

BILGE VORTICES ALONG A SERIES-60 MODEL

by
Jean-Claude Tatinclaux

This research was carried out under the
Naval Ship Systems Command
General Hydromechanics Research Program
SR 009 01 01, administered by the
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IIHR Report No. 117

Iowa Institute of Hydraulic Research
The University of Iowa
Iowa City, Iowa

July 1969

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Abstract

By measuring the velocity components by means of a Five-hole directional probe, the secondary flow in the transverse plane at the stern of a Series-60 model has been investigated and show the presence of a vortex. The drag induced by the bilge vortices is estimated to be equal to about two percent of the surface drag. The streamlines in the bow region are determined and permit to conclude that the spiral motion which eventually develops into vortices already begins at the bow. It is suggested that the influence of the shape of the bow on the flow pattern in the bow region be further investigated.

Introduction

The previous experimental studies at the Institute of Hydraulic Research on the formation and development of bilge vortices and on the determination of vortical drag were performed on an ogive. These experiments were concerned with the formation and growth of the bilge vortices [1]*, the influence of the radius of curvature at the bilge [2], and with the effect of bilge keels and bulbous bow [3].

The ogive is, at best, an ideal representation of a ship-form. Since a 4-foot double model of the Series-60, 0.60 block ship form, originally used by Jin Wu for studying the turbulence in the wake [4], was available at the Institute, it was decided to investigate the bilge

* Numbers in brackets designate References at the end of report

vortices generated along an actual ship form, and to determine their induced drag. Furthermore, the flow pattern in the bow region was also studied experimentally in an attempt to shed some light on the processes of formation of these vortices.

Measurements

The double model used in this study was suspended in the test section of the open-throat wind tunnel of the Institute, see Fig. 1, by eight thin wires located so as to interfere as little as possible with the vortices. The measurements of the velocity components u , v , w were performed using a five-hole probe [5]. This probe is mounted in such a way as to rotate about a vertical axis passing through the tip of the probe. The determination of the components of the velocity vector proceeds as follows. The probe is rotated until its horizontal axis is located in the vertical plane containing the velocity vector, when the pressure difference between the two side holes in the horizontal plane is zero. The angle of rotation α is read directly on a protractor attached to the probe. The ratio of the head difference between the top and bottom holes Δh to the head registered by the center hole h_c is proportional to the angle β of the velocity vector with the horizontal plane. A graphic description of the foregoing procedure is given in Fig. 2-a and the calibration curve of $\Delta h/h_c$ versus β is shown in Fig. 2-b. If U is the magnitude of the velocity, then

$$u = U \cos \beta \cos \alpha$$

$$v = U \cos \beta \sin \alpha$$

$$w = U \sin \beta$$

and since, in the present case, the ambient pressure is the atmospheric pressure, the quantity $U \cos \beta$ is obtained directly from h_c . When the wind tunnel is of the closed type, the average of the pressures registered

by the four side holes gives the ambient pressure [5].

1) Bilge Vortices

Previous investigations [1] had shown that a bilge vortex reaches its maximum strength at the stern of the body, and in the present study the measurements were limited to the transverse plane at the stern of the model. The components v and w of the velocity in this plane have been determined and a picture of the vortex can be obtained as shown in Fig. 3. The parameters "b", distance of the center of the vortex to the x-z plane of symmetry of the model, and "d", distance of the center of the vortex from the horizontal plane of symmetry of the double model, and the mean radius "a" of the vortex can be obtained directly from the figure. The circulation Γ is computed from the experimental data around a rectangular path enclosing the vortex. The drag induced by a pair of bilge vortices is then determined using the formula derived in [3] as

$$D_v = \frac{\rho \Gamma^2}{2\pi} \left[\frac{1}{4} + \ln \frac{b-a+\sqrt{b^2-a^2}}{-b+a+\sqrt{b^2-a^2}} + \frac{1}{2} \ln \frac{(-b+a+\sqrt{b^2-a^2})^2 + 4d^2}{(b-a+\sqrt{b^2-a^2})^2 + 4d^2} \right]$$

From Fig. 3 we obtain

$$a = 0.025 \text{ ft.}$$

$$b = 0.0375 \text{ ft.}$$

$$d = 0.1625 \text{ ft.}$$

and Γ has been computed to be

$$\Gamma = 1.41 \text{ ft.}^2/\text{sec.}$$

thus

$$D_v = 8.81 \cdot 10^{-4} \text{ lbs.}$$

The experiments were conducted at a Reynolds number of about 1.24×10^6 .

