RTD-TDR-63-4044
PART II

PRESSURE MEASUREMENTS FOR MACH 8 FLOWS OVER EXPANSION CORNERS AND RAMPS ON AN INTERNALLY COOLED MODEL

PART II — FLOWS OVER A FLAT PLATE WITH AND WITHOUT A PARTIAL SPAN RAMP

PART OF AN INVESTIGATION OF HYPERSONIC FLOW SEPARATION AND CONTROL CHARACTERISTICS

TECHNICAL DOCUMENTARY REPORT No. RTD-TDR-63-4044, PART II

OCTOBER 1964

AIR FORCE FLIGHT DYNAMICS LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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Bethpage, New York; Author: Louis G. Kaufman II)

NOTICES

500 - December 1964 - 448-18-453

FOREWORD

This entire report, written in three parts under separate covers, presents the results of a portion of the experimental program for the investigation of hypersonic flow separation and control characteristics being conducted by the Research Department of Grumman Aircraft Engineering Corporation, Bethpage, New York. Mr. Donald E. Hoak of the Flight Dynamics Laboratory, Research and Technology Division, located at Wright-Patterson Air Force Base, Ohio, is the Air Force Project Engineer for the program, which is being supported primarily under Contract AF33(616)-8130, Air Force Task 821902.

The author wishes to dedicate this to the memory of his beloved Grandmother: MARY SOMERVILLE WELCH. He also wishes to express his appreciation to the staff of the von Karman Facility for their helpfulness in conducting the tests, and particularly to Messrs. Schueler and Baer for providing the machine plotted graphs of the experimental data included in this report. Ozalid reproducible copies of the tabulated data are available on loan from the Flight Control Division of the Flight Dynamics Laboratory.

The parts which constitute a complete report for this segment of the over-all program are:

Part I: Expansion Corner Flows

Part II: Flows Over a Flat Plate with and without a Partial Span Ramp

Part III: Flows Over Full Span Ramps Mounted on a Flat Plate

ABSTRACT

Pressure distributions were obtained for Mach 8 flows over a sharp 40 degree expansion corner and ahead of ramps on an internally cooled model. Full and partial span ramps, having wedge angles up to 30 degrees, were tested at model angles of attack from -45 to +10 degrees for Reynolds numbers ranging from 1.1 to 3.3 million. The model wall temperature was maintained at fairly constant levels ranging from 450 to 1150 degrees Rankine.

This report has been reviewed and is approved.

C. R. Bryan

for W.A. SLOAN, Jr.
Colonel, USAF
Chief, Flight Control Division
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LIST OF ILLUSTRATIONS

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*See Table II, page 9, for figure numbers corresponding to particular test conditions.

LIST OF SYMBOLS

C_p	pressure coefficient, $C_p \equiv (p-p_\infty)/q_\infty$
M_∞	free stream Mach number
p	pressure (psia)
p_o	stagnation pressure (psia)
p_∞	free stream static pressure (psia)
q_∞	free stream dynamic pressure (psia)
Re_∞/ft	Reynolds number per foot, $Re_\infty/ft \equiv \rho_\infty U_\infty/\mu_\infty$
T_{aw}	adiabatic wall temperature (°R)
T_o	stagnation temperature (°R)
T_w	wall temperature (°R)
T_∞	free stream static temperature (°R)
U_∞	free stream velocity (ft/sec)
α	angle of attack of model (deg.)
μ_∞	viscosity of air in the free stream (slugs/ft sec)
ρ_∞	density of air in the free stream (slugs/ft^3)

INTRODUCTION

The experimental data generated for an investigation of hypersonic flow separation and aerodynamic control characteristics are presented in a series of reports, of which this is one. Pressure, heat transfer, and force data are being obtained for hypersonic flows over "basic geometries," such as a wedge mounted on a flat plate, and for "typical" hypersonic flight configurations with aerodynamic control surfaces. The experimental portion of the program required a total of 11 models (see Fig. 1, p. 12); 8 for tests in the von Karman Facility of the Arnold Engineering Development Center and 3 for tests in the Grumman Hypersonic Shock Tunnel (Refs. 1 and 2). The data obtained from AEDC tests of one of the models are given in this three-volume report (see Foreword).

Pressure distributions were obtained over a sharp expansion corner and ahead of wedge shaped ramps mounted on an internally cooled flat plate. The data are to be used in investigating the effects of wall temperature on the pressure distribution and region of separated flow ahead of ramps. These effects must be clearly understood before comprehensive conclusions can be drawn from earlier tests during which aerodynamic heating data were obtained on "cold" models and pressure data were obtained on the same models after they had reached their equilibrium temperatures. The data presented herein were obtained in the AEDC 50-inch Mach 8 Tunnel (Ref. 3). Geometrically similar models, without internal cooling but with both heat transfer and pressure instrumentation, were tested in the AEDC 40-inch and 50-inch tunnels and in the Grumman Hypersonic Shock Tunnel (see Fig. 1).

This report (Part II) presents data obtained on the upper, flat plate, surface of the model and on the face of a 30°, partial span, ramp mounted on the flat plate. Data were obtained for three internal coolant flow rates both with and without the ramp mounted on the flat plate.

MODEL

Photographs of the model, installed in the AEDC 50-inch Mach 8 Tunnel, are shown in Figs. 2 and 3. The model has a nominally sharp leading edge and a 12-inch square planform. The ramp, shown mounted

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on the flat plate in Fig. 3, has a 3-inch chord and 4-inch span. As shown in the photographs, both the ramp and the basic model have coolant exhaust fairings attached to their bases.

The coolant, a mixture of low temperature oxygen and nitrogen, was supplied through 1-inch lines to settling chambers in the basic model and in the ramp. The coolant then passed through channels adjacent to the face of the ramp and the flat plate surface of the model, thereby cooling these surfaces by conduction and convection.

The channels were 1/10 inch thick by 4 inches wide and extended essentially from the ramp and flat plate leading edges to their trailing edges. Turning vanes were installed at the trailing edge of the channel for the flat plate surface. Thus, upon leaving the channel, the coolant for the basic model was deflected upstream into the outboard, interior, portions of the model. The coolant was then allowed to exhaust into the stream flow downstream of the fairings attached to the base of the model. The channels were slightly restricted at their trailing edges so that the minimum cross-sectional areas occurred at the channel exits, thereby ensuring that the coolant flows were choked at the exits and subsonic throughout the channels.

Although the coolant pressure never exceeded 60 psia in the model stilling chamber, and was allowed to expand greatly upon exiting from the channel into the outboard portions of the model, fairings were attached to the base of the model as well as to the base of the ramp. The fairings were designed to prevent possible "pluming" of the coolant exhausting into the tunnel stream air from the base of the model; the openings in the sides of the fairings further ensured that any pluming of the coolant flow would be in the horizontal rather than in the vertical plane.

The coolant channels were fabricated of 0.10 inch thick berrylico sheet. The upper surface of the channel, (the inside wall of the berrylico sheet forming the central portion of the flat plate surface of the model), was roughened and the entrance to the channel from the stilling chamber was made through a sharp expansion corner. This design, along with the pressure tubes passing through the channel, was intended to make the coolant flow turbulent in the channel; thereby increasing the heat transfer to the coolant and hence the coolant effectiveness. Because of its high thermal conductivity, relatively thick berrylico sheet was used in the attempt to maintain as uniform a wall temperature as possible throughout the central portion of the flat plate surface of the model. Furthermore, the central portion of the flat plate surface was insulated from the remainder of the model. The internally cooled ramp was supplied by a separate cooling line and had a similarly designed cooling system.

Although it had been desired to cool the entire upper surface of the model, the necessary coolant mass flow rate would have been tripled and would have exceeded the supply of liquid nitrogen readily available at the test facility. Thus, just the central portion was cooled directly. The coolant was then allowed to expand into the outboard portions of the model and thereby minimize, as much as practical, the temperature differential between the central and outboard portions of the flat plate.

Thermocouples were mounted 0.010 inch below the surfaces of the flat plate and face of the internally cooled ramp so that the surface wall temperatures could be monitored and recorded. Locations of the thermocouples and pressure taps are indicated in Fig. 4. Four thermocouples were located in the cooled portion of the flat plate; three thermocouples were positioned in the outboard portions of the flat plate; and two thermocouples were mounted in the face of the internally cooled ramp.

Detailed pressure distributions were afforded by closely spaced pressure taps along the centerlines of the flat plate and the face of the ramp. The flat plate surface has 61 static pressure taps arranged, essentially, in five streamwise lines; three on the cooled portion and two further outboard. Nine of these taps are covered by the ramp which has 16 taps in its face.

TEST CONDITIONS

Pressure data and wall temperature distributions were obtained at $M_\infty = 8$ for free stream Reynolds numbers per foot of 1.1, 2.2, and 3.3 million. The tunnel conditions corresponding to the different Reynolds numbers are shown in Table I.

The basic, flat plate, model was pitched from 43° nose down to 10° nose up; the model with the ramp attached was tested at angles of attack from -15 to +10°. Configuration, model angles of attack (referenced to the flat plate upper surface of the model), and free stream Reynolds numbers are indicated in Table II.

The coolant flow rate (also indicated in Table II), was adjusted to yield three different temperature levels for the upper surface of the model. The minimum temperature (maximum cooling) was just sufficient to avoid condensation and icing on the model; the maximum temperature was essentially the equilibrium wall temperature for the upper surface of the model with no cooling. The medium coolant flow rate was adjusted so that the flat plate temperature level was approximately midway between the minimum and maximum values. The temperature levels were, approximately, 500, 800, and 1100° Rankine.

The thermocouples mounted in the upper surface of the model (see Fig. 4) were used to monitor the temperatures and adjust the coolant flow rate. Typical temperature distributions are given in Table III. As indicated in the table, it was not possible to maintain either uniform or constant temperatures on the flat plate during any one set of test conditions. Temperatures measured by the thermocouples varied as much as 15° during the five-minute intervals required to record the pressure data for one set of test conditions. Further, the temperature varied over the flat plate surface by as much as 30°.

Although the ramp and the flat plate had separate cooling systems, it was necessary to join them to a common supply of coolant. Thus, because of the equal coolant flow rates and higher aerodynamic heating rates, the ramp surface temperatures were considerably higher than those on the flat plate. The reduced temperatures on the outboard portions of the model, indicated in Table III, are attributed to the coolant deflected into these portions after exiting from the flat plate coolant channel (see model).

The flat plate surface temperature was independent of the angle of attack and Reynolds number when the model was being cooled, but varied substantially for the uncooled cases. Thus, for a negative 43° angle of attack and a free stream Reynolds number of 3.3 million, a maximum temperature of 1240° Rankine on the flat plate surface was recorded. For the same test conditions, using a maximum coolant flow rate requiring approximately one gallon of liquid nitrogen per minute, a minimum temperature of 450° Rankine was indicated by the same thermocouple. For this maximum cooling condition, the pressure of the coolant gas in the model settling chamber was less than 65 psia, the pressure in the tank of liquid nitrogen was 75 psia.

DATA REDUCTION AND ACCURACY

The pressure data were reduced to standard pressure coefficient form:

$$C_p = \frac{p - p_\infty}{q_\infty}$$

where p is the measured pressure, p_∞ is the free stream static pressure, and q_∞ is the free stream dynamic pressure. The inaccuracy in the measured pressure varies from ±0.003 psia for pressures below 0.40 psia, to 0.026 psia for pressures greater than 15 psia. Pressure coefficient uncertainties vary, for example, from 0.004 for $C_p < 0.3$ and $Re_\infty/ft = 1.1$ million, to 0.013 for $C_p = 2.0$ and $Re_\infty/ft = 3.3$ million. At the higher pressure coefficients, the greatest part of the inaccuracy is due to the deviations in the Mach 8 free stream dynamic pressure (Ref. 5).

The automatic plotting machines, used in presenting the data herein, introduce another source of possible error. The discrepancy in the plotted pressure coefficients due to this machine error should not exceed ±0.01. Nevertheless, there is always the rare possibility that a point will be completely misplotted. Each graph has been inspected and questionable points checked with the tabulated pressure coefficients.

RESULTS

Table II summarizes the data obtained on the upper surfaces of the model and indicates the corresponding figure numbers where the sets of data are presented. The AEDC group number is presented in the last column. This number indicates the order in which the data were obtained and is to be used when referring to the tabulated data.

Shadowgraph flow photographs were obtained for the conditions indicated in Table II. These photographs show just the flow over the upper portion of the model. In order to include the entire upper surface flow in just one photograph, the camera was rotated in several instances (as apparent from the orientation of the model and the test conditions indicated on the flow photographs).

Streamwise and spanwise plots of the pressure coefficients are presented in Figs. 63 through 128. The first page of each figure presents streamwise plots of the pressure coefficients at five semispan stations, three on the cooled portion of the flat plate and two further outboard (see Fig. 4). The second page of each figure presents cross plots of the data for six streamwise stations, three ahead of the ramp leading edge. In the streamwise plots, the pressures measured by tap numbers 921 and 929 (on the port side of the model), are presented just downstream of the values obtained from the corresponding taps (numbers 221 and 229) on the starboard side of the model.

Although the accuracy of the plotted data should suffice for engineering purposes, ozalid reproducible copies of the tabulated data are available on loan (see Foreword). The plotted data may be read accurately using standard 20/inch grid, tracing graph paper overlays.

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3. Arnold Center, Test Facilities Handbook, Arnold Air Force Station, January 1961.

4. Kaufman, Louis G. II, Pressure and Heat Transfer Measurements for Hypersonic Flows Over Expansion Corners and Ahead of Ramps; Part I: Mach 5 and 8 Data for Expansion Corner Flows, Part II: Mach 5 Pressure Data for Flows Ahead of Ramps, Part III: Mach 8 Pressure Data for Flows Ahead of Ramps, Part IV: Mach 8 Heat Transfer Data for Flows Ahead of Ramps, ASD-TDR-63-679, July 1963.

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10. Baer, A.L., An Investigation of Separated Flows on Two-Dimensional Models at Mach Numbers 5 and 8, AEDC-TDR-63-200, October 1963.

TABLE I

TUNNEL CONDITIONS

$\frac{Re_\infty}{10^6 ft}$	1.1	2.2	3.3
M_∞	8.04	8.08	8.09
p_∞ (psia)	0.025	0.049	0.074
q_∞ (psia)	1.13	2.24	3.37
p_o (psia)	252	510	770
T_o (°R)	1,350	1,350	1,350

TABLE II

TEST CONDITIONS

(Sheet 1 of 2)

RAMP Off	RAMP On	Coolant Flow Rate*	Re_∞ / 10^6 ft	α (deg.)	Fig. Nos. Photo+	Fig. Nos. C_p	AEDC Group Nos.
X		Off	1.1	-43		63	131
X		Off	2.2	-43		64	125
X		Off	3.3	-43	5	65	121
X		Maximum	3.3	-43	6	66	122
X		Off	1.1	-40		67	130
X		Off	3.3	-40	7	68	120
X		Off	1.1	-35		69	129
X		Off	3.3	-35	8	70	119
X		Off	1.1	-30		71	128
X		Off	2.2	-30		72	124
X		Off	3.3	-30	9	73	118
X		Maximum	3.3	-30	10	74	123
X		Off	1.1	-25		75	127
X		Off	3.3	-25	11	76	117
X		Off	1.1	-20		77	126
X		Off	3.3	-20	12	78	116
X		Off	1.1	-15	13	79	43
X		Maximum	1.1	-15	14	80	45
X		Off	3.3	-15	15	81	20
X		Medium	3.3	-15	16	82	29
X		Maximum	3.3	-15	17	83	34
	X	Maximum	1.1	-15	18	84	11
	X	Off	3.3	-15	19	85	19
	X	Maximum	3.3	-15	20	86	5
X		Off	1.1	-10	21	87	42
X		Maximum	1.1	-10	22	88	46
X		Off	3.3	-10	23	89	21
X		Maximum	3.3	-10	24	90	33
	X	Maximum	1.1	-10	25	91	10
	X	Off	3.3	-10	26	92	18
	X	Maximum	3.3	-10	27	93	4
X		Off	1.1	-5	28	94	41
X		Maximum	1.1	-5	29	95	47
X		Off	3.3	-5	30	96	22
X		Medium	3.3	-5	31	97	28
X		Maximum	3.3	-5	32	98	32

TABLE II

TEST CONDITIONS

(Sheet 2 of 2)

RAMP		Coolant Flow Rate*	$\frac{Re_\infty}{10^6 \text{ ft.}}$	α (deg.)	Fig. Nos.		AEDC Group Nos.
Off	On				Photo+	C_p	
	X	Maximum	1.1	-5	33	99	9
	X	Off	3.3	-5	34	100	17
	X	Maximum	3.3	-5	35	101	3
X		Off	1.1	0	36	102	40
X		Maximum	1.1	0	37	103	48
X		Off	2.2	0	38	104	36
X		Maximum	2.2	0	39	105	38
X		Off	3.3	0	40	106	23
X		Medium	3.3	0	41	107	26
X		Maximum	3.3	0	42	108	31
	X	Off	1.1	0	43	109	13
	X	Maximum	1.1	0	44	110	8
	X	Off	2.2	0	45	111	14
	X	Maximum	2.2	0	46	112	6
	X	Off	3.3	0	47	113	16
	X	Maximum	3.3	0	48	114	2
X		Off	1.1	+5	49	115	39
X		Maximum	1.1	+5	50	116	49
X		Off	3.3	+5	51	117	24
X		Maximum	3.3	+5	52	118	30
	X	Off	1.1	+5	53	119	12
	X	Maximum	1.1	+5	54	120	7
	X	Off	3.3	+5	55	121	15
	X	Maximum	3.3	+5	56	122	1
X		Off	1.1	+10	57	123	44
X		Maximum	1.1	+10	58	124	50
X		Off	2.2	+10	59	125	37
X		Off	3.3	+10	60	126	25
X		Medium	3.3	+10	61	127	27
X		Maximum	3.3	+10	62	128	35

*See pages 3, 4 and 11 for discussion of coolant flow rates and typical temperature distributions.

+Shadowgraph flow photographs.

TABLE III

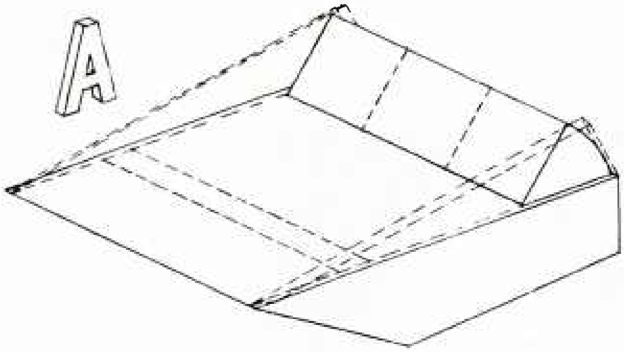
TYPICAL TEMPERATURE DISTRIBUTIONS

Cooling Flow Rate	$\frac{Re_\infty}{10^6 \text{ ft}}$	Thermocouple numbers (refer to Fig. 4 for location) All temperatures in degrees Rankine 991	992	993	995	996	997	998	999
OFF	1.1	870°	860°	860°	900°	910°	1080°	970°	900°
MAXIMUM		510°	490°	480°	590°	590°	970°	770°	710°
OFF	2.2	920°	900°	900°	990°	1000°	1110°	1020°	960°
MAXIMUM		510°	480°	480°	580°	580°	1030°	800°	720°
OFF	3.3	1090°	1090°	1090°	1030°	1160°	1160°	1140°	1130°
MEDIUM		730°	720°	720°			1120°	970°	980°
MAXIMUM		480°	470°	470°	600°	610°	1070°	830°	760°

NOTES: Thermocouple No. 994 did not work throughout tests.

For the maximum cooling flow rate, temperatures varied as much as 15 degrees about the values shown above during one set of test conditions (one group no.).

For no cooling flow, the surface temperatures varied considerably for different angles of attack; a maximum temperature of 1240 degrees Rankine was recorded for the 43 degree angle of attack cases.

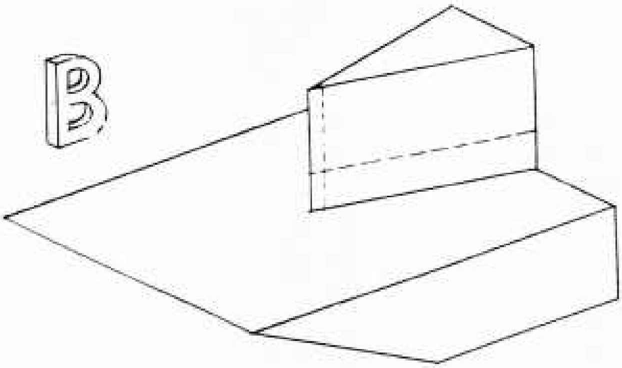


Separated Flows ahead of a Ramp
Fore and aft flaps, end plates
3 separate models:

1) Pressure and heat transfer, AEDC Tunnels A & B, M = 5 & 8, results in Refs. 4 and 10.

2) Controlled wall temperature, pressure, AEDC Tunnel B, M = 8, results herein.

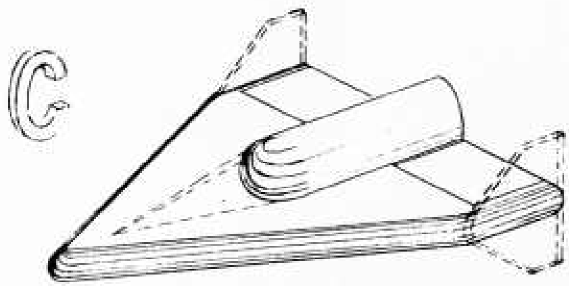
3) Pressure and heat transfer, Grumman Shock Tunnel, M $\approx$ 13 & 19, results not available yet.



Wedge - Plate Interaction
Small and large fins with sharp and blunt leading edges
2 separate models:

1) Pressure and heat transfer, AEDC Tunnels A & B, M = 5 & 8, results in Refs. 5, 6 and 10.

2) Pressure and heat transfer, Grumman Shock Tunnel, M $\approx$ 13 & 19, results not available yet.

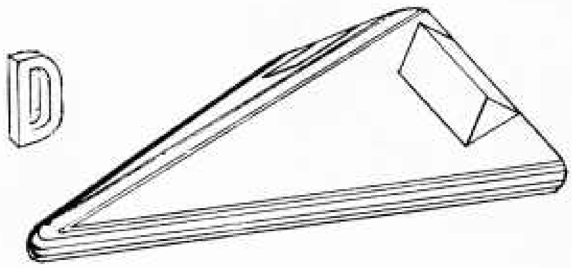


Clipped Delta, Blunt L.E.
Center body, T.E. flaps, drooped nose, spoiler, tip fins
3 separate models:

1) Pressure and heat transfer, AEDC Tunnels A & B, M = 5 & 8, results not available yet.

2) Pressure, AEDC Hotshot 2, M $\approx$ 19, results in Ref. 7.

3) Six component force, AEDC Tunnels A & B, M = 5 & 8, results in Ref. 8.



Delta, Blunt L.E., Dihedral
T.E. flaps, carard, ventral fin
3 separate models:

1) Pressure and heat transfer, AEDC Tunnels A & B, M = 5 & 8, results in Ref. 9.

2) Pressure and heat transfer, Grumman Shock Tunnel, M $\approx$ 19, results not available yet.

3) Six component force, AEDC Tunnels A & B, M = 5 & 8, results not available yet.

