UNSTABLE MEAN VELOCITY PROFILES IN THE TWO - DIMENSIONAL TRANSITIONAL BOUNDARY LAYER .

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SUMMARY

An experimental study of the two-dimensional laminar - transitional boundary layer beneath a turbulent free stream is presented . It is shown that the mean velocity profiles develop a wavy shape prior to transition that contains local points of inflexion . These waviness is made clear by plotting the deviations of the profiles from the Blasius solution of the laminar bounary layer which is shown to be valid even for a turbulent free stream .

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INTRODUCTION.

The boundary layer transition is sensitive to parameters which may or may not leave their marks on the average properties of the layer . Examples of the former category are high intensity free stream turbulence and pressure gradient .

One of the existing theories for predicting transition , namely, the stability theory regards the laminar boundary layer as a medium capable of performing " natural oscillations " around its mean .

Another theory for predicting transition due to Taylor (1936), assumed that transition is caused by momentary separation (or points of inflexion in the velocity profiles) in the region of adverse pressure gradient associated with the turbulent velocity fluctuations .

It is interesting to note that both theories anticipated transition at a position in the laminar layer with an inflexional velocity profile in either a local or intermittent fashion . It is also interesting to know that Dhawan et al (1958), Klebanoff et al (1959 and 1962), Wortmann (1969), Chen et al (1971) and Nishioka et al (1975) reported experiments showing that the turbulent bursts in the laminar layer are produced from mean or instantaneous velocity profiles with points of inflexion. Kim et al (1971) observe that even in the process of turbulence production in the innermost layer of the turbulent boundary layer, a form of oscillatory breakdown of momentarily inflexional velocity profile is the mechanism responsible for such turbulence production . In the present work, measurements of the mean velocity profiles in the transitional region of the boundary layer beneath a turbulent free stream over a flat plate are reported with the aim of throwing some light on the development of the mean velocity profiles in such a region and studying its modes of instability .

EXPERIMENTAL APPARATUS AND TECHNIQUES.

Measurements are made using the hot wire anemometers. The velocity profiles are measured on a 1.5 inch thick flat plate having an 8 inch elliptic nose section installed in a 3x3 wind tunnel . Turbulence is generated in the test section by means of bi-planner grids inserted at the begining of the test section . For more details, see Abdel-Kareem (1978) .

RESULTS AND DISCUSSION.

The measurements are made at stations covering the laminar -transitional-turbulent regions of the boundary layer for the free stream speeds of (6 , 8.5 & 20 m/s) for the following values of the free stream turbulence intensity:

0.1 % , 1.85 % , 2.0 % , 2.2 % , 5.4 % & 5.9 %

Figure 1 shows the normalised mean velocity profile at some stations over the plate in the laminar region for different values of the free stream turbulence intensity together with the Blasius profile for the laminar boundary layer in the quiescent stream . The fig. shows a very good collapse on the Blasius profile of the reported data . One can, therefore, say that the development of the laminar boundary layer over the plate at least within the same range of Reynolds' no. and before the onset of the amplified disturbances follow the Blasius profile very closely .

Figures 2 to 5 show the mean velocity profile development in the X-direction for the mean free stream speed of 6.3 and 20 m/s . We notice that some waviness seems to exist for some profiles e.g. the ones taken at X = 45 cm in fig. 2 and at X = 15 cm in fig. 3 and at X = 15 cm in fig. 4 and at X = 14 cm in fig. 5 . These waviness are repeated too often with the same definite trend to be simply dismissed as inaccuracy on the part of the measuring equipment, although such inaccuracy is not unlikely in such a highly agitated thin layer . We notice the same phenominon even without turbulence in the free stream, as is clear from fig. 6 at the station X=50 cm which shows that this phenominon is characteristic to the instability of the two-dimensional boundary layer in general .

It is interesting to see how the reported profiles in the above figures deviate from the Blasius profile for the laminar boundary layer . Figures 7 to 11 show such differences for the above profiles . We notice that, the comparison between the first profile and the second one in both of figures 10 & 11 suggests a rather locally steep pattern of the mean speed or a region of high velocity gradient that may be due to a localised tendency to develop a point of inflexion . While the second profile in both plots indicate that such a process is well under way, yet the first profile in fig. 11 and the second profile in fig. 10 indicate by their regions of positive and negative deviation that such a point of inflexion is developed after some oscillations of the mean velocity profiles around the value given by the Blasius solution .