From the ITTC correlation formula, the corresponding value of the surface-drag coefficient is

$$C_s = \frac{0.075}{(\log_{10} R - 2)^2} = 4.48 \cdot 10^{-3}$$

and since the surface of the half double-model, representing the wetted area of the corresponding ship model, is $A = 2.82 \text{ ft.}^2$, the surface drag is

$$D_s = C_s A \frac{\rho U^2}{2} = 3.82 \cdot 10^{-2} \text{ lbs.}$$

then

$$D_v/D_s = 0.023$$

The vortical drag represents approximately 2 percent of the surface drag of the Series-60 model.

2) Flow Pattern in Bow Region

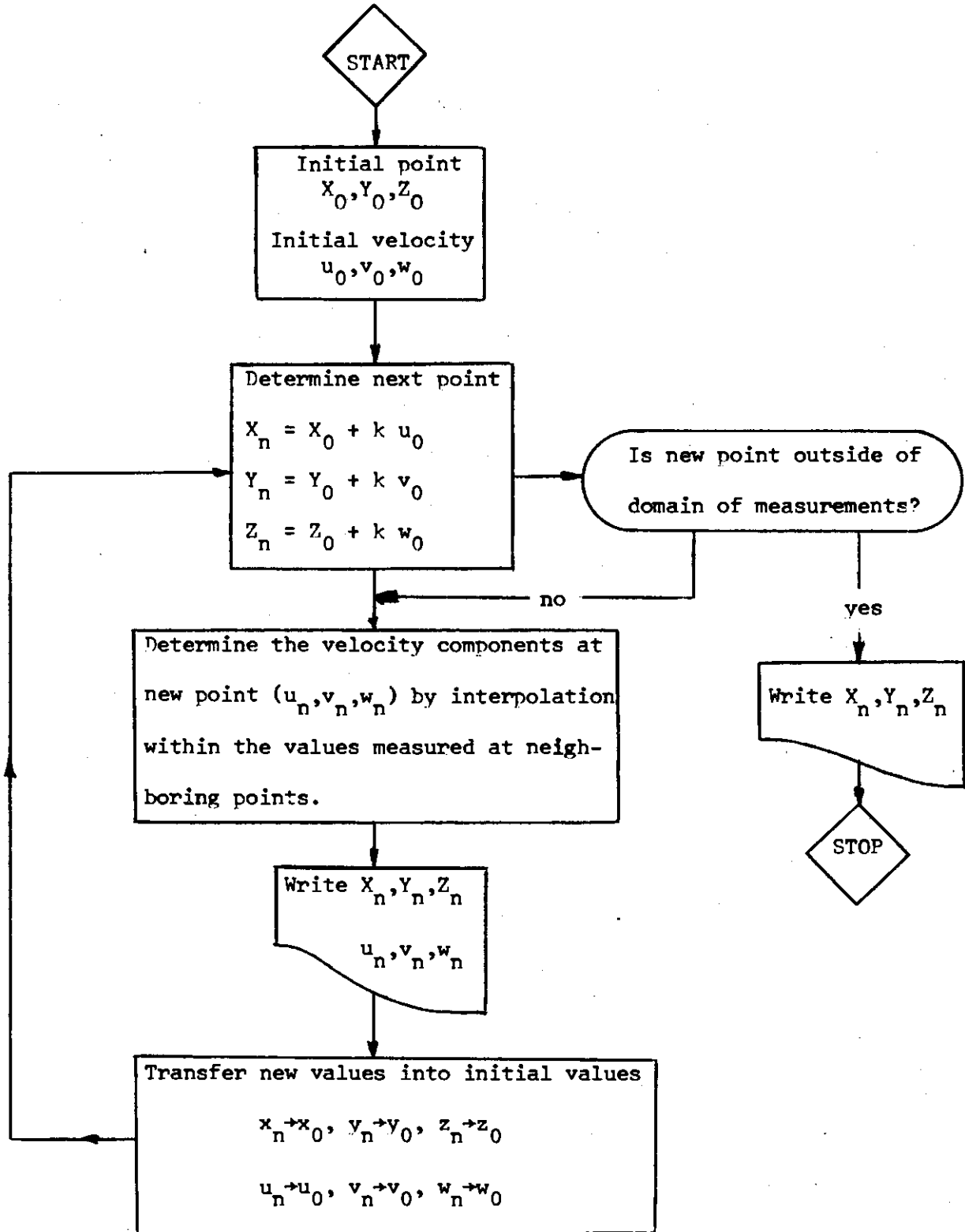
The velocity components u , v , w , have been measured at numerous points in the vicinity of the model in the bow region. The measurements have been limited to an eighth of the body length from the bow. The origin of the system of coordinates has been chosen as the intersection of the bow with the free surface, the x -axis coincides with the longitudinal axis of the model in the direction of the mean flow, the z -axis is vertical upward, and the y -axis completes this right-handed system of coordinates. Since the differential equation of a streamline is given by

