Wave forerunners of localized structures on straight and swept wings at a high free stream turbulence level

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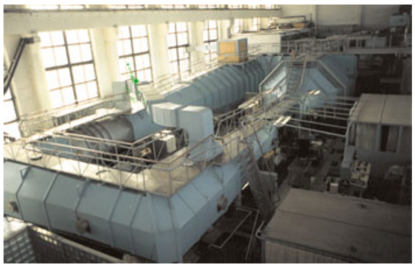
Main building



Low-turbulence wind tunnel T-324

Journal of Applied Mechanics and Technical Physics, Vol. 42, No. 5, pp. 765–772, 2001

GENERATION OF PERTURBATIONS BY A LOCALIZED VIBRATOR IN THE BOUNDARY LAYER OF A NONSWEPT WING

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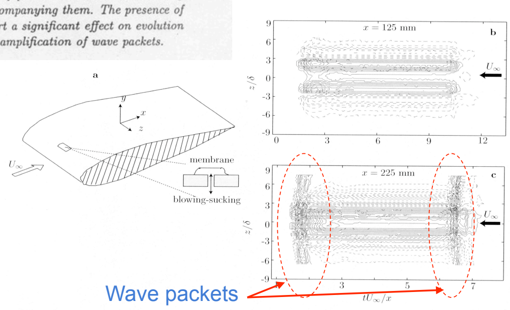
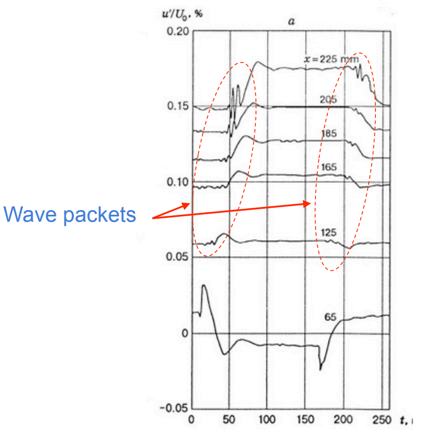
UDC 532.526

Origination and development of perturbations generated by a three-dimensional vibrating surface in the boundary layer on an airfoil with a zero slip angle is experimentally studied. Surface vibrations were generated by a Mylar membrane. It is shown that high-amplitude vibrations of a three-dimensional surface lead to simultaneous formation of two types of perturbations in the boundary layer: quasi-stationary streamwise structures and wave packets accompanying them. The presence of regions with favorable and adverse pressure gradients does not exert a significant effect on evolution of streamwise structures but leads first to attenuation and then to amplification of wave packets.

At this paper an wave packets were detected at the leading and trailing front of the localized disturbance, which is generated at the boundary layer by membrane. At further experiments those wave packets were named as "Forerunners".



Localized disturbances generation by membrane vibration on a straight wing: **a** overview of experimental set-up; **b** the structure of localized disturbances at a favourable pressure gradient (velocity excess and defect is 3.6% and 2.1% of U_∞, respectively); **c** the structure of localized disturbances at an unfavourable pressure gradient (velocity excess and defect is 4.2% and 3.6% of U_∞, respectively). *Solid lines*, velocity excess; *dashed lines*, velocity defect. U_∞ = 6.6 m/s, $y = y(u'_{max})$ (Spiridonov and Chernorai 2000)

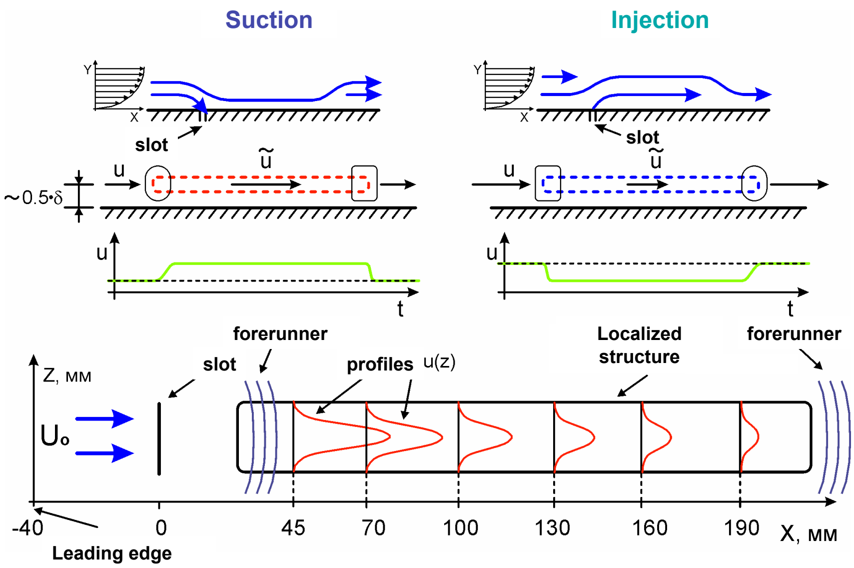


Oscillograms of velocity fluctuations u' for various values of x at $z = 0$

Time traces of a 3-D vibrator generating simultaneously two types of perturbations in the boundary layer: quasi-steady streamwise structures of the "puff" type and wave packets accompanying the streamwise structures.

