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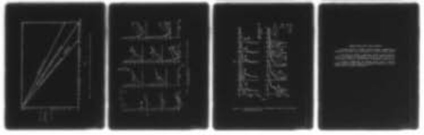

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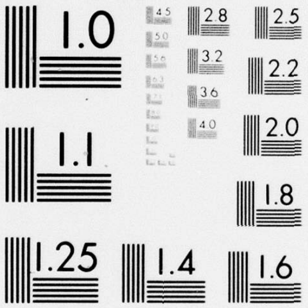

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A NOTE ON THE DECAY OF BODY-INDUCED HYDRODYNAMIC DISTURBANCES IN A TOWING TANK

by

Ming-Shun Chang

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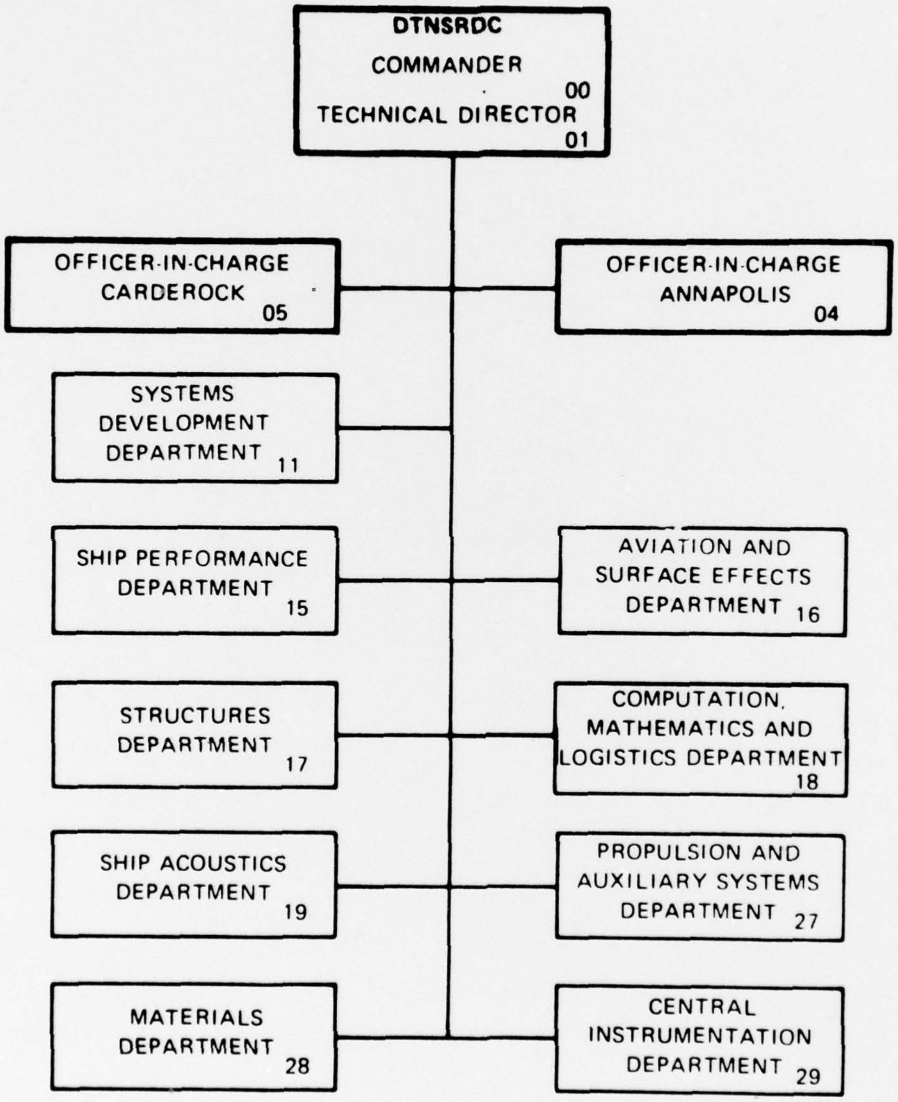

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The decay characteristics of disturbances generated from towing an axisymmetric body in a towing tank are estimated. The intensities of the mean velocity defect in a turbulent wake, wake turbulence, and a turbulent two-dimensional line vortex are estimated to be respectively of the order of 10^{-2} x U and 10^{-3} x U at 32 and 320 seconds, after the passage of a body which is 20 inches (50 cm) in diameter and towed at U = 50 ft/sec (15 m/s). Sample calculations of the influence of flow disturbances in altering the body's axisymmetric pressure distribution are included.