$$\frac{dx}{u} = \frac{dy}{v} = \frac{dz}{w} = \text{constant} = k$$

a set of streamlines could be determined from the flow chart outlined on page 6. The results of the computations are shown on Fig. 4, where the coordinates have been made dimensionless with respect to the beam of the ship, as the projections of the streamlines on the x - z and x - y planes. A three-dimensional figure drawn in perspective would have been easier to read, but the artistic talent of the writer has proven to be insufficient for such a task. However, by following concurrently the two projections

of each streamline, one can see that the streamlines both follow a downward trend and pass underneath the model while staying at approximately a constant distance from the hull; furthermore at the downstream edge of the domain of measurements the component v of the velocity changes sign. This shows that the flow follows a spiral motion which, already begun at the bow, then develops into vortices. This spiral motion increases in strength all along the ship model up the stern. Once the vortex has left the body it will eventually damp out through viscous effects.

Since, as we see here, the spiral motion begins at the bow, the shape of which might therefore affect the original stages of the vortex formation, it is suggested that a study similar to the present one be performed on a Series-60 model equipped with a bulbous bow, to investigate if the spiral motion is hampered or not by such a shape.



Flow Chart for the Determination of the Streamlines in the Bow Region

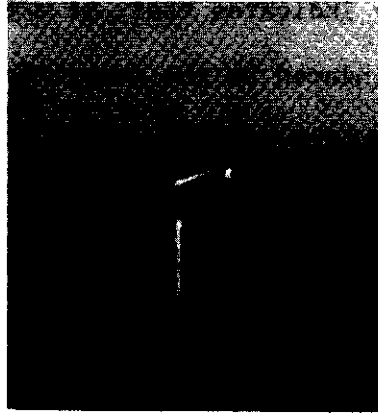
Conclusions

The present study indicates that, at a Reynolds number equal to 1.24×10^6 , the drag induced by the generation of vortices along the bilges is of the order of 2 percent of the surface drag for a Series-60 ship-model.

The spiral motion which develops into these bilge vortices begins already at the bow as can be seen in Fig. 4. This spiral motion at first follows the hull of the ship; when the flow lines depart from the hull, vortices are formed, as shown in Fig. 3. Since this motion originates at the bow, it will be affected by the shape of the bow. It is therefore suggested that the study be pursued by performing a similar series of experiments on a Series-60 ship model equipped with a bulbous bow.