Fig. 1 General Outline of Models and Remarks for Over-all Program

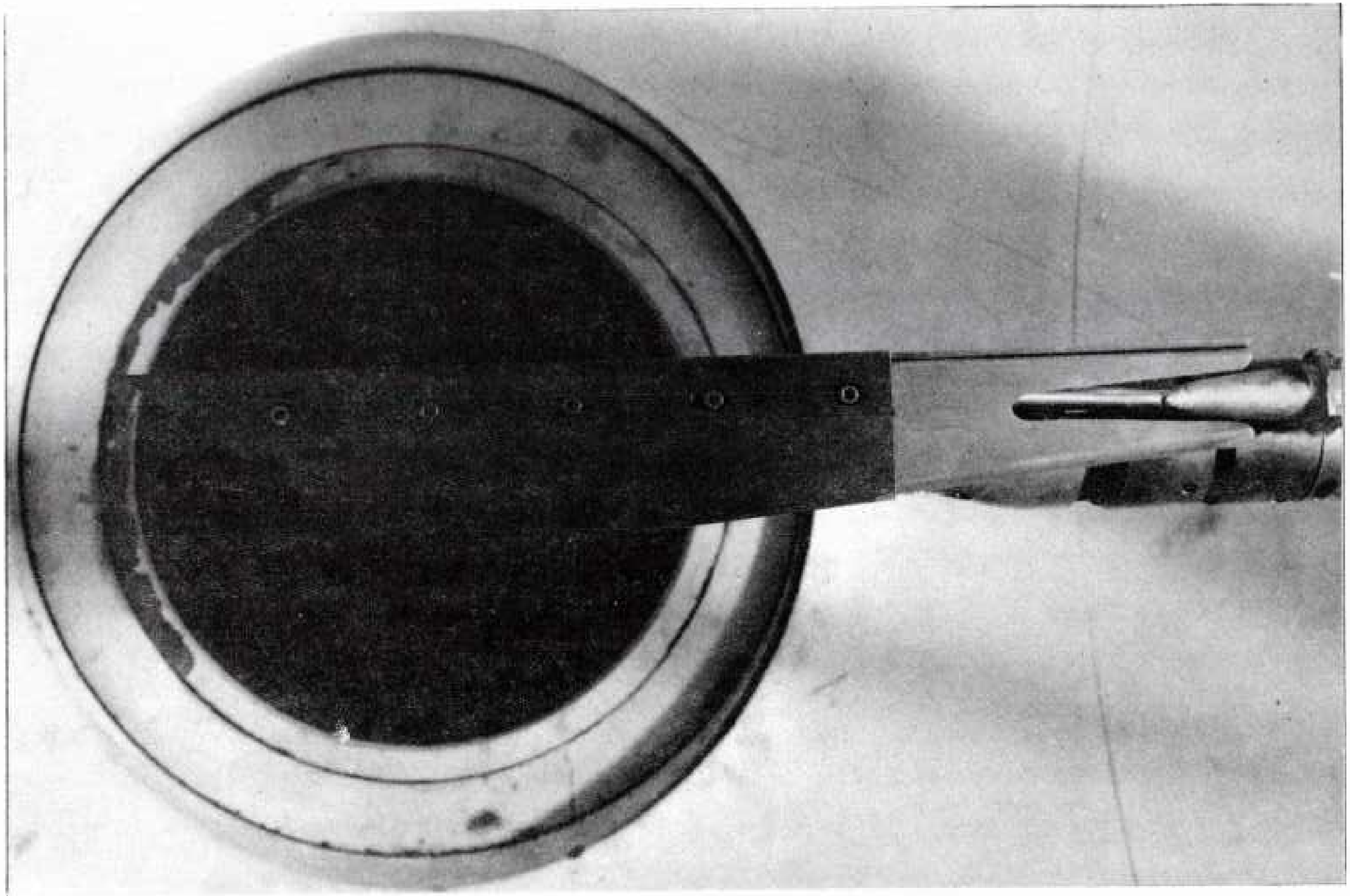


Fig. 2a Photograph of Model with Coolant Exhaust Fairing and without Ramp, Installed in the AEDC 50-inch Mach 8 Tunnel

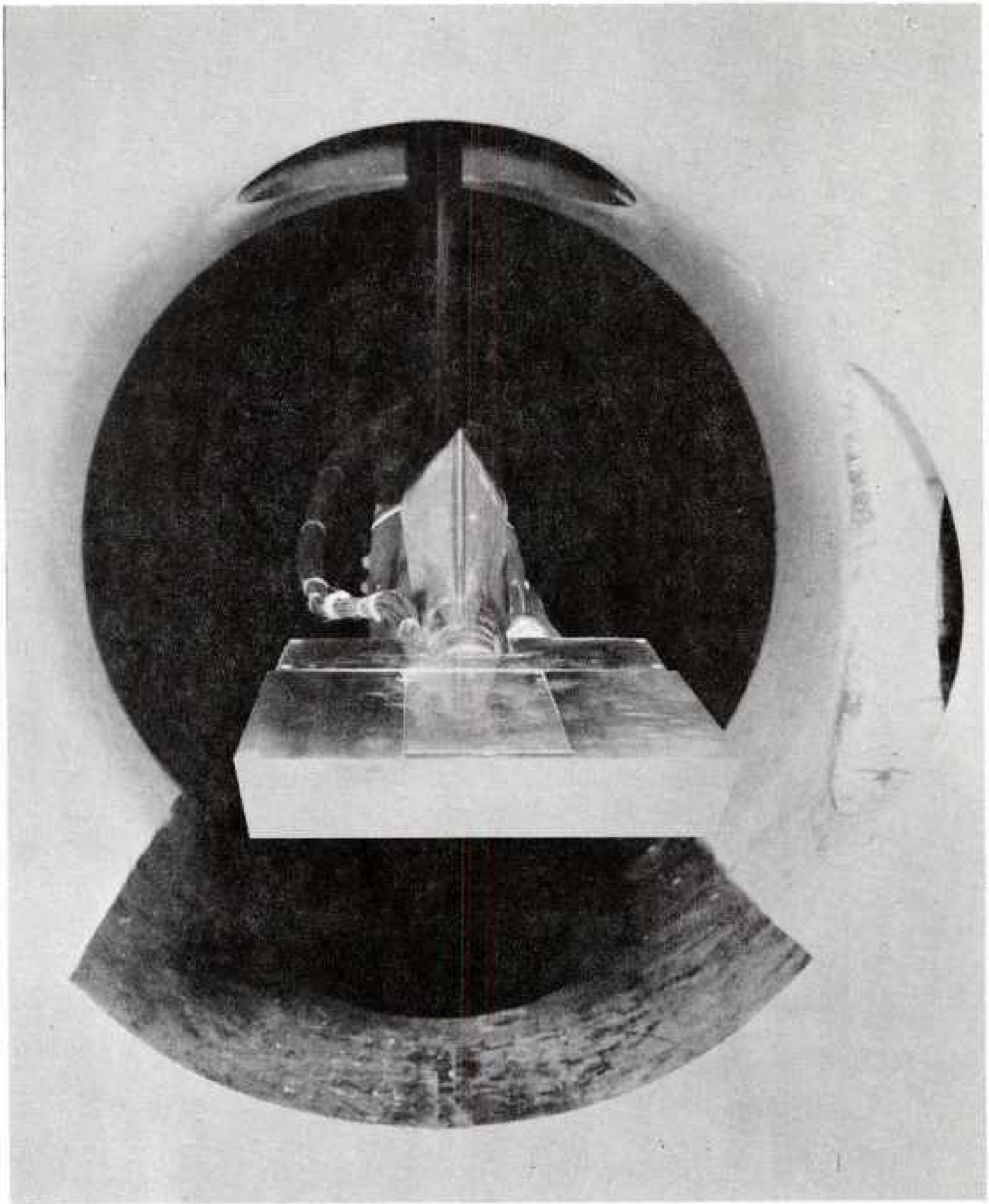


Fig. 2b Photograph of Model with Coolant Exhaust Fairing and without Ramp

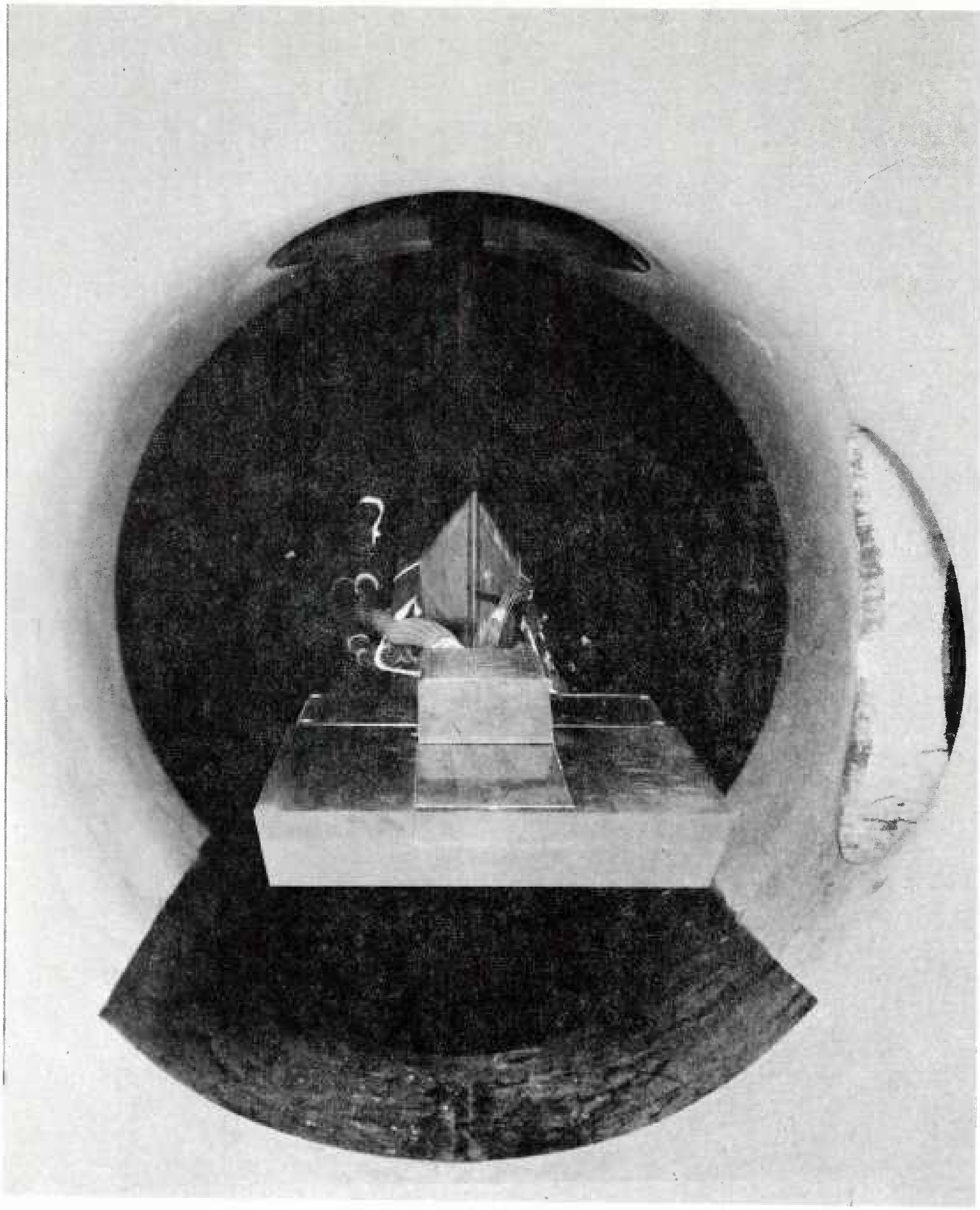


Fig. 3 Photograph of Model with Ramp and with Coolant Exhaust Fairings

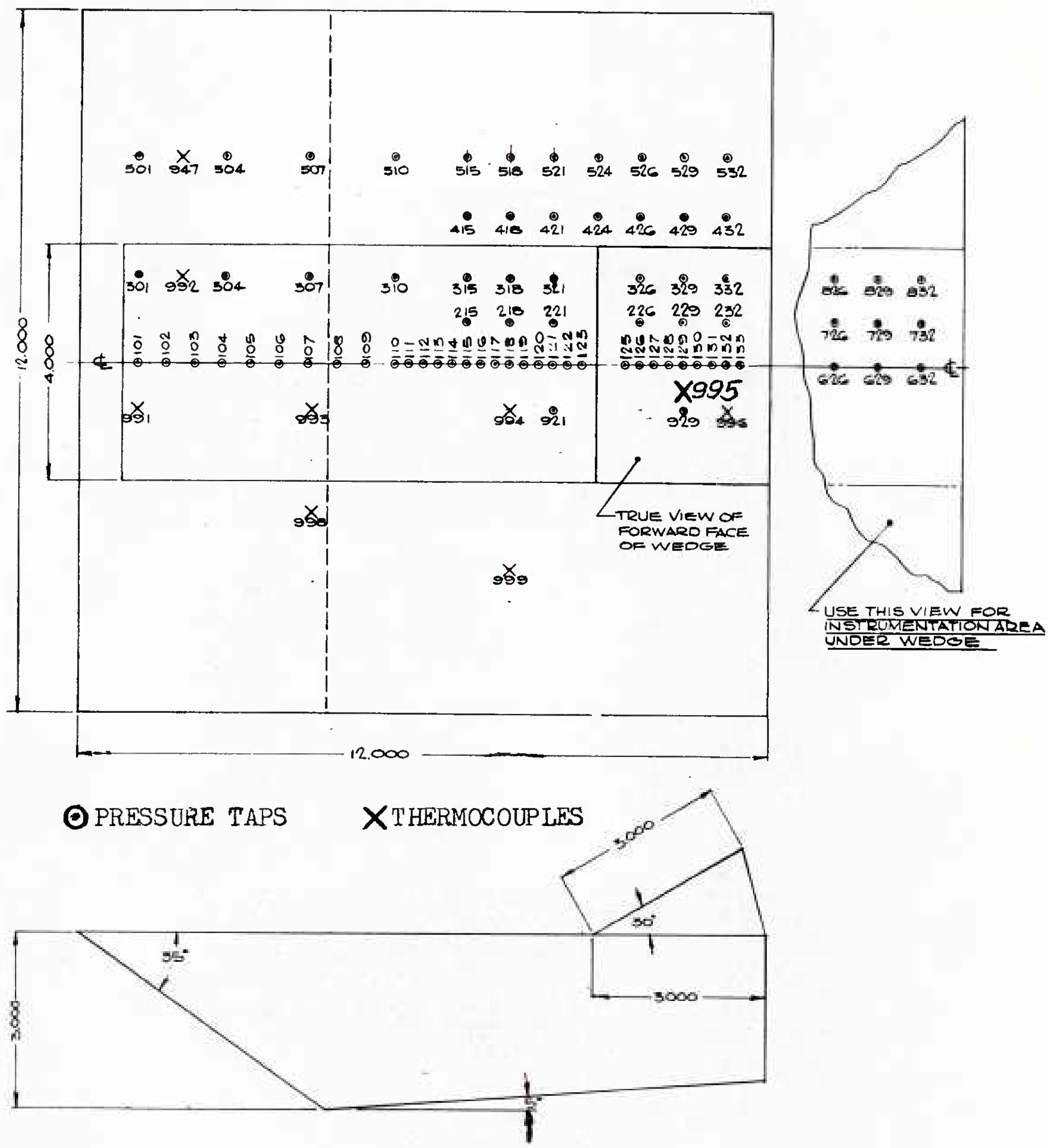


Fig. 4 Model Instrumentation

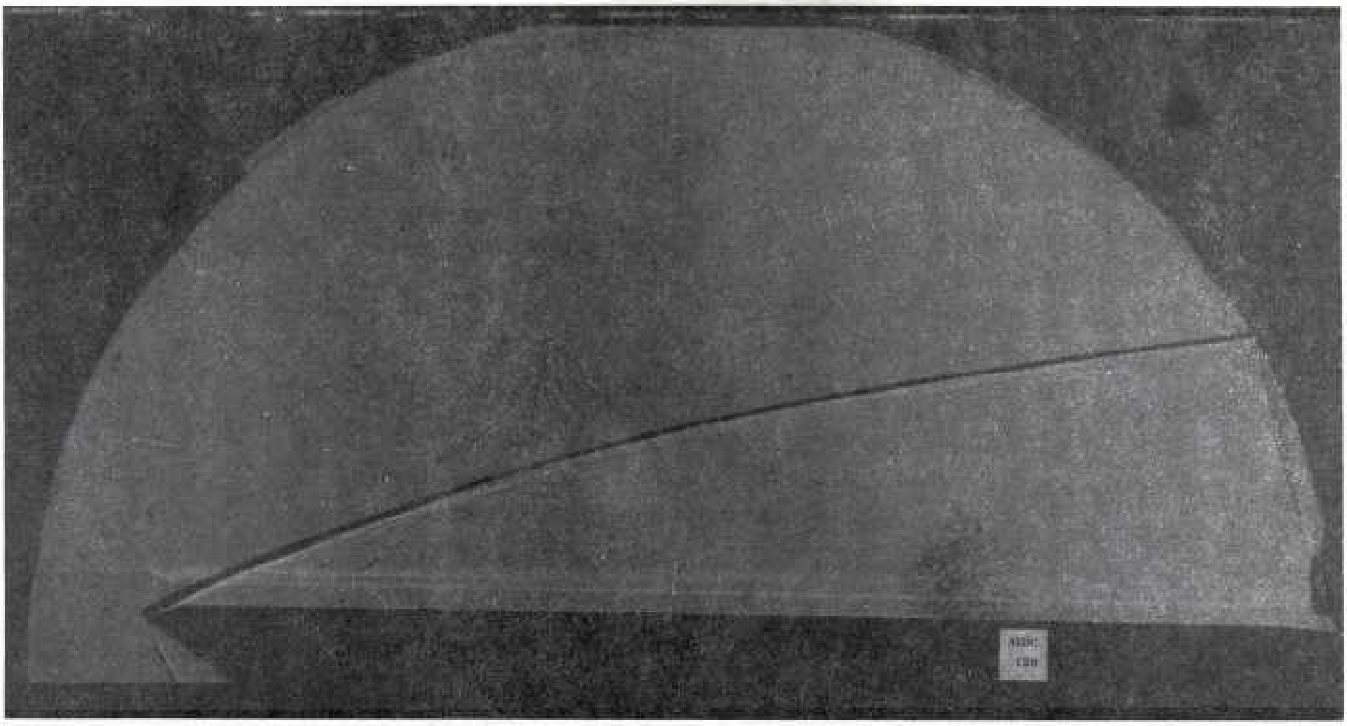


Fig. 5 Shadowgraph Flow Photograph; Ramp Off, No Coolant Flow, $\alpha = -43^{\circ}$, $Re_{\infty}/ft = 3,300,000$

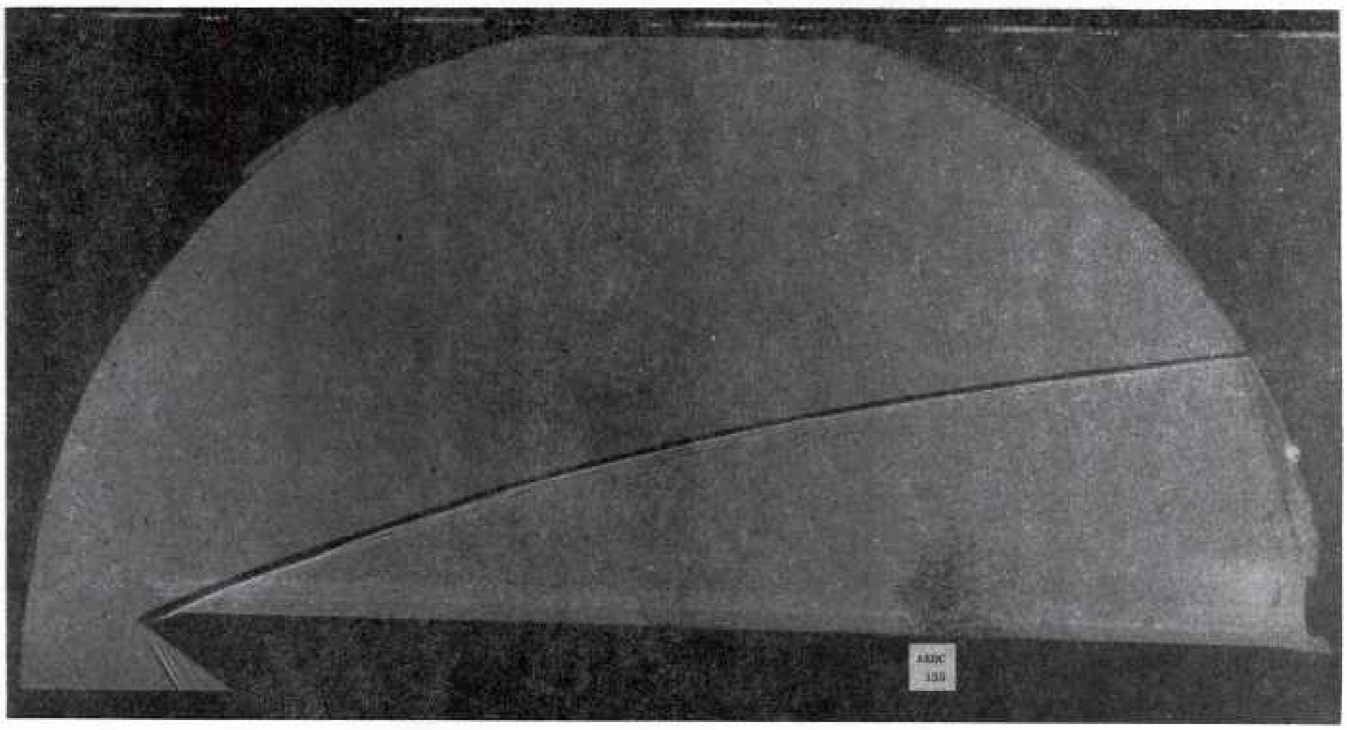


Fig. 6 Shadowgraph Flow Photograph; Ramp off, Maximum Coolant Flow Rate, $\alpha = -43^{\circ}$, $Re_{\infty}/ft = 3,300,000$

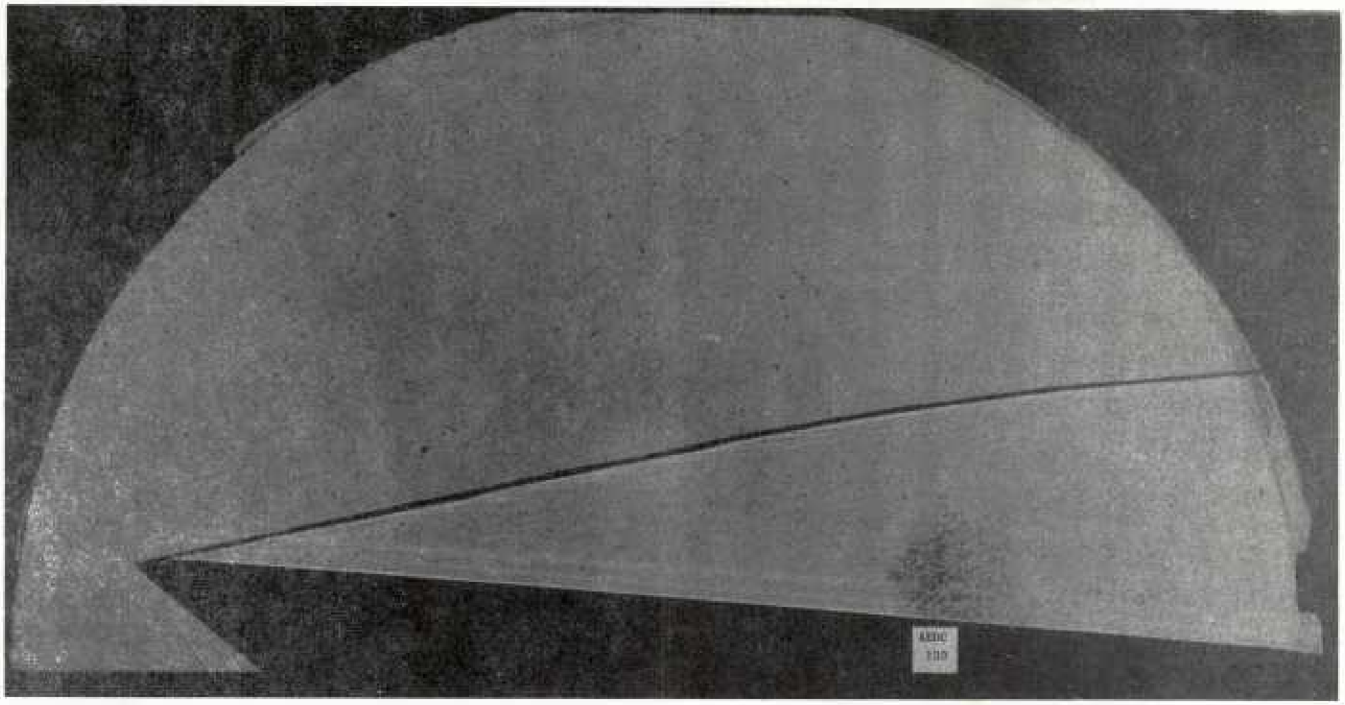


Fig. 7 Shadowgraph Flow Photograph; Ramp Off, No Coolant Flow, $\alpha = -40^{\circ}$, $Re_{\infty}/ft = 3,300,000$

