EXPERIMENTAL STUDY OF BOUNDARY LAYER WAVES AT LARGE AMPLITUDES

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Experimental Study of Boundary Layer Waves at Large Amplitudes

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Summary

The two-dimensional theory of Tollmien waves predicts for increasing amplitudes an expanding area of the neutral curve and for some flows a saturation effect at very large amplitudes. We hoped to improve the flow qualities of a water tunnel /1/ to such a degree that those effects could be observed. Additionally, such flow qualities would enable us to study the 2D-3D coupling under much more controlled conditions than in the past. However, we finally were not able to produce 2D Tollmien waves with amplitudes larger than 1%. This paper gives reasons for the difficulties to reduce the perturbation level of the tunnel below a certain degree and describes an example of a new lighting method for hydrogen bubbles. Then some amplification results, which certify an influence of the wave amplitude on the branch II of the neutral curve are given.

Flow uniformity

The test section is preceded by a contraction cone and a settling chamber with screens. In our case we made sure that all unsteady perturbations due to pump vibrations, to the turbulence of the diffusor and to thermal inequalities between air and water had been eliminated in the settling chamber. However, the flow leaving the last screen was by no means without perturbations in spanwise direction. Obviously, those small changes in the velocity distribution are produced by the screens themselves. Because the Reynolds number of the screen threads is of the order of one the flow even in the wake of the screen is completely laminar. If the wave length of the spanwise perturbation is in the range of some centimeters, the lateral exchange of momentum is much too small to smooth out these perturbations before they flow into the contraction cone. Therefore, any residual perturbations of larger wave length are practically frozen into the flow and establish a vorticity distribution. The longitudinal components of this vorticity may be amplified in the contraction cone.

There are three main reasons for lateral perturbations downstream of a set of screens:

a) interference between a sequence of screens (Moiré effect)

b) non-uniformities in the geometry of a screen due to the manufacturing process

c) non-uniformities due to non-uniform bonding between screen and holding frame.

When the manufacturing process of the screens guarantees a - say - 1 % deviation from uniformity then the influence on the flow would depend on the drag of the screen. For some time, therefore, we followed the idea to put screens with - in flow direction - decreasing drag coefficients into the settling chamber. However, at these low Reynolds numbers, the drag of a screen can hardly be influenced by the thread diameter but rather by the mesh size. Low drag then means large meshes which in turn produce wakes which persist for too long distances. Thus, interference or superimposed effects of successive screens become the dominant source of perturbations.

We had to rule out stainless steel screens because they were not available in the necessary size. We also conjectured that the mesh size is not uniform enough to guarantee a non-uniformity of less than 1 %. We prefer woven polyester screens, where the cross points of the threads are more rigid. Such textile screens, however, have no bending stiffness and are therefore prone to irregularities in the bond between screen and frame. Small differences in the internal stress distribution, which are not discernible in the unloaded case, will, when loaded lead to local deviations from a smoothly curved screen. It is surprising to see the large influence which such small curvature gradients have on the streamline direction and hence the local convergence of the flow. Close to the wall, due to the shear flow these effects are even more pronounced. Obviously, the mounting of a slack screen to the frame with uniform stress poses a serious mechanical problem if one aimes at good lateral uniformity.

Presently, we think that a single screen with a mesh width of about one millimeter and relatively high drag which is carefully bonded to its frame may be the best, but by no means an ideal solution.

In order to investigate the quality of different screens and the influence of the screen-frame bonding stresses, we put some screens into the test section. The lowest possible Reynolds number there was around five times larger than in the settling chamber.

Fig.1 shows the development of the wakes behind a screen at increasing distances. The mesh size is 0.7 cm. The photographs are taken at 5, 7, 9, 11 and 13 cm behind the screen. The velocity is 2 cm/s and the Reynolds number of the threads is about seven. The last picture indicates a small perturbation with a much larger wave length than the width of the meshes, which will persist downstream for a long distance.

Fig.2 gives an evaluation of these photographs and shows the fast decrease of the short wave amplitudes.

Flow visualization

Hydrogen bubbles are very often used for flow visualization. Sometimes it is difficult to have sufficient light intensity to observe the tiny bubbles as bright stars on a dark background. Therefore, we have adopted an inverse method, where the bubbles are not reflecting only a very small part of the total light, but absorb the light of a bright background and appear as black points. We are using reflecting foil sheets covered with very small mirrored glass spheres as a background; they reflect each light beam into its own axis within a very small divergence angle. This enhances the contrast between the background and the bubbles and reduces the necessary light intensity by a factor of more than 1000. Fig.1 has been taken in this way. The possibility to save light intensity may be especially important if one has to make fast movie pictures.

