Wingtip vortex in a NACA0012 airfoil and its active control

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Abstract

We conduct experiments in a towing-tank to analyse the flow patterns of wingtip vortices in a NACA 0012 airfoil. In this experimental research, we provide PIV measurements and flow visualisations. Without active control, several parameters are given experimentally as function of the Reynolds number, so we compare these data with the theoretical models of Batchelor, and Moore and Saffman together with DNS. Secondly, we analyse the effect of a continuous injection in the spanwise direction. The continuous jet has a strong influence on the wing-tip vortex formation. We explore this effect at low chord based Reynolds number ranging from 7000 up to 20000. We change the aspect ratio of the injection, *R*, defined as the ratio of the velocities between the jet (*Uj*) and free-stream (*U*). For *R*=1, we find that the jet strongly affects the wingtip vortex formation with a sudden decrement of the axial vorticity and the azimuthal velocity. This technique is a challenge and a promising tool to reduce the intensity of the vortex core.

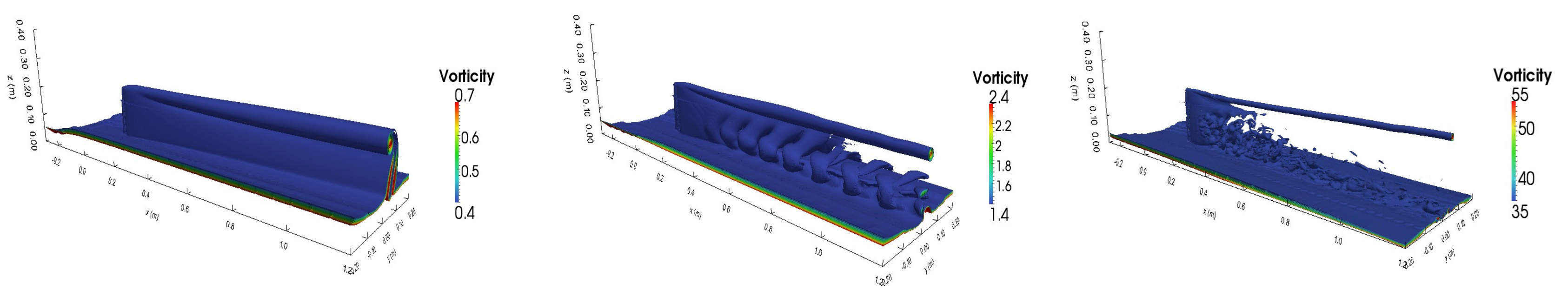
Introduction

Wing-tip vortices are circular patterns of rotating air left behind a wing as it generates lift. We study this phenomenon with a NACA0012 airfoil using three different points of view:

Direct Numerical Simulations (DNS)
Hydrodynamic instabilities
Experiments

DNS (Dominguez2014)

Re=666 *Re*=1333 *Re*=7000



Hydrodynamic instabilities

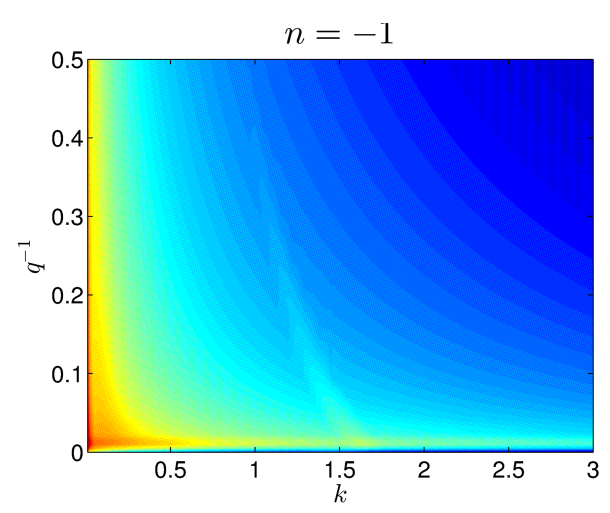
Non-modal stability analysis $(t \sim 0)$

- Response to initial conditions (Optimal perturbation)
  - Transient growth (Mao2012)
- Response to external forcing (**Optimal response**)
  - Time-harmonic forcing (Guo2011)
  - Stochastic forcing (Fontane2008)

