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INVESTIGATION OF UNSTEADY FLOW ON A HIGH ASPECT RATIO WING

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Abstract

The purpose of this report is to review some data, received as a result of experimental investigations of non-stationary flow near swept wings at subsonic and transonic speeds.

1 General remarks

Investigations of non-stationary flow regimes of a wing represent large interest for some reasons. It concerns to effects of the aeroelastic oscillations, atmospheric gusts, atmospheric turbulence, to a rerun of control surfaces at execution of maneuvers, etc. Non-stationary aerodynamic loads arising thus can reach high values and can be dangerous to the airplane. One of such actual problems is definition of the wing aerodynamic loads at high angles of attack. ,[1-7].

Despite the successes reached the last years in CFD aerodynamics, non-stationary separation flow regimes are researched, basically, using experimental tools, including wind tunnel tests of high scale models of airplanes. Though cost of such investigations is high, they ensure demanded reliability of received results. We will note, that calculations lasting many hours on multiprocessor computers too demand considerable costs. Thus, the split-hair accuracy and reliability of received result are not guaranteed. Preparation of mathematical model, build-up of calculation grids from hundreds million nodes on costs are commensurable with cost of design and manufacture of scale models for experimental investigations in wind tunnel. Therefore, computational investigation not always appear less labour-consuming and wasteful, than experimental. Though computer facilities and software are fast explicated, and the situation gradually varies, the experimental methods while remain the main instrument of investigations such complicated flows.

Experimental investigations of flow parameters in the conditions of non-stationary flow can be done by means of various measurement methods. Among them, it can be possible to select optical methods, starting from the old and checked up methods using tufts, finishing up-to-date PIV methods. The wide expansion was received by thermoanemometric fluctuation measurements of velocities of a non--stationary flow. In the present work for measuring of flow parameters a broad-band pressure sensors are used. Unlike optical and thermoanemometric methods, such method allows to carry out immediate fluctuation measurements of pressures in breakpoints of a surface of test model. That is large advantage of a method, in comparison with others.

2 Description of control system

Fluctuation measurements of pressures were conducted by means of high-frequency pressure pulsation sensors Kulite XCS-062-5D connected to the multi-channel measuring system, designed on the basis of blocks MIC-300M. The system allows conducting synchronous measuring and a record of results with a high frequency of inquiry of channels with sensors of various type. Measuring of flow parameters inside the wing wake were carried out using six-barrel nozzle, equipped with the same sensors.

The special software is developed for the most complete usage of resources of the measuring system, allowing to hold testing and system tuning, and also operative handling of experimental results.

3 Description of models

Investigations have been made for two passenger airplane models. First model was half-model with semispan equals to 2.2m. Second model was full model with span equals to 1.98m. Pressure oscillations have been made on a wing surface of half-model (figure 1). The model has been put on external five-component strain-gage balance, located outside the working section. Half-model has been equipped by sensors XCS-062-5D. Two main sections on the outer wings allocated on 59 % and 82 % of a semispan have been selected. Pressure pulsations sensors have been positioned starting from 30% and to 90 % of a local chord. Such position of sensors was accepted for support of measurements of pressure pulsation in expected area of shocks moving and position of a flow separation.

Investigations of wing wake parameters were conducted on the full model (a figure 2).

Fig. 1 . The research half model in WT T-128 TsAGI

Fig. 2 . The research model in WT T-103 TsAGI

4 Test conditions

Experimental investigations of pressures pulsations on the wing upper surface were made in TsAGI's transonic wind tunnel T-128 with the closed working section (figure 1). The Reynold's number in transonic wind tunnel T-128 was ensured with appropriate selection of pressure in a settling chamber. The Reynold's number was based on a mean aerodynamic chord of wing. Tests were made in the free flow of a wind tunnel.

Investigations has been carried out at following Mach and Reynolds numbers:

- Subsonic Mach number M=0.4, Re = 14mln.,
- Low transonic Mach number M=0.78, Re = 10mln.,
- Transonic Mach number M=0.82, Re = 9mln.

The range of angles of attack α =-0.6÷12 ° was considered at subsonic flow regime. The range of angles of attack α =-0.6÷8.8 ° was considered at a transonic flow regimes.

Investigation of flow parameters in a wing wake were carried out in TsAGI's subsonic wind tunnel T-103 with an open working section (a figure 2). The studies were performed at angles of attack varied from -4° to 24° and at flow rates over the range from 20 m/s to 80 m/s.

