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ABSTRACT

A numerical study of flow phenomena in a two-dimensional valve channel is presented. The steady flow in constant channel geometry and periodic flow in the case of oscillating wall are considered. Calculations are limited to low Reynolds number only.

INTRODUCTION

In recent years a number of papers concerning the flow field in a valve channels, taking into account the gas viscosity and flow inertia have been presented [1, 2, 3].

The reed valves have a particular geometry with relatively high ratio of plate area to port area. In such geometry the flow field in valve gap has significant influence on the valve reed movement.

In this paper a results of finite element analysis of two-dimensional flow of incompressible viscous fluid are presented. The steady flow in constant channel geometry and periodic flow in a channel with one wall oscillating are considered.

BASIC EQUATIONS

The analysis is restricted to two-dimensional flow of incompressible viscous flow. The governing equations are continuity equation

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$

and momentum equations

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \frac{\mu}{\rho}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right)$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial y} + \frac{\mu}{\rho}\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right)$$

This set of equation deal with transient fluid motion.

FINITE ELEMENT ANALYSIS

The formulation used here involves velocity and pressure as variables. Application of Galerkin method and Green's theorem (following Zienkiewicz and Taylor [4, 5]) provides to following set of equations for a single node.

$$\sum_{1}^{ne}\int_{S_e}\left(N_i\frac{du_j}{dt}N_k + N_iN_ku_k\frac{\partial N_j}{\partial x}u_j + N_iN_kv_k\frac{\partial N_j}{\partial y}u_j + \frac{1}{\rho}N_i\frac{\partial M_L}{\partial x}p_L + \frac{\mu}{\rho}\left(\frac{\partial N_i}{\partial x}\frac{\partial N_j}{\partial x}u_j + \frac{\partial N_i}{\partial y}\frac{\partial N_j}{\partial y}u_j\right)\right)ds - \frac{\mu}{\rho}\int_{L}N_i\frac{\partial u_j}{\partial n}dl = 0$$

$$\sum_{1}^{ne}\int_{S_e}M_i\left(\frac{\partial N_j}{\partial x}u_j + \frac{\partial N_j}{\partial y}v_j\right)dS = 0$$

$$\sum_{1}^{ne}\int_{S_e}\left(N_i\frac{dv_j}{dt}N_k + N_iN_ku_k\frac{\partial N_j}{\partial x}v_j + N_iN_kv_k\frac{\partial N_j}{\partial y}v_j + \frac{1}{\rho}N_i\frac{\partial M_L}{\partial y}p_L + \frac{\mu}{\rho}\left(\frac{\partial N_i}{\partial x}\frac{\partial N_j}{\partial x}v_j + \frac{\partial N_i}{\partial y}\frac{\partial N_j}{\partial y}v_j\right)\right)ds - \frac{\mu}{\rho}\int_{L}N_i\frac{\partial v_j}{\partial n}dl = 0$$

The four node quadrilateral elements with bilinear velocity interpolation and constant pressures were adopted [6]. All equations were directly coupled to obtain solution. The boundary conditions of velocity and pressure were applied directly to the matrix equation. The steady state solution was obtained using the iteration method. In this case nonsteady terms in last set of equations have been neglected.

Denoting the unknown vector U, which represents u_i, p_i, v_i one can write the last set of equations in a short form.

$$M\frac{dU}{dt} + UKU + DU - F = 0$$

The first term represents inertia, the second it is convection term, third diffusion term and fourth represents body forces.
Assuming that the motion of flow is periodic, the variational Galerkin approach (following Kawahara [7]) can be applied to the integration with respect to time. Variational equation in time can be presented in form

$$\int_0^{2\pi/\omega} N_t M\frac{dU}{dt}dt + \int_0^{2\pi/\omega} N_t\,(UKU)dt + \int_0^{2\pi/\omega} N_t DU dt - \int_0^{2\pi/\omega} N_t F dt = 0$$

where the weighting function Nt, trial function U and given force F have the form of trigonometric series.

f.e. $U = U^{(0)} + \sum_{m=1}^{N} a^{(m)} \sin(k\omega t) + \sum_{n=1}^{N} b^{(n)} \cos(k\omega t)$

