Theoretical parameters of trailing vortices versus aspect ratio of wing models

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We perform 2D-PIV measurements to characterize trailing vortices in NACA0012 wing models for aspect ratios ranging between 1 and 2.5, and for chord-based Reynolds numbers from 7000 to 40000. Firstly, and regarding the influence of the Reynolds number, the increase of this dimensionless parameter generates a more concentrated and intense vortex, presenting, therefore, an increase in all its characteristic magnitudes: maximum azimuthal velocity and vorticity. Secondly, the greater the aspect ratio, the greater the vortex strength is observed. Thirdly, the radial location of the peak of the azimuthal velocity has a strong decay as the aspect ratio increases for Re_c=7000, but it changes its trend for Re_c=40000.

The knowledge and study of flows with high rotation or vortices originated as a consequence of the aerodynamic forces produced in aircraft, has been a subject of great interest in the last decades. They are a severe problem as they generate dangerous turbulence in airport environments that can endanger the stability of other aircraft. According to predictions by the International Air Transport Association (IATA), the world's airline association, in 2035, around 7200 million people will take a plane to some destination, which will lead mainly to problems of CO2 pollution and adequacy of airport infrastructure. For these reasons, the theoretical characterization of these huge vortices in taking-off and landing operations are linked to plausible solutions or technologies that would be able to break them. Hence, Batchelor and Moore and Saffman models [1, 2] has been widely used to characterized this type of trailing vortices behind wing models [3].

The initial idea of this piece of research is to characterize experimentally, using the technique 2D-PIV the flow generated by a wing model with the aerodynamic profile NACA 0012 for chord-based Reynolds numbers ranging between 7000 and 40000 and four different aspect ratios AR= 1, 1.5, 2 and 2.5. On one hand, the chord-based Reynolds number is defined by $Re_c = U_\infty c/\nu$ where U_∞ is the free-stream velocity, c=100 mm is the chord and ν is the temperature dependent kinematic viscosity. On the other hand, the aspect ratio is given by $AR = l/c$ where l is the length of the wing model in the wingspan direction.

The experiments are carried out in a hydraulic channel. It has a length of 10 m and a square cross section of 50x50 cm^2, with a thickness of 25 mm made of perspex, to allow an excellent optical visualization for the use of the 2D-PIV technique and consequently obtain an undistorted velocity field.

The azimuthal velocity in the radial direction is depicted in FIG. 1. for different Reynolds numbers, AR=1.5, and the axial distance $\overline{Z} = z/c$=20. We can observe how there is a maximum value at R_{max} and afterward the strength of the vortex has a strong decay. The peak increases with the Reynolds number. Thus, the increase in the number of Reynolds implies a decrease in the radius at which the azimuthal velocity is maximum as the vortex became more intense and focussed near the core.

We characterize the vortex strength obtaining the parameter S from Batchelor model [1]. This parameter

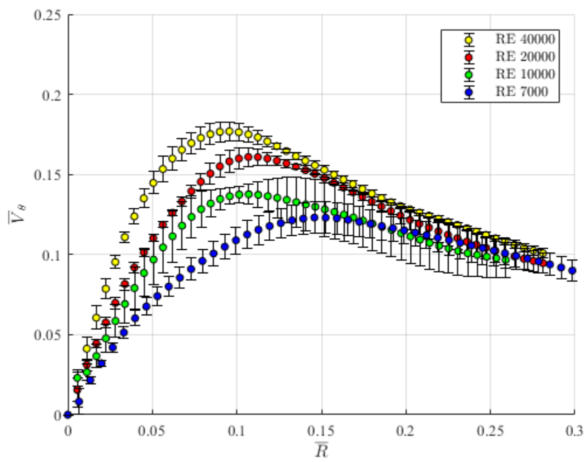

FIG. 1. Azimuthal velocity $\overline{V_\theta}$ against radial direction for AR=1.5 and $\overline{Z} = z/c$=20.

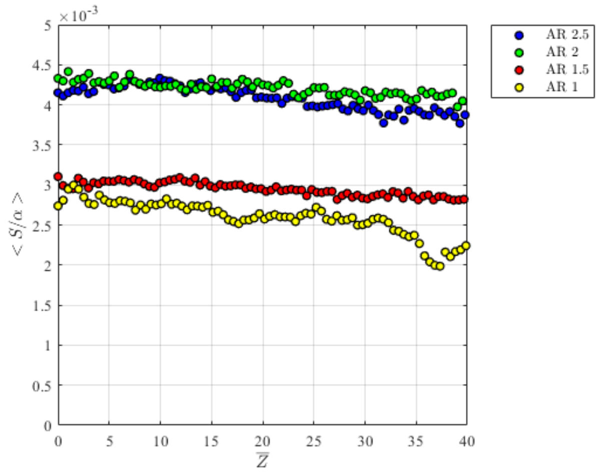

FIG. 2. Spatial evolution in the stream direction $\overline{Z} = z/c$ of parameter $< S/\alpha >$ where α=AoA is the angle of attack.

is shown in FIG. 2 as function of the non-dimensional streamwise coordinate $\overline{Z}$ for Re_c=40000. In this case, we conclude that the higher the aspect ratio, the higher the strength of the vortex up to AR=2. For this critical aspect ratio, the increment is not significant.