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Detail of the Five-Hole Probe

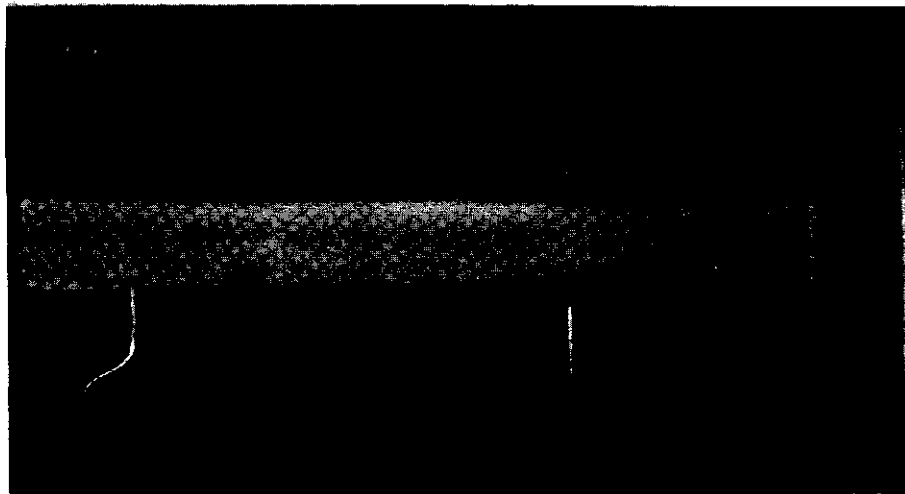


Fig. 1. Photograph of the Series-60 Double Model Installed in Wind Tunnel