The streamwise structures induce unstable flow regions at their fore and back fronts. At those regions an intense growth of wave packets occurs in the case of an adverse pressure gradient.

Suction-injection tecnique



Thermophysics and Aeromechanics, 2001, Vol. 8, No. 2

LAMINAR-TURBULENT TRANSITION CONTROL AT HIGH LEVEL OF TURBULENCE OF EXTERNAL FLOW USING LOCALIZED INJECTION/SUCTION METHOD*

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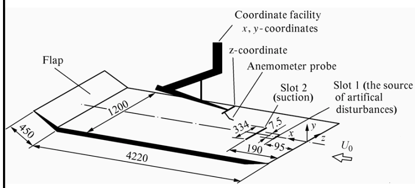
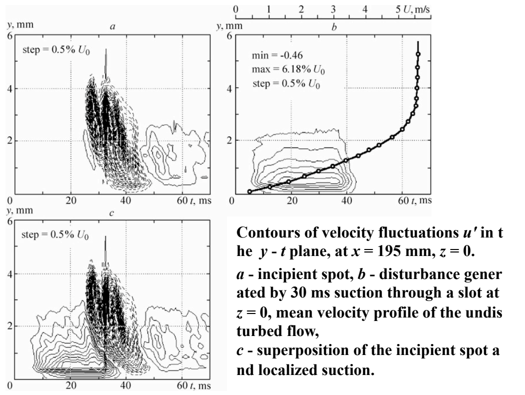
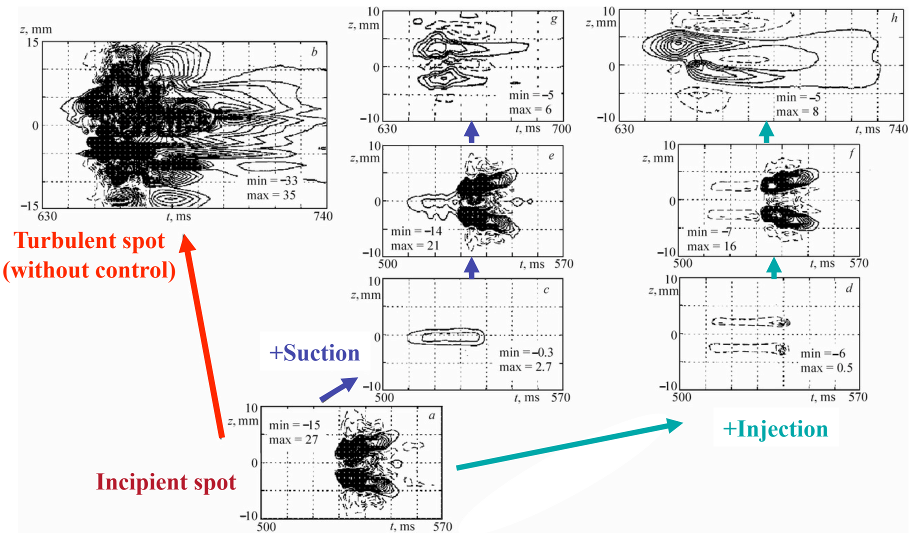
A localized injection/suction effect on development of longitudinal streaky disturbances originated in the boundary layer in consequence of a high level of free stream turbulence under controlled conditions was studied experimentally. It was shown that injection/suction character significantly depends on their position relative to interior structure of the investigated longitudinal disturbances. Influence of localized injection/suction on the region with velocity gradient in transverse direction *dU/dz*, which, as it is known, is favorable for development of the secondary (relative to the longitudinal disturbance) high-frequency instability, was investigated.



