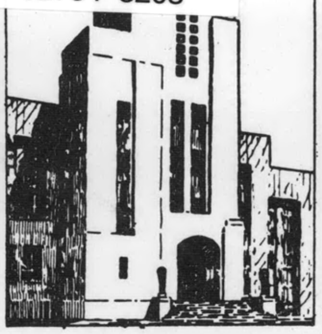

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# INDUCED VELOCITIES FORWARD AND AFT OF A PROPELLER

by

Mary Dickerson

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HYDROMECHANICS LABORATORY
RESEARCH AND DEVELOPMENT REPORT

March 1959

Report No. 1310

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# INDUCED VELOCITIES FORWARD AND AFT OF A PROPELLER

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Mary Dickerson

March 1959 Report No. 1310

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# NOTATION

| | |
|---|---|
| $b_{0.7}$ | Blade section length at 0.70 radius |
| D | Diameter of propeller |
| $f_a$ | Average factor |
| G | Nondimensional bound circulation of one blade |
| $g_a$ | Distance factor |
| J | Speed coefficient, $J = \frac{V}{n \cdot D}$ |
| $K_t$ | Thrust coefficient, $K_t = \frac{T}{\rho \cdot n^2 \cdot D^4}$ |
| n | Revolutions per unit time |
| P | Pitch of propeller at 0.70 radius |
| R | Propeller radius |
| r | Radial co-ordinate |
| $R_e$ | Reynolds number, $R_e = \frac{b_{0.7}\sqrt{V^2 + (0.7 \cdot \pi \cdot n \cdot D)^2}}{\nu}$ |
| T | Thrust |
| $U_a$ | Average axial component of induced velocity |
| $U_t$ | Average tangential component of induced velocity |
| V | Tunnel water speed |
| $W_a$ | Axial component of induced velocity at the lifting line |
| $W_t$ | Tangential component of induced velocity at the lifting line |
| x | $^r/R$ at the propeller |
| $x_h$ | Value of x at hub |
| Z | Number of blades |
| z | Axial co-ordinate distance from the propeller plane (Positive is forward of the propeller) |
| $\delta$ | Contraction ratio |
| $\mu$ | Variable of integration |
| $\nu$ | Kinematic viscosity |
| $\rho$ | Density of water |

# INDUCED VELOCITIES FORWARD AND AFT OF A PROPELLER

## ABSTRACT

This report gives the measured values of propeller induced velocities determined from a survey conducted in the 24-inch Water Tunnel. The axial and tangential components of the velocity were obtained at various radial and axial positions forward and aft of the propeller. Comparisons with theoretically computed values show, in general, good agreement.

## INTRODUCTION

A research program on the measurement of propeller induced velocities was initiated as part of the Fundamental Hydromechanics Research Program, motivated by need for information in two important areas:

1. Propeller-hull interaction, concerned with the prediction of mutually induced velocities and their effects.
2. Interaction effects between counterrotating propellers.

Considerable theoretical work has been done in this field,[1,2,3] but there was need for experimental corroboration. To supply this need a program was set up to study experimentally propeller induced flow. This report gives the results

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[1] References are listed on page 28

of tests designed to get experimental data on velocities induced by a propeller of known design and compares these values with values derived from theoretical calculations.

## INSTRUMENTATION

The velocity survey was conducted with a model of a propeller, (Propeller Number 3551*) in the 24-inch Water Tunnel. A 3-hole cylindrical pitot tube was used to determine the direction of flow and the magnitude of the relative velocities. This tube could be moved radially, axially and transversely as well as rotated about its own axis. Figures 1 and 2 show the arrangement for supporting and positioning the pitot tube and the relative sizes of pitot tube and propeller. The tunnel water speed was determined by means of a Prandtl tube located midway between the propeller tip and the tunnel jet boundary.

## PROCEDURE

The tests were conducted at a number of speed coefficients, J, (over and under propelled from the operating condition, $J = 0.842$) using a constant water velocity (12.9 ft/sec) and varying the rpm. These test conditions correspond to a Reynolds number variation from $2.6 \times 10^6$ to $1.9 \times 10^6$. Thrust measurements during the tests indicated a discrepancy of 8 - 10% lower than equivalent measurements of the same propeller operating in open water and are shown in Figure 3.

---

* Characteristics of Propeller 3551 are given in Figure 3

During the test the direction of the local flow velocity was obtained by rotating the cylindrical pitot tube until the pressures measured at the side holes were equalized and the resultant time average total pressure was determined from the central hole. This procedure was repeated at various radial and axial positions of the pitot tube, both ahead of and behind the propeller.

## RESULTS

The results are presented as a ratio of the axial ($U_a$) and tangential ($U_t$) components of the induced velocity to the total velocity (V) outside the slip stream. They are given in the form of curves (Figures 4 to 15, inclusive) showing the radial and axial distribution of velocities and the variation with propeller loading.

It will be noted from Figures 12 to 15, that experimental results could not be obtained in the vicinity of the propeller plane due to the interference of the pitot tube and the propeller.

The experimental results have been compared with theoretical computations[2,3,4] for two speed coefficients (J = 0.808 and 0.842). The formulas used for the calculations are given in the Appendix.

It should be noted that the nondimensional radial co-ordinate r/R refers to a radial distance from the propeller axis, independently of the contraction of the slip stream. A constant radial co-ordinate, therefore, is equivalent to a varying percentage of the propeller slip stream for various axial positions.

## DISCUSSION OF RESULTS

Comparison of the experimental and theoretical results for the axial and tangential induced velocities show, in general,good agreement. There are instances, however, particularly near the outer radii, where the absolute values do not quite agree although the distribution is similar. In order to minimize the possibility of differences resulting from local velocity variations which affect the propeller loading, the theoretically computed induced velocities have been corrected for the flow irregularities which exist in the 24" Water Tunnel. Although such corrections are somewhat approximate, they are of small magnitude.

It will be noted that the trends of theory and experiment are similar. For the axial induced velocity the results computed using Reference 2, indicate a much closer agreement forward of the propeller and near the propeller tip. However, the computed values using Reference 3 indicate a more correct trend aft of the propeller and near the propeller tip, particularly when they tend to decrease with increasing distance from the propeller plane (Figure 12).

The tangential induced velocities computed using References 2 and 3 are extremely close and, in general, agree well with the measured values.

It is difficult to determine at this time the relative merits of the theoretical computations, as a number of effects about which little is known may influence such results. Such effects include the blockage or tunnel wall effects and its effect on the actual radial distribution of loading, the effect of wide blades, the effect of finite number of blades which produce time dependent induced velocities while the measured velocities are averaged.

However, it is interesting to note that the ratio of axial to tangential components $(\frac{U_a}{U_t})$ as obtained experimentally show better agreement with theory than each individual component.

## CONCLUSIONS

In general, the experimentally measured velocities agreed with theoretical calculations. The trend of radial and axial distribution of velocities were similar. Forward of the propeller the values were in agreement, but aft of the propeller the experimental results were higher. Although the cause for this discrepancy is not completely understood, it is believed that as the tests were conducted in a water tunnel, there may have been blockage and wall effects. Further experimentation in open water is recommended to evaluate these effects in conjunction with a more detailed survey of velocities outside the slipstream, as well as an investigation of the average and instantaneous velocities inside the slipstream.

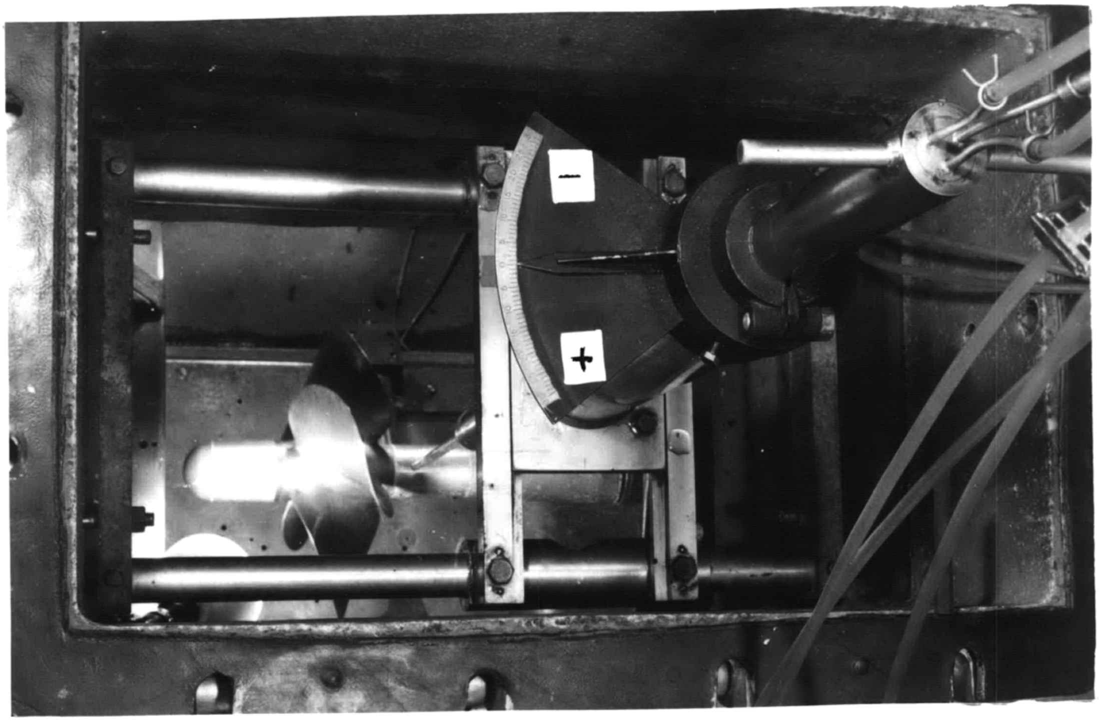

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Figure 1 - Photograph of Cylindrical Pitot Tube Assembly (Top View)