The experiments were performed with the ADC channels sampling rate of 54 kHz. The analogue filters of the measuring channels have been set to 10 kHz, the operating frequency range of pressure sensors with pneumatic ducts has been 0÷5kHz. Thus, pneumochannels and analogue filters did not skip harmonics of signals with frequencies above 5kHz. That has eliminated effect of superposition of frequencies at conversion of a signal to an analogue-digital converter. Considering a scale of models, the measuring system effective range has ensured reliability of observed data in a demanded range (0-1000Hz).

5 Investigation of pressure oscillation spectra in control points of wing

Next figures show graphs of pressures oscillation in points of a wing section (η=82% semispan) at Mach numbers M=0.4, 0.78 and 0.82 and at various angles of attack. Color of the graph corresponds to color of a measurement point.

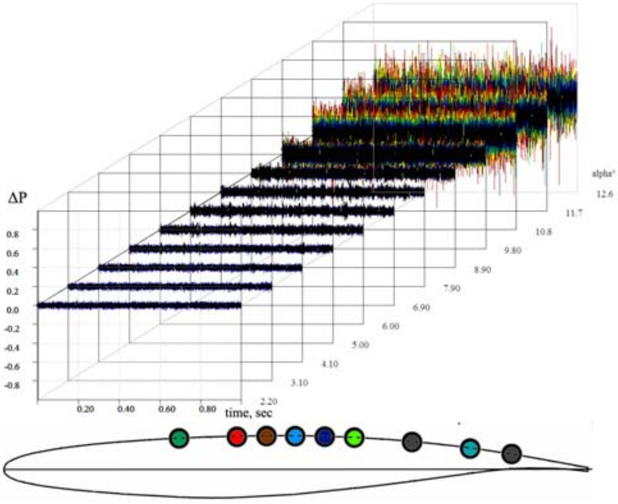


Fig. 3.Values of pressure oscillation in points of wing section η =82% (time =1sec, M=0.4, Re=14 mln.). Angle of attack changes from 2.2 deg to 12.6 deg.

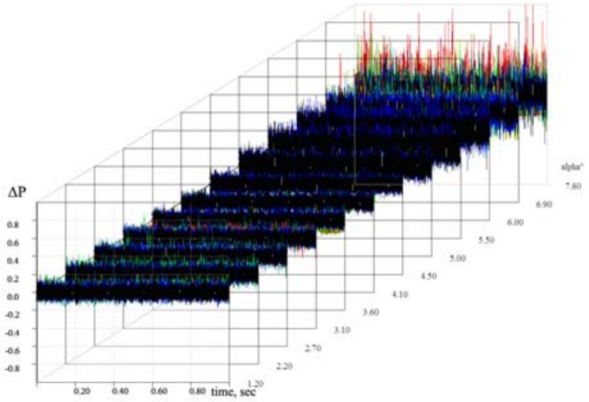


Fig. 4. Values of pressure oscillation in points of wing section η =82% (time =1sec, M=0.78, Re=9 mln.). Angle of attack changes from 1.2 deg to 7.8 deg.

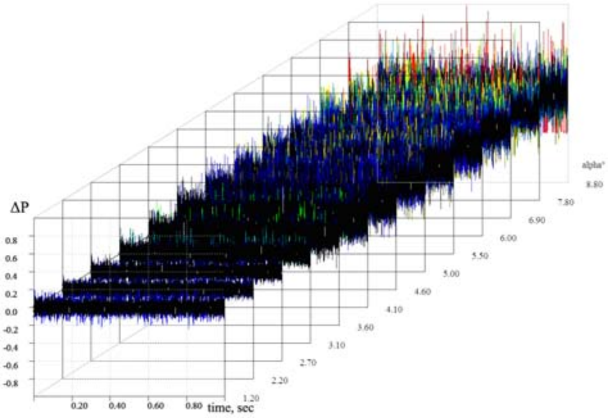
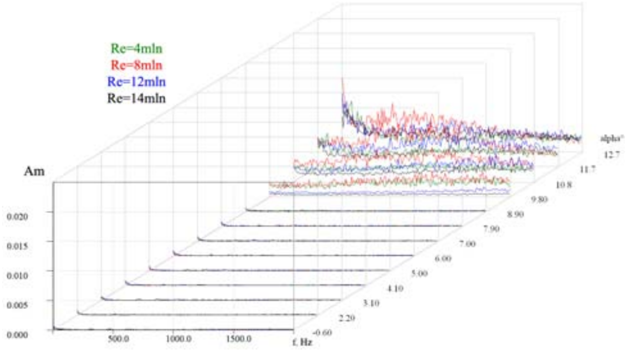


Fig. 5. Values of pressure oscillation in points of wing section η =82% (time =1sec, M=0.82, Re=9 mln.). Angle of attack changes from 1.2 deg to 8.8 deg.

