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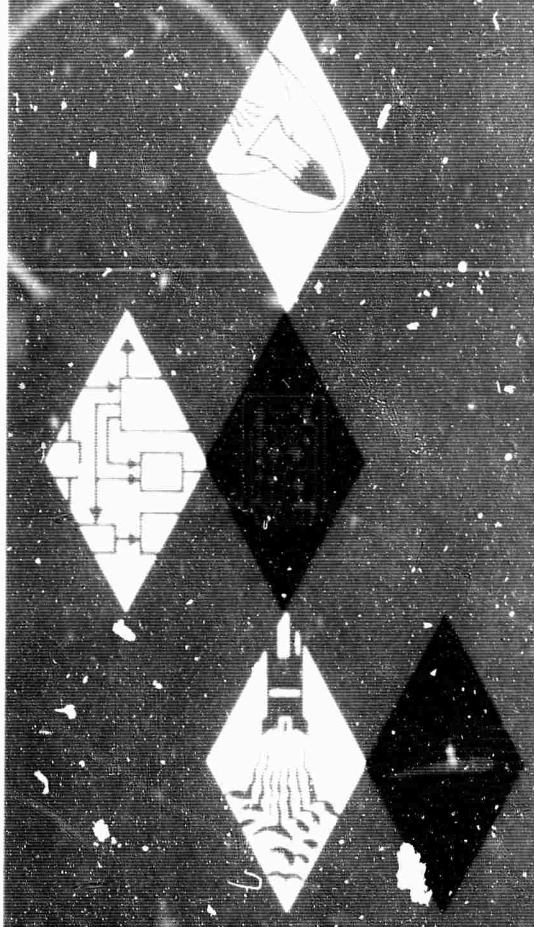

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TECHNICAL REPORT NO. 478

FLOW FIELD OF A SPHERICAL PELLET AT BALLISTIC RANGE CONDITIONS IN ARGON

By G. F. Widhopf

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TECHNICAL REPORT NO. 478

FLOW FIELD OF A SPHERICAL PELLET AT BALLISTIC RANGE CONDITIONS IN ARGON*

By G. F. Widhopf

Prepared for

Advanced Research Projects Agency
Washington 25, D. C.

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Project Engineer - W. Daskin
Code 516 - ED 3-6960

Prepared by

General Applied Science Laboratories, Inc.
Merrick and Stewart Avenues
Westbury, L. I., New York

Approved by: Walter Daskin for
Antonio Ferri
President

December 8, 1964

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* This research is sponsored by the Advanced Research Projects Agency

LIST OF SYMBOLS

P	pressure
P_s	$\rho_\infty u_\infty^2$
ρ	density
R_N	nose radius
S	coordinate along body
T	temperature
U	velocity
X	axial coordinate measured from nose of body
x'	axial coordinate measured from origin of trailing shock
Y	radial coordinate
Y_s	shock coordinate

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∞	free stream conditions
Δ	edge of viscous region

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6-13 Profiles of Viscous and Inviscid Layers in Wake Region at Axial Stations $X'/R_N = 0, 5.0, 10.0$

14-19 Streamwise Variation of Viscous Wake Axis and Edge Properties

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FLOW FIELD OF A SPHERICAL PELLET AT BALLISTIC RANGE CONDITIONS IN ARGON

By G. F. Widhopf

This report was prepared in response to a request by personnel of Lincoln Laboratory to have available a detailed description of the flow field of a spherical pellet, at a specified ballistic range condition (V_∞ = 20 kfps; P_∞ = 50 mm Hg), in argon. A similar calculation of flow field details has been performed for an air atmosphere at the aforementioned velocity and pressure; the results are reported in Ref. 1.

In a regime where the Reynolds number is high and the Prandtl[*] and Schmidt[**] numbers are on the order of one, transport property effects can be assumed to be localized. Therefore viscous phenomena which occur in the flow about a reentry vehicle are assumed to be restricted to the boundary layer and thus the inviscid and viscous portions of the field may be

---

[*] Prandtl No. $\equiv P_r \equiv \dfrac{C_p\mu}{k} = \dfrac{\text{viscous}}{\text{thermal}}$ transports.

[**] Schmidt No. $\equiv S_c \equiv \dfrac{\mu}{\rho D_{12}} = \dfrac{\text{viscous}}{\text{diffusive}}$ transports.

calculated independently. Chemical diffusion effects are also localized; thus a chemically reacting field, as well as one in equilibrium, can be solved locally and independently.

Utilizing these assumptions and the analyses reported in Refs. 2-4 the flow field about a 3/16 inch diameter spherical pellet, at the forenoted ballistic conditions in argon, has been examined. Whereas the previously reported air flow field (Ref. 1) was calculated as being a chemical non-equilibrium continuum, the argon field has been assumed to be in thermochemical equilibrium.

Since argon is a monatomic gas it cannot dissociate, thus the extreme shock heating resulting from the strong curved bow shock cannot be absorbed by a dissociation process as in air. The translational temperature for argon is therefore much higher than that for air (e.g. Fig. 4 and Fig. 16, Ref. 1).

An examination of Fig. 1, which compares the physical dimensions of the air and argon flow fields, shows a marked difference between the stand-off distances of the corresponding bow shock $\left(\frac{\text{argon}}{\text{air}} \approx 2.7 \text{ at the stagnation point}\right)$. The angle of the trailing shock and the initial wake dimensions also differ while the viscous wake growth rate is seen to be lower for argon than air. This difference in growth rates can be accounted for by the higher temperatures existing in the argon wake and the associated larger diffusion time scale.

Similar to Ref. 1 this report includes the pertinent distributions of properties along the body streamline and streamwise variations in the viscous wake. Also included are viscous and inviscid profiles at various axial stations. These properties are shown in Figs. 1-19 where the different regions of the flow field are presented separately, as indicated in the List of Figures.

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1. Widhopf, G., Zeiberg, S.L., Flow Field of a Spherical Pellet at Ballistic Range Conditions in Air, GASL TR No. 464, Dec. 1964.

2. Lieberman, E., Description of IBM 709/90/94 Computer Programs and Analysis for Flow Fields about Bodies of Revolution in Hypersonic Flight, GASL TR 340, May 1963.

3. Zeiberg, S.L., Bleich, G.D., Finite Difference Calculation of Hypersonic Wakes, AIAA Preprint 63-448, AIAA Journal, August 1964

4. Zeiberg, S.L., Bleich, G.D., The Blunt Body Hypersonic Wake, GASL TR No. 451, August 1964.

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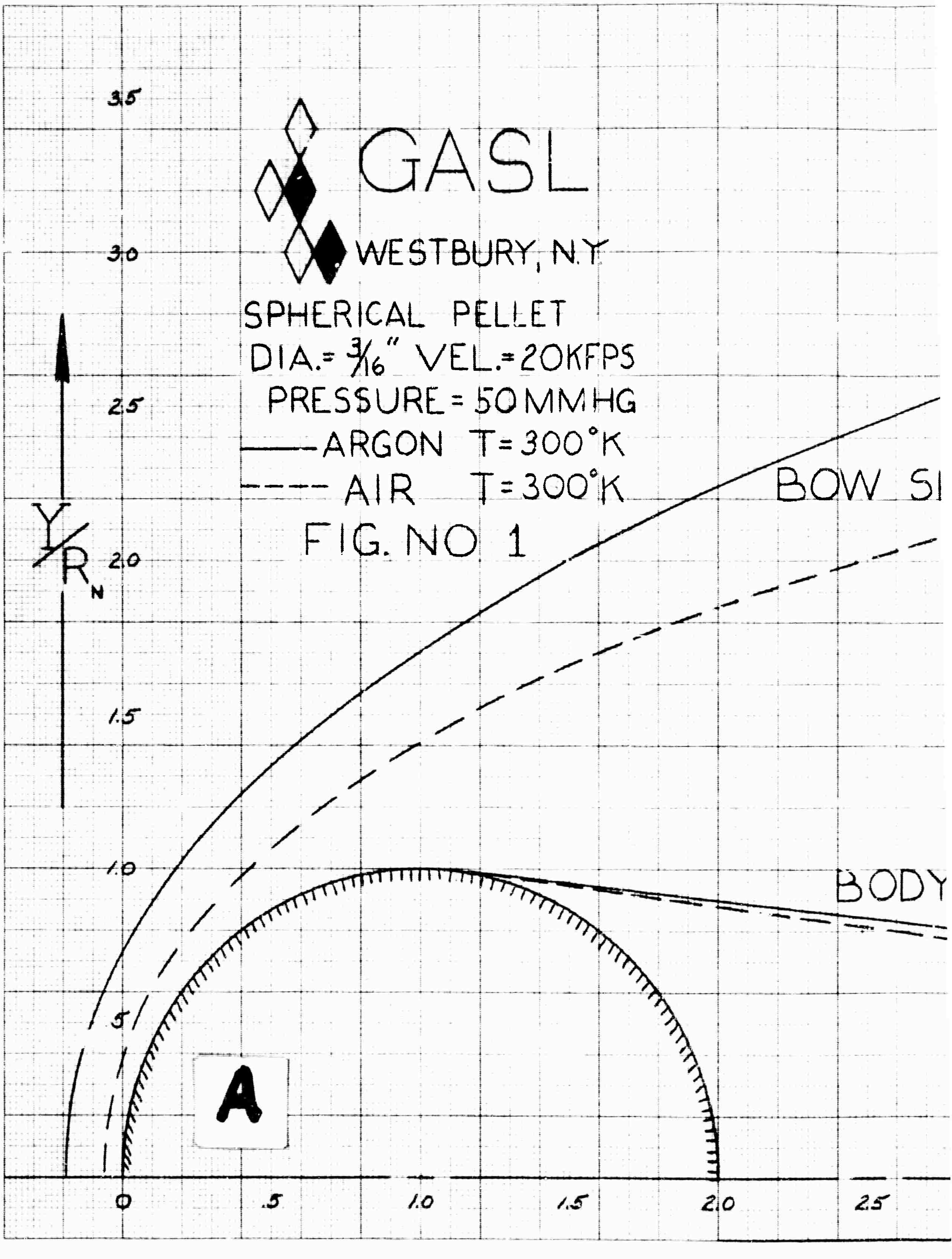