Then at a chosen speed of 8.5 m/s and a free stream turbulence intensity of 1.85% , a comprehensive study of the mean velocity profiles in the laminar and transitional regions is made and the results are presented in fig. 12 . The deviation of each profile from that given by Blasius solution of the laminar boundary layer is presented in fig. 13 .

Inspection of the two curves reveals the presistance of the phenominon of waviness of the U - profiles which indicates that the points of inflexion may be created locally due to the preliminary negative mean strain rate caused by the wall retardation at some parts of the profiles in the streamwise direction ($\partial U/\partial x$) or some other three-dimensional instability pattern which will induce the U-profile to develop points of inflexion .

CONCLUSION .

The present experiment has shown that, prior to transition, the laminar boundary layer develops wavy mean velocity profiles that contain local points of inflexion . This waviness is very clearly indicated when the deviations of the profiles from the Blasius profile for the laminar boundary layer (which is shown to be valid in the present experiment even for a turbulent free stream) are plotted . This waviness may be due to a three-dimensional instability pattern that may develop possibly with some resemblence to the reported three-dimensional instability by Dhawan et al (1958) , Klebanoff et al (1959 , 1962) , Wortmann(1969) & Nishioka et al (1975) .

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The reported results is a part of the auther's work which is reported in his Ph.D. thesis .

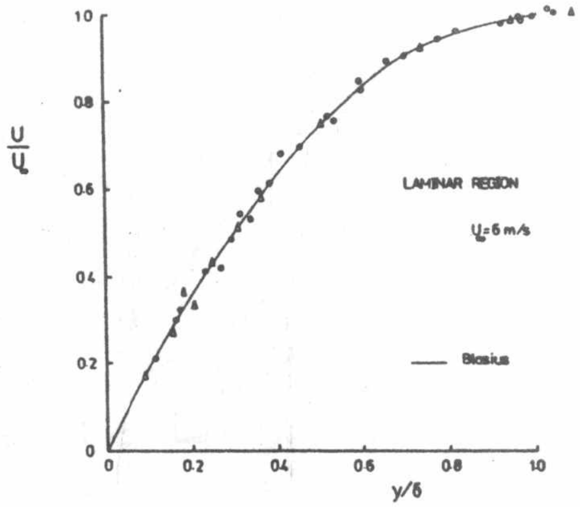


Fig. 1
U-profiles in the laminar region

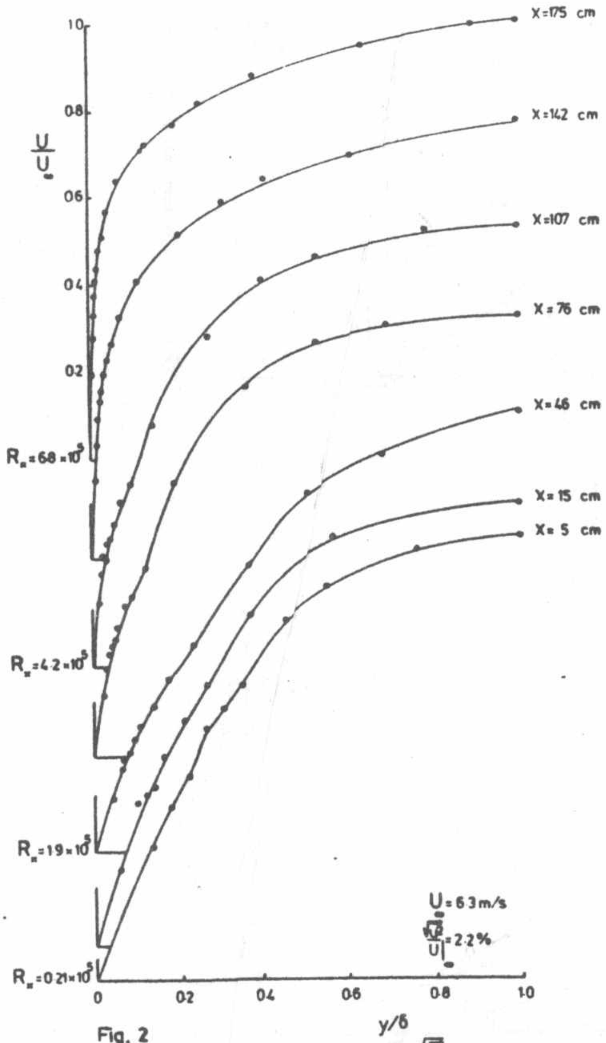


Fig. 2
The U-profiles over the plate (for different $\sqrt{\overline{u'^2}}/U_\infty$)

