INFLUENCE OF THE RADIUS OF CURVATURE ON THE DRAG INDUCED BY BILGE VORTICES

by

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ABSTRACT

Wind-tunnel experiments were conducted in order to study the influence of the bilge curvature on the generation of bilge vortices. The geometric characteristics of the vortices were determined, the circulation and the vortical drag computed. The results show that the vortical drag decreases rapidly from 14 to 2 percent of the surface drag when the ratio of the radius of curvature to the maximum thickness of the ogive is increased from 0 to 0.12. It is therefore concluded that production of vortices at the bilge does not contribute significantly to the resistance to motion of actual ships.

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NOMENCLATURE

a	radius of vortex core
b	half the distance between two parallel vortices
d	half the distance between two vortex pairs
D_E	drag induced by a pair of vortices (energy expression)
D_v	drag induced by a pair of vortices (Lagally expression)
D_s	reference drag
h	maximum thickness of the ogive
L	length of the ogive
R_c	radius of curvature at the bilge
U	mean-flow velocity
w	velocity component in the vertical direction
Γ	circulation
ρ	fluid density

Influence of the Radius of Curvature on the Drag Induced by Bilge Vortices

Introduction

In a previous report [1]* experimental results were obtained on the formation and development of vortices generated at the bilge of an ogive with infinite bilge curvature. It was then suggested to study the influence of increasing bilge radius on the generation of the vortices and on the induced vortex-drag. The results of such a study are reported herein.

Experiments and Results

Using the experimental setup already described in the first report, the measurements of the total head and of the velocity vector components have been performed in a transverse plane at the stern of the ogive for a range of radius of curvature at the bilge from 0 to 3/4 inches, in increments of 1/4 inch. The measurements were taken using a five-hole probe and a hot-wire anemometer. In the previous report the results obtained by the two methods were in poor agreement and no reasonable explanation for the discrepancy could be given at the time. Since then it has been found that one connection between a manometer and the top hole of the five-hole probe was faulty, thus resulting in an incorrect determination of the z-component w of the velocity vector. After improving the different connections the two methods of measurements gave results in fair agreement as will be shown.

The results of the total-head measurements are shown in Figs 2 to 5 as lines of constant ratio of the local total head H to the total head H_0 of the mean flow. Using the calibration curve shown in Fig. 1, the velocity components at numerous points of the transverse plane at the stern, were determined and are presented in Figs. 6 to 9. These results are in very good agreement with those obtained with the hot-wire anemometer which are presented in Figs. 10 to 13. The size of the bilge vortex appears to decrease rapidly as soon as the bilge curvature decreases from an infinite

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*Numbers in [] refer to references at the end of this report.

value to a finite one. As the radius of curvature is further increased the size of the vortex continues to decrease, but less rapidly. As it can be expected, the strength of the vortex follows the same trend. This fact is illustrated by the variation of the circulation presented in Fig. 14 and in the following table, together with the geometric characteristics a, b, and d, of the vortex, where a is the radius of the vortex core, b half the distance between two parallel vortices and d half the distance between two vortex pairs.

R_c in inches	Γ/UL Hot-Wire Anemometer	a in ft.	b in ft.	d in ft.	Γ/UL 5-Hole Probe
0	0.0273	0.050	0.100	0.173	0.0187
1/4	0.0170	0.050	0.075	0.180	0.0168
1/2	0.0120	0.025	0.050	0.155	0.0138
3/4	0.0092	0.0125	0.0375	0.158	0.0113

Table 1. Circulation and Geometric Characteristics of the Bilge Vortex as a Function of the Radius of Curvature

Determination of Vortex Drag

The drag due to the pair of vortices is given by the expression derived in [1] for the energy per unit length of a pair of vortices

$$D_E = \frac{\rho\Gamma^2}{2\pi}\left\{\frac{1}{4} + \ell_n\left(\frac{b}{a} + \sqrt{\frac{b^2}{a^2} - 1}\right) + \frac{1}{2}\,\ell_n\,\frac{\left(-\frac{b}{a} + 1 + \sqrt{\frac{b^2}{a^2} - 1}\right)^2 + 4\,\frac{d^2}{a^2}}{\left(\frac{b}{a} - 1 + \sqrt{\frac{b^2}{a^2} - 1}\right)^2 + 4\,\frac{d^2}{a^2}}\right\}$$

and the equation derived by Echávez and already mentioned in the previous report, using the Lagally theorem, [2]

$$D_v = \frac{\rho\Gamma^2}{2\pi}\left\{\ell_n\left(\frac{2b}{a} - 1\right) + \frac{1}{4}\right\}$$

The drag was computed using the values of the circulation obtained with the hot-wire anemometer for we had then a complete set of reliable data. The results of the computations are given in the following table and are plotted versus the radius of curvature in Fig. 15.

R_c in inches	D_E lb	D_v lb	D_E/D_s	D_v/D_s
0	$1.19\ 10^{-2}$	$1.07\ 10^{-2}$	0.140	0.126
1/4	$0.36\ 10^{-2}$	$0.29\ 10^{-2}$	0.042	0.034
1/2	$0.24\ 10^{-2}$	$0.27\ 10^{-2}$	0.028	0.025
3/4	$0.18\ 10^{-2}$	$0.17\ 10^{-2}$	0.021	0.020

Table 2. Variations of the Vortex Drag as a Function of the Radius of Curvature

The reference drag D_s used for comparison is the surface drag of the ogive at the same Reynolds number.

The vortical drag, since it is proportional to the square of the circulation, exhibits a very sharp drop when the radius of curvature is slightly increased. The final value obtained for the higher radius investigated is of the order of 2 percent of the surface drag as compared to the value of 14 percent for an infinite bilge curvature ($R_c = 0$).

Conclusion

Ship forms usually have a greater ratio of the radius of curvature at the bilge to the maximum thickness of the hull than the higher value of the range investigated here. Therefore, the vortical drag can be expected to be less than 1 or 2 percent of the surface drag, and its contribution to the resistance encountered by ships in motion can then be neglected if the accuracy of the measurements is no better than one percent.

