VISUALIZATION OF BOUNDARY LAYER TRANSITION BY SHEAR SENSITIVE LIQUID CRYSTALS AT SUBSONIC FLOW VELOCITIES

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KEYWORDS:

Main subjects: laminar-turbulent transition, flow visualization
Fluid: subsonic flows
Visualization method(s): shear sensitive liquid crystals

ABSTRACT**:** Method of visualization of the laminar-turbulent boundary layer transition by shear stress sensitive liquid crystals on the models in subsonic wind tunnels (WT) was under research in this paper. The tests were performed at flow velocities in the range of V = 10 m/s to V = 80 m/s (and corresponding dynamic pressures from 57 to 3922 Pa) at different angles of attack in T-103 subsonic wind tunnel with an open test section in TsAGI. The method was investigated on a wing panel of a metallic fuselage-wing model. The transition of the boundary layer was successfully observed at flow velocities V = 30-80 m/s and angles of attack α = 0-6º.

INTRODUCTION

It is necessary to know the position of the laminar-turbulent transition on the model surface in the wind tunnel for recalculation of the wind tunnel results to the conditions of flight. Usually the following effects are used for visualization of laminar-turbulent boundary layer transition: the effect of the heat transfer increase (temperature sensitive paints, infrared technique) or mass transfer increase (china clay, naphthalene, acenaphthene) in the laminar-turbulent transition zone. The possible alternative is the method of shear stress sensitive liquid crystals (LC) as the laminar-turbulent transition is also characterized by significant shear stress increase. This method allows visualization of the transition on metallic models in contrast to temperature sensitive paints and infrared technique and also allows investigation of several flow regimes (angles of attack) in one wind tunnel test without flow interruptions and re-preparation of the model due to the liquid crystals' reversibility. This method is well known but it is rarely used in industrial tests.

The objective of this work is the adjustment of the method of shear stress sensitive liquid crystals to industrial subsonic wind tunnels by the example of T-103 wind tunnel in TsAGI (Central Aero-Hydrodynamic Institute) and also the clarification of common questions of liquid crystals application in wind tunnels with closed test sections. In particular different layouts of illuminating and registration equipment were investigated.

EXPERIMENTAL METHOD AND PROCEDURE

The experimental method is based on registration of the optical response of the liquid crystals on the shear stress induced by the flow in the wind tunnel [2]. The periodical helical structure of cholesteric liquid crystals defines their ability to reflect the falling light selectively. In temperature range of the selective reflection the layer of the cholesteric LC seems to have one color at the fixed registration angle and this color is defined by the helix pitch P. The pitch in turn depends on the external factors, temperature and shear stress in particular. In out tests the cholesteric shear stress sensitive liquid crystals with poor temperature sensitivity in the range of ΔT= (293-323)К were used.

The LC coating is applied on the model surface by sprayer or even by brush and it forms a thin layer (dozens of micrometers) that does not change the model shape. The appropriate molecular orientation is initialized by brush and the coating starts to reflect the falling light selectively with the wavelength depending on the helix pitch of the liquid crystals [3]. This initialization process transforms the focal-conic texture to planar texture by applying shear stress. Under the shear stress induced by the flow the local helix pitch changes (deviates from its initial value) and the dominant wavelength of the reflected light shifts to the shorter wavelength region. At the same time the wavelength shift is proportional to the value of the shear stress and it allows visualization of the boundary layer transition. The falling light reflects from the surface with the LC coating as a three-dimensional color spectrum. The spectrum change depends not only on the value (amplitude) of the shear stress but also on the angle between the observation direction and the direction of the shear stress vector in horizontal plane. The light reflected by the model surface is registered by the color photo-camera. In case of the decrease of the LC coating thickness the wavelength of the maximal emission is the same and only the decrease of the reflected signal intensity appears [1].

The model surface is black painted before applying the LC coating. Such painting is necessary for reducing the light diffused by the model surface and for increasing the visualization image contrast made by light reflected by liquid crystals thereby.

Painting was performed by spraying by black water-soluble acrylic paint. To speed up the paint drying the model was heated with incandescent lamps after painting. The drying process took near 15 minutes.

The thickness of the black paint coating according to visual estimation does not exceed 20 µm.

