On the effect of low blowing ratio continuous jet on wingtip vortex characteristics

Francisco J. Blanco-Rodríguez[1], *J. Hermenegildo García-Ortiz*[1,2], *L. Parras*[1] *and C. del Pino*[1]

[1] Universidad de Málaga, Escuela de Ingenierías Industriales, C/ Dr. Ortiz Ramos, s/n, 29071 Málaga (SPAIN)
[2] Universidad de Cádiz, Escuela Superior de Ingeniería, Avda. Universidad de Cádiz, 10, 11519 Puerto Real, Cádiz (SPAIN)

I. INTRODUCTION

Vortices are an unavoidable effect of flight, which appear behind the wing with a bounded length. The strength of these vortices, which are **extremely stable**, is due to the lift force.

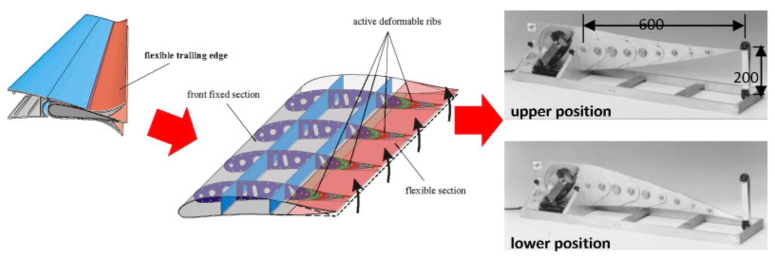
Wingtip vortex control

PASSIVE CONTROL

Winglets are the most widely extended solution to decrease the vortex strength.

ACTIVE CONTROL

Techniques that affect the vortex through forcing by an actuator.
- Wingtip blowing [Carafoli1964]
- Syntetic jets [Margaris2006]
- Morphed wings [Li2018]



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

Objective: Characterize qualitatively/quantitatively the effect of continuous jet on wingtip vortex

Why? ↓

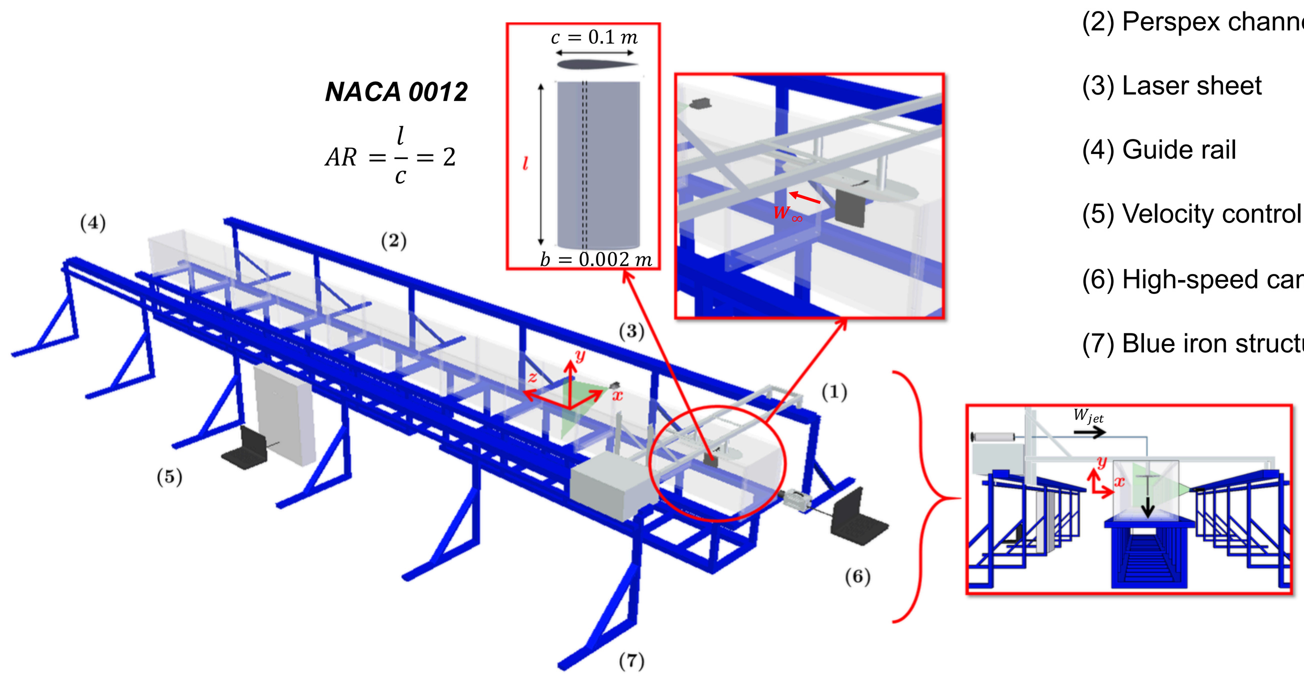
Because vortices should be controlled and broken for several applications

