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THE ROUGHNESS POSITION INFLUENCE ON LAMINAR AEROFOIL AERODYNAMIC CHARACTERISTIC IN TRANSONIC FLOW REGIME

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Abstract

The test with a roughness application on the laminar aerofoil has been conducted in the N-3 trisonic wind tunnel of the Institute of Aviation in Warsaw. The main goal of tests was to investigate the influence of different transition positions between the leading edge and a shock wave position on a laminar profile characteristic. As a local roughness on the upper model surface the carborundum strip was applied. Investigation results shown that some of transition positions improves an aerodynamic characteristic by reducing the drag coefficient value and decreasing shock wave unsteadiness in the transonic regime.

1 General Introduction

Worldwide air carriers companies are modifying their aircrafts to be more safe and even more economic. This two advisable features are tight connected with aircrafts design. The wing is such an important factor that influences both: on safety and economic of flight. The "economical" wing should provide good flight performance. This of course is connected with lift and drag forces. In general, the best economic situation is when the lift from a wing reach highest values and a drag is reduced to a minimum during flight. Such are laminar type aerofoils. However, laminar aerofoils maintain advantageous laminar boundary layer (BL), the shock wave boundary interaction (SWBLI) could cause severe flow separation and instabilities. The idea of fixing problem of disadvantageous SW behaviour is to change the laminar shock wave interaction on the turbulent one in front of the SW. This could be achieved by adding various types of transition triggers: roughness, self-supplying and conventional AJVGs, hot wire, plasma, and others. Some of methods allowing for decrease the SW oscillations are described in [4].

The main purpose of the TFAST (Transition Location Effect on Shock Wave Boundary Layer Interaction, project in 7th EU Framework Programme) project was to study the roughness position influence on the SWBLI phenomenon. During wind tunnel tests performed in the Institute of Aviation (IoA), the incipient transition was initiated by the carborundum strips. Various locations on the upper model surface in front of the SW were considered. The roughness height was determined by method described in [1] and on base IoA numerical calculations.

In order to maintain laminar BL up to SW for base model, designed by Dassault Aviation the V2C laminar airfoil was used (mentioned in work [2]). Numerical predictions revealed that the laminar boundary layer at M=0.7 and Re= 3.42mln was maintaining up to angle of attack $\alpha=7^0$.

2 Tests equipment and methods

2.1 Wind tunnel

Experimental tests were conducted in the trisonic wind tunnel N-3 of IoA in Warsaw [3]. The wind tunnel is a blow-down type with partial re-circulation of the flow. The square cross section dimensions are: 0.6 m x 0.6 m , Length 1.58 m (Figure 1). During investigation solid walls (top and bottom) were mounted.

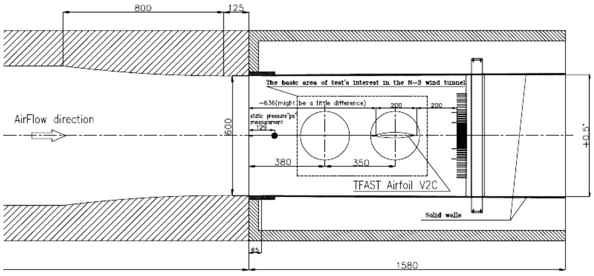

Fig. 1: The N-3 wind tunnel test section

2.2 Model and tests equipment

The tested V2C airfoil model thickness was of about 15%, chord 0.2 [m] and span 0.6 [m]. Model shape accuracy was equal ±0.06-0.08 [mm] and surface roughness accuracy was ~1 [µm]. The model surface was darkened.

The model was equipped with static pressure tubes for steady pressure measurements. Straight rows of static pressure points were located both on the top and bottom surface of the model (Figure 2). In order to measure drag the aerodynamic rake was mounted behind the model at distance one chord behind. Model was connected to the pressure DTC INITIUM system.

The strain gauge sensor for model vibration RMS was also used. The frequency rate was 10 kHz.

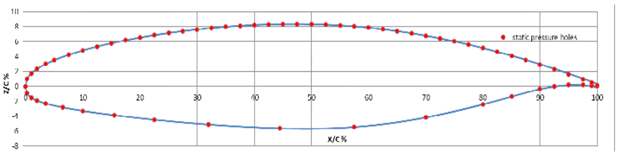

Fig. 2: The static pressure orifices locations at the model surface

2.3 Transition means

The carborundum strip was 0.10 [mm] height and 4 [mm] width. Carborundum grains were attached to model surface by the use of varnish and fixed through the wingspan. The roughness on the model upper surface (in respect to airfoil chord) were located in : 50%c, 40%c, 30%c, 20%c, 10%c.

2.4 Test methodology and data reduction

Wind tunnel tests were performed for two constant Mach numbers: M=0.7, 0.75 . Corresponding Reynolds numbers were Re≈2.85 mln and ≈3 mln. The angle of incidence was changed in range α_i: 0-8° and 0-5°. Clean and with roughness model configurations were tested. The measured pressure on the model surface was averaged from 2-3 seconds data collecting time. Pressure coefficient and aerodynamic coefficients were calculated analogical to [5].