Experimental scheme



Contours of velocity fluctuations u' in the y - t plane, at x = 195 mm, z = 0.
a **- incipient spot,** ***b*** **- disturbance generated by 30 ms suction through a slot at** z **= 0, mean velocity profile of the undisturbed flow,**
c **- superposition of the incipient spot and localized suction.**



Contours of velocity fluctuations u' in the z – t plane at $y = y_{u'max} U = 0.5U_0$.
a **is the incipient spot at x = 195 mm,** ***b*** **is the turbulent spot, x = 700 mm,** ***c*** **is the suction region, x = 195 mm,** ***d*** **is the injection region, x = 195 mm,** ***e*** **is at interaction between the suction region and the incipient spot, x = 195 mm,** ***f*** **is at interaction between the injection region and the incipient spot, x = 195 mm,** ***g, h*** **are the results of interaction, x = 700 mm.**

Reactive control of streamwise streaks

Fredrik Lundell & P. Henrik Alfredsson

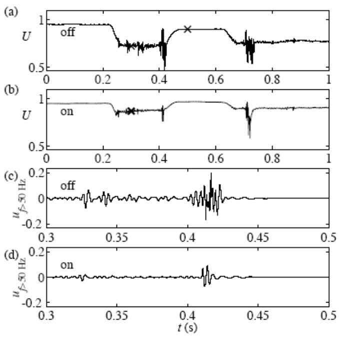


FIGURE 10. Velocity traces from the setup with triggering of the secondary instability. In (a) and (c) no control was applied, in (b) and (d) reactive control was applied so that the control suction was turned on during the passing of the low-velocity streak in question. In (c) and (d), the signal has been high-pass filtered at 50 Hz in order to isolate the high frequency oscillations. The position is $(x, y, z) = (200, 0.2, 0)$. In the controlled case the controller parameters are $\tau = 0$ and $\Delta = 0.6$.

The experiments showed a possibility of real-time control of the growth of longitudinal structures (incipient spots) by affecting to them by localized injection/suction. Optimum position and duration of injection/suction were found for more effective application. The injection/suction should be applied before the front of longitudinal structure.

The localized suction can decrease the growth of the secondary, high- frequency oscillations on the streaks.

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GENERATION AND DEVELOPMENT OF "PASSIVE" DISTURBANCES IN THE BLASIUS BOUNDARY LAYER

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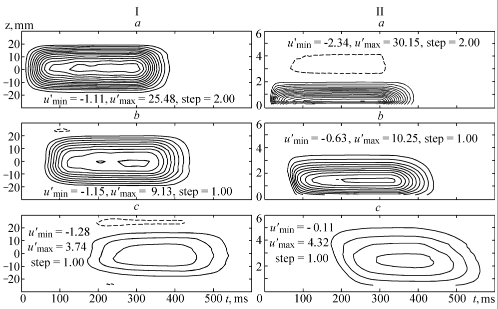
(*Received April 19, 2001*)

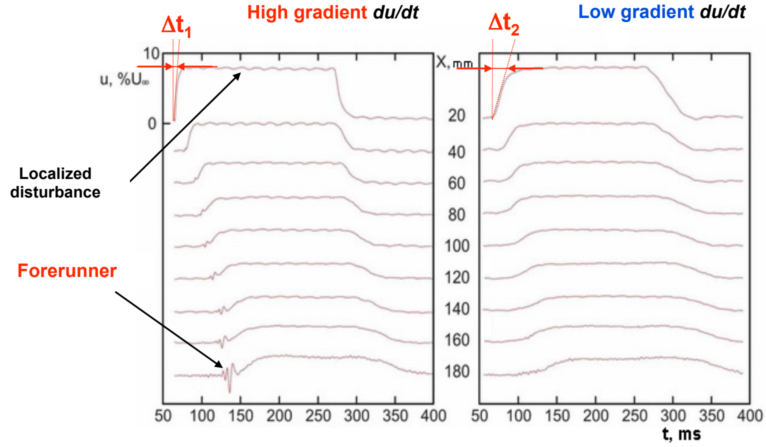
The characteristics of specific disturbances localized in space under modelling conditions in the Blasius boundary layer on a flat plate were investigated. The experiments were carried out in low-turbulent subsonic wind tunnel using a hot-wire anemometer for disturbances registration. It is shown that in the boundary layer among other known disturbances (the Tollmien — Schlichting waves or wave packets, longitudinal localized structures or so-called puffs, turbulent spots, vortices [1, 2]) the other disturbances with the strictly definite characteristics determined as passive can be present. The term "passive" means that the disturbances cannot be a straight source of turbulence and do not create other disturbances in the development process (as, for example, puff-structures which generate the Tollmien — Schlichting wave packets in the propagation process). At the same time, they can create the necessary condition for other types of disturbances growth, for example, the secondary high-frequency fluctuations, and, by this means, participate indirectly in a flow turbulization. The considered structures can be used for a control of laminar-turbulent transition process, i. e., to delay or to provoke an onset by effecting on the other disturbances (puff-structures, the incipient spots), which are responsible for the flow turbulization.



