ON THE SKIN FRICTION COEFFICIENT EVOLUTION IN TRANSITIONAL BOUNDARY LAYER FLOWS

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ABSTRACT

The present study deals with the transition to turbulence in the boundary layer developed over turbomachinery blading. Although even today we have not been able to fully comprehend it, transitions' impact on the characteristics of the boundary layer is well established. Through complementary theoretical and experimental analysis, this work aims to improve the understanding of this process, and eventually develop relevant correlations between important flow quantities.

INTRODUCTION

Transition to turbulence is a phenomenon that has a key role in the aerodynamic and thermal behavior of the boundary layer. Despite its significance, its complete description remains elusive, largely due to its inherent non-linear behavior and multi-modal nature. Improved understanding of this process can enable more optimized designs and enhanced performance across a wide range of engineering applications on land, sea, and air. This work is divided into two main sections; first to establish the theoretical foundations, the identified mechanisms governing transitional flows and their characteristics are discussed, together with the influence of parameters such as free-stream turbulence intensity and surface roughness. Then, an experimental investigation through hot-wire anemometry is discussed and the data acquired are handled through an in-house developed post-processing code. Critical boundary layer integral parameters are calculated through the velocity signals measured. For the sake of the stochastic and chaotic behavior of turbulence, statistical parameters (i.e. distribution moments) are also introduced, which help us to identify the state of the boundary layer and its intermittent character in a reliable manner. Following these calculations and their visualization in a dimensionless way in order to produce a universal way of thinking around transition, the Clauser chart method is implemented to calculate the main quantity of interest of this study, the skin friction coefficient across the boundary layer. Ultimately, useful correlations based on the experimental results are developed by using the boundary layer quantities mentioned and their applicability to relevant turbomachinery flow conditions is also addressed.

RESULTS AND DISCUSSION

Following the determination of the skin friction coefficient, we are now able to derive quantities like the shear stress at the wall and the friction velocity, and eventually allow us to calculate the y+ for each downstream point of measurement. Towards a universal graphical representation of the development of the boundary layer from laminar to finally fully turbulent, we have generated the following 4 contour plots of u+, Tu, S and T in the dimensionless space y+ vs Re_x. Looking at these contours, we can detect various remarkable aspects of transition. For low Re_x we observe the features of laminar flow, which are then followed by the transition process with the highest Tu values and then eventually reach the fully turbulent flow where we observe the restabilization of velocity profiles. From the skewness and flatness factors, we can detect clearly two distinct regions; the viscous sublayer and the outer (wake) layer. The region between these two cores is where turbulence intensity reaches is maximum values.

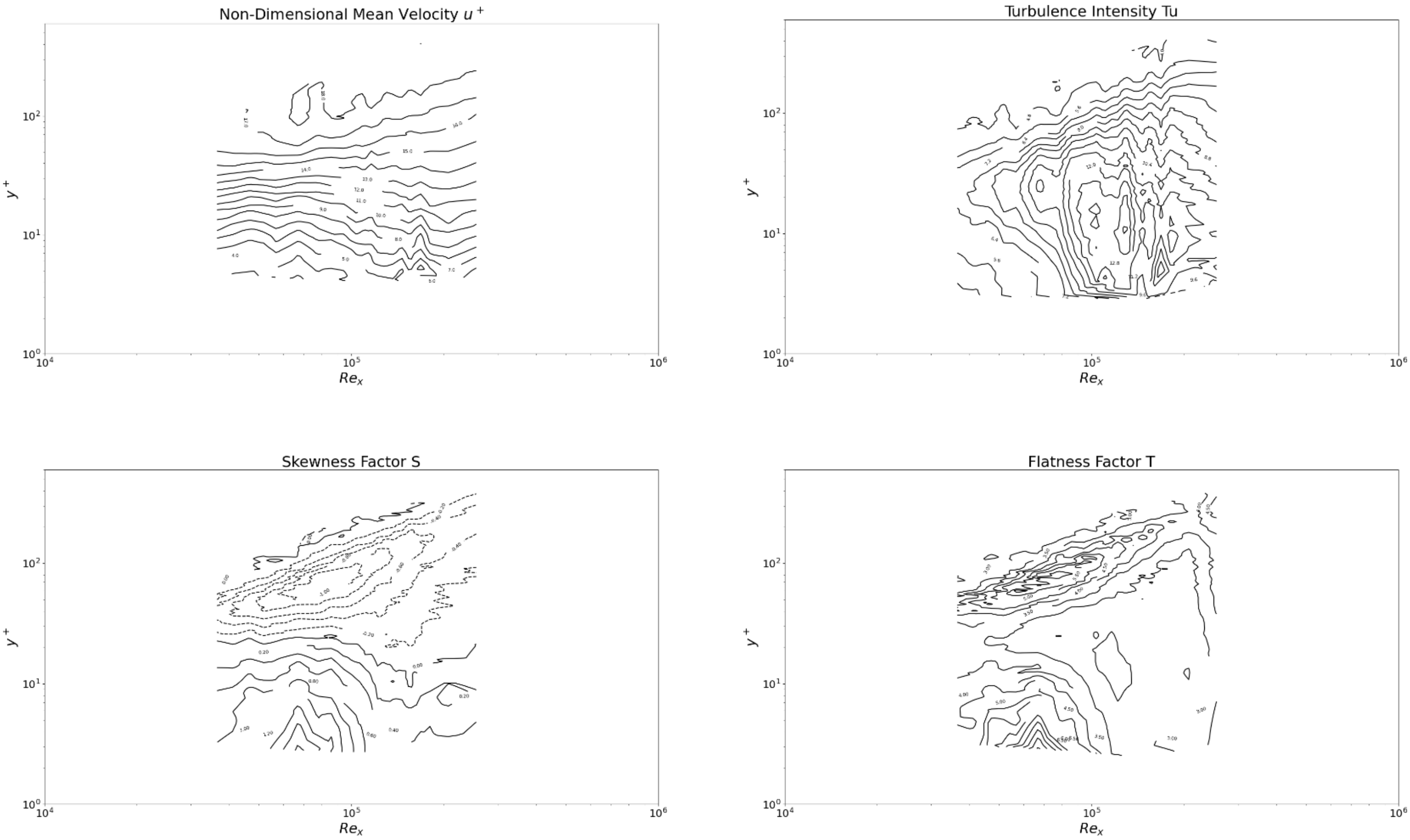

Figure 1. Distribution of u+, Tu, S and T in the dimensionless space y+ vs Re_x