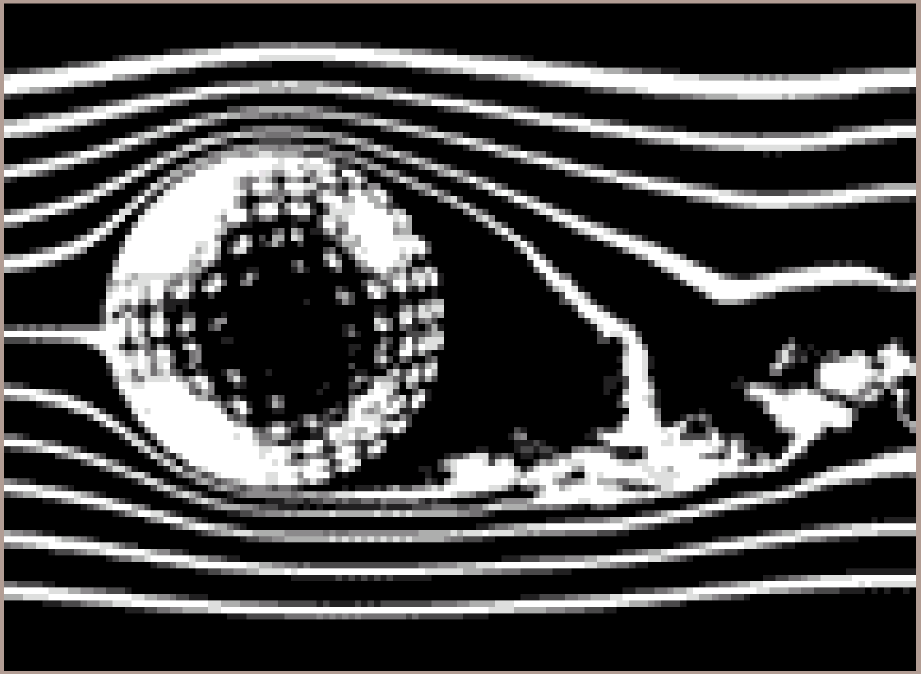


Picture F.N.M. Brown

Mechanism of Drag Reduction by Dimples on a Sphere

Colin Smith
ME 801
Nov 23, 2010

The Big Ideas

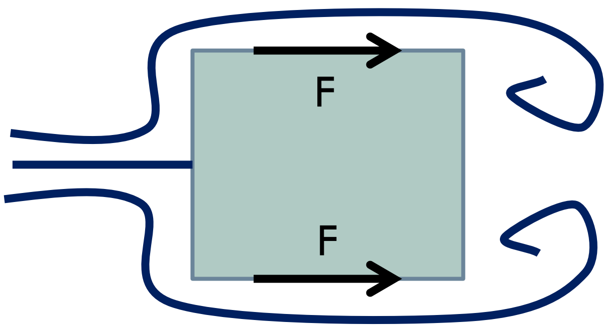
Previous experiments have found:

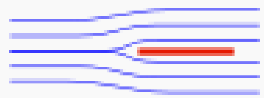
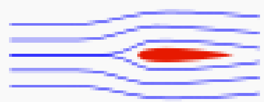
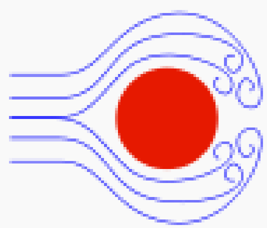
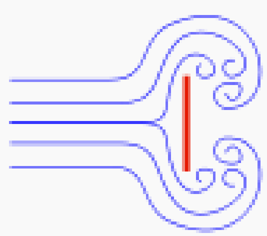
- Dimpled spheres to have up to 50% reduction of drag of smooth spheres
- The drag on a ball to become constant above certain Reynolds' Numbers (Ball Speeds)

Basics of Drag

Skin Friction:

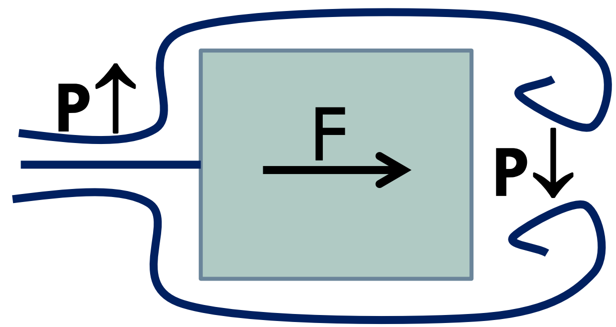
Viscous shear stresses on surface of the object



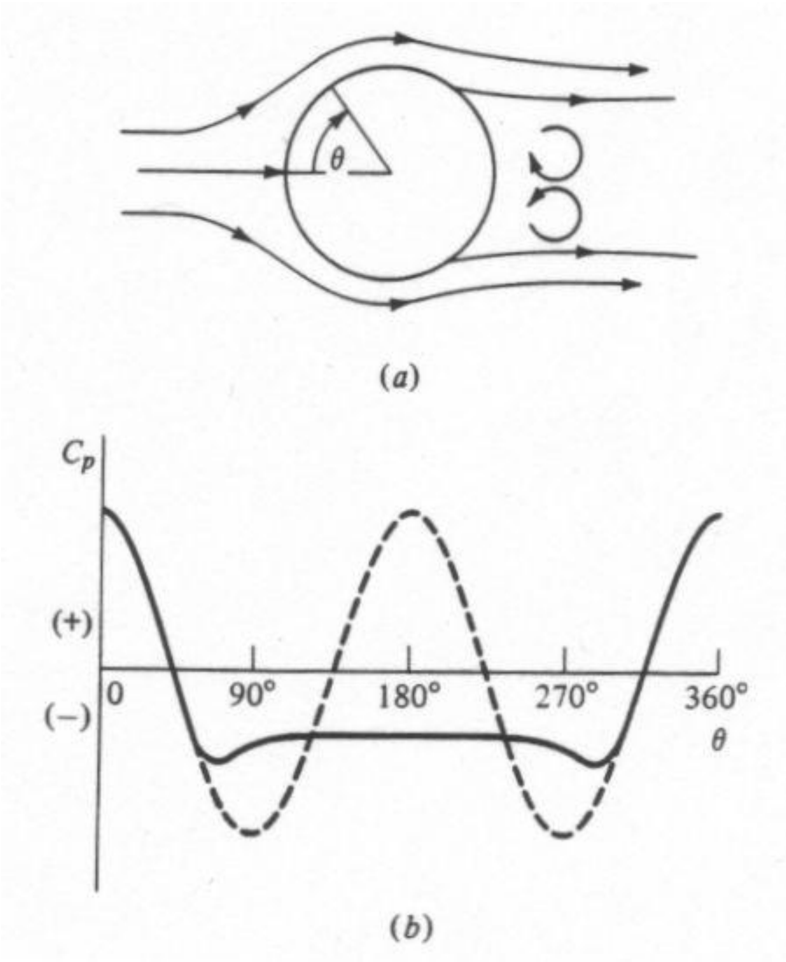
Shape and flow	Form drag	Skin friction
	0%	100%
	~10%	~90%
	~90%	~10%
	100%	0%

