Dynamics of Sphere Wake Transition

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As the Reynolds number is increased the wake behind a sphere undergoes a series of well-defined transitions on its way to becoming fully turbulent. The development can be compared and contrasted with the better known and studied circular cylinder wake.

At low Reynolds number the separation bubble is axisymmetric. The attached separation bubble grows in length until the Reynolds number reaches approximately 210. The first transition involves the symmetry-breaking topological change from an steady axisymmetric wake with an attached separation bubble wake to a steady non-axisymmetric wake consisting of a shortened separation bubble with two trailing counter-rotating vortices. In experimental visualisations dye is trapped in the vortex cores and this leads to a dramatic two-threaded structure. The second transition occurs at a Reynolds number of about 270 when the wake changes from a steady to a periodic state.

These transitions have been the focus of many studies, for example: Johnson and Patel (1999), Tomboulides et al (1993) (numerical); Margarvey and Bishop (1961), Nakamura (1976), Ormières and Provansal (1999), Sakamoto and Hanui (1995) (experimental); and Natarajan and Acrivos (1993) (analytical).

The aim of the present study is to examine the dynamics of the transitions, in particular, whether they are *subcritical* or *supercritical*, and what are the physical processes leading to transition. The initial regular transition, shows a distinct (apparently discontinuous) change in flow topology and it is *a priori* difficult to imagine how the transition could take place smoothly. For the transitions of the cylinder wake, the initial transition (Mode A, Williamson, 1988) is subcritical or hysteretic as shown by Henderson (1997) by examining the non-linear behaviour of the mode as it saturates. The second transition, however, turns out to be supercritical (also Henderson, 1997).

Numerical simulations were performed at Reynolds numbers between 200 and 300. This covers the regular and periodic transitions. We assume and verify that the transitions behave according to the Landau model:

$$\frac{dA}{dt} \approx \sigma A - lA^3,$$

where A represents the (global) perturbation of some quantity from the base flow.

The initial transition is regular (i.e., steady flow to steady flow). The transition was monitored by recording the aximuthal velocity component at a point in the wake. Figure 1a shows the growth and saturation of the instability for $Re = 215$. Figure 1b is an isosurface plot of the imaginary component of the complex eigenvalue of the velocity gradient tensor highlighting the vorticity distribution of the two-threaded structure for $Re = 250$. In terms of the Landau equation, the value of l was determined to be 3.78 and since it is positive the transition is supercritical (i.e., soft and non-hysteretic). The underlying physical process leading to the apparently discontinuous transition will be described at the conference.

The second transition was also analysed. The growth and saturation of the periodic wake when the Reynolds number is suddenly switched from 270 to 280 is shown in figure 2a and a typical snapshot of the wake is shown in figure 2b. Again, fitting the Landau model reveals that the cubic coefficient is positive. This indicates that this transition is also supercritical. The vorticity distribution in the two-threaded wake has been measured to try to fit this transition to physical models. The results will be presented at the conference.

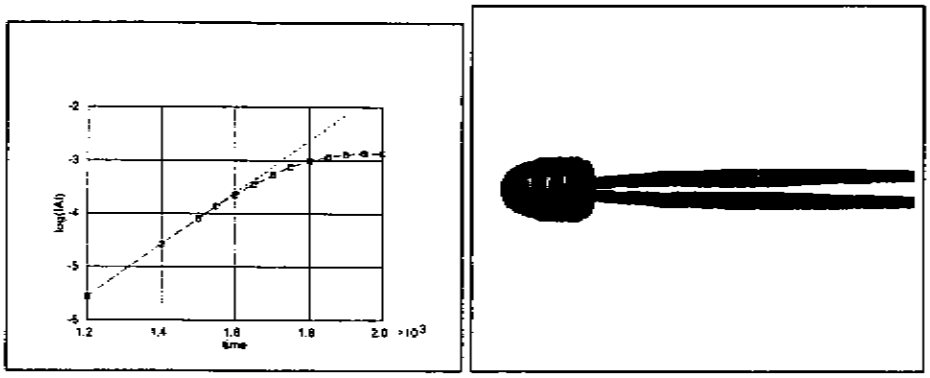

Figure 1: Left: Growth and saturation of the first instability. The dashed straight line shows the linear growth behaviour. Right: Isosurface plot showing the two-threaded wake at $Re = 250$.

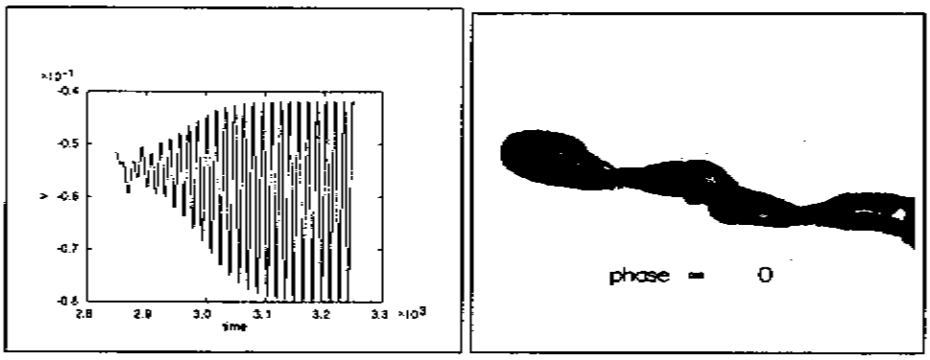

Figure 2: Left: Growth and saturation of the wake instability at $Re = 280$. Right: Wake structure at Re=290 showing the structure of the periodic wake.

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