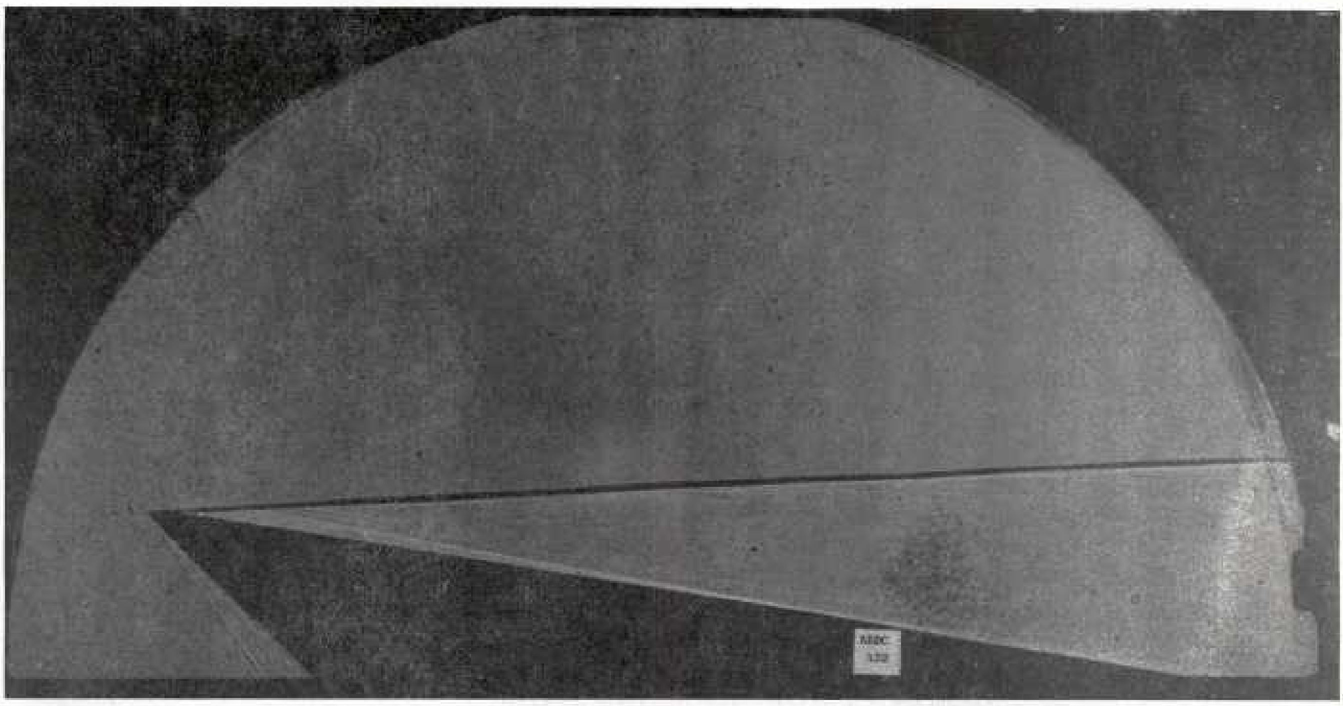


Fig. 8 Shadowgraph Flow Photograph; Ramp Off, No Coolant Flow, $\alpha = -35^{\circ}$, $Re_{\infty}/ft = 3,300,000$

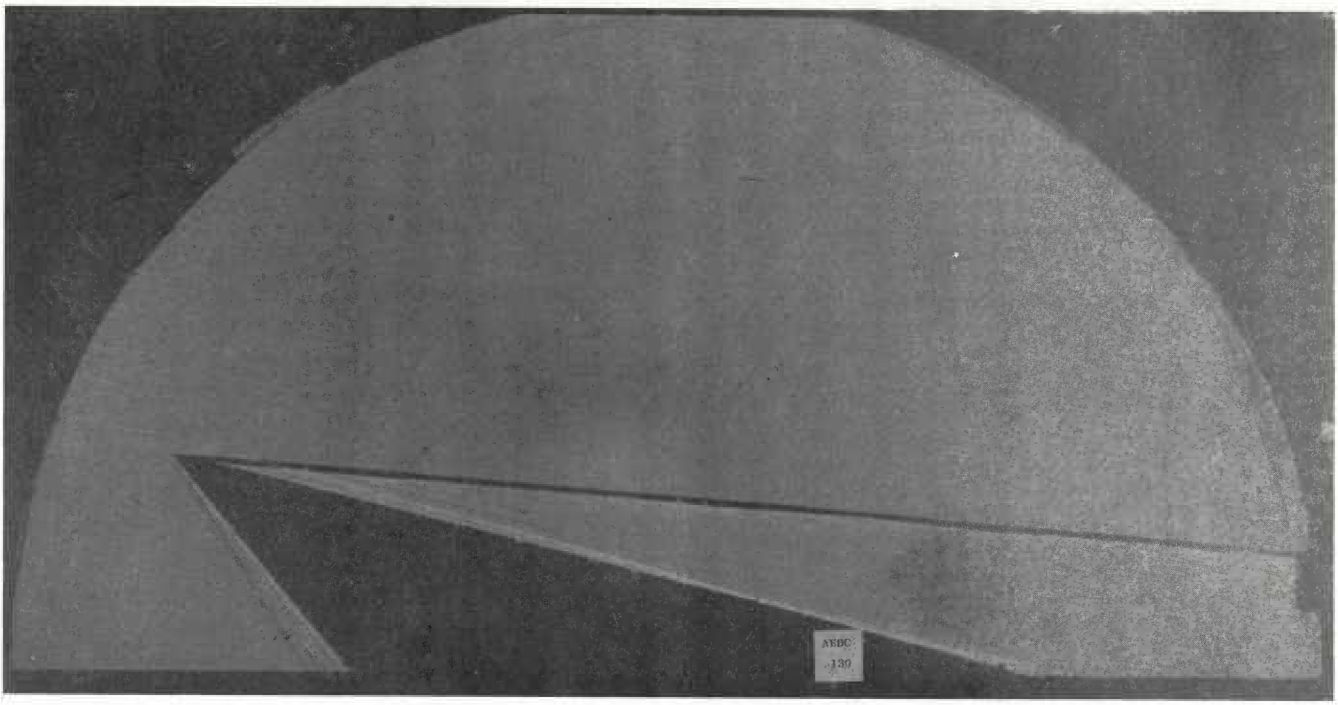


Fig. 9 Shadowgraph Flow Photograph; Ramp Off, No Coolant Flow, $\alpha = -30^{\circ}$, $Re_{\infty}/ft = 3,300,000$

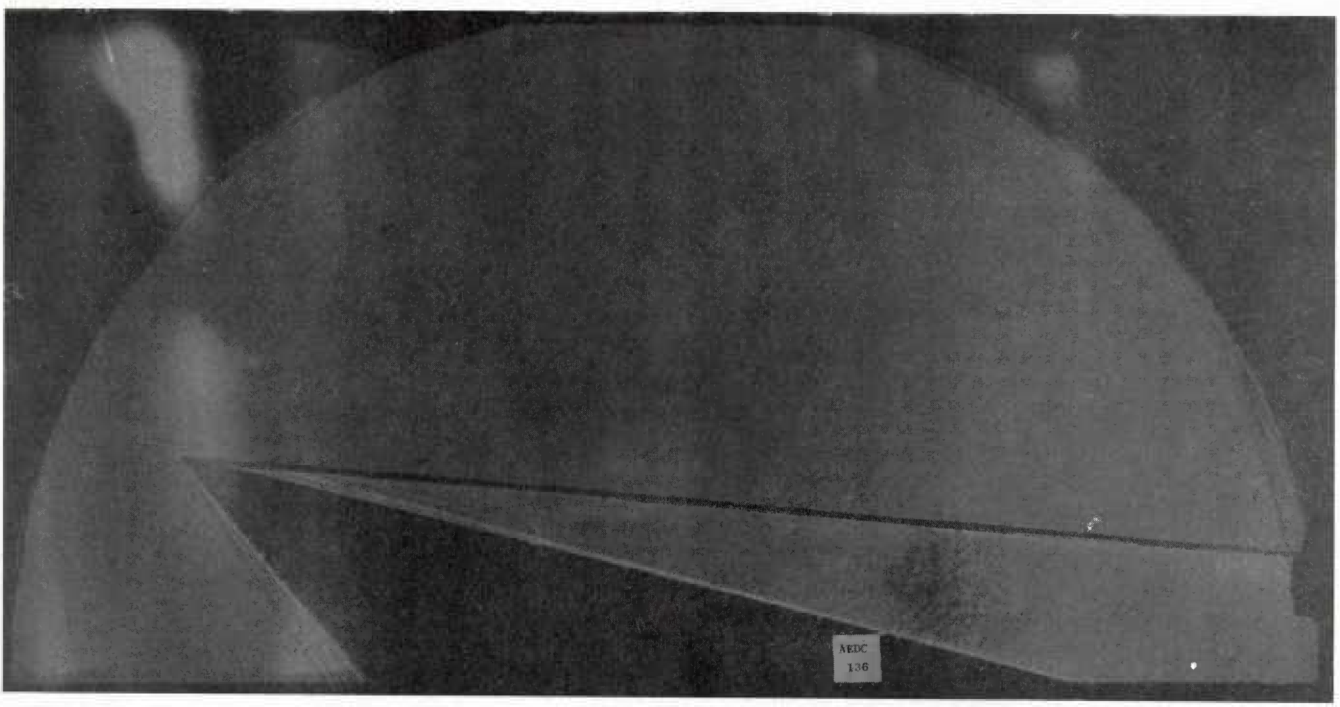


Fig. 10 Shadowgraph Flow Photograph; Ramp Off, Maximum Coolant Flow Rate, $\alpha = -30^{\circ}$, $Re_{\infty}/ft = 3,300,000$

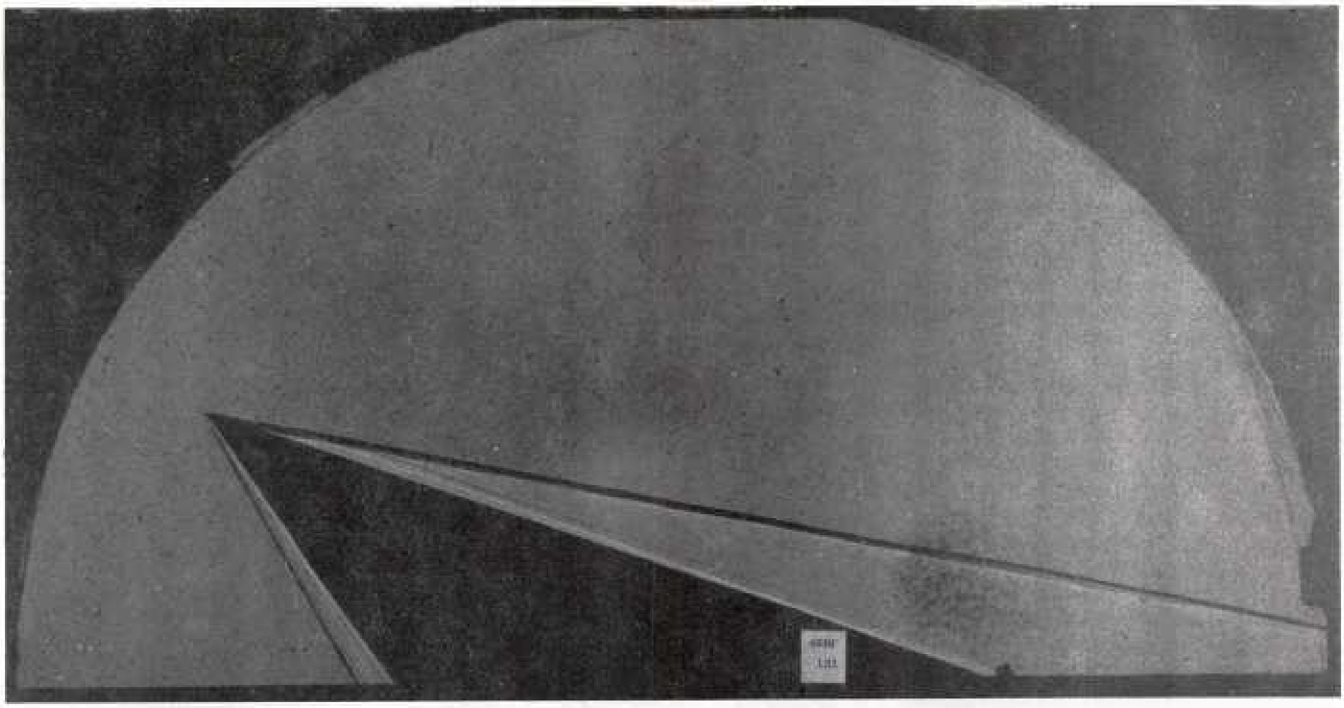


Fig. 11 Shadowgraph Flow Photograph; Ramp Off, No Coolant Flow, $\alpha = -25^{\circ}$, $Re_{\infty}/ft = 3,300,000$

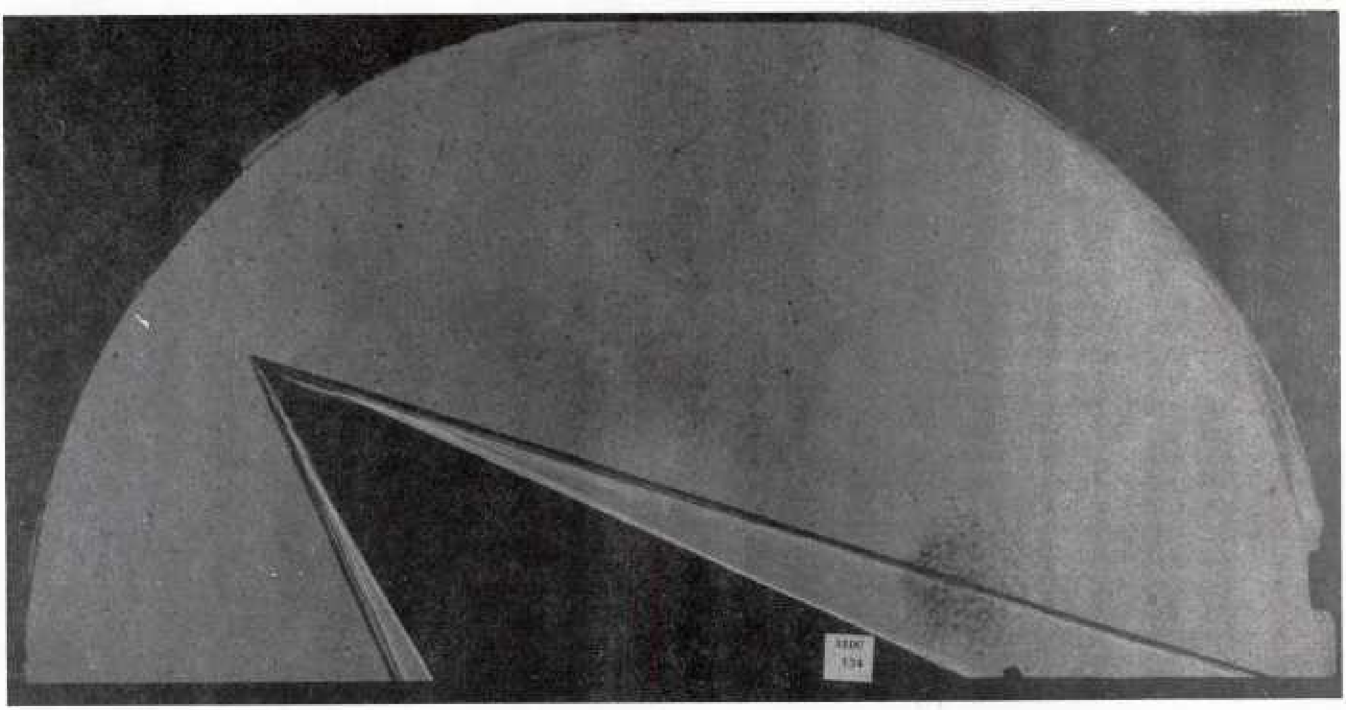


Fig. 12 Shadowgraph Flow Photograph; Ramp Off, No Coolant Flow, $\alpha = -20^{\circ}$, $Re_{\infty}/ft = 3,300,000$

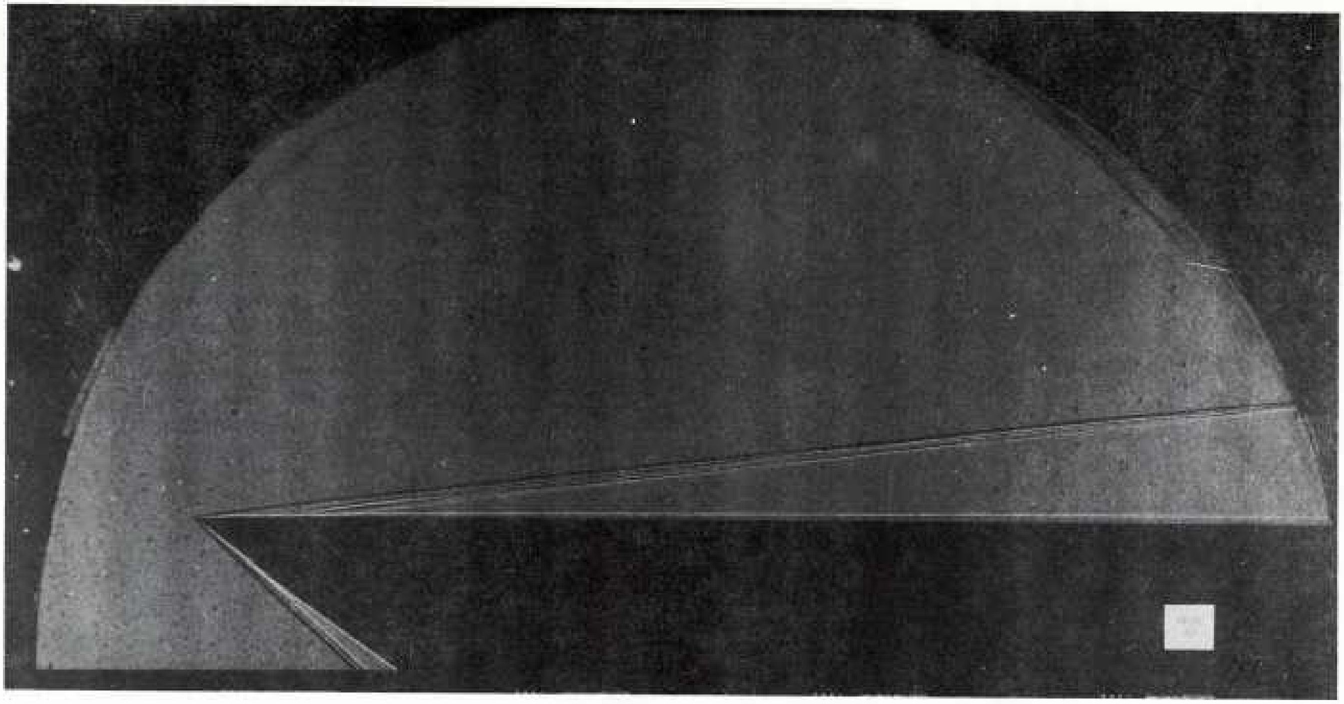


Fig. 13 Shadowgraph Flow Photograph; Ramp Off, No Coolant Flow, $\alpha = -15^{\circ}$, $Re_{\infty}/ft = 1{,}100{,}000$

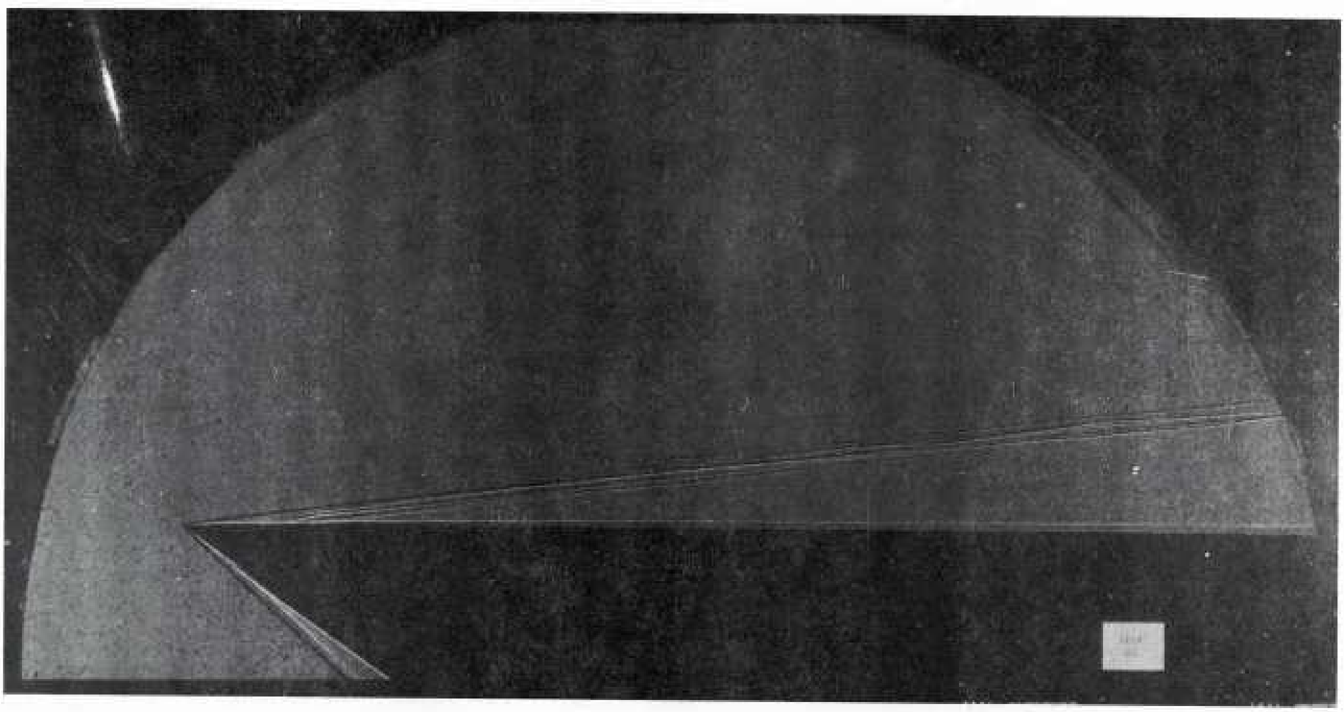


Fig. 14 Shadowgraph Flow Photograph; Ramp Off, Maximum Coolant Flow Rate, $\alpha = -15^{\circ}$, $Re_{\infty}/ft = 1{,}100{,}000$

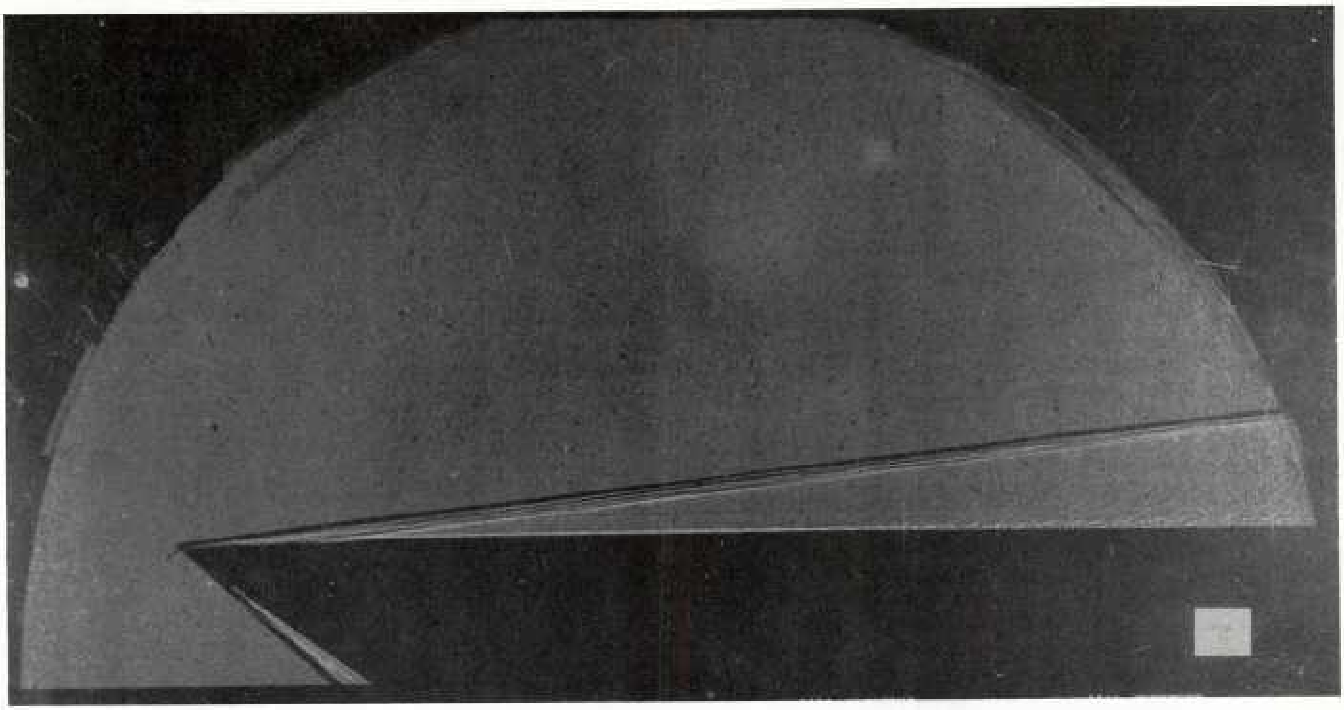


Fig. 15 Shadowgraph Flow Photograph; Ramp Off, No Coolant Flow, $\alpha = -15^{\circ}$, $Re_{\infty}/ft = 3,300,000$