Form Drag:

Pressure difference on the object



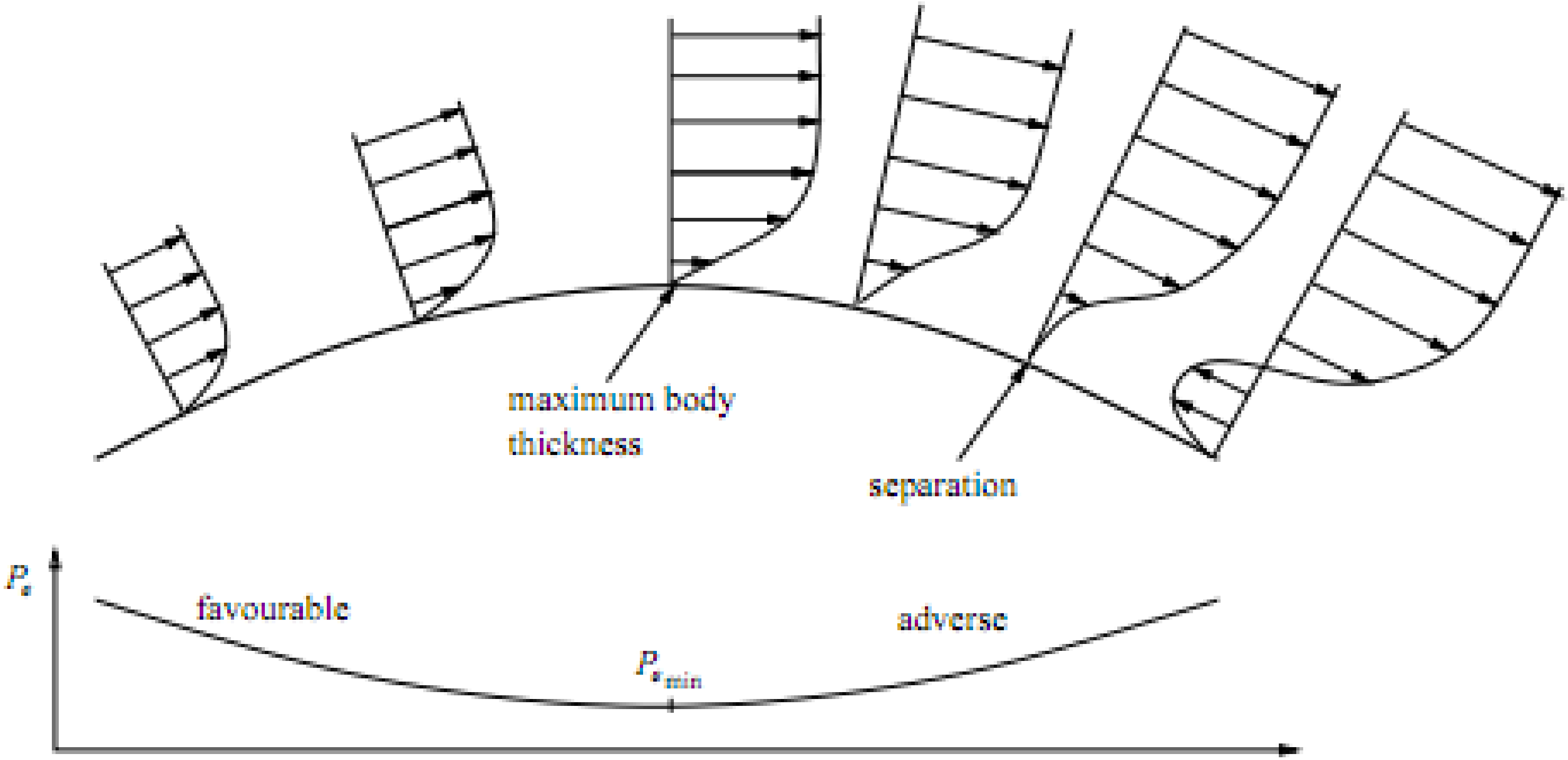
Pressure Coefficient over a Sphere



- Potential flow solution predicts no drag due to pressure [D'Alembert's Paradox] (dotted line)
- When viscosity is accounted for, separation occurs and the flow is no longer symmetric (solid line)

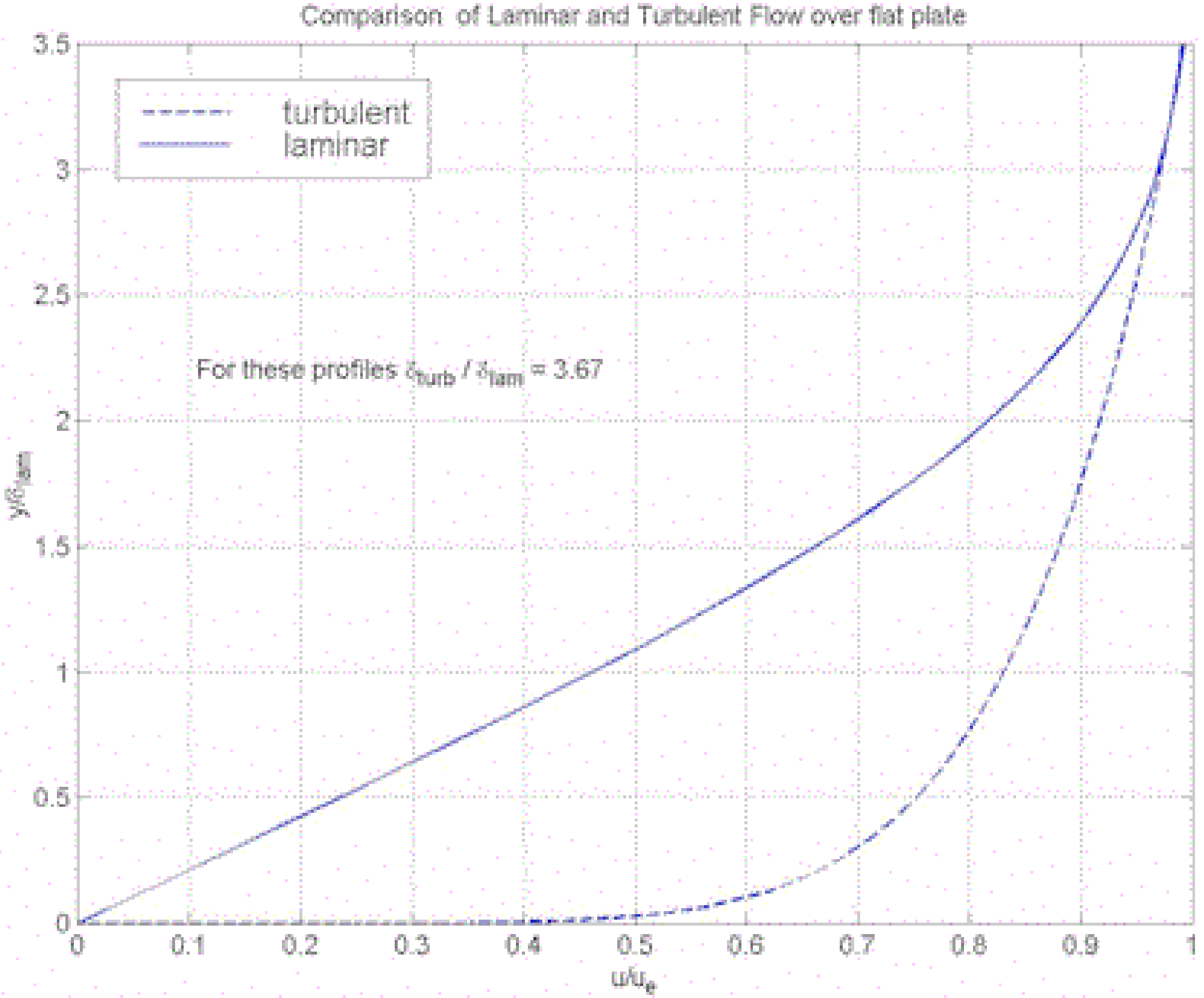
http://qm-aerospace.blogspot.com/2007/03/why-do-golf-balls-have-dimples.html