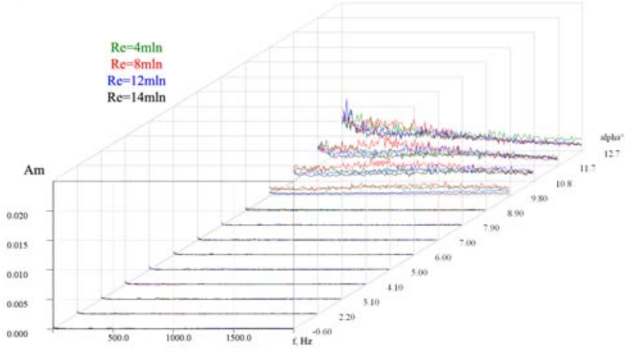
Growth of pressures oscillation with increasing of an angle of attack is visible at all Mach numbers. On small angles of attack the greatest values of oscillations are reached in the points allocated near to a trailing edge of the airfoil (curves of dark color). For large angles of attack the separation area extend to a leading edge and oscillations in the points allocated in this zone (curves of red color) increase. On small angles of attack the values of pressure oscillation at transonic Mach numbers several times above, than at subsonic speeds. The reason for that is the influence of wall perforation which creates the considerable high-frequency perturbations of flow at transonic Mach numbers.

6 Investigation of pressure oscillation spectra on wing surface

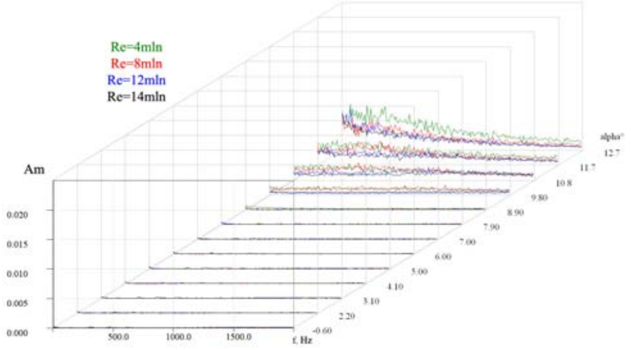
Next figures show graphs of pressures pulsation spectrums in selected points. Tests were made for the free and fixed transition. Graphs of spectrums in a frequency range 0÷2000Гц are shown. The perturbations brought in a flow by wall perforation, have more high frequencies. It gives the chance not to consider their influence on character of spectrums, especially, in the low-frequency effective range, representing the greatest interest.