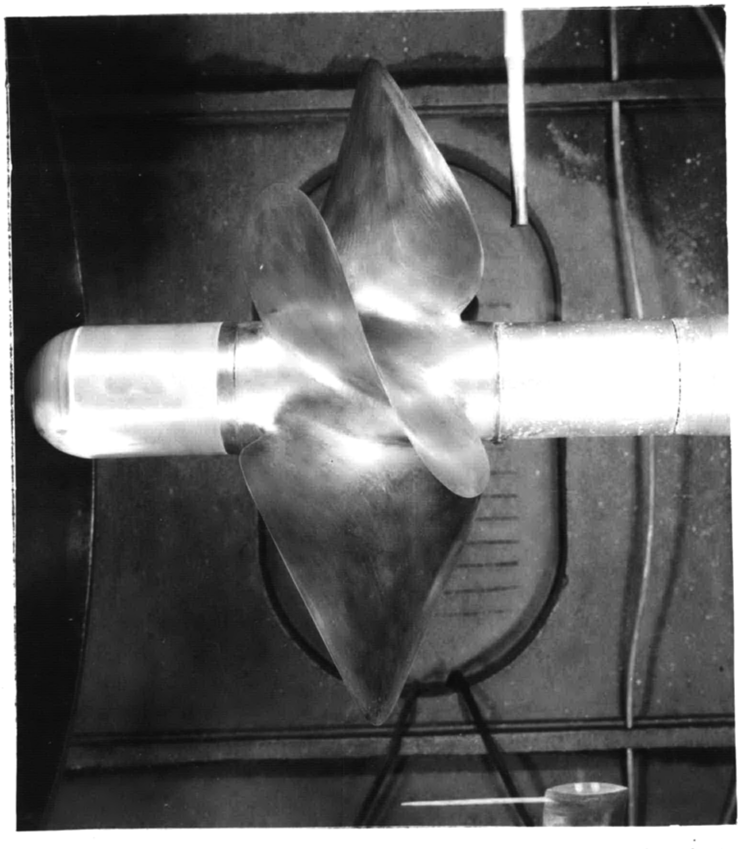

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Figure 2 - Photograph Showing Positions of Pitot Tubes and Propeller in Tunnel (Profile View)

| | |
|---|---|
| Number of blades | 4 |
| Expanded area ratio | 0.832 |
| Mean width ratio | 0.407 |
| Blade thickness fraction | variable |
| Diameter | 1.333 feet |
| Pitch (at 0.7 R) | 1.414 feet |
| P/D | 1.061 |

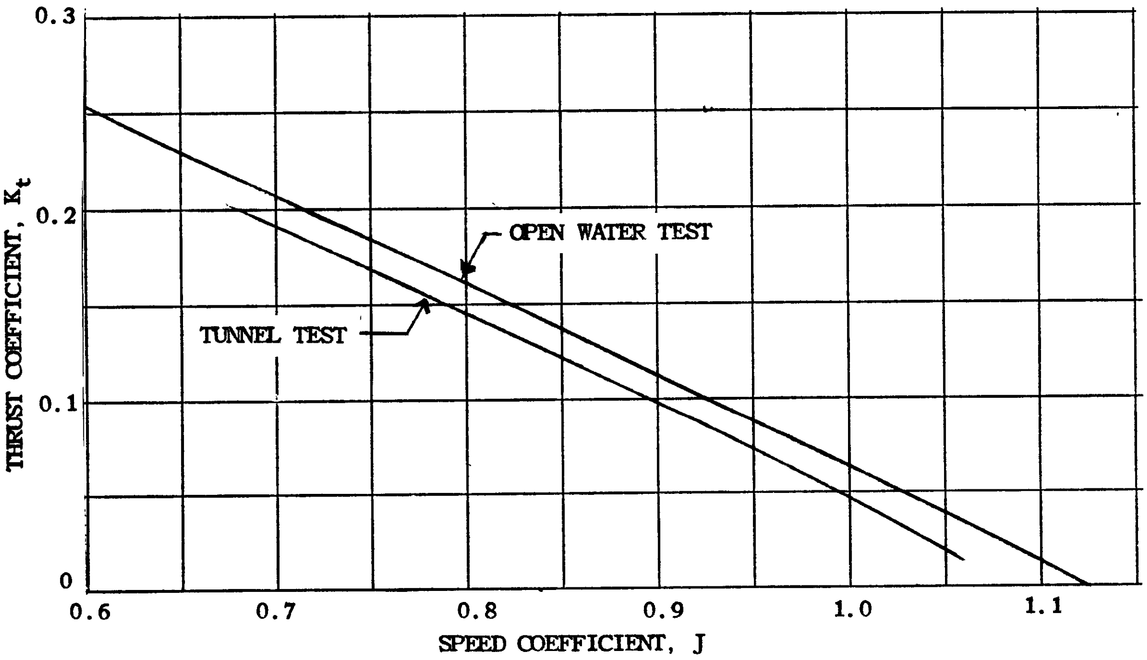

Figure 3 - Characteristics of Propeller 3551

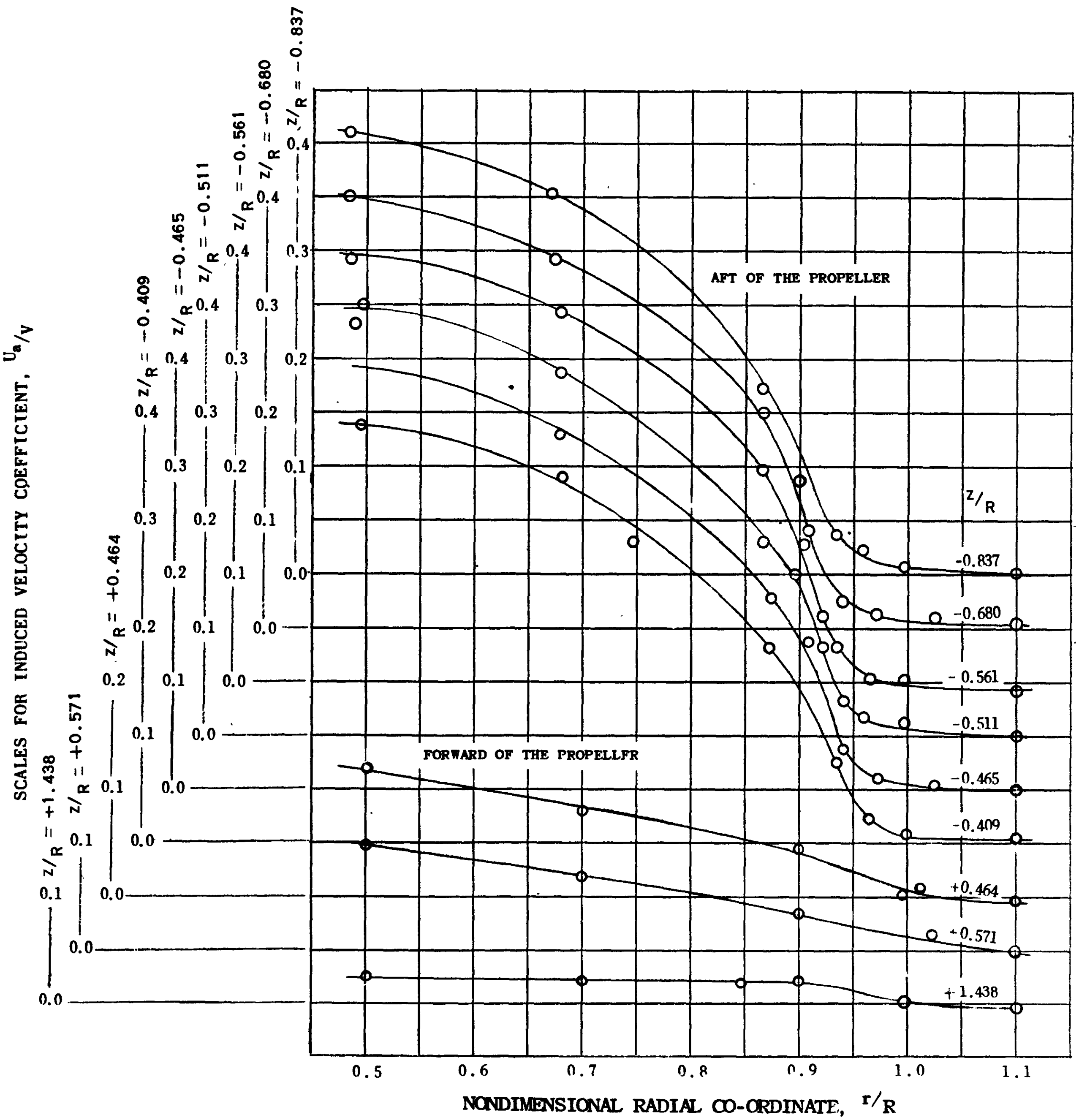

Figure 4 - Radial Variation of Axial Component of Induced Velocity Coefficient (J = 0.808)

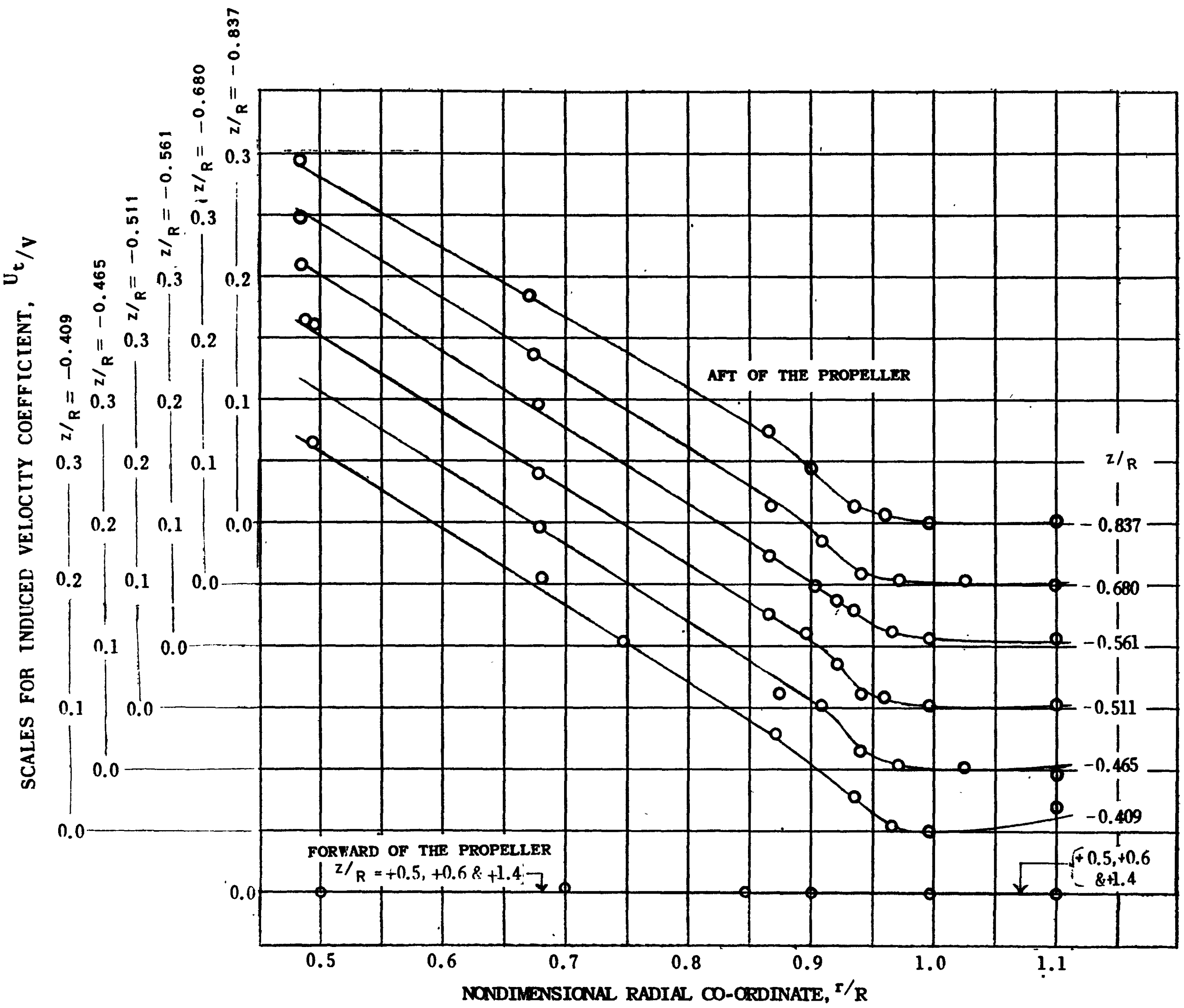

Figure 5 - Radial Variation of Tangential Component of Induced Velocity Coefficient ( J = 0.808)