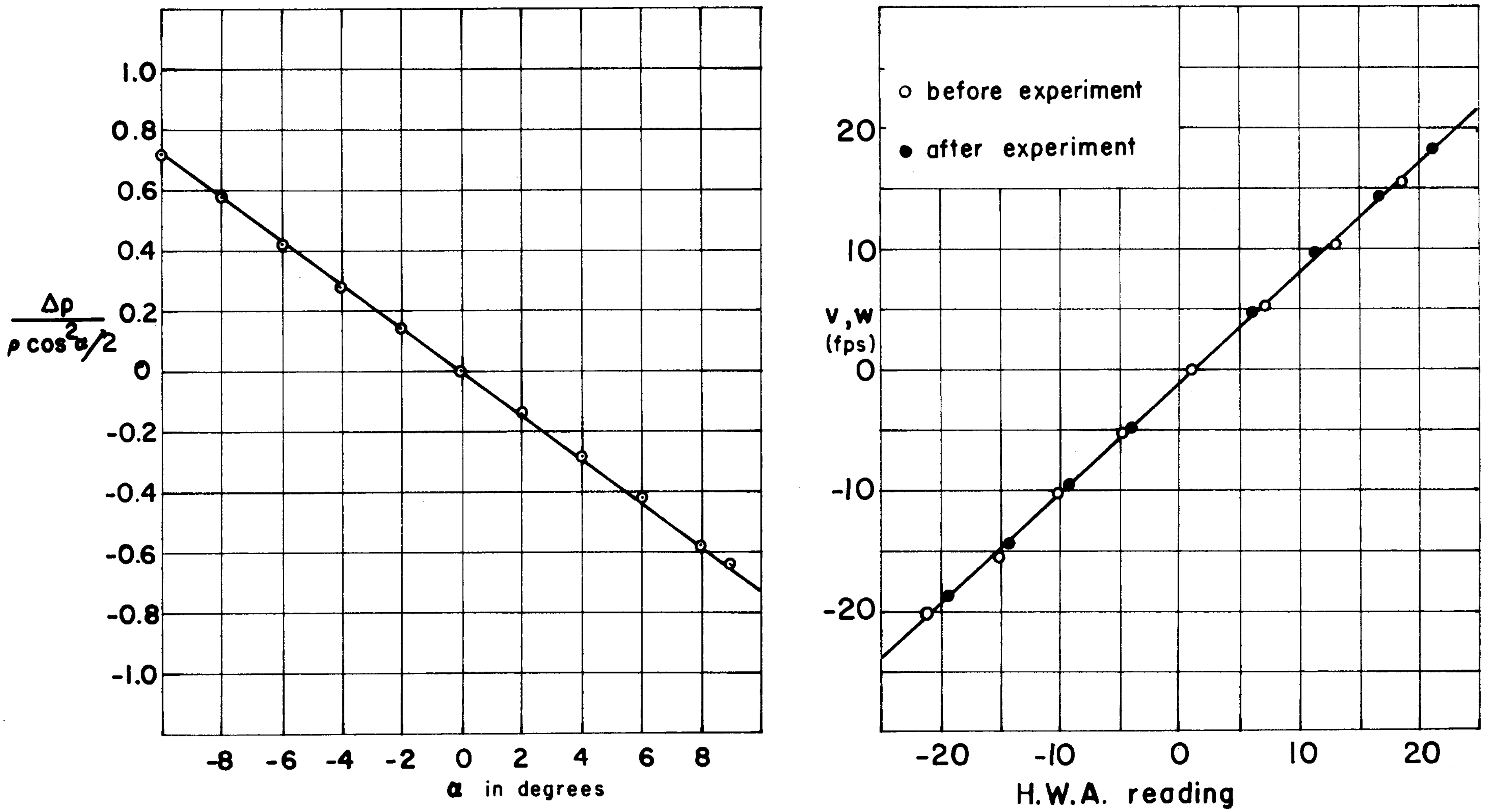

Fig. 1. Calibration Curves for the Five-Hole Probe and the Hot Wire Anemometer

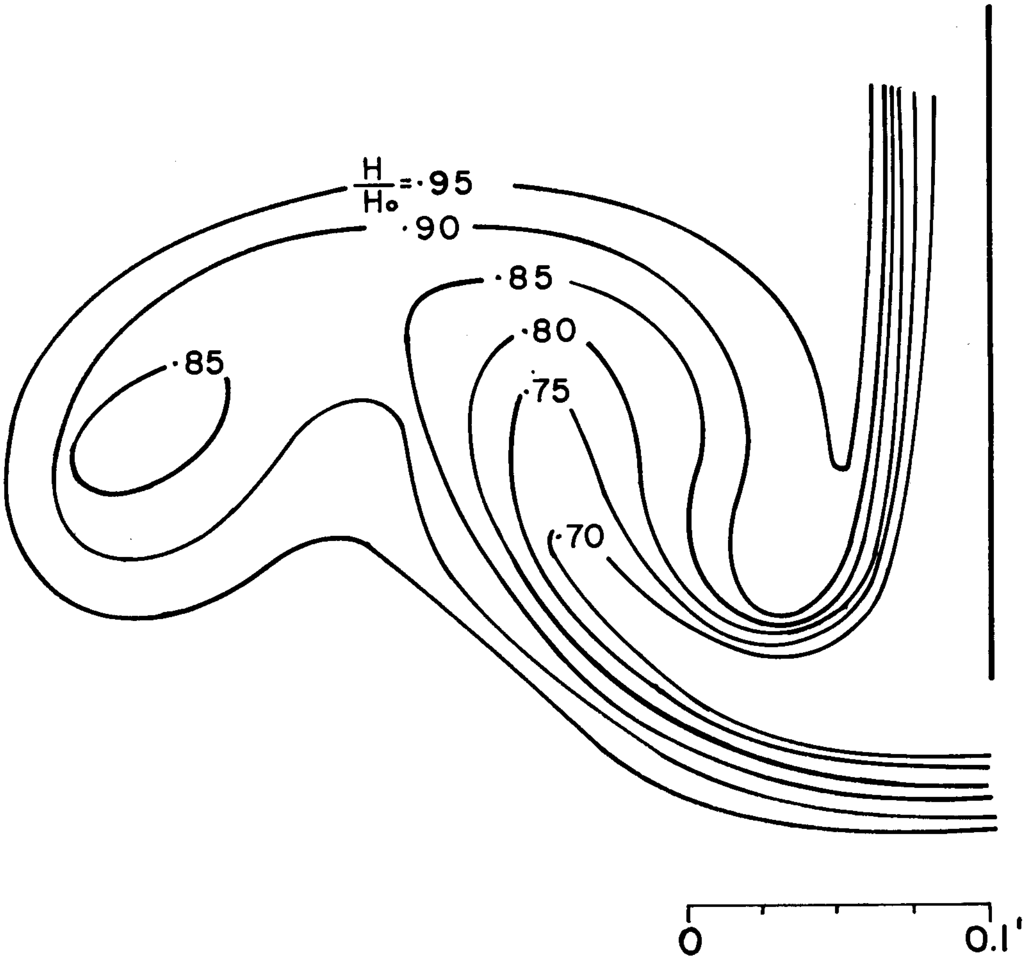

Fig. 2. Lines of Equal Total Head in a Normal Plane at the Stern (R_c = 0)