After substitution, rearranging and integration the discretized non-linear simultaneous equation system for m,n can be derived. If we limit the series only to first periodic component the particular case with linear equation set appears

$$-\omega M b^{(1)} + D a^{(1)} + U^{(0)} K a^{(1)} + a^{(1)} K U^{(0)} - F^{(1)} = 0$$

$$\omega M a^{(1)} + D b^{(1)} + U^{(0)} K b^{(1)} + b^{(1)} K U^{(0)} - F^{(1)} = 0$$

Vector $U^{(0)}$ is known from the steady state solution so the set of equations can be easily solved to obtain $a^{(1)}$ and $b^{(1)}$ vectors.

BOUNDARY CONDITIONS

Steady flow. The parabolic velocity distribution, characteristic for laminar flows, at the inlet crossection has been assumed. At the outlet crossection the ambient pressure condition has been taken. At the both sides (at the inlet and at the outlet) the zero velocity gradients were applied. The natural boundary conditions on channel walls (zero velocity components) were included in numerical scheme.

In the case of periodic flow the steady state boundary conditions were extended by periodic boundary conditions. It was stated that the upper channel wall is oscillating with the frequency f and velocity amplitude equal one tenth of maximum inlet velocity. The periodic component of pressure at the outlet crossection was assumed to be zero.

RESULTS

In the following drawings results of numerical calculation are shown. Due to symmetry only a half of channel geometry was considered. Calculation were performed for two basic geometries: a narrow channel (height of valve gap equal of half of port width) and wide channel (height of valve gap equal three quarter of port width). The highest Reynolds number was limited by instability of used numerical scheme.

Fig 1 presents velocity vectors for the flow through the narrow channel with different velocities (Reynolds numbers).

In Fig 1a a typical laminar velocity profile can be easily noticed. The characteristic changes of flow direc-

tion in the channel outlet have been predicted.
Fig 1b presents slightly modified velocity profile. Due to the inertia the maximum of velocity profile lies close to the upper wall. The flow separation near the corner can be noticed. The change of flow direction in the outlet is much weaker.
Fig 1c shows a long separation bubble near the bottom wall. Some instabilities in flow can be observed. One can notice the change of velocity direction in front of the corner.
Drawings in Fig 2 present velocity vectors in a wide channel.
In Fig 2a the short separation just near the corner can be observed. Velocity profile seems to be characteristic to laminar flow.
In Fig 2b the long separation bubble is visible. The reatachment point is located in some distance outside of the outlet crossection.
Fig 2c presents a fully separated flow with irregular vortex structure in dead water region.

Corresponding pressure distribution on the channel walls are presented on the next two figures. The convention of positive pressure sign in inside direction of the wall was used.
Fig 3 presents pressure distribution on the walls of narrow channel. In the case of flow with low Reynolds number the pressures have only positive values. Pressure distributions for higher Reynolds numbers have significantly different form. Zones of negative pressures can be observed. From the pressure distribution the position of separation bubbles can be predicted.

In Fig 4 similar curves for the wide channel are presented. There are not significant changes of pressure distribution form in this geometry.

The next drawings present results of calculation corresponding to the flow through the channel with oscillating upper wall.
Fig 5 presents 5 following phases of the periodic flow in a narrow channel. The last drawing (Fig 5f) shows the superposition of velocity vectors in one cycle of oscillation. In this drawing the changes of velocity amplitudes and directions are easily noticeable.
Fig 5b and 5c corresponds to the case of wall moving up.
Fig 5d and 5e presents the phases of wall moving down.
The wall moving periodically has influence only the part of flow field in vicinity of oscillating wall. Position of separation bubble is stable.
Similar conclusions can be obtain from the analysis of next figure.
Fig 6 presents phases of flow in a wide channel with os-

cillating upper wall for low Reynolds number.
Completely different situation is presented in Fig 7. This figure corresponds to the flow with higher Reynolds number.
The velocities in separated part of flow are strongly influenced by the wall motion. The wall which moves down produces regular verticies. These verticies are than destructed when the wall moves up.