The LC coatings were applied by brush. The mixture of acetone and toluene was used as a solvent and it is preferable to apply the coating by brush to reduce the pestiferous exhalations and to economize the LC mixture. Two types of liquid crystals developed in ITAM (Institute of Theoretical and Applied Mechanics) were applied. The total thickness of black paint and LC coating was about 40-50 µm.

When LC coating dries up it is necessary to carry out its' initialization if the coating was applied by sprayer. Initialization is not needed if the coating was applied by brush. At the same time it was found that there is a tendency of reverse transformation of the planar texture to focal-conic and that's why it is better to carry out the initialization directly before the test.

ILLUMINATION AND REGISTRATION SYSTEMS

The measurement system for using the method of liquid crystal coatings consists of two parts: the white light illuminator and the color photo-camera.

The illumination of the model with the white light was performed by «Integra Pro-1000» flash-lamp made by «Hensel» with the electric flash energy up to 1 kJ. The pulse illumination is preferred in conditions of the external lighting and the vibration of the model or/and of the photo-camera. Digital color photo-camera Nikon D3X was used for registration of the color images of the model.

Three spatial layouts of the equipment arrangement were investigated:

- The lighter is down-stream the model on the WT diffuser, the camera is up-stream the model on the nozzle;
- The lighter is above the model on the coordinate device, the camera is up-stream the model on the nozzle;
- The lighter is up-stream the model on the nozzle, the camera is above the model on the coordinate device.

The first layout was found unacceptable due to the glare that was practically in the centre of the wing and occupied its considerable part.

The second layout is recommended in literature and the optimal observation angle is considered to be 30º in respect to the LC sensitivity. The design of the wind tunnel (short test section) allowed to obtain only 51º observation angle (at the angle of attack α=0º). The distance from the camera to the wing was 2.250 m. The illuminator was installed perpendicularly to the wing surface at a distance of 2.630 m.

The third layout differs from the second one only in the interchange of the positions of the illuminator and the camera. The third layout is the most attractive in respect to the perspective of the model observation and to the realization convenience, especially in wind tunnels with closed test sections. It is easier to arrange the illuminator than the camera up-stream the model.

At the second and the third layouts the glare was situated at the front edge of the model wing and does not really prevent the transition visualization.

It was found that the electric energy of the flash lamp that was needed to acquire the image of the model surface with the LC coating by the camera at all spatial arrangements of the equipment was only 30 J.

TEST CONDITIONS

The tests were performed in conditions of T-103 subsonic wind tunnel in TsAGI. It is a continuous wind tunnel of a closed-loop type with one reverse channel and an open test section. The flow velocity varied in the range of V = 10 m/s to V = 80 m/s (and corresponding dynamic pressures from 57 to 3922 Pa). The method was investigated at a wing panel of a metallic fuselage-wing model. Two types of liquid crystal coatings developed in ITAM were used while performing tests. Seven wind tunnel runs were made and its parameters are presented in the table.

Table. Flow parameters of the tests performed in the T-103 wind tunnel.

№of the launch	Velocity, m/s	Angle of attack, deg.	Duration of the launch, min	Optical layout	Initialization direction
1	Technological launch: examination of the system operation				
2	60	0-26	5	2	Across the flow
3	10-80	0	5	2	Across the flow
4	10-80	3	5	2	Across the flow
5	60	0-26	5	3	Across the flow
6	10-80	3	5	3	Along the flow
7	60	1-5-1	15	3	Along the flow

The air temperature in the wind tunnel was 18ºC while preparing the model and performing the tests and only during the last continuous launch the temperature increased up to 20ºC.

The layout of the T-103 test section and the researched model mounted on the support mechanism is presented in the figure 1. Tufts that were used in the previous tests can be seen on the model. These tufts were eliminated only from the investigated wing panel.