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ABSTRACT

The decay characteristics of disturbances generated from towing an axisymmetric body in a towing tank are estimated. The intensities of the mean velocity defect in a turbulent wake, wake turbulence, and a turbulent two-dimensional line vortex are estimated to be respectively of the order of $10^{-2} \times U$ and $10^{-3} \times U$ at 32 and 320 seconds, after the passage of a body which is 20 inches (50 cm) in diameter and towed at $U = 50$ ft/sec (15 m/s). Sample calculations of the influence of flow disturbances in altering the body's axisymmetric pressure distribution are included.

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A NOTE ON THE DECAY OF BODY-INDUCED HYDRODYNAMIC DISTURBANCES IN A TOWING TANK

When a sequence of tests is conducted in a towing tank, the hydrodynamic disturbances generated in previous runs may remain above a significant level and affect the characteristics of the phenomena undergoing observation. The magnitudes of the disturbances depend on the physics of the observed phenomena and the characteristics of the disturbances themselves. Since some of the hydrodynamic phenomena under investigation in the DTNSRDC towing tanks could be sensitive to seemingly small perturbations in the water, an attempt has been made to estimate the decay characteristics of the disturbances generated from towing an axisymmetric body. The estimates presented in the following are the intensities and the radii of the mean velocity defect in a turbulent wake, wake turbulence, and a turbulent two-dimensional line vortex.

The decays of turbulent-flow disturbances are usually approximated by power laws[1] which may be derived from Prandtl's mixing length hypothesis. The proper power associated with a specific type of disturbance must be experimentally determined.[2] The appropriate power law in the region of turbulence generation depends upon the generating mechanics. However, in the far field or for large times, the appropriate power law for a given type of disturbance should be the same regardless of the differences in the origin of the turbulence. Following the above hypothesis, body-induced towing-tank disturbances will be estimated from existing empirical information appropriate to deeply-submerged axisymmetric bodies.

The decay laws for the mean velocity defect in a turbulent wake, turbulence and a turbulent two-dimensional line vortex in an infinite fluid are summarized in reference 3. They can be written in similarity forms as:

(1) Maximum mean velocity defect, U_1, and associated wake radius, r, are given by:

$$U_1/U = (\pi C_D D^2/4\beta^2 X^2)^{1/3} \qquad (1)$$

$$r/D = 3(\pi C_D \beta X/4D)^{1/3} \qquad (2)$$

where D is diameter of the body,

C_D is body drag coefficient based on maximum cross-section area,

β is a constant,

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1. Schlichting, H., Boundary-Layer Theory, McGraw-Hill, New York (1960).

2. Townsend, A.A., The Structure of Turbulent Shear Flow, Cambridge University Press, London (1956).

3. Tennekes, H. and J.L. Lumley, A First Course in Turbulence, MIT Press, Cambridge, MA (1972).

x is distance aft of the body,
U is body speed.

(2) Maximum turbulence intensity $\overline{q^2}$ in the wake, and associated wake radius, r_q, are given by:

$$\overline{q^2}/U^2 = C_0 (D/x)^{5/3} \tag{3}$$

$$r_q/D = C_1 (x/D)^{1/3} \tag{4}$$

(3) Maximum rotational velocity, V_1, of a turbulent two-dimensional vortex in a turbulent wake, and the associated radius, r_1, are given by:

$$V_1/D = 0.065 (\Gamma/\nu)^{3/4} (R_e)^{-1/2} (D/x)^{1/2} \tag{5}$$

$$r_1/D = 3 (\Gamma/\nu)^{1/4} (R_e)^{-1/2} (x/D)^{1/2} \tag{6}$$

where Re is Reynolds number with respect to body diameter D, the C's are constants, Γ is vortex circulation strength, and ν is kinematic viscosity.

