IMAGE OF PHENOMENA IN TRANSIENT BOUNDARY LAYER OF A FREE ROTATING DISC

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This report presents the imaging of the transition process of the laminar boundary layer (BL) in a turbulent BL on a free rotating disc. The imaging is based on an experimental investigation[1] which aims to analyse the structure of the BL by relating to the ratio between turbulent energy and vortex energy, the critical and the transient Reynolds numbers (Re No), the vortex numbers and their dependence on Re No, and on the distance from the rotating disc.

INTRODUCTION

Comprehensive investigations of the thermal and dynamic characteristics were performed (e.g. heat transfer between disc and fluid, vibrations of disc i.e. of device, etc.) during the realisation of the experimental device. The disc of aluminium alloy with a radius of 0.323 m ensured an approximate isothermal temperature field. By means of a measuring probe, the periodical time change of the characteristic physical scalar quantity (i.e. of static pressure) in the BL was recorded. The probe for static pressure was designed and manufactured so that it maximally preserves the fundamental characteristics of the flow field. Measurements of the periodical change of static pressure in the BL were performed in about 320 points of *r-z* planes. The measurements yielded the critical Reynolds number $\boldsymbol{Re}_c$= 289 and the transient Reynolds number $\boldsymbol{Re}_T$= 590. These results match very well the measured results[2-4], which were carried out by using a hot wire.

ANALYSIS OF PERIODIC PRESSURE DISTURBANCES

The analysis of the number of periodical pressure disturbances, i.e. the vortex number, during one disc turning shows that the process of development and break-down of vortices in the BL is performed in three characteristic stages. In the first stage (Fig. 1), which follows the stable laminar

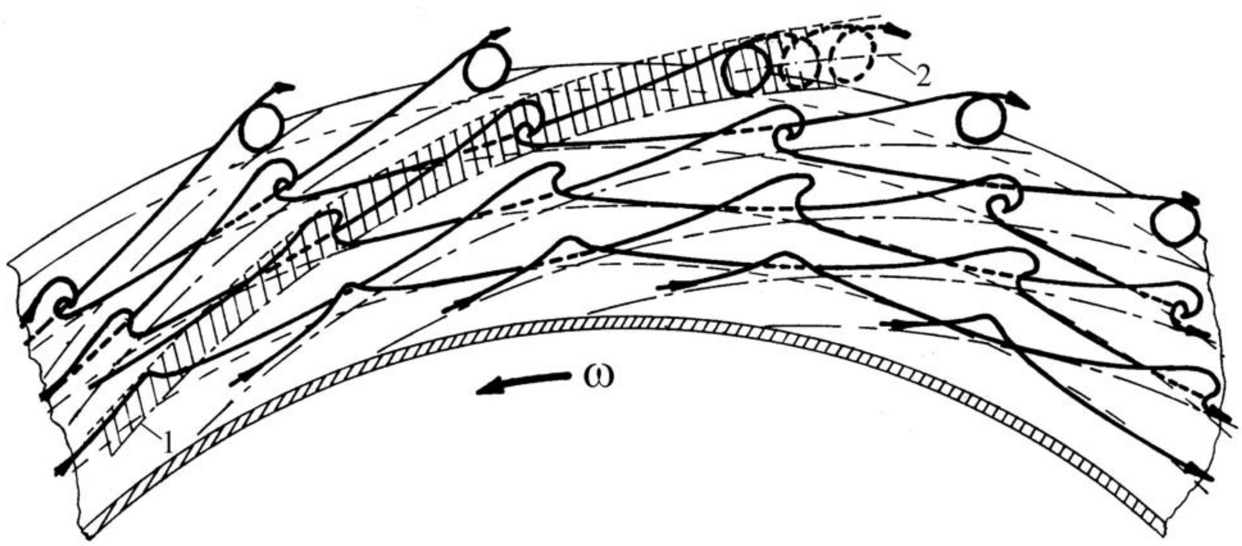

Fig. 1 The image of flow in the first stage - transition from wavy to vortex form:
1- the axis of waves in the first stage; 2- the axis of vortices in the second stage

BL, there are between 15 and 19 periodical disturbances, depending on the Re No. The power spectra of the signals shows that there is no turbulent noise in the first stage.
In the second stage (Fig. 2) there are 24 stable spiral vortices. The relative amplitude of disturbance does not increase with the increase in Re No. Similarly, the distance from the disc at which the periodical disturbances were registered does not change. The power spectra of the signals from the second stage of transition shows no turbulence noise. At the end of the second stage some of the spiral vortices are periodically duplicated (Fig. 3), and newly originated vortices do not necessarily have the same dimensions. There are 24-26 periodical disturbances. The duplication is accompanied by the occurrence of turbulent noise, which disappears from the signal by expulsion from disc, and the frequency peak 24 remains in the signal.