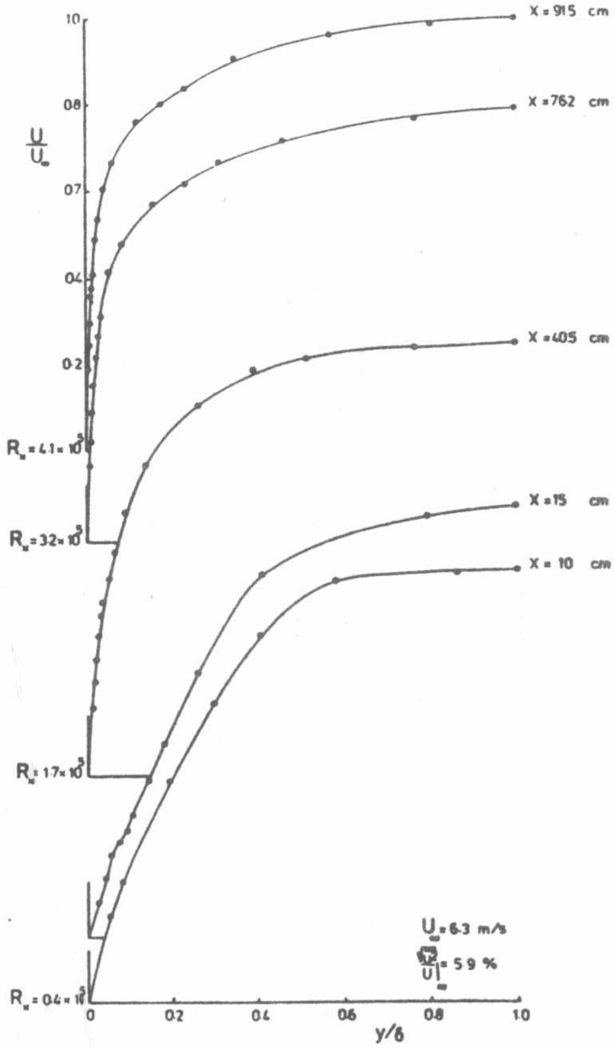


Fig. 3 (For legend see fig. 2)