The above power laws are expressed in terms of nondimensional distance x/D. This may be replaced by the nondimensional parameter Ut/D when one evaluates the decay of disturbances at a fixed location as a function of time. For a model with D = 20 inches (50 cm) towed at speeds of U = 40 to 80 ft/sec (12 to 24 m/s), this nondimensional parameter ranges from 10^3 to 2×10^3 at t = 50 sec and from 10^3 to 2×10^4 at t = 500 sec. Graphically, the power laws as a function of time are shown in Figures 1 and 2. The parameters plotted are the ratios of the disturbances to those at some given initial time t_o. It is seen from Figures 1 and 2 that the maximum rotational velocity of a vortex is reduced by an order of magnitude at $t=100t_o$, while its radius has grown to an order of magnitude larger. During the same time period, the mean velocity defect and wake turbulence respectively undergo about 50-percent and 80-percent greater reduction in intensity.

In estimating the decay rate of the disturbances in a finite region such as in a towing tank, the above power laws may be applied only up to times for which the dimensions of the disturbances are smaller than the dimensions of the tank. Beyond this region, modifications should be made to the estimated intensities of the disturbances, to account for the influence of the tank walls.

Table 1 lists disturbance estimates for a body having a diameter of 20 inches (50 cm) traveling at speeds of 40 to 80 ft/sec (12 to 24 m/s) at a submergence depth of 100 inches (2.5 m) along the center plane of a tank of 200-inch (5 m) depth and 240-inch (6 m) width. The results presented in Table 1 are calculated from the above equations only to times for which the radii of the disturbances are smaller than the dimensions of the tank. When the radii of the disturbances grow larger than the dimensions of the tank, imaginary disturbances have been added to the present calculation to insure that the flux of disturbances is zero at the wall. The constants in equations (1) through (6) are obtained from estimated disturbance radii and/or intensities at eight diameters downstream of the towed body. The initial radius of the mean velocity defects in the turbulent wake, r, and the radius of the wake turbulence are both estimated to be approximately 1 x D; the square of the initial intensity of the wake turbulence, $\overline{q^2}$, is taken to be $1.6 \times 10^{-4} \times U$ for $Ut/D = 8$. Estimation of the initial circulation strength of a vortex is not so straightforward, because the strength of the vortex depends very much on the angle of attack of the body and the local geometry of the towing strut. Theoretically, the angle of attack should be zero and no vortex should be generated. But, due to misalignments or inaccuracies in the construction of the strut, small angles of attack may be possible. The vortex strength estimated for the present calculations[4] corresponds to an angle of attack of approximately 0.3 degree; that is the circulation, Γ, is $\Gamma = 0.04 \times U$ in ft^2/sec for a strut of aspect ratio 1 and a span of approximately 5 feet (1.5 m). The drag coefficient used in calculating the velocity defect in a turbulent wake is taken to be 5×10^{-2}. Table 2 is similar to Table 1 except that it uses somewhat larger initial values of the disturbance radii at Ut/D = 8. It may be seen, by comparison of Table 2 with Table 1, that a twenty-percent change in the estimated initial radii of disturbances results in a change of less than a factor of two in the intensities of the disturbances at a later time. Thus, one can expect that the present estimates are of the correct order.

