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Optimization of acoustic signals in a vortex-shedding flowmeter using numerical simulation

E. von Lavante [a,*], S. Perpéet [a,1], V. Hans [b], G. Poppen [b]

[a] Institute of Turbomachinery, University of Essen, Schuetzenbahn 70, D-45127 Essen, Germany

[b] Institute of Measurement and Control, University of Essen, Schuetzenbahn 70, D-45127 Essen, Germany

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Abstract

Most commercial vortex-shedding flowmeters rely on a known relationship between the vortex-shedding frequency and the mass flow, needing a regular and well-defined vortex structure as well as a shedding mechanism. However, in most known current designs, the pressure sensors are included into the bluff body, imposing severe restrictions on the shape of the body. This results in rather irregular pressure signature of the vortex system, leading to problems in the signal processing. In the present work, the flow about the bluff body in a vortex-shedding flowmeter is numerically investigated using a Navier–Stokes solver, capable of handling unsteady, compressible and viscous flows in two-dimensional and three-dimensional geometries. The computations are compared with experimental results obtained by ultrasonic measurements downstream of the bluff body. Several different body shapes are studied, trying to optimize the resulting pressure signature downstream of the body. Recommendations regarding an aerodynamically optimal shape of the bluff body are made. © 1999 Elsevier Science Inc. All rights reserved.

Keywords: Vortex-shedding flowmeter; Ultrasonic measurement; Bluff body shape

Notation

CFL	Courant-Friedrichs and Lewy number
d	bluff body height
f	vortex-shedding frequency
Re	Reynolds number
Sr	Strouhal number
v	pipe mean velocity

1. Introduction

This communication deals with numerical investigation of the flowfield around bluff bodies in a vortex-shedding flowmeter. Commercial flowmeters use a large variety of bluff body shapes, often restricted by the attachment of sensors, or patent laws. The simulation of some current bluff body designs leads to fairly irregular pressure signatures. It was, therefore, decided to investigate a few alternate bluff body designs.

The relation between the pipe mean velocity v and the vortex-shedding frequency f is given by the non-dimensional Strouhal number: $\mathrm{Sr} = f \cdot d/v$ with d the bluff body height. For Sr independent of the Reynolds number, in the case of particular bluff body shape, the pipe mean velocity is proportional to the vortex-shedding frequency. The shedding frequency of cylindrical bluff body shape depends upon the Reynolds number due to drift of the separation position of the vortices. In the case of triangular designs, however, the Strouhal number is nearly invariant with regards to the Reynolds number and, therefore, often found in commercial flowmeters. Using e.g. ultrasonic measurement, the bluff body shape is restricted only by the required minimum strength to avoid vibrations. The design could be optimized regarding the pressure signature or the pressure drop downstream of the body.

2. Numerical algorithm

The numerical algorithm employed uses three-dimensional, time-dependent full Navier–Stokes equations describing the conservation of mass, momentum and energy of the flow. The program is based on the finite–volume formulation, using a cell–centered organization of the control-volumes. The spatial discretization is carried out with the help of Roe‘s Flux Difference Scheme, a Godunov-type method providing an approximate solution of the Riemann problem on the cell interfaces (Vatsa et al., 1987). The method has been proven to be accurate and effective in the simulation of low Mach number viscous flows (von Lavante and Yao, 1993).

Starting with a constant initialization of the scalar variables and body-fitted velocity components, the integration in time is carried out by a modified explicit Runge–Kutta time stepping as well as, optionally, an implicit Approximate-Factorization

* Corresponding author. E-mail: erni@tigger.turbo.uni-essen.de

[1] E-mail: stephan@tigger.turbo.uni-essen.de

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method (Jameson et al., 1981). The implicit AF method has a higher stability limit, making CFL numbers of up to 30 possible, but is, unfortunately, of lower accuracy in time. It is, however, a good procedure to reach the periodic solution in a relatively short time. The periodic flow is then computed with the R–K scheme using a fixed time step.