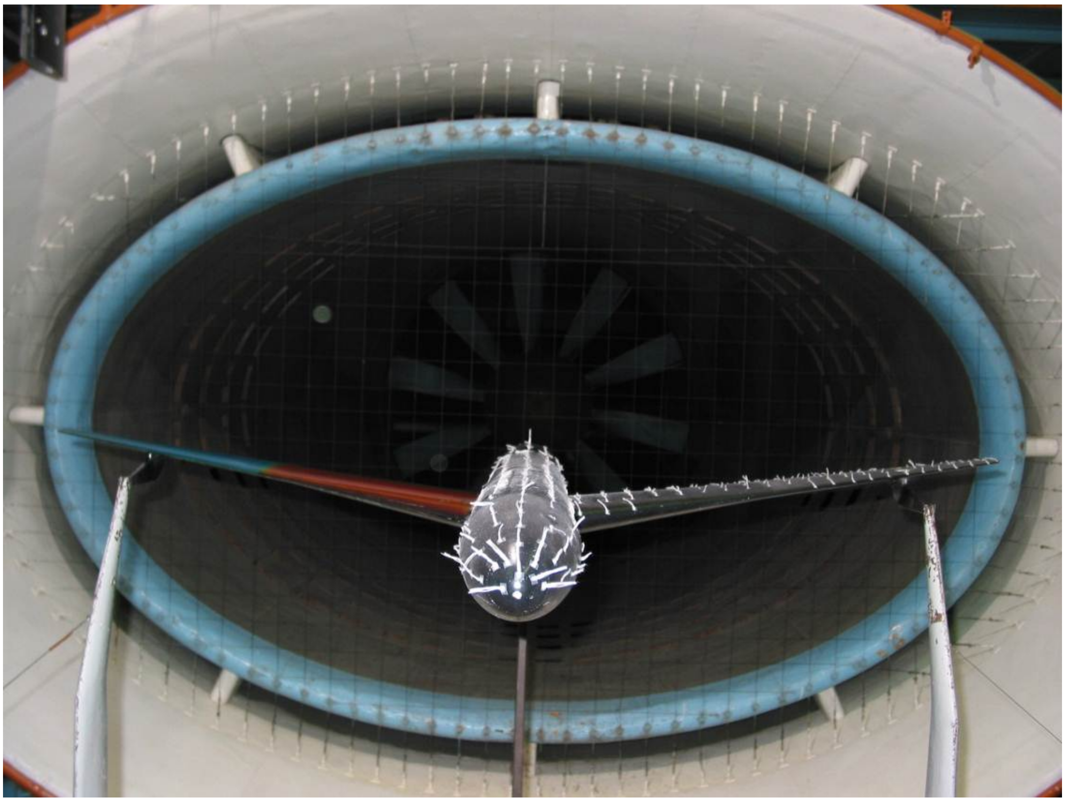

Fig. 1 Layout of the model in the T-103 test section

EXPERIMENTAL RESULTS

The color images obtained as the result of the tests were contrasted in Adobe Photoshop by changing the color hue in the colorimetric system HSI (Hue, Saturation, Intensity). Hue – is the color tone or a color coordinate of the image; it is measured in degrees form 0 to 359 (namely, 0 degrees – red, 60 degrees – yellow, 120 degrees – green, 180 degrees – blue, 240 degrees – dark blue and 300 degrees – purple).

The results of visualization of the boundary layer transition at different flow velocities at the angle of attack $\alpha = 3^{o}$ are presented in the figure 2. At the flow velocities V = 10 and 20 m/s the transition was not detected. Apparently the flow is entirely laminar at these velocities. In this example the camera was situated perpendicularly to the model surface.