Normal mode stability analysis $(t \sim \infty)$

- Strong inviscid helical instability (Heaton2007)
- Weak viscous instabilities (Khorrami1991)
- Weak viscous centre instabilities (Fabre2004)
- Cooperative instability (Hattori2009)

Batchelor vortex, *Re*=1000



Applications:

Aeronautics: Optimization of airport traffic decreasing the current spacing between aicrafts in complete safety

Wind energy: Increase the performance in wind farms of turbines since the funcionality of one rotor depends on the incident flow given by the precedent one

Objective:

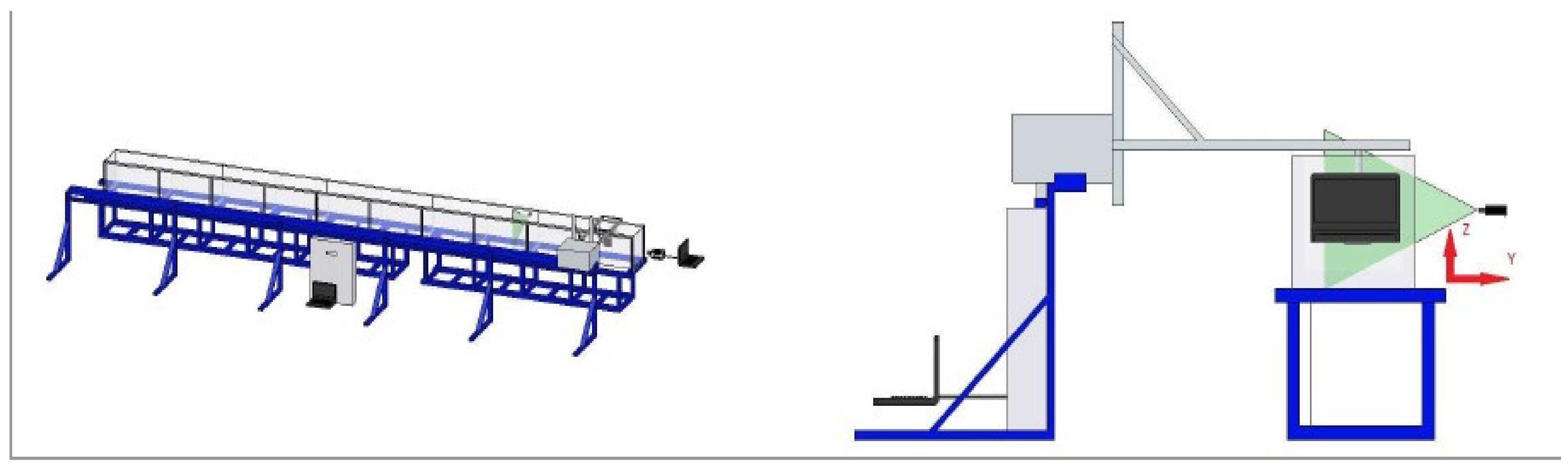
To characterize experimentally the response of continuous jets with different strengths in order to know the paremeters of theoretical models

