Chapter 5 Methods of flow visualization

Flow visualization is an effective means to obtain better understandings of the flow physics. There are various methods of flow visualization, ranging from very simple and easy to access, to very complicate and expensive. For all the methods, a most important issue concerned is how to present the flow phenomenon of interest by clear photo images to touch people who might have no knowledge of the flow. “A good picture is worth thousands of words”.

Examples of flow visualization images
Dye-injection method

This method is employed in a water tunnel or water channel. The method is to introduce dye by an injection tube (needle) to the location of interest in the flow field.

Issues of concern:

The disturbance introduced by the dye injection tube (*Reynolds number based on the diameter of the tube*)

The density of dye has to be close to that of the working fluid

The velocity of the dye should be smaller but comparable to the flow velocity to minimize the disturbance.


59°-sweep delta wing
Pitching up centering at ½ chord
K=0.04

\[ K = \frac{\dot{\alpha}}{c/2 U_\infty} \]
\( \dot{\alpha} \): pitching rate

59°-sweep delta wing
Pitching up centering at ½ chord
K=0.02

(張瑞賢, 1991)
Fig. 5.1 A view of the breakdown flow
\[ Re_0 = 1.26 \times 10^4 \]
\[ \text{Re}_0 = 5.02 \times 10^4 \]
Oil-film method

This method is to apply some viscous fluid mixed with solid powder, whose color is easily visualized by eye, on the tested model. Having had the model in the test section of a wind tunnel subject to a desirable speed, the pattern revealed by the oil film provides the information of flow near the model surface, i.e., limiting streamline pattern which implies the shear stress pattern.

Reference for limiting streamline and skin friction line:


—目前圓柱油流測試初步結果(尾流區域)

(李信宏 2006)

Re=1.06×10^5
目前圓柱油流測試初步結果（尾流區域）

(E. Chen 2006)

Re = 2.66 \times 10^5
—目前圓柱油流測試初步結果(Free end)

Aspect ratio 6

(李信宏 2006)  
Re=1.06×10^5
Circular Cylinders

Material: Acrylics
Aspect ratio= 8.5
Blockage ratio= 7.4%
Rz=0.73 \mu m

Material: Stainless Steel
Aspect ratio= 8.125
Blockage ratio= 8%
Rz=12.4 \mu m
Flow visualization

(Wei, 2006)

\[ \text{Re} = 3.08 \times 10^5 \]
Flow visualization

(李嘉文 2006)

\[ \text{Re} = 3.75 \times 10^5 \]
Flow visualization

(Chen et al. 2006)

Re = \(4.04 \times 10^5\)
圖4.16 基本翼衝流觀察圖，$\alpha = 0^\circ$、$M=0.85$，
上表面翼端處特寫，(b) 渐近流線示
（邊界層自由轉換）

張國政, 1996

圖4.23 (b)

$\alpha = 0^\circ, M=0.80$
張國治, 1996

\[ \alpha = 0, \ M = 0.85 \]

図 4.26 (b)
圖4.3 基本翼的昇華物質觀察圖，\( \alpha = 0^\circ \)、\( M = 0.85 \)

（張國治，1996）
Ink-dot method

Similarly, ink or paint dots can be applied on model surface for experiment in a water channel or tunnel. The traces of ink or paint due to the viscous stresses on the model surface provide the information of flow near the model surface.


Figure 3. Flow visualization photographs obtained at $\alpha=15$ deg: (a) a limiting streamline photograph.

Figure 4. Flow visualization photographs obtained at $\alpha=15$ and $\beta=20$ deg: (a) a dye streak photograph.

Figure 5. A limiting streamline photograph obtained at $\alpha=20$ deg and $\beta=0$ deg.

Figure 6. A limiting streamline photograph obtained at $\alpha=30$ deg and $\beta=0$ deg.

Figure 2. Flow visualization photographs obtained at $\alpha=10$ deg: (b) a limiting streamline photograph.

Figure 1. Flow visualization photographs obtained at $\alpha=15$ deg: (a) a limiting streamline photograph.
(c) $\alpha = 20^\circ$, $\beta = 20^\circ$

Fig. 3.12(a)-(c) Limiting-streamline patterns for $50^\circ - 80^\circ$-sweep double delta wing at $\alpha = 20^\circ$
$0^\circ \leq \beta \leq 20^\circ$

(張繼乾, 1991)

Fig. 3.3 The spiral core revealed by water color $\alpha = 15^\circ$, $\beta = 20^\circ$
(周志堅, 2000)
Smoke-wire technique

With oil coated on a wire, which is heated by electric current continuously, the smoke is generated and carried downstream by the flow to reveal the flow motion.

Issues of concern:

- the disturbance introduced by the wire (Reynolds number based on the diameter of the wire)
- to feed the oil continuously to the wire (by gravity)


圖 4-9. 視法法觀察振動平板對分離泡之影響，\( U=0.5 \text{m/s} \), \( k=0.1 \), \( h_s=1.5 \text{cm} \), \( L_s=4 \) \( h_s \), \( h_f/h_s=0.67 \) (a) \( t/T=0 \)  
(b) \( t/T=1/4 \) (c) \( t/T=2/4 \) (d) \( t/T=3/4 \)
Pulsed-wire technique

Same as the smoke-wire set-up, except that the wire is heated by pulsed electric current, this technique shows the timeline of flow.

Hydrogen bubble technique in water or channel

(王嘉年，1990)
Laser-sheet fluorescence dye technique in water channel or tunnel

(邱英吉, 1991)
(印英云, 1991)
Qualitative analysis of the flow visualization results are possible with some techniques, for instance, liquid-crystal thermal images, PIV (particle image velocimeter)


Discussion of the images obtained by the methods above in regard of timeline, pathline, streakline, and streamline.