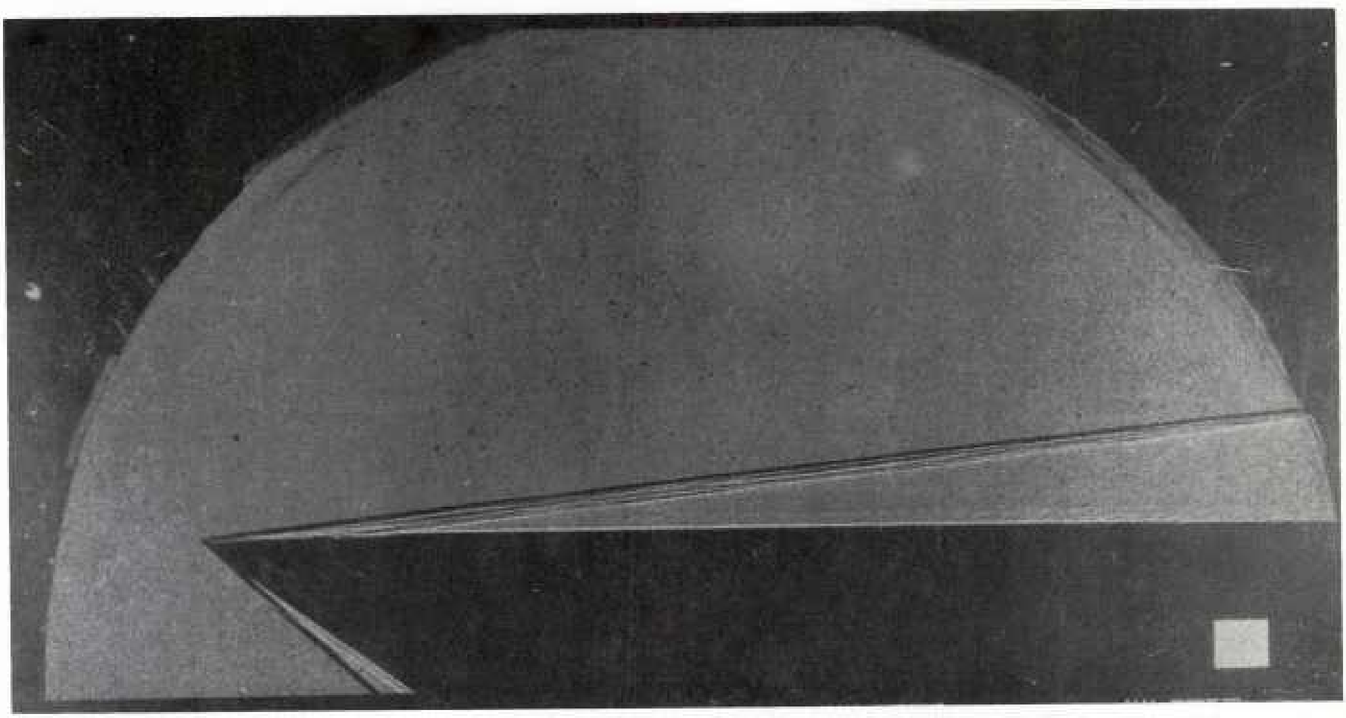


Fig. 16 Shadowgraph Flow Photograph; Ramp Off, Medium Coolant Flow Rate, $\alpha = -15^{\circ}$, $Re_{\infty}/ft = 3,300,000$

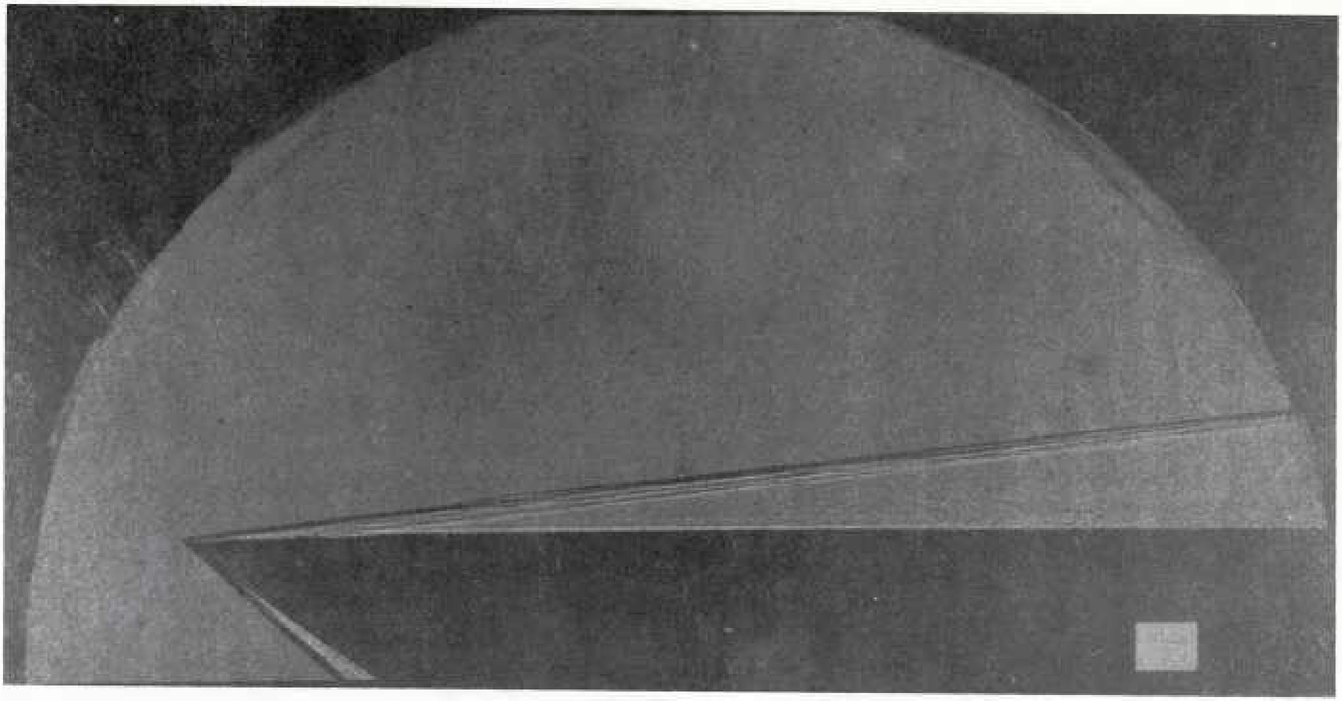


Fig. 17 Shadowgraph Flow Photograph; Ramp Off, Maximum Coolant Flow Rate, $\alpha = -15^{\circ}$, Re_{∞}/ft = 3,300,000

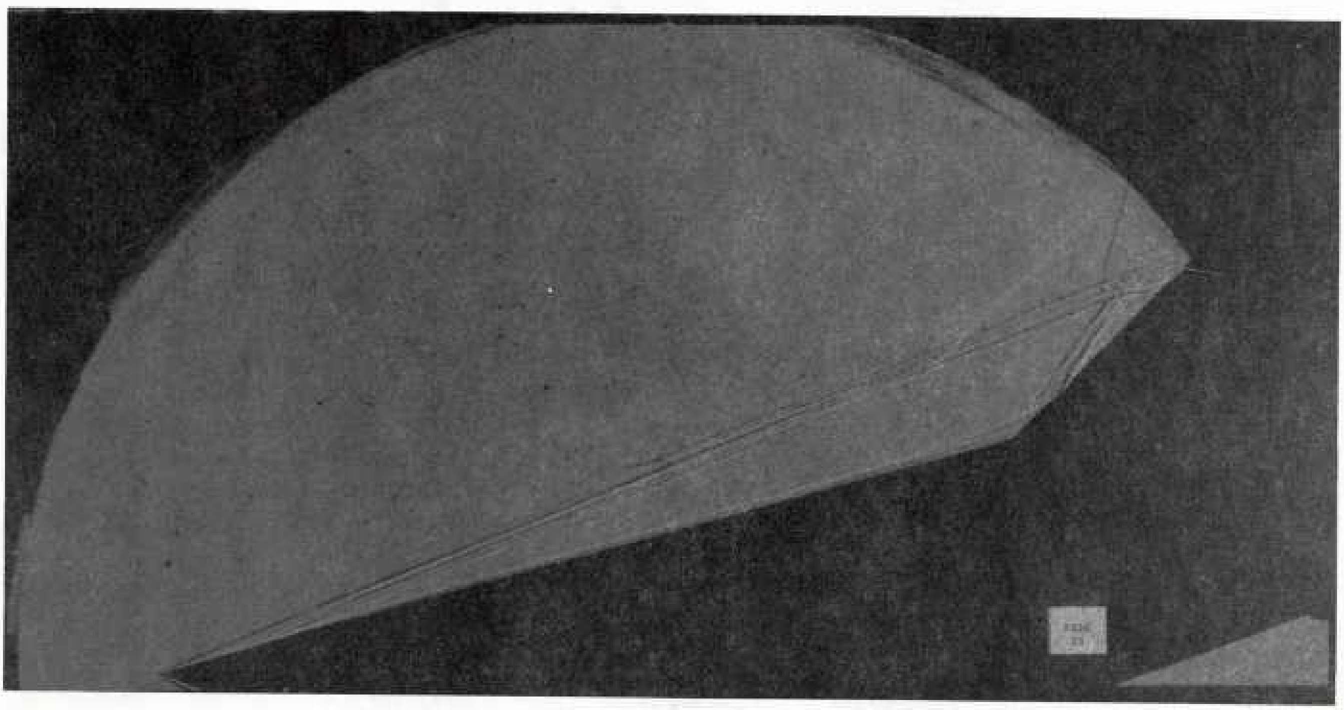


Fig. 18 Shadowgraph Flow Photograph; Ramp On, Maximum Coolant Flow Rate, $\alpha = -15^{\circ}$, Re_{∞}/ft = 1,100,000

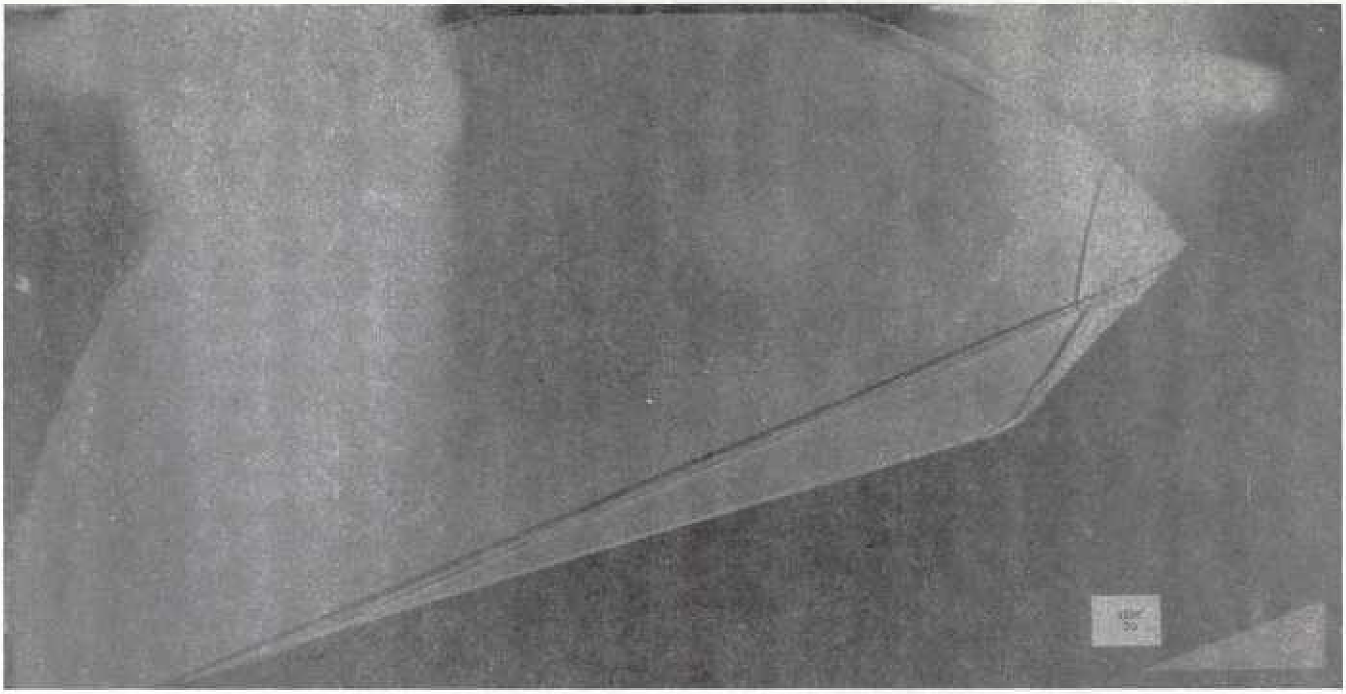


Fig. 19 Shadowgraph Flow Photograph; Ramp On, No Coolant Flow, $\alpha = -15^{\circ}$, $Re_{\infty}/ft = 3,300,000$

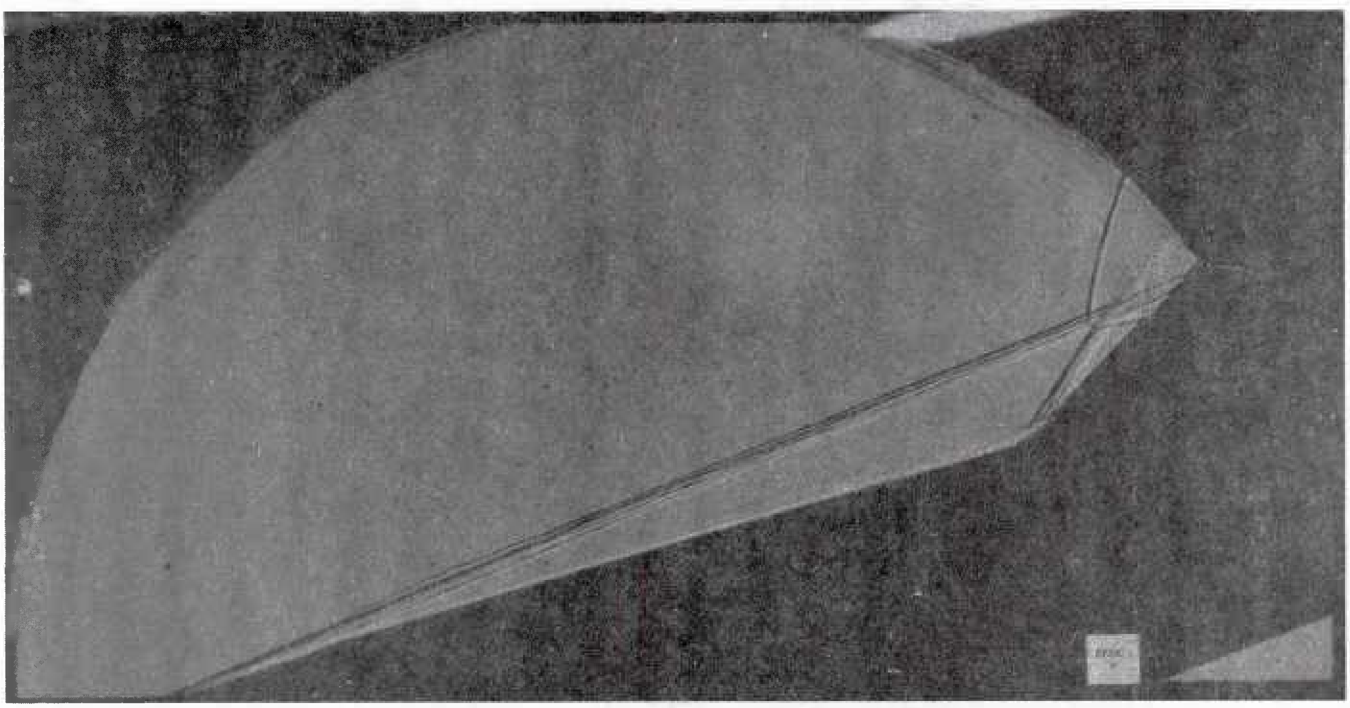


Fig. 20 Shadowgraph Flow Photograph; Ramp On, Maximum Coolant Flow Rate, $\alpha = -15^{\circ}$, $Re_{\infty}/ft = 3,300,000$

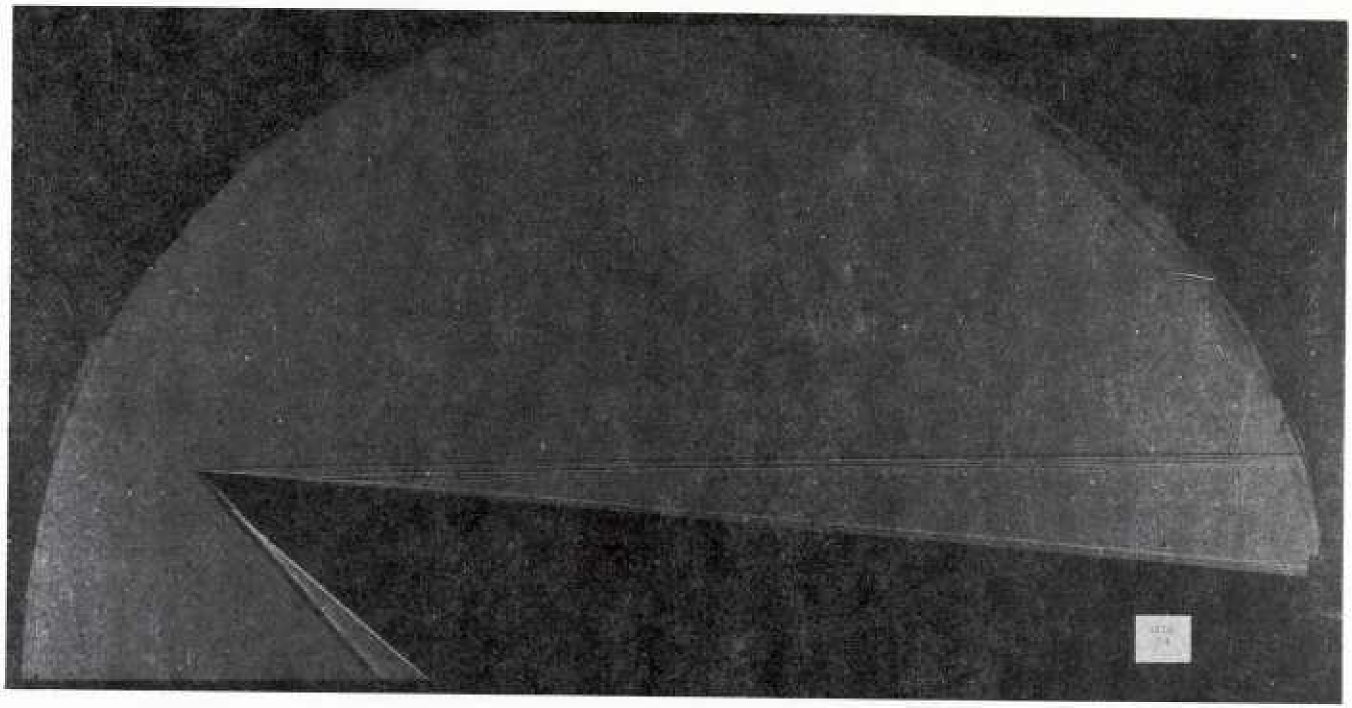


Fig. 21 Shadowgraph Flow Photograph; Ramp Off, No Coolant Flow, $\alpha = -10^{\circ}$, $Re_{\infty}/ft = 1,100,000$

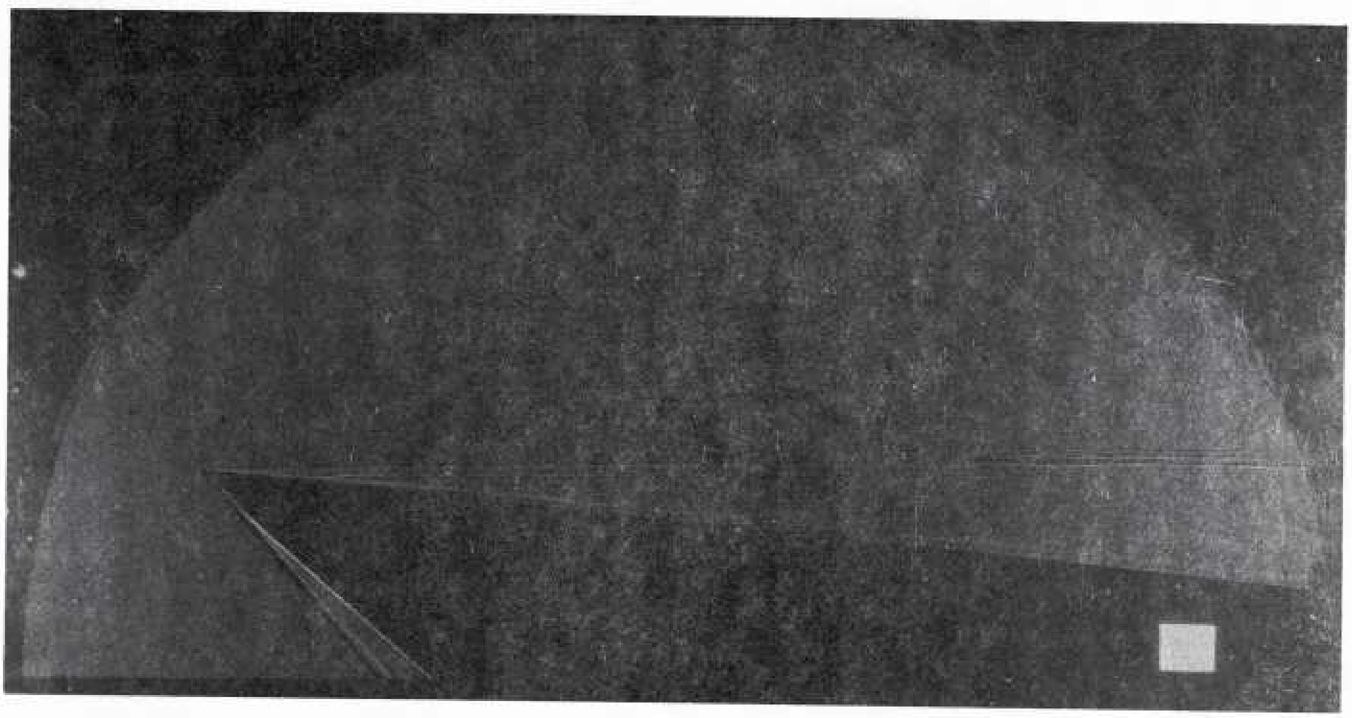


Fig. 22 Shadowgraph Flow Photograph; Ramp Off, Maximum Coolant Flow Rate, $\alpha = -10^{\circ}$, $Re_{\infty}/ft = 1,100,000$