THUS
- → Compare the experimental results with wingtip vortex models proposed by Batchelor and Moore & Saffman.
- → Analize the effect of the blowing on spanwise vorticity for different Reynolds numbers and momentum coefficients.

[Carafoli1962] E. Carafoli, "The influence of lateral jets, simple or combined with longitudinal jets, upon the wing lift coefficient", **1**, *Int. Council of Aeronaut. Sciences (ICAS)*, (1962).
[Margaris2006] P. Margaris, "Wingtip vortex control using synthetic jets", **3079**, *Aeronautical Journal*, (2006).
[Li2018] D. Li *et al*. "A review of modelling and analysis of morphing wings", *Progress in Aerospace Sciences*, (2018).

II. EXPERIMENTAL SETUP

3D layout of the experiment



(1) Wing model in a moving support
(2) Perspex channel
(3) Laser sheet
(4) Guide rail
(5) Velocity control of guide rail
(6) High-speed camera
(7) Blue iron structure

Problem parameters

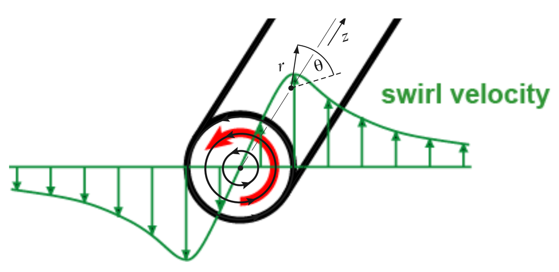
$$C_\mu = \frac{2\,b}{c}\left(\frac{W_{jet}}{W_\infty}\right)^2 = 0.04\left(\frac{W_{jet}}{W_\infty}\right)^2 \quad \text{[Amitay2001]}$$

$$Re = \frac{W_\infty\, c}{\nu}$$

KEY

Effect of the blowing jet on the destabilization process of the wingtip vortex for different

Re, C_μ



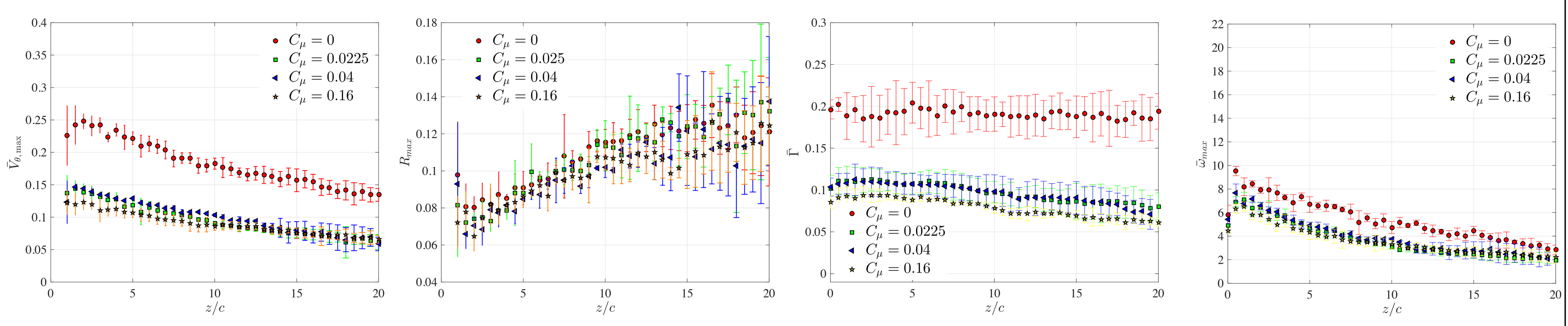
[Amitay2001] M. Amitay, D. R. Smith, V. Kibens, D. E. Parekh and A. Glezer, "Aerodymanic flow control over an unconventional airfoil using synthetic jet actuators", **39**, *AIAA Journal*, (2001).