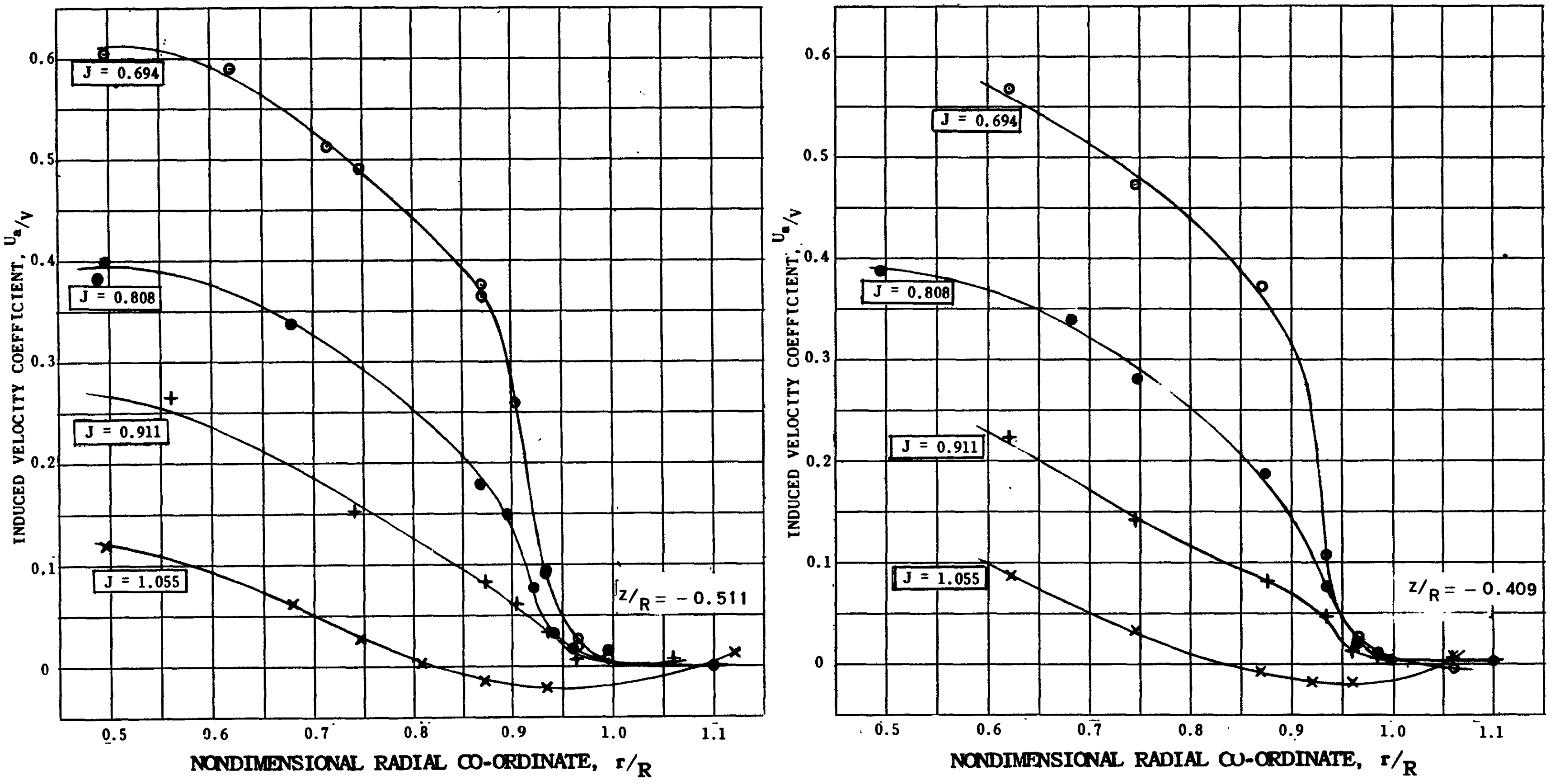

**Figure 6-a - Aft of the Propeller**

Figure 6 - Radial Variation of Axial Component of Induced Velocity Coefficient

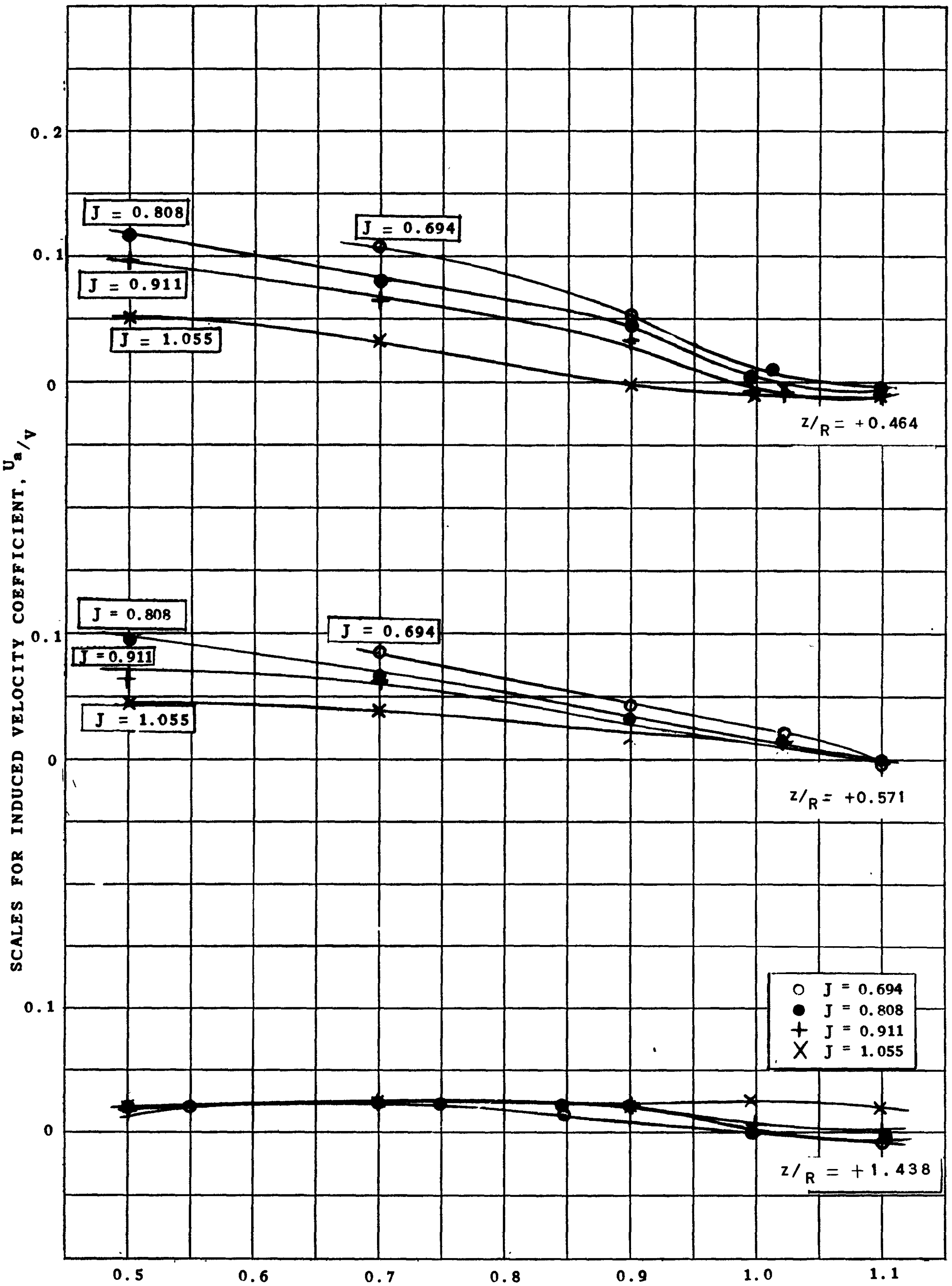

Figure 6-b - Forward of the Propeller

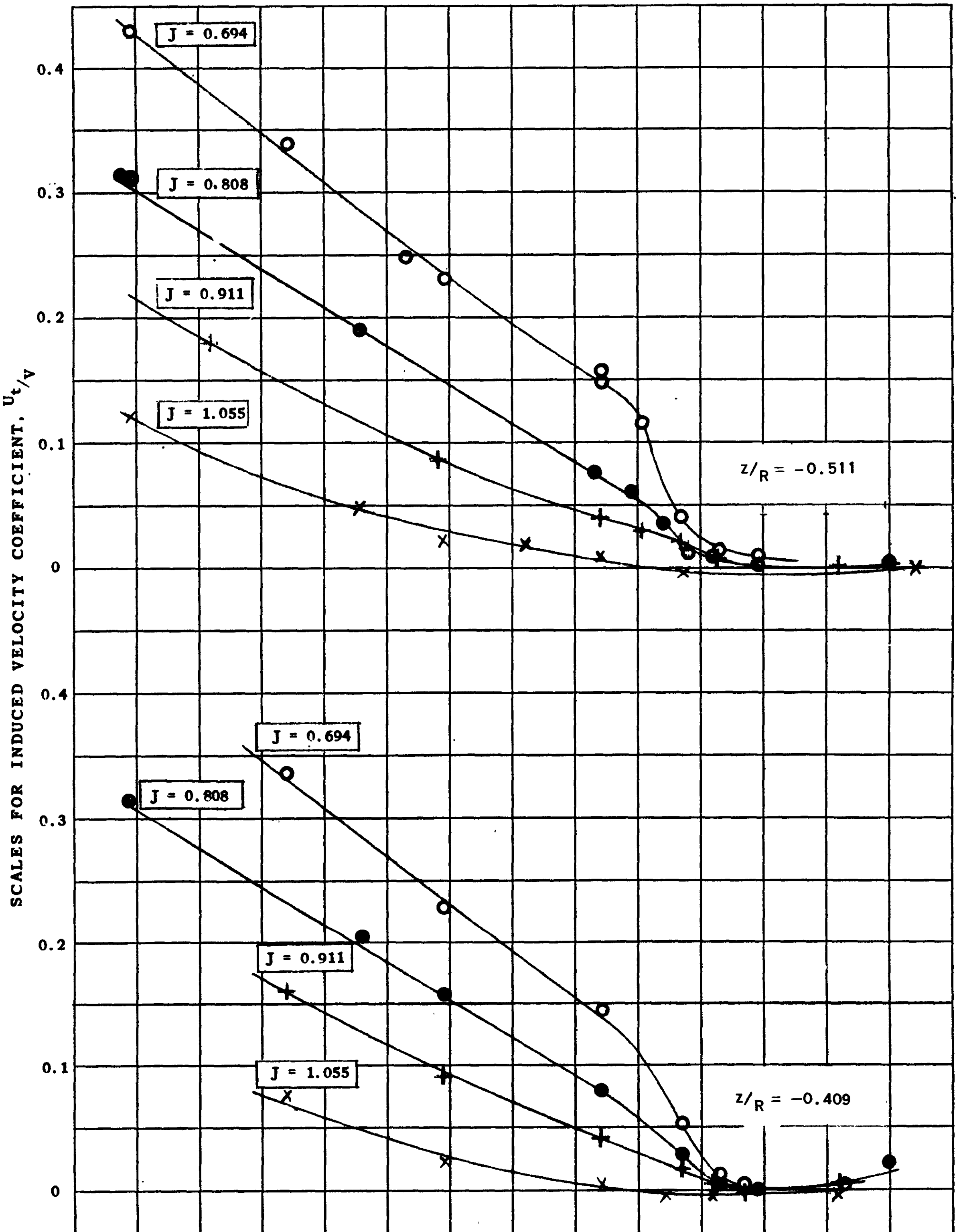

Figure 7 - Radial Variation of Tangential Component of Induced Velocity Coefficient (Aft of the Propeller)