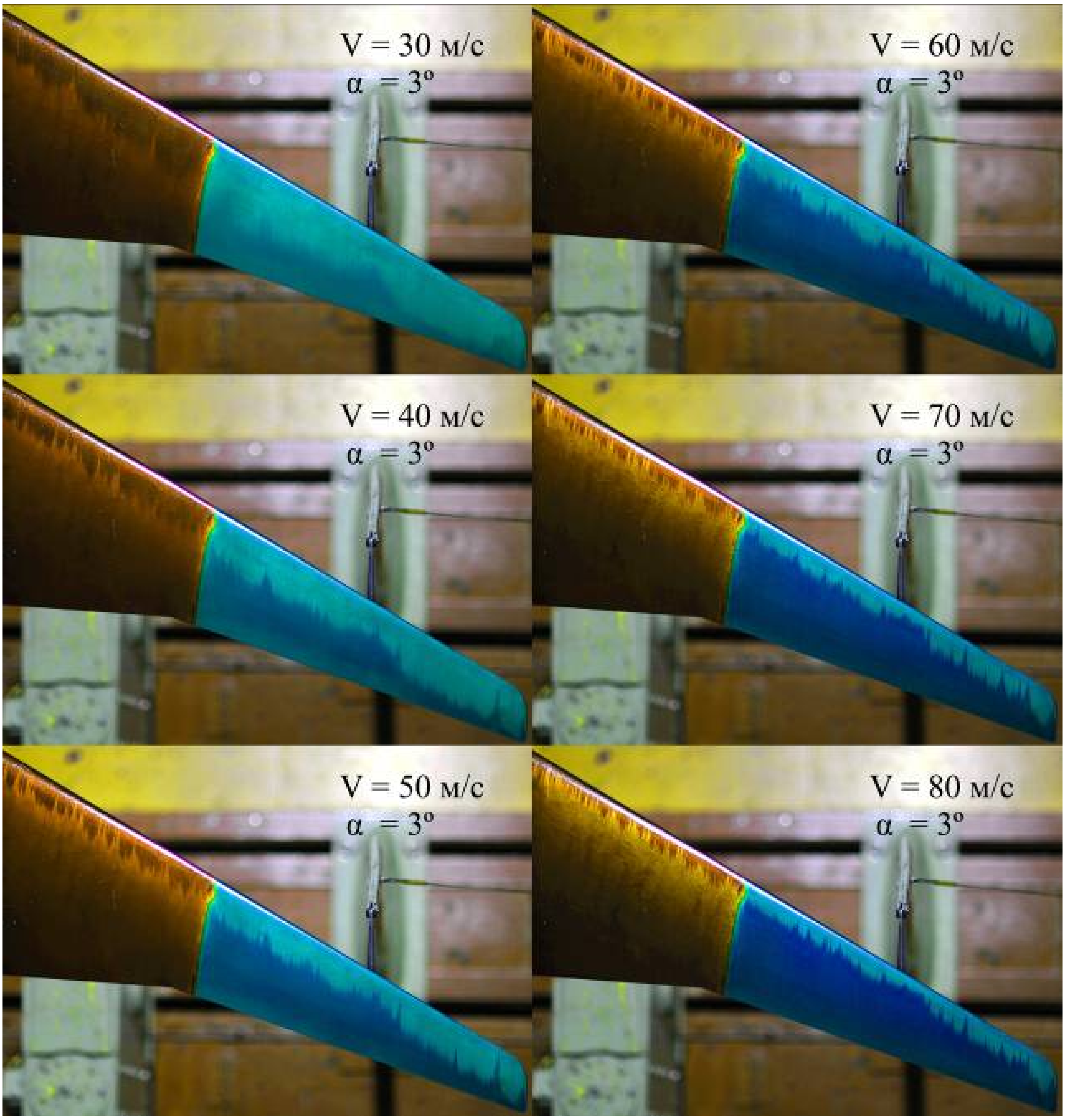

Fig. 2 Visualization of laminar-turbulent transition by shear stress sensitive liquid crystals at different flow velocities, angle of attack $\alpha = 3^{o}$, LC initialization along the flow

In the figure 3 the results of visualization of the boundary layer transition at different angles of attack at the flow velocity V = 60 m/s are presented. It is seen that when the angle of attack changes and the transition line moves the previous transition line is still visible. It was found that this effect is connected with the direction of initialization of the LC coating. Before the launch presented in the figure 3 the initialization of the coating was performed across the flow. When the initialization is performed along the flow the laminar-turbulent transition looks less contrasting but at the same time the memory effect is less considerable. To a greater extent the memory effect is peculiar to the blue LC coating.