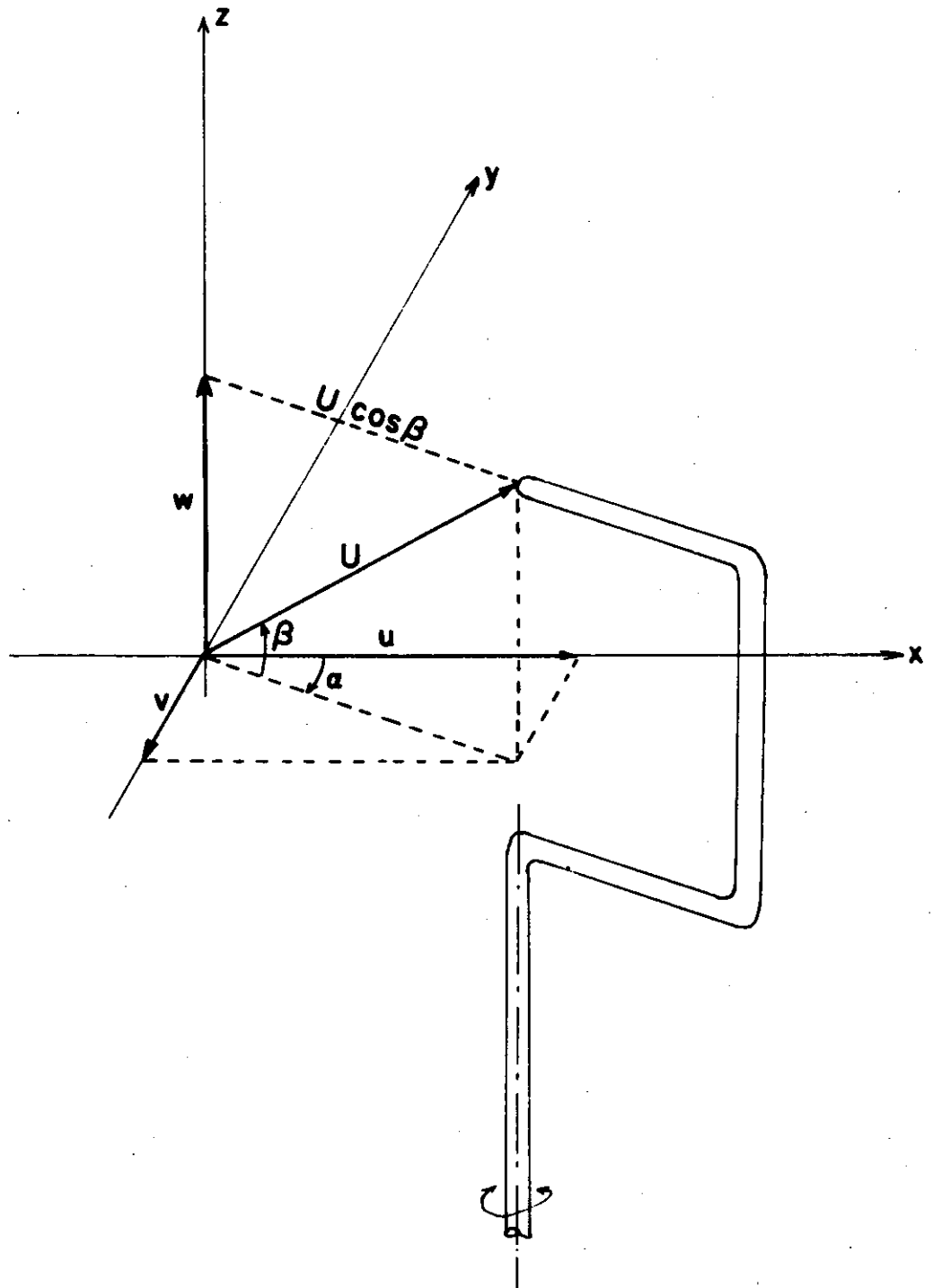


Fig. 2a. Operating Principle of the five-hole Probe

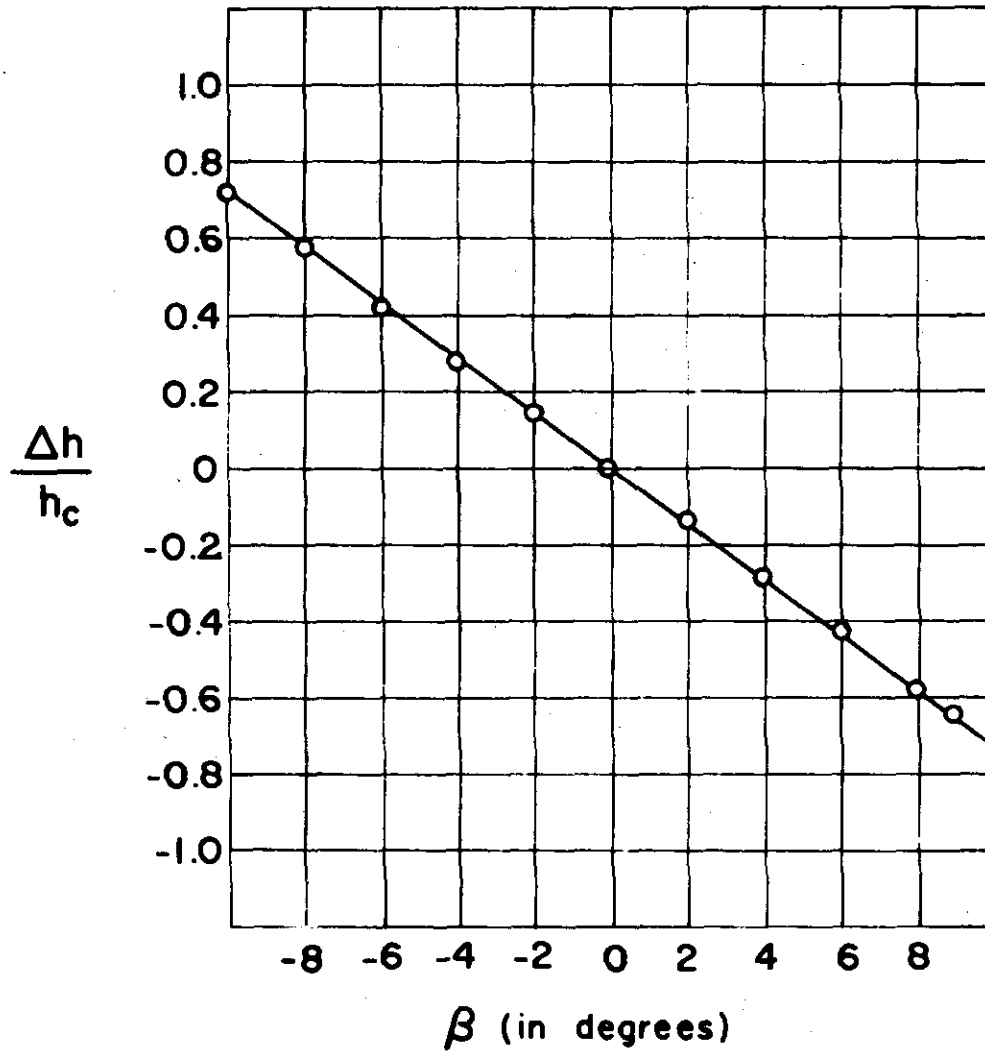