Other two interesting parameters are the maximum dimensionless vorticity ($\overline{\omega}_{max}$), and the value of the radial location for which the azimuthal velocity is maximum ($< \overline{R}_{max} >$), with respect to the direction of propaga-

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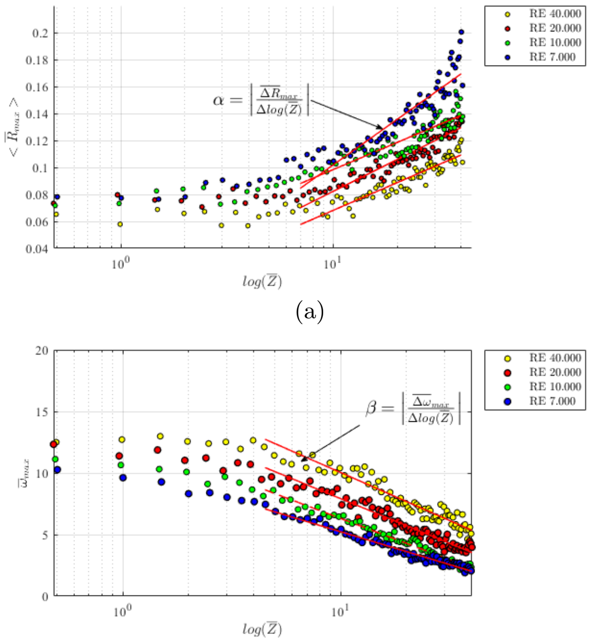

FIG. 3. Parameter α (a), and β (b) corresponding to the decay of the dimensionless maximum radius and maximum non-dimensional vorticity, respectively, for the case AR=1.5 and different Reynolds numbers.

tion of the vortex core on a logarithmic scale ($log(\overline{Z})$) have been represented. Observing that from a certain critical distance, both magnitudes present linear trends, as can be seen in FIGS. 3 (a) and (b), respectively, and the parameters β and α corresponding to their slopes, are mathematically expressed as:

$$\beta = \left|\frac{\overline{\Delta\omega}_{max}}{\Delta log(\overline{Z})}\right|, \tag{1}$$

$$\alpha = \left|\frac{\overline{\Delta R}_{max}}{\Delta log(\overline{Z})}\right|. \tag{2}$$

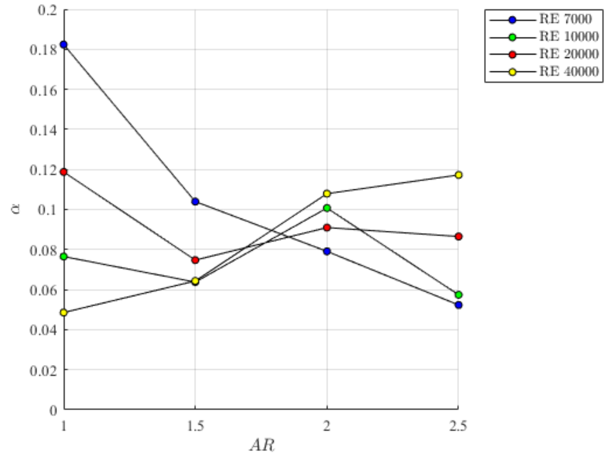

FIG. 4. α as function of AR and different Reynolds numbers.

Finally, FIG. 4 represents the parameter α versus the aspect ratio and different Reynolds numbers. The influence of both the Reynolds number and the aspect ratio on the behaviour and evolution of trailing vortices is evident from this plot (and β against AR, not shown): (i) there is again a critical aspect ratio AR=2 in which the vorticity decay is not any more increasing for any Reynolds number, and (ii) the slope of the maximum radial location with $\overline{Z}$ change its tendency as the chord-based Reynolds number increases again at AR=2. This change in trend depicted in FIG. 4 is due to two opposing effects obtained from Re_c and AR contributions. On the one hand, the increase in Reynolds number implies that the vortex is more concentrated and therefore decreases R_{max}, and on the other hand, the increase in wingspan generates a vortex of larger dimensions, and consequently an increase in R_{max} is produced.

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