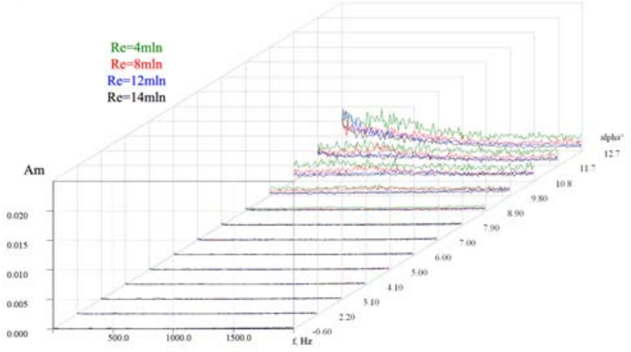
a) X=30%



b) X=50%

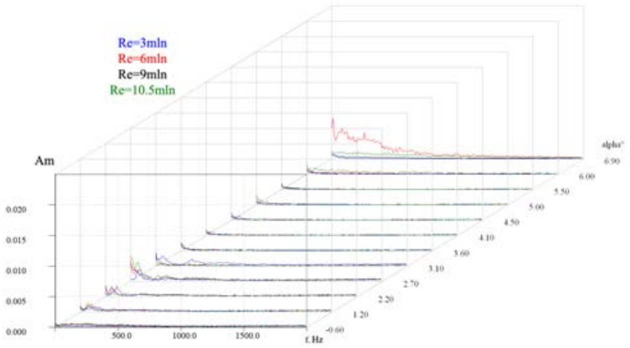


c) X=70%

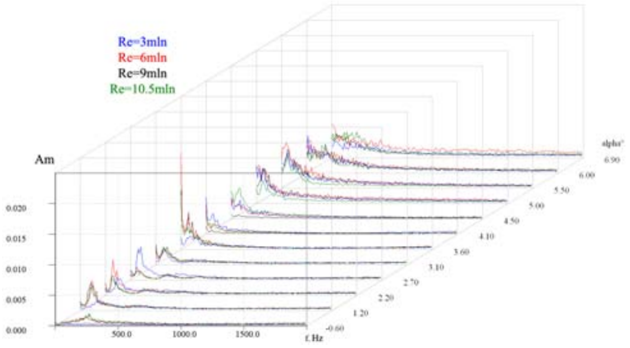


d) X=87%

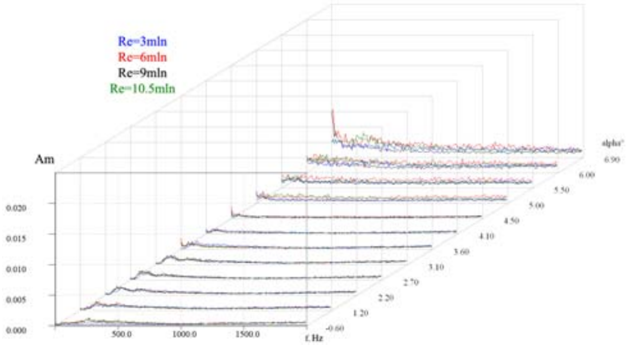
Fig. 6. Amplitude of pressure oscillation at M=0.4, Re=4, 8, 12, 14 mln. Fix transition position



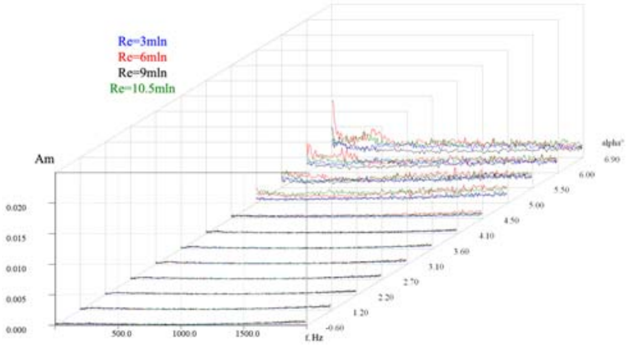
a) X=30%



b) X=50%

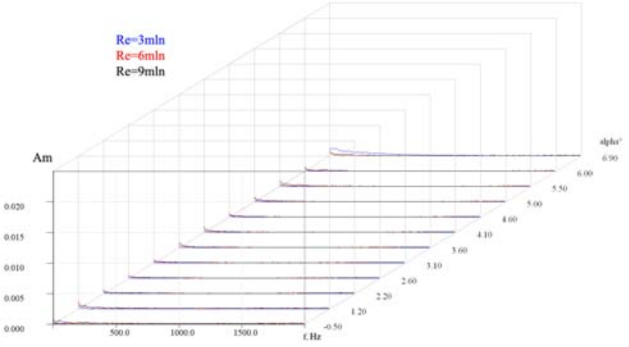


c) X=70%

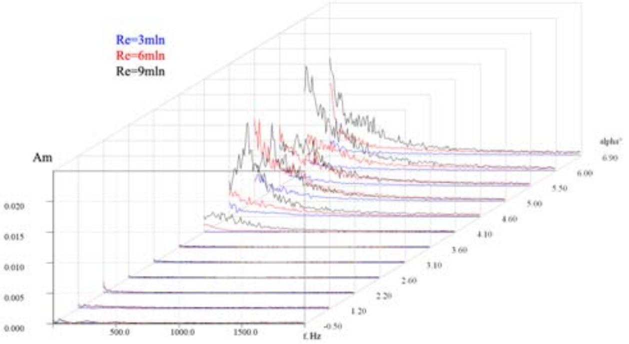


d) X=87%

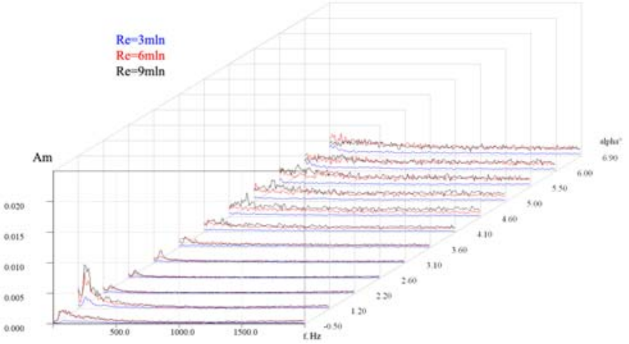
Fig. 7. Amplitude of pressure oscillation at M=0.78, Re=3, 6, 9, 10 mln. Free transition position