3 Results and discussion

3.1 M=0.7, Re=2.85mln

Wind tunnel results indicated, that highest values of the lift coefficient, independently of the angle of incidence were estimated for clean model configuration. There were few exceptions of this rule for carborundum cases, where a grain strip was just ahead of the shock wave. This was because the pressure distribution over model surface in vicinity of a turbulent trigger was modified.

This happens especially at higher angles of incidence. However, the roughness strip located close to SW could sometimes generating higher lift coefficient value, the change was minor. As far as only carborundum cases are taken into account, these located closest to the SW indicated on the highest lift values.

The exemplary Cp distribution (averaged) plot for α_i=4° and Mach number M=0.7 is presented in Figure 3. The smooth Cp value drop for clean model configuration is observed. The shifting of the carborundum strip upstream made the pressure drop closer to the leading edge and more rapid. The presented Cp distributions were compared with the CFD computations performed in the Institute of Aviation. The comparison shown quite well agreement [6].

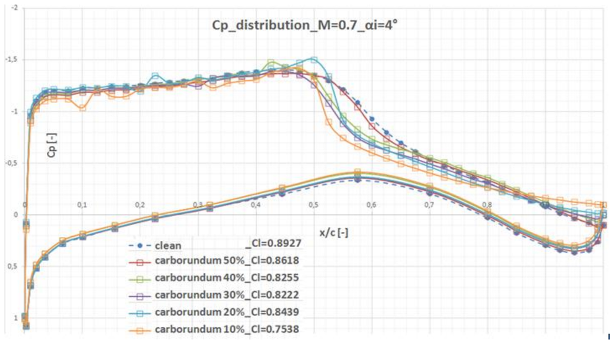

Fig. 3: The static pressure orifices location at the model surface, M=0.7, αi=4 ^{0}

Drag coefficient values for clean and carborundum model configurations are presented in (Table 1). Lowest drag coefficient values were reached at low angles of incidence and for clean model configuration.

At moderate angles of incidence the lowest drag value referred to different carborundum configurations. At higher incidence, turbulised BL near the leading edge influenced on decreasing the drag value. The lowest drag value was achieved for carborundum strip at 10% of model chord position.

Table 1. Drag coefficient values, M=0.7

Config.	clean	50%c	40%c	30%c	20%c	10%c
αi [°]	**Drag coefficient**					
0	0,0103	0,0108	0,0104	0,0108	0,0116	0,012
1	0,0106	0,0112	0,0109	0,0116	0,0121	0,0128
2	0,0139	0,0149	0,0135	0,0133	0,014	0,0144
3	0,0347	0,038	0,0399	0,0218	0,0194	0,0205
4	0,0657	0,0682	0,0722	0,0574	0,0393	0,0422
5	0,0966	0,0985	0,0966	0,1	0,0903	0,069
6	0,1239	0,1282	0,1294	0,1197	0,1144	0,0798
7	0,1518	0,1595	0,1511	0,1468	0,1188	0,0904
8	0,1728	0,1782	0,1692	0,173	0,1532	0,1086

In Table 2 the approximate shock wave % of chord position (from Schlieren picture), lift, drag coefficients and lift/drag ratio values were presented. At Mach number M=0.7 and α_i=4° the best flow performance was noticed for 20% chord carborundum location.

Table 2: Test data for α_i =4° and Mach number M=0.7

carborundum	clean	50%_c	40%_c	30%_c	20%_c	10%_c
x_sw	0,61	0,605	0,595	0,575	0,56	0,535
Cl	0,8927	0,8618	0,8255	0,8222	0,8439	0,7538
Cd	0,0657	0,0682	0,0722	0,0574	0,0393	0,0422
Cl/Cd	13,58752	12,63636	11,43352	14,32404	21,47328	17,86256

Strain gauge measurements shown that the increase of the root mean square (RMS) value of model vibration appears at higher angle od incidence for (Figure 4). Moreover, the measured frequency (of SW movement) increases a little when shifting carborundum strip into the leading edge direction (Figure 5).