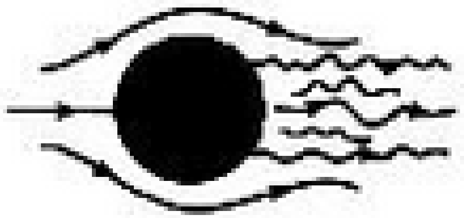
Boundary Layer Separation



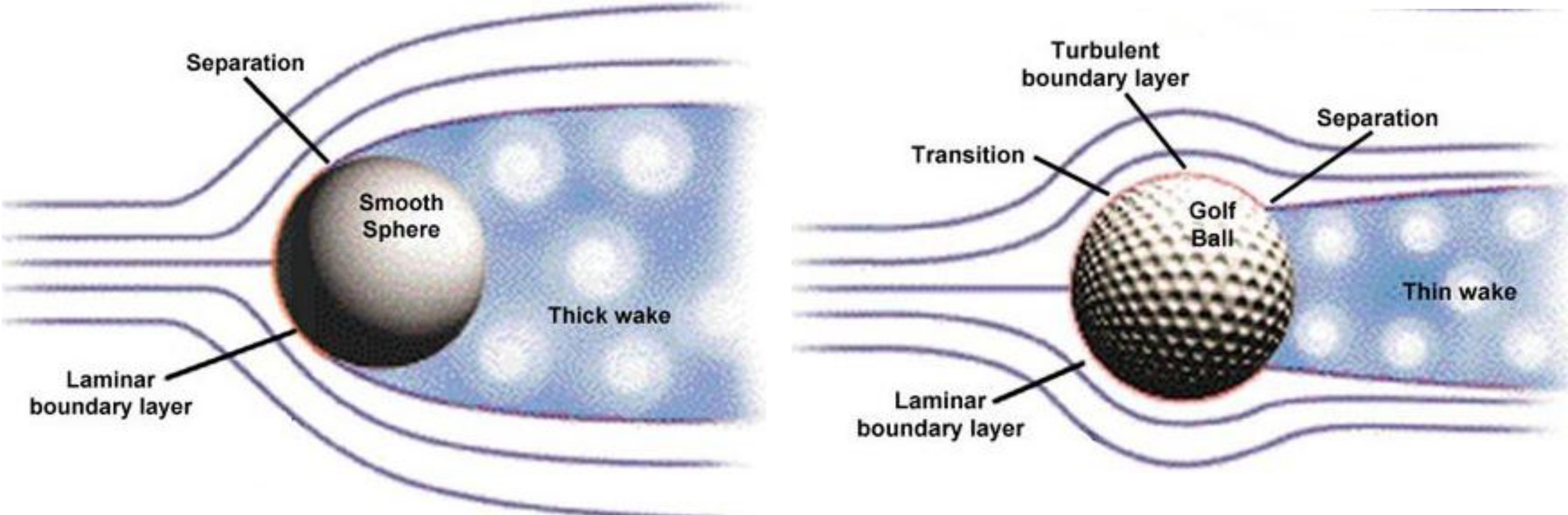
Separation occurs when the pressure gradient overcomes the momentum

Laminar vs Turbulent Boundary Layers





Motivation



http://www.sciencebuddies.org/science-fair-projects/project_ideas/Sports_p012.shtml

- Dimples induce a turbulent boundary layer, which has higher momentum and thus delays separation
- At Re>10^4, the majority of drag on a sphere is due to pressure difference, not skin friction

Findings

- Dimples reduce drag on a sphere as much as 50% when compared to a smooth surface
- The drag coefficient remains constant over a range of Reynolds numbers
- Turbulent boundary layer is caused by separation bubbles in dimples

Definitions

Reynolds Number

$$Re_d = \frac{U_o d}{\nu}$$

d= sphere diameter
U_o= Free Stream Velocity
v= kinematic viscosity

Drag Coefficient

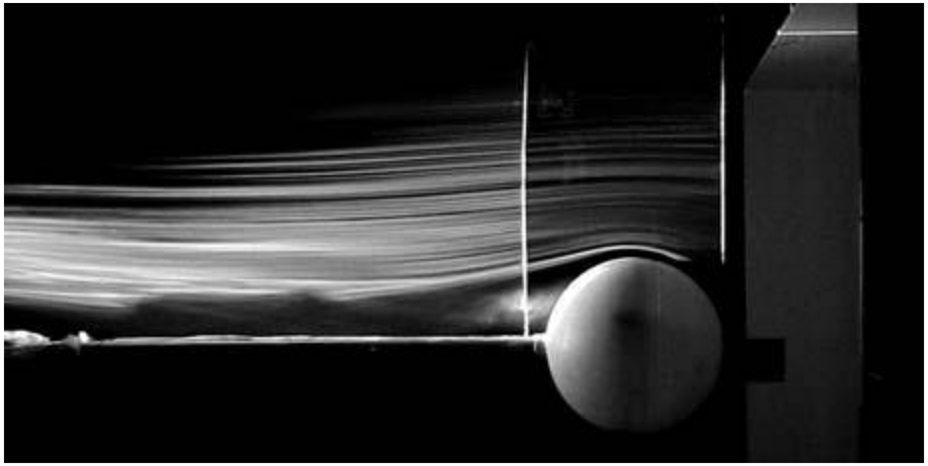
$$C_D = \frac{D}{\frac{1}{2}\rho U_o^2 A}$$

D= Drag Force
A=Cross Sectional Area
ρ= Density
U_o= Free Stream Velocity

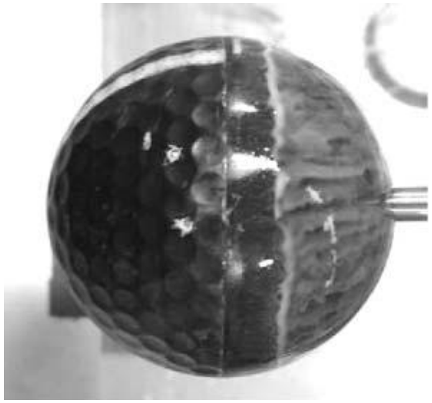
Experimental Setup

Tiger Woods ball speed
185mph=83m/s

- Free stream velocities varied from 5-28 m/s
- Reynolds numbers $0.5x10^5$-$2.8x10^5$
- Maintains laminar boundary layer over smooth sphere