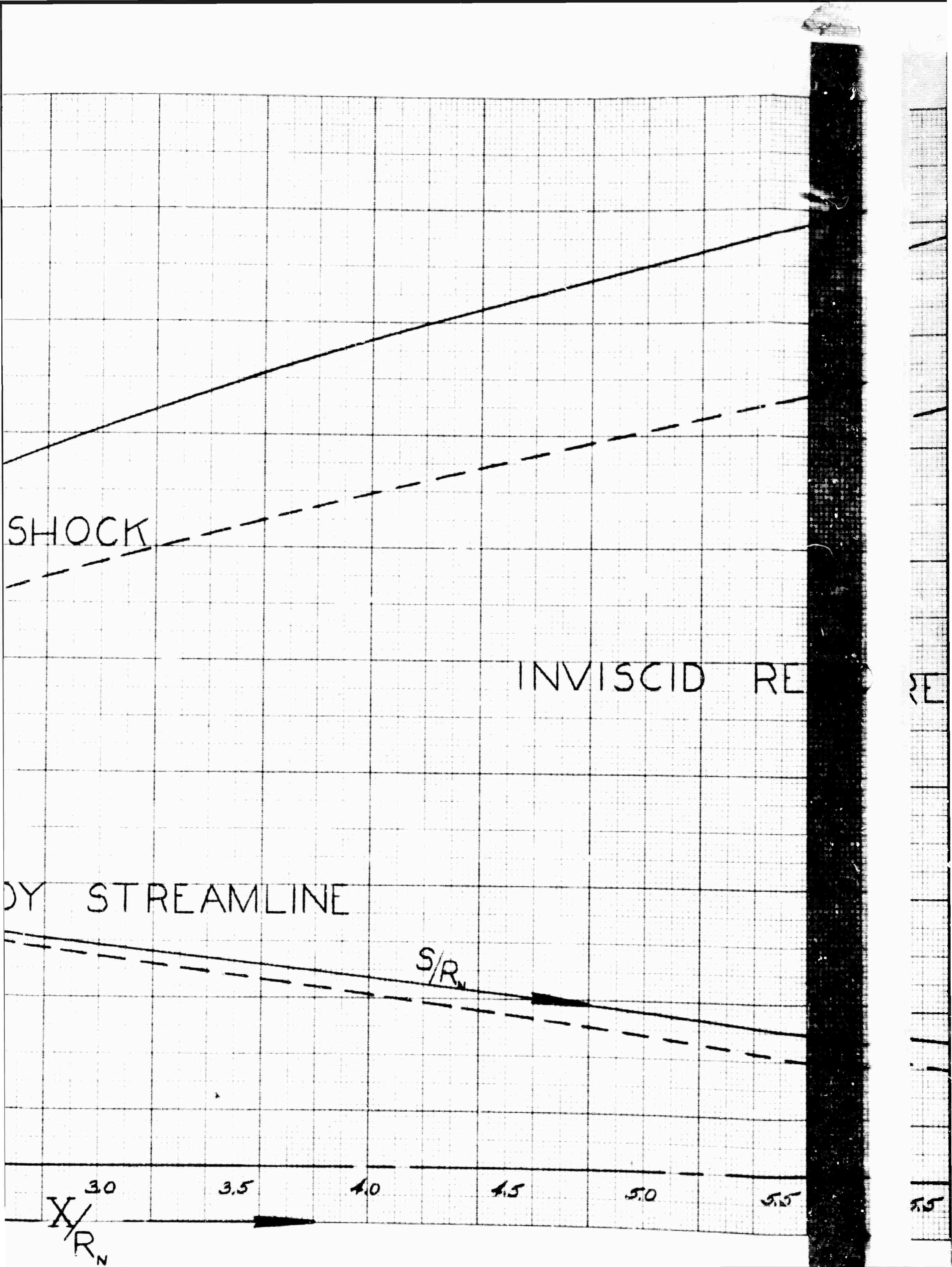
SHOCK
INVISCID RE
RE
DY STREAMLINE
S/R_N
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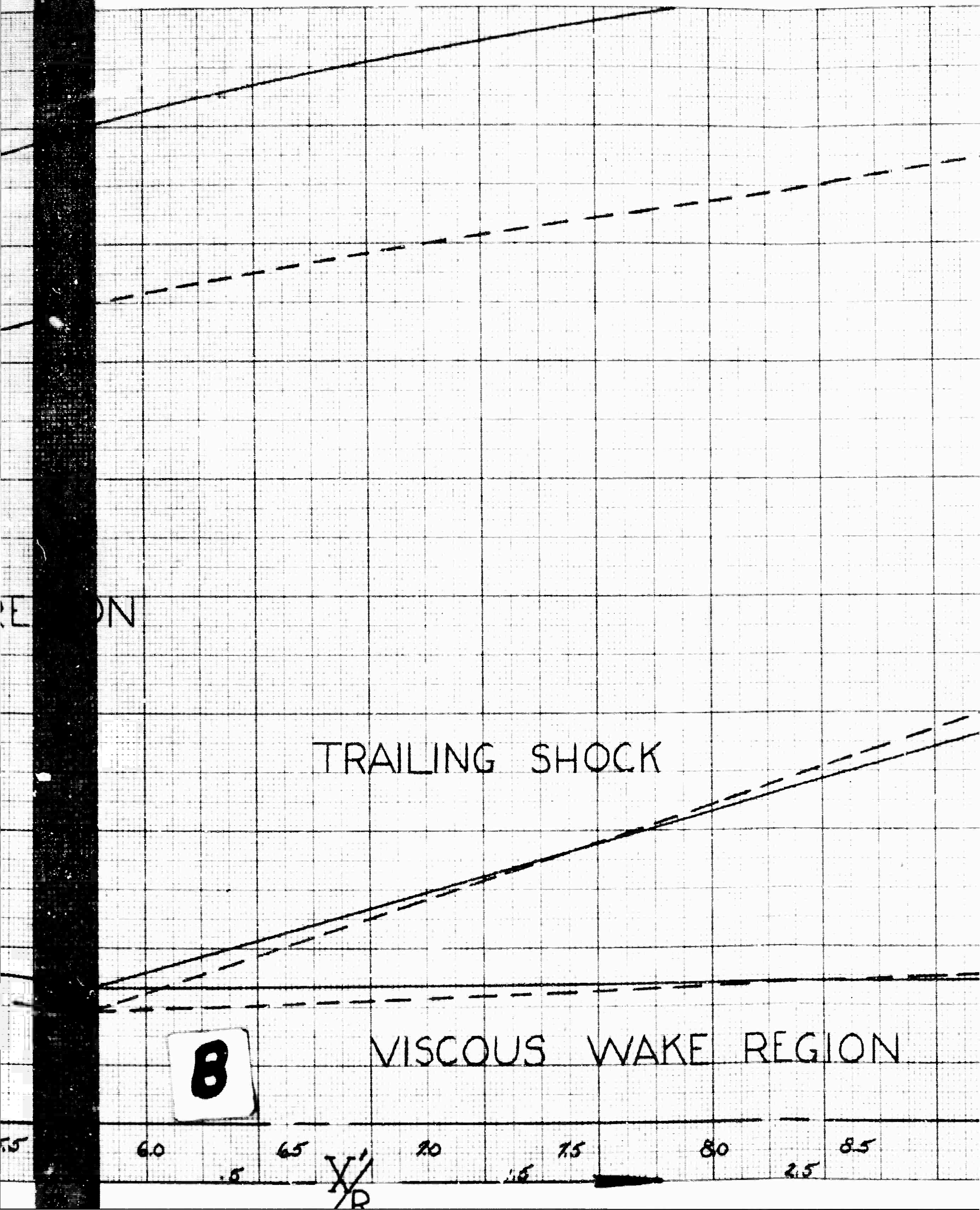
3.5
4.0
4.5
5.0
5.5
5.5
X/R_N


RE ON
TRAILING SHOCK
B
VISCOUS WAKE REGION
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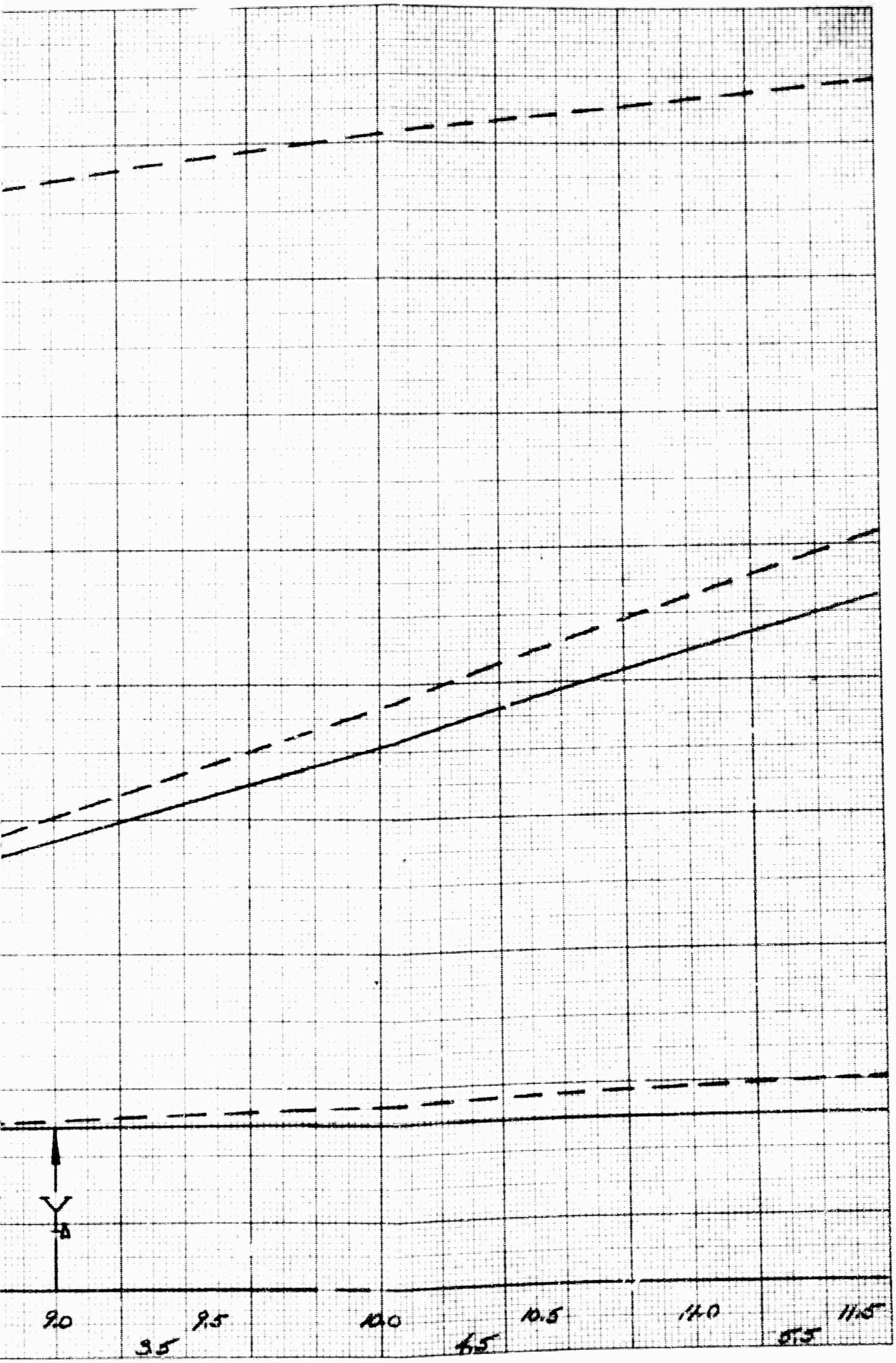
6.0
6.5
7.0
7.5
8.0
8.5
.5
1.5
2.5
X'/R