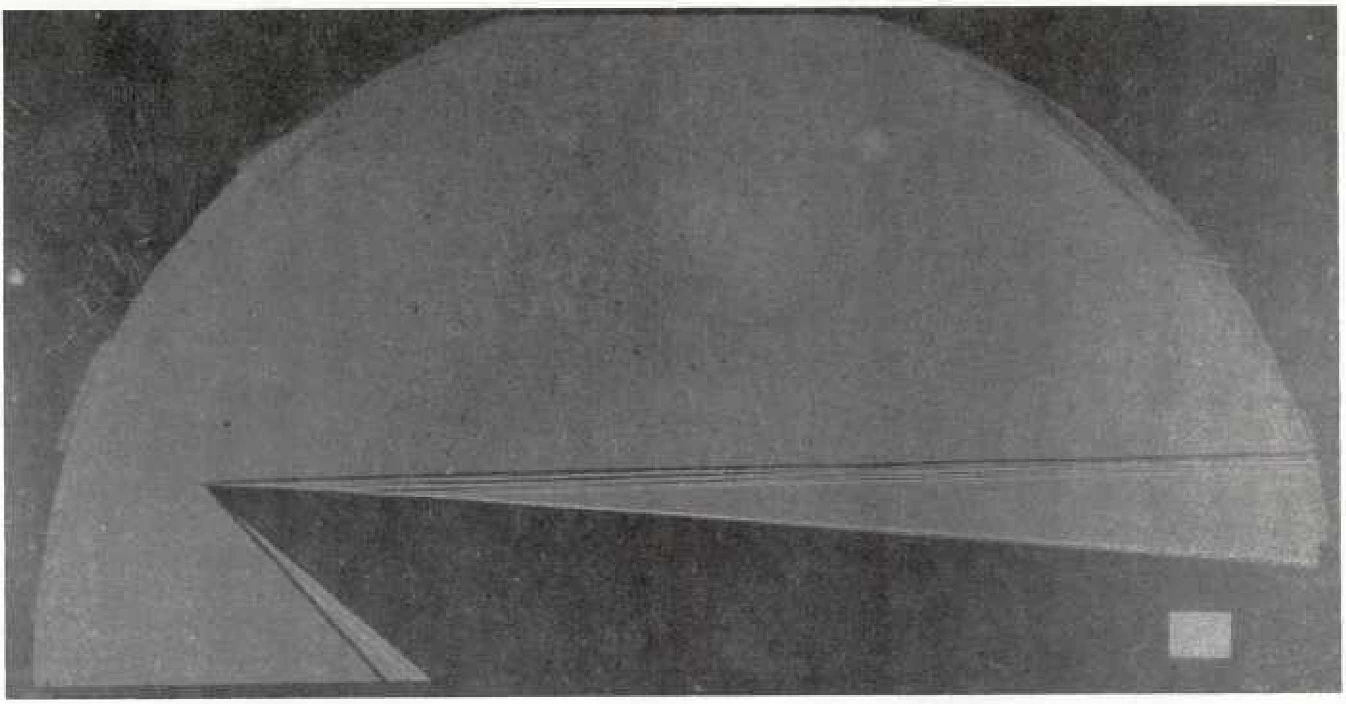


Fig. 23 Shadowgraph Flow Photograph; Ramp Off, No Coolant Flow, $\alpha = -10^{o}$, $Re_{\infty}/ft = 3,300,000$

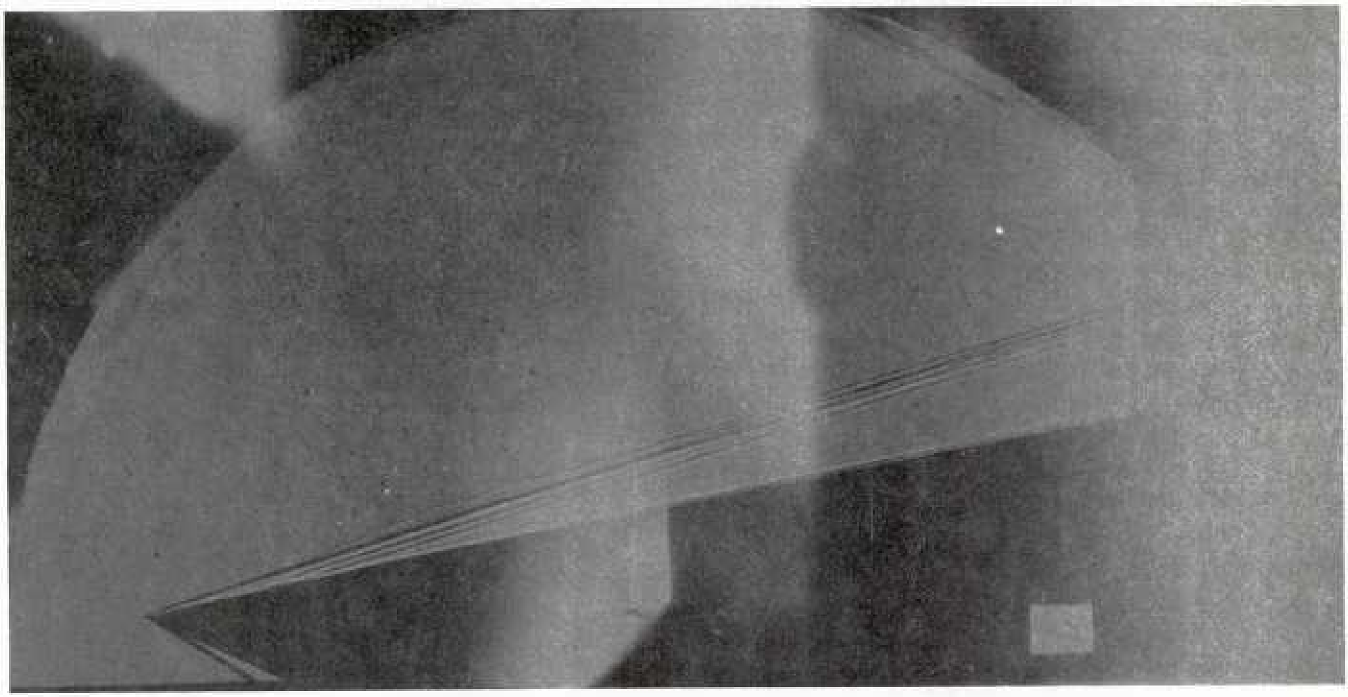


Fig. 24 Shadowgraph Flow Photograph, Ramp Off, Maximum Coolant Flow Rate, $\alpha = -10^{o}$, $Re_{\infty}/ft = 3,300,000$

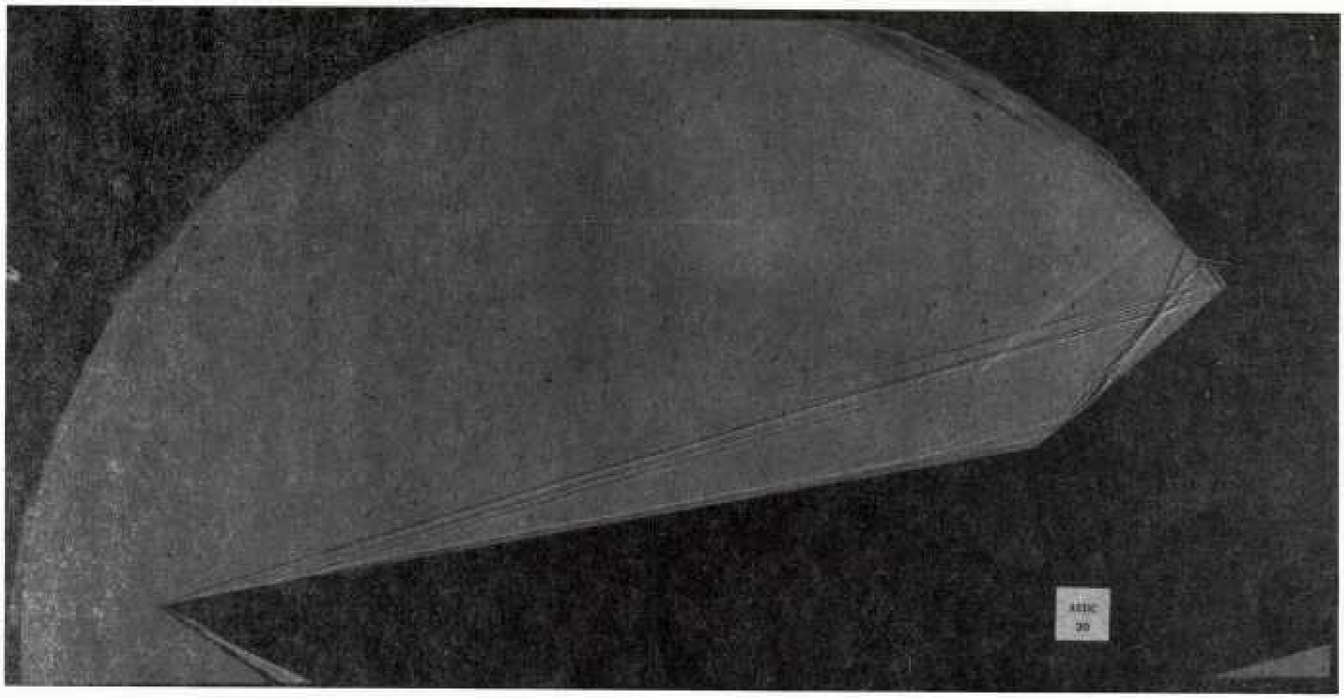


Fig. 25 Shadowgraph Flow Photograph; Ramp On, Maximum Coolant Flow Rate, $\alpha = -10^{o}$, Re_{∞}/ft = 1,100,000

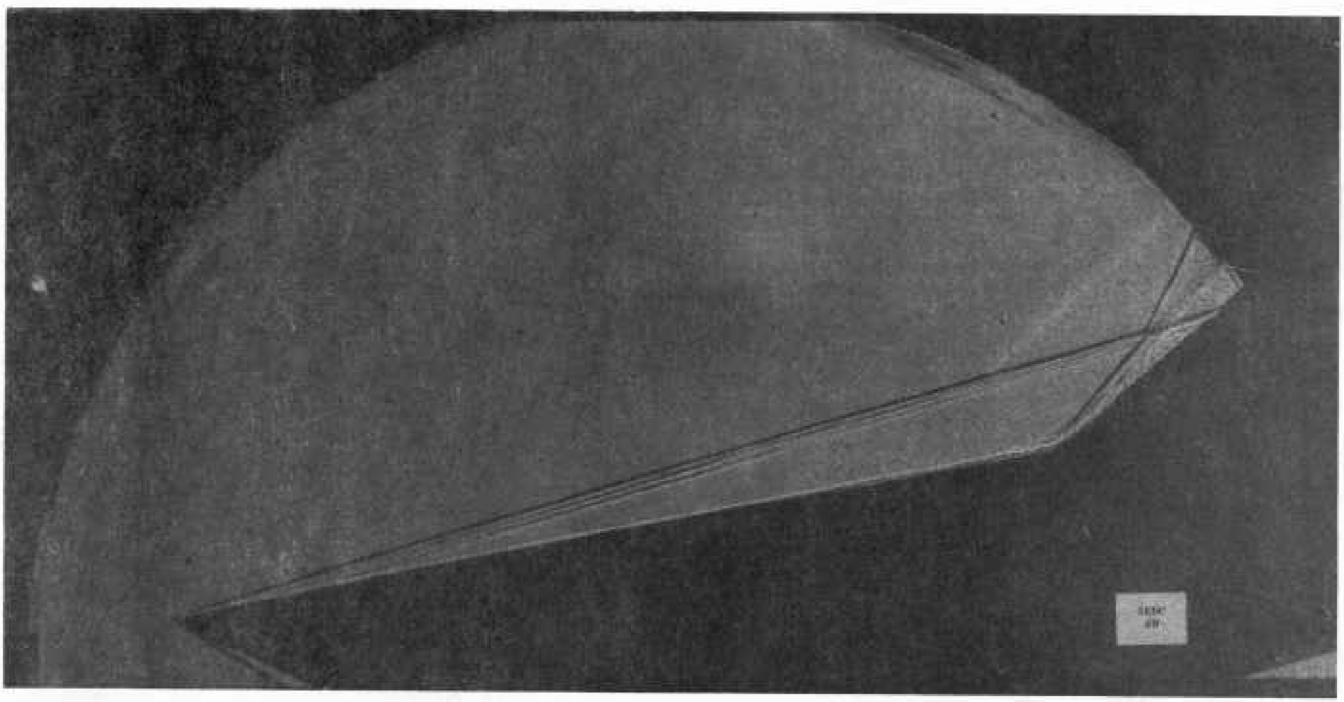


Fig. 26 Shadowgraph Flow Photograph; Ramp On, No Coolant Flow, $\alpha = -10^{o}$, Re_{∞}/ft = 3,300,000

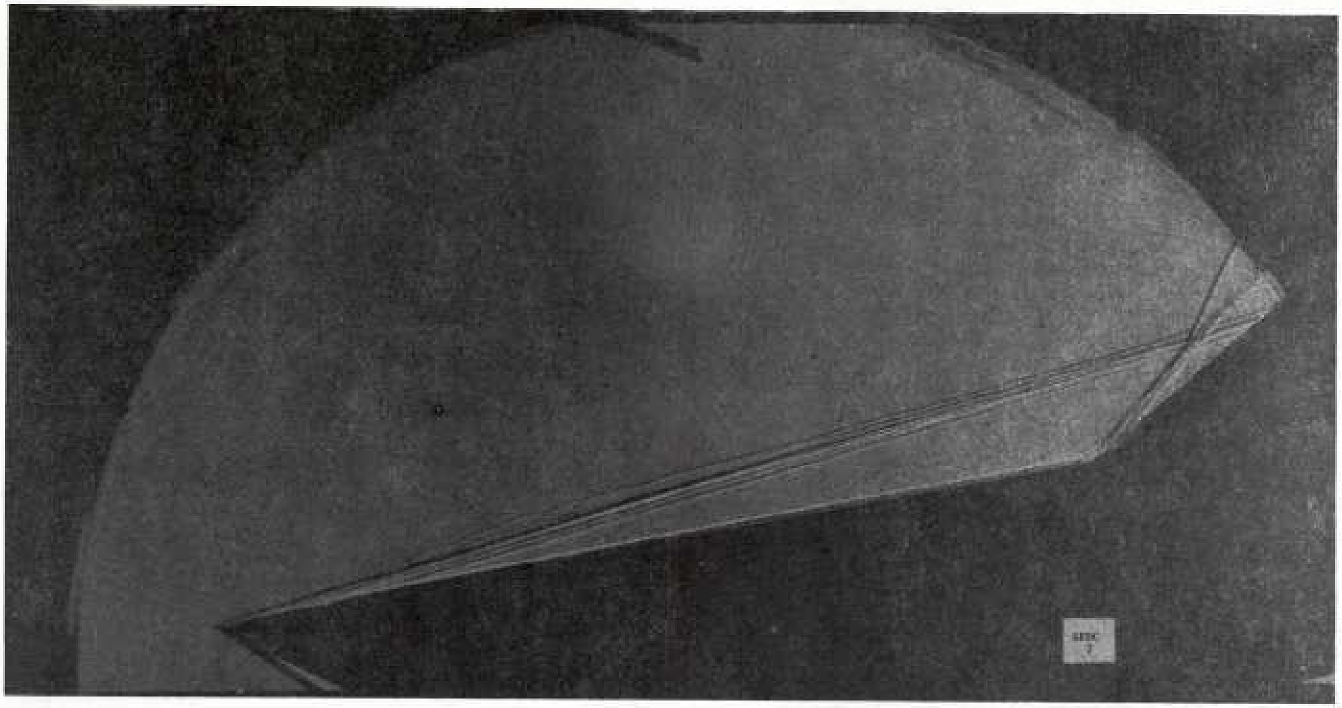


Fig. 27 Shadowgraph Flow Photograph; Ramp On, Maximum Coolant Flow Rate, $\alpha = -10^{\circ}$, $Re_{\infty}/ft = 3,300,000$

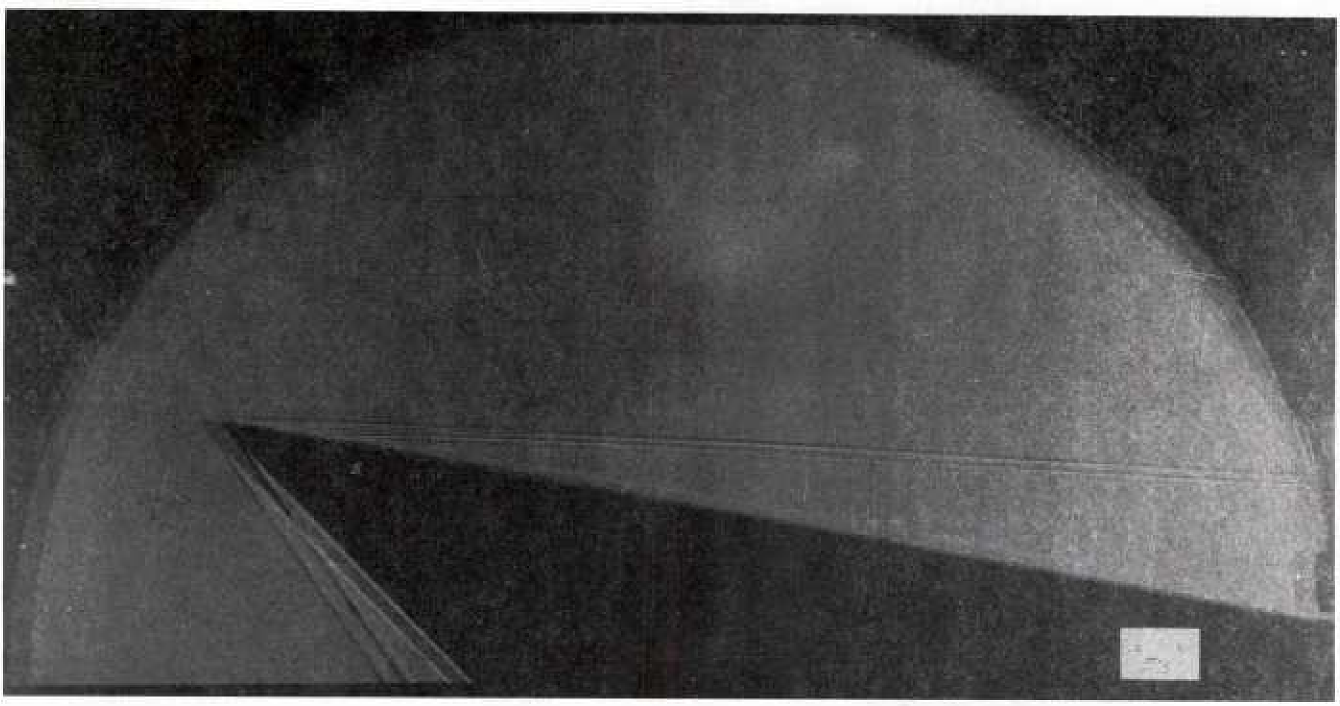


Fig. 28 Shadowgraph Flow Photograph; Ramp Off, No Coolant Flow, $\alpha = -5^{\circ}$, $Re_{\infty}/ft = 1,100,000$

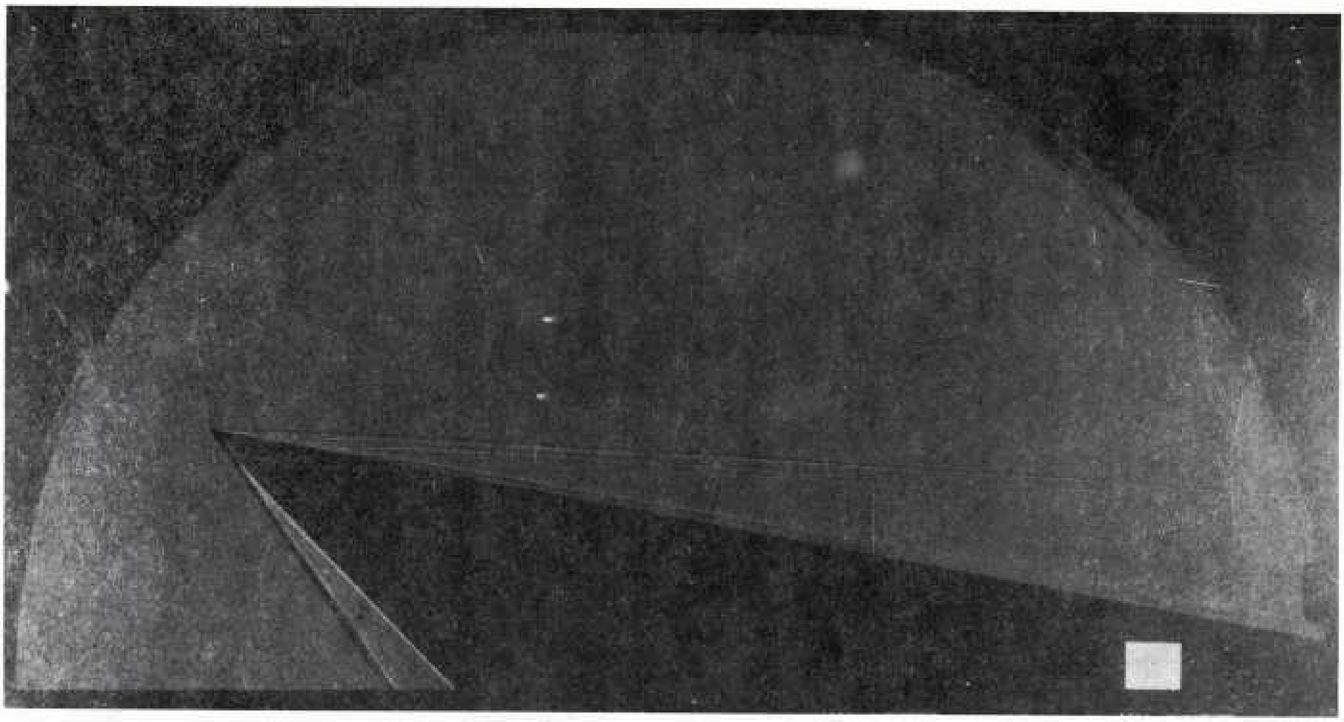


Fig. 29 Shadowgraph Flow Photograph; Ramp Off, Maximum Coolant Flow Rate, $\alpha = -5^{\circ}$, $Re_{\infty}/ft = 1,100,000$

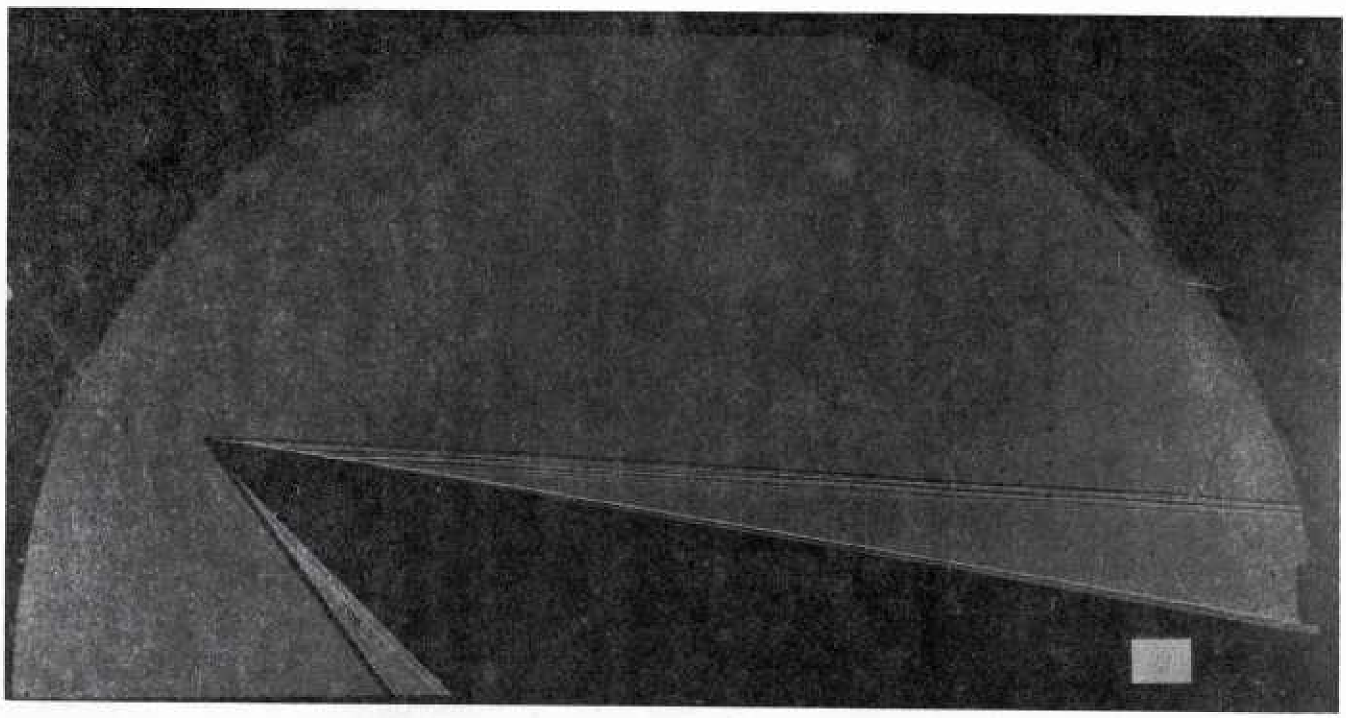


Fig. 30 Shadowgraph Flow Photograph; Ramp Off, No Coolant Flow, $\alpha = -5^{\circ}$, $Re_{\infty}/ft = 3,300,000$