Amplification rate as function of the amplitude

In the test section of the water tunnel we installed a flat plate of glass with a length of 2,4 m. As usual the boundary layers at the side and top walls were stabilized by suction. With $U_\infty = 12{,}9$ cm/s we could establish at the end of the glass plate a boundary displacement thickness of 6,6 mm, yielding a local Reynolds number $Re_{\delta^*} = 850$. The pressure gradient in flow direction was adjusted to zero. The conventional vibrating ribbon was installed at a distance of 150 cm from the leading edge of the plate. Fig.3 shows the results of the amplification measurement in the range between 155 cm $\leq x <$ 185 cm for different amplitudes of the two-dimensional wave. They were measured with a hotfilm probe at distance from the wall, where the amplitude has its maximum.

The convex curvature of the amplification curve indicates that these measurements were taken near branch II of the neutral curve. The horizontal part of the amplification curve indicates a neutral state. It can be seen that at small amplitudes the neutral state is achieved at a dimensionless frequency of $F = 166$ and that at a constant Reynolds number this frequency is shifted for the largest amplitude to a value of $F = 192$, which is a frequency shift of nearly 13 %.

In order to check the two-dimensionality of the observed waves, the amplitude and phase distribution for different spanwise positions were measured. As long as the wave amplitude stayed below 1 % we could not detect any deviation from two-dimensional conditions neither in the amplitude nor in the phase distribution along the span.

References

1. Wortmann, F.X.: The incompressible fluid motion downstream of twodimensional Tollmien-Schlichting waves. AGARD Conference Proceedings No.224, 1977