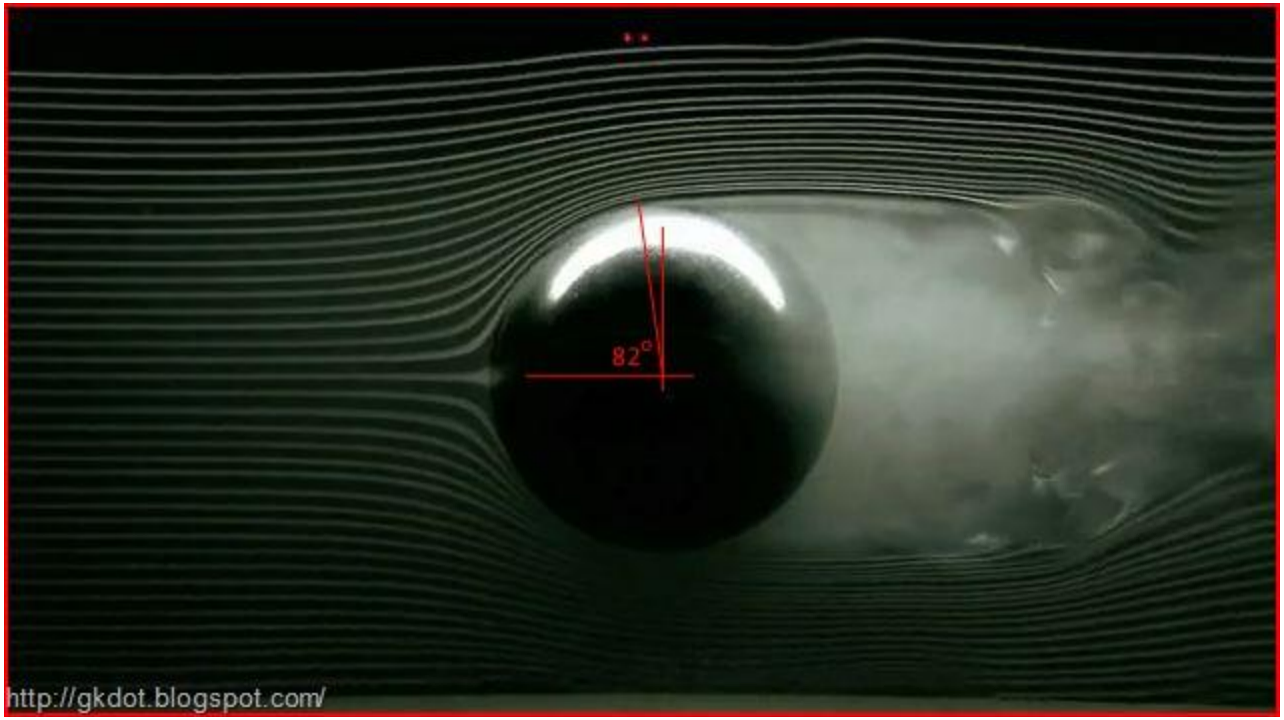


(Jeon S, Choi J, Jeon WP , Choi H, Park J)



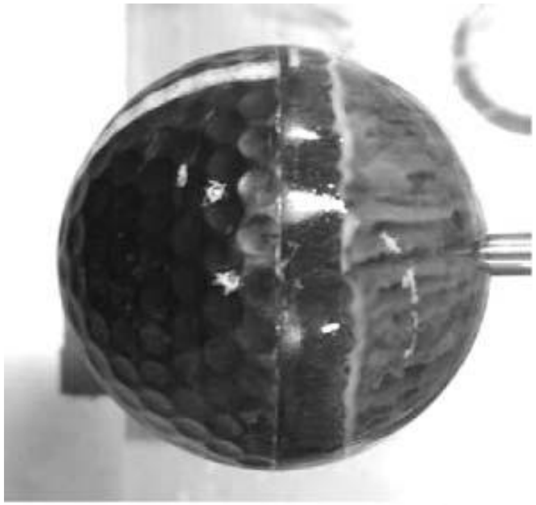
(Choi J, Jeon WP, Choia H)

Flow Over a Smooth Cylinder

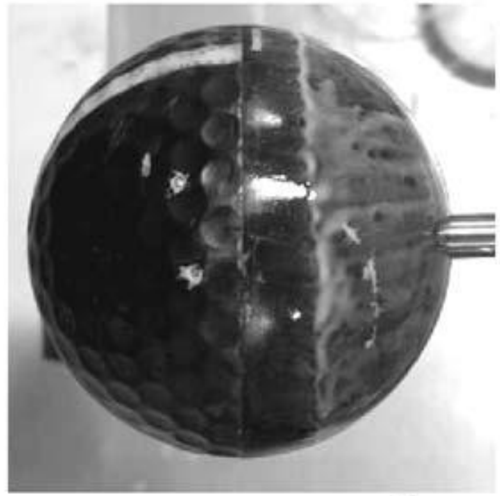


The separation angle over a smooth golf ball sized sphere was measured at 82° for $0.5\times10^5 \leq Re \leq 2.8\times10^5$