III. EXPERIMENTAL RESULTS

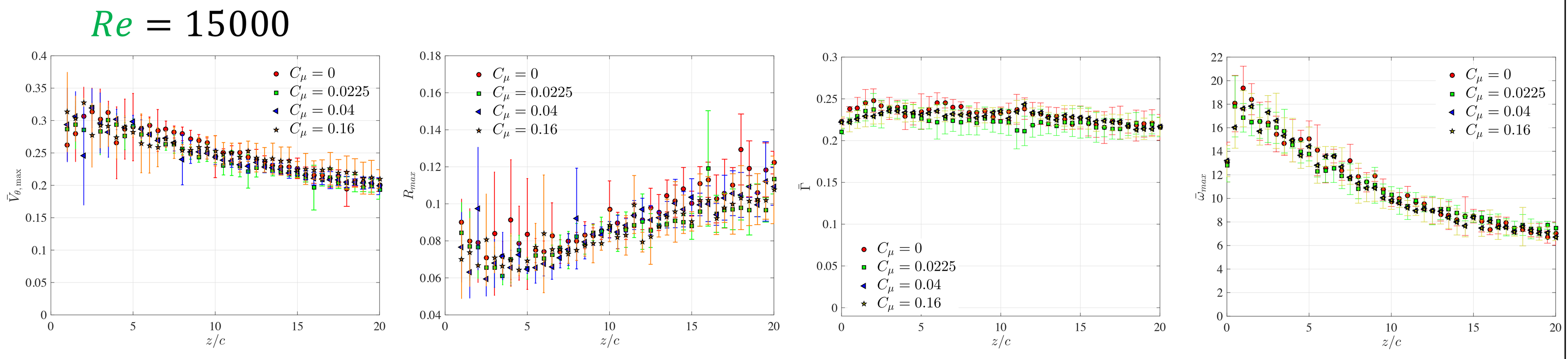
Vortex flow properties

$$\bar{V}_\theta = \frac{V_\theta}{W_\infty} \qquad \bar{z} = \frac{z}{c\,Re} \qquad \bar{r} = \frac{r}{c} \qquad \bar{\Gamma} = \frac{\Gamma}{W_\infty c} \qquad \bar{\omega} = \omega\frac{W_\infty}{c}$$

$Re = 7000$



$Re = 15000$



Four experiments are performed for different Reynolds numbers and each momentum coefficients. Error bars correspond to the standard deviation of one set of experiments.
Vortex core was determined by obtaining the position of maximum vorticity [Igarashi2010]

[Igarashi2010] H. Igarashi, P. A. Durbin, M. Hongwei and H. Hui, "A stereoscopic PIV study of a near-field wingtip vortex", **48**, *AIAA Journal*, (2010).

IV. THEORETICAL MODELS

Batchelor vortex model [Batchelor1964]