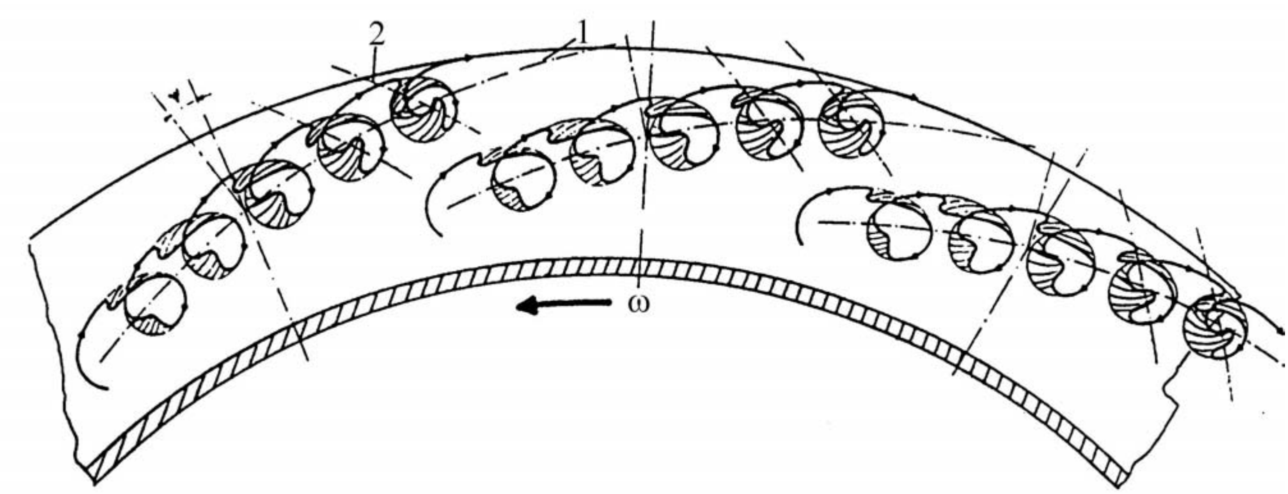

Fig. 2 The image of flow in the second stage – formation of secondary vortices:
1- the axis of basic vortex; 2- the axis of secondary vortex

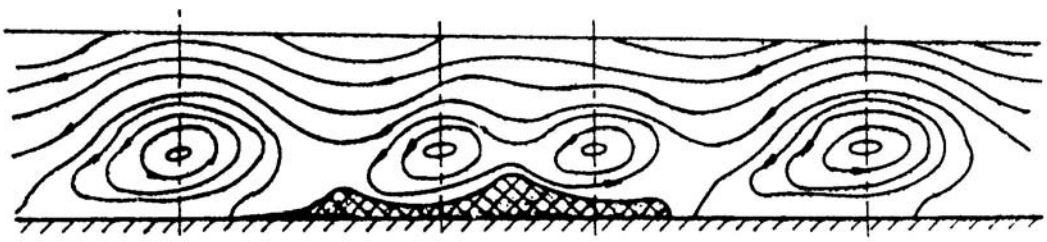

Fig. 3 The image of duplication some of the spiral vortex

In the third stage of the transition, the flow becomes non–stationary, which is manifested in periodical breakdown of vortices, which existed in the second stage, so that besides 26 vortices, 29 and 30 appear now. Non–stationary characteristic of the vortices number results in the relative motion of their axis against the disc, which is manifested by modulation of the phase and amplitude of the signal. The time duration of the various numbers of vortices is not equal and it changes with the increase of Re No: longer duration of a bigger number of vortices responds to a larger Re No. The accompanying occurrence of the vortices breakdown processes is an increase of the turbulent part of the energy, which is manifested by an increase of turbulent noise in the signal power spectrum. The share of turbulent noise on the same radius decreases with the distance from the disc. The increase of the turbulent part of energy and a decrease of vortices energy when the Re No aspires to $\boldsymbol{Re}_T$ point on successively «hulling» of vortices periphery. When the distance from the disc towards the outside border of the BL increases there are again 24 periodical disturbances dominating during one disc turning, as a result of the wave shape of fluid flow which did not participated in the vortex flow at all.

RESULTS

A large number of power spectra of signals, recorded at points of the *r–z* plane of the BL, yielded the images of the transition process from the laminar into the turbulent BL on the free rotating disc. The flow in the first transition stage has a wavy form (Fig. 1). The number of waves during one disc turning, the wave amplitudes and the intermittence factor increase with the increase in the Re No. This was also shown in the graphic interpretation of measured results[2], and is now once again validated by our measurements. By increasing the Re No, the peak of the wave is successively swaddled up in the direction of the axis of the future vortex, until the crest assumes the shape of a hairpin. At the end of the first stage the broadening peak of the wave is broken off and it twists into a vortex, the axis of which has the shape of a logarithmic spiral. The first stage is characterised by the successive increase of the relative amplitude (measured normal to the disc), and a considerably bigger increase of the absolute amplitude (measured in the direction of the lengthened peak of the wave). Entering the second stage (Fig. 2), the number of spiral vortices remains stable. However, with increase of Re No, additional deformations of stream–lines appear. Adjacent to the disc they are twisted in the direction of the vortex axis and disc periphery, and at the outside border of the BL they are also twisted in the direction of vortex axis but in the direction of the disc axis. In the middle of the second stage these deformations become expressed and assume the shape of an hairpin, and are further twisted into a secondary vortex, whose existence in the period of the third stage is very short. The formation of secondary vortices has also been registered in experiments using visualisation[3,5]. The secondary vortex is broken-down into entirely turbulent flow. The core of the vortex is still preserved, with considerably smaller dimensions. A sudden decrease of the dimension of the remaining vortex core starts when the Re No approaches its transient value $\boldsymbol{Re_T}$. The changes of flow characteristics at the end of the third stage, when even the last forms of periodical flow disappear, occur at a small increase of the Re No, and the flow is very stormy. The transient Re No depends primarily on disturbances, which affect to the remainder of the undisturbed flow from the turbulent part of the BL and less on the activity of disturbances outside the BL.

CONCLUSION

The work presented here is based on experimental measurements. By using human senses, it peers into less visible occurrences during the transition from laminar into turbulent flow inside the BL on the free rotating disc.

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