Skin friction reduction characteristics of variable ovoid non-smooth surfaces

Key words: Variable ovoid dimple, Non-smooth surface, Numerical simulation, Skin friction reduction

Cite this as: Xiao-wen Song, Peng-zhe Lin, Rui Liu, Pei Zhou, 2017. Skin friction reduction characteristics of variable ovoid non-smooth surfaces. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 18(1):59-66.
http://dx.doi.org/10.1631/jzus.A1500324

How a variable ovoid dimple was created?

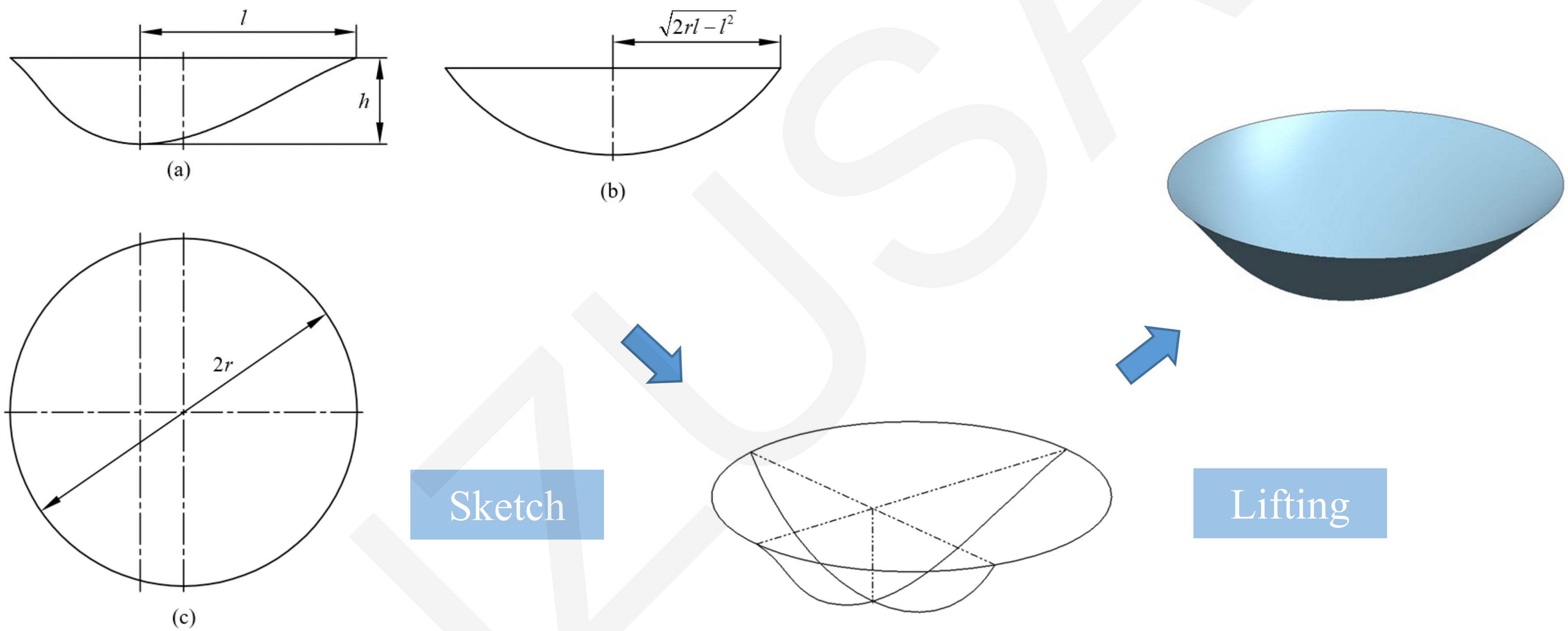

Fig. 1 Variable ovoid dimple

(a) Longitudinal cross section; (b) Transverse cross section; (c) Opening curve

Square tube model and grid generation

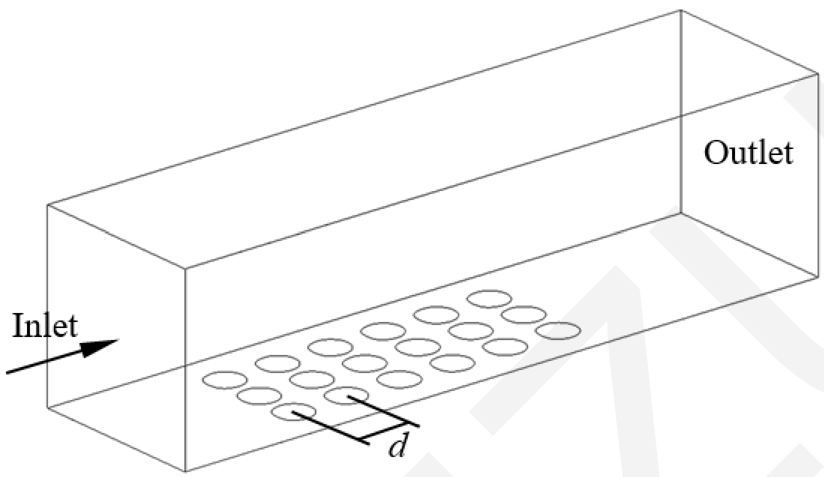

Fig. 2 Simulation model of a flat surface with variable ovoid dimples

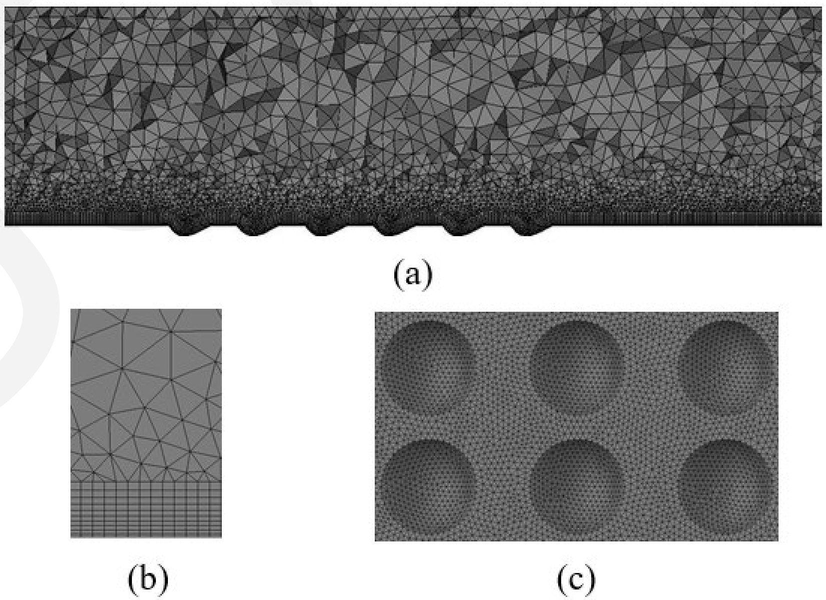

Fig. 3 Grid model

(a) Whole grid; (b) Refinement layer; (c) Grid of the variable ovoid

Numerical simulation results

Table 1 Table of level factors

Level	Radius r (mm)	Semimajor l (mm)	Depth h (mm)	Spacing d (mm)
1	0.6	1.25×r	0.2	2.0
2	0.7	1.50×r	0.3	2.5
3	0.8	0.50×r	0.4	3.0