TABLE 1

Estimated Body-Induced Perturbations

	Velocity Defect		Turbulence		Vortex	
Ut/D	r/D	U_1/U	r_q/D	$\overline{q}^2/U^2$	r_1/D	V_1/U
10000	11	5.4×10^{-3}	11	1.9×10^{-7}	1.41	1.0×10^{-3}
2000	6.3	9.5×10^{-3}	6.3	1.7×10^{-6}	0.64	2.3×10^{-3}
1000	5.0	1.4×10^{-2}	5.0	5.0×10^{-6}	0.45	3.16×10^{-3}
8	1.0	3.5×10^{-1}	1.0	1.6×10^{-2}	0.041	3.5×10^{-2}

TABLE 2

Estimated Body - Induced Perturbations

Ut/D	r/D	U_1/U	r_q/D	$\overline{q}^2/U^2$	r_1/D	V_1/U
10000	12.8	3.6×10^{-3}	12.8	1.3×10^{-7}	1.77	2.0×10^{-3}
2000	7.5	7.6×10^{-3}	7.5	1.3×10^{-6}	0.80	4.6×10^{-3}
1000	6.0	1.1×10^{-2}	6.0	3.5×10^{-6}	0.56	6.3×10^{-3}
8	1.2	2.5×10^{-1}	1.2	1.0×10^{-2}	0.05	7.0×10^{-2}

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4. Kuethe, A.M. and J.D. Schetzer, Foundations of Aerodynamics, John Wiley and Sons, New York (1964).

The body-induced disturbances are expected to be of the order of 10^{-2} and 10^{-3} at 32 and 320 seconds, respectively, after passage of a 20-inch (50 cm) body which is towed at speeds of 50 ft/sec. The magnitudes of these estimated disturbances are small. Yet, their significance cannot be assessed in general. Since the importance of the disturbance is dependent upon the physics of the phenomena of interest, it is worth mentioning again that the estimates were calculated from the estimated initial disturbance radii at $Ut/D = 8$. The estimated initial values are considered conservative.

To demonstrate the application of the information obtained, an example is given of the influence of ambient velocity perturbations on the pressure distribution of an axisymmetric body. The computations were performed using a rather simplified theory[5] which represents velocity perturbations by a local two-dimensional vertical cross-flow jet. The computed distributions of the pressure coefficient, C_p, along two meridians, when a body passes through the two-dimensional jet, are presented in Figures 3 and 4 for a torpedo-like body and Reichardt body. For the present calculations, the width of the jet was chosen to be 1/30 of the body length and jet velocities were chosen: $0.10 \times U$, $0.07 \times U$, and $0.03 \times U$. Since the pressure distribution is not axisymmetric in the presence of a jet, the distributions of the pressure coefficients C_p are plotted for two meridians on the body surface; one on the upper side and one on the lower side of the body. These locations are shown in the insert diagrams in the figures, while the relative locations of the jet as a function of time are indicated by the figure by dots. The calculated results show that when the jet velocity is less than 3 percent of the forward speed, the effect of the jet is quite small. For a jet velocity which is 10 percent of the forward speed, the effect on pressure can be significant.

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[5] Chang, M.S. and P.C. Pien, "Hydrodynamic Forces on a Body Moving Beneath a Free Surface," First International Conference on Numerical Ship Hydrodynamics (1975).

Large-scale non-axisymmetric pressure perturbations on a body's surface could also be generated by body/strut-induced surface waves. Internal waves are not expected to be a problem because a towing tank is relatively shallow and the running time of a model is relatively small in comparison to the wave length and wave period of the internal waves. The magnitude of the perturbation has been estimated from potential theory[5] to be of order of 10^{-2} at the nose. This perturbation is independent of the time interval between the runs.

In conclusion, the body-induced velocity perturbations have been estimated to be small, on the order of 10^{-3} x U about five minutes after a body run at 50 ft/sec (15 m/s). With longer time intervals, such as an hour, residual perturbations will be reduced to intensity levels considerably less than 10^{-3} x U.