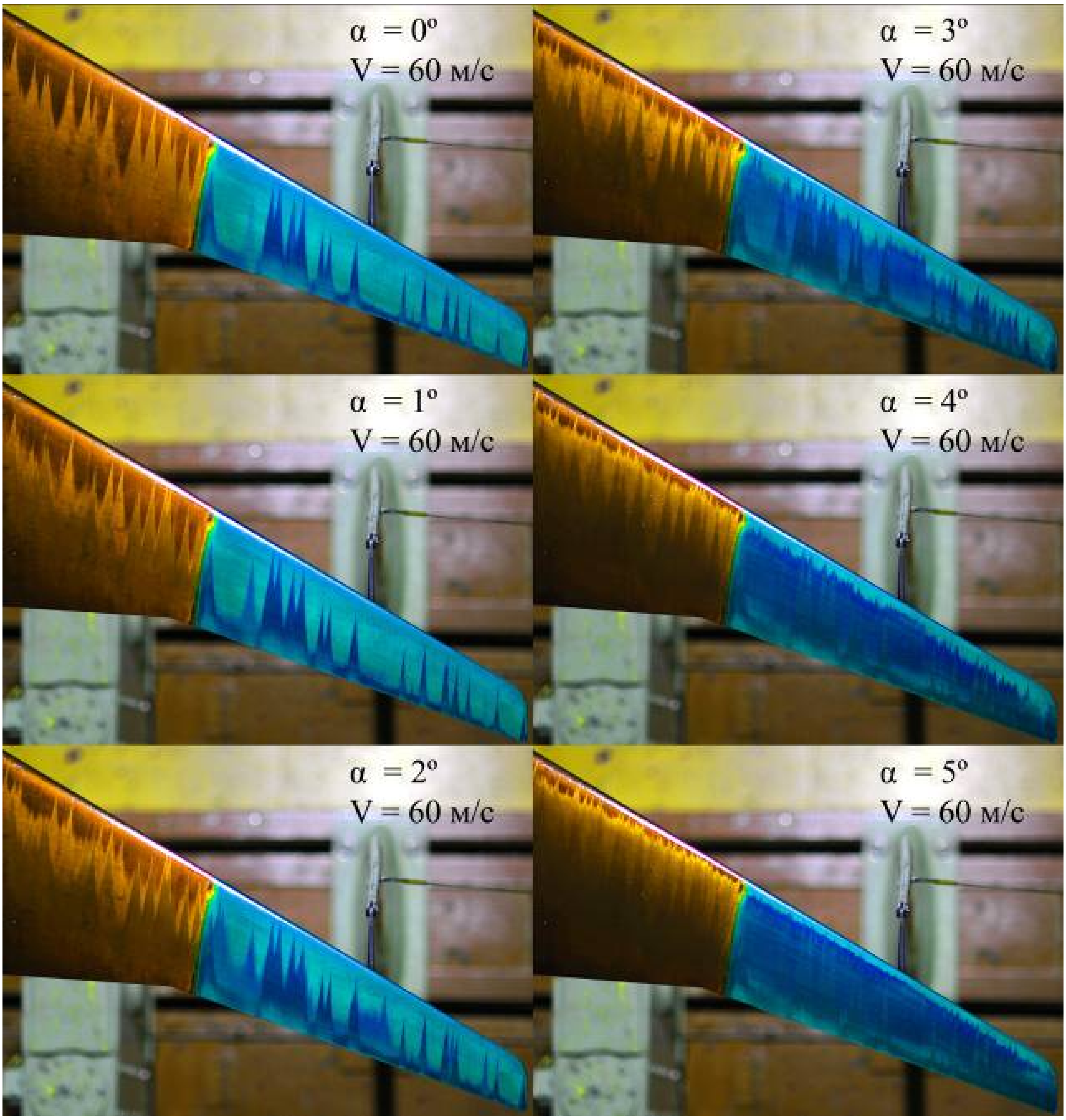

Fig.3 Visualization of laminar-turbulent transition by shear stress sensitive liquid crystals at different angles of attack, flow velocity V=60m/s, LC initialization across the flow

It is significant that the both types of LC coatings showed good efficiency. It is difficult to define the best one. The blue coating obtains a little bit higher sensitivity but at the same time it reveals the memory effect to a greater extent than the red one.

CONCLUSION

The laminar-turbulent transition of the boundary layer was successfully visualized at the flow velocities V = 30-80 m/s and the angles of attack α = 0-6º during the tests performed in T-103 wind tunnel with an open test section in TsAGI. Two types of LC coatings developed in ITAM were investigated and the both of them were efficient in the conditions of the performed tests.

The important result of the performed tests is the fact that the camera and the illuminator can be interchanged and the angle between them is the only significant aspect. The possibility of arranging the camera above the investigated surface and the illuminator up-stream the model improves the observation perspective of the model surface and opens up the possibilities of using the method in the wind tunnels with closed test sections where there are no optical windows in the walls up-stream the model as a rule.

References

1. Zharkova G.M. et al. *Liquid crystal composites.* Nauka, Novosibirsk, 1994 (in russian)
2. Reda D. et al. *Measurement of surface shear stress vectors using liquid crystal coatings*. *AIAA J.,* 1994, 32, p.1576.
3. Belyakov V.A., Sonin A.S. *Optics of cholesteric liquid crystals.* Moscow: Nauka, 1982, 360 p. (in russian)