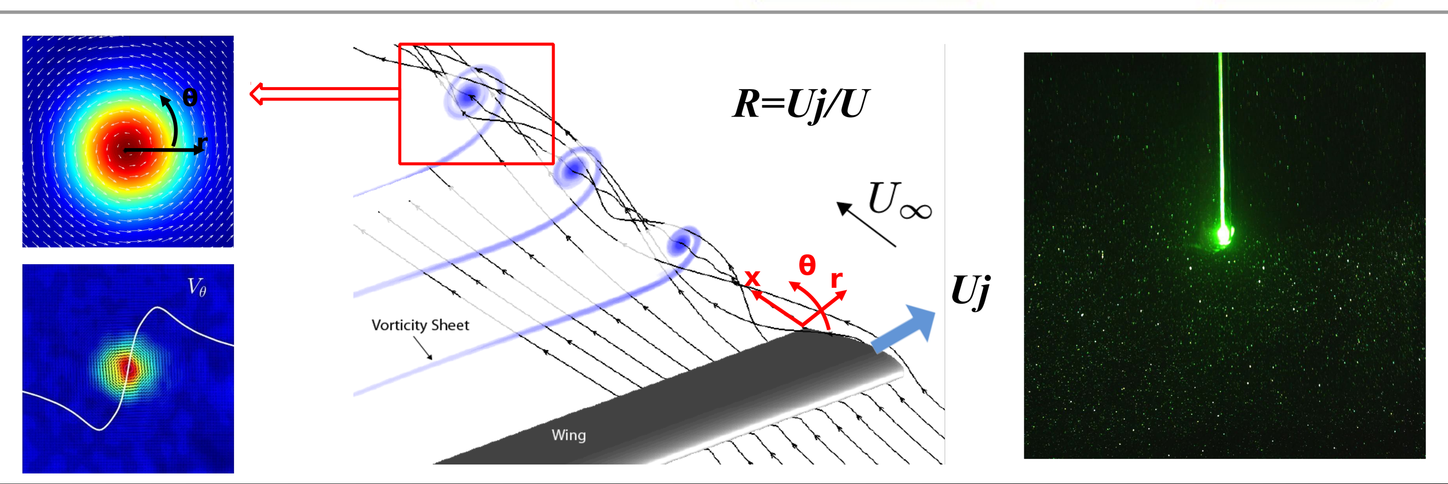
Why?

Because Batchelor and Moore and Safmann models are widely adopted in Aeronautics

[Dominguez2014] A. Dominguez Vazquez, L. Parras and C. del Pino *The Aeronautical Journal (submitted, 2014)*
[Guo2011] Z.-W Guo and D.-J. Sun, **375**, *Phys. Letters A*, (2011)
[Fontane2008] Fontane et al. , **613**, *J. Fluid Mech.*, (2008)
[Khorrami1991] M.R. Khorrami, **225**, *J. Fluid Mech.*, (1991)
[Fabre2004] D. Fabre and L. Jacquin, **500**, *J. Fluid Mech.*, (2004)
[Mao2012] X. Mao and S.J. Sherwin, **697**, *J. Fluid Mech.*, (2012)
[Heaton2007] C. J. Heaton, **576**, *J. Fluid Mech.*, (2007)
[Hattori2009] Y. Hattori and Y. Fukumoto, **21**, *Phys. Fluids*, (2009)