Contours of velocity fluctuations *u'* in the z-t (I) and y -t (II) planes, large amplitudes. The source of disturbances is a transverse slot at x = 95 mm. The disturbance is generated by suction during 300 ms. I: x = 100 (a), 200 (b), 500 mm (c); II: a- x = 100 mm, δ = 3 mm; b- x = 200 mm, δ = 4 mm; c- x = 500 mm, δ = 6 mm.

1. **It was shown that the "passive" disturbances can exist in the boundary layer in a wide range of their amplitudes.**
2. **It was revealed a principal role of the velocity gradient *dU/dx* (*dU/dt*) in the regions of the leading and back fronts of the disturbances for excitation of the different flow structures in the boundary layer.**

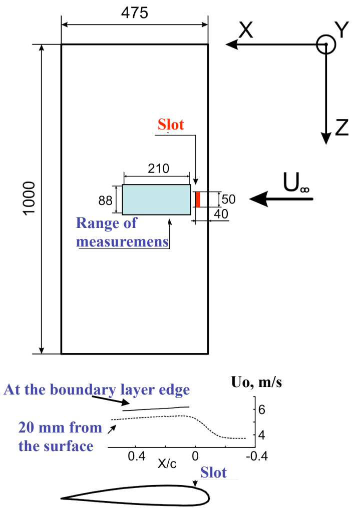
Origination of the forerunners



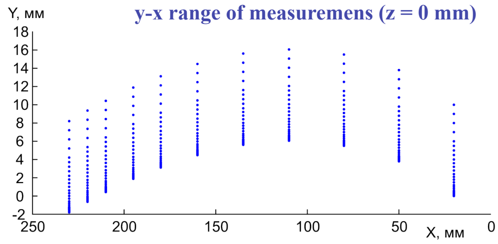
Time traces illustrating the influence of *du/dx (du/dt)* gradient on the origination of forerunners. Suction.

Detailed investigations of the wave forerunners on the straight wing

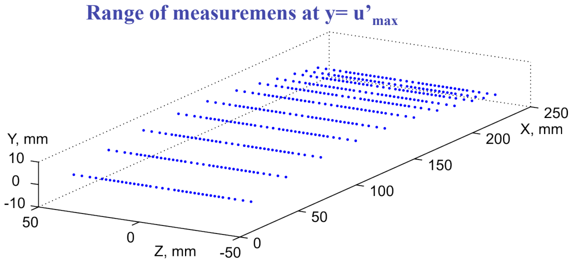
Experiment setup



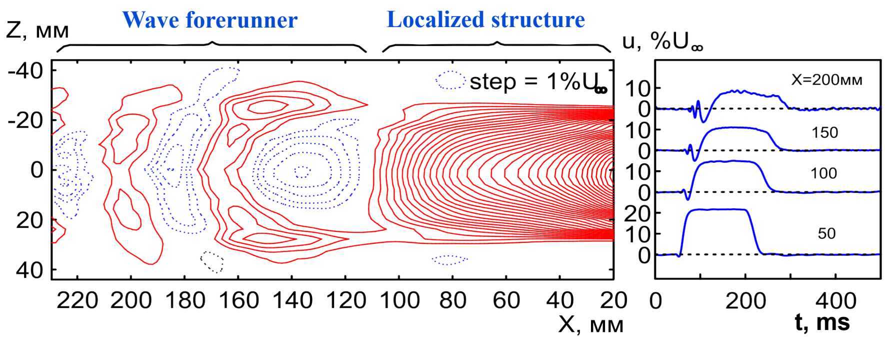
y-x range of measuremens (z = 0 mm)



