AIAA JOURNAL
Vol. 47, No. 4, April 2009

Technical Notes

TECHNICAL NOTES are short manuscripts describing new developments or important results of a preliminary nature. These Notes should not exceed 2500 words (where a figure or table counts as 200 words). Following informal review by the Editors, they may be published within a few months of the date of receipt. Style requirements are the same as for regular contributions (see inside back cover).

Fluid Dynamic Force Acting on a Rectangular Solid in a Stokes Flow

S. Sunada,* R. Ishida, and H. Tokutake
Osaka Prefecture University, Osaka 599-8531, Japan

DOI: 10.2514/1.42386

Introduction

MICROFLOW sensors composed of a cantilever have been developed by some groups [1,2]. This type of sensor has the following strong points:

1) Lower pressure can be measured as its thickness decreases.

2) It can be used with unsteady motion because inertial force decreases as its thickness decreases.

3) It does not disturb the air around it as does a hot wire.

Theoretical analysis estimating the fluid dynamic forces acting on a cantilever (that is, a rectangular solid) is required for checking the characteristics of this sensor. This Note shows the fluid dynamic forces acting on a rectangular solid with various aspect ratios and various thicknesses in Stokes flow, which are obtained numerically.

Numerical Method

Stokes flow around a rectangular solid was analyzed by a boundary-element analysis [3,4]. A rectangular solid $L_X \times L_Y \times L_Z$ shown in Fig. 1 is divided into $20 \times 20 \times 20$ blocks. The solid in a uniform flow U_X or U_Y or U_Z is considered. Note that fluid dynamic forces in the X, Y, and Z directions that act on an object in Stokes flow are determined by the flow in each direction [5]. The Reynolds number is defined as $Re = U_* L_Y/\gamma$ (γ is kinematic viscosity). The force coefficients in the X, Y, Z directions (C_X, C_Y, and C_Z) are defined by

$$C_* = F_*/0.5\rho U_*^2 L_X L_Y \qquad (* = X, Y, Z) \tag{1}$$

Furthermore, the force coefficient in a Stokes flow can be expressed by

$$C_* = k_*/Re \tag{2}$$

Results

Figures 2–4 show the results of a rectangular solid when $L_X/L_Y = 1, 6,$ and 3, respectively. Figures 2a, 3a, and 4a show the k_Z for U_Z. Figures 2b, 3b, and 4b show the k_X for U_X. Moreover, Figs. 3c and 4c show the k_Y for U_Y. Note that from the symmetry, Fig. 2b shows the k_Y for U_Y. In Figs. 2a, 3a, and 4a, the k_Z obtained theoretically by Clift et al. [6] is also shown. These values agree with those obtained by the present analysis numerically. This agreement shows the validity of the present analysis. In Fig. 2a, the value measured by Thom and Swart [7] is also shown. In their experiment, the section shape in the X–Y plane is not rectangular, and the value of L_Z/L_Y shown in this figure is its mean thickness ratio. The value shown in [7], which was obtained by the water-tunnel test, is much larger than the k_Z obtained by the present analysis. The measured value might be enlarged by the interference effect between the object and the water-tunnel wall.

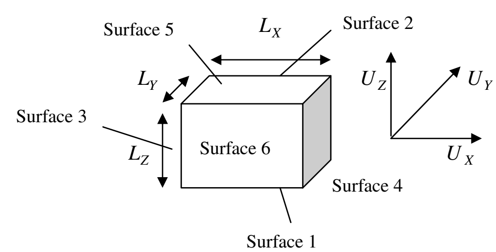

Fig. 1 A rectangular solid.

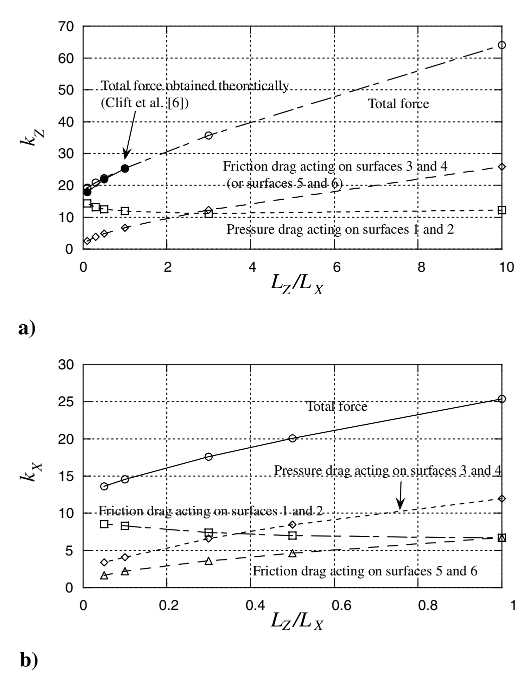

Fig. 2 Force coefficients: a) k_Z of a rectangular solid with $L_X/L_Y = 1$ for U_Z and b) k_X of the rectangular solid for U_X.

Received 25 November 2008; accepted for publication 30 December 2008.

*Associate Professor, Department of Aerospace Engineering; sunada@aero.osakafu-u.ac.jp.