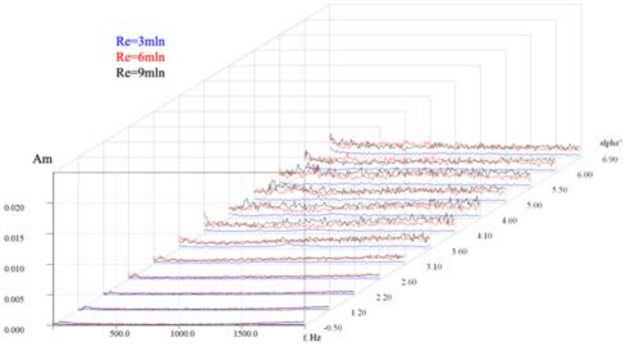
a) X=30%



b) X=50%



c) X=70%



d) X=87%

Fig. 8. Amplitude of pressure pulsation at M=0.82, Re=3, 6, 9 mln. Fix transition position

From results of spectra investigations it is possible to make some conclusions:

1. Amplitudes of pressure oscillation on the upper wing surface are inappreciable when there is no shocks and flow separation
2. In the conditions of transonic flow owing to possible instability of shocks there are local allowed zones with raised amplitudes of pressures oscillation. Their position is defined by combinations of geometrical parameters of a wing, Mach and Reynolds numbers and angles of attack.
3. At large angles of attack sharp growth of amplitudes of pressures oscillation is observed at all researched values of Mach and Reynolds numbers.
4. With increasing of angle of attack and separated area spectrums of amplitudes move in low-frequency field. There is an accelerated growth of low-frequency components of a spectrum.
5. At high angle of attack there is a dominating tone in a low-frequency part of a spectrum of pressures oscillation in the points located near to a trailing edge.
6. Effect of values of Mach and Reynolds numbers, angle of attack, free or fixed transition to a spectrum of amplitudes of pressures oscillation, first of all, is defined by a common flow pattern, presence and position of shock and separation zones.

7 Investigation nonstationary characteristics flow behind the wing

Investigations of non-stationary characteristics of a flow behind a wing have a great interest at the decision of practically important problems, including:

- definition of wing flow stability;

- detection of local flow separation in wing sections;

-estimation of the nonstationary aerodynamic loads on flaps;

-estimation of the nonstationary aerodynamic loads on tail unit, first of all, a horizontal tail;

- estimation noise level caused by a vortex wake and nonstationary shock position ;

- development CFD codes, etc.

The special interest is represented by the task of interaction of the plane with a wake from other flight vehicle, especially on take-off and landing. This task has great value from the point of view of safety control of flights in the conditions of intensive motion near to the large airports.

The analysis of nonstationary features of a wing wake allows to determine the local zones, sections with separated flow, availability and position of local disturbing sources. It creates possibility for further improving of layouts of the airplane, improving of its aerodynamic characteristics.

In this part of paper high-frequency pressure pulsation sensors with relatively large working frequency range (0 - 5000Hz) were used to determine the steady and unsteady flow characteristics in the wake of the wing (Figure 2).

As an example, in following figures presented average values of flow components velocities and values root mean square (RMS) measured in control points behind a wing.

In a figure 9 distributions of average flow velocities vectors is shown. Points of measurings were selected in zone of a wing wake. Distribution of values of standard deviations of flow velocities in breakpoints is displayed in figures 10 and 11. An ellipse vertical dimension corresponds to RMS a vertical component of velocity; horizontal dimension corresponds to RMS a horizontal component of velocity. Components RMS of velocity in other projections are similarly shown. Red color in this pictures corresponds great value of parameter, black - small. Intermediate values are selected by dark blue and green colors.