Range of measuremens at y= u'_{max}



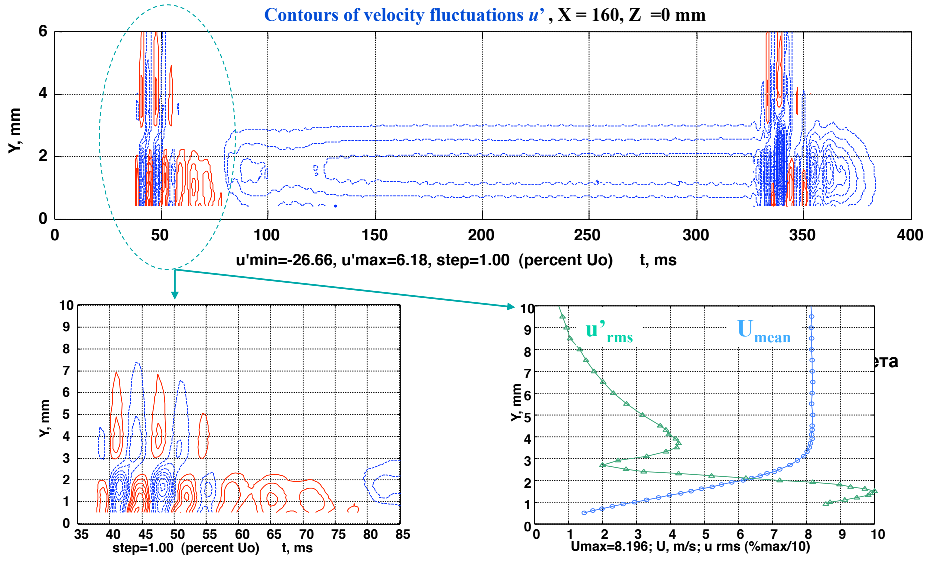
Wave forerunners on the straight wing



Hot-wire anemometry visualization of the localized structure and the wave forerunner near the leading front of the streak. The localized structure was generated by suction through the spanwise slot.

Wave forerunners on the straight wing

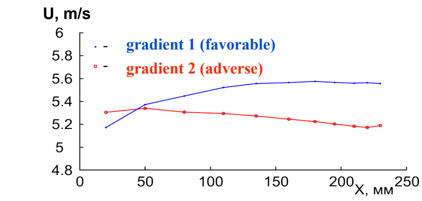
Contours of velocity fluctuations *u'*, X = 160, Z =0 mm



Contours of velocity fluctuations *u'*

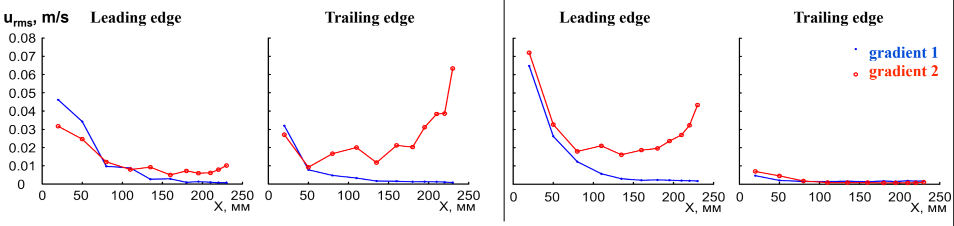
Mean velocity U_{mean} and velocity fluctuations *u'*

Influence of the streamwise pressure gradient on the development of wave forerunners



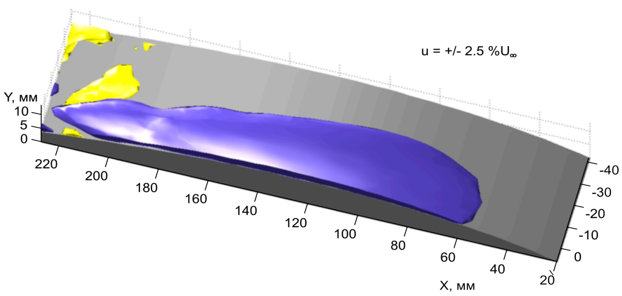
Streamwise variations of the external flow velocity at two different angles of attack of the wing profile

Localized structure generated by *injection* | Localized structure generated by *suction*



Streamwise variations of the wave forerunners amplitude u_{rms}

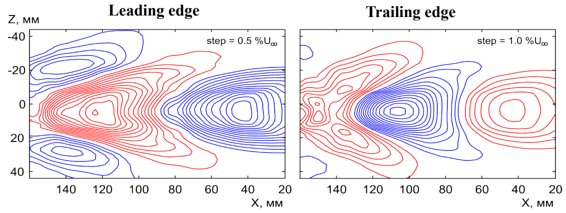
The late-stage spatial development of the wave forerunners (injection)



The trailing edge of the localized structure.

Yellow -high speed area ($u'=+2.5\ \%U_\infty$), blue - low speed area ($u' = -2.5\ \%U_\infty$), grey - wing surface. Wave forerunner is located at 140 mm<X<230 mm.