Y_Δ
9.0
9.5
10.0
10.5
11.0
11.5
3.5
4.5
5.5

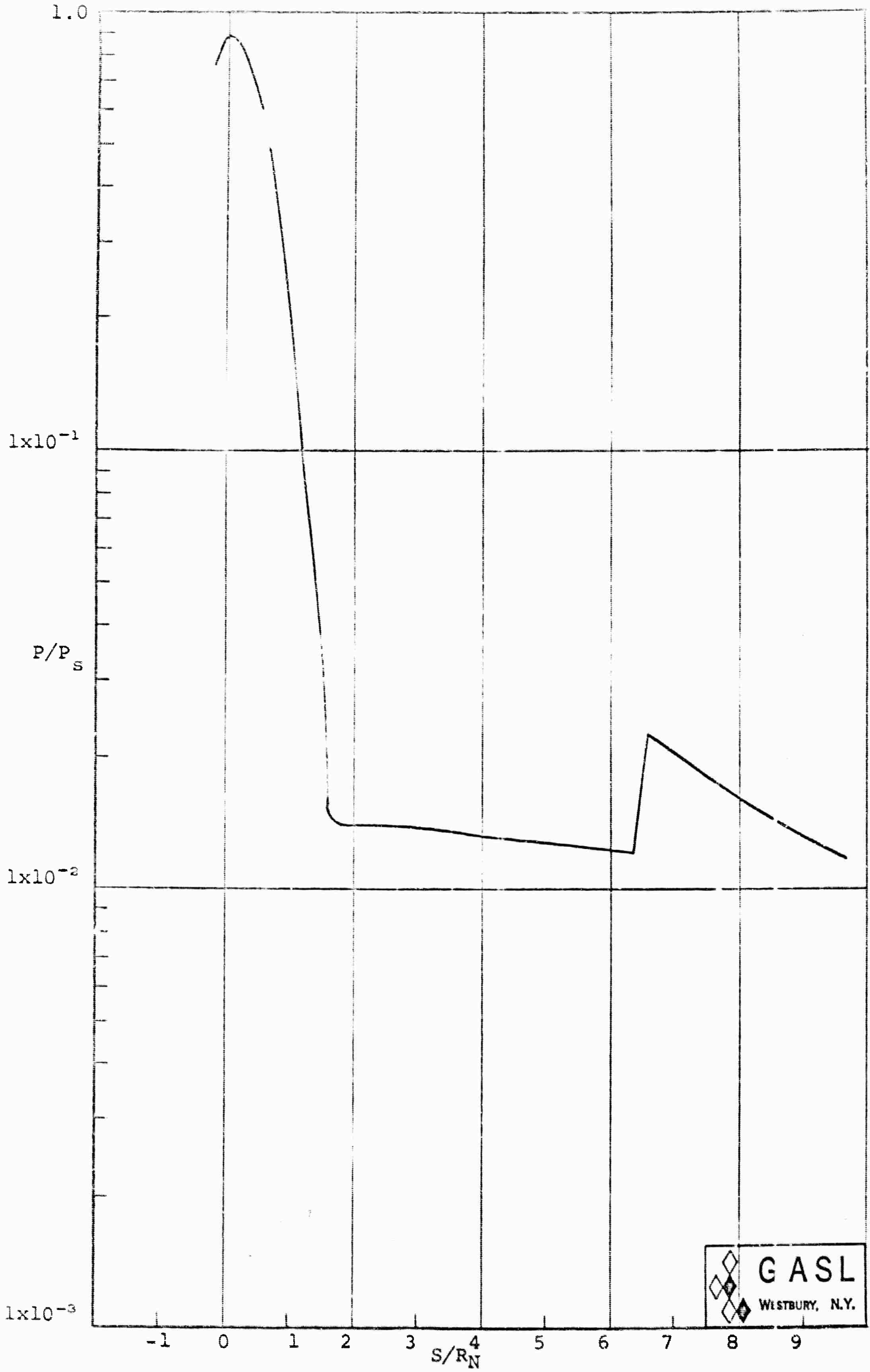


FIG. 2: BODY STREAMLINE PRESSURE DISTRIBUTION

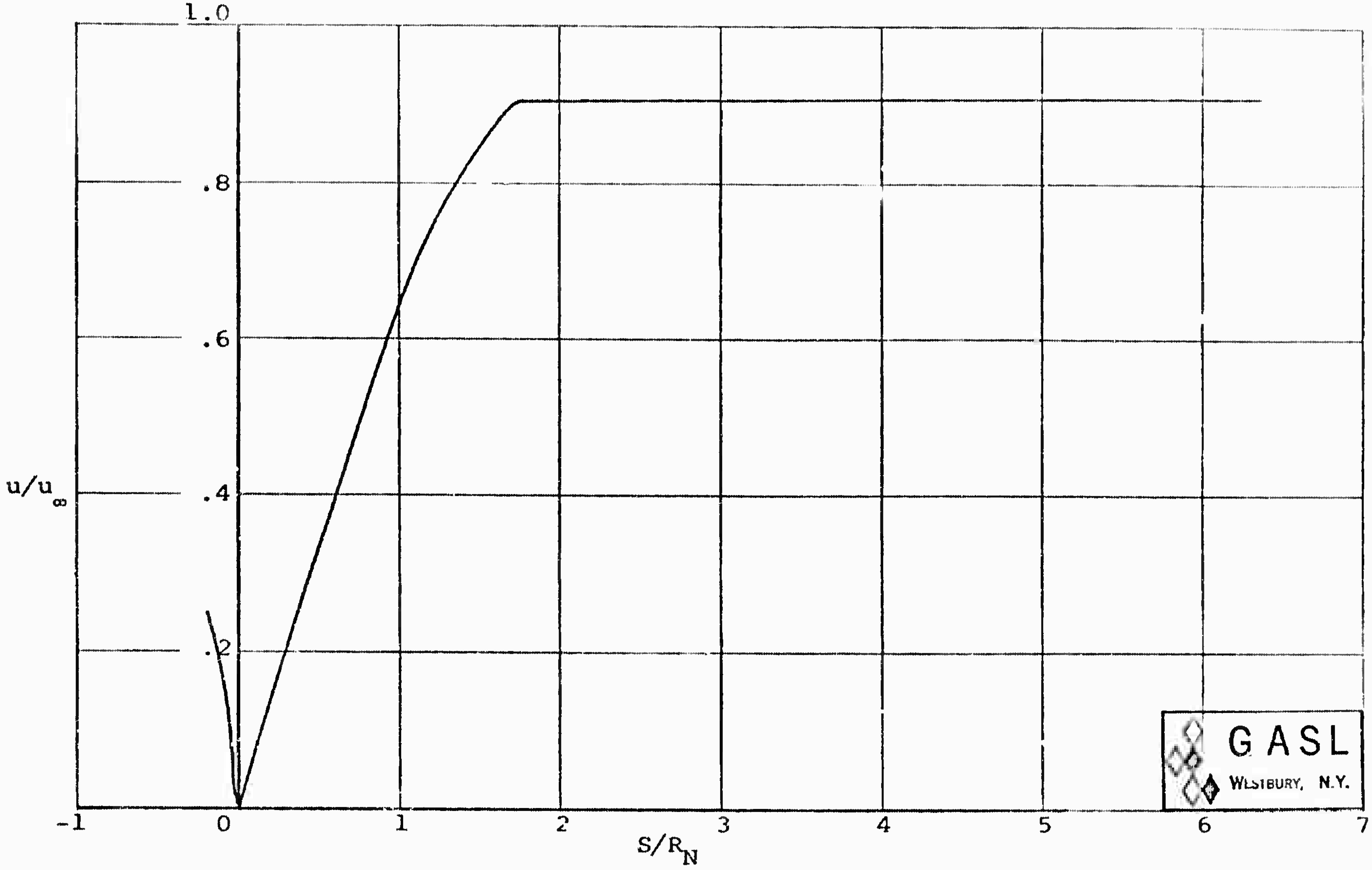


FIG. 3: VELOCITY ALONG BODY STREAMLINE

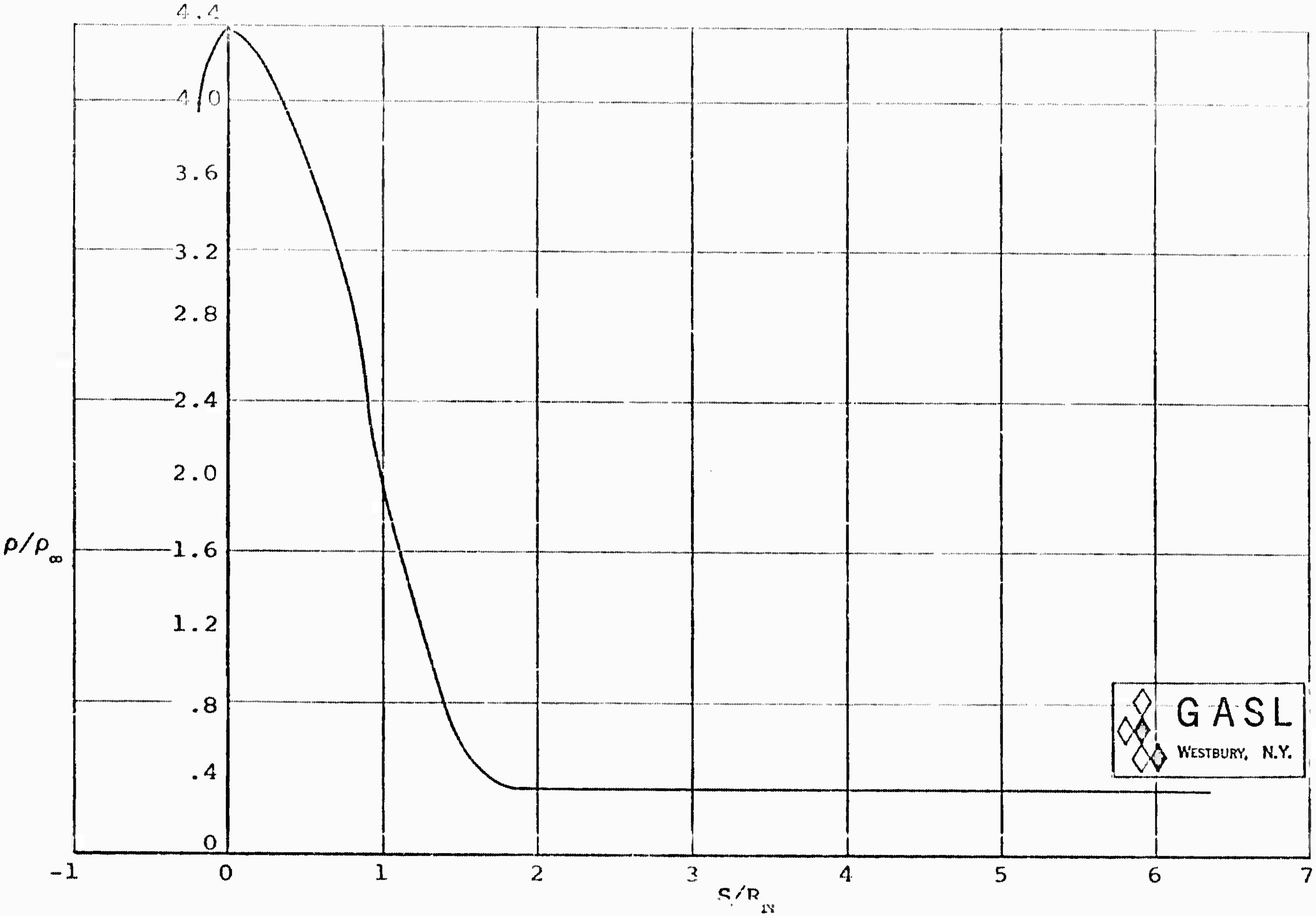