REFERENCES

1. Schlichting, H., Boundary-Layer Theory, McGraw-Hill, New York (1960).

2. Townsend, A.A., The Structure of Turbulent Shear Flow, Cambridge University Press, London (1956).

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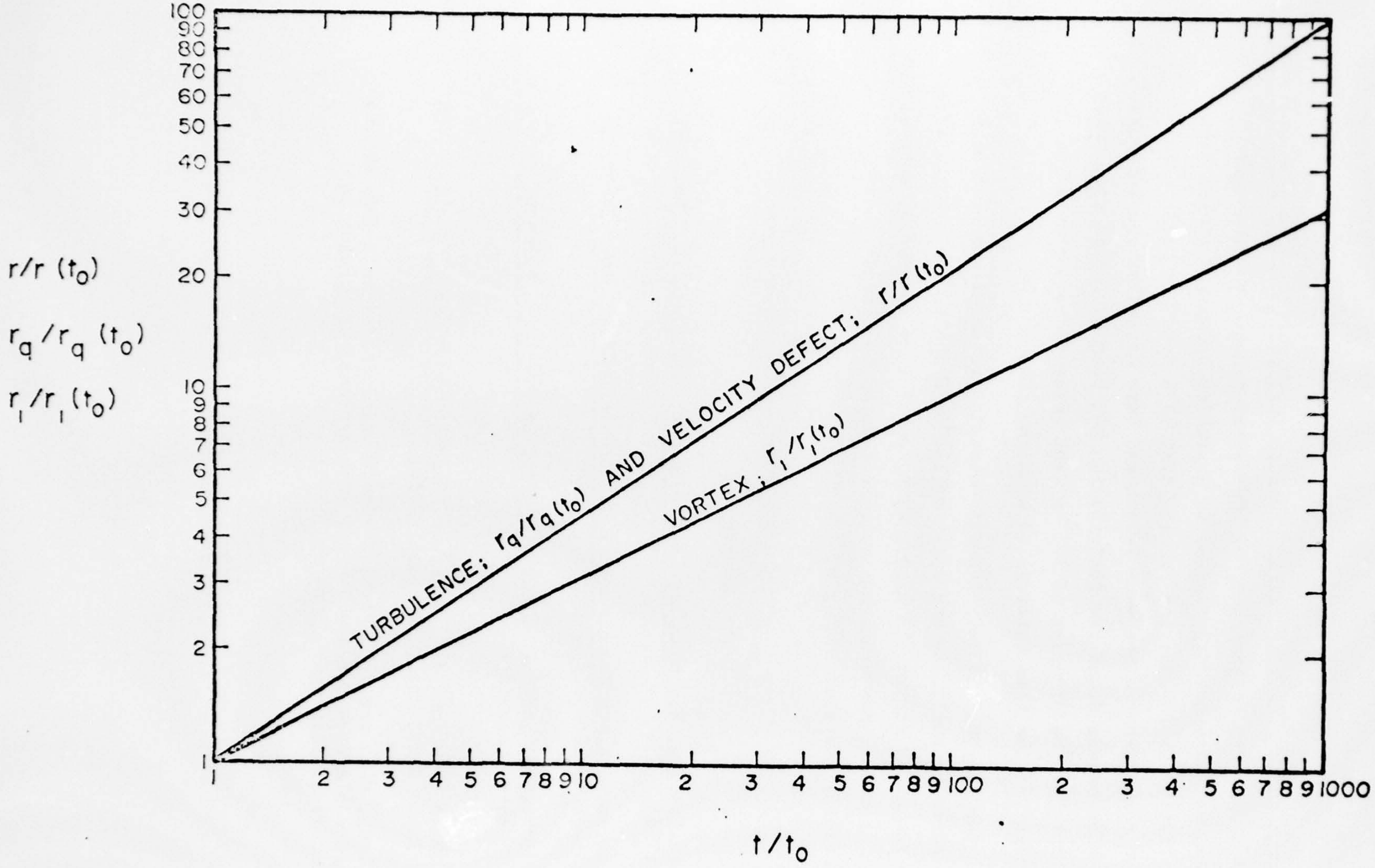