Fig. 2b. Calibration Curve of the five-hole Probe

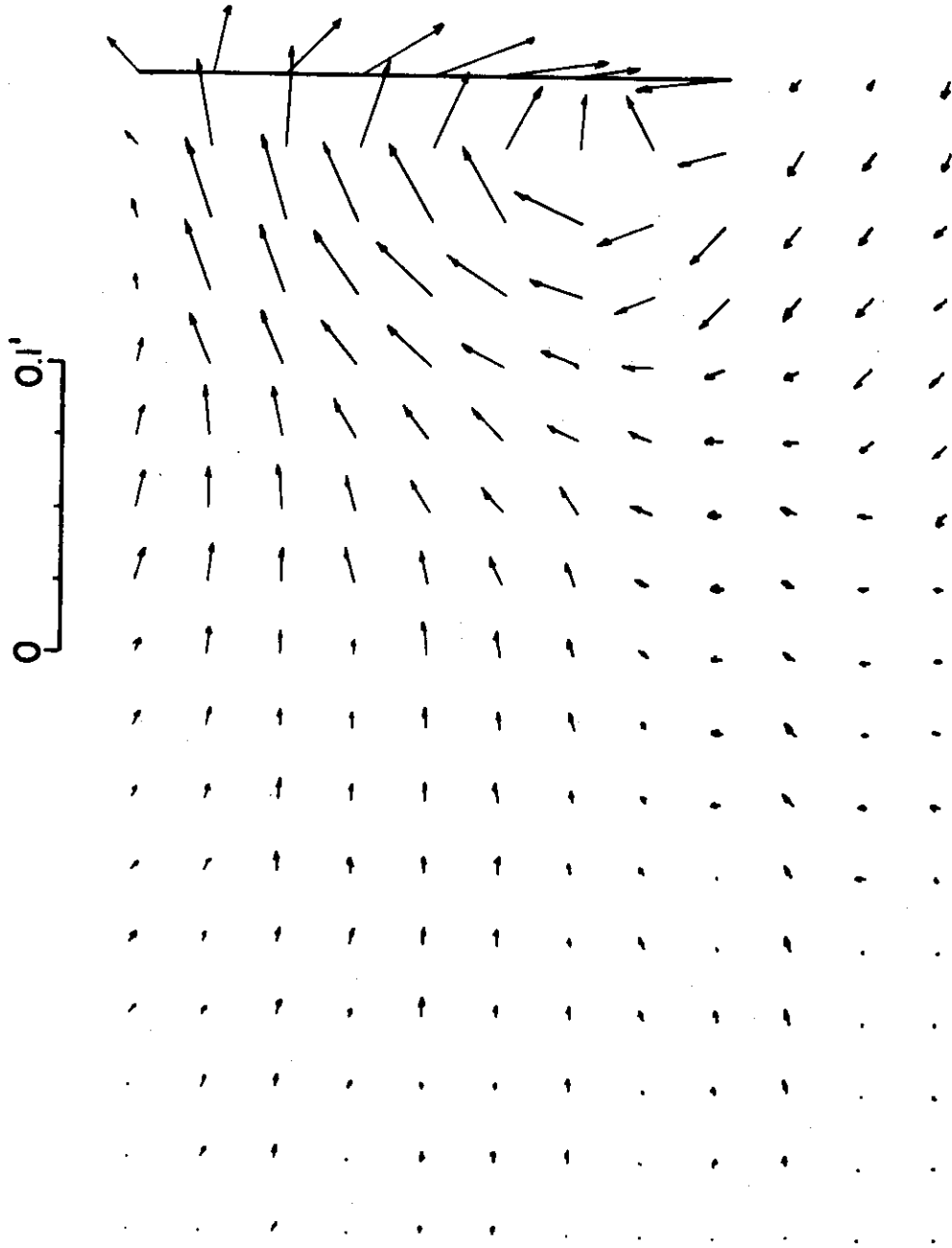


Fig. 3. Secondary Motion in the Transverse Plane at the Stern of the Model