CONCLUSIONS

Presented results of numerical investigation are limited to low Reynolds numbers flows. Nevertheless they show some interesting aspects of flow phenomena in valve channels. Important seems to be the information that the moving wall can generate and breakdown a vortex structures inside the valve channel. Such periodic production of the vorticity may be connected with a noise generation.

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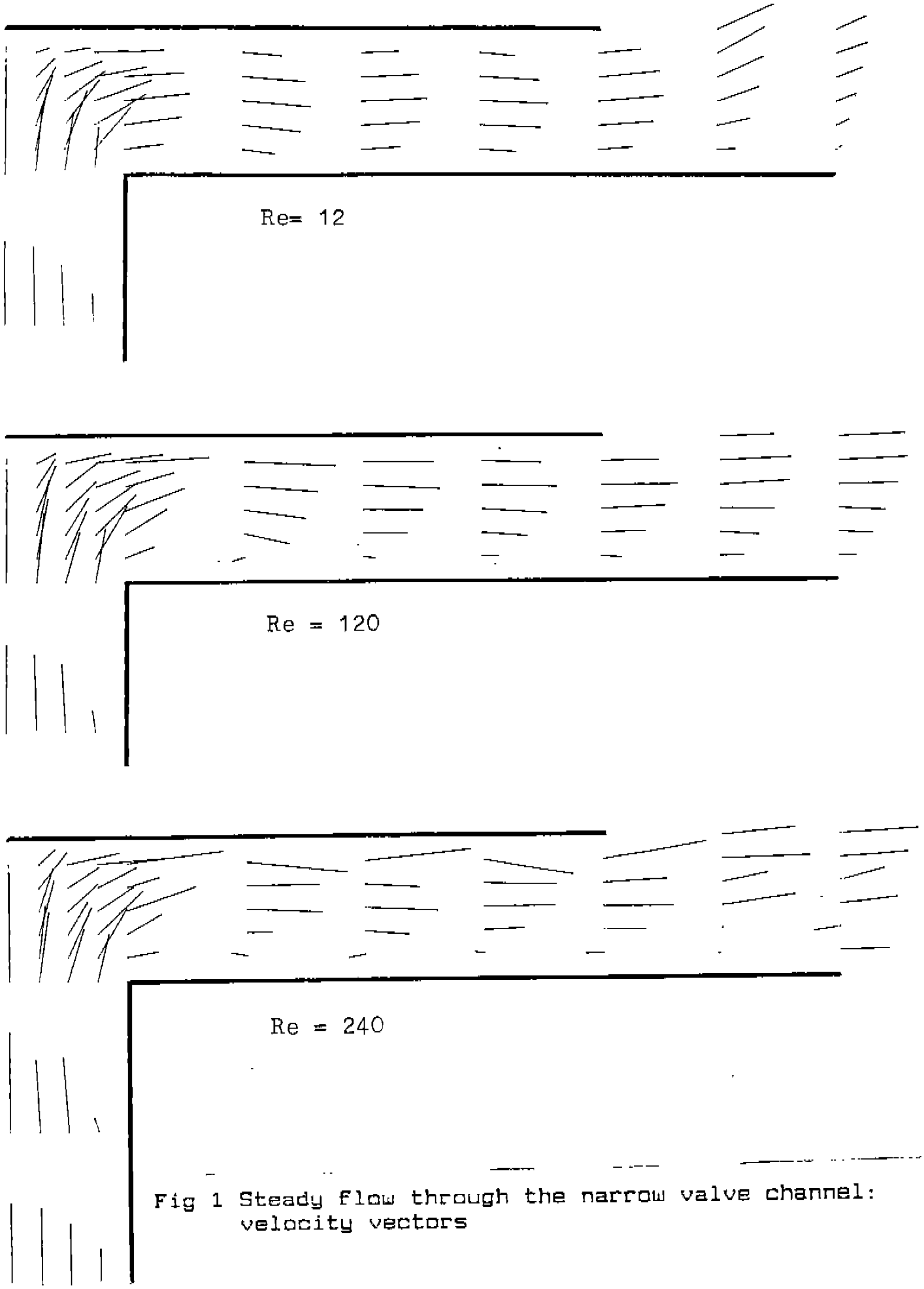