FIG. 5: DENSITY DISTRIBUTION ALONG BODY STREAMLINE

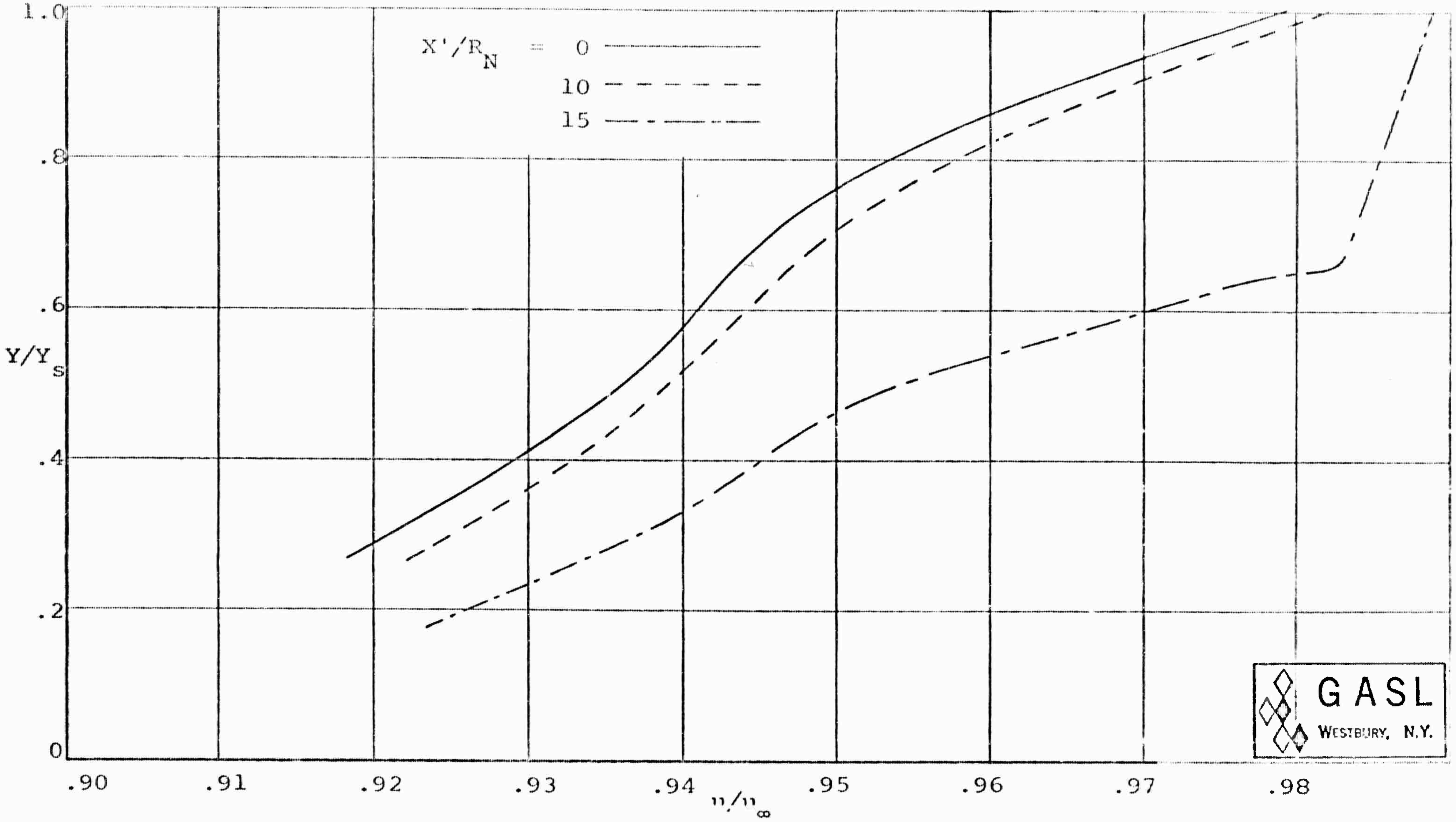


FIG. 7: VELOCITY PROFILES IN INVISCID REGION

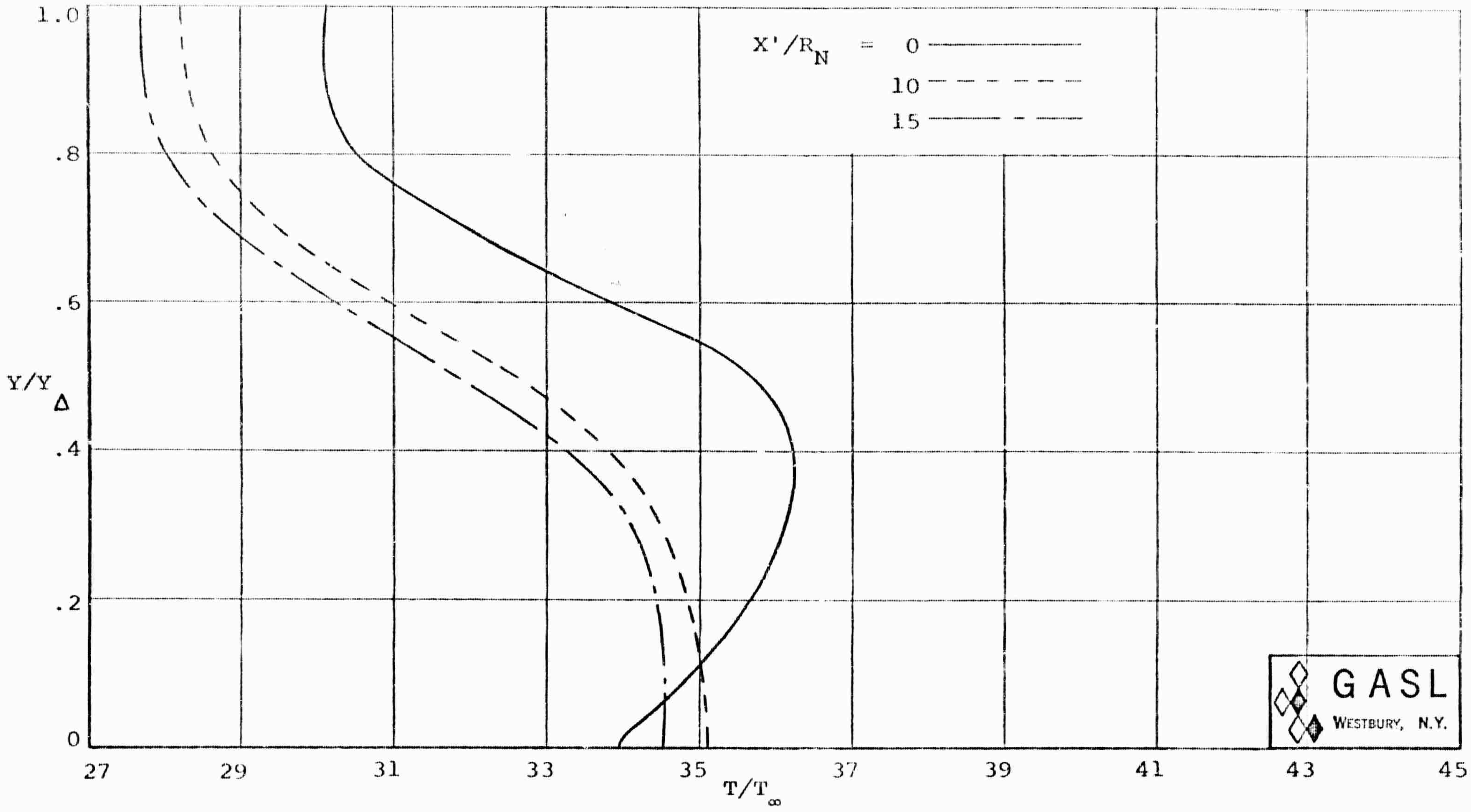


FIG. 8: TEMPERATURE PROFILES IN VISCOUS WAKE REGION

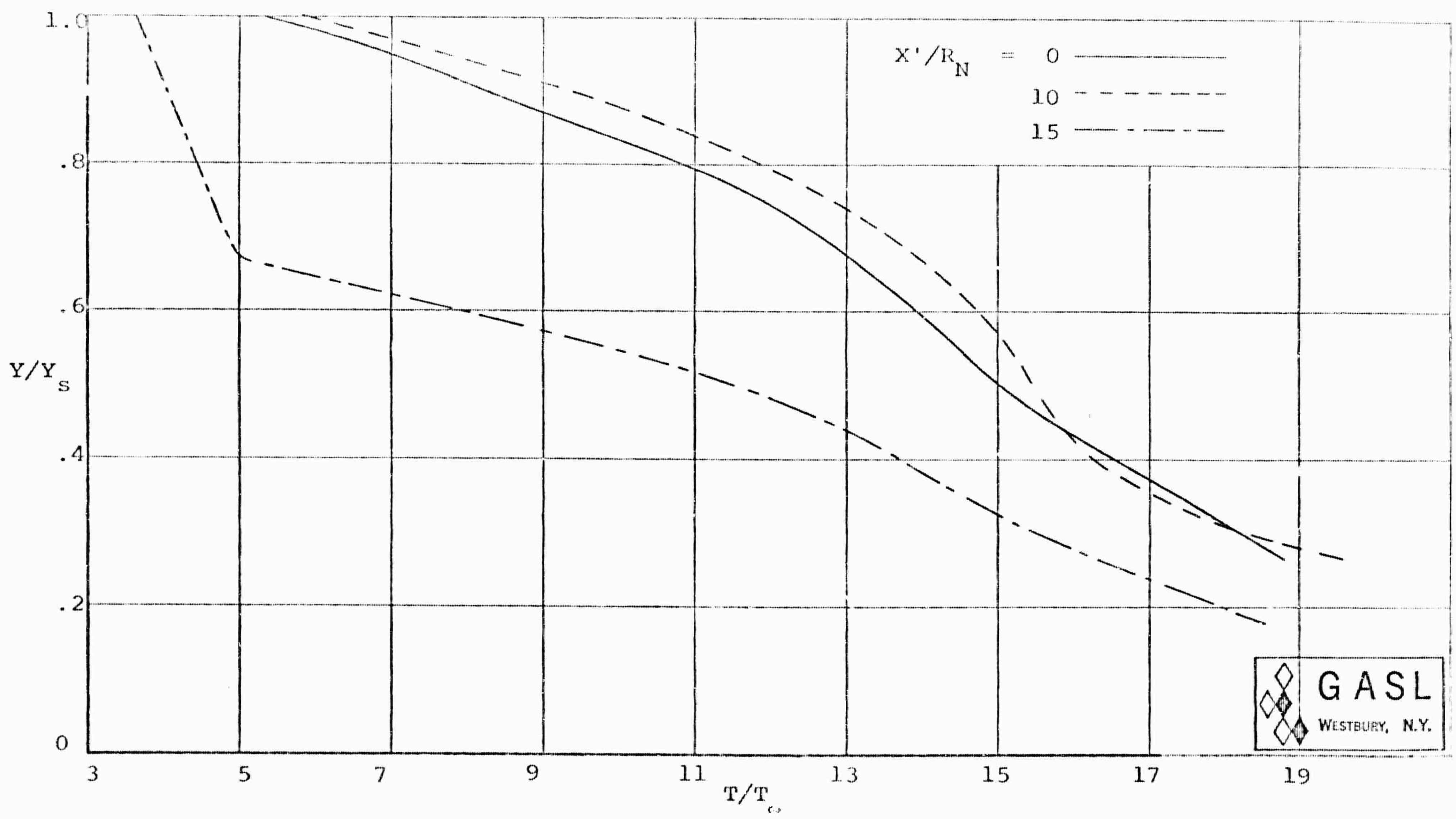