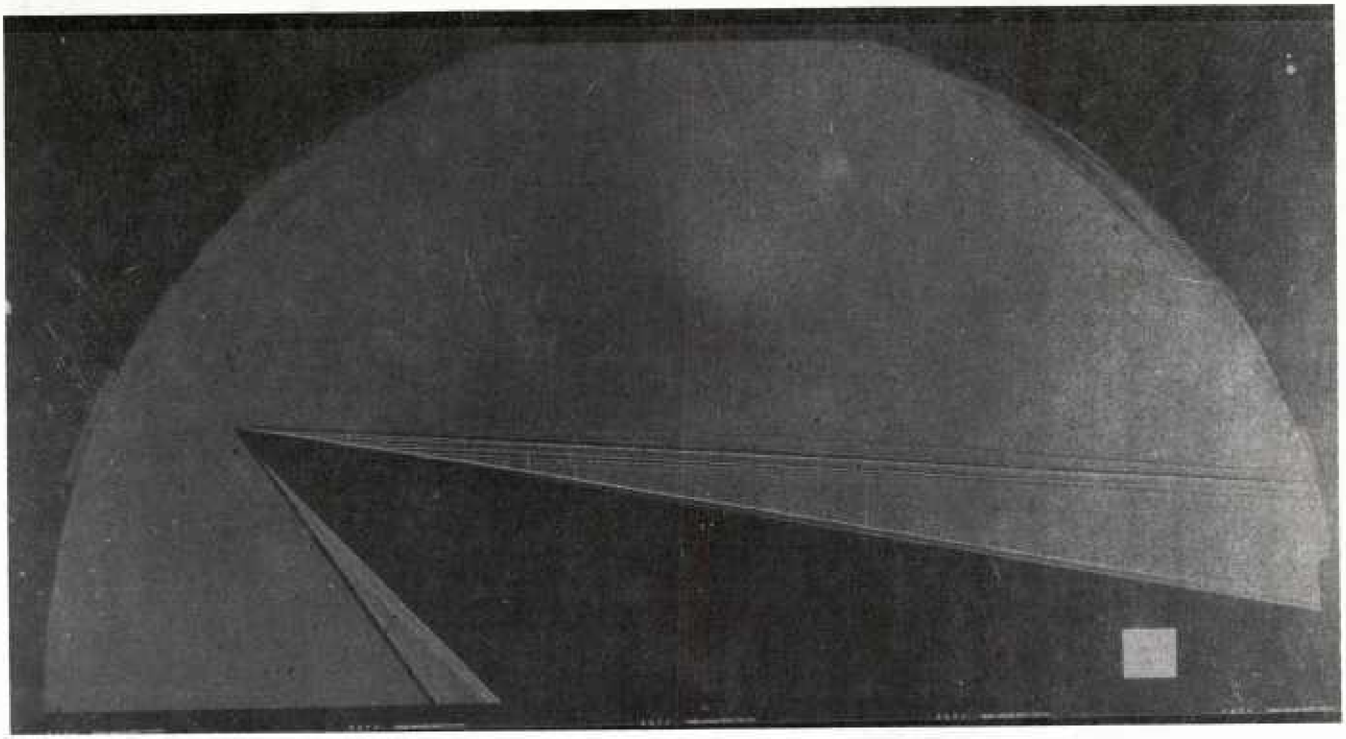


Fig. 31 Shadowgraph Flow Photograph; Ramp Off, Medium Coolant Flow Rate, $\alpha = -5^{\circ}$, $Re_{\infty}/ft = 3,300,000$

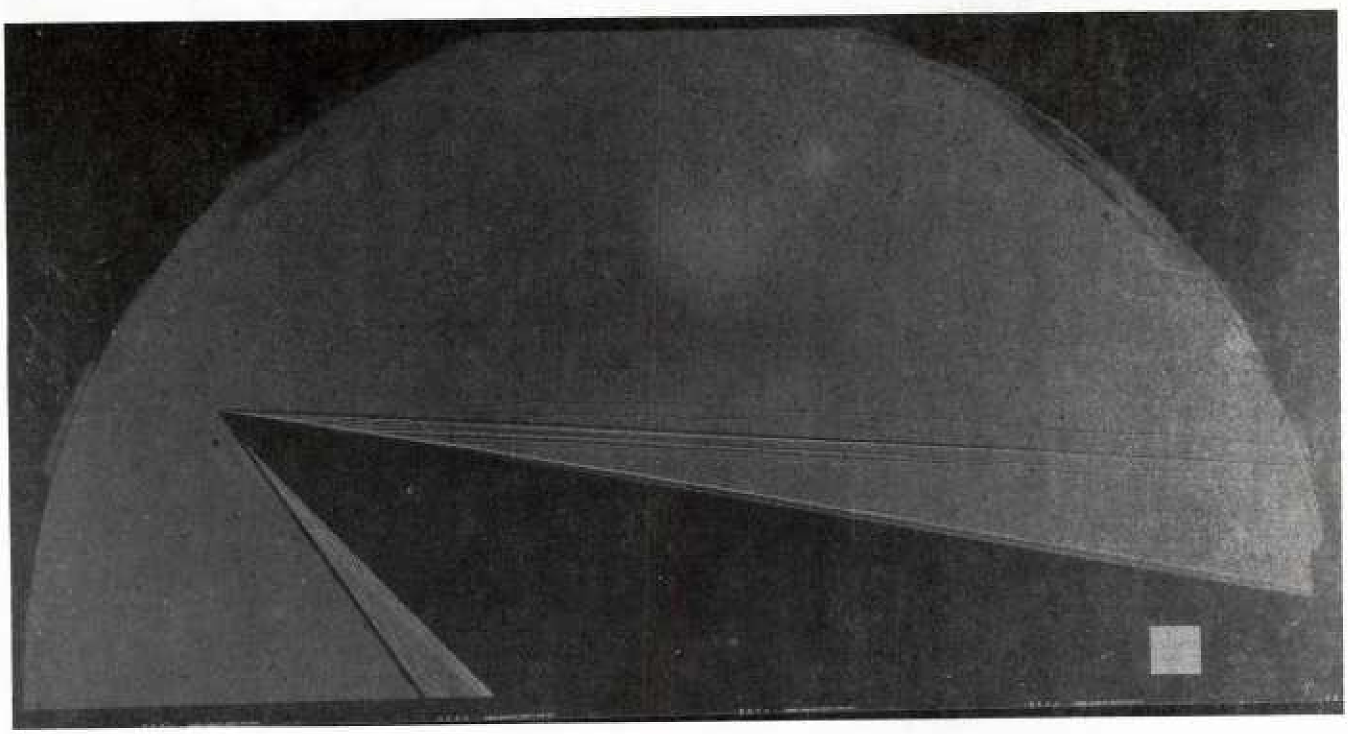


Fig. 32 Shadowgraph Flow Photograph; Ramp Off, Maximum Coolant Flow Rate, $\alpha = -5^{\circ}$, $Re_{\infty}/ft = 3,300,000$

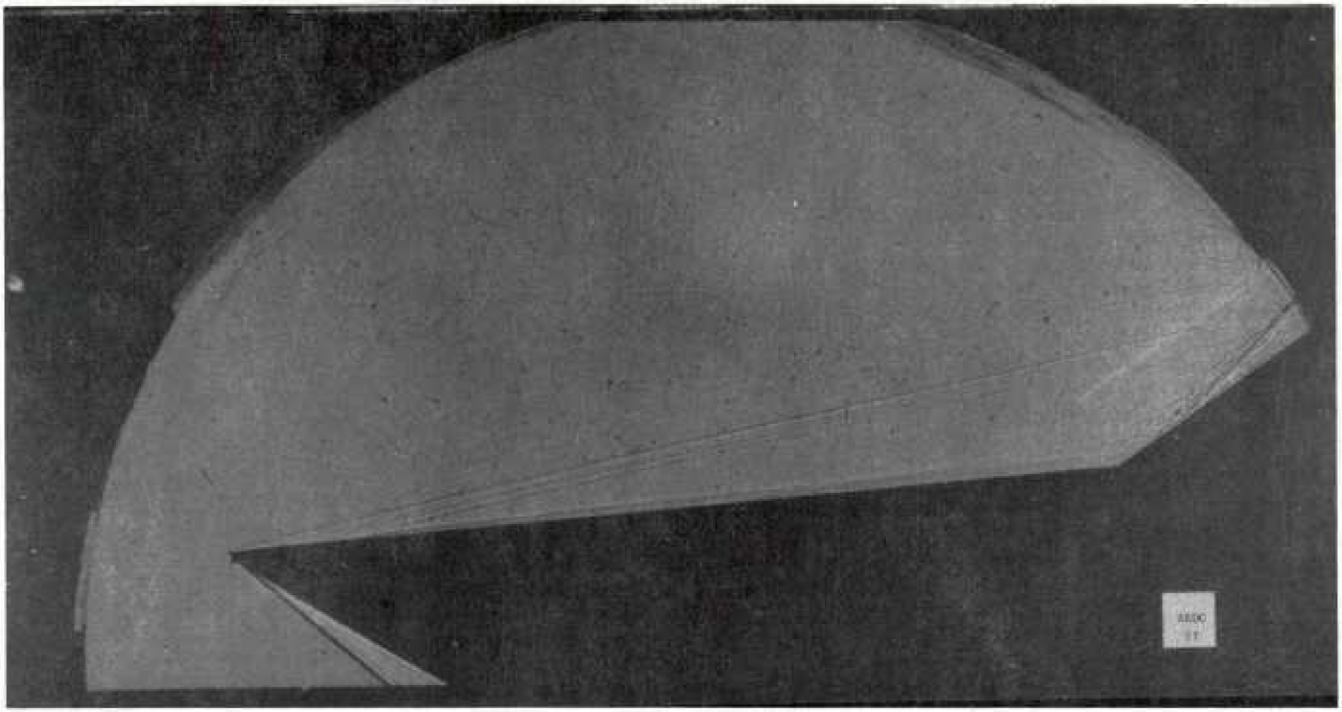


Fig. 33 Shadowgraph Flow Photograph, Ramp On, Maximum Coolant Flow Rate, $\alpha = -5^{\circ}$, $Re_{\infty}/ft = 1,100,000$

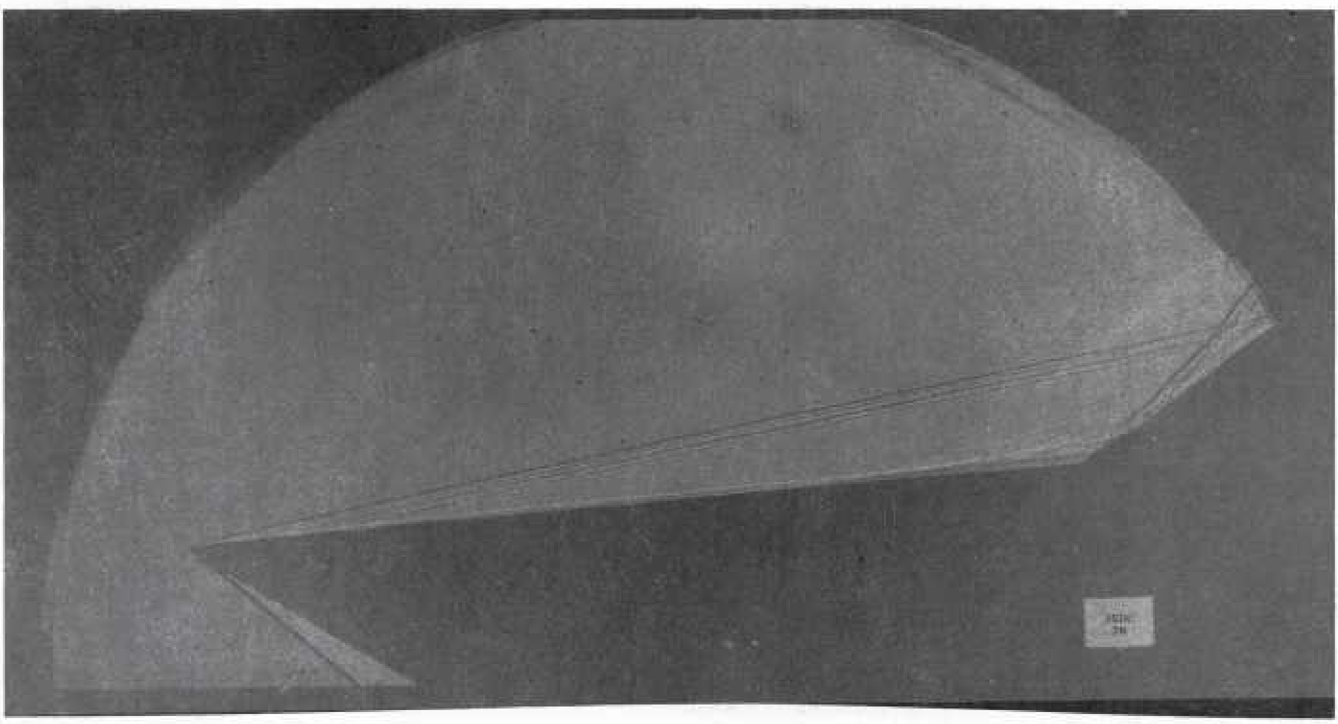


Fig. 34 Shadowgraph Flow Photograph, Ramp On, No Coolant Flow, $\alpha = -5^{\circ}$, $Re_{\infty}/ft = 3,300,000$

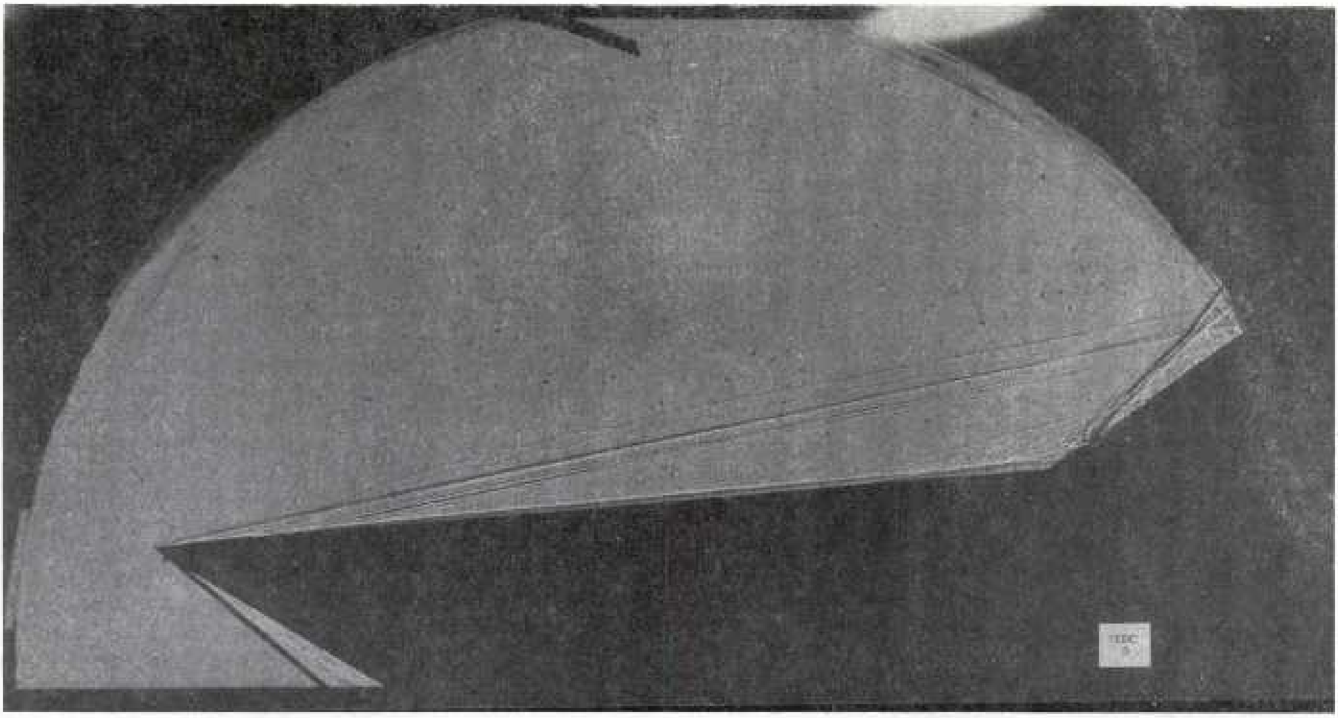


Fig. 35 Shadowgraph Flow Photograph, Ramp On, Maximum Coolant Flow Rate, $\alpha = -5^{o}$, Re_{∞}/ft = 3,300,000

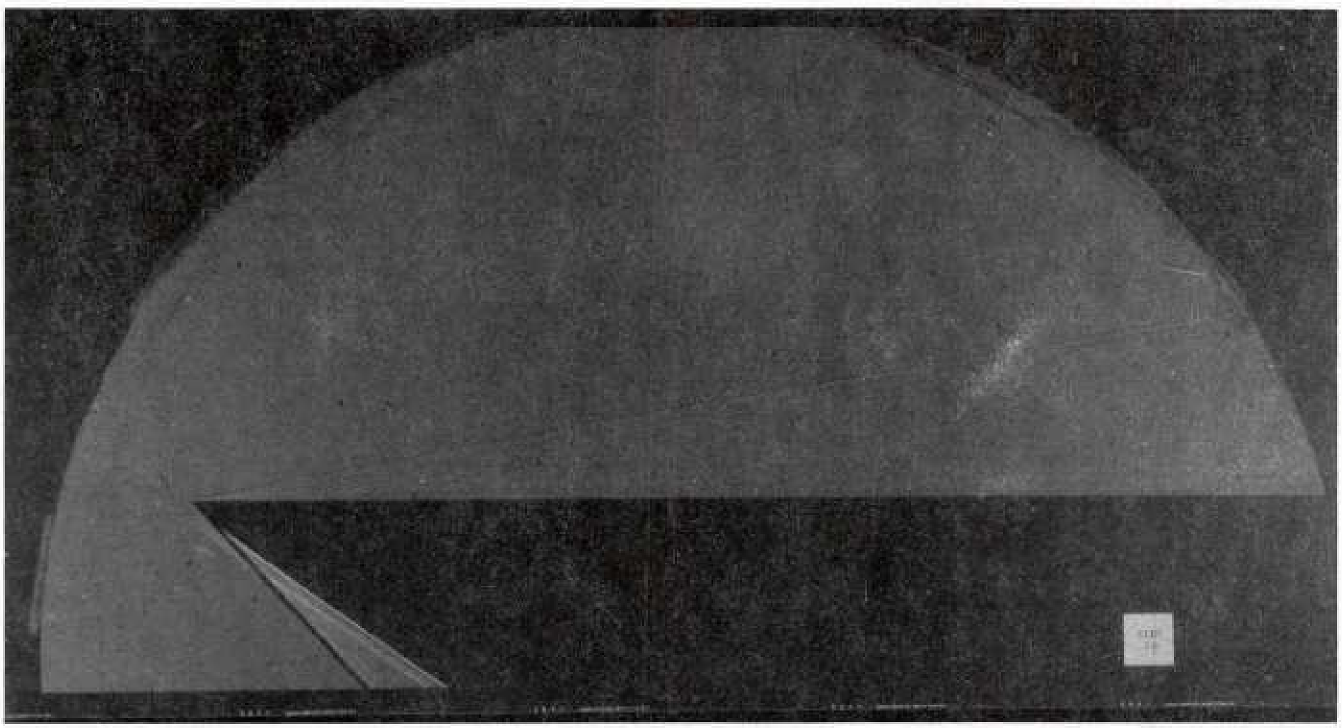


Fig. 36 Shadowgraph Flow Photograph, Ramp Off, No Coolant Flow, $\alpha = 0$, Re_{∞}/ft = 1,100,000

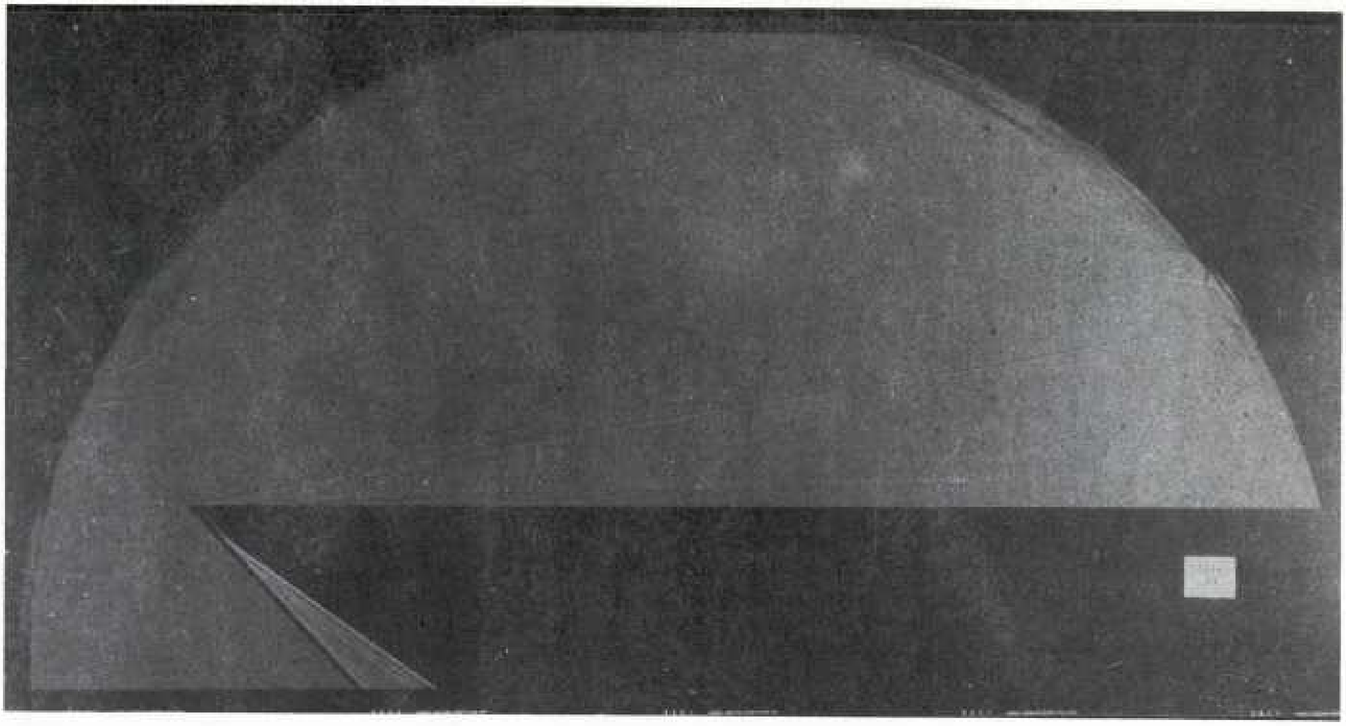


Fig. 37 Shadowgraph Flow Photograph; Ramp Off, Maximum Coolant Flow Rate, $\alpha = 0$, $Re_{\infty}/ft = 1,100,000$