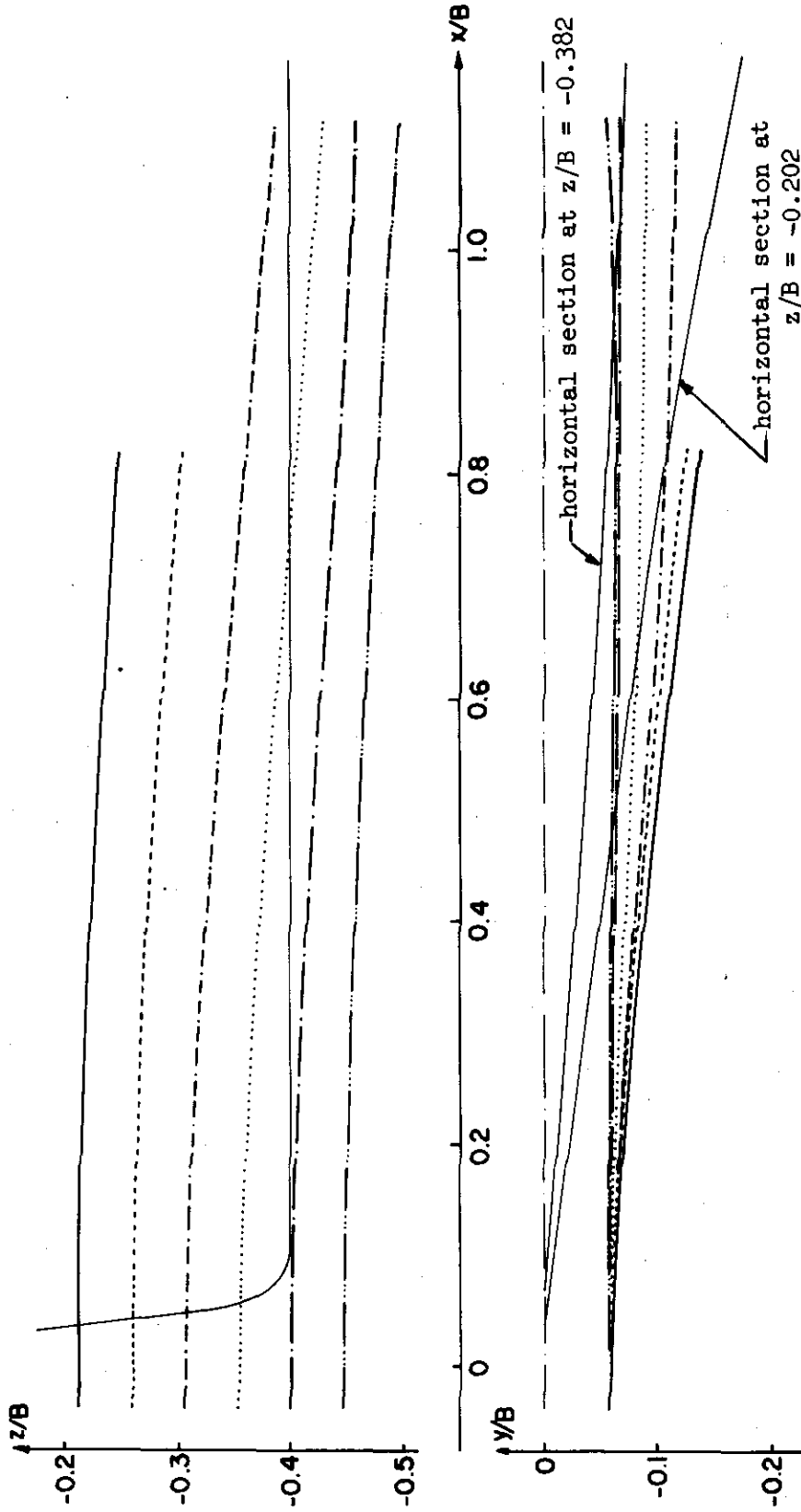


Fig. 4. Flow Pattern in the Bow Region of the Series-60 Model, as Shown by a Set of Streamlines

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