3. Results

Various shapes of bluff bodies (Fig. 1) have been tested with regard to their linear vortex-shedding frequency. Special attention was paid to possibly disturbing secondary effects. The numerical simulations were compared with experimental data, achieved by modulating an ultrasonic signal with a carrier frequency of 111 kHz, positioned downstream of the body (Hans et al., 1997, 1998). Two simple bluff body shapes and a third "new design" shape, proposed by the present authors, were investigated. In the case of the T-shape, the vortex-shedding frequency to mean flow velocity ratio was about 21 Hz per m/s, with the Strouhal number constant for the whole velocity range, corresponding to Reynolds numbers from 10,000 to 300,000. Experimental and numerical results showed a good agreement. Estimates of the bluff body bending dynamics have shown that even a rectangular body of small dimensions could be used. In comparison to the T-body, the vortex-shedding frequency of the I-body decreased about 20% to 17 Hz per m/s. The deviation from linear behaviour was smaller than for the T-shaped body. The Strouhal number also decreased accordingly, and was constant in the same range of Reynolds numbers within 2% of the mean Strouhal number. The third body had a special new design with a height of

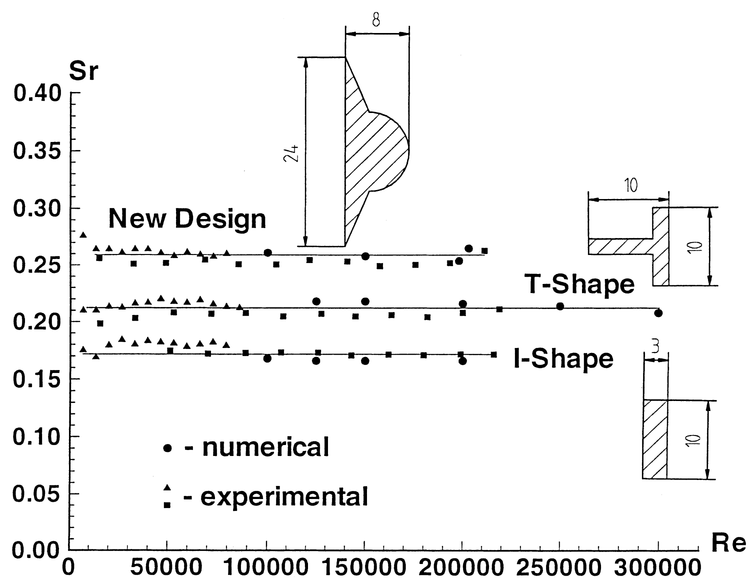

Fig. 1. Strouhal number versus Reynolds number.

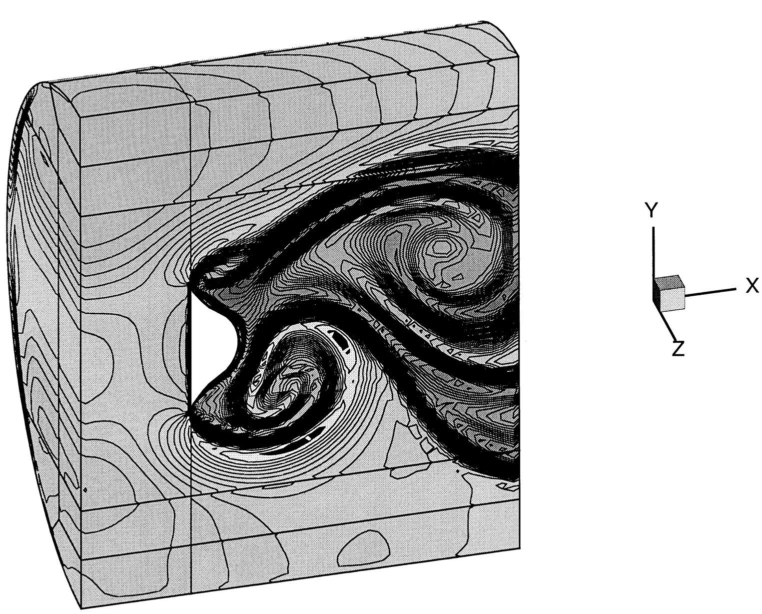

Fig. 2. Density contours over the pipe cross-section.

24 mm. It's shape was optimized using the present numerical method to achieve vortex generation without any secondary effects. The back side was formed as a bulge without any sharp edges. For this shape, the dependency of the frequency on the mean flow velocity is highly linear, resulting in a constant Strouhal number in the given Reynolds number range. Preliminary computations were accomplished using a two-dimensional version of the solver; however, most of the simulations discussed here were carried out in three dimensions. A typical picture of the density contours for the "new design" is shown in Fig. 2.

4. Conclusions

Numerical simulations of flow about various bluff bodies in a vortex-shedding flowmeter using a verified and validated Navier–Stokes solver for two-dimensional and three-dimensional simulations of compressible, viscous and unsteady flow, were presented. The unsteady solutions obtained in the present work show good agreement with experimental data. Based on these results, the expected acoustic signature of these bluff bodies was predicted. The "new design" body displayed the most regular signal and is, therefore, recommended.

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