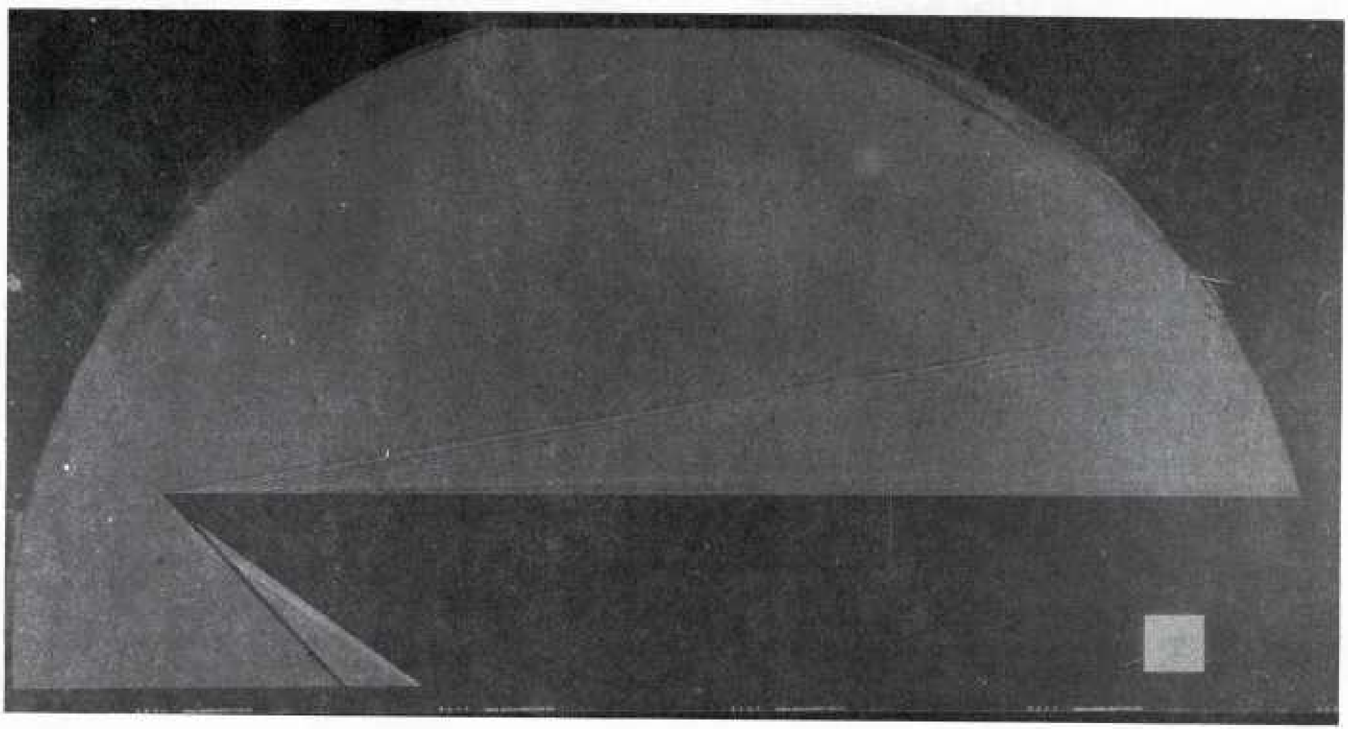


Fig. 38 Shadowgraph Flow Photograph; Ramp Off, No Coolant Flow, $\alpha = 0$, $Re_{\infty}/ft = 2,200,000$

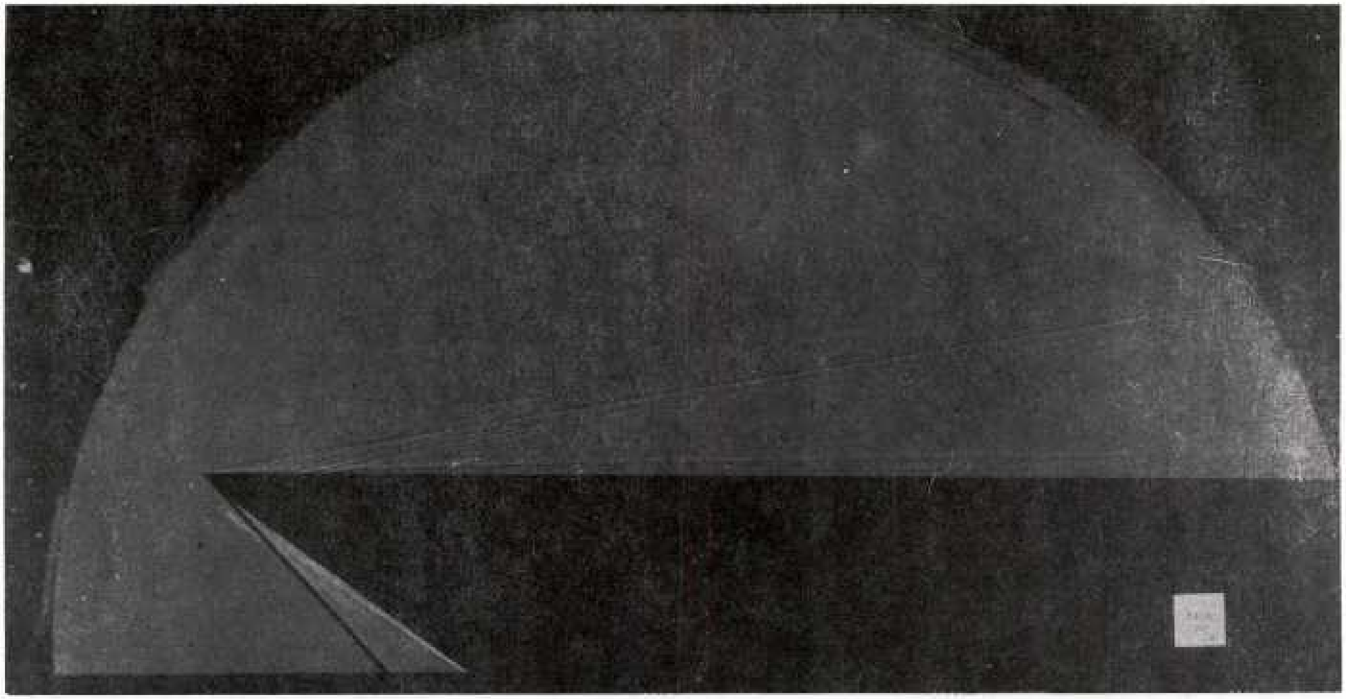


Fig. 39 Shadowgraph Flow Photograph; Ramp Off, Maximum Coolant Flow Rate, $\alpha = 0$, $Re_{\infty}/ft = 2,200,000$

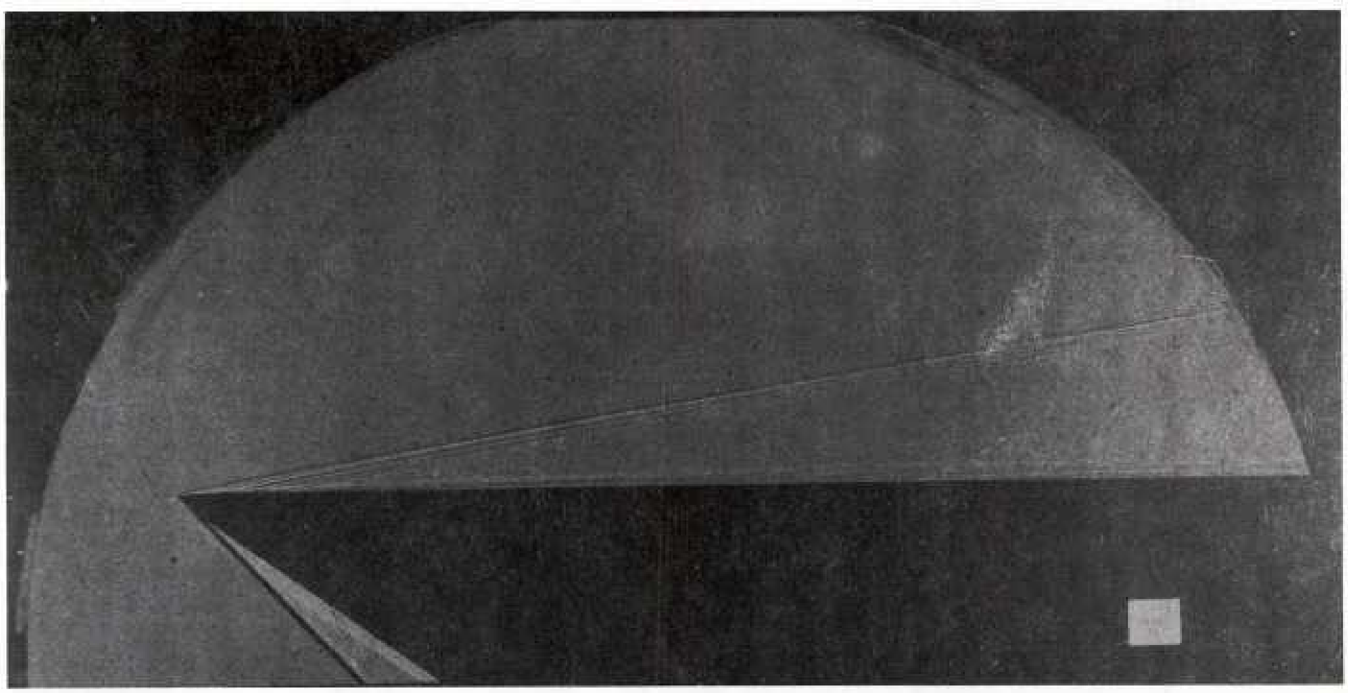


Fig. 40 Shadowgraph Flow Photograph; Ramp Off, No Coolant Flow, $\alpha = 0$, $Re_{\infty}/ft = 3,300,000$

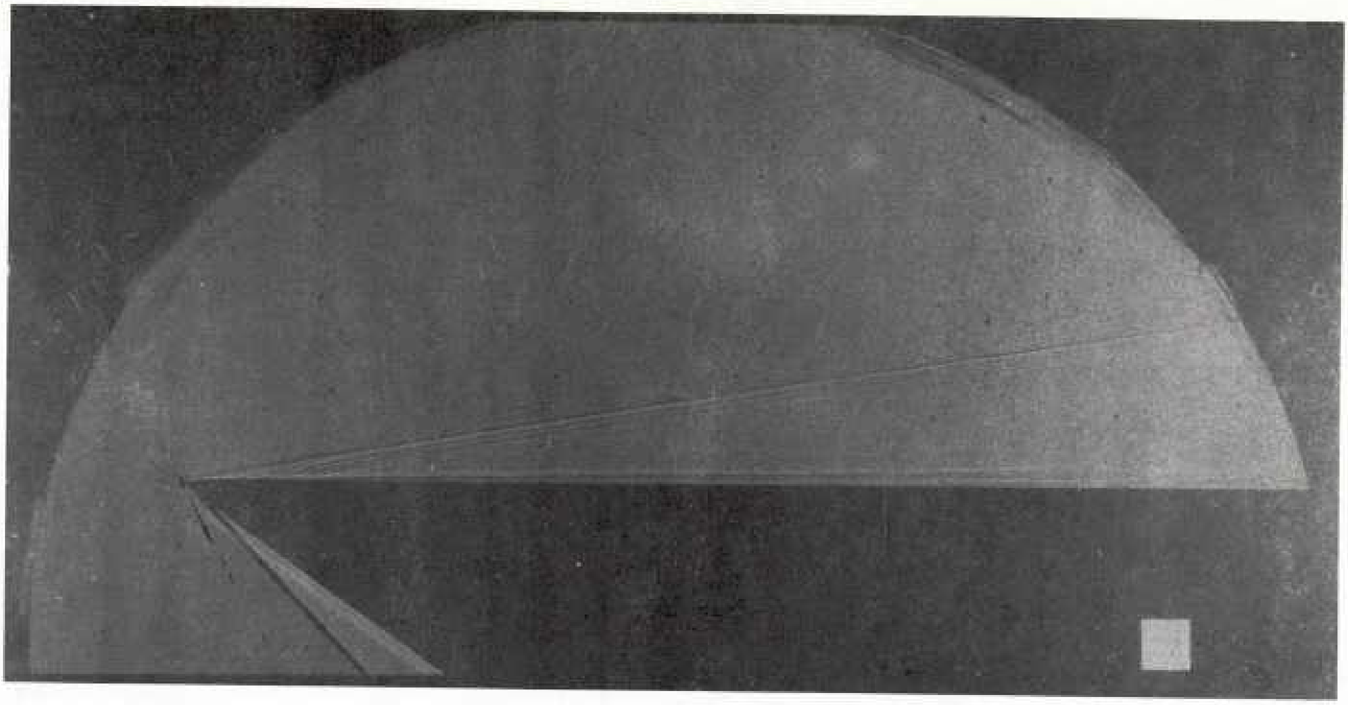


Fig. 41 Shadowgraph Flow Photograph; Ramp Off, Medium Coolant Flow Rate, $\alpha = 0$, $Re_{\infty}/ft = 3,300,000$

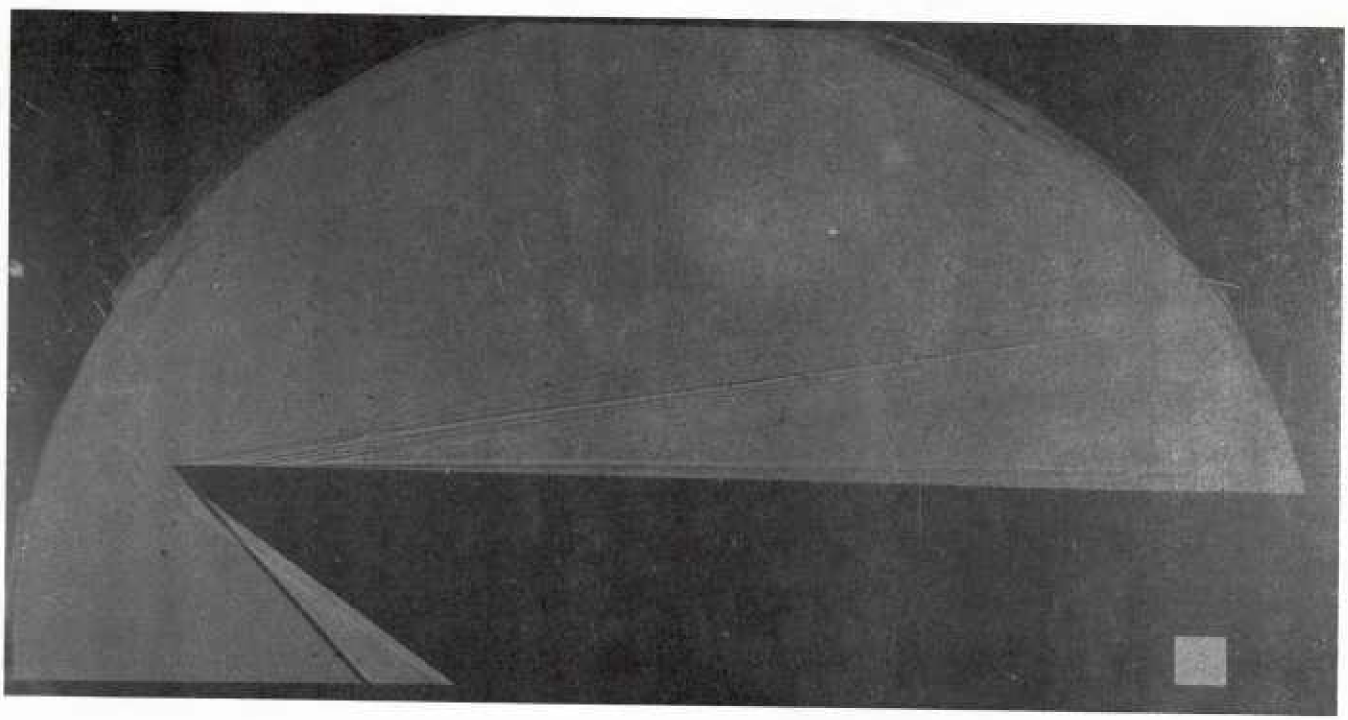


Fig. 42 Shadowgraph Flow Photograph; Ramp Off, Maximum Coolant Flow Rate, $\alpha = 0$, $Re_{\infty}/ft = 3,300,000$

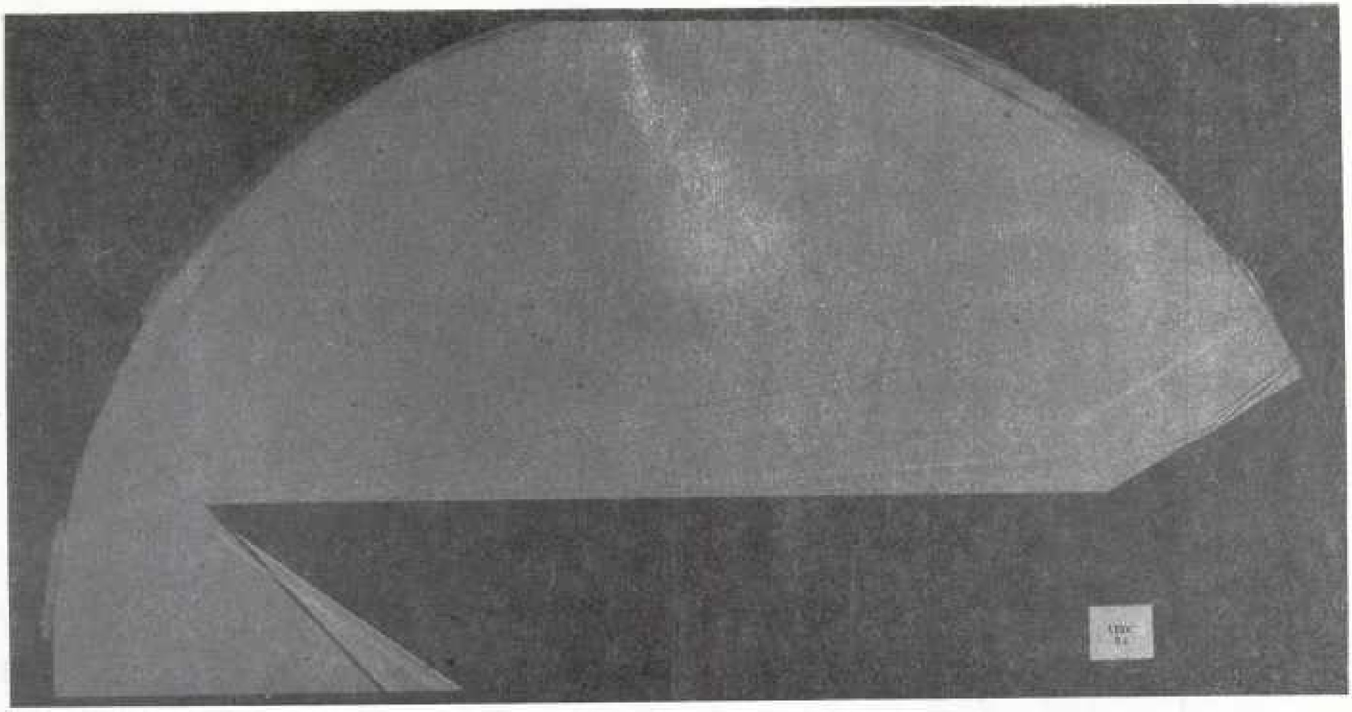


Fig. 43 Shadowgraph Flow Photograph; Ramp On, No Coolant Flow, $\alpha = 0$, $Re_{\infty}/ft = 1,100,000$

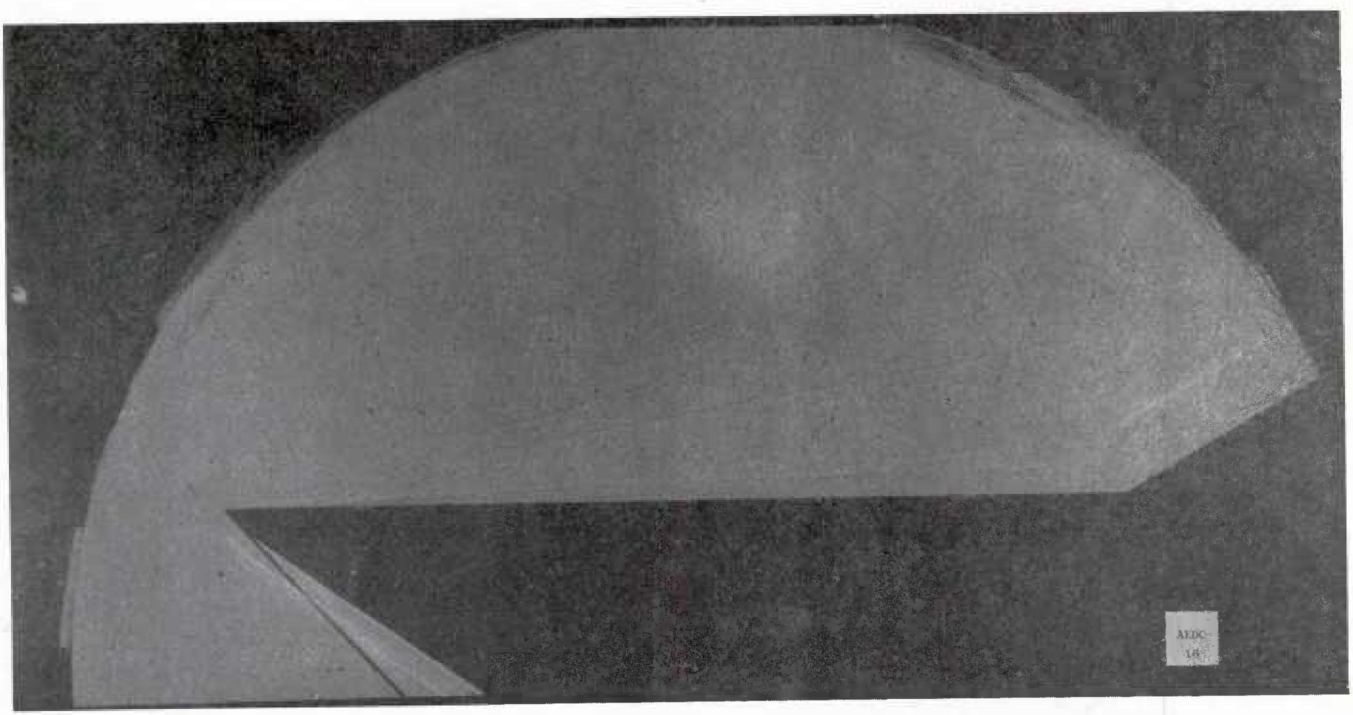


Fig. 44 Shadowgraph Flow Photograph; Ramp On, Maximum Coolant Flow Rate, $\alpha = 0$, $Re_{\infty}/ft = 1,100,000$

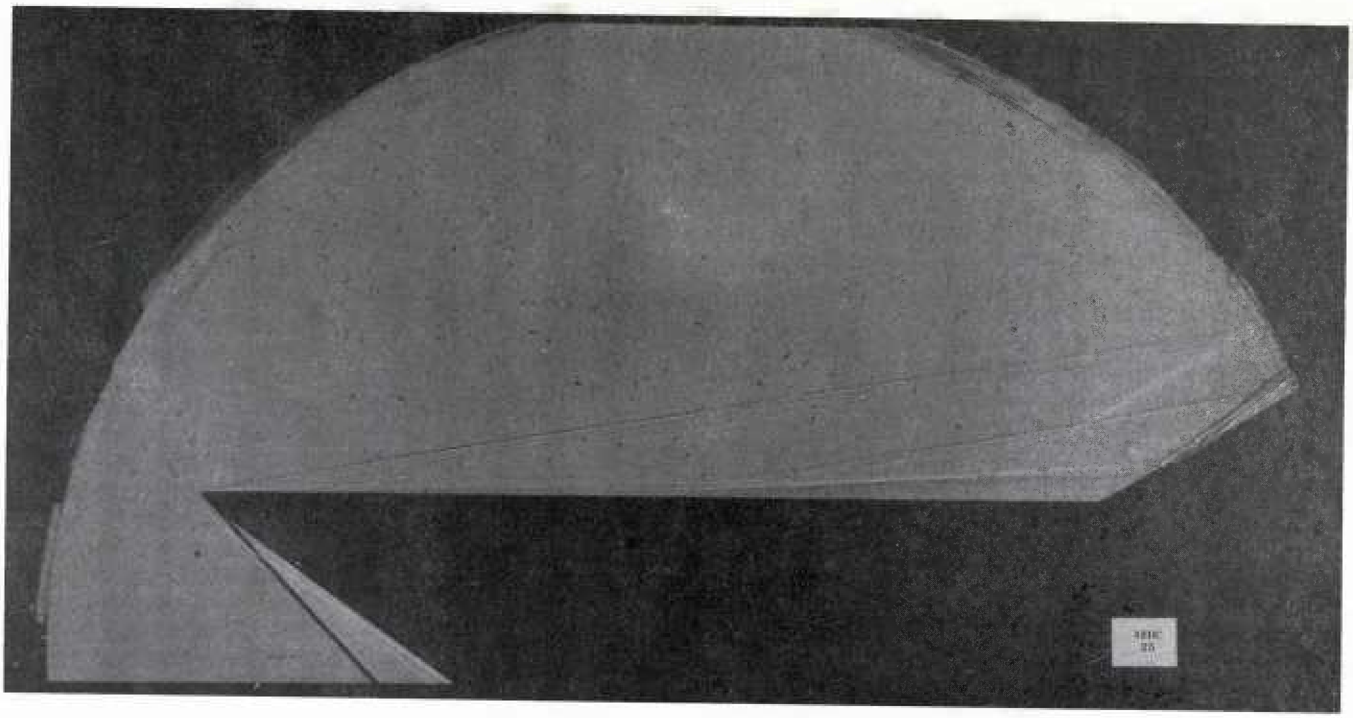


Fig. 45 Shadowgraph Flow Photograph; Ramp On, No Coolant Flow, $\alpha = 0$, $Re_{\infty}/ft = 2{,}200{,}000$