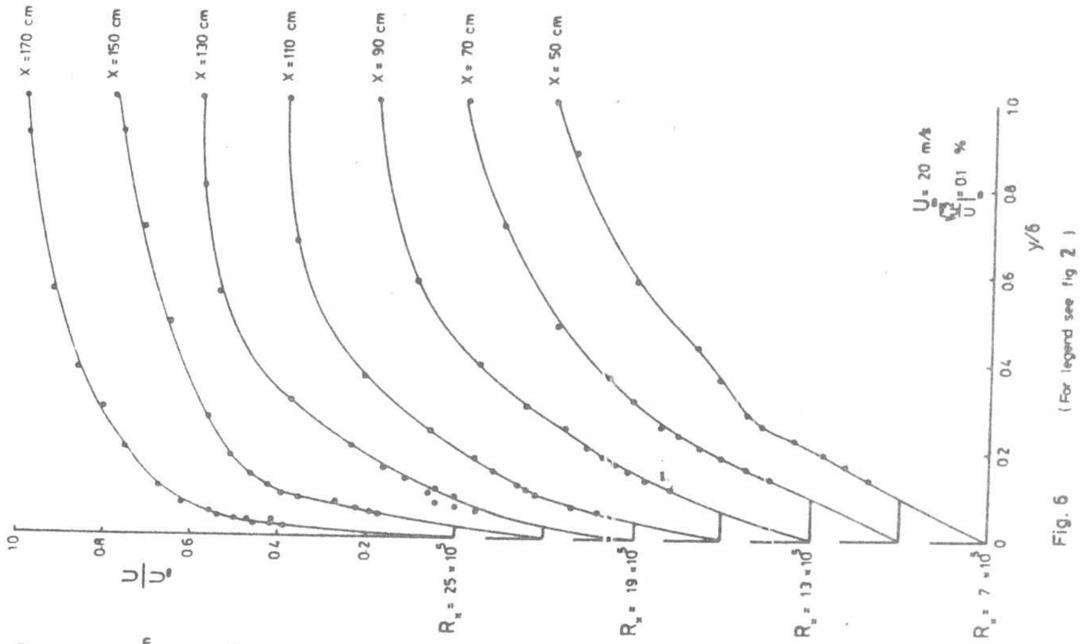


Fig. 6

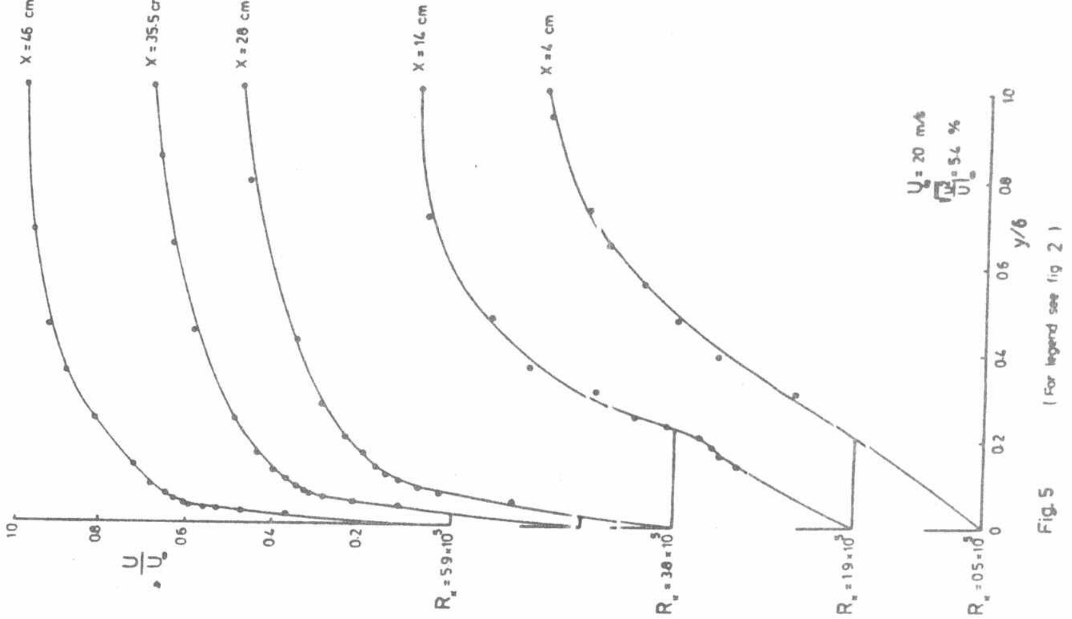


Fig. 5