- Three levels of dimensions of the variable ovoid dimple were set (Table 1).
- Numerical simulation tests results were substituted into the intuitionistic analysis table for analysis (Table 2).
- The experimental results were then studied by square-difference analysis (Table 3).

Table 2 Intuitionistic analysis table of results from numerical simulation tests

Trial	Radius r (mm)	Semimajor l (mm)	Depth h (mm)	Spacing d (mm)	Result C_D (%)
Test 1	1 (0.6mm)	1 (1.25×r mm)	1 (0.2 mm)	1 (2.0 mm)	2.78
Test 2	1 (0.6mm)	2 (1.50×r mm)	2 (0.3 mm)	2 (2.5 mm)	5.05
Test 3	1 (0.6mm)	3 (0.50×r mm)	3 (0.4 mm)	3 (3.0 mm)	6.71
Test 4	2 (0.7mm)	1 (1.25×r mm)	2 (0.3 mm)	3 (3.0 mm)	6.85
Test 5	2 (0.7mm)	2 (1.50×r mm)	3 (0.4 mm)	1 (2.0 mm)	8.00
Test 6	2 (0.7mm)	3 (0.50×r mm)	1 (0.2 mm)	2 (2.5 mm)	5.13
Test 7	3 (0.8mm)	1 (1.25×r mm)	3 (0.4 mm)	2 (2.5 mm)	10.19
Test 8	3 (0.8mm)	2 (1.50×r mm)	1 (0.2 mm)	3 (3.0 mm)	10.14
Test 9	3 (0.8mm)	3 (0.50×r mm)	2 (0.3 mm)	1 (2.0 mm)	10.14
K1	14.54	19.82	18.05	20.92	
K2	19.98	23.19	22.04	20.37	
K3	30.47	21.98	24.90	23.70	
k1	4.85	6.61	6.02	6.97	
k2	6.66	7.73	7.35	6.79	
k3	10.16	7.33	8.30	7.90	
R	5.31	1.12	2.28	1.11	