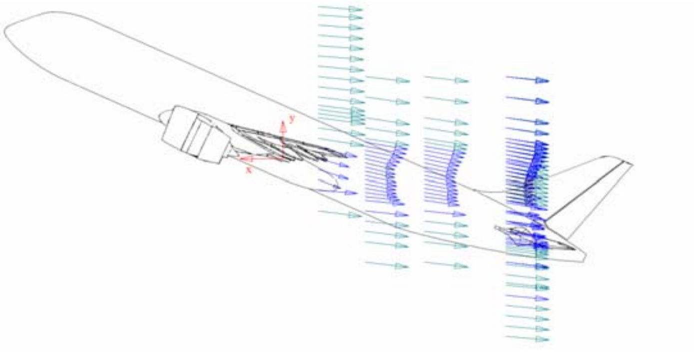


Fig. 9 Distribution flow velocity vectors behind the wing

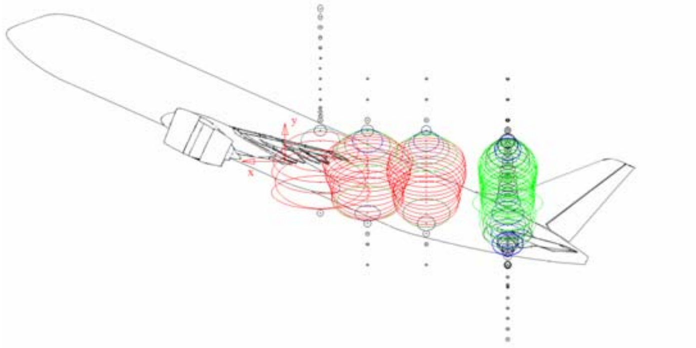


Fig. 10 Distribution of RMS vertical and horizontal flow velocity vectors components Vx,Vy behind the wing

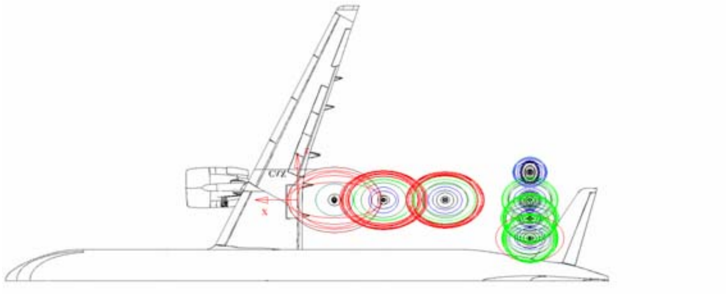


Fig. 11 Distribution of RMS horizontal flow oscillation component Vx,Vz in wake behind the wing

Graphs of dynamic head losses distributions and corresponding RMS behind the wing and in zone of allocation of a horizontal tail are shown in figures 12, 13. Amplitude-frequency spectrum of the dynamic head is shown also here in some points inside wake.

Presence of dominating tone is determined at small and moderately large angles of attack (a figure 12). In the conditions of developed separation this dominating tone "is blurred" (figure 13) and growth of all low-frequency harmonics takes place. Dominating tone in a spectrum appears better for the points selected on an external boundary of wake. This effect is saved and for the points of a wake allocated close horizontal tail area, but in this case, it is less expressed.

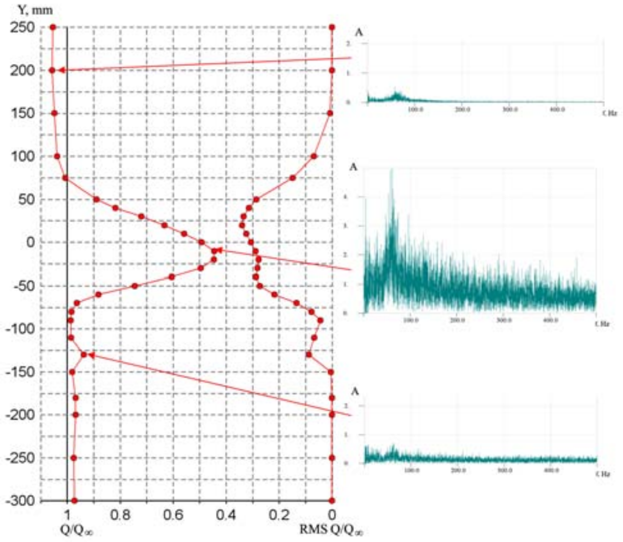


Fig. 12. Dynamic head losses profile Q/Q∞ and RMS Q/Q∞ Amplitude-frequency spectrum of the dynamic pressure Q/Q∞ (α=12deg)