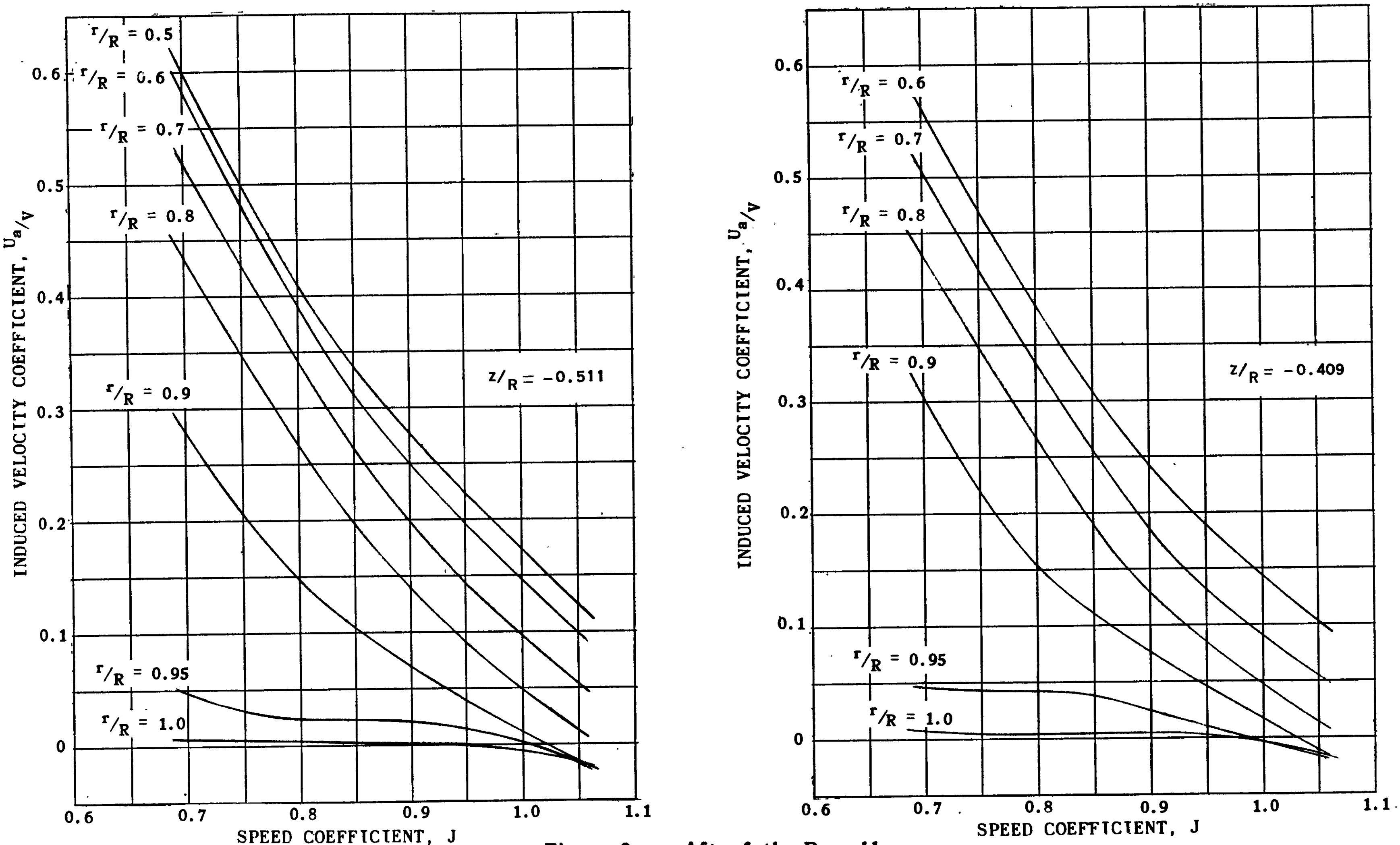

**Figure 8-a - Aft of the Propeller**

Figure 8 - Axial Component of Induced Velocity Coefficient as a Function of J

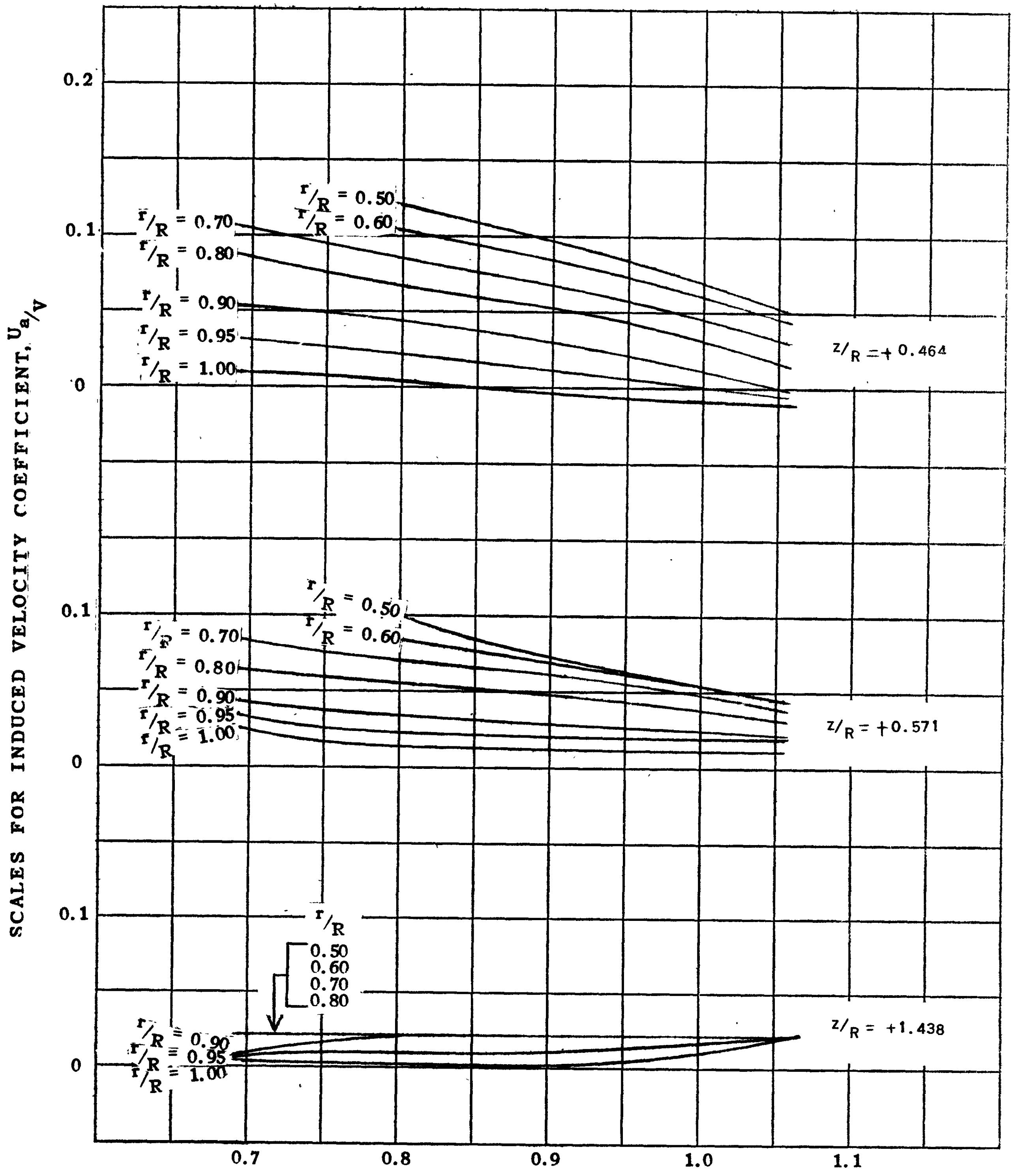

Figure 8-b - Forward of the Propeller

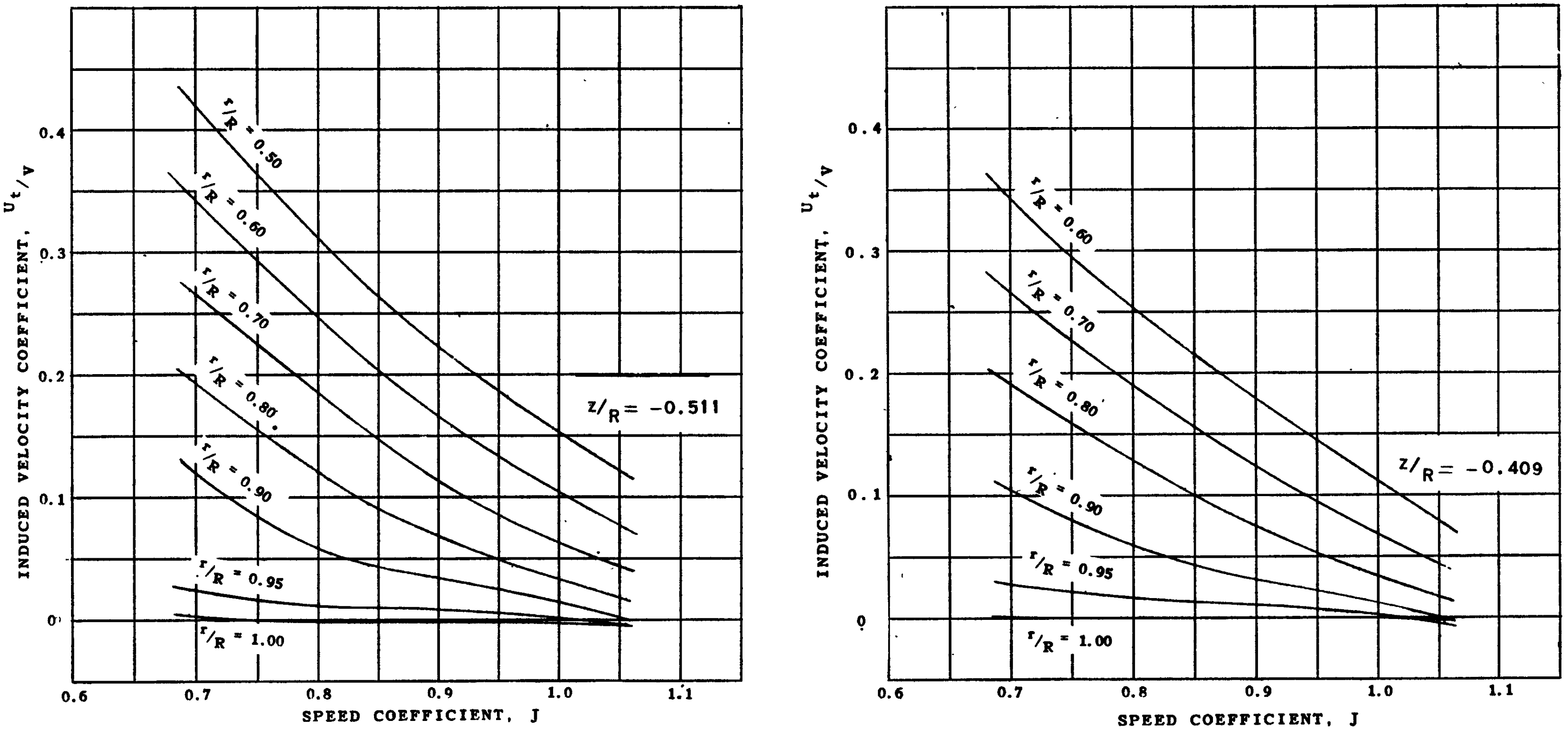