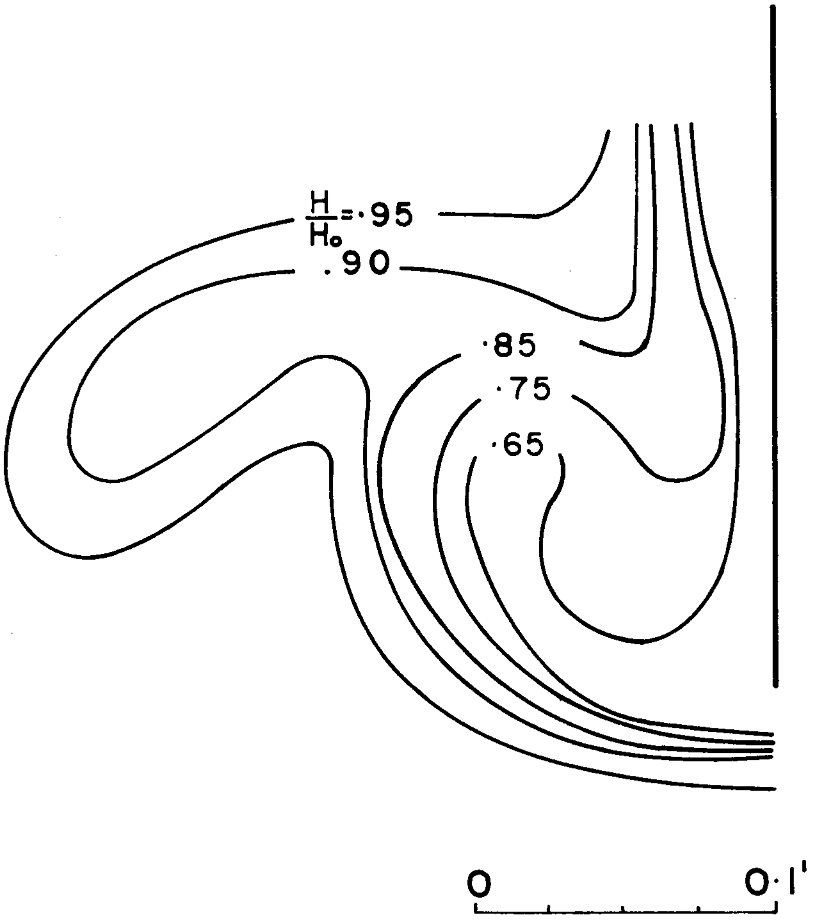

Fig. 3. Lines of Equal Total Head in a Normal Plane at the Stern (R_c = 1/4")

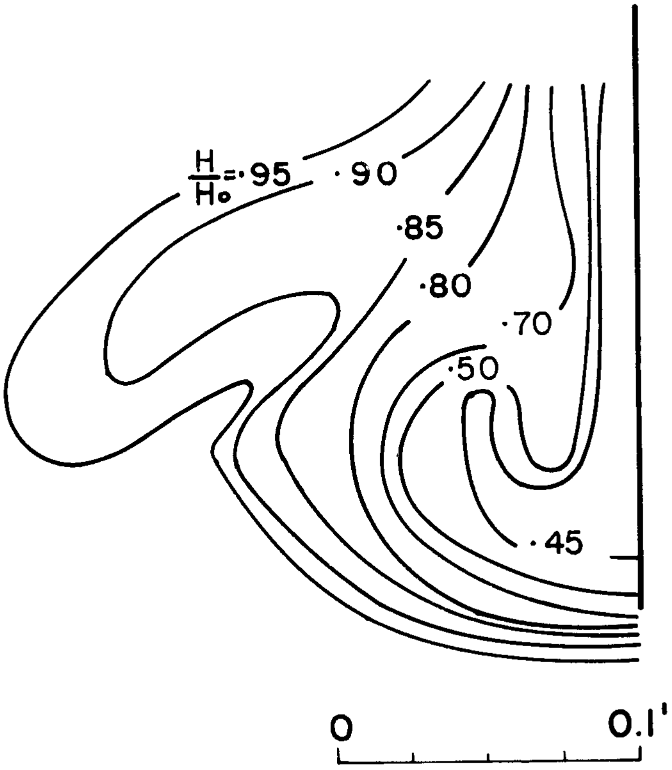

Fig. 4. Lines of Equal Total Head in a Normal Plane at the Stern (R_c = 1/2")

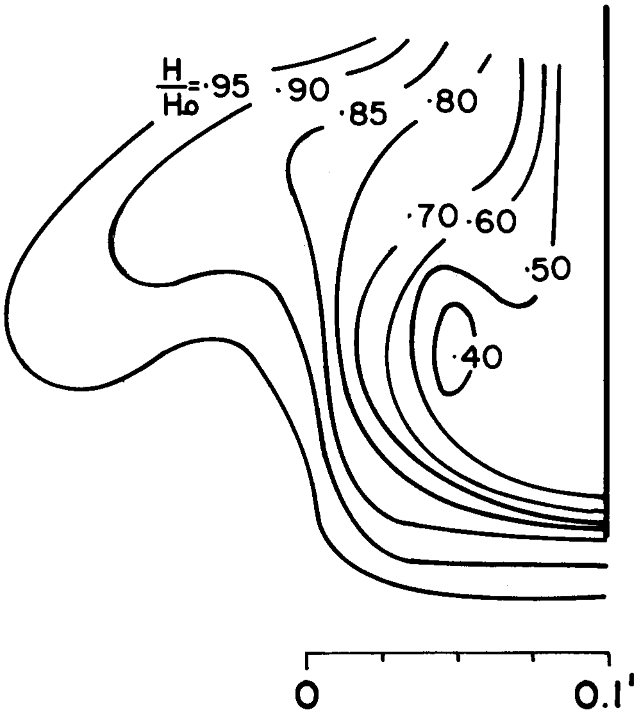

Fig. 5. Lines of Equal Total Head in a Normal Plane at the Stern (R_c = 3/4")