Experimental setup and procedure





Results

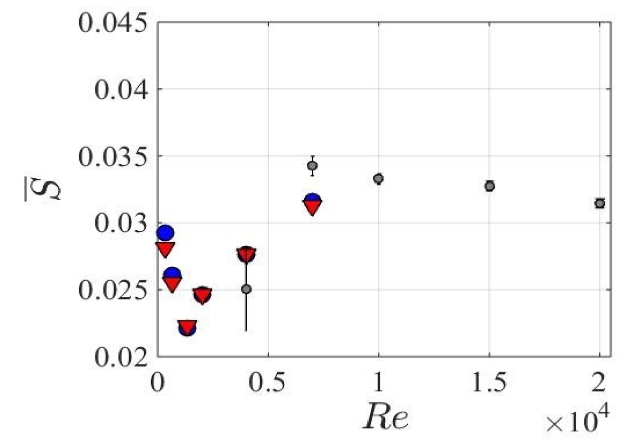
No injection, R=0

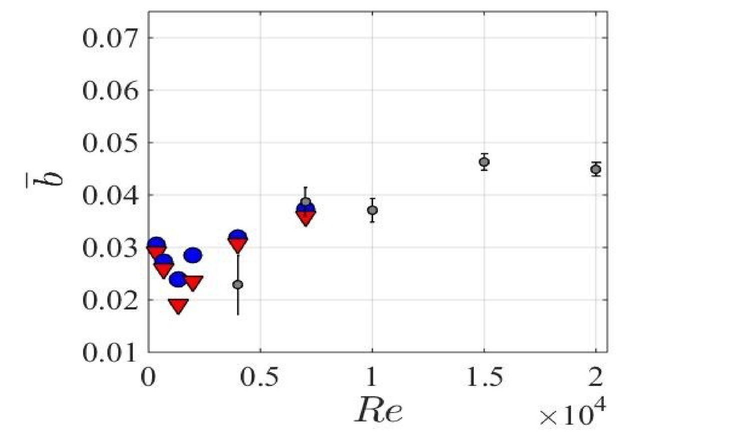
Batchelor's model

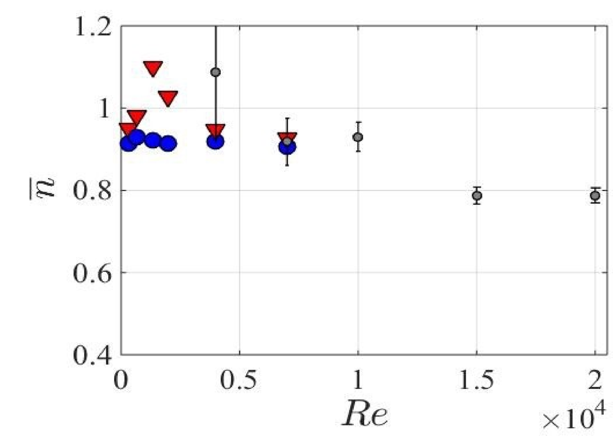
$$\bar{v} = \frac{\bar{S}}{\bar{r}}(1-e^{\eta}) \quad \eta \overset{\text{def}}{=} -\frac{\bar{r}^2}{4\bar{x}}$$

Moore and Saffman's model

$$V_n(\eta) = 2^{-n}\Gamma\left(\frac{3}{2}-\frac{1}{2}n\right)(-\eta)^{1/2}M\left(\frac{1}{2}-\frac{1}{2}n;2;\eta\right)$$