$$\bar{v} = \frac{S}{\bar{r}}\left(1 - e^{-\eta}\right)$$

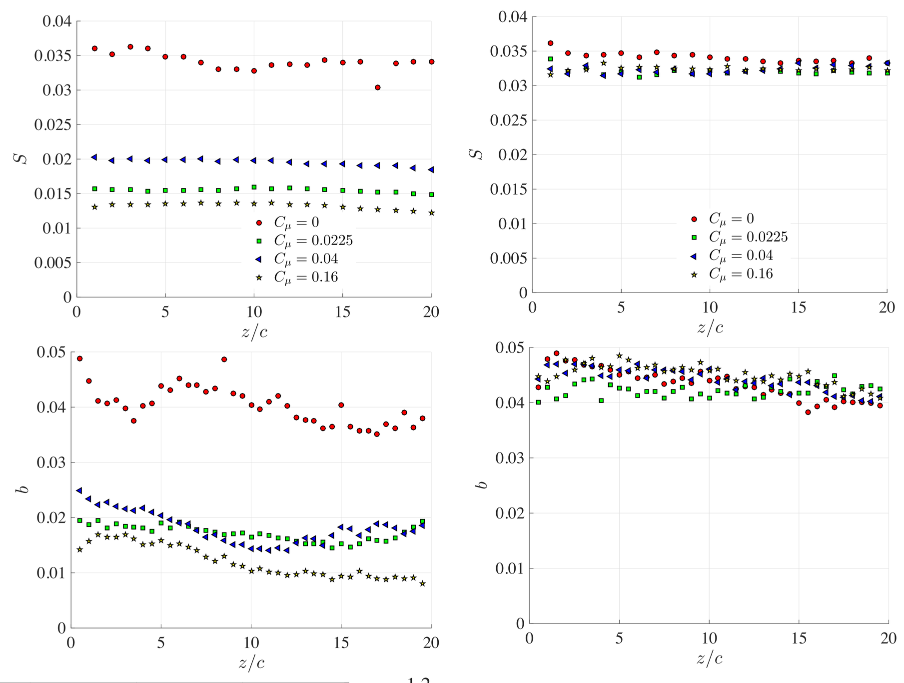
$$S = \frac{\Gamma}{2\,\pi\,c\,W_\infty} = \frac{\bar{\Gamma}}{2\,\pi}$$

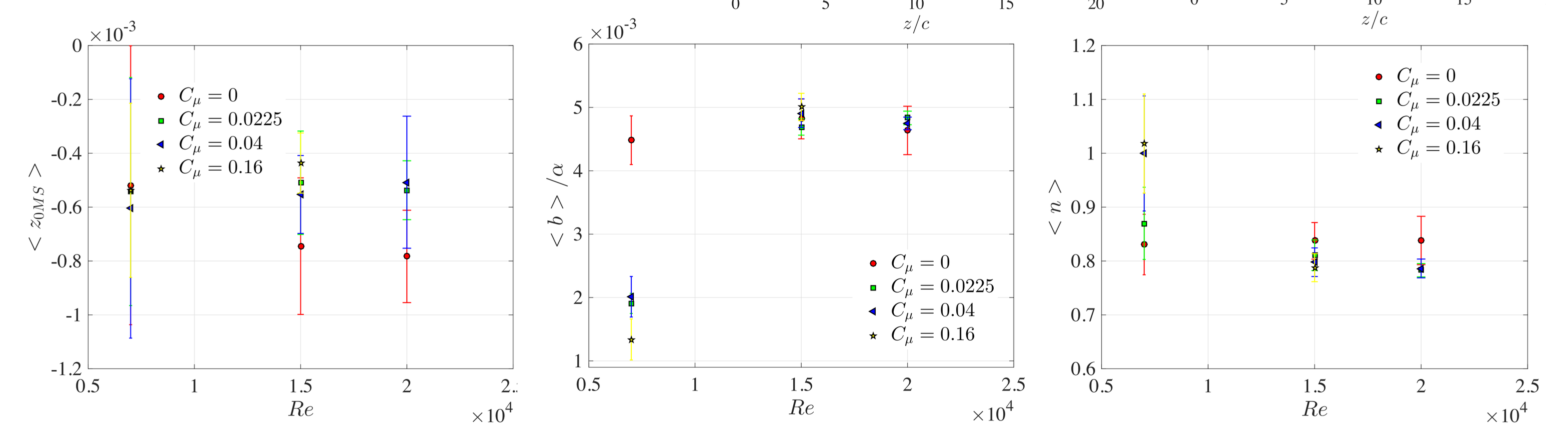
$$\eta(\bar{r},\bar{z}) = \frac{\bar{r}^2}{4\,(\bar{z} - \bar{z}_{0B})}$$