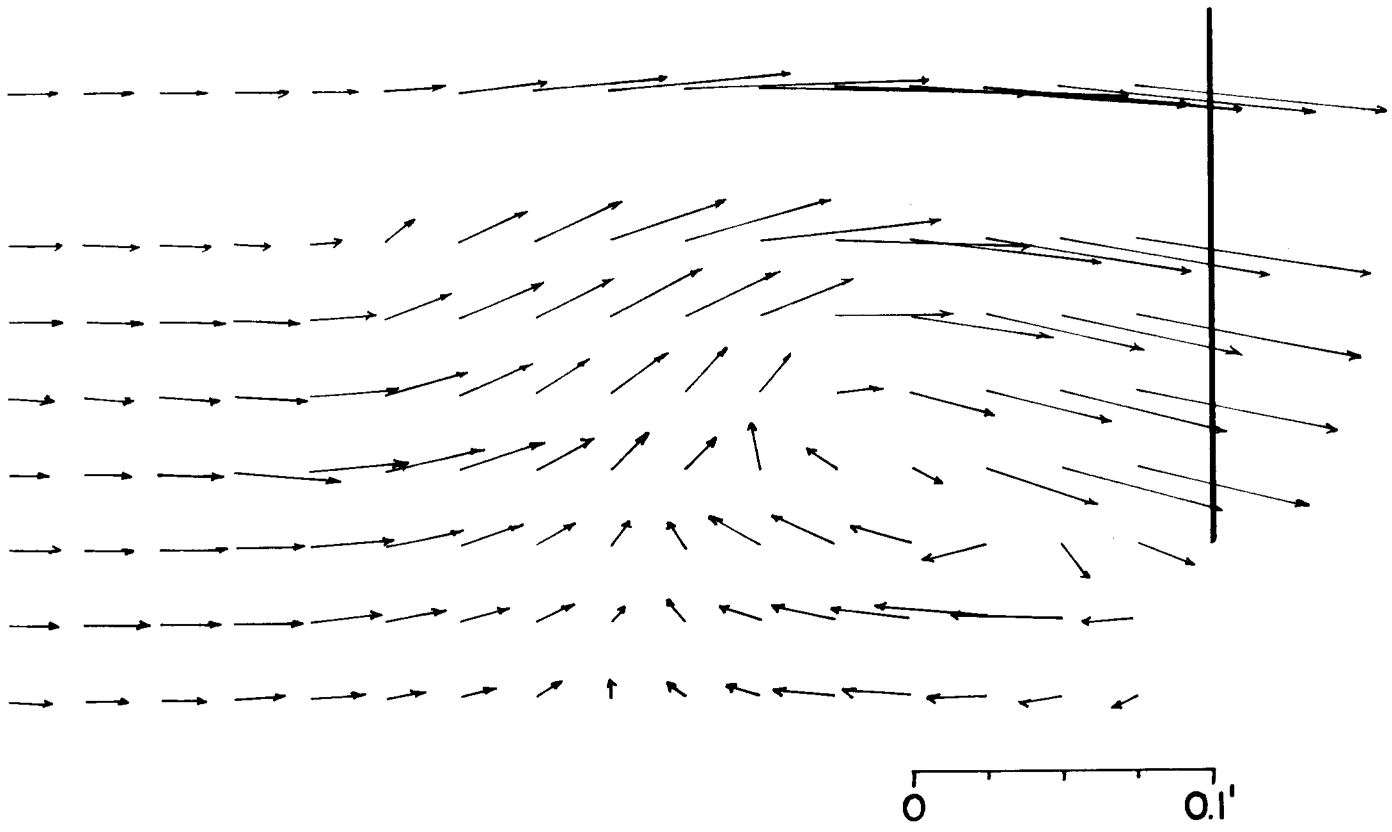

Fig. 6. Secondary Flow in a Normal Plane at the Stern for $R_c = 0$
(Five-Hole Probe)

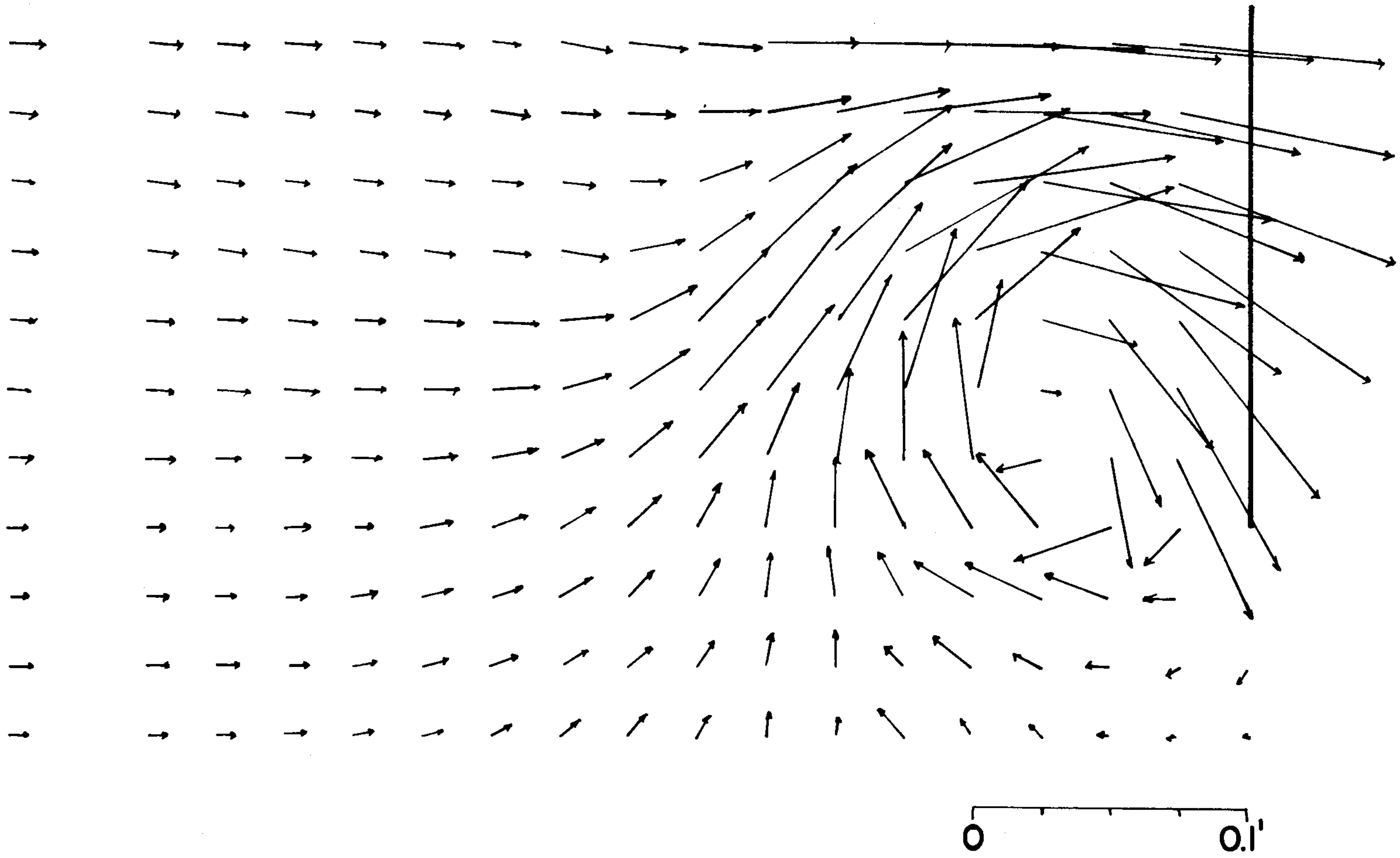

Fig. 7. Secondary Flow in a Normal Plane at the Stern for $R_c = 1/4''$

(Five-Hole Probe)