Figure 9 - Tangential Component of Induced Velocity Coefficient as a Function of J

(Aft of the Propeller)

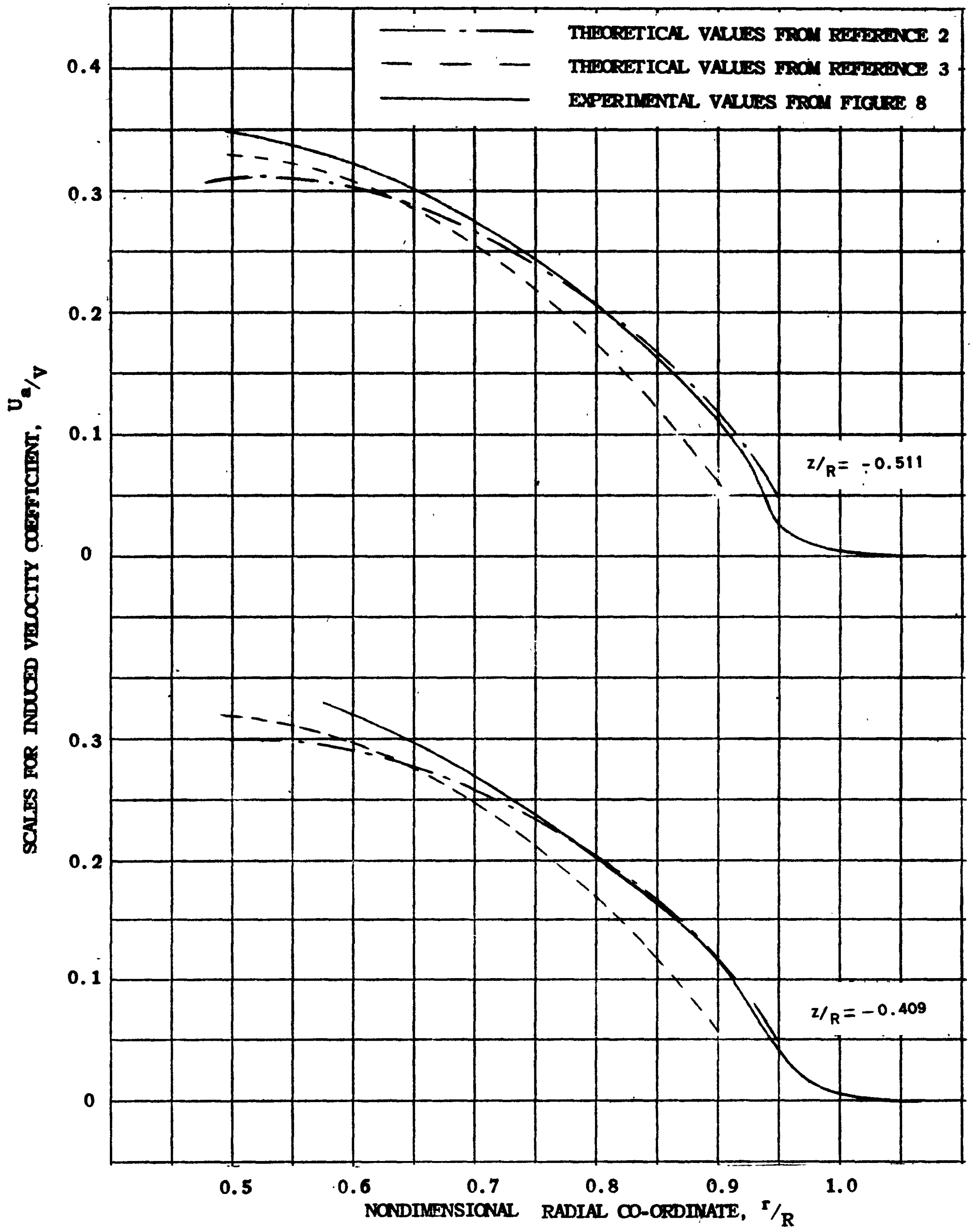

**Figure 10-a - Aft of the propeller**

Figure 10 - Axial Component of Induced Velocity Coefficient
(Design J = 0.842)