Moore & Saffman vortex model [Moore1973]

$$\bar{v} = \frac{b}{(\bar{z} - \bar{z}_{0MS})^{\frac{n}{2}}} V_n(\eta)$$

$Re = 7000$ $Re = 15000$





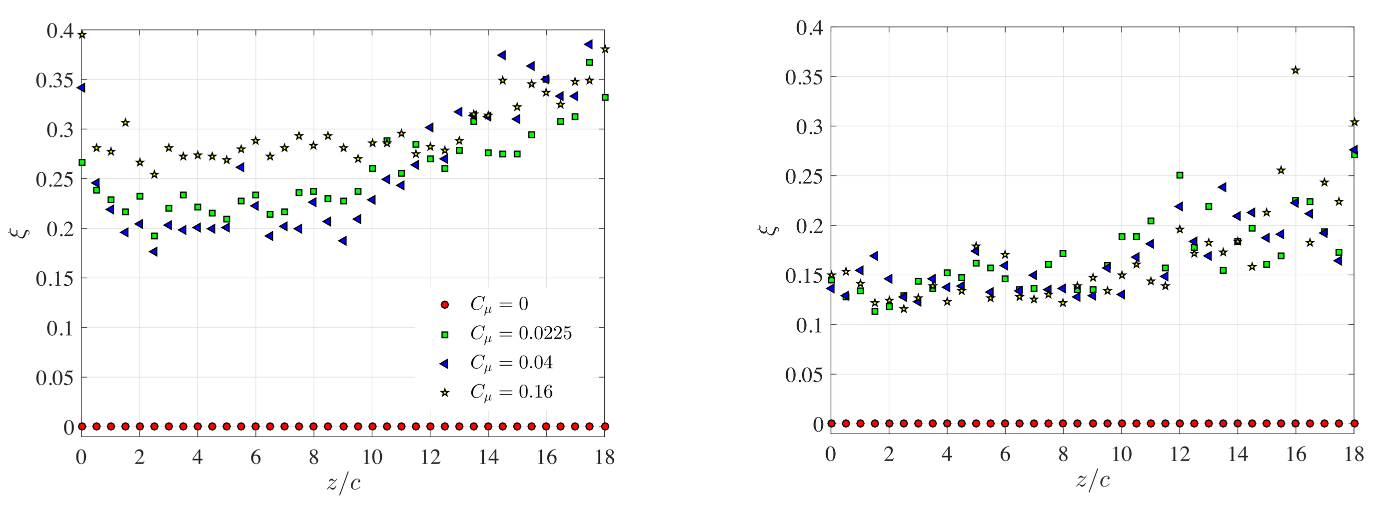
[Batchelor1964] G. K. Batchelor, "Axial flow in trailing line vortices", **20**, *J. Fluid Mech.*, (1964).
[Moore1973] D. W. Moore and P. G. Saffman, "Axial flow in laminar trailing vortices", **333**, *Phil. Trans. Royal Soc. London A*, (1973).

V. DISCUSSION

Vorticity disturbance parameter

$$\xi(x; Re, C_\mu) = \frac{\iint \left(\omega_{C_\mu}(x,y) - \omega_0(x,y)\right)^2\, dx\,dy}{\iint \omega_0(x,y)^2\, dx\,dy}$$