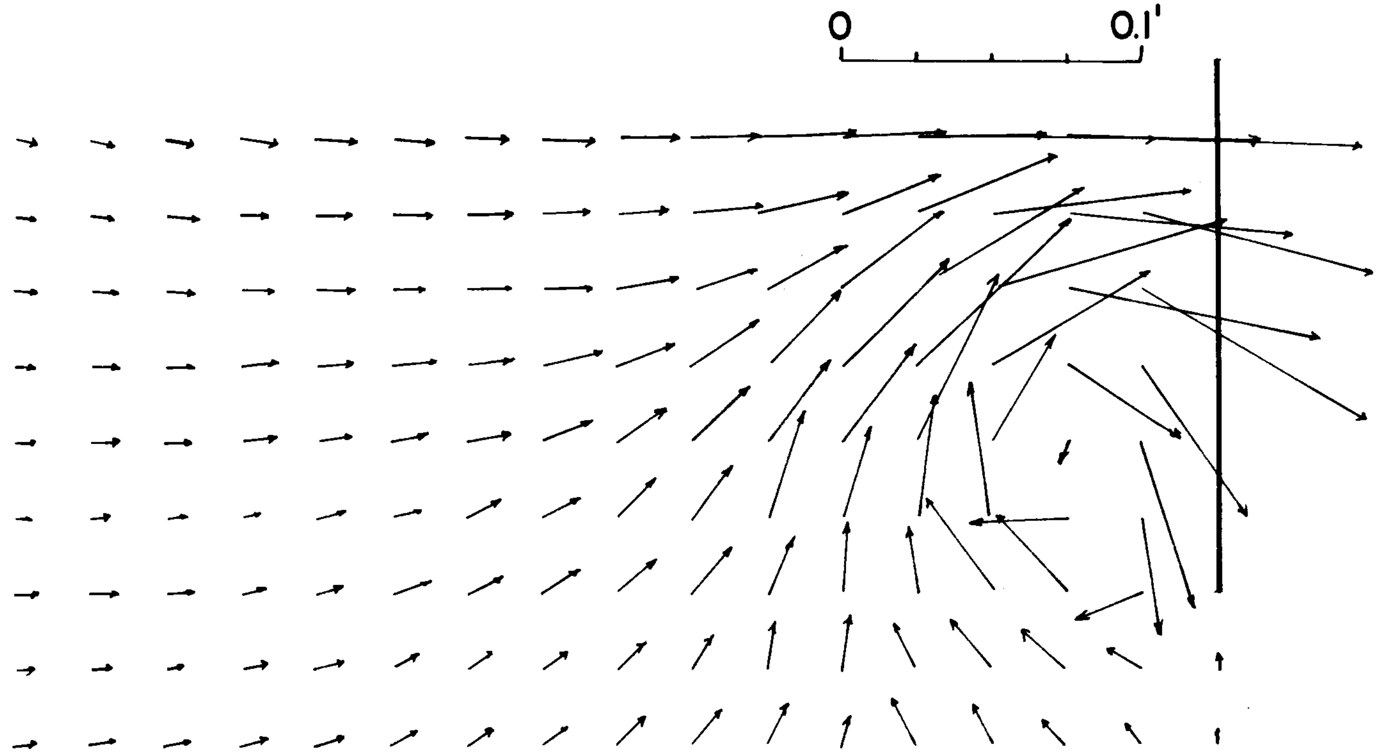

Fig. 8. Secondary Flow in a Normal Plane at the Stern for $R_c = 1/2''$
(Five-Hole Probe)

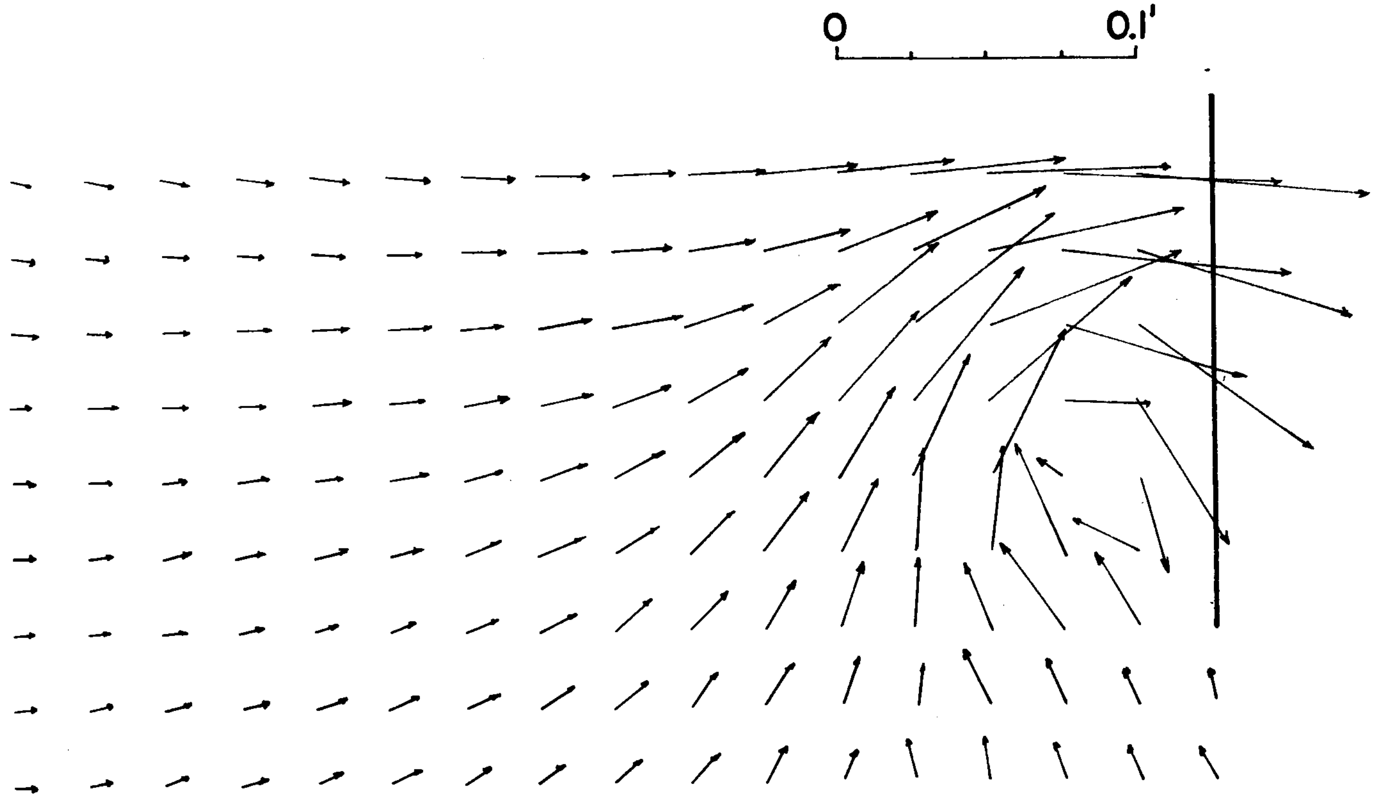

Fig. 9. Secondary Flow in a Normal Plane at the Stern for $R_c = 3/4''$
(Five-Hole Probe)