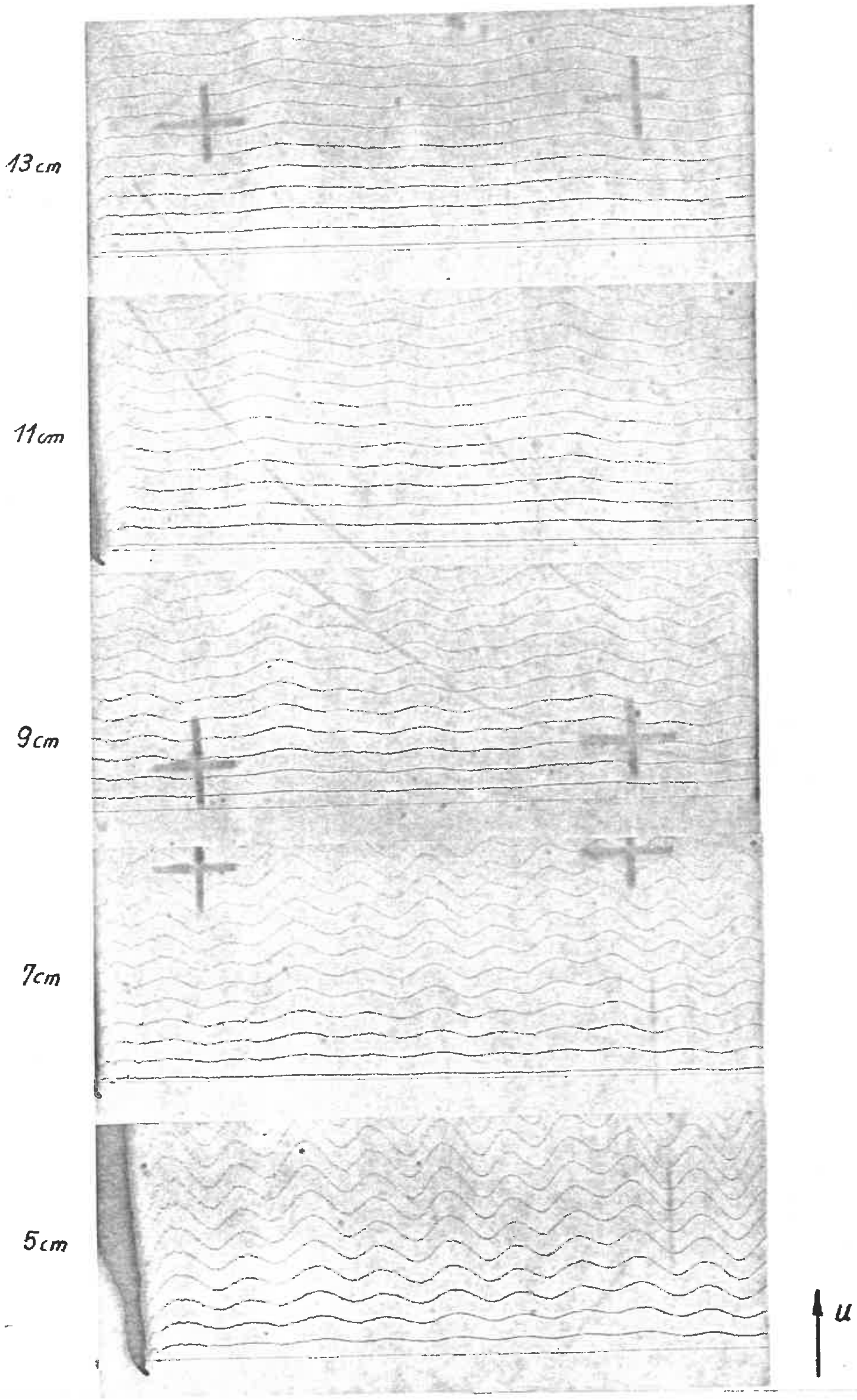

Fig.1 The development of the wakes taken at 5, 7, 9, 11 and 13 cm behind the screen (u = 2 cm/s).

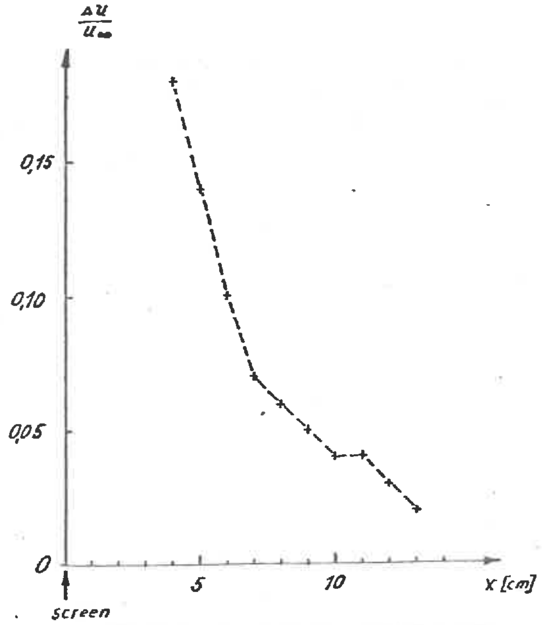

Fig.2 Decrease of the laminar wake behind a screen.

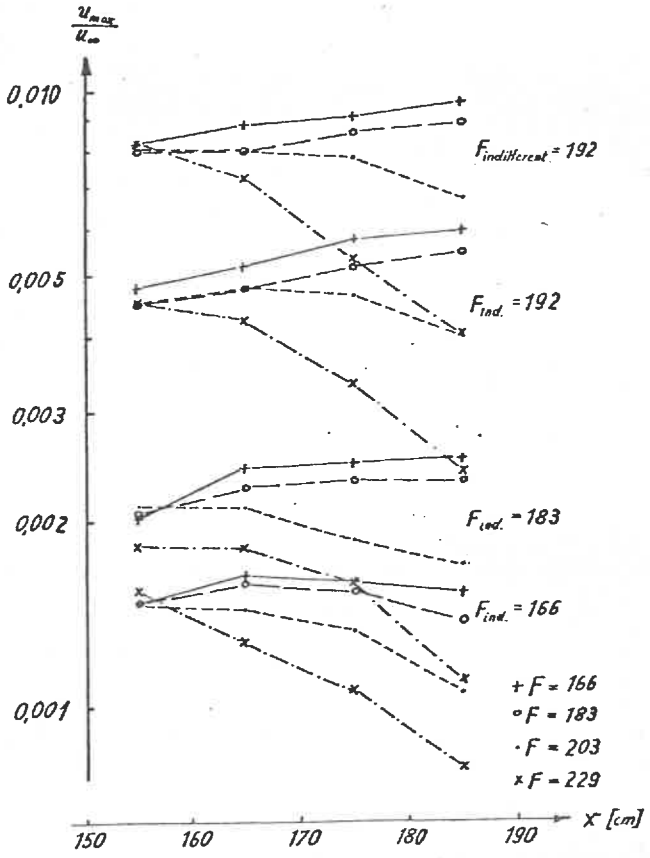

Fig.3 Amplification measurements of twodimensional waves.