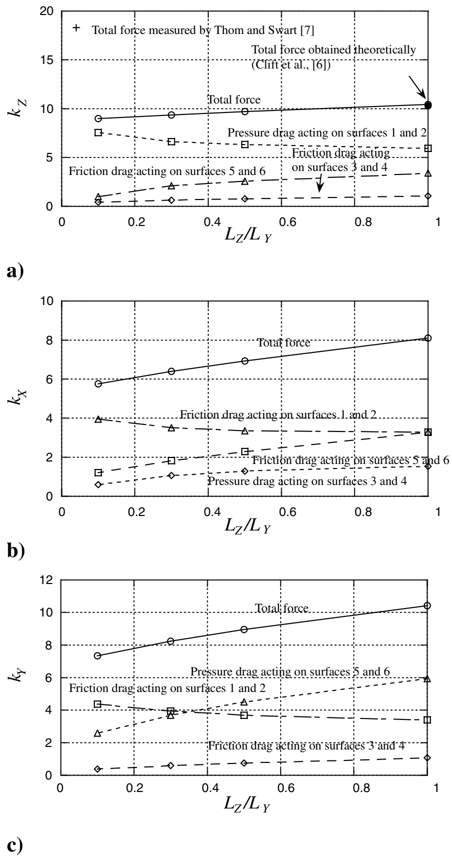

Fig. 3 Force coefficients: a) k_Z of a rectangular solid with $L_X/L_Y = 6$ for U_Z, b) k_X of the rectangular solid for U_X, and c) k_Y of the rectangular solid for U_Y.

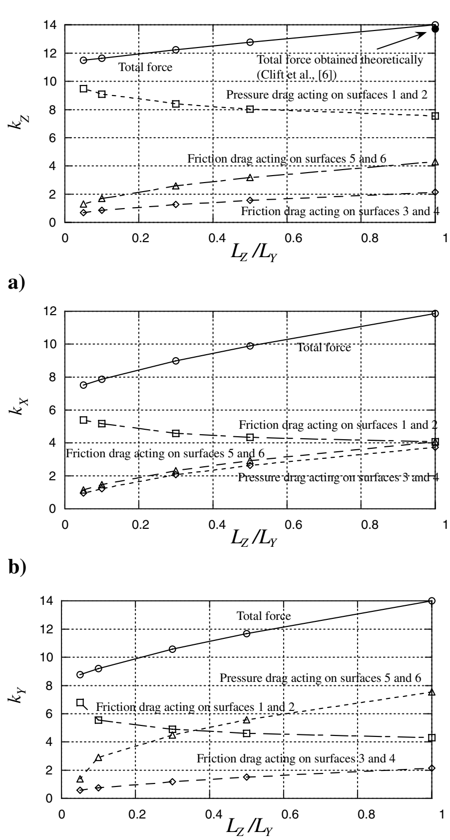

Fig. 4 Force coefficients: a) k_Z of a rectangular solid with $L_X/L_Y = 3$ for U_Z, b) k_X of the rectangular solid for U_X, and c) k_Y of the rectangular solid for U_Y.

Conclusions

Aerodynamic forces acting on a rectangular solid in Stokes flow, which are calculated by the boundary-element method, are shown. These results will be used for designing a cantilever in a microflow sensor, which can be mounted on a small vehicle.

Acknowledgment

This research was partly supported by Ricoh Company, Ltd.

References

[1] Ozaki, Y., Ohyama, T., Yasuda, T., and Shimoyama, I., "An Air Flow Sensor Modeled on Wind Receptor Hairs of Insects," *Proceedings of the IEEE International Conference of MEMS 2000*, Inst. of Electrical and Electronics Engineers, Piscataway, NJ, 2000, pp. 531–536.

[2] Takahashi, H., Iwase, E., Matsumoto, K., and Shimoyama, I., "Air Flow Sensor for an Insect-Like Flapping Wing," *Proceedings of the IEEE International Conference of MEMS 2000*, Inst. of Electrical and Electronics Engineers, Piscataway, NJ, 2008, pp. 916–919.

[3] Phan-Thien, N., Tran-Cong, T., and Ramia, M., "A Boundary-Element Analysis of Flagellar Propulsion," *Journal of Fluid Mechanics*, Vol. 184, 1987, pp. 533–549. doi:10.1017/S0022112087003008

[4] Goto, T., Taga, Y., and Takano, Y., "Study on Resistive Force Theory for Flagella with Boundary Element Method," *Transactions of the Japan Society of Mechanical Engineers. Series B*, Vol. 63, No. 605, 1997, pp. 188–193 (in Japanese).

[5] White, F. M., *Viscous Fluid Flow*, McGraw–Hill International Editions, Tokyo, 1991.

[6] Clift, R., Grace, J. R., and Weber, M. E., *Bubbles, Drops, and Particles*, Dover, New York, 1978.

[7] Thom, A., and Swart, P., "The Forces on an Aerofoil at Very Small Low Speeds," *Journal of the Royal Aeronautical Society*, Vol. 44, 1940, pp. 761–770.

M. Glauser
Associate Editor