Fig 1 Steady flow through the narrow valve channel: velocity vectors

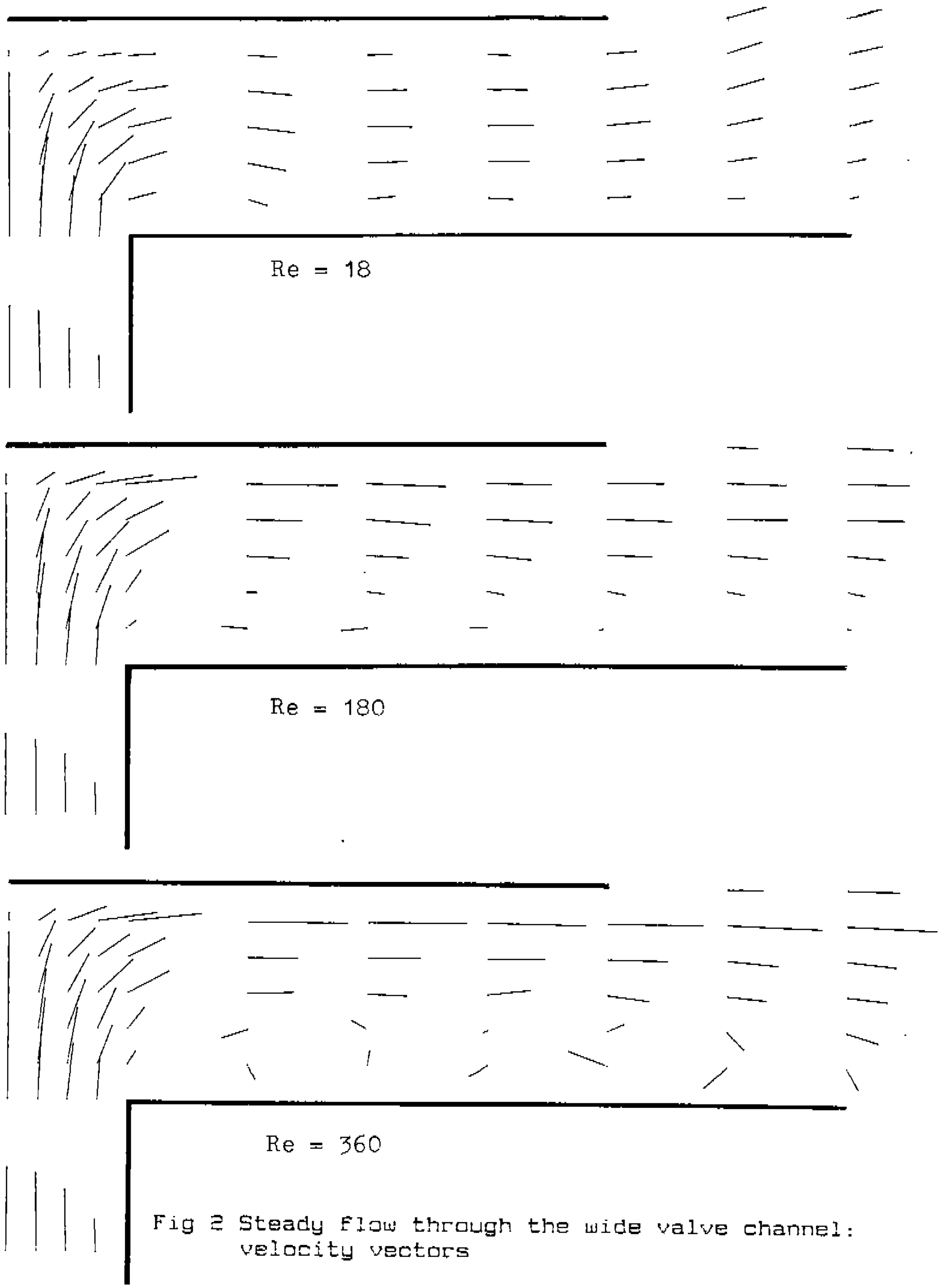


Fig 2 Steady flow through the wide valve channel: velocity vectors

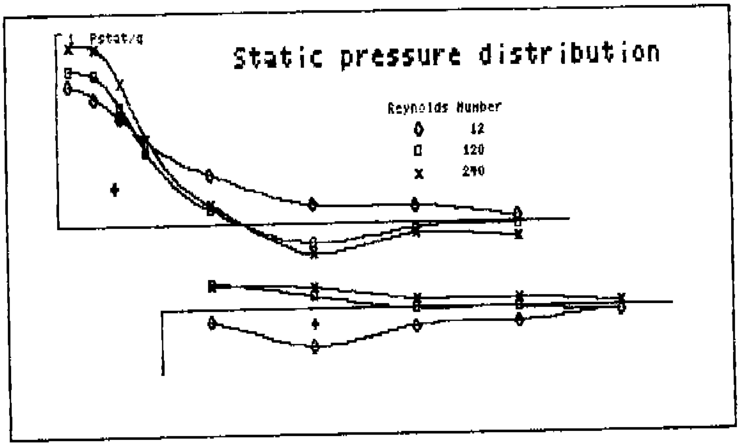


