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THERMAL RIBLETS: CONCEPTUAL APPROACH TO FLOW CONTROL

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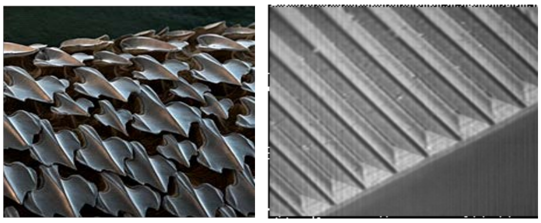
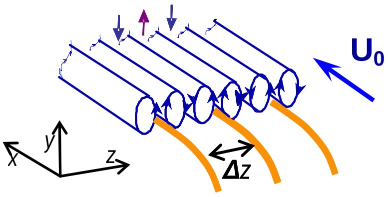
INTRODUCTION

Prototyping evolution-optimized features of living systems, engineering solutions are sought and applied in technology. One of such features is skin-flow interaction of high-speed marine creatures that served as a basis for riblets aimed to improve the aerodynamic performance. Further investigations of this idea resulted in the development of virtual thermal riblets (figure 1).



(a) Shark scale (b) Mechanical riblets [1]



(c) Thermal riblets

Figure 1: Research stages aimed at flow structure optimization

On the one hand, this sequence of steps enabled to generalize separate findings into a strategy of smart flow control [2, 4]. On the other hand, it displayed a spectrum of options which can be realized in practice for passive, active, and remote flow control in the framework of the same strategy. It is based on purposeful maintenance of a given vortical structure. For that spanwise arrays of mechanical or thermal disturbers are applied to generate a system of given scale vortices. A resultant favorable impact is expected in a form of a more reliable, simple, and fuel efficient aerodynamic performance.

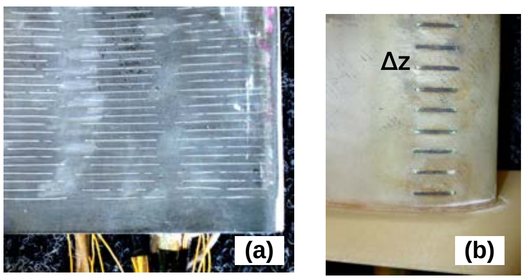
REALIZATIONS OF THERMAL RIBLETS

Advantages of thermal methods of flow control are as follows

- They enable active and remote flow control.
- Applied control factor maintains the surface smooth.
- A number of control parameters (intensity and character) can be chosen in a broad range.
- Scales of initiated vortices are adjustable to the body geometry as well as to current flow conditions.
- Separate sections over a body can be independently controlled.

The goal of the present analysis is to demonstrate feasibility of the strategy of a purposeful flow structure modification using thermal riblets to gain aerodynamic performance improvement. The research is organized as matched numerical and experimental modeling. Numerical simulation of the controlled flow field gives an insight into structural features of of fluid motion. Obtained results guide experiments in part of choosing optimal control parameters correlated with basic flow characteristics. They are a spanwise distance Δz between thermal sources in the array (figure 1, c), their downstream x location over a test model, intensity and modes of heating, e.g. continuous of pulsating.

A few engineering realizations of thermal riblets were considered. Two of them relate to the direct localized surface heating like that shown in figure 1,c. In experiments it was made using resistive heating with applied voltage of embedded streamwise strips (figure 2, a) and with microwave heating of MW absorbing elements (figure 2,b). The latter case enables



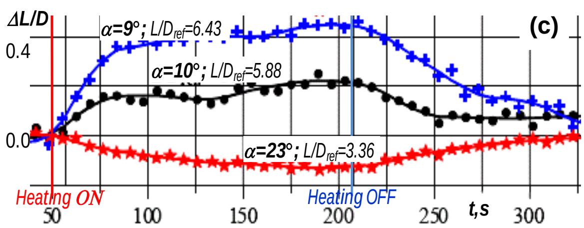


Figure 2. Increments of lift-to-drag ratio ΔL/D *vs* time (c) for near-critical angles of attack α = 9˚ and 10˚ and for supercritical α = 23˚ of the model (a): Δz = 5 mm, $\Delta T_z \approx 40˚$

active and remote flow control which is free of extensive wiring of the first case. Figure 2, c shows that the model aerodynamic performance L/D can be improved using thermal riblets with properly chosen parameters.

The third engineering solution relates to generation of virtual thermal riblets with spanwise arrays of plasma discharges (figures 3 and 5, a). Plasma discharges were generated with MW radiation between ends of an open loop mounted inside a model.