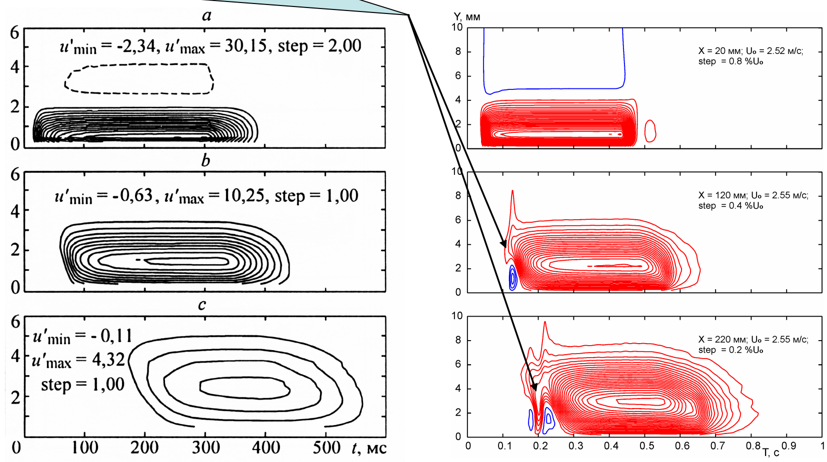
Contours of the high-frequency components of velocity fluctuations



Note about the forerunner development

Development of the wave packet near the leading front of the localized disturbance. Flat plate boundary layer, suction technique.

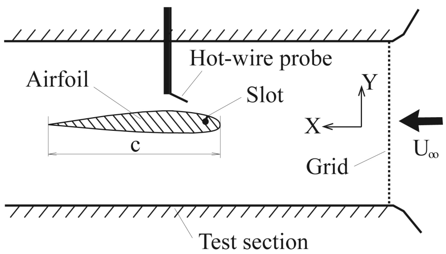
The upper part of the localized disturbance interact with wave packet.



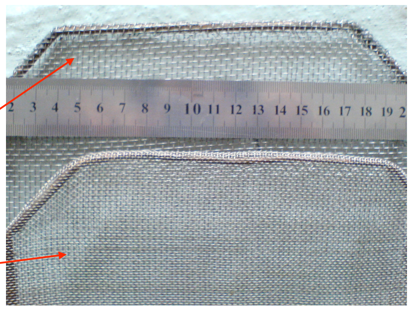
P.H.Alfredsson, M.M.Katasonov, V.V.Kozlov. **Generation and development of "passive" disturbances in the blasius boundary layer.** *Thermophysics and aeromechanics, 2001, Vol. 8, № 3.*

Experiment 2006, flat plate, T-324

High free stream turbulence level



Examples of grids



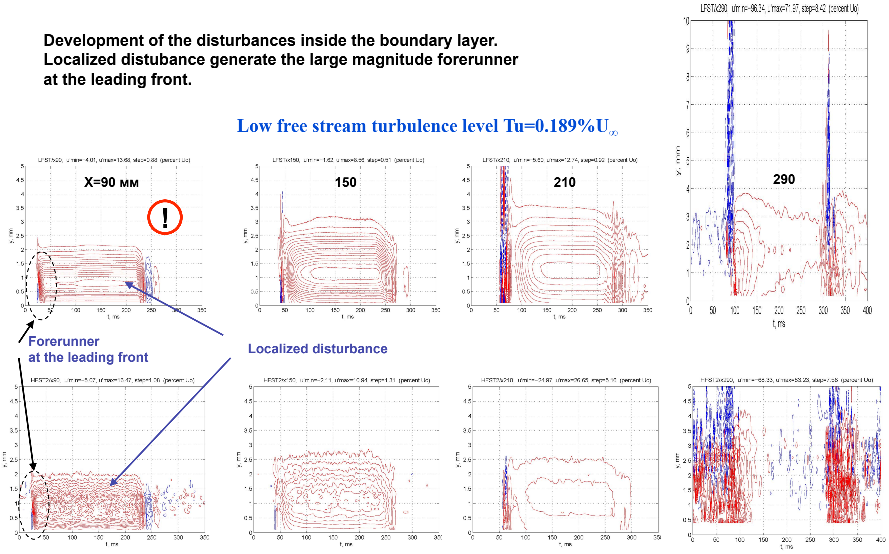
($Tu=0.79\%U_\infty$)

($Tu=0.27\%U_\infty$)