Fig 3 Pressure distribution on the walls of narrow valve channel

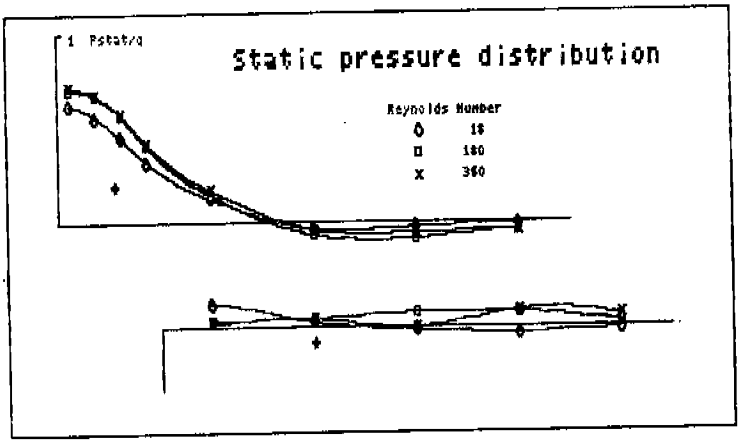


Fig 4 Pressure distribution on the walls of wide valve channel

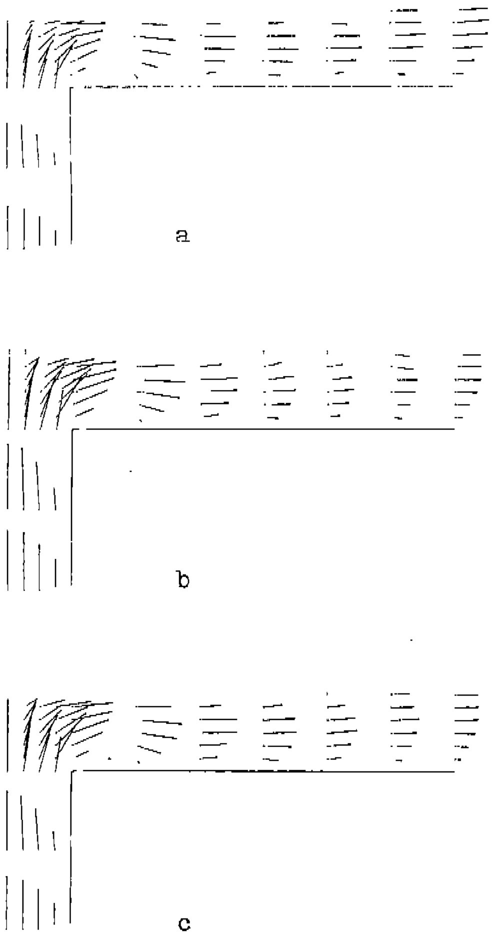
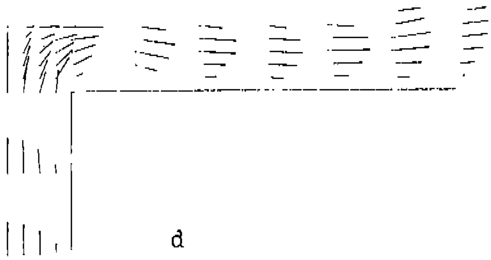