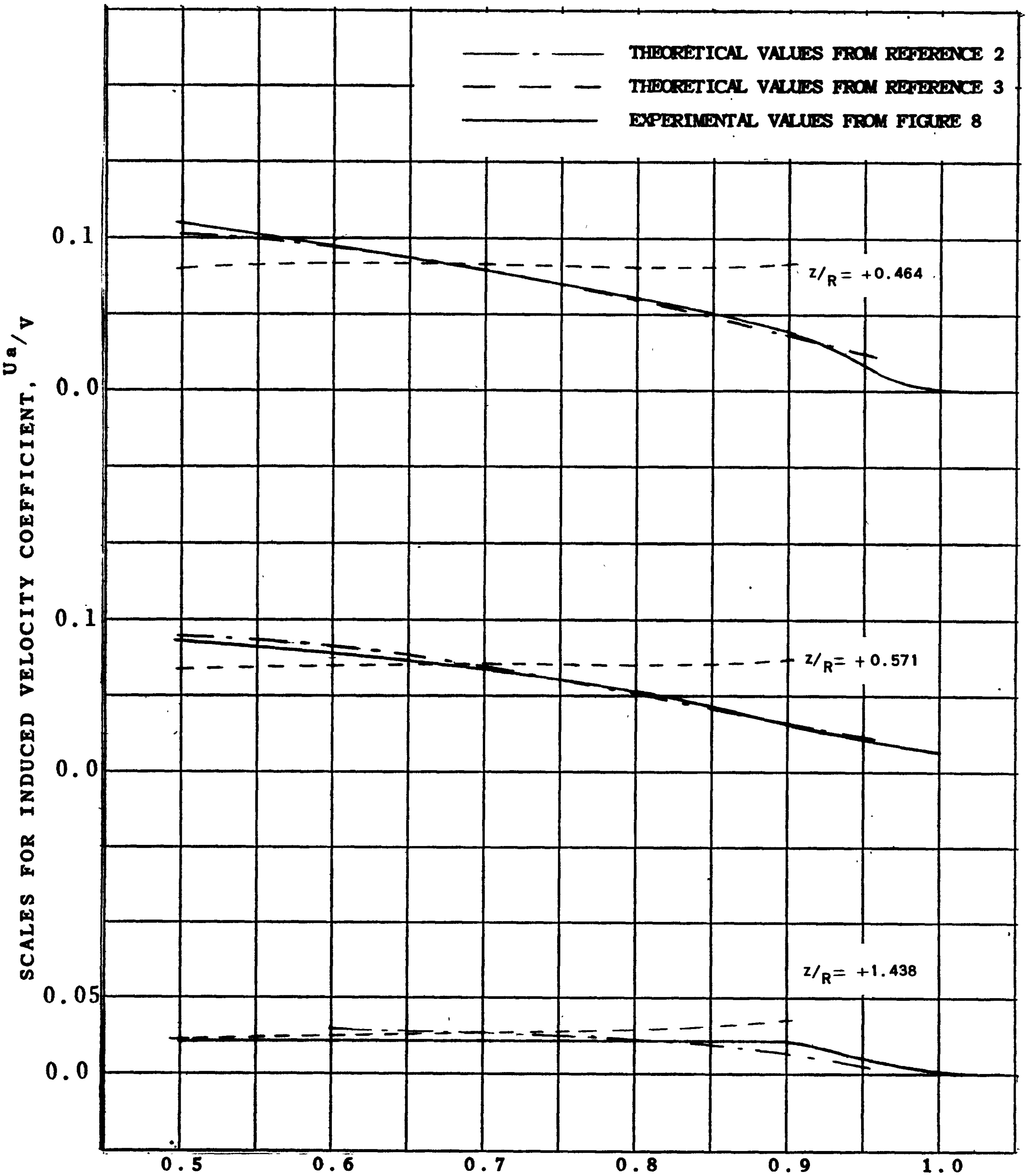

Figure 10-b - Forward of the Propeller

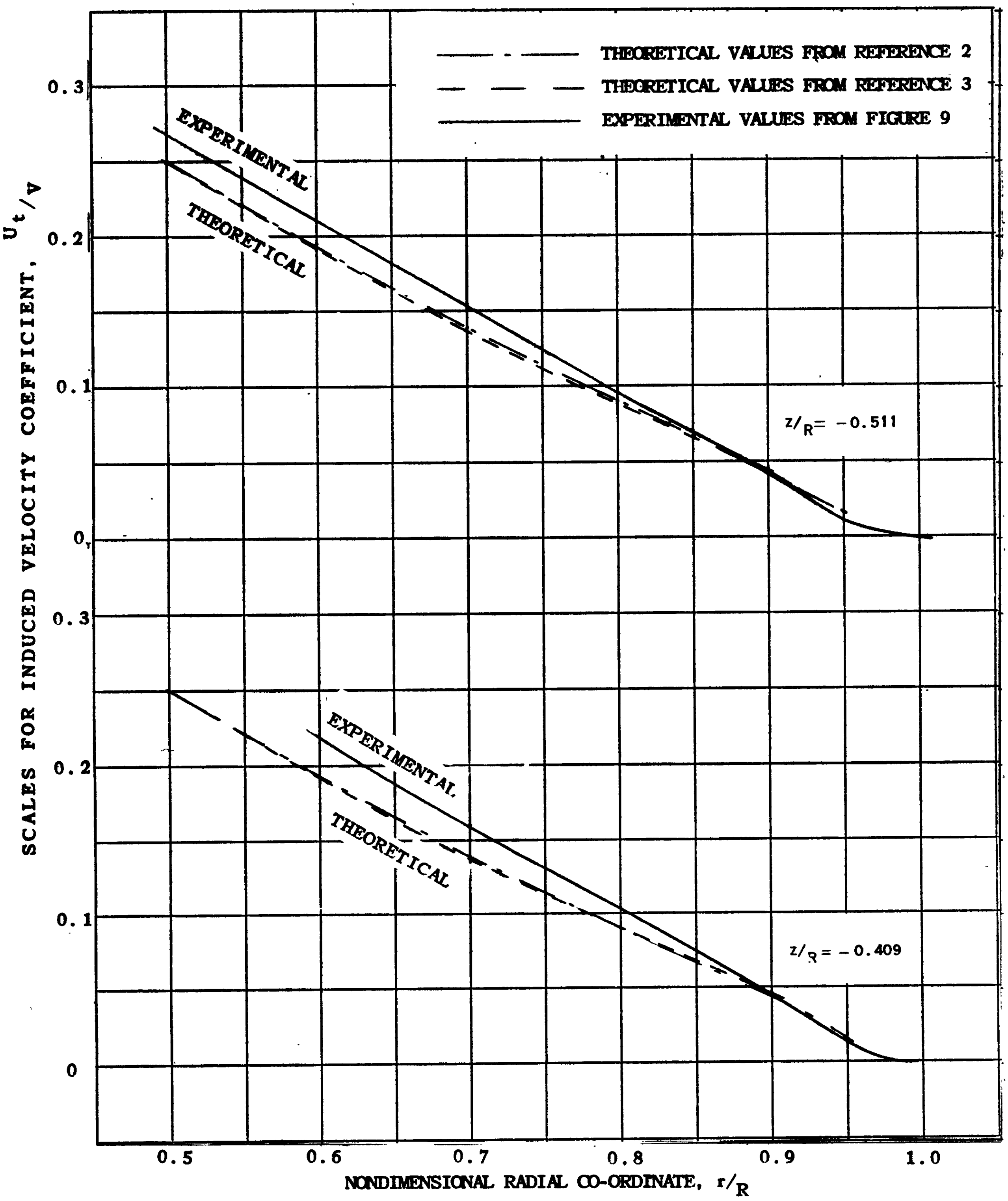

Figure 11 - Tangential Component of Induced Velocity Coefficient (Design J = 0.842) (Aft of the Propeller)

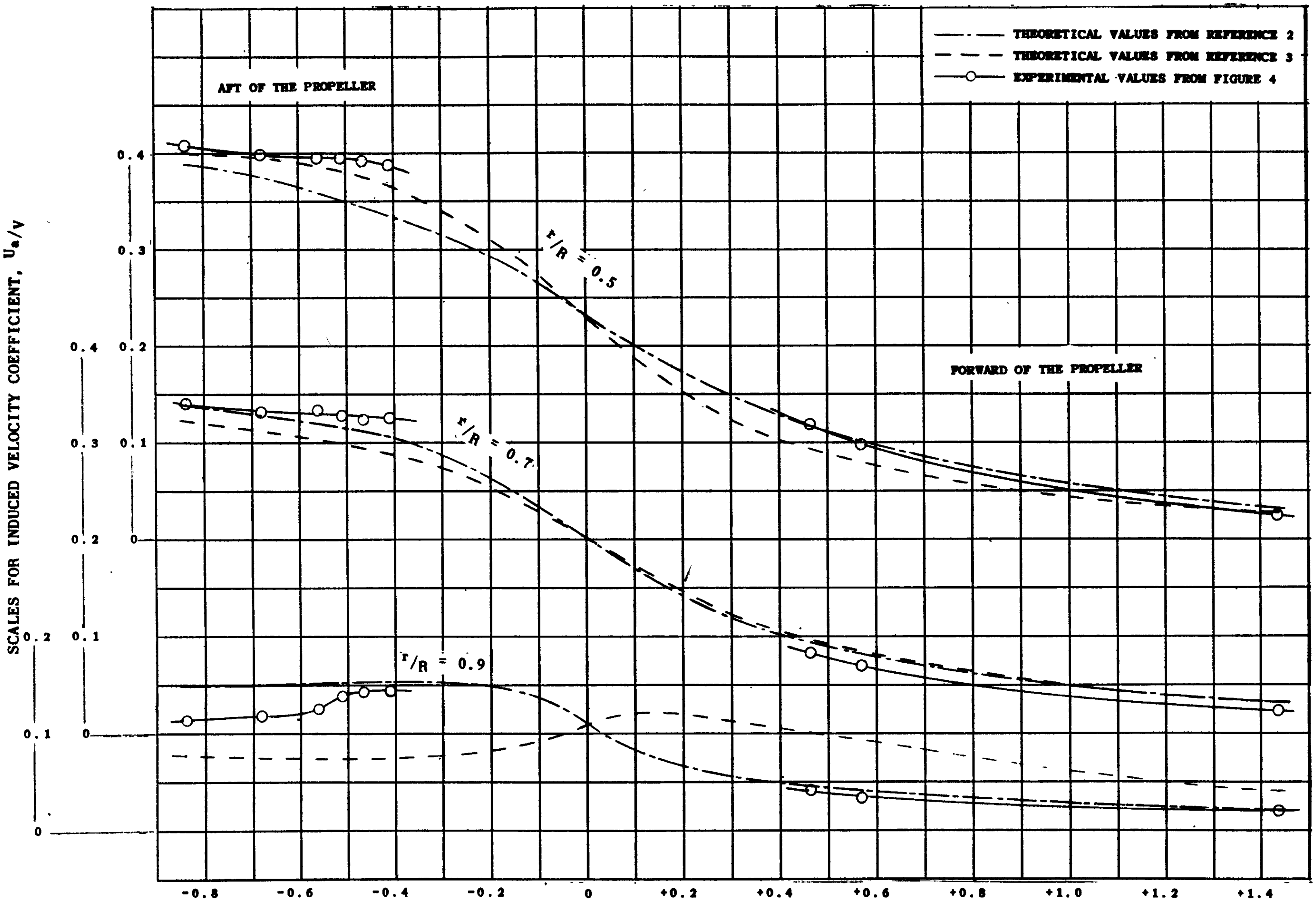

Figure 12 - Axial Variation of Axial Component of Induced Velocity Coefficient (J = 0.808)