Figure 1 - Growth of the Size of Hydrodynamic Disturbance with Time

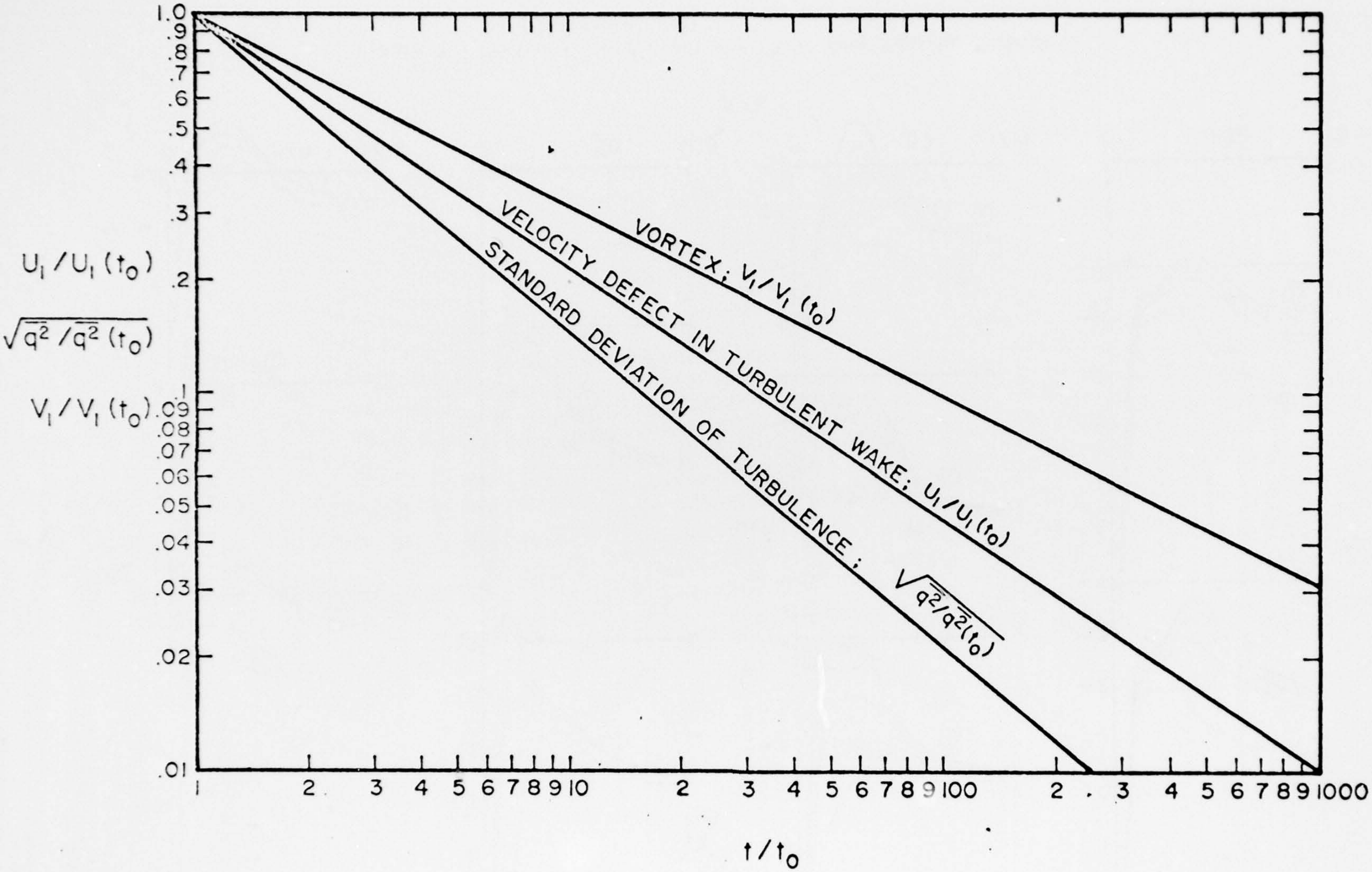

Figure 2 - Decay of the Intensity of Hydrodynamic