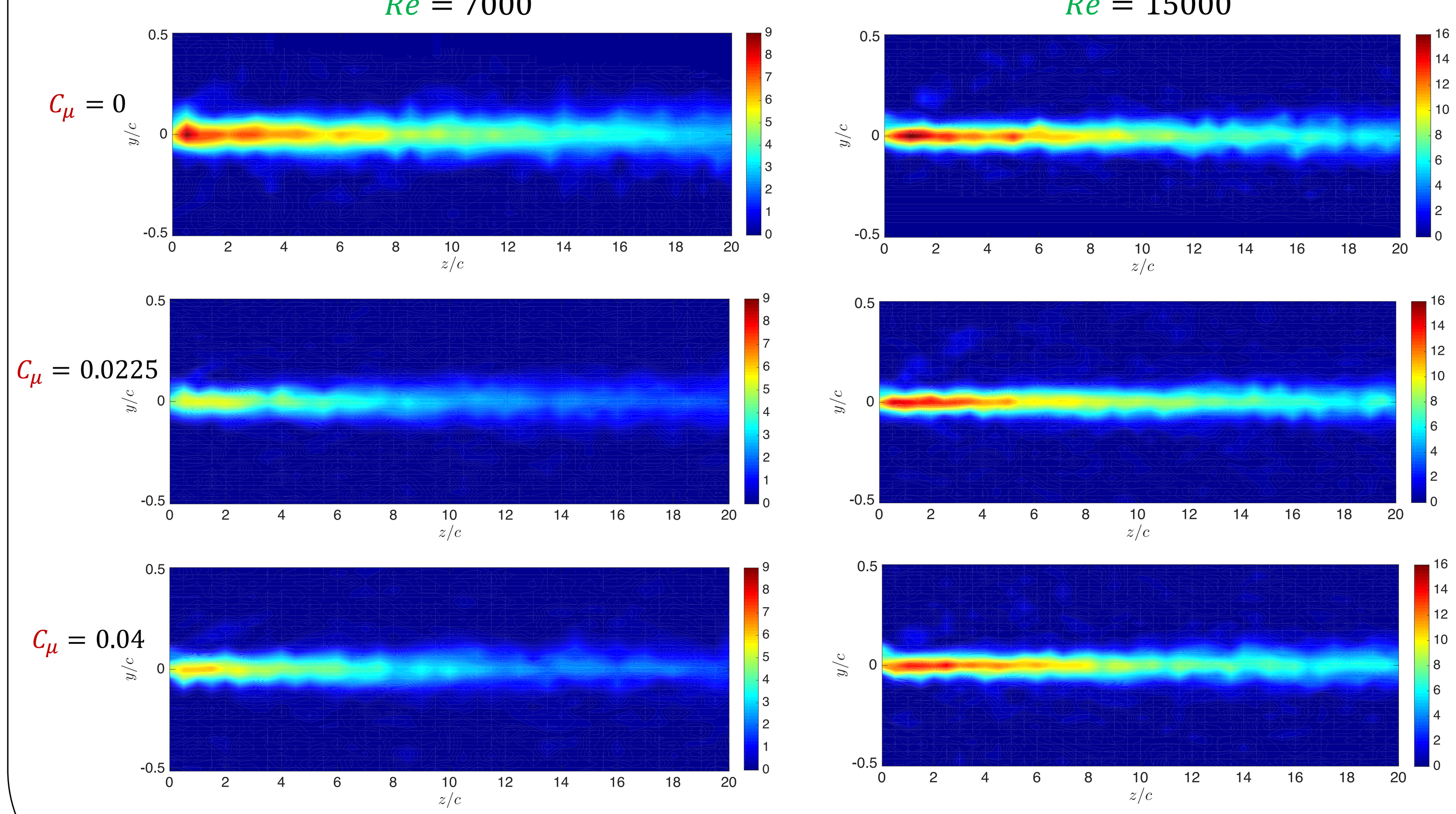
$Re = 7000$ $Re = 15000$



- $\xi = 0$ means that there is no influence of the active control on the trailing vortex. The greater ξ, the more effect caused by the continuous jet.

Spanwise vorticity evolution

$Re = 7000$ $Re = 15000$



- Continuous blowing jets are good candidates to reduce the strength of the wingtip vortex at the lowest Re.

VI. CONCLUSIONS AND PERSPECTIVES

Conclusions
- Experimental investigation on the effect of continuous jets perpendicular to the moving direction blowing from the tip of a NACA0012 airfoil.
- Three different Reynolds (Re) and four momentum coefficients (C_μ) considered.
- Characterization of the influence of continuous jets have been performed providing the parameters of some clasical vortex models.
- Jets are good candidates to reduce strength of the vortex only for $Re = 7000$.
- The forcing has a weak influence on the vortex strength once the rolling-up process has already finished ($Re = 15000 - 20000$).

Perspectives
- Effect of a synthetic or pulsating jets. Do they break the vortex at certain frequencies properly?

Acknowledgments

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