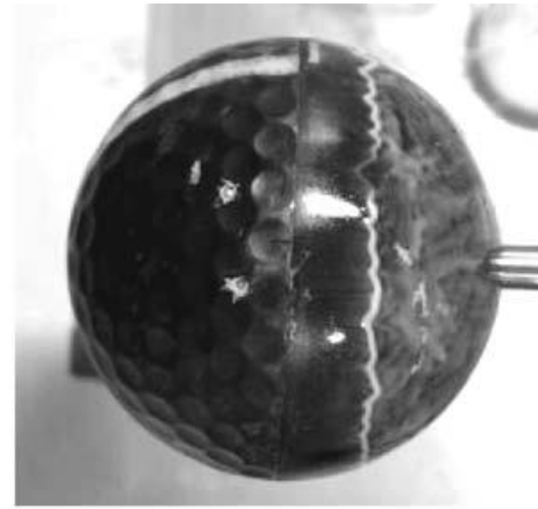
Visualization of Flow Separation



$Re = 1.0 \times 10^5$



$Re = 1.4 \times 10^5$

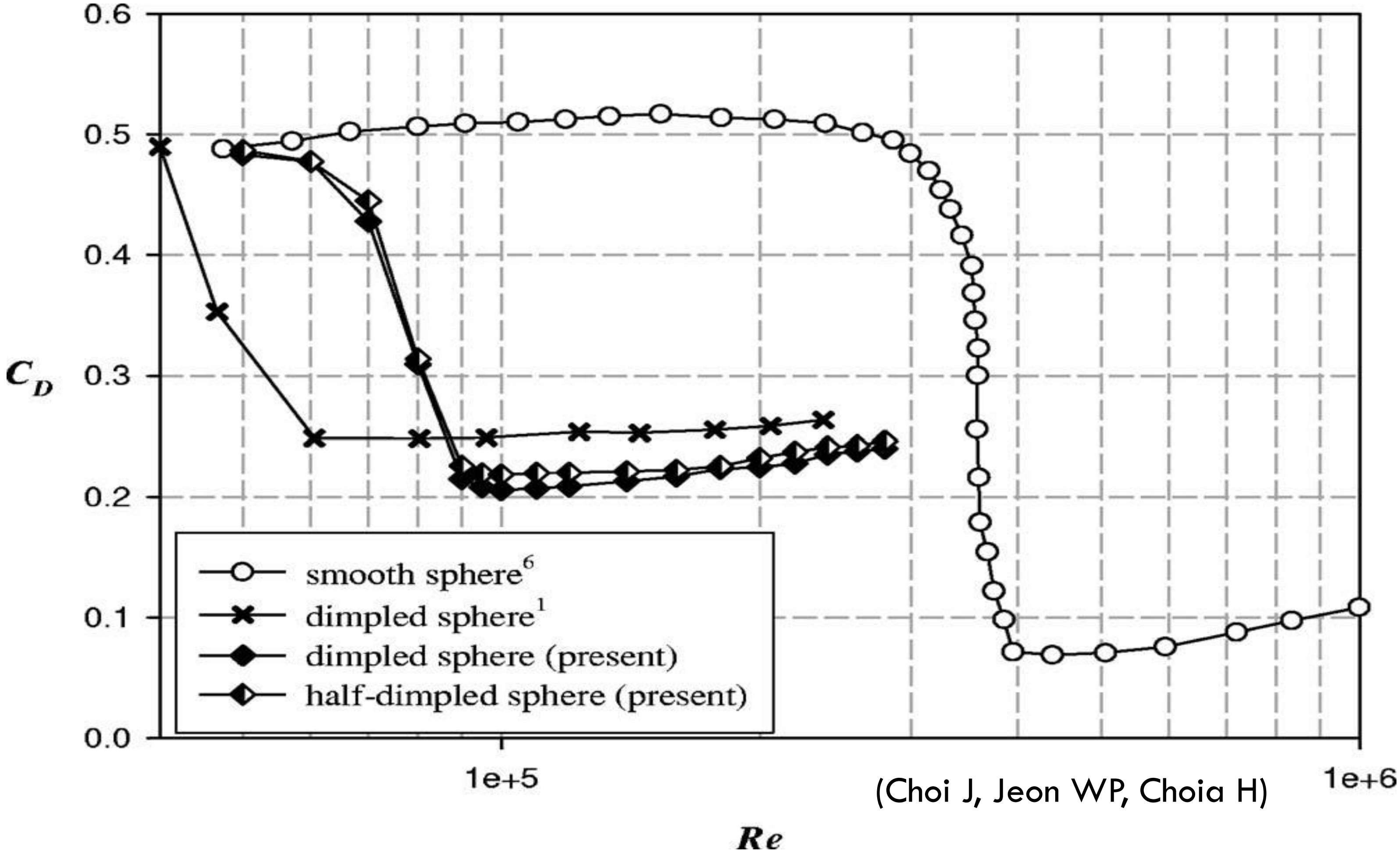


$Re = 2.0 \times 10^5$

(Choi J, Jeon WP, Choia H)

- Separation is delayed to $\phi = 110^o$
- Separation angle constant for $Re \geq 0.9 \times 10^5$
- The trailing edge of the tested sphere is smooth to better show separation

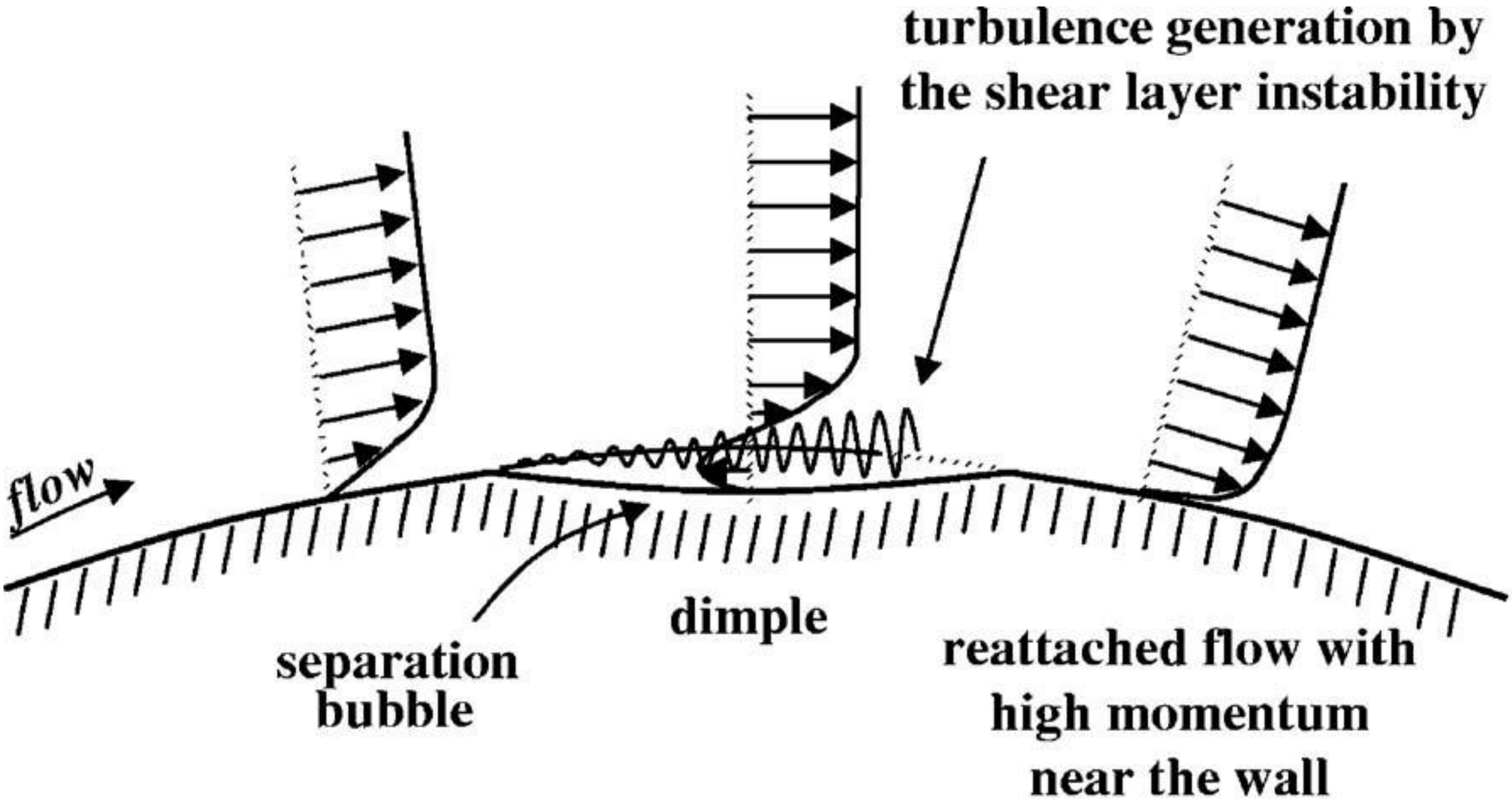
Measured Drag Coefficient



(Choi J, Jeon WP, Choia H)

