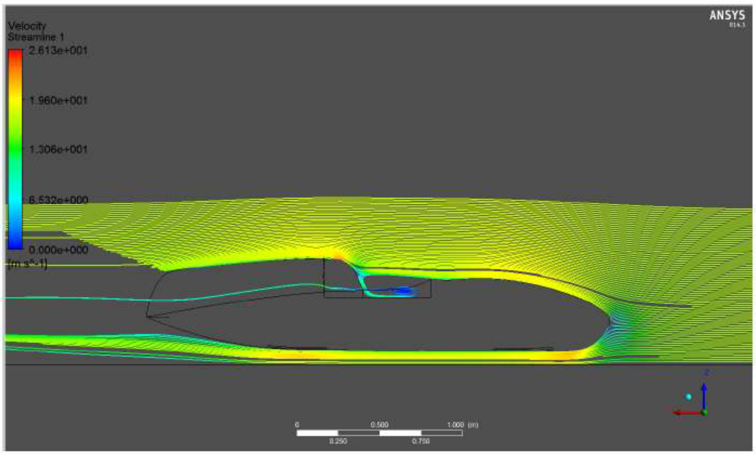

Fig. 4. The course of streams of air around the race car SG2013 [8]

Air circulation against the helmet is visible - the gas repeatedly rotates inside the driver's cab and then leaves it on the one side of driver's helmet. While leaving the cockpit it also interacts with air, at higher speed, and then moves directly from the front of the vehicle and cause turbulent behavior. Under this conditions it results in multiple air change of velocity of flow. Irregular and rough flow is unfavorable and leads to increasement of aerodynamic drag [8,9].

3. Conclusion

As a result of research conducted on the coating with shark skin denticles and smooth coating and comparing the results received from simulation environment with the same parametres for both, it was found that it is possible to reduce transport costs and energy consumption resulting from the reduction of aerodynamic drag forces.

Artificial shark skin inspired surface on the shell of the car would allow to: spread out air stream, reduce the viscosity of the air and transfer the positive effects of the applied coating in relation to the vehicle. The difference between the density and viscosity of the centers, which were conducted simulations require further testing issues, but because both are considered fluids, it can be a significant improvement in aerodynamics of the vehicle.

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