FIG. 9: TEMPERATURE PROFILES IN INVISCID REGION

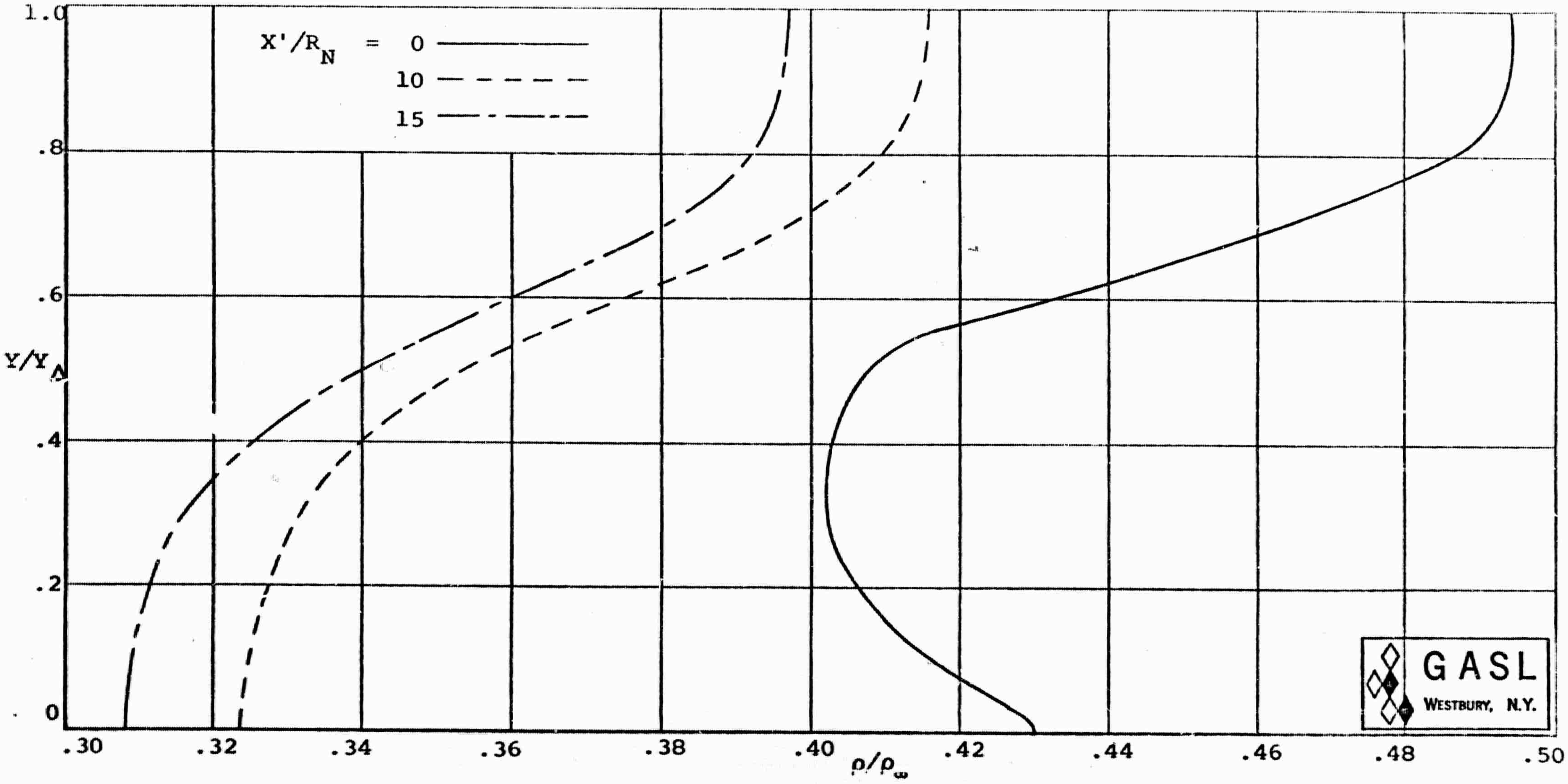


FIG. 10: DENSITY PROFILES IN VISCOUS WAKE REGION

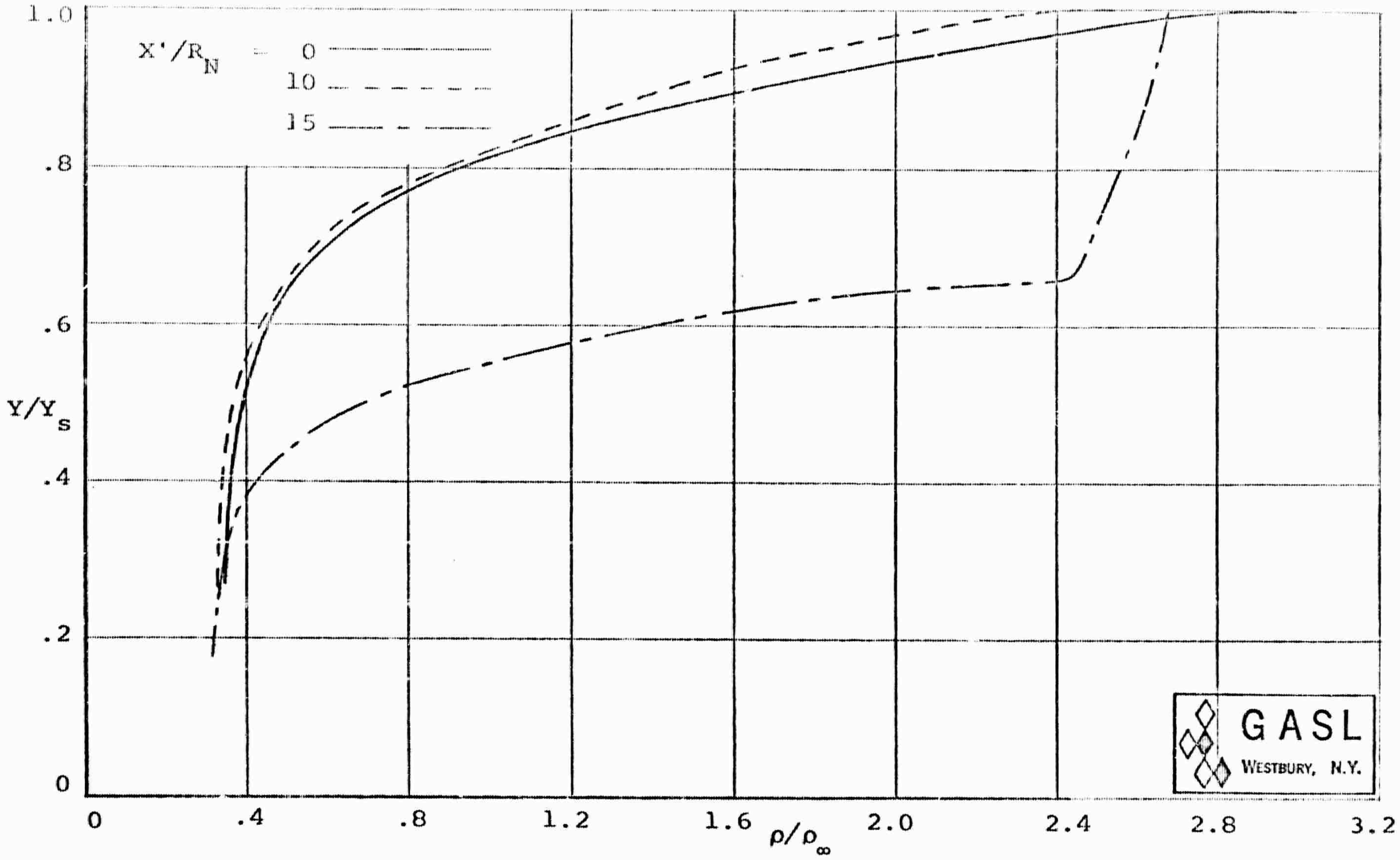


FIG. 11: DENSITY PROFILES IN INVISCID REGION

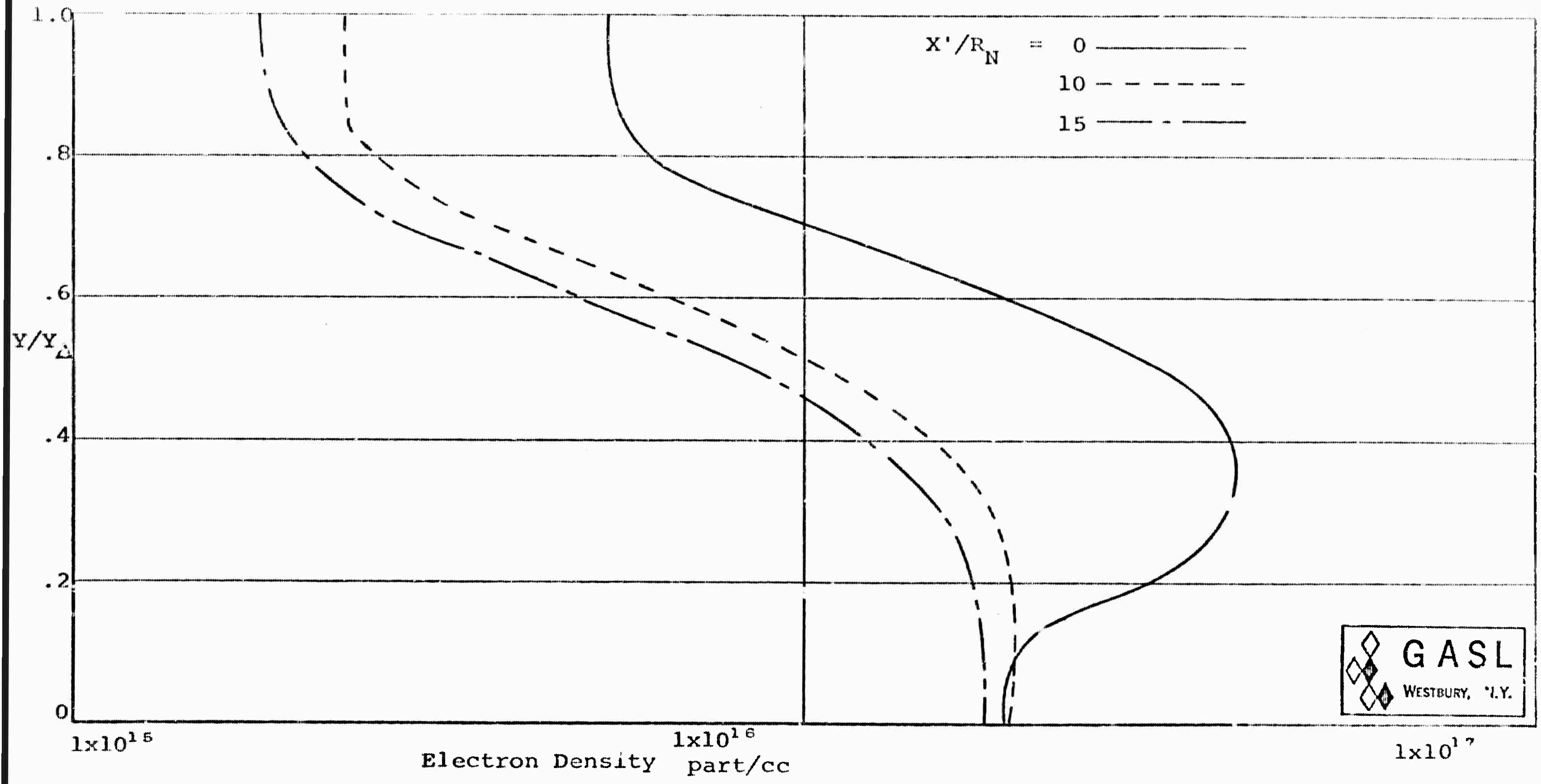