Table 3 Square-difference analysis table

Source	Sum of squares	DOF	F value	F (0.05)	
Radius r	43.71	2	22.50	19	Significant
Semimajor l	1.94	2	1	19	
Depth h	7.89	2	4.06	19	
Spacing d	2.12	2	1.09	19	
Grand total	55.66	8			

Skin Friction Reduction Mechanism

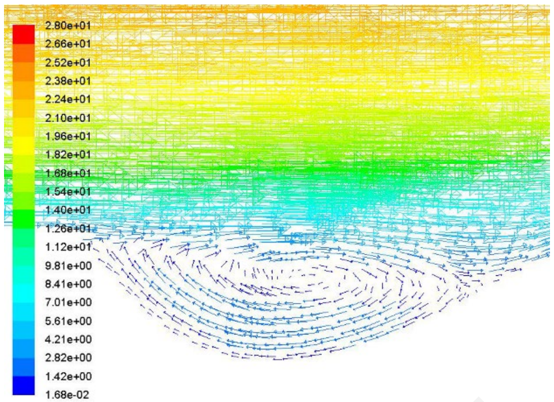

Fig. 4 Velocity vectors graph

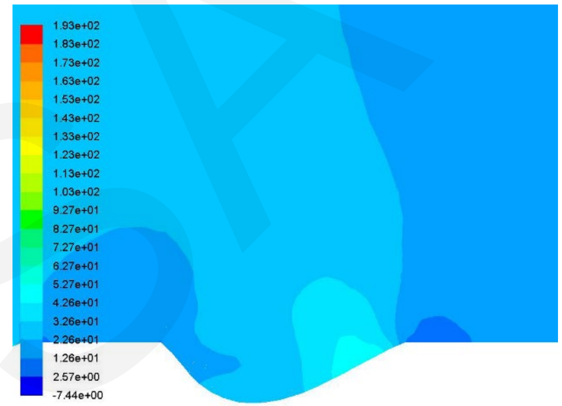

Fig. 5 Pressure contour

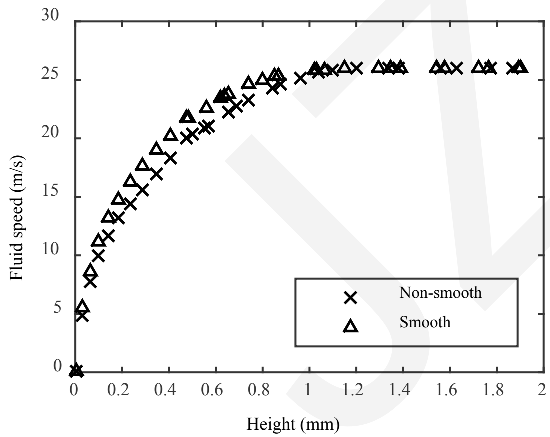

Fig. 6 Variation in fluid speed with the height of the flow area

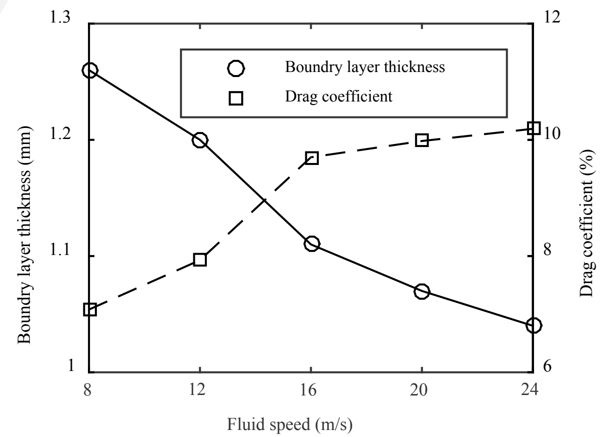

Fig. 7 Variation in boundary layer thickness and drag coefficient with fluid speed

Conclusions

- Numerical simulation tests indicated that variable ovoid non-smooth surfaces have good skin friction reduction property. When the air flow velocity is 24 m/s, the skin friction reduction rate is up to 10%.

- According to the intuitionistic analysis, four design parameters include radius *r*, depth *h*, semimajor *l* and spacing *d*, influence the skin friction reduction rate in order of their friction reduction effect.

- The variable ovoid dimples can increase the thickness of the boundary layer and reduce the velocity gradient of the near-wall flow, which leading to the reduction of the wall shear stress, and finally reduce the skin friction.