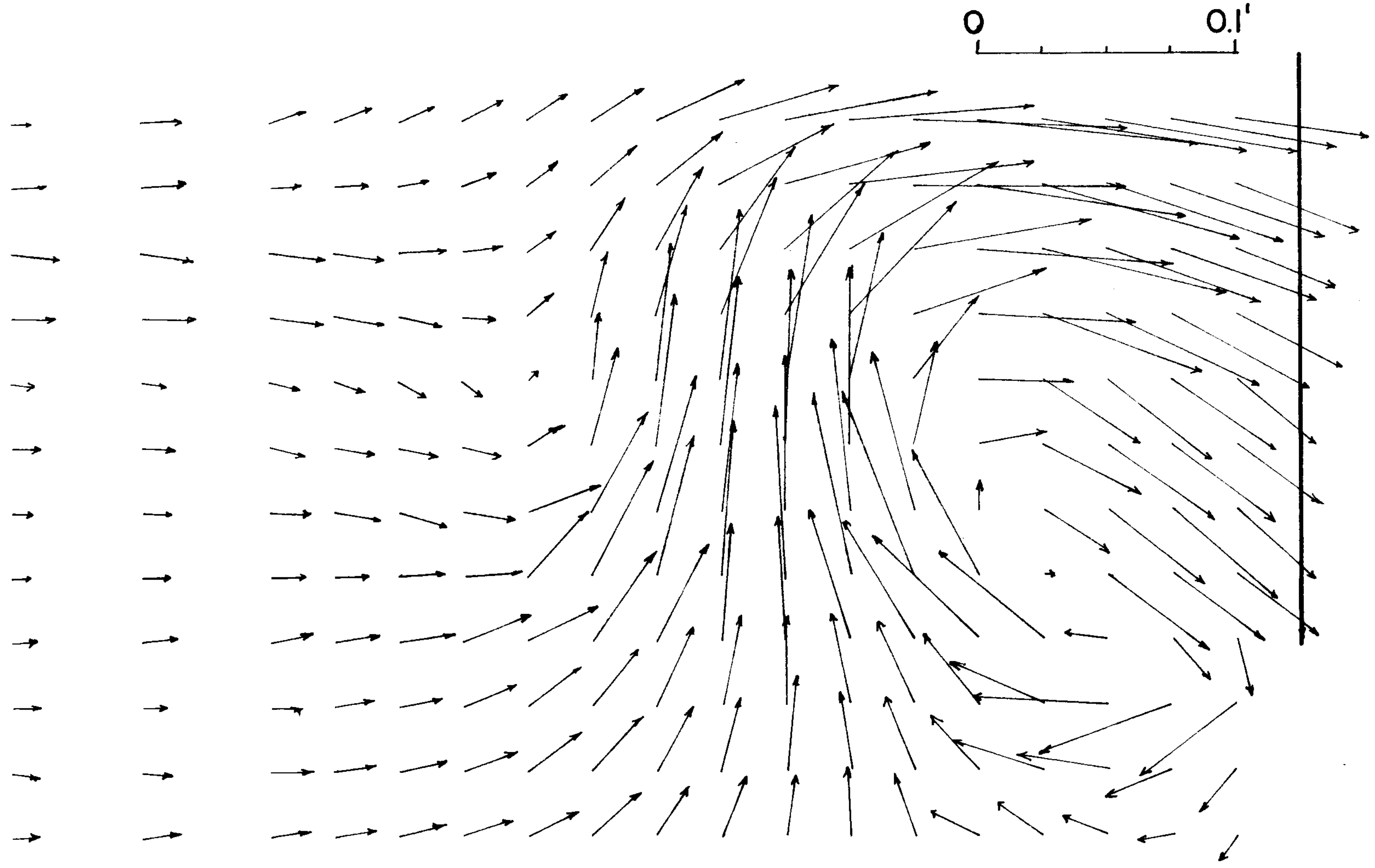

Fig. 10. Secondary Flow in a Normal Plane at the Stern for $R_c = 0$
(Hot Wire Anemometer)

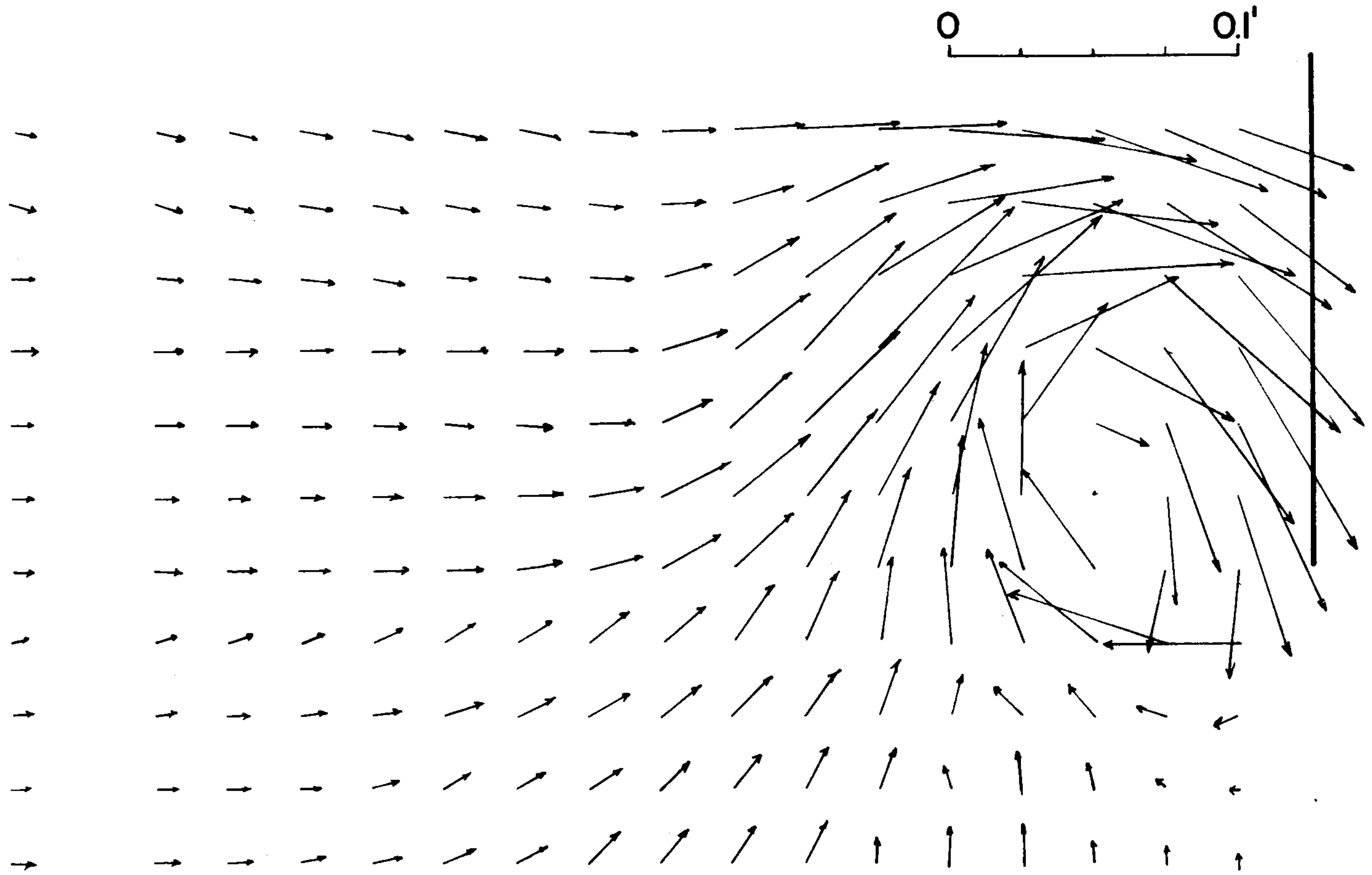

Fig. 11. Secondary Flow in a Normal Plane at the Stern for $R_c = 1/4"$ (Hot Wire Anemometer)