FIG. 12: ELECTRON DENSITY PROFILES IN VISCOUS WAKE REGION

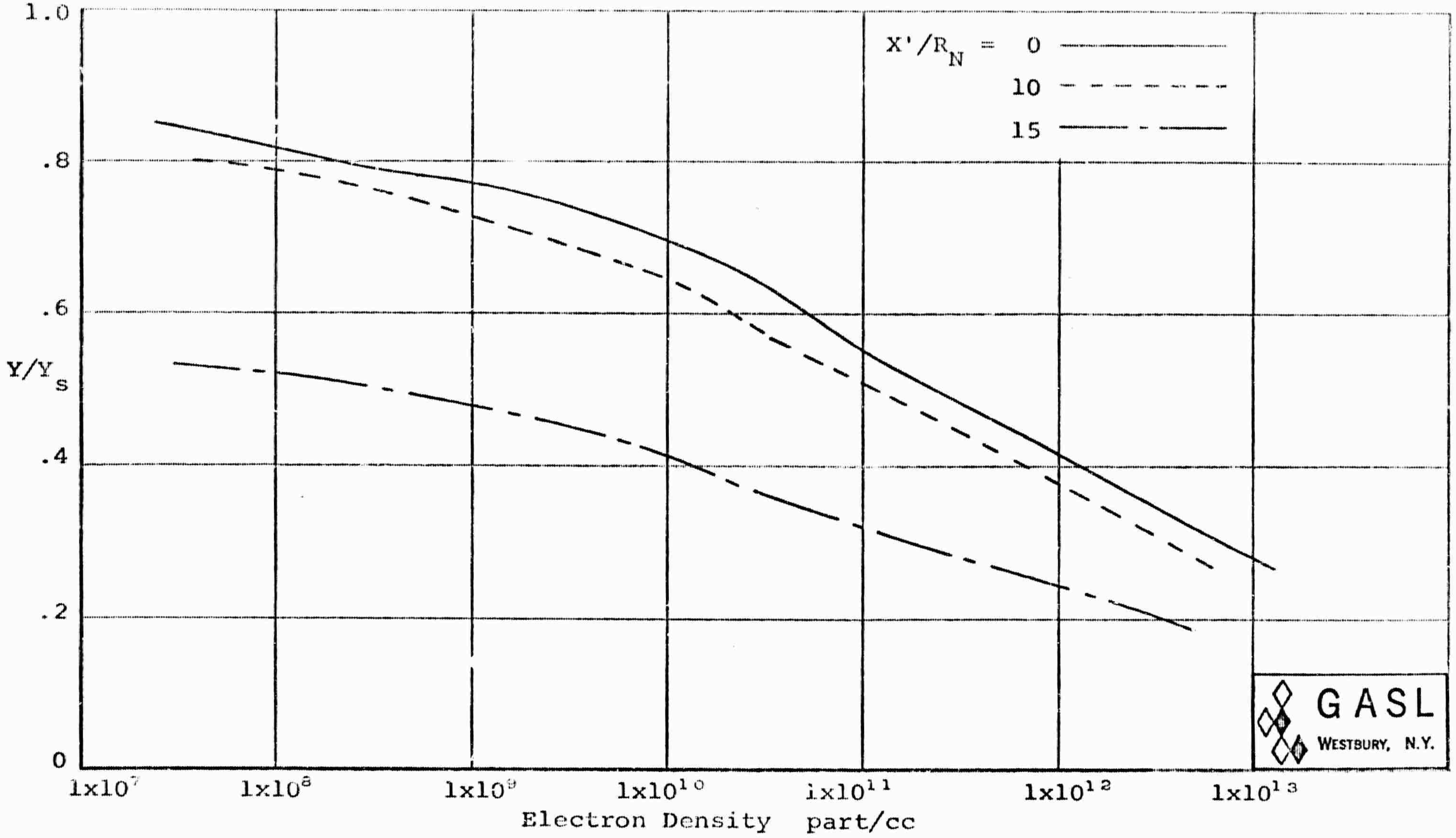


FIG. 13: ELECTRON DENSITY PROFILES IN INVISCID REGION

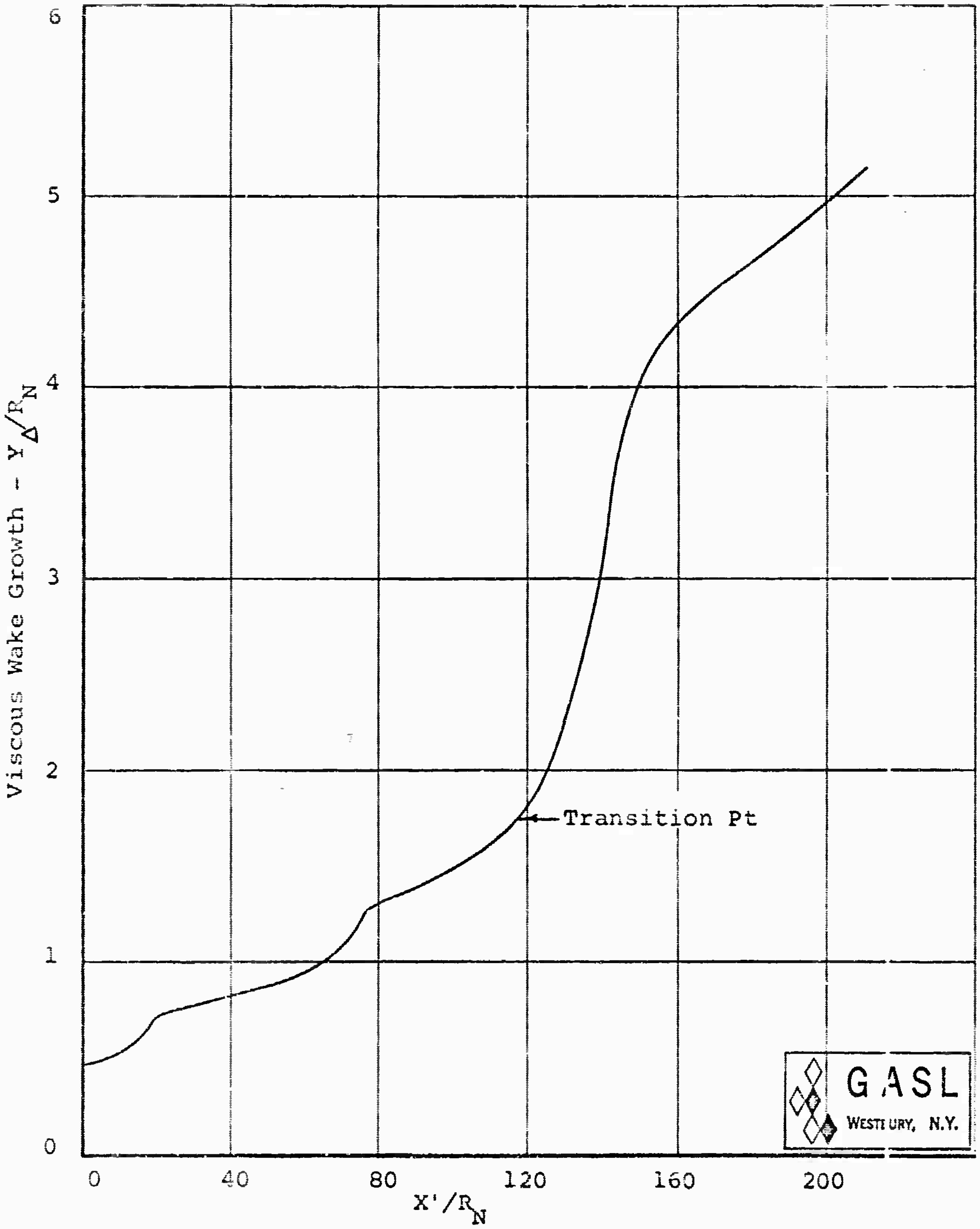


FIG. 14: GROWTH OF VISCOUS WAKE

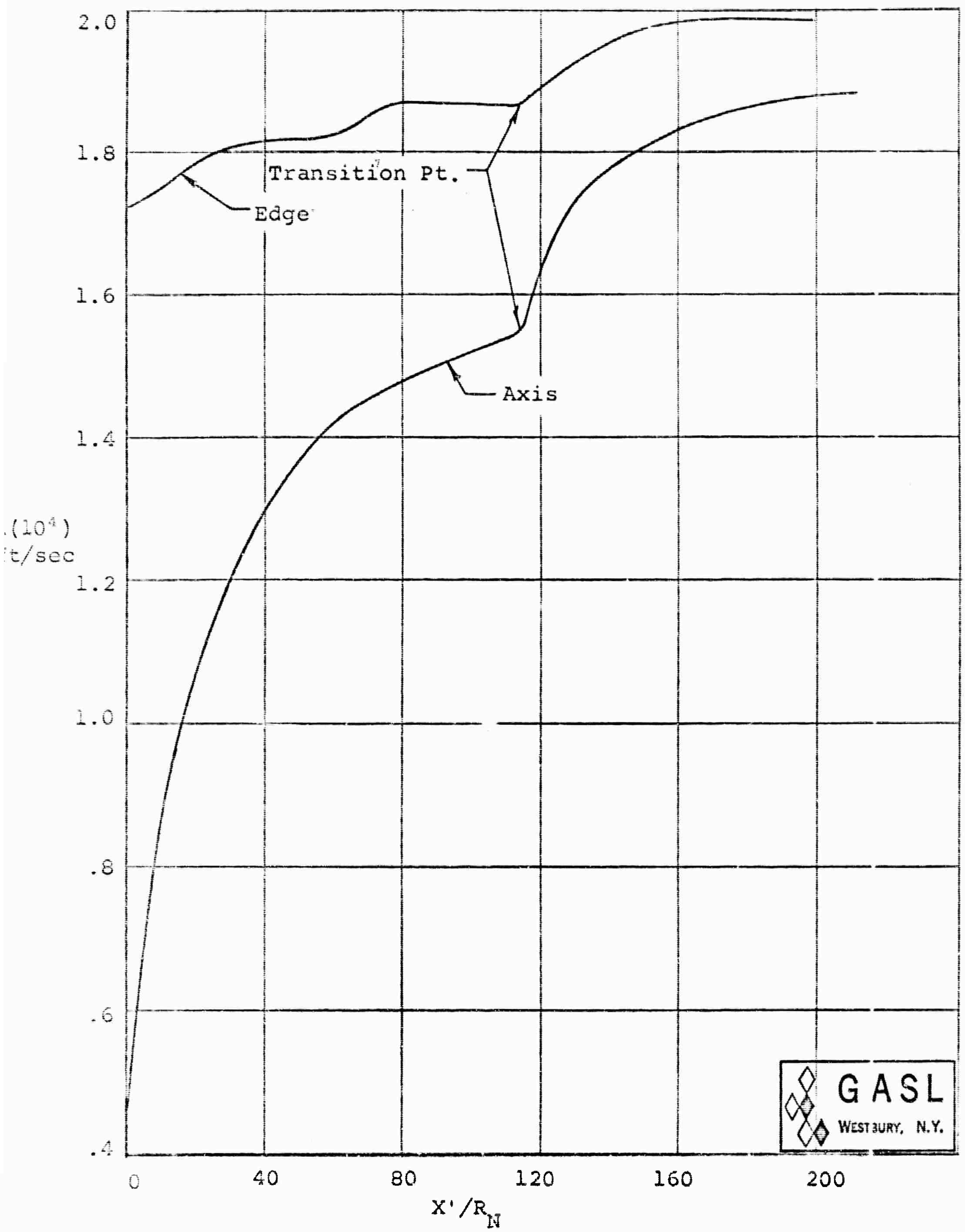