Disturbance with Time

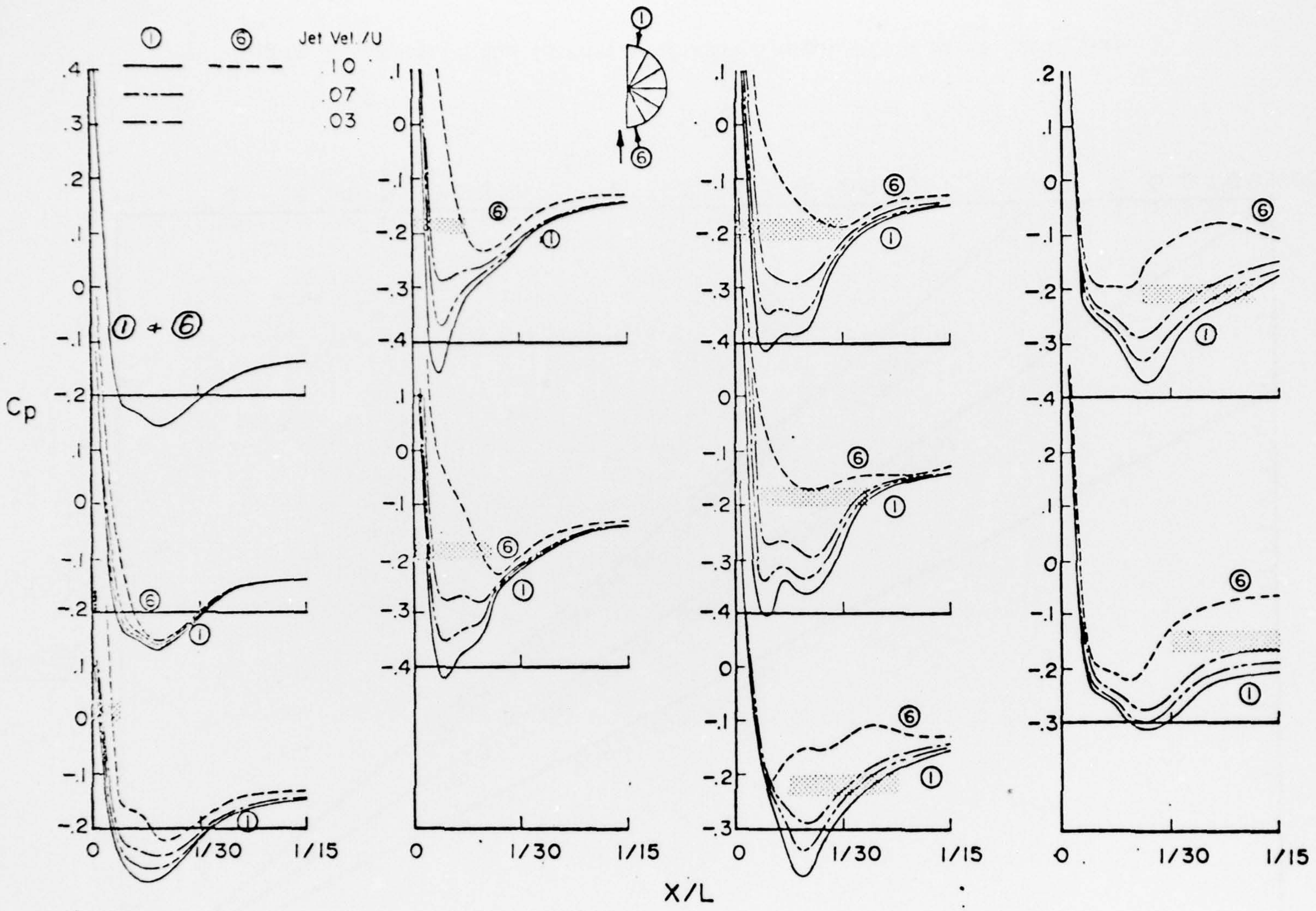

Figure 3 - Pressure Coefficient for "H-9" Body Passing Through a Two-Dimensional Jet