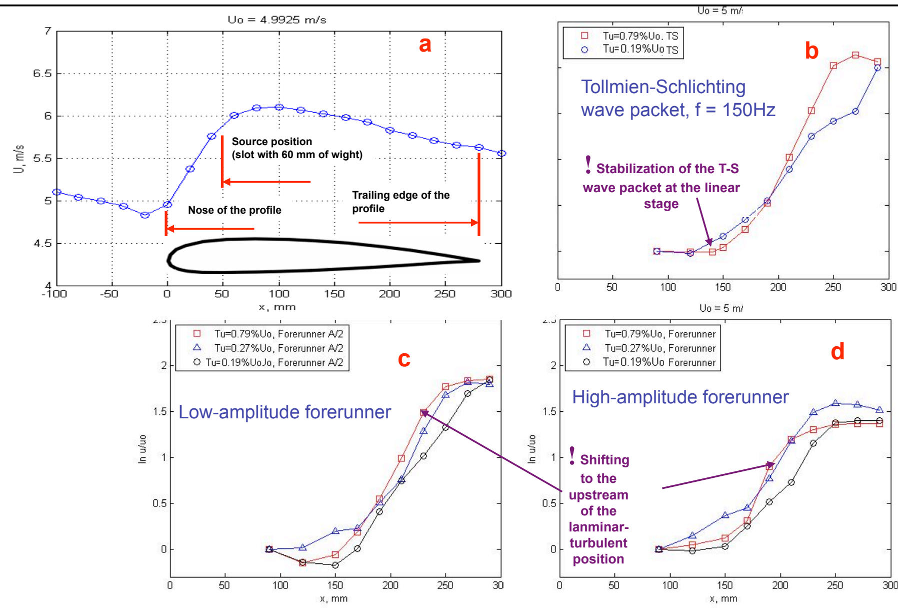
Wave forerunners on the straight wing

Development of the disturbances inside the boundary layer.
Localized distubance generate the large magnitude forerunner at the leading front.

Low free stream turbulence level Tu=0.189%U$_\infty$

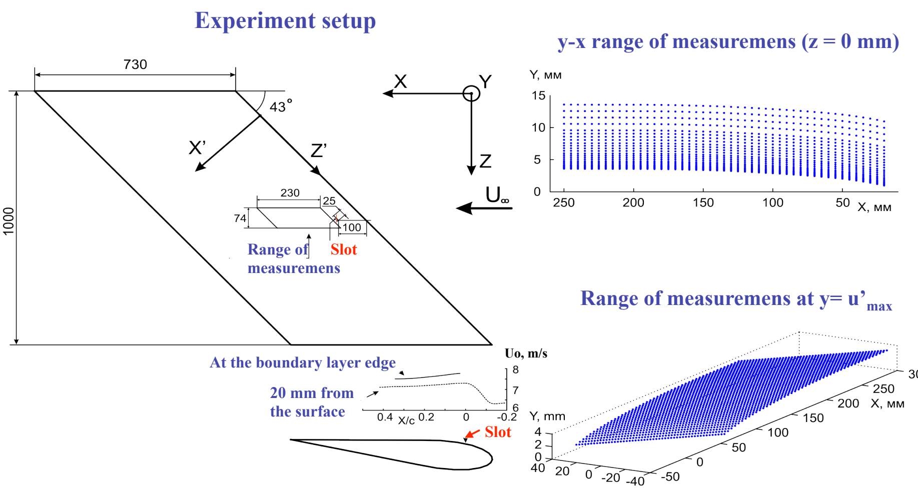


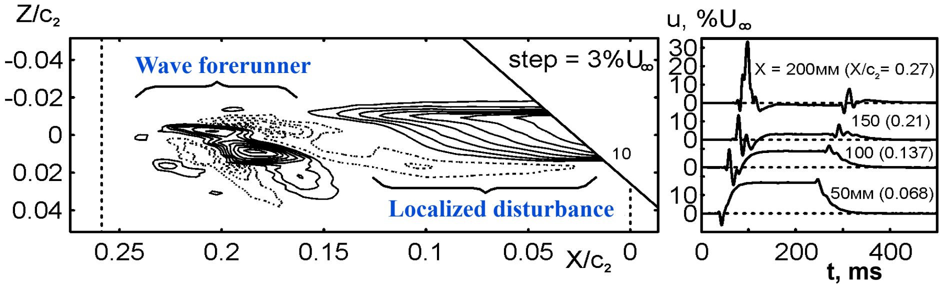
High free stream turbulence level Tu=0.79%U$_\infty$



(a)-mean velocity U distribution outside the boundary layer; (b,c,d)-distribution of the velocity fluctuations (u_{ymax}) at the maximum level of fluctuations in Y direction along the wing chord.

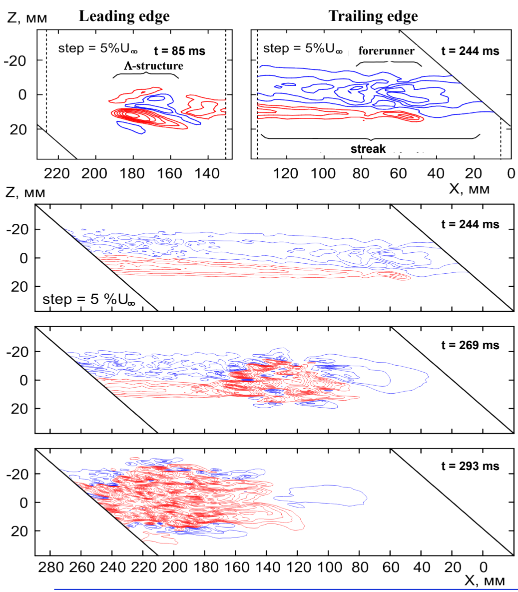
Detailed investigations of the wave forerunners on the *swept* wing





Hot-wire anemometry visualization of the localized disturbance and the wave forerunner at the leading edge. The localized disturbance generated by suction through the spanwise slot.