FIG. 15: VISCOUS WAKE AXIS AND EDGE VELOCITY

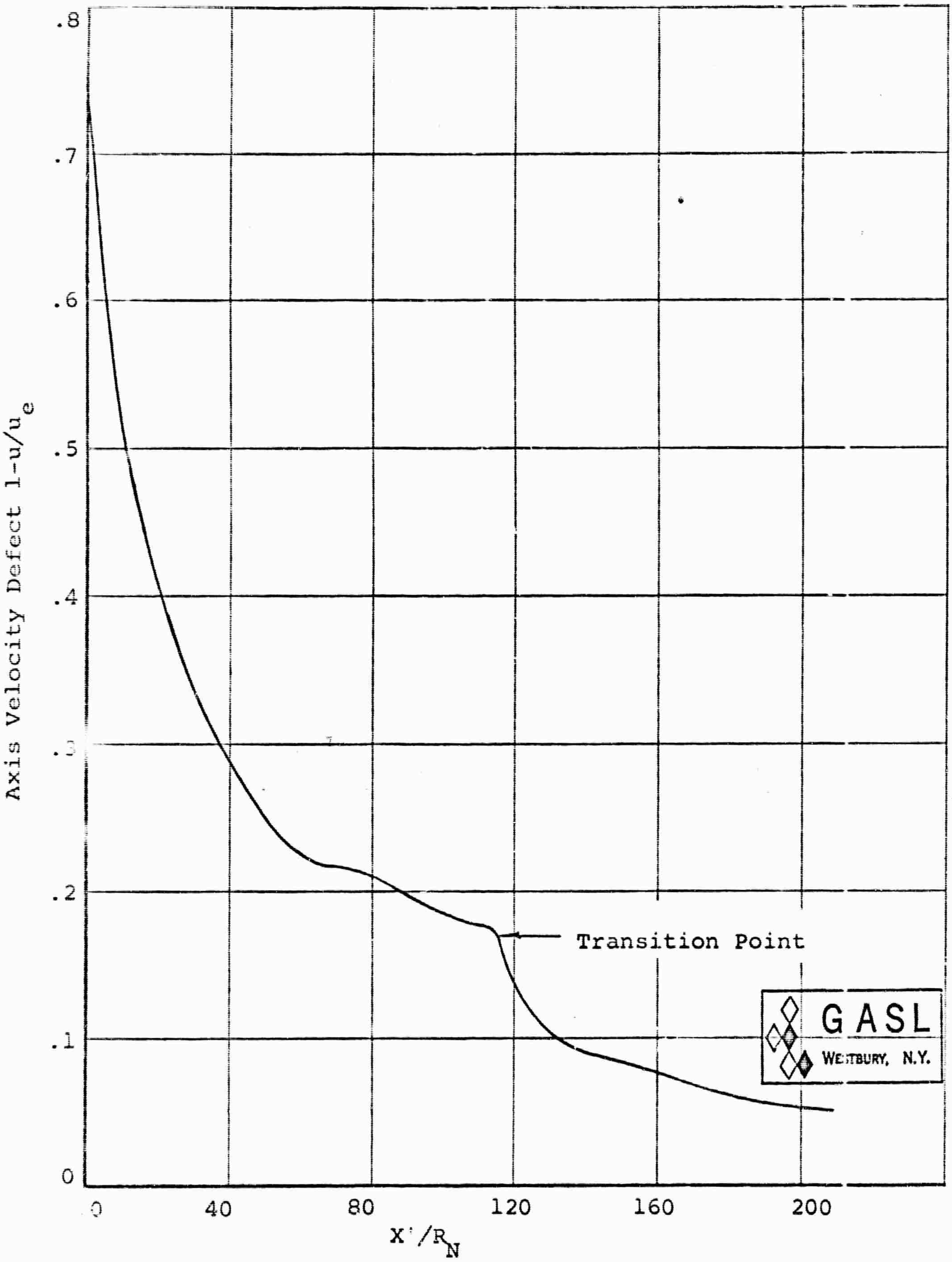

.8
.7
.6
.5
.4
.3
.2
.1
0
0
40
80
120
160
200
Axis Velocity Defect $1-u/u_e$
X'/R_N
Transition Point
GASL
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FIG. 16