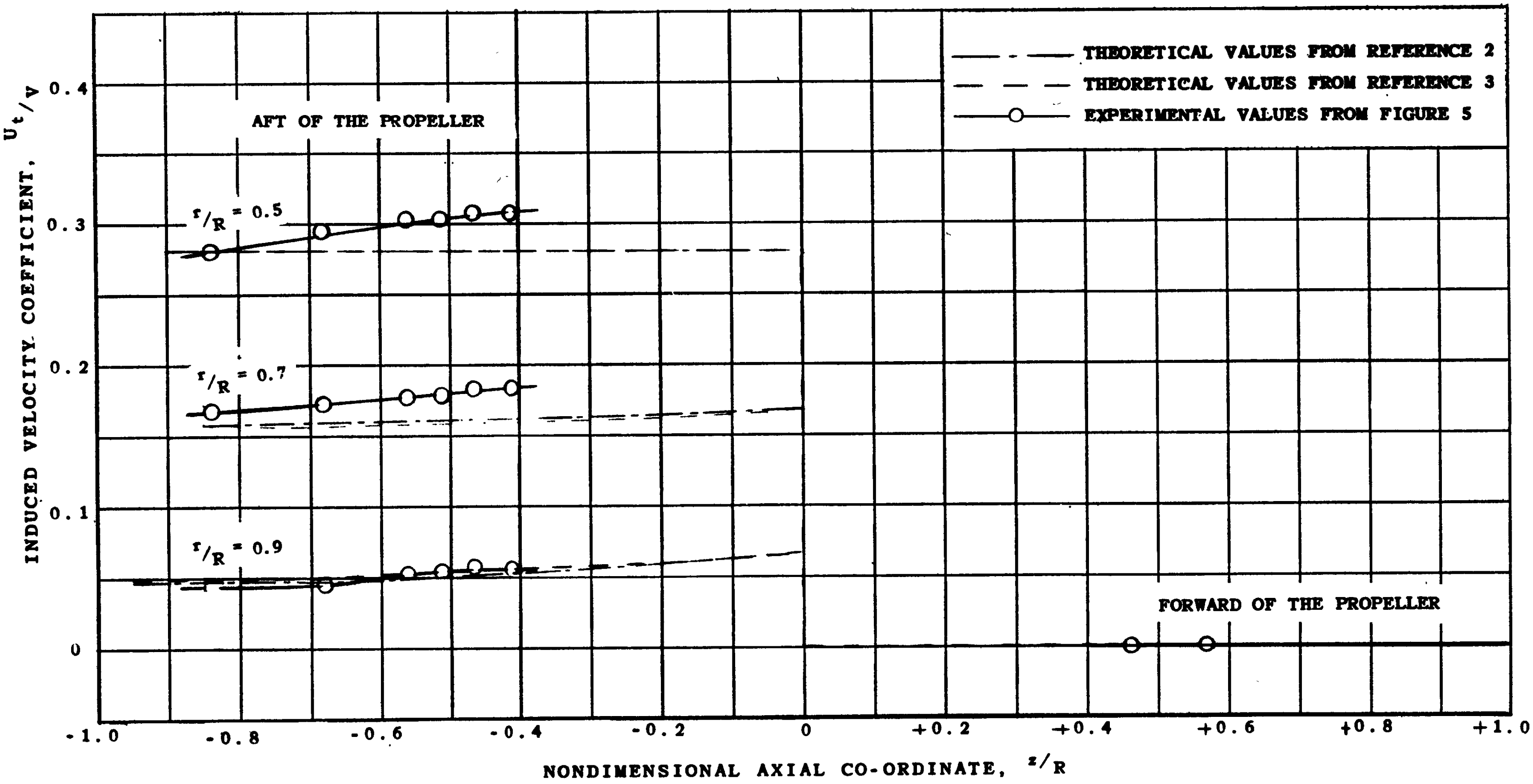

Figure 13 - Axial Variation of Tangentional Component of Induced Velocity Coefficient (J = 0.808)

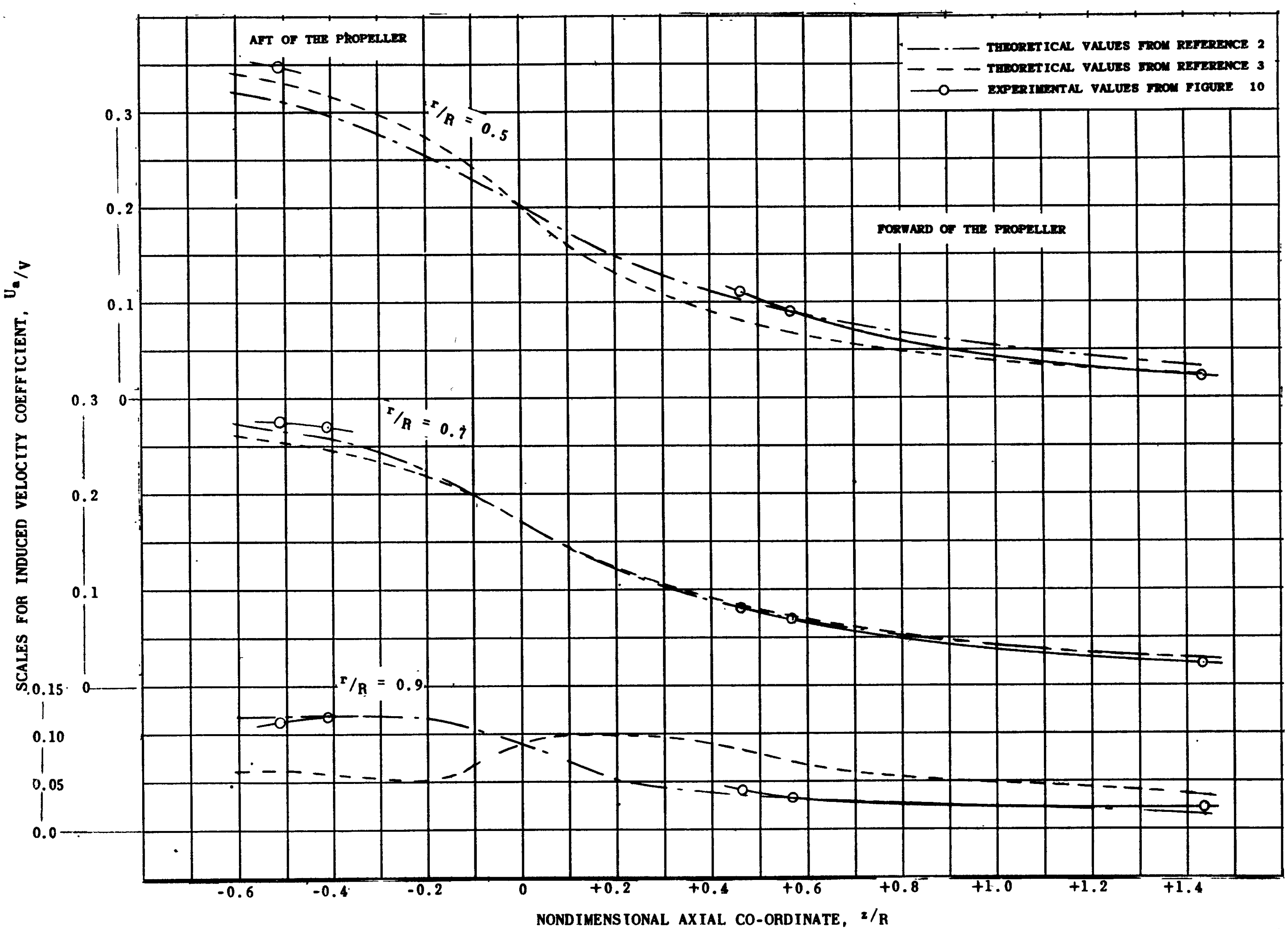

Figure 14 - Axial Variation of Axial Component of Induced Velocity Coefficient (Design J = 0.842)

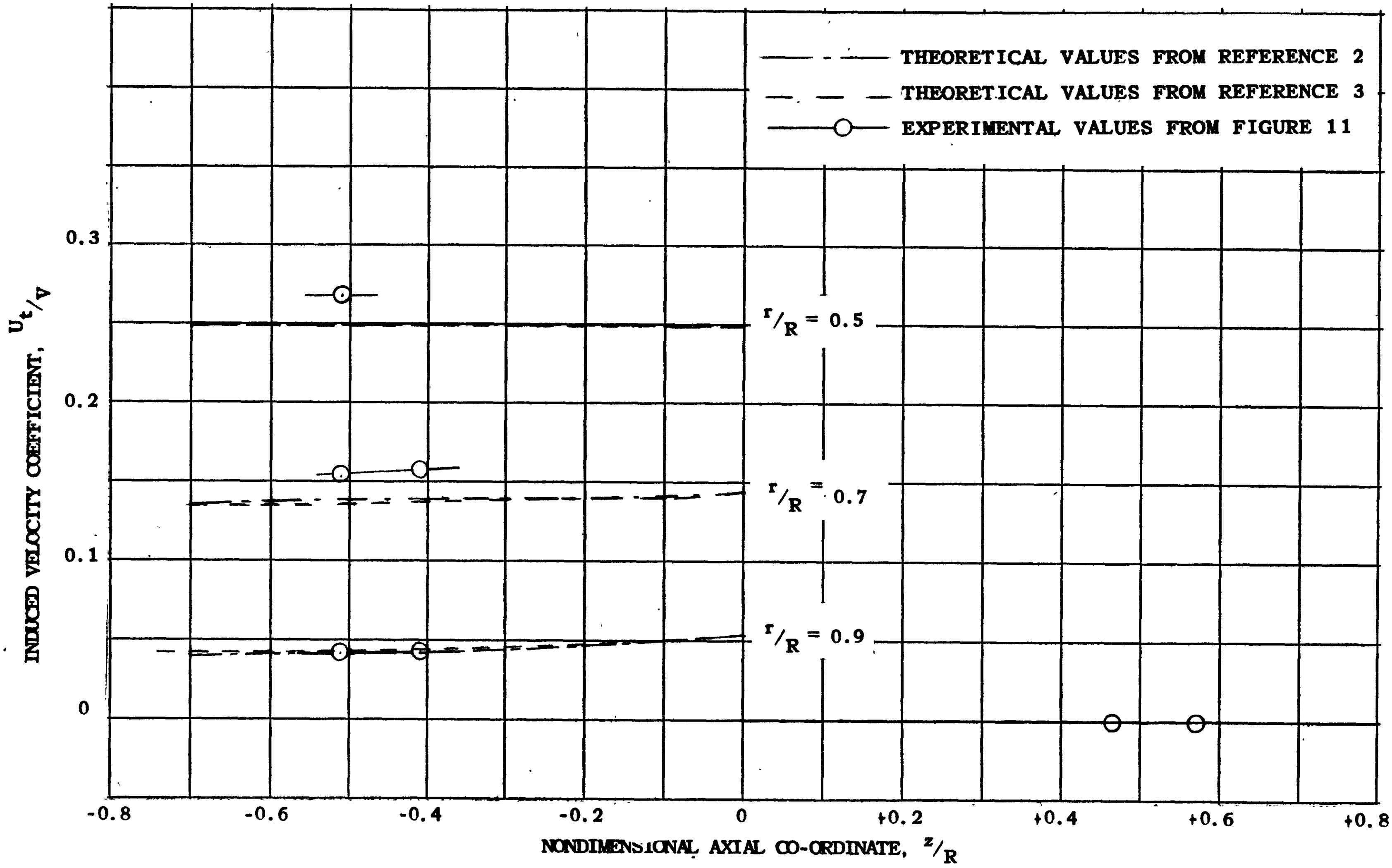

Figure 15 - Axial Variation of Tangential Component of Induced Velocity Coefficient (Design J = 0.842)