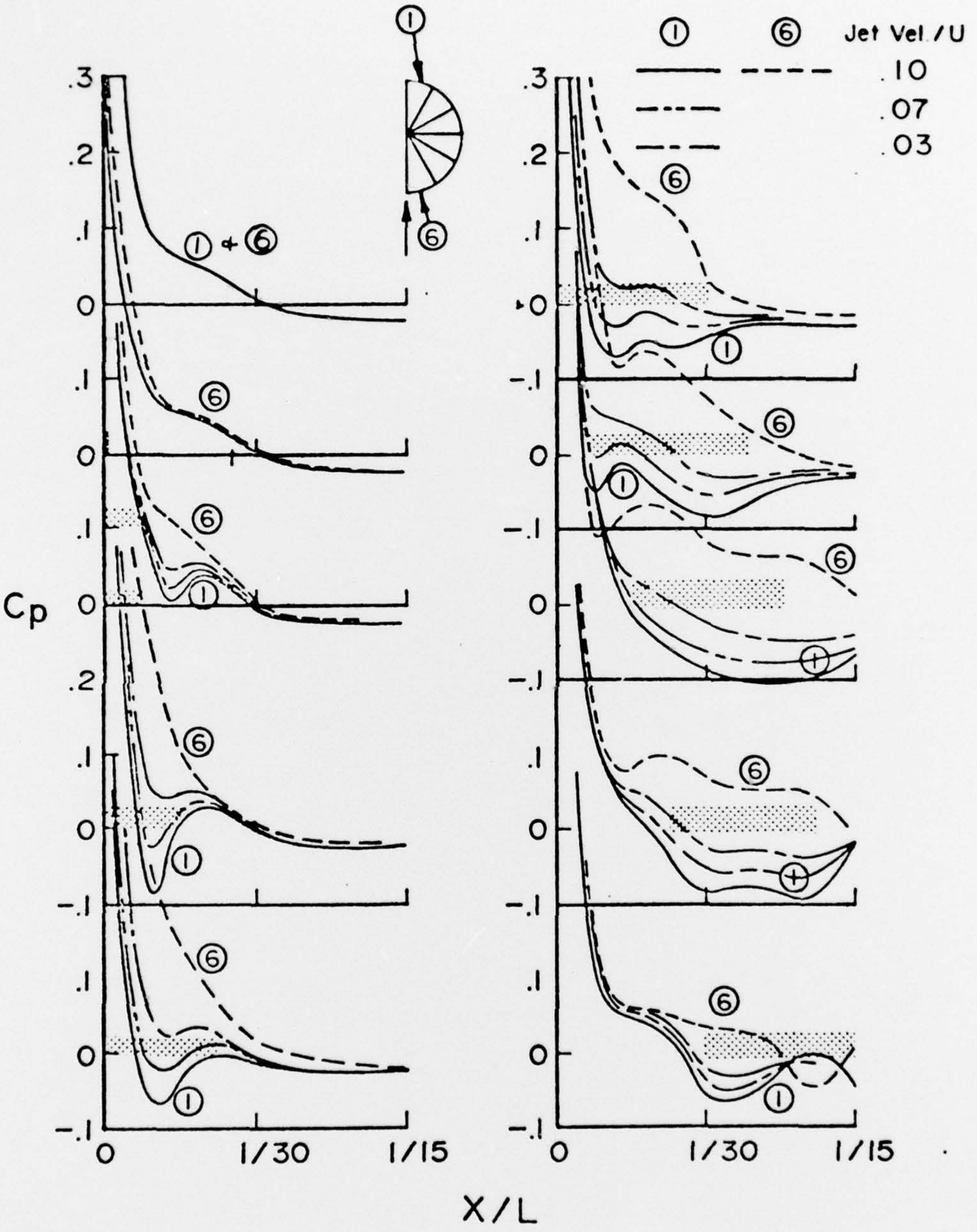

Figure 4 - Pressure Coefficieint for "Reichardt" Body Passing Through a Two-Dimensional Jet

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