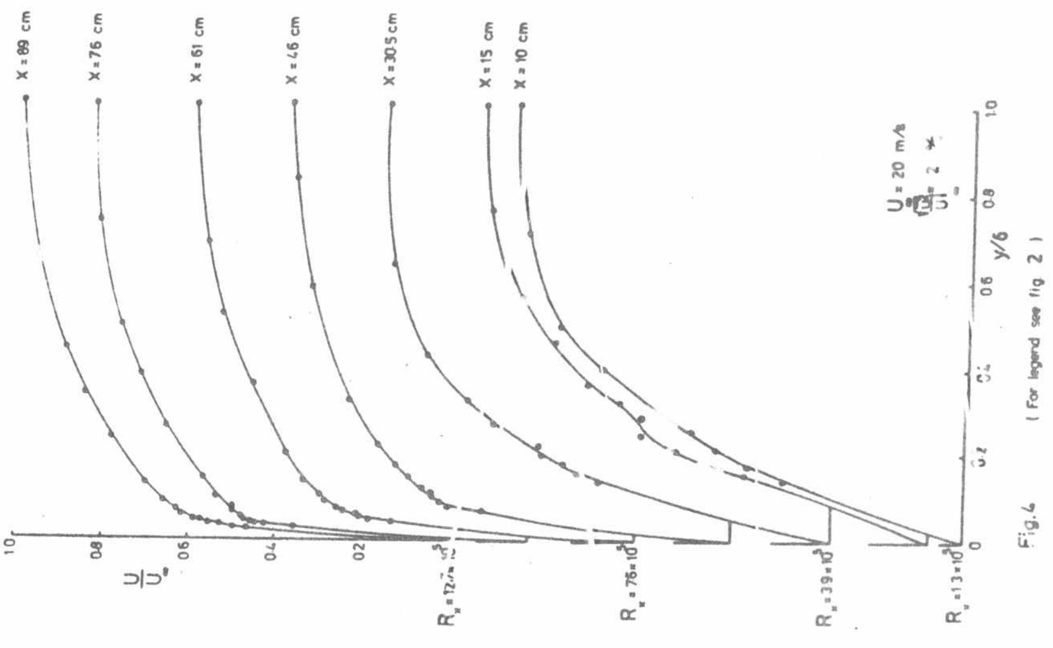


Fig. 4

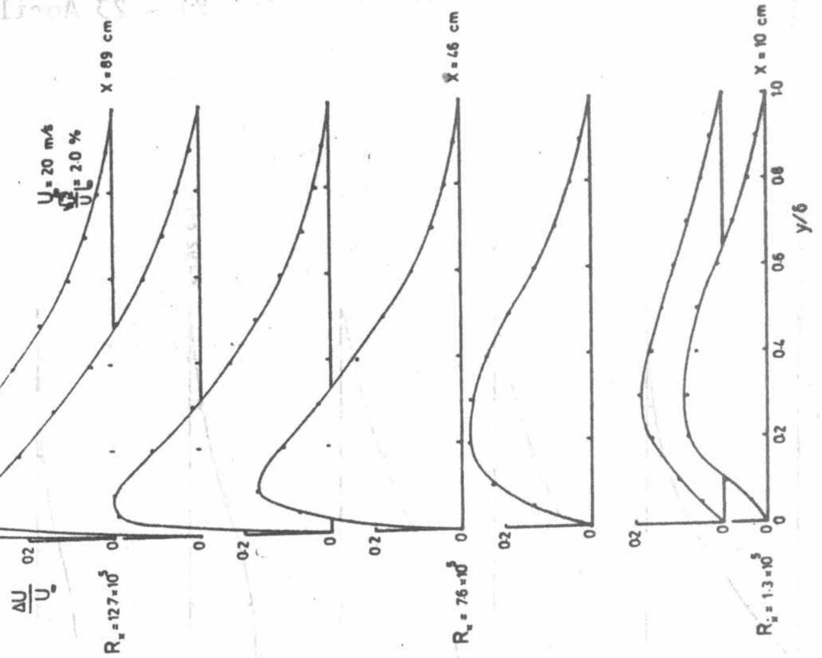


Fig. 9 (For legend see fig 11)