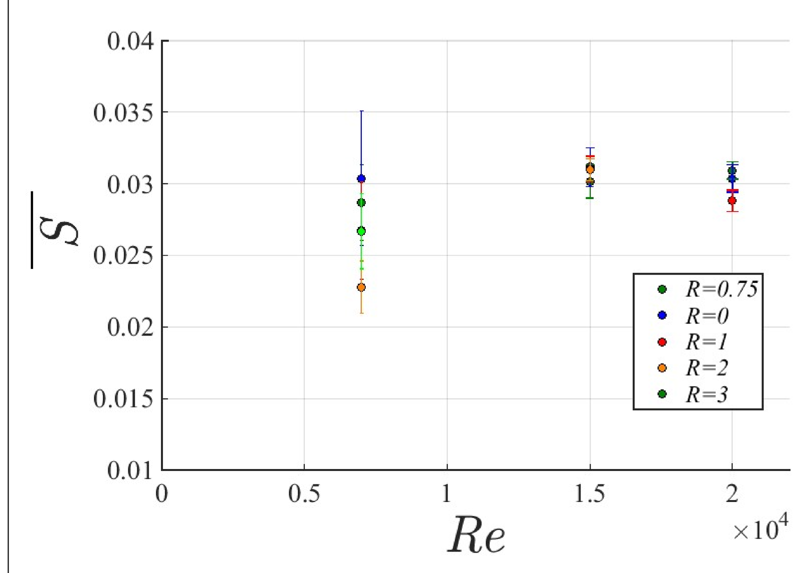


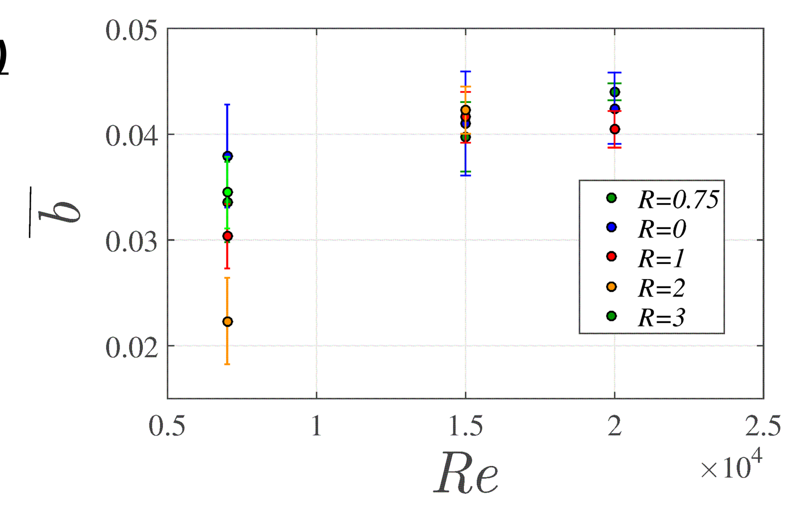


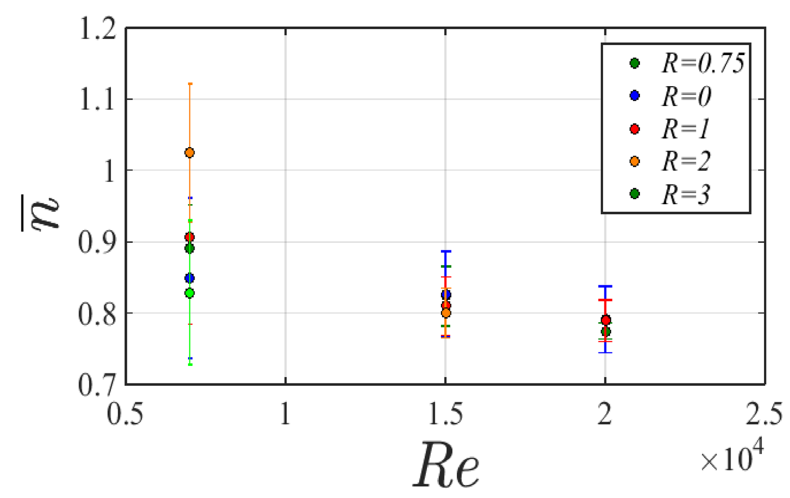
Excellent agreement between DNS (blue circles and red triangles) and experiments (grey circles)!!

Change in the trend due to instabilites at Re=1200 approximately!!

Injection, different R (only experiments)

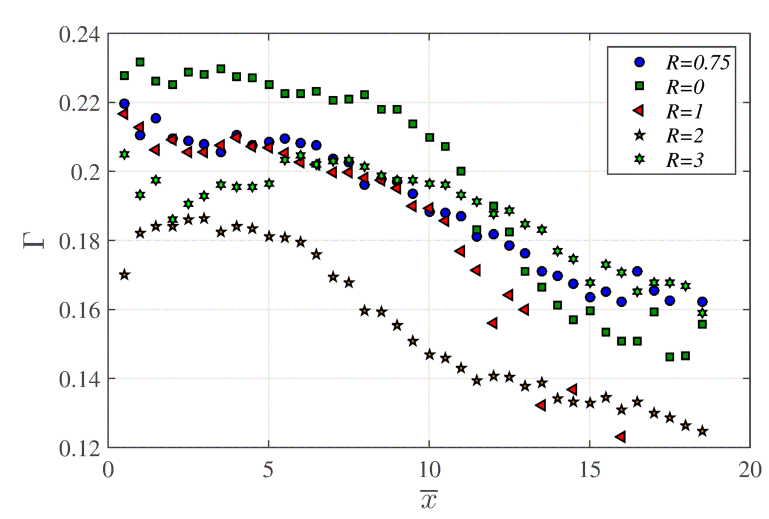






There is no difference in the theoretical parameters as Reynolds number increases!!

How to destroy the wingtip vortex. Circulation versus axial distance for Re=7000



The continuous jet is a powerful tool to destroy the wingtip vortex for R greater than 1.

Conclusions and perspectives

- Theoretical models for trailing vortices are investigated using DNS and experiments. We compute the parameters with and without injection to explore the influence of the Reynolds number.
- Realistic ratios *R* between 1 and 2 are candidates to destroy the wingtip vortex. More effort is required to know the effect of pulsating jets.
- Futher research will deal with the effect of the axial flow on the optimal response of the Batchelor vortex. Optimal forcing structure is so complicated that it is not possible to reproduce experimentally. Understanding the mechanism will provide an insight of the forcing location.

Acknowledgments

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