Fig 5 Phases of periodic flow through the narrow valve channel with oscillating upper wall: velocity vectors



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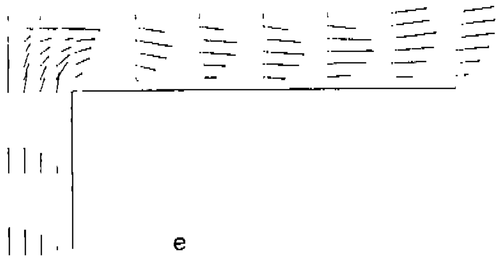

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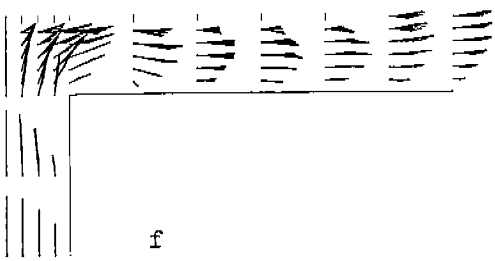

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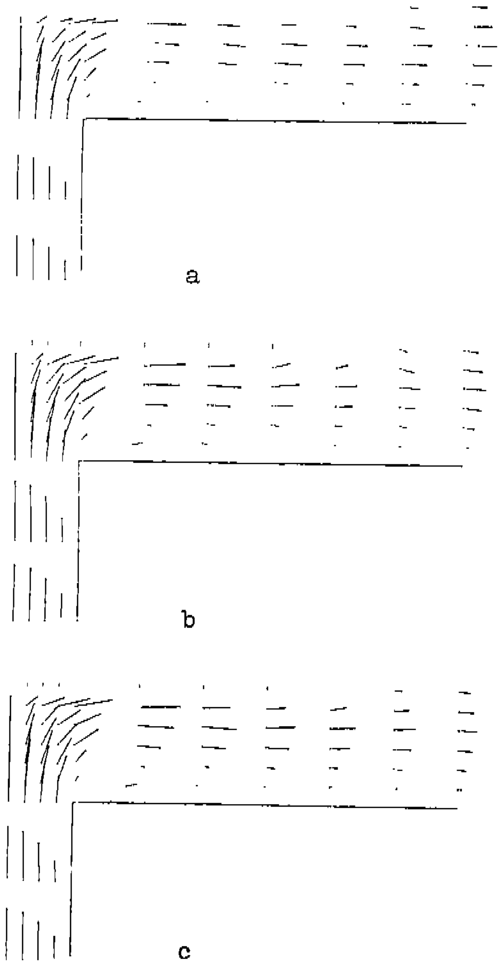
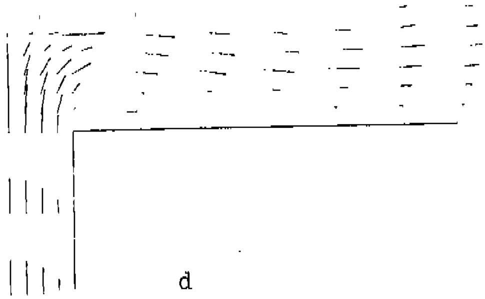


Fig 6 Phases of periodic flow through the wide valve channel with oscillating upper wall: velocity vectors - Reynolds number=10



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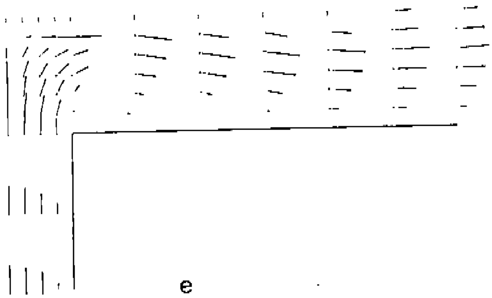