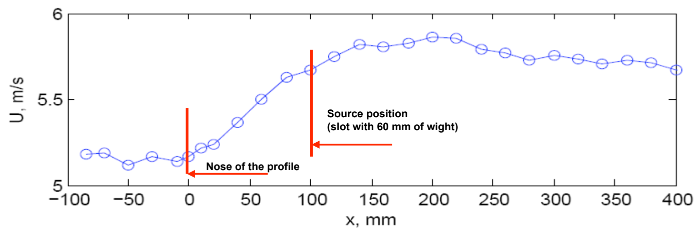
The late-stage spatial development of the wave forerunners (injection)

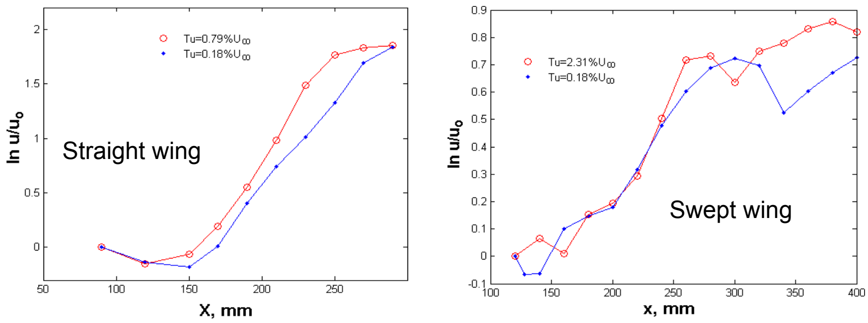


Origination of the Λ – structure from the wave forerunner at the leading edge of the localized disturbance.

Origination of the turbulent spot from the wave forerunner at the trailing edge of the localized disturbance.

High free stream turbulence level Tu=2.31%U_∞





Downstream behavior of the boundary layer disturbances amplitude at the low and hi free stream turbulence level

Conclusions

In the present experiments the high-frequency perturbations, i.e. wave forerunners, at the leading and back fronts of the localized structures evolving in the laminar boundary layer have been found.

It was observed that the forerunners are strongly amplified in the adverse pressure gradient flow being much influenced by local velocity gradients.

The results of the study make reason to consider the forerunners as wave packets of 3D instability waves.

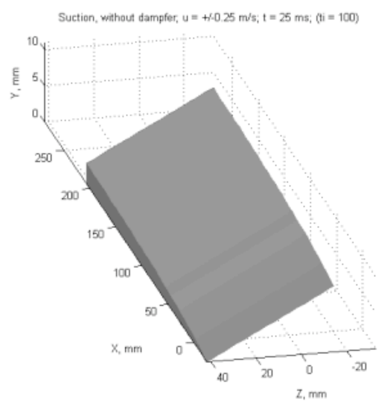
It was found that at downstream development of the forerunners they transform into the Λ- structures.

It is shown, that at high free stream turbulence conditions the T-S wave packet and low-amplitude foferunners are damped at the linear stage of development. That is in accordance with results of the previous researches.

It is revealed, in a gradient flow with high free stream turbulence level, with the increasing of the initial amplitude of a forerunner the laminar-turbulent transition shifted upstream.

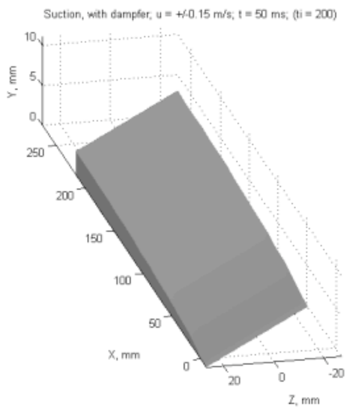
It is found, that with increase in a level of free stream turbulence at the gradient flow, the forerunners transforms in to the turbulent spot faster.

Swept wing. Localized disturbance with forerunners at the leading and trailing fronts



Blue color – low velocity fluctuation region
Yellow color – high velocity fluctuation region

Swept wing.
Localized disturbance
without forerunners



Blue color – low velocity fluctuation region
Yellow color – high velocity fluctuation region

THANK YOU VERY MUCH !