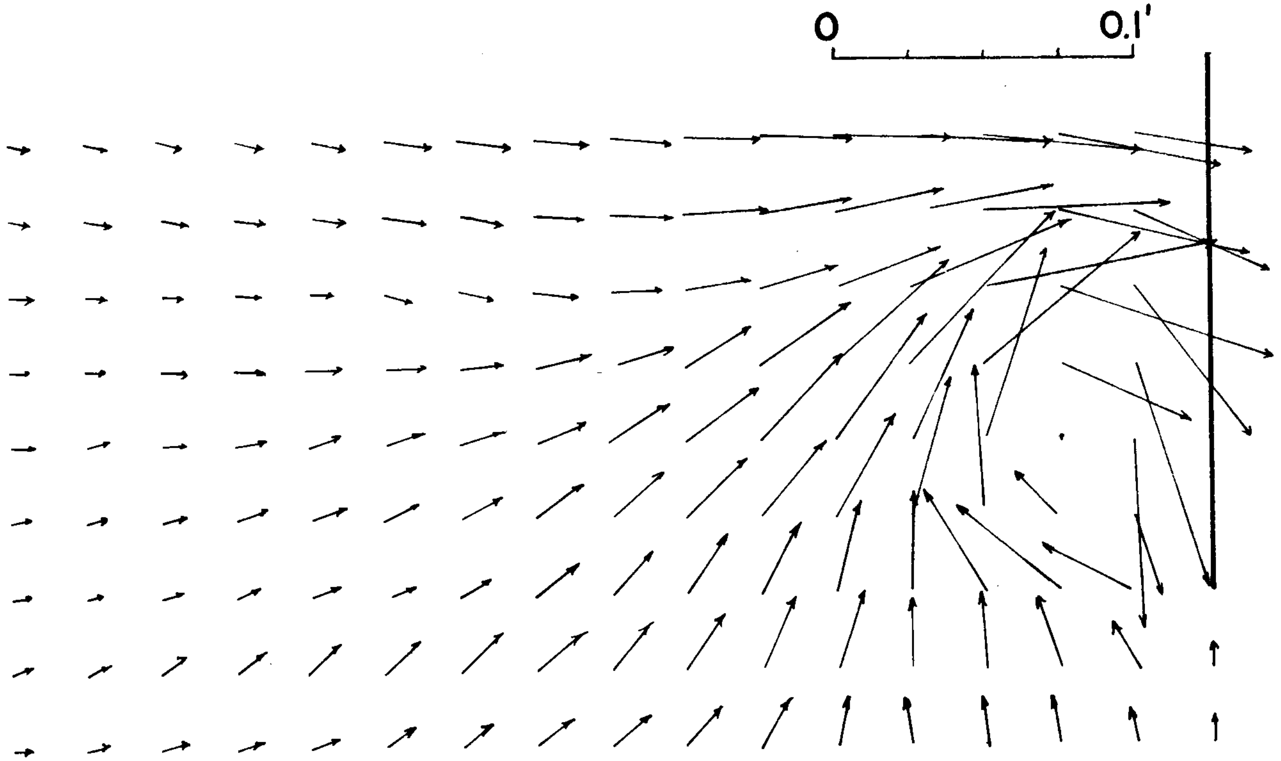

Fig.12. Secondary Flow in a Normal Plane at the Stern for $R_c = 1/2''$
(Hot Wire Anemometer)

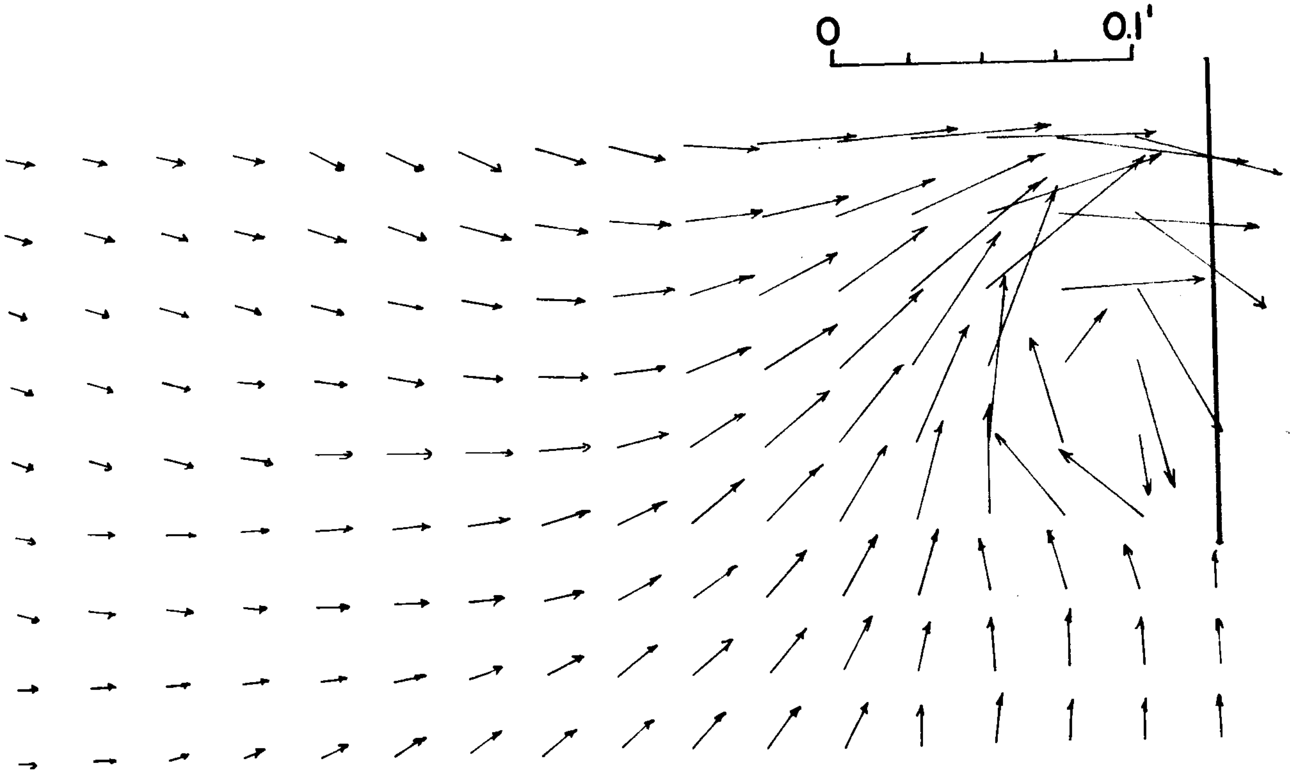

Fig. 13. Secondary Flow in a Normal Plane at the Stern for $R_c = 3/4''$

(Hot Wire Anemometer)