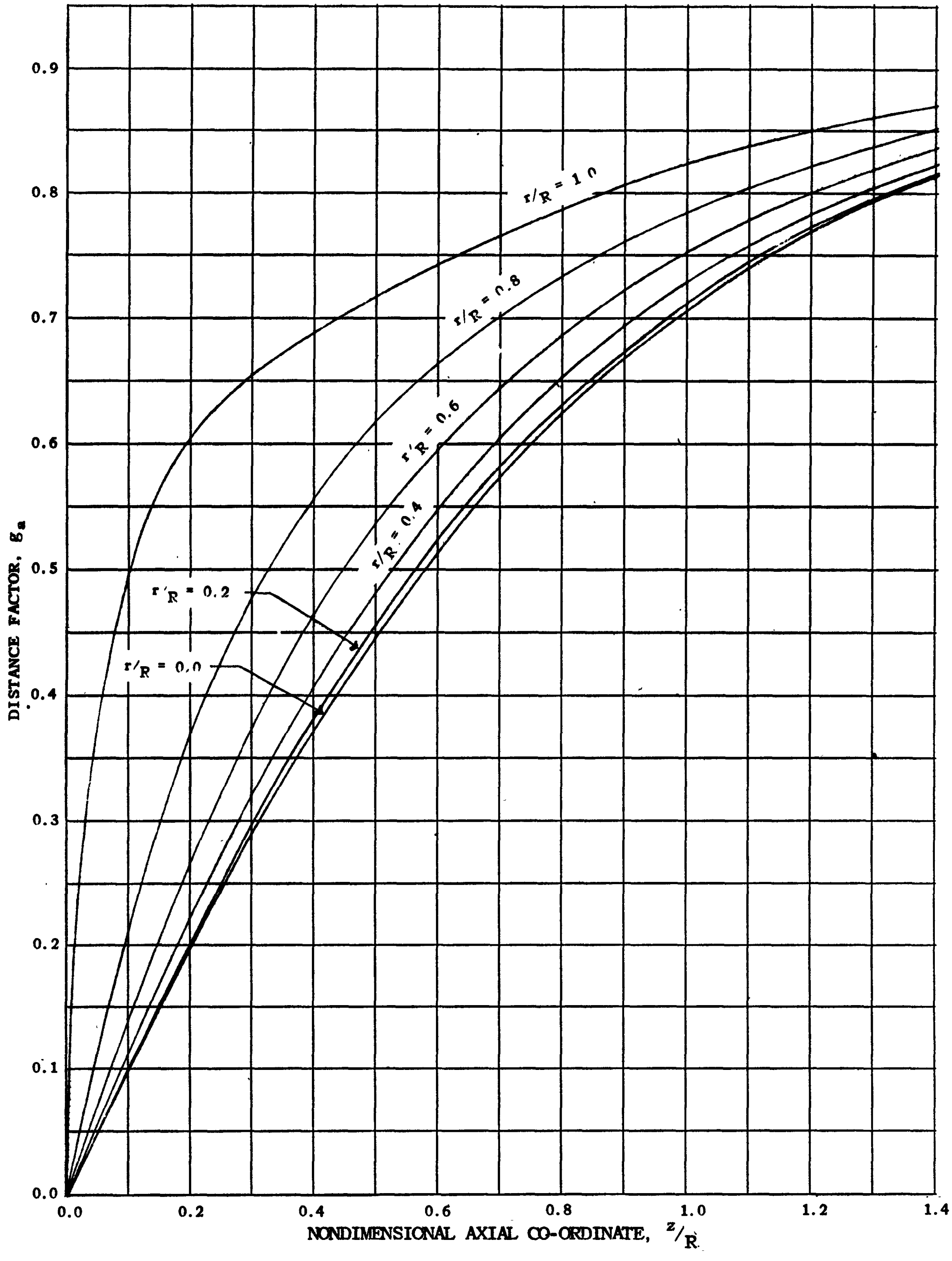

Figure 16 - Distance Factor, $g_a$, Reference 2

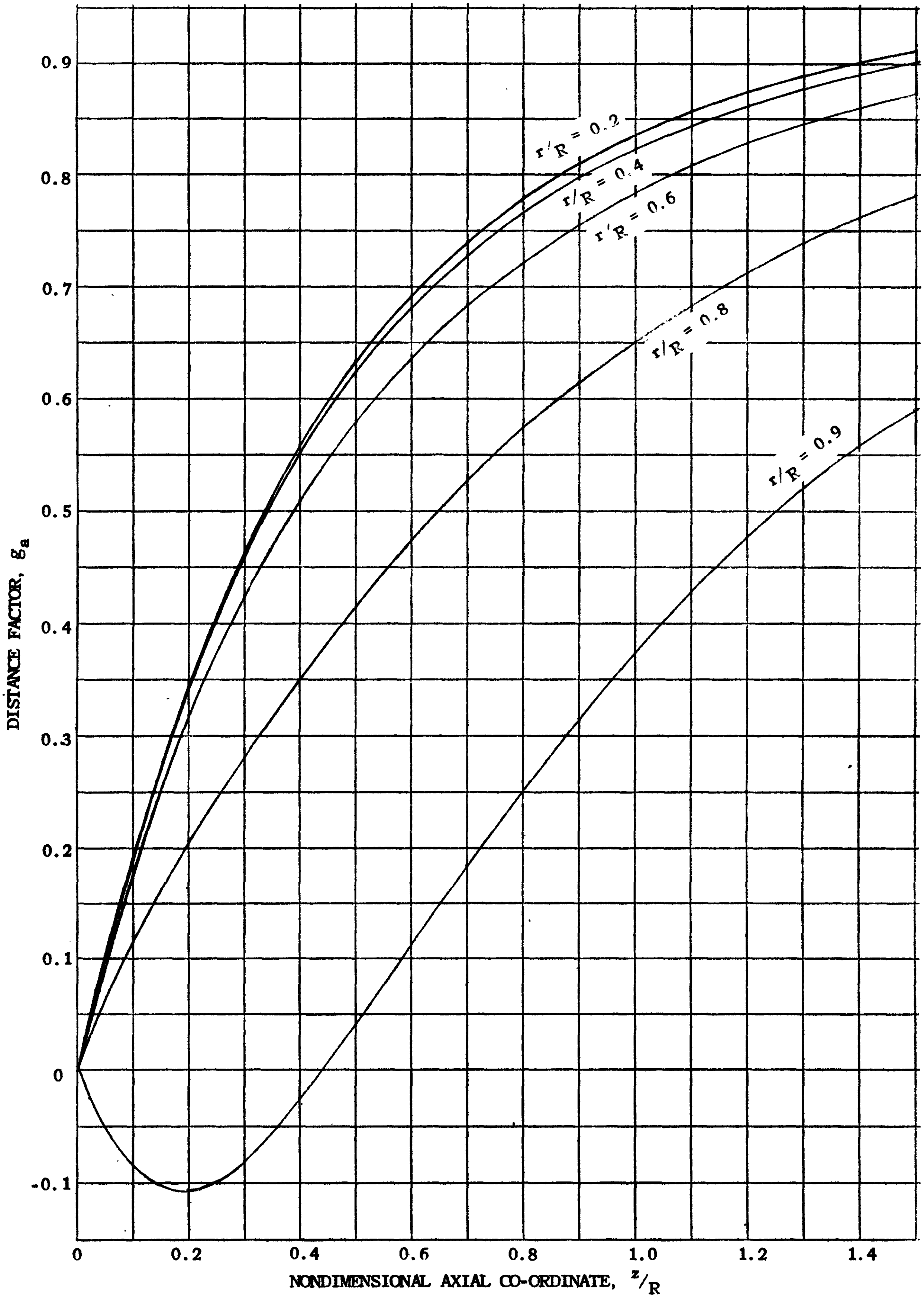

Figure 17 - Distance Factor, $g_a$, for Propeller 3551, Reference 3

## APPENDIX A - THEORETICAL CALCULATIONS OF INDUCED VELOCITIES

Theoretical values of the average induced velocity coefficients presented in this report were calculated using Lerbs's induction factors(4) and a distance factor, $g_a$ similar to the method used in the theory of counterrotating propellers.(2,3) The values of $g_a$ obtained from References 2 and 3 are given in Figures 16 and 17.

For the case of the single propeller the contraction ratio, Formula 18, Reference 2 becomes:

$$\delta = \frac{1}{x^2} \int_{x_h}^{x_i} \frac{\mu \left( \frac{W_a}{V} \cdot f_a \right) g_a}{1 + \left( \frac{W_a}{V} \cdot f_a \right) \left( 1 + g_a \right)} \, dx$$

Similarly, the formulas for the average of the induced velocities are:

$$\left( \frac{U_a}{V} \right)_{\text{forward}} = \left( \frac{W_a}{V} \cdot f_a \right) \left( 1 - g_a \right)$$

$$\left( \frac{U_a}{V} \right)_{\text{aft}} = \left( \frac{W_a}{V} \cdot f_a \right) \left( 1 + g_a \right)$$

$$\left(\frac{U_t}{V}\right)_{\text{forward}} = 0$$

$$\left(\frac{U_t}{V}\right)_{\text{aft}} = 2\left(\frac{W_t}{V} \cdot f_a\right)\left(1 + \delta\right)$$

where the average factor:

$$f_a = \frac{Z \cdot G}{2(x)\left(\frac{W_t}{V}\right)}$$

The contraction of streamlines are given by:

$$\frac{r_2}{R}_{\text{forward}} = \left(1 + \delta\right)x$$

$$\frac{r_2}{R}_{\text{aft}} = \left(1 - \delta\right)x$$

The values for $\frac{W_a}{V}$, $\frac{W_t}{V}$ and G were obtained from a high speed computer by methods outlined in Reference 5. Hence, the values for $\frac{U_a}{V}$ and $\frac{U_t}{V}$ could easily be computed.

## REFERENCES

1. Dickmann, H. E., "Schiffskörpersog, Wellenwiderstand eines Propellers und Wechselwirkung mit Schiffswellen," Ingenieur Archiv 9 Band 1938, pp 452-486.

2. Lerbs, H. W., "Contra-Rotating Optimum Propellers Operating in a Radially Non-uniform Wake," DTMB Report 941, May 1953.

3. Tachmindji, A. J., "Axial Velocity Field of an Optimum Infinitely Bladed Propeller," DTMB Report 1294, January 1959.

4. Lerbs, H. W., "Moderately Loaded Propellers with a Finite Number of Blades and an Arbitrary Distribution of Circulation," paper presented at the annual meeting of The Society of Naval Architects and Marine Engineers in New York, November 1952.

5. Hecker, Richard, "Manual for Preparing and Interpreting Data of Propeller Problems which are Programmed for the High Speed Computers at David Taylor Model Basin," DTMB Report 1244, Feburary 1959.

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2. Fluid flow – Velocity
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