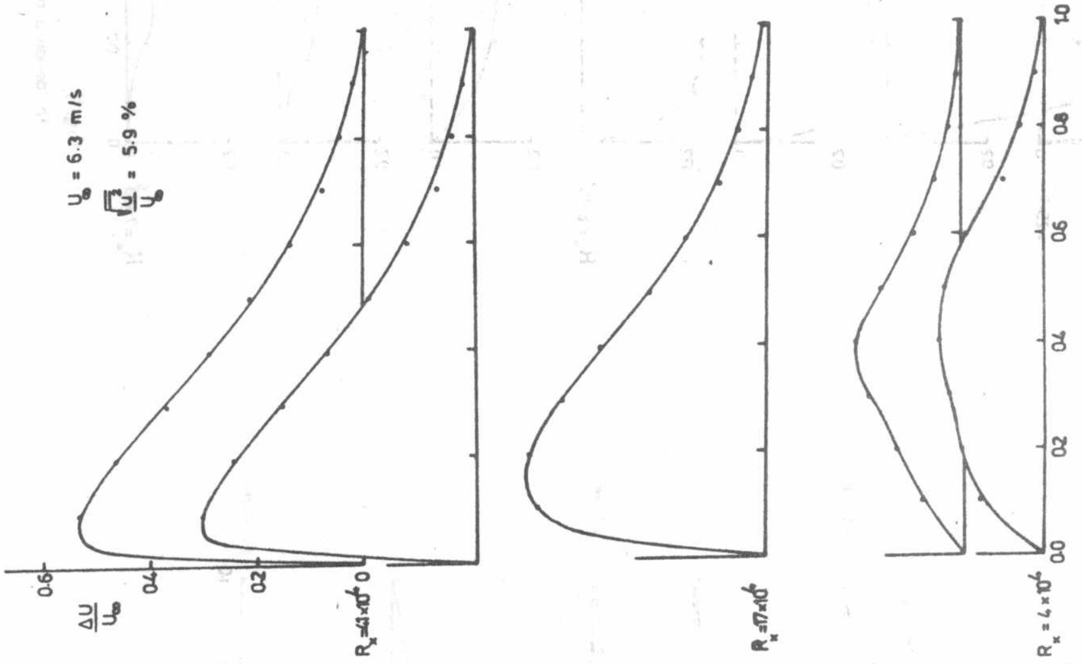


Fig. 8 (For legend see fig. 11)

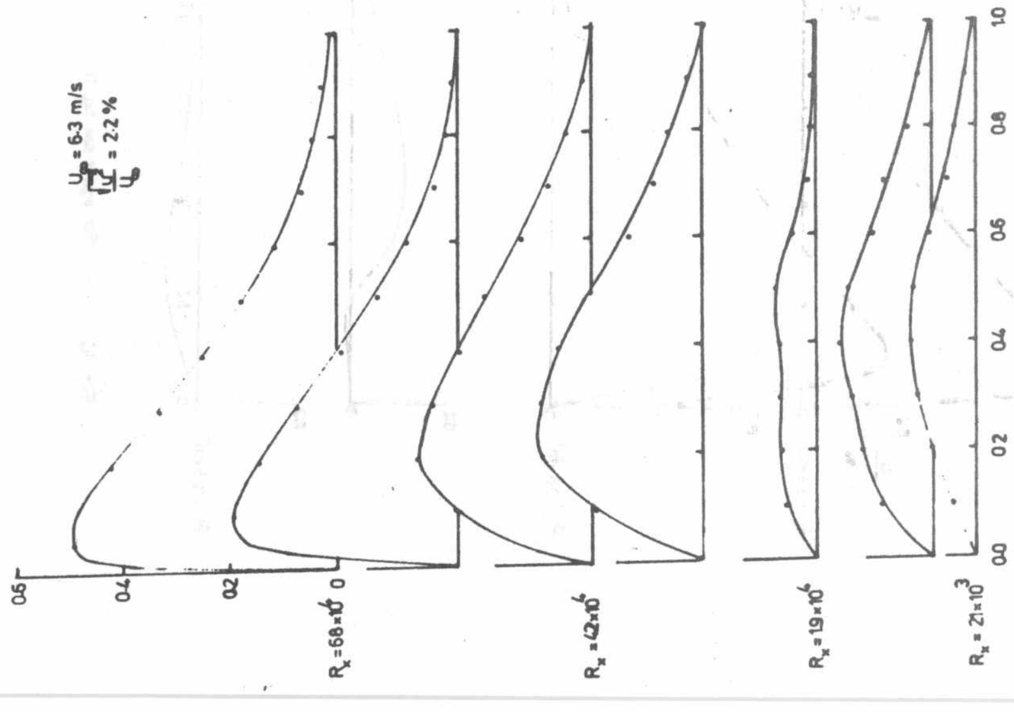


Fig. 7 (For legend see fig. 11)