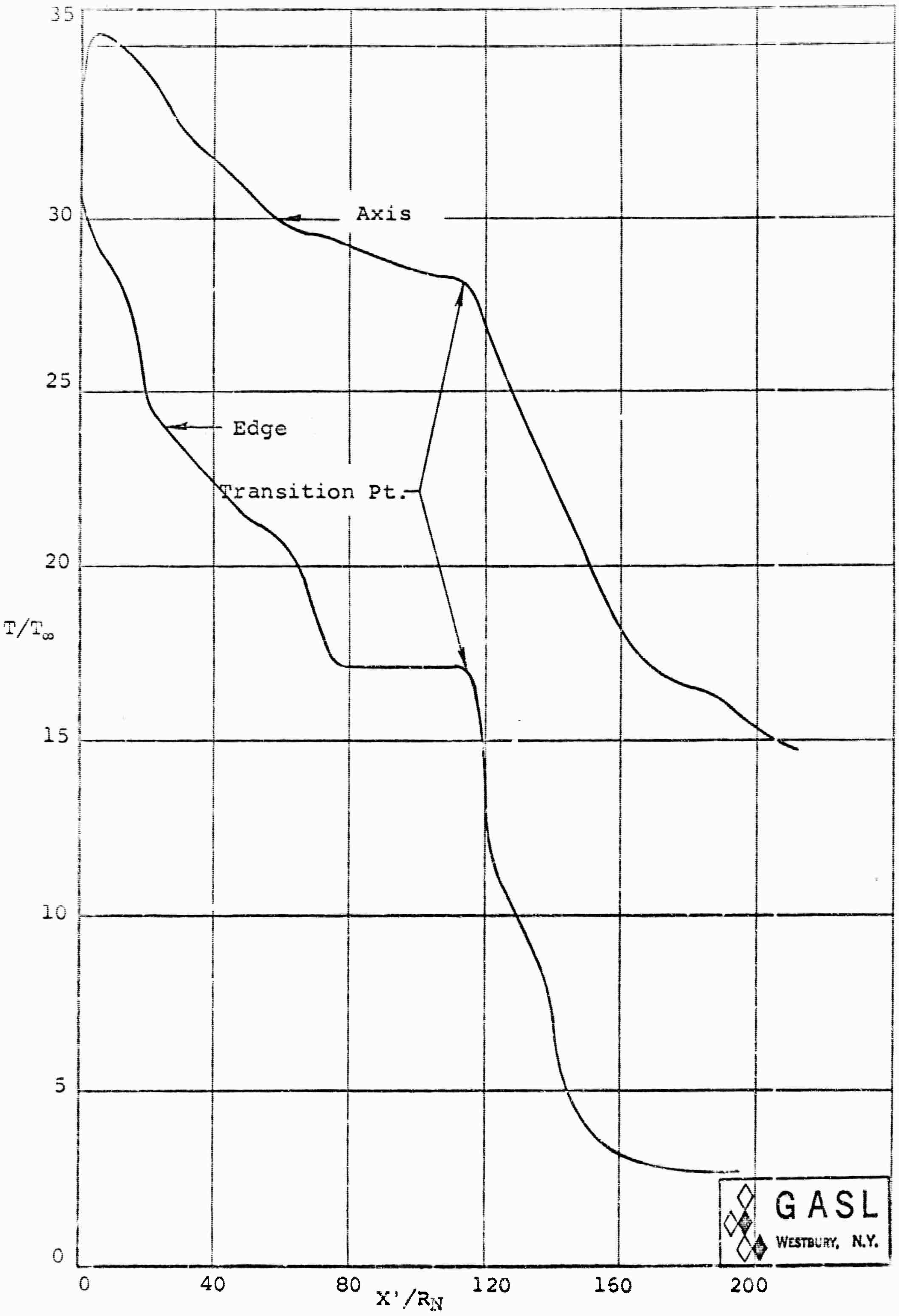

FIG. 17: AXIS AND EDGE TEMPERATURES IN VISCOUS WAKE REGION

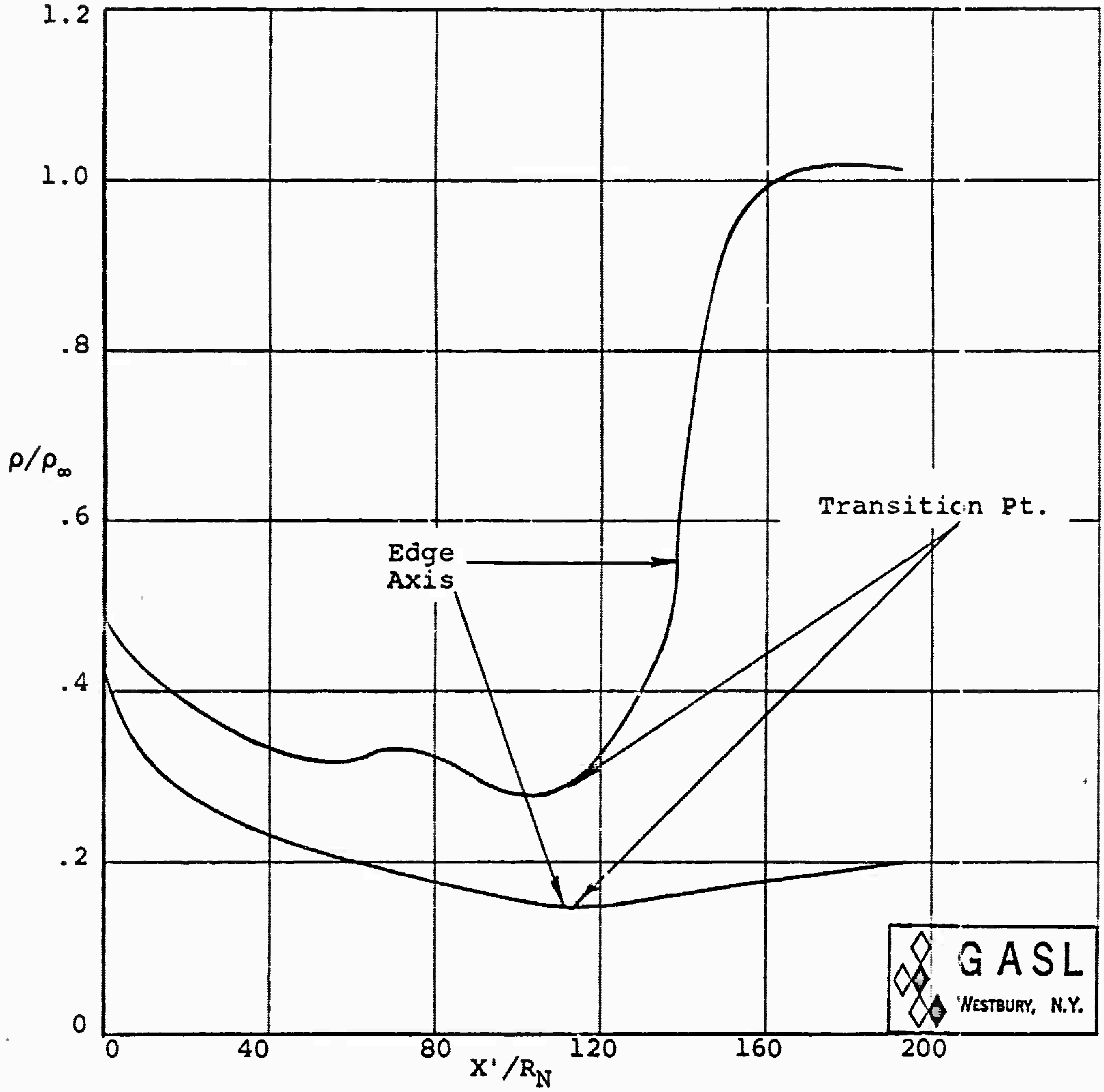

FIG. 18: AXIS AND EDGE DENSITIES IN VISCOUS WAKE REGION

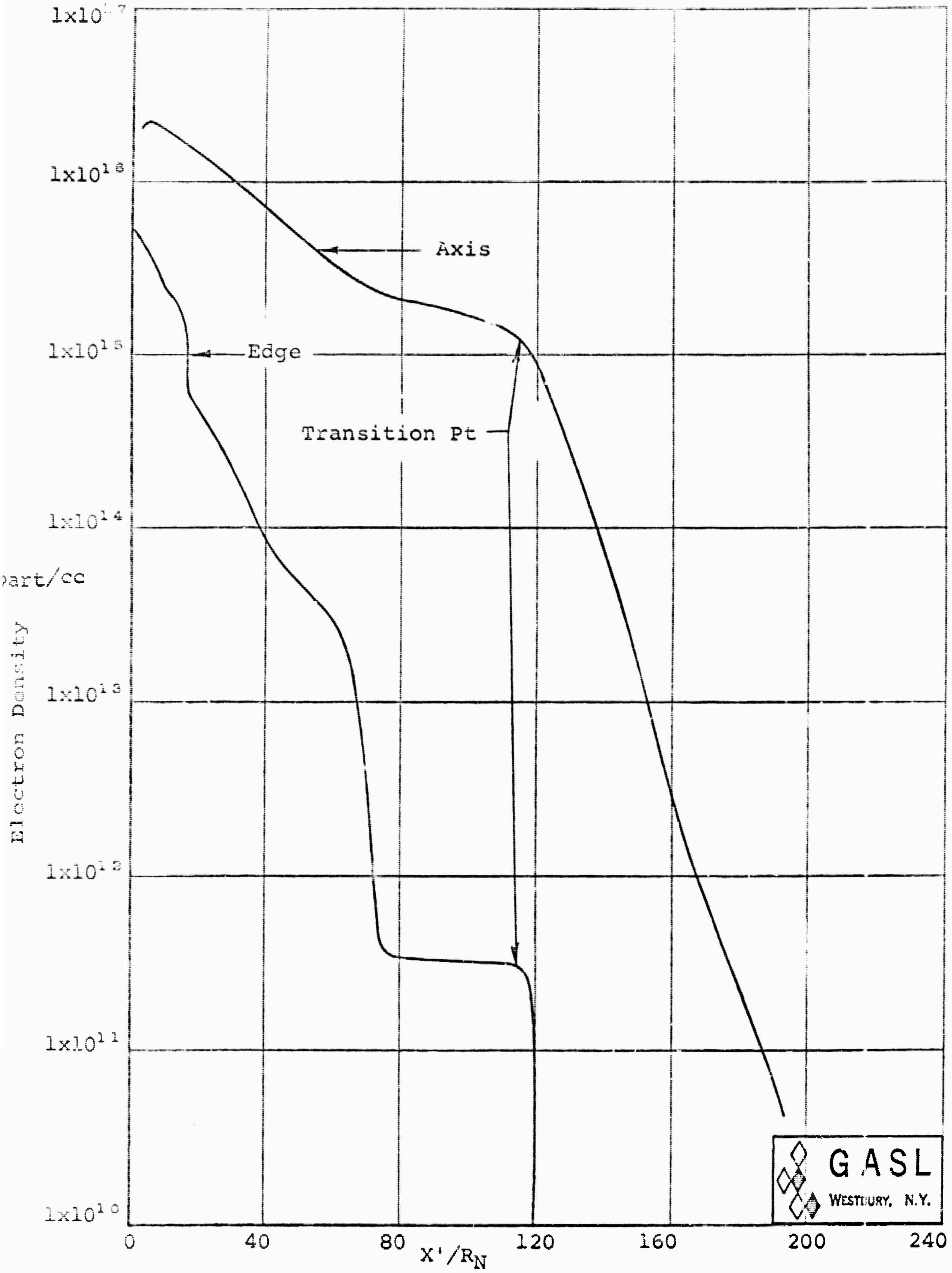

FIG. 19: AXIS AND EDGE ELECTRON DENSITIES IN VISCOUS WAKE

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