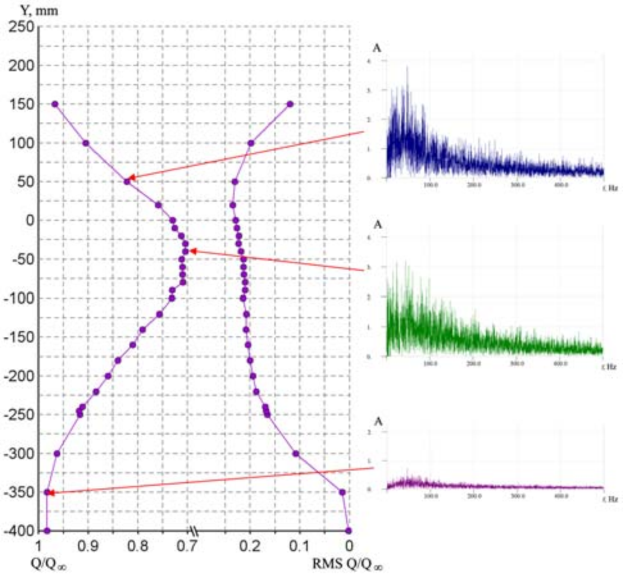


Fig. 13. Dynamic head losses profile Q/Q∞ and RMS Q/Q∞ Amplitude-frequency spectrum of the dynamic pressure Q/Q∞ (α=16deg)

Amplitude-frequency spectrum of the dynamic pressure, up-wash angles and side- wash angles in various points are presented in figures 14÷16

They also allow to receive introducing about allocation and a structure of perturbations in a flow in a wing wake.

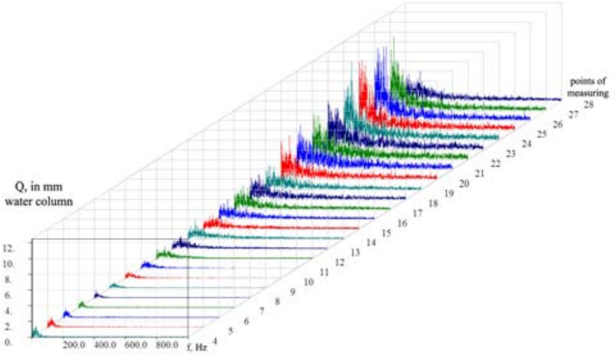


Fig. 14. Amplitude-frequency spectrum of the dynamic pressure Q/Q∞ in different points (α=12deg)

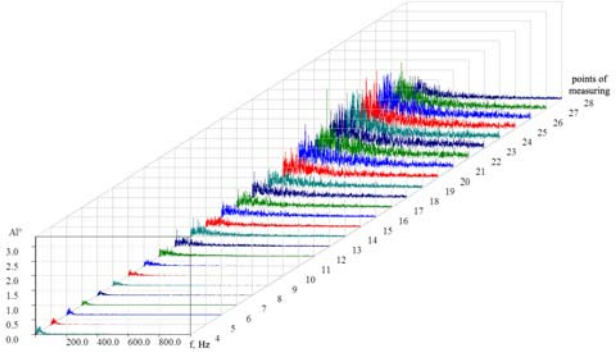


Fig. 15. Amplitude-frequency spectrum of the up-wash angles in different points (α=12deg)

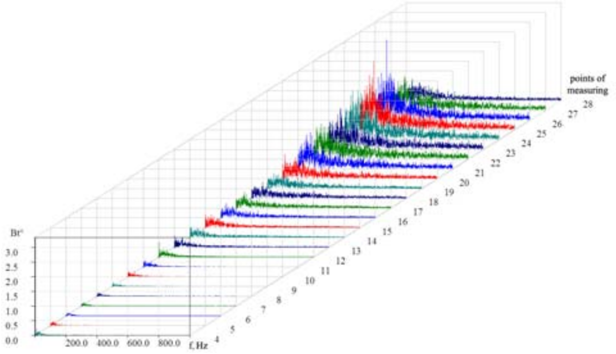


Figure 16. Amplitude-frequency spectrum of the side-wash angles in different points (α=12deg)

Conclusions

Some features of nonstationary flows on a wing surface and in a wing wake are considered at subsonic and transonic Mach numbers. The analysis is made by results of experimental investigations of two models of the typical subsonic passenger airplane.

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