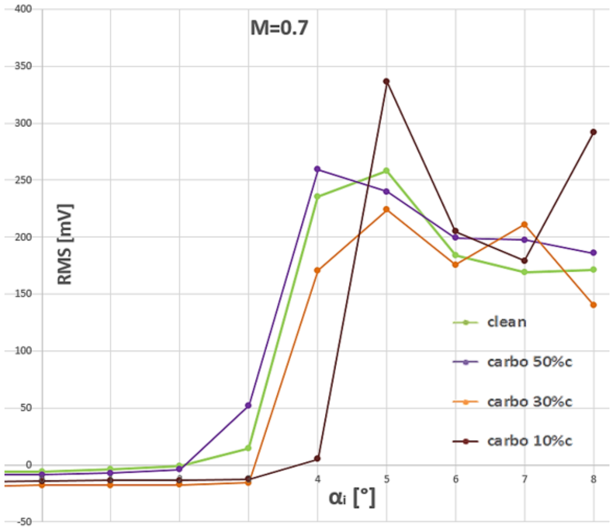

Fig. 4: The RMS of measured value from strain gauge balance, M=0.7

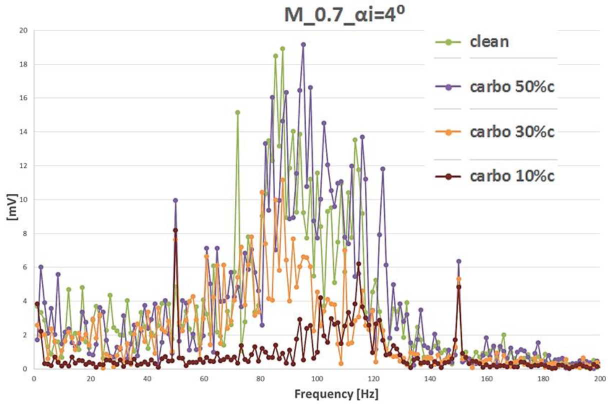

Fig. 5. The frequency analysis of measured value from strain gauge balance, M=0.7, αi=4 ^{0}

3.2 M=0.75, Re=3 mln

Highest values of the lift coefficient, (similar at it was at M=0.7) independently of the angle of incidence were estimated for clean model configuration.

Drag coefficient values for clean and carborundum model configurations are presented in (Table 3). Lowest drag coefficient values in tested range of the angle of incidence were reached for model with carborundum strip located at 10% of chord.

The increase of RMS value of model vibration for all tested configurations was already present at $\alpha_i=0^o$ (Figure 6). The rate of its increase was lowered when shifting carborundum strip into the leading edge.

The measured frequency (of SW movement) increases a little when shifting carborundum strip into the leading edge direction (Figure 7).

Table 3. Drag coefficient values, M=0.75

Config.	clean	50%c	40%c	30%c	20%c	10%c
αi [°]	**Drag coefficient**					
0	0,0232	0,0184	0,019	0,0202	0,018	0,0178
1	0,0413	0,0543	0,0383	0,0294	0,0265	0,0257
2	0,062	0,0616	0,0595	0,0347	0,0376	0,0291
3	0,0738	0,0762	0,0759	0,0456	0,0466	0,0439
4	0,0915	0,0901	0,0867	0,0598	0,0576	0,0547
5	0,0795	0,1055	0,0998	0,0812	0,0655	0,0634

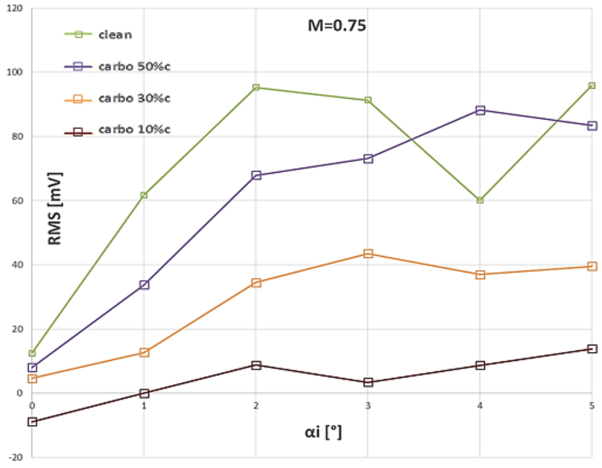

Fig. 6. The RMS of measured value from strain gauge balance, M=0.75

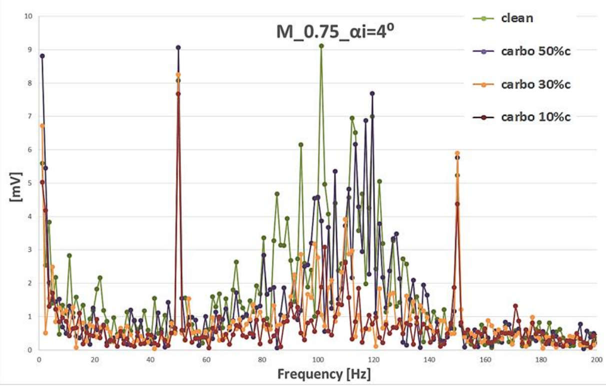

Fig. 7. The frequency analysis of measured value from strain gauge balance, M=0.7, αi=4 ⁰

4 Conclusions

The roughness strip application on laminar aerofoil could improve aerofoil aerodynamic characteristic in transonic flow regime, especially at higher angle of incidence. Additionally the shock wave oscillation amplitude is decreased due to turbulent SWBLI, when applying transitions triggers. The optimum position of transition trigger depends on airfoil angle of incidence and Mach number. At low angle of incidence, for low speed, where SW and separation behind is weak, it was observed that clean case model has better performance than with applied transition triggers.

However, the optimum trigger position was estimated for chosen Mach number and angle of incidence in this work, the height of the carborundum grain influence should be investigated.

During the study the BL status on the model surface wasn't checked. There was a possibility, that for clean model configuration the BL would tubulise by itself. So then, in future investigations the model surface quality influence on BL condition will be investigated.

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