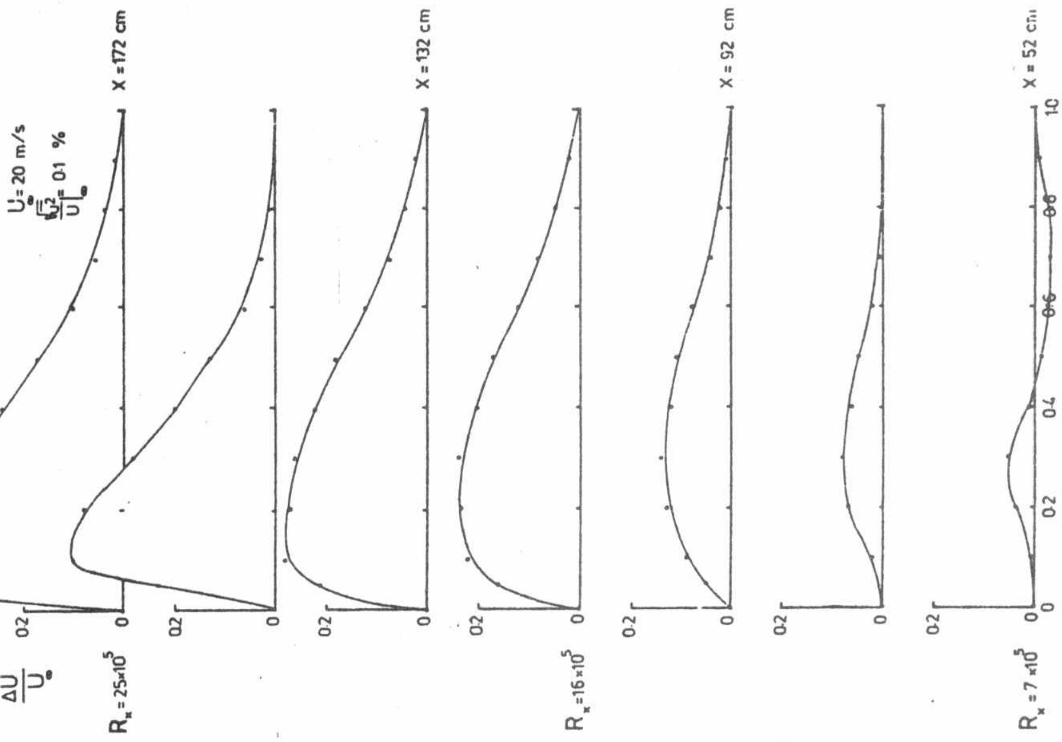
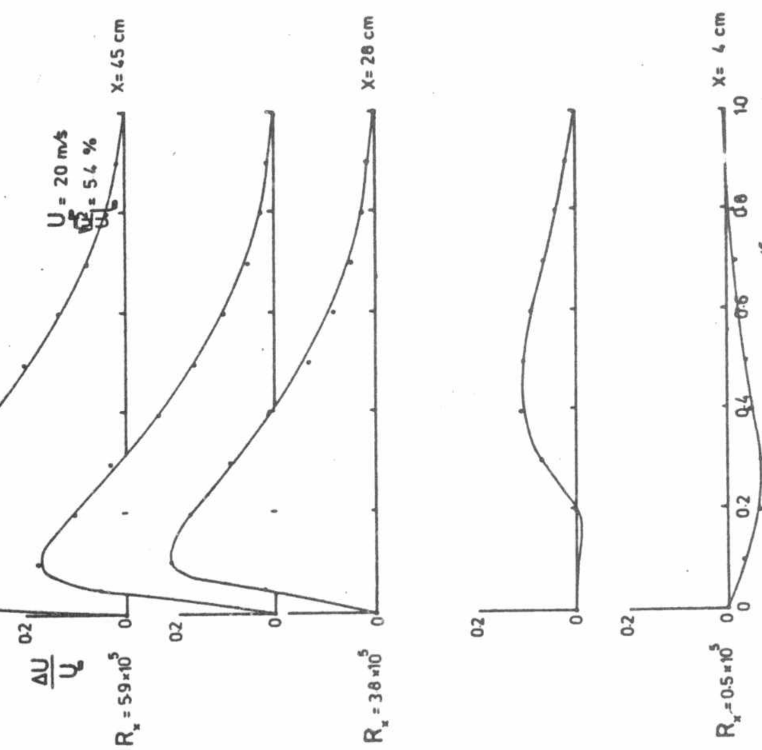


Fig. 11 The deviation of the U-profiles from the Blasius profile.