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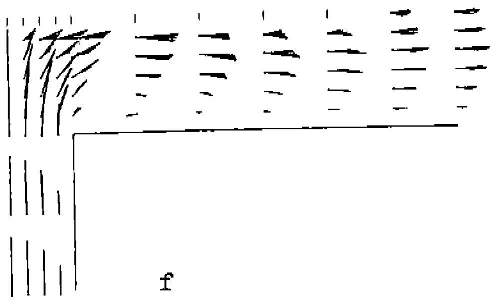

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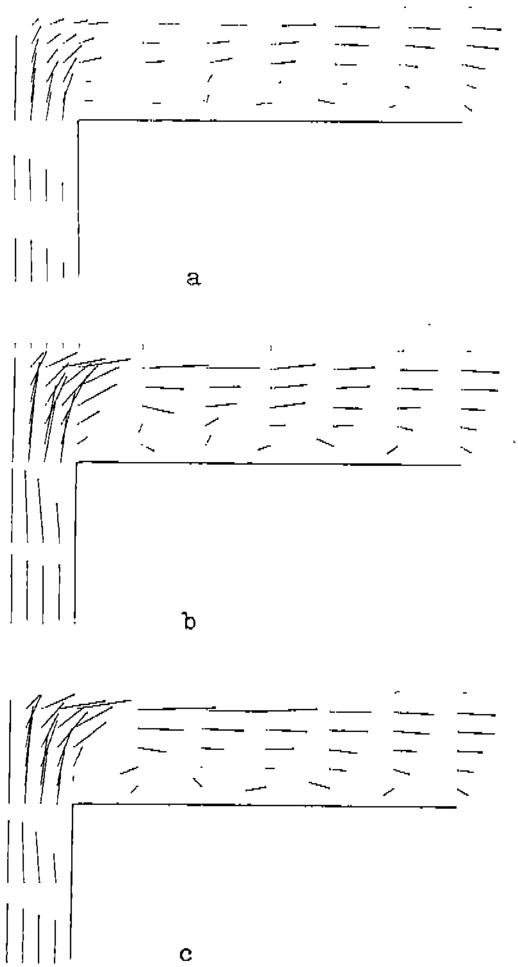
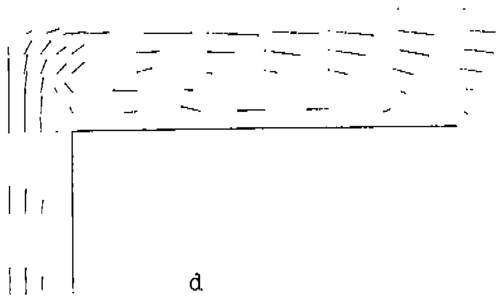


Fig 7 Phases of periodic flow through the wide valve channel with oscillating upper wall: velocity vectors - Reynolds number=180



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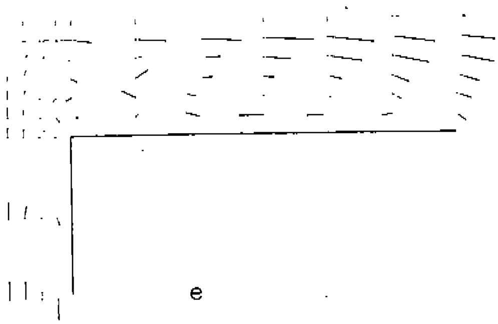

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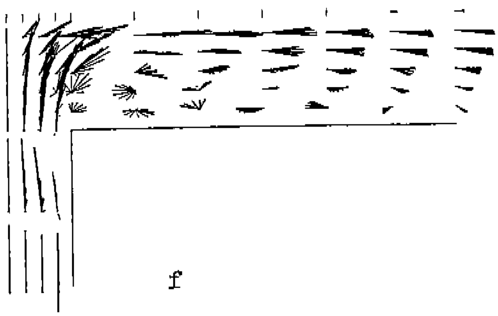

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