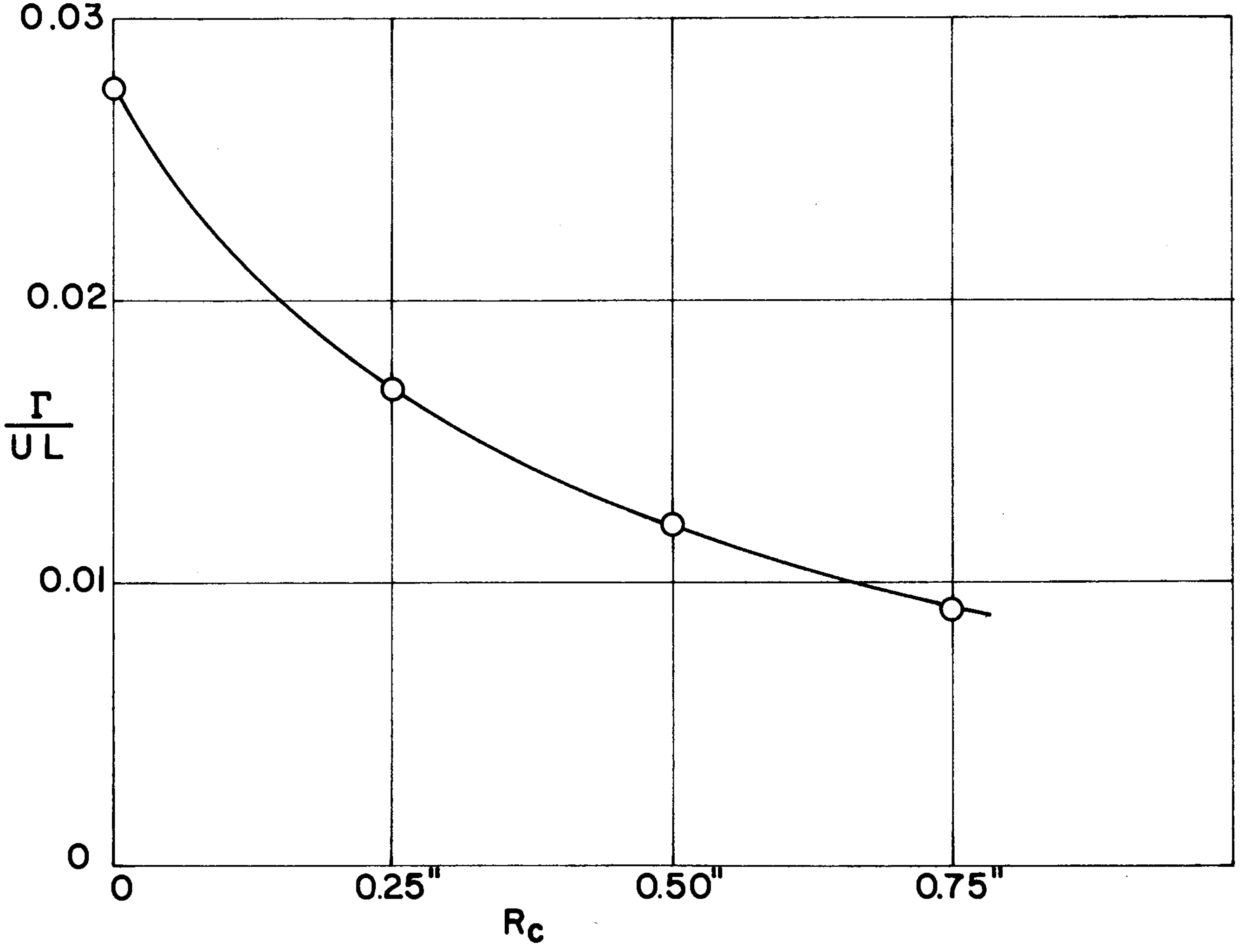

Fig. 14. Variation of the Circulation as a Function of the Radius of Curvature

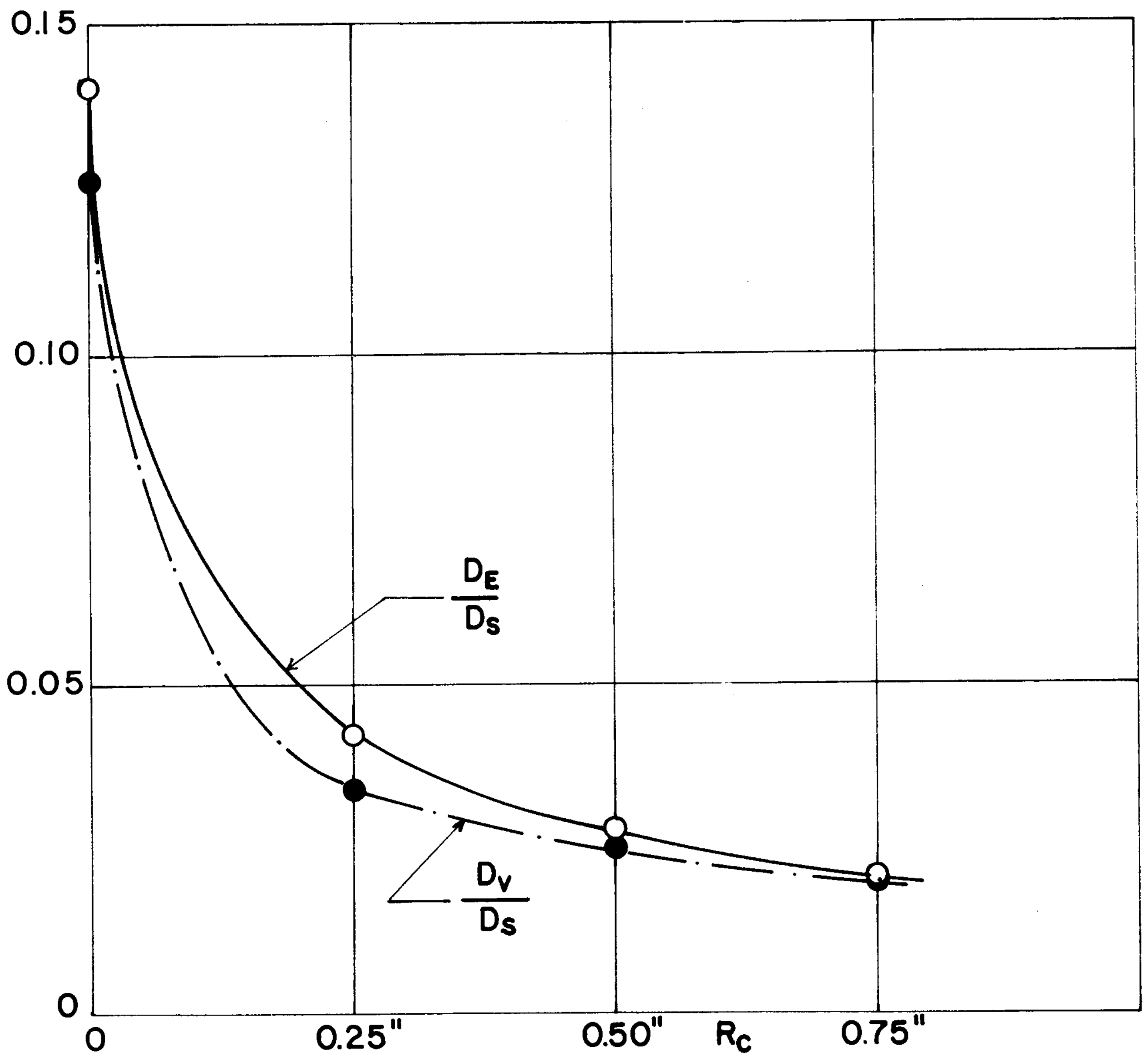

Fig.15. Variation of the Vortical Drag as a Function of the Radius of Curvature

References

[1] J. C. Tatinclaux, "Experimental and Analytical Determination of the Induced Drag Due to Bilge Vortices," I.I.H.R. Progress Report to D.T.M.B., November 1966.

[2] G. Echávez, "Induced Drag Due to Bilge Vortices," M. S. Thesis, University of Iowa, Iowa City, Iowa, February 1966.

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