(For legend see fig. 11)

Fig. 10

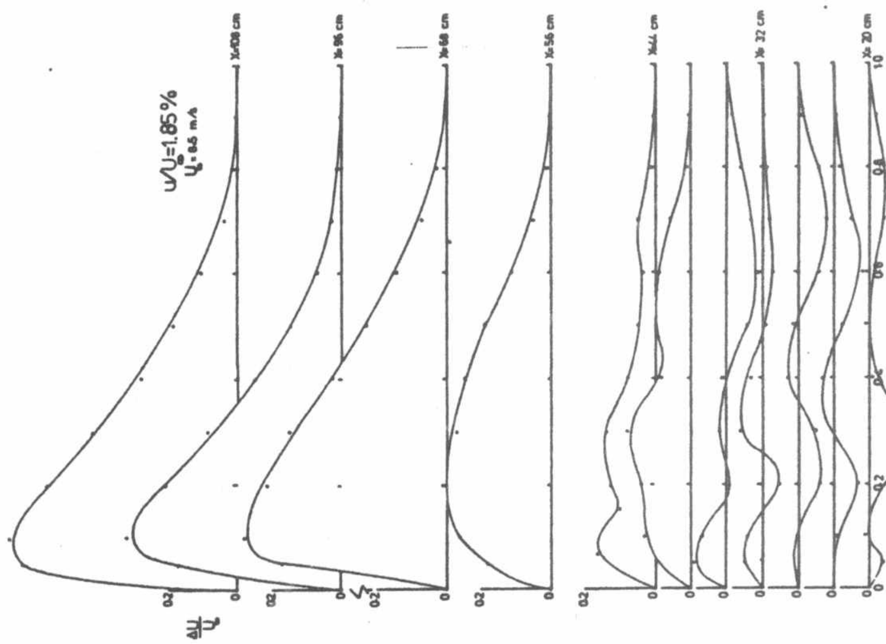
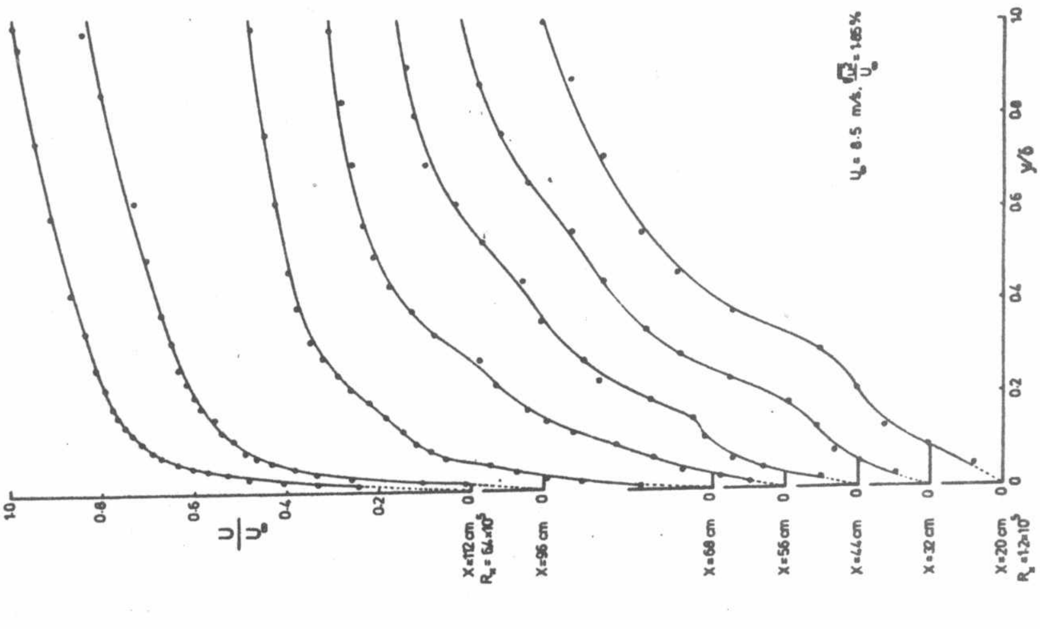


Fig.13 The deviations of the U-profiles (fig.12) from the Blasius profile.



U-profiles within the laminar-transitional boundary layer.

Fig. 12