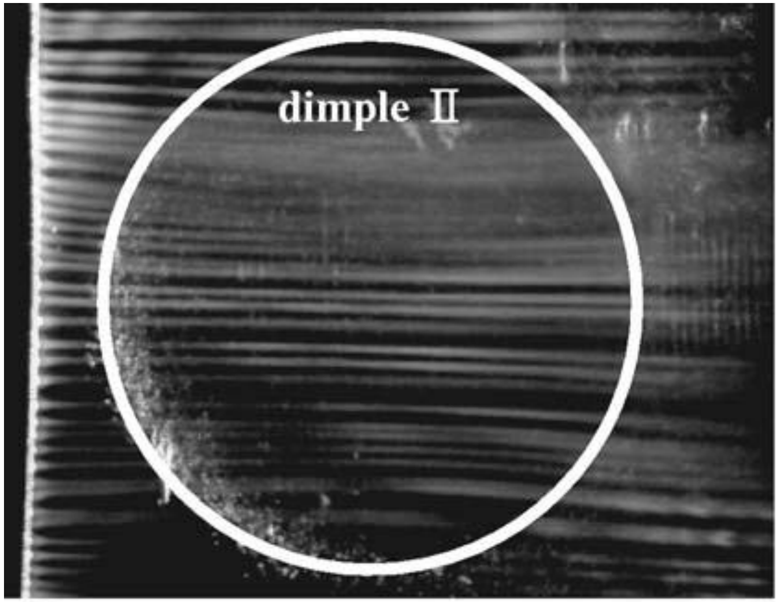
Drag Coefficient constant for Re≥ 0.9×10^5

Effect of Dimples



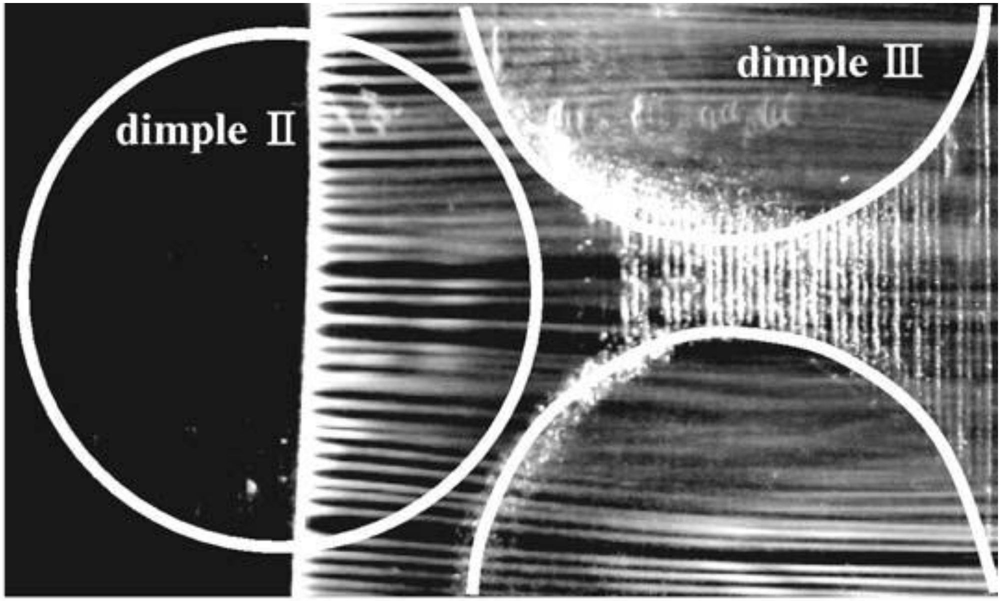
(Choi J, Jeon WP, Choia H)

Smoke Wire Test



(a)

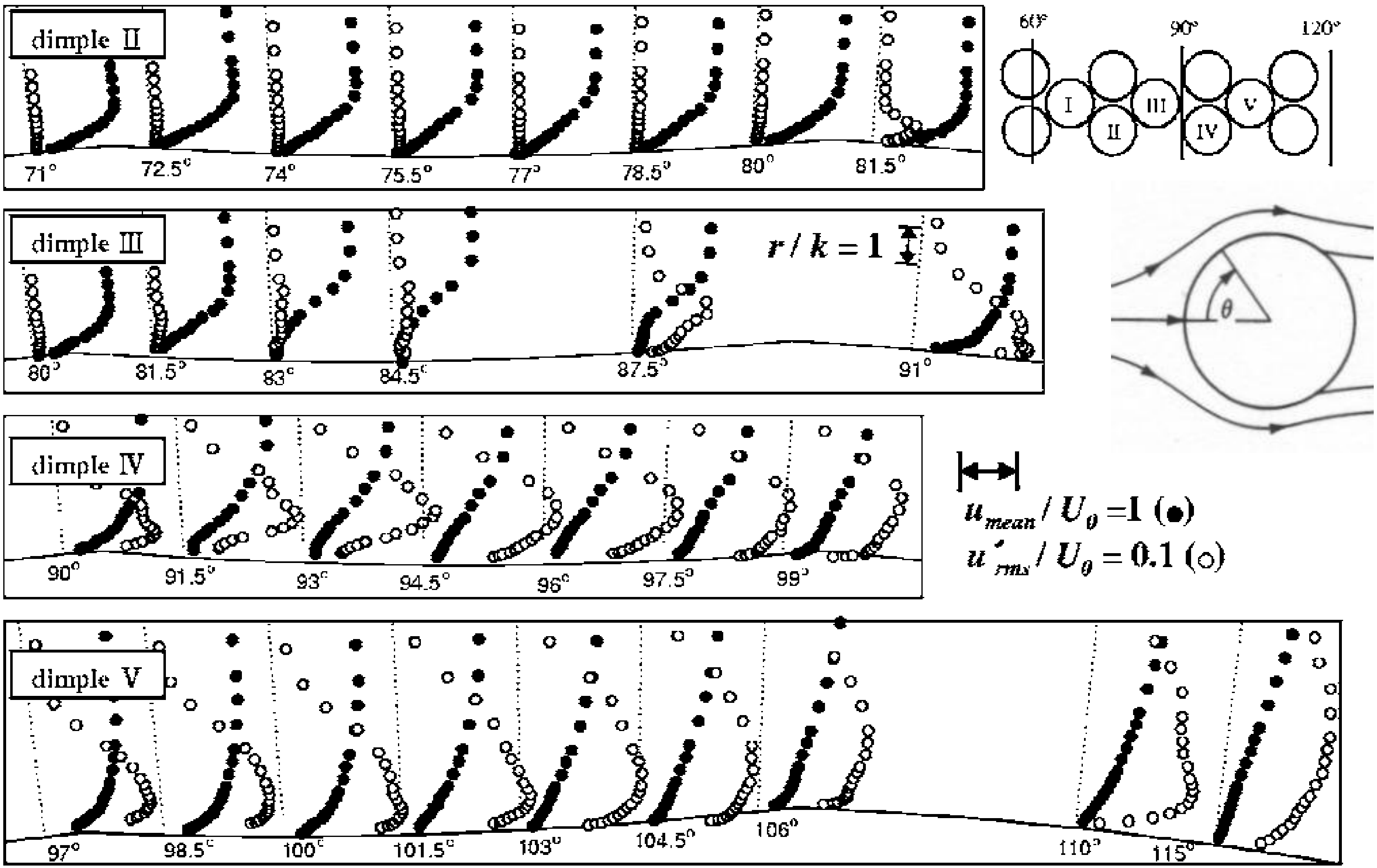
(Choi J, Jeon WP, Choia H)



