DNS INVESTIGATIONS OF STEADY RECEPTIVITY MECHANISMS ON A SWEPT CYLINDER

Grégoire Casalis[1], Estelle Piot[2]
ONERA DMAE, Toulouse, FRANCE

Summary This paper deals with the generation of steady crossflow waves by micro roughness elements placed on a swept cylinder. This receptivity process is investigated by DNS and linear stability analyses.

INTRODUCTION

Laminar-turbulent transition in swept wing boundary layer flows is often due to the spatial amplification of instability waves. Their initial amplitude comes from the so-called receptivity phenomenon. The present work deals with steady instability waves initiated by micron-sized roughness elements placed on a swept cylinder. The study is performed thanks to the DNS home-made code "SABRINA", see [1].
It must be noted that the roughness elements are integrated in the grid : they are fully taken into account in the present computations, thanks to no-slip conditions on their whole surface. The computations are done in two successive steps. First the flow without roughness element is computed, which leads after a transient phase to a steady flow. The latter is then introduced as an initial solution for the second computation performed with a roughness element. As shown in [2], the discontinuity induced by forcing a roughness element in the previous flow may lead in some cases to an unsteady crossflow mode. In the present configuration, the unsteady response is temporally damped and after some transients only the steady perturbation remains.
The present abstract begins with the general assumptions and the considered geometry. Then an example of results is given which clearly shows that the obtained steady perturbation induced by the roughness elements corresponds to a steady crossflow mode.

GEOMETRY AND ASSUMPTIONS

The main geometry is displayed in figure 1. Some roughness elements are placed periodically

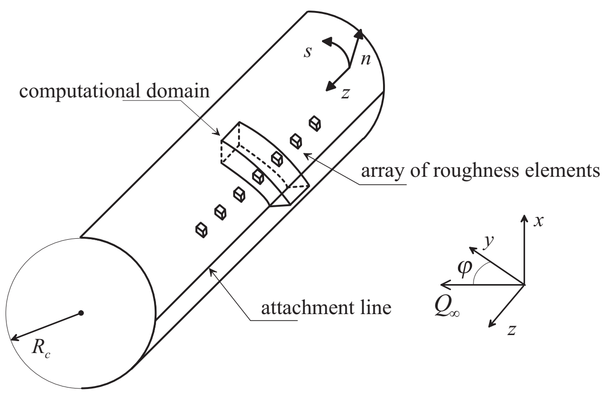

Figure 1. Geometry and main notations

along a line parallel to the swept cylinder leading edge. The swept angle is $\varphi = 60°$, the incoming velocity norm $Q_\infty = 50$ m/s and the cylinder radius $R_c = 0.1\ m$. The flow is assumed to be periodic with respect to the spanwise coordinate z, so that the numerical domain contains a single roughness element. The streamwise coordinate is denoted by s, the normal to the wall by n.

[1]gregoire.casalis@onera.fr
[2]estelle.piot@onera.fr

The full Navier-Stokes equations are then solved with the code SABRINA, using a fourth order scheme in space and a third order one in time.

EXAMPLE OF RESULTS

With the roughness element placed around 14° from the leading edge, the flow obtained after some computing time can be decomposed into a mean part with respect to z and a periodic one. The first part is very close to the theoretical laminar viscous solution around a smooth cylinder. The second one is periodic in z. At a distance to the wall close to a quarter of the boundary layer height δ, left hand part of figure 2 shows the streamwise velocity component of

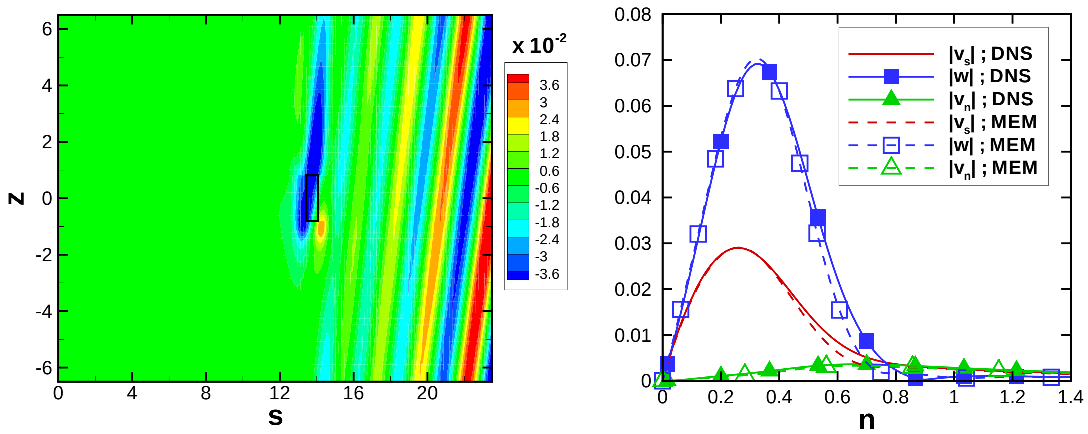

Figure 2. Steady perturbation. Left : amplitude of the steady streamwise velocity perturbation at the height $n \simeq \delta/4$. Right : comparison between the DNS results and the ones coming from the multiple scale analysis (MEM), for $s = 20°$.

the obtained steady flow from which the smooth cylinder solution has been subtracted. Except in a region very close to the roughness element this perturbation looks like a steady crossflow eigenmode. This is proven by the right hand part of figure 2 which shows a comparison between the first Fourier mode in z of the DNS solution and the linear stability solution obtained by the multiple scale analysis (in order to include the non parallel terms and the body curvature effect). The three velocity components are shown versus the distance n from the wall at an abscissa corresponding to $s = 20°$. The amplitude of the linear stability results has been adjusted to fit with the DNS result.

GENERALIZATION

Figure 2 shows that the difference between the DNS solution computed with a roughness element and the theoretical smooth cylinder solution corresponds in this case (size and shape of the roughness element) to a steady crossflow mode as it can be obtained from the linear stability analysis. The final paper will provide more details on the DNS computations themselves and will also give a short parametric study of the amplitude and the phase of the obtained steady perturbation as function of the geometrical shape (height and width) of the roughness element.

References

[1] M. Terracol. *Développement d'un solveur pour l'aéroacoustique numérique : SABRINA.* Technical Report RT 5/07383 DSNA, Rapport technique ONERA, 2003.

[2] E. Piot. *Simulation numérique directe et analyse de stabilité de couches limites laminaires en présence de micro-rugosités.* PhD, SUPAERO, Université de Toulouse, september 2008.