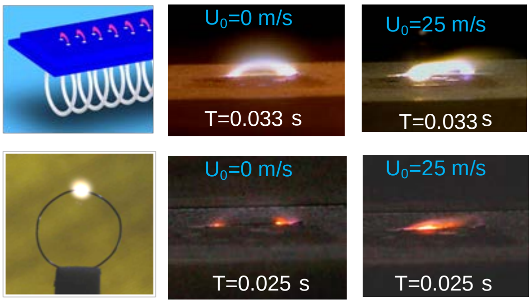


Figure 3. Quality (temperature) of single plasma discharges depending on free-stream velocity and MW-pulse duration, MW power P_{MW}=1.2 KW

Experiments aim at measurements of lift, drag, pitch moment coefficients and pressure distribution over test models depending on a free-stream velocity, model angle of attack as well as a set of thermal control parameters [4].

To minimize energy consumption for plasma assisted flow control, pulsating modes of MW radiation were tested. To choose optimal values of pulsation parameters (MW pulse duration τ and repetition rate F), aerodynamic modeling was implemented. Figure 5 shows patterns of longitudinal vorticity at consecutive moments downstream of the MW initiated plasma array. Under conditions of correctly chosen pulse parameters, thermal wakes generated by subsequent pulses merge resulting in a regular vortical structure propagating downstream.

An adequate flow response to the scale of introduced disturbances supposes certain sustainability of the organized structure and its impact on integral flow characteristics.

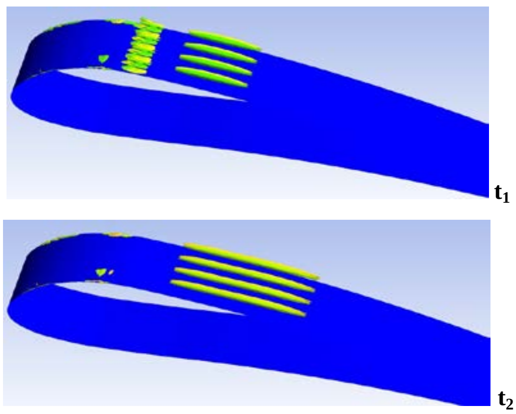


Figure 4. Development of longitudinal vorticity at a pulsed mode of plasma discharges:
U_0=20 m/s, α=5°, τ=100μs, F=1000 Hz

Figure 5 shows results of wind-tunnel testing of the model equipped with an array of MW plasma actuators.

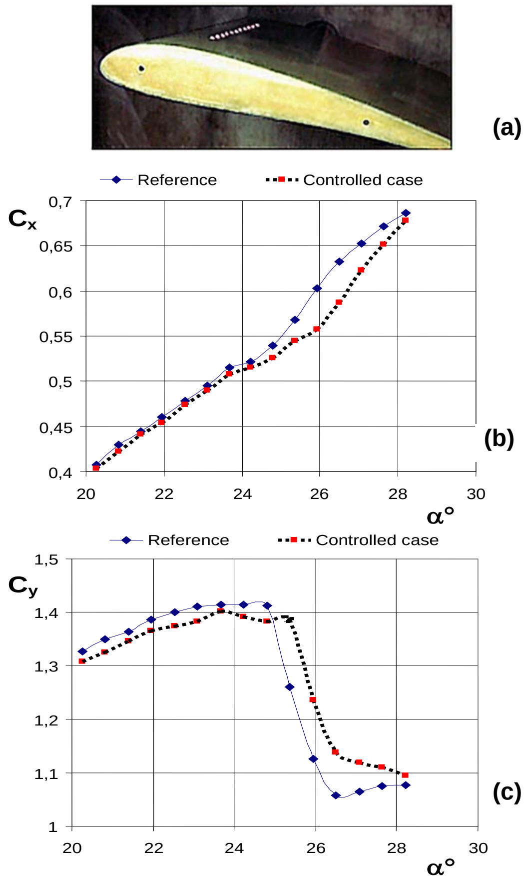


Figure 5. Measured drag (b) and lift (c) coefficients of a plasma-controlled model (a): U_0=15 m/s, Δz=10 mm; MW pulse parameters, τ=0.1 ms, F=1000 Hz

CONCLUSION

The developed concept of flow control is validated numerically and experimentally. It consists in generation of a spanwise thermal regularity in the flow (thermal riblets). This boundary condition can be realized in a form of the "streaky" surface heating or similar fluid heating with an array of plasma discharges (virtual thermal riblets) which affect the flow identically. A possibility to reduce drag with the simultaneous raise of lift was found in a range of the model angles of attack.

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