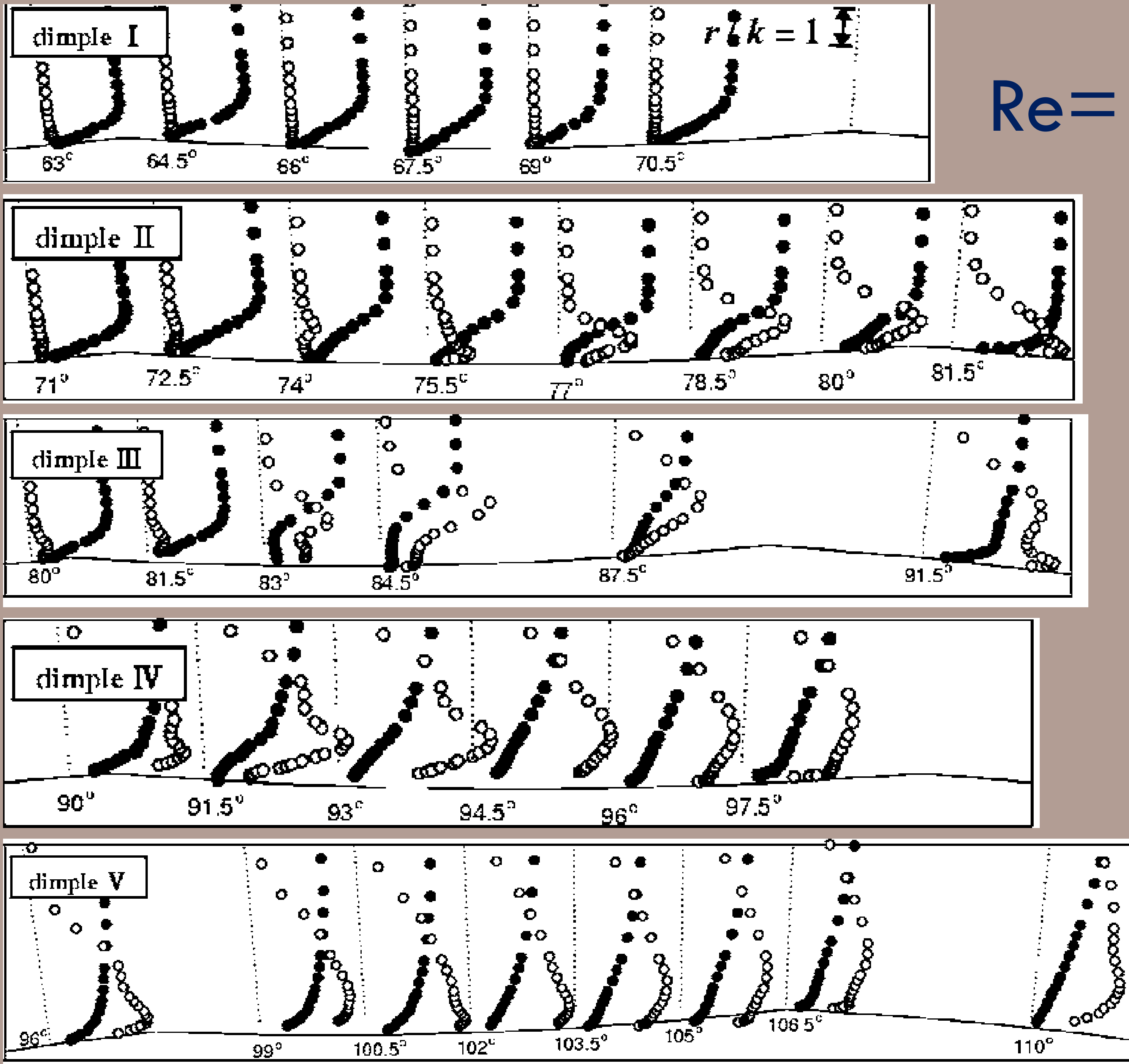
(b)

Shows no vortices are ejected

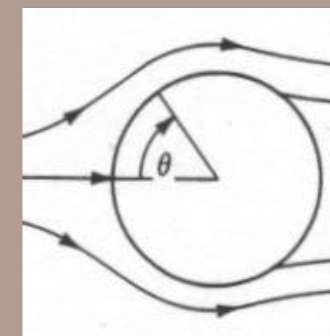
Velocity Profile at Re=1.0×10^5



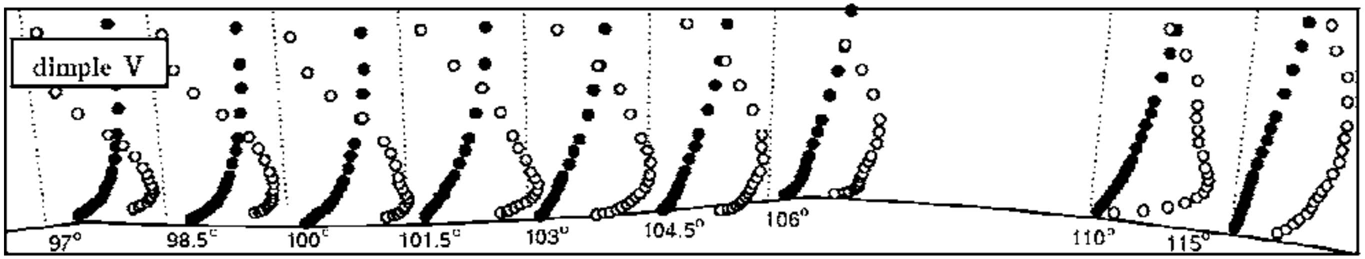
(Choi J, Jeon WP, Choia H)


dimple I
$r/k = 1$
63°
64.5°
66°
67.5°
69°
70.5°
dimple II
71°
72.5°
74°
75.5°
77°
78.5°
80°
81.5°
dimple III
80°
81.5°
83°
84.5°
87.5°
91.5°
dimple IV
90°
91.5°
93°
94.5°
96°
97.5°
dimple V
96°
99°
100.5°
102°
103.5°
105°
106.5°
110°

$Re=1.5x10^5$

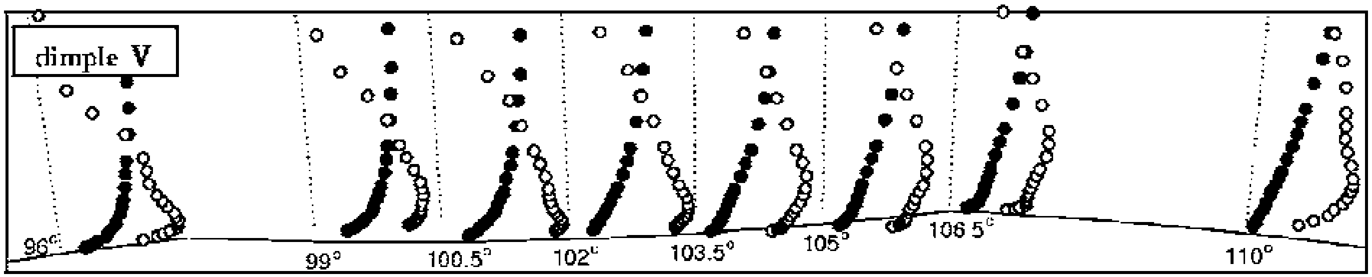

θ

Velocity Profiles at Increasing Re



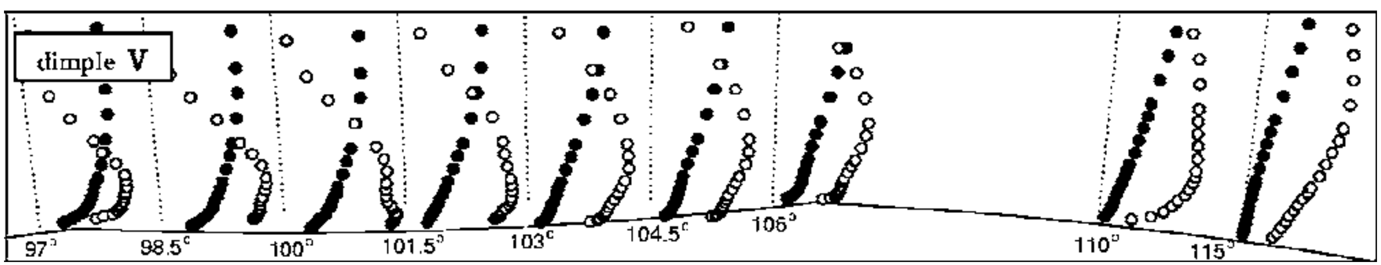
Re= 1.0×10^5

First Separation at Dimple III (80°)



Re= 1.5×10^5

First Separation at Dimple II (71°)



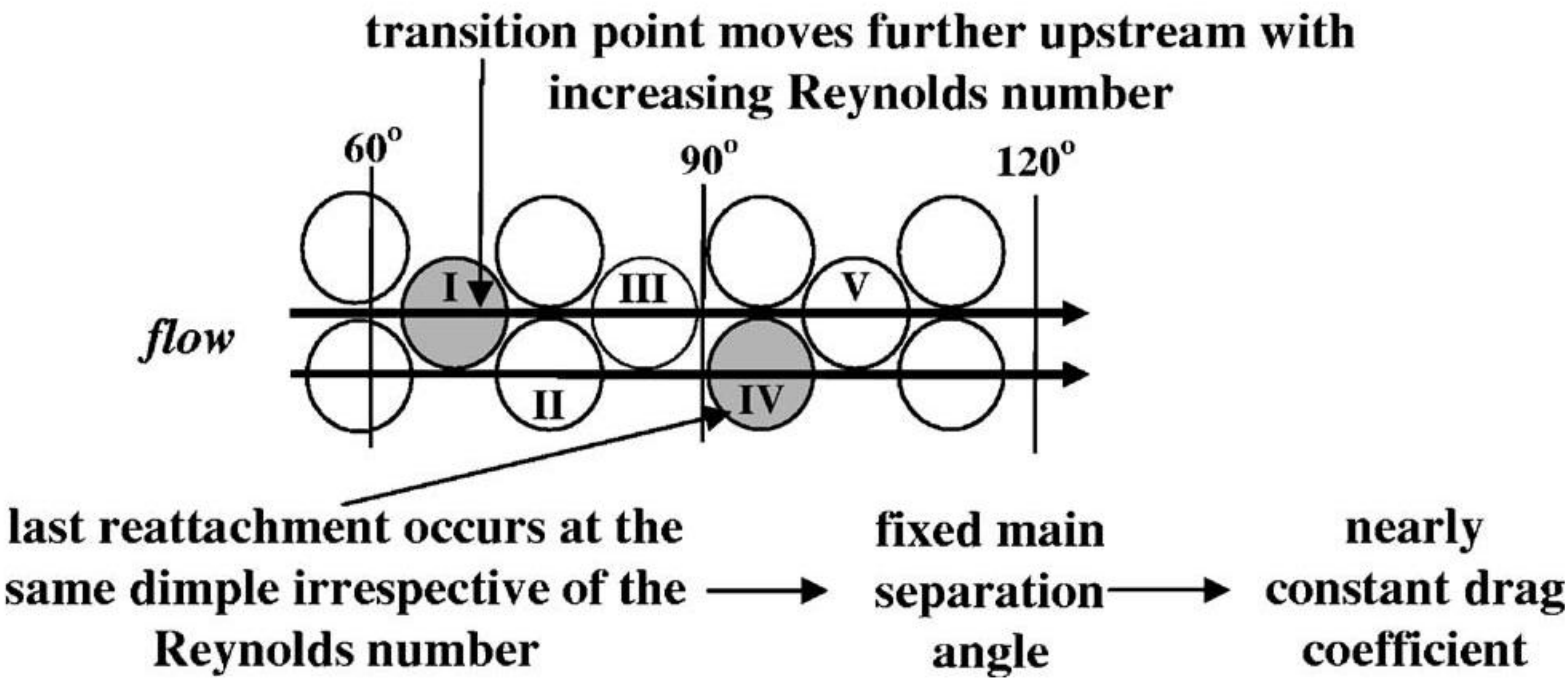
Re= 2.0×10^5

First Separation at Dimple I (63°)

(Choi J, Jeon WP, Choia H)

If Re> 0.9×10^5 flow always separates from the surface after dimple V

Conclusion



(Choi J, Jeon WP, Choia H)

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Jeon S, Choi J, Jeon WP , Choi H, Park J, “Active control of flow over a sphere at a sub-critical Reynolds number,” J. Fluid Mech. **517, 113** 2004.

Olson, A. “A Cure for Hooks and Slices? Asymmetric Dimple Patterns and Golf Ball flight.” 2007. http://www.sciencebuddies.org/science-fair-projects/project_ideas/Sports_p012.shtml

Scott, Jeff. “Why do Golf Balls Have Dimples.” 2005. http://qm-aerospace.blogspot.com/2007/03/why-do-golf-balls-have-dimples.html

Questions?