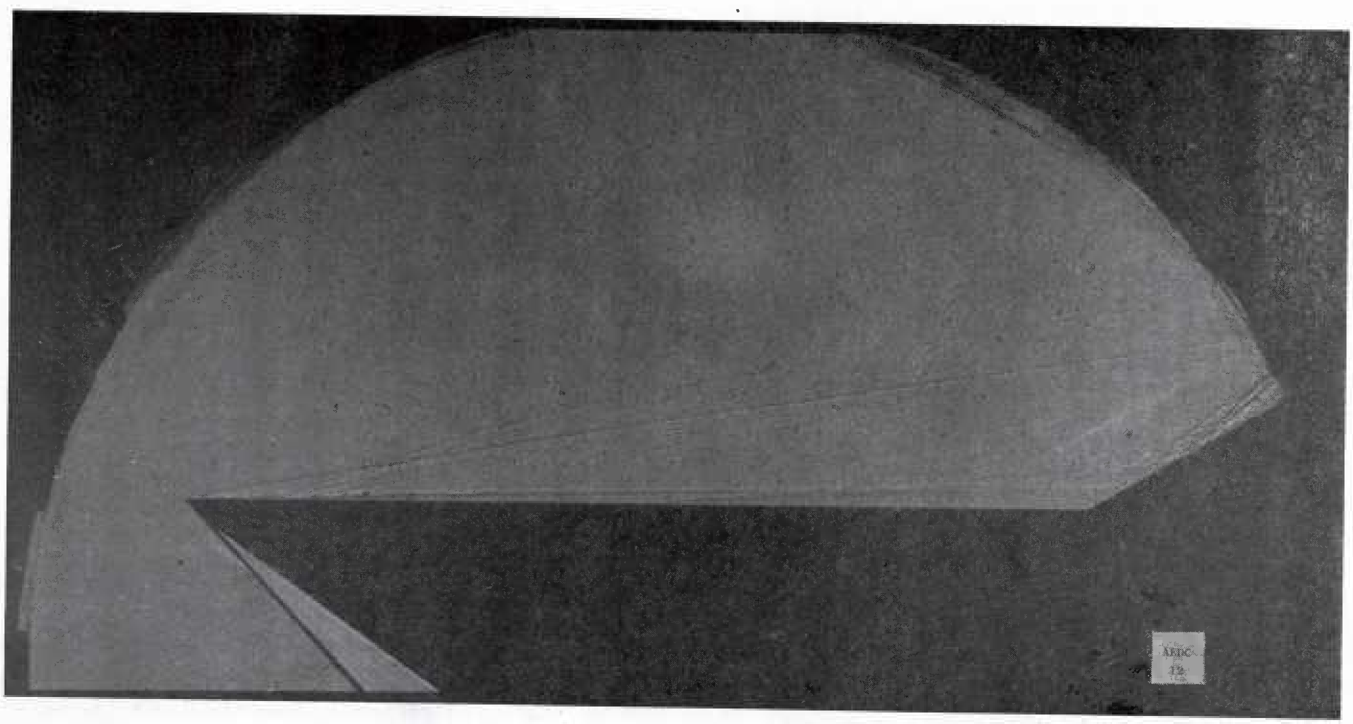


Fig. 46 Shadowgraph Flow Photograph; Ramp On, Maximum Coolant Flow Rate, $\alpha = 0$, $Re_{\infty}/ft = 2{,}200{,}000$

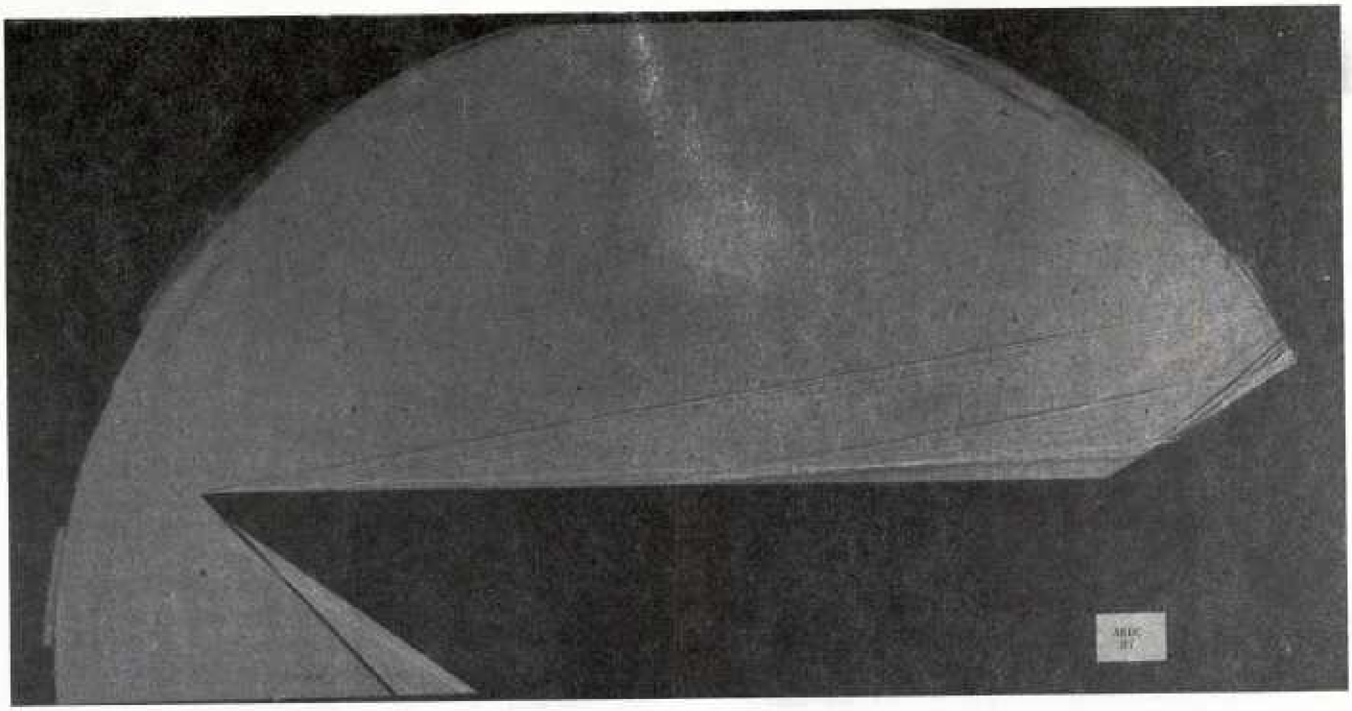


Fig. 47 Shadowgraph Flow Photograph; Ramp On, No Coolant Flow, $\alpha = 0$, $Re_{\infty}/ft = 3,300,000$

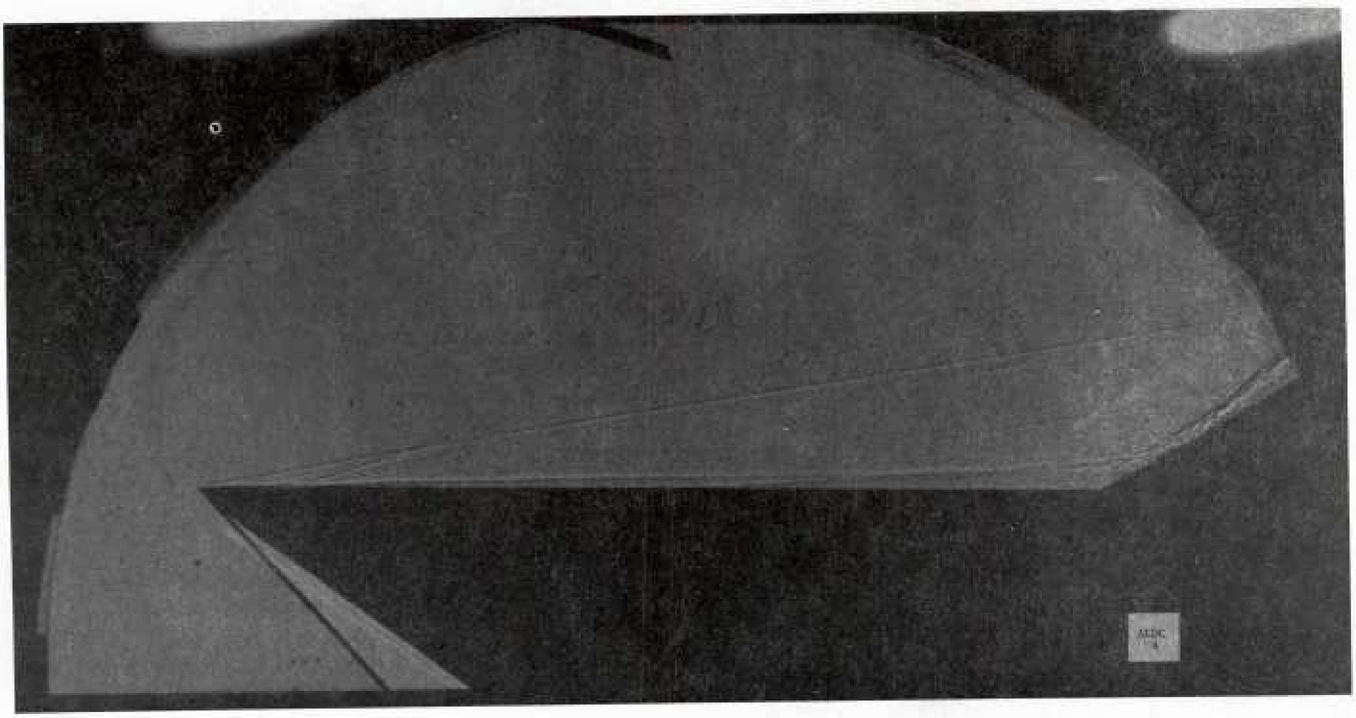


Fig. 48 Shadowgraph Flow Photograph; Ramp On, Maximum Coolant Flow Rate, $\alpha = 0$, $Re_{\infty}/ft = 3,300,000$

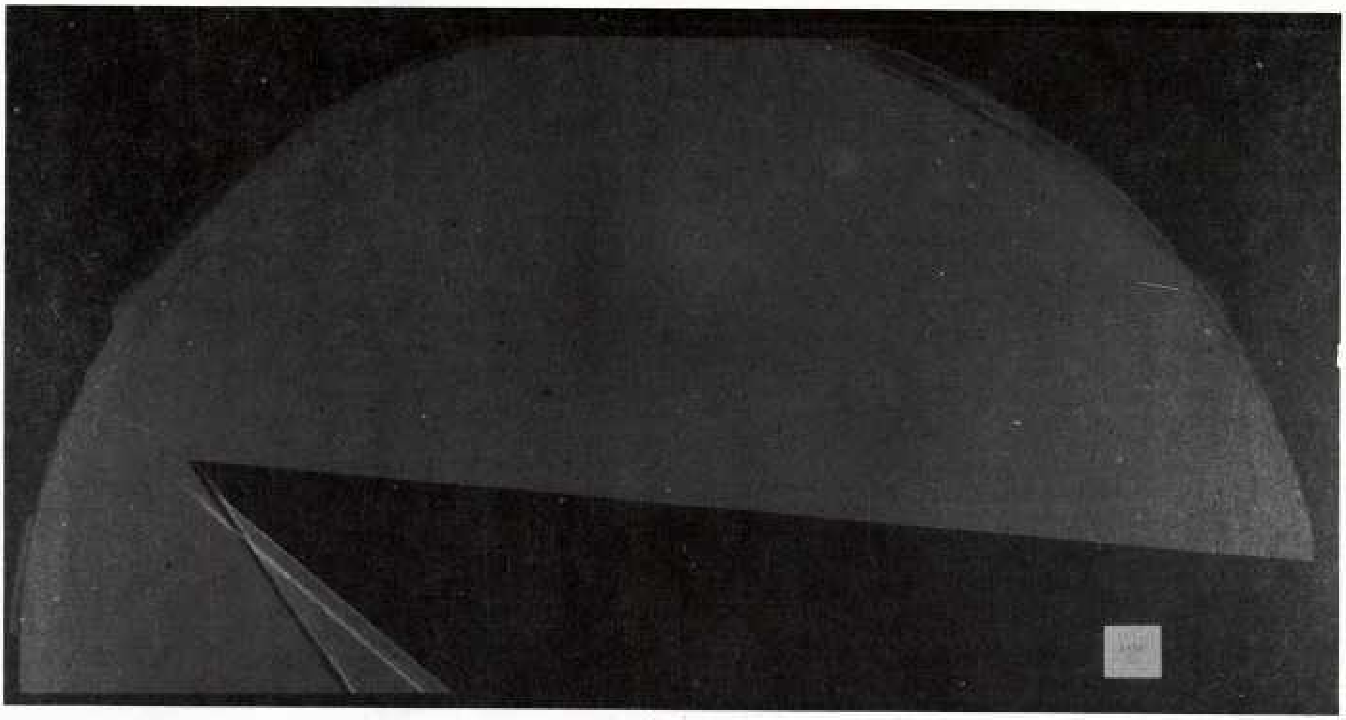


Fig. 49 Shadowgraph Flow Photograph; Ramp Off, No Coolant Flow, $\alpha = +5^{o}$, Re_{∞}/ft = 1,100,000

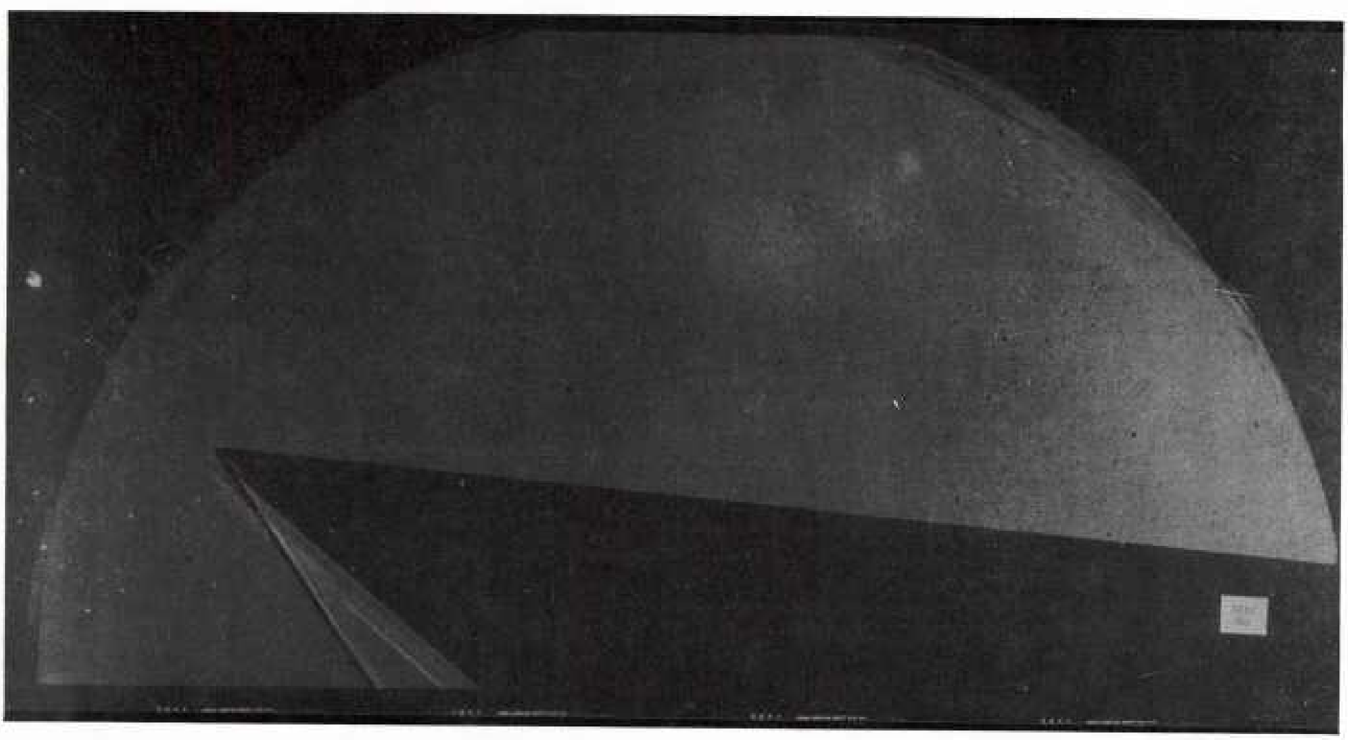


Fig. 50 Shadowgraph Flow Photograph; Ramp Off, Maximum Coolant Flow Rate, $\alpha = +5^{o}$, Re_{∞}/ft = 1,100,000

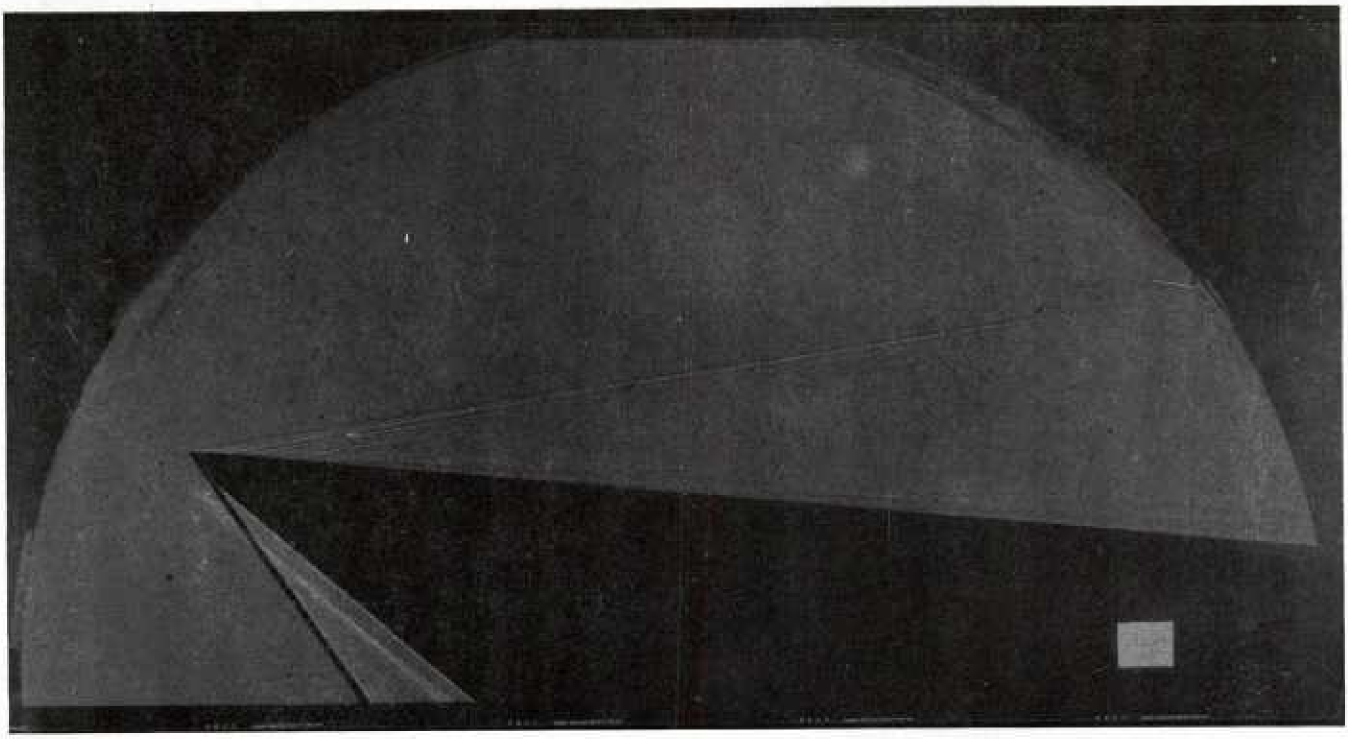


Fig. 51 Shadowgraph Flow Photograph; Ramp Off, No Coolant Flow, $\alpha = +5^{\circ}$, Re_{∞}/ft = 3,300,000

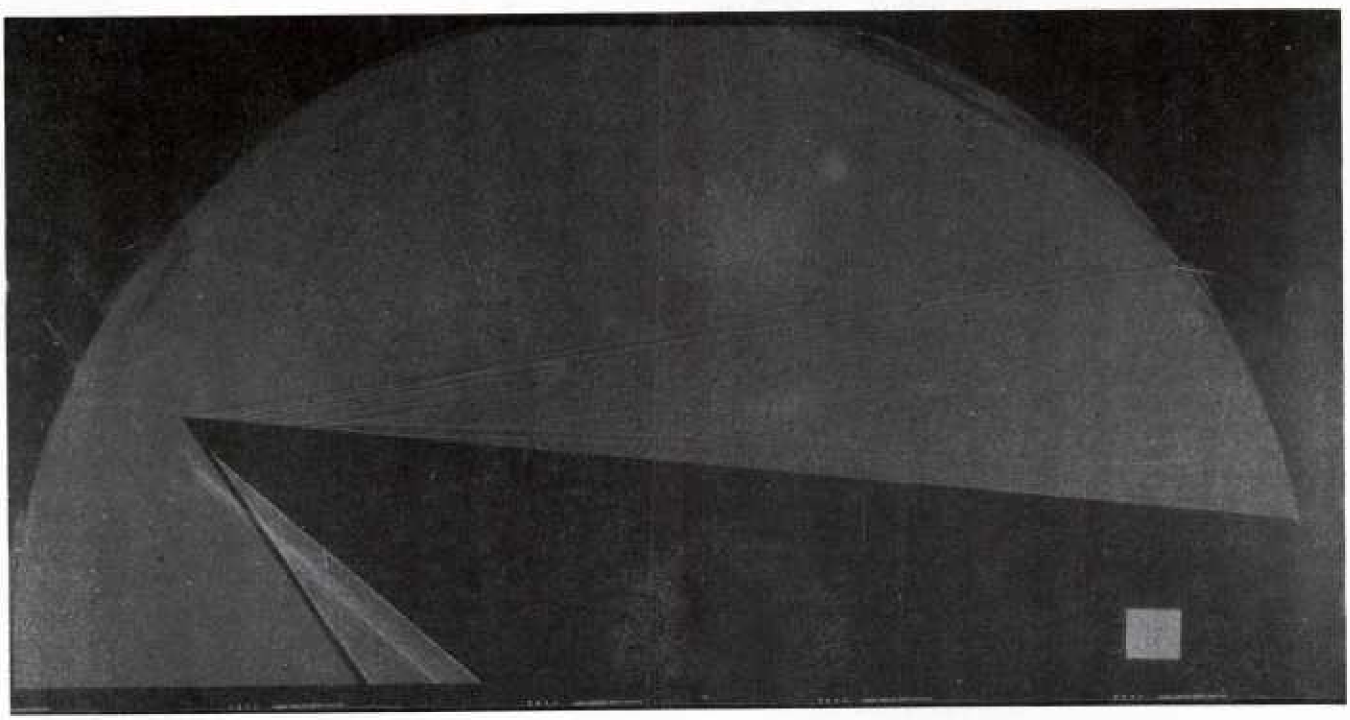


Fig. 52 Shadowgraph Flow Photograph; Ramp Off, Maximum Coolant Flow Rate, $\alpha = +5^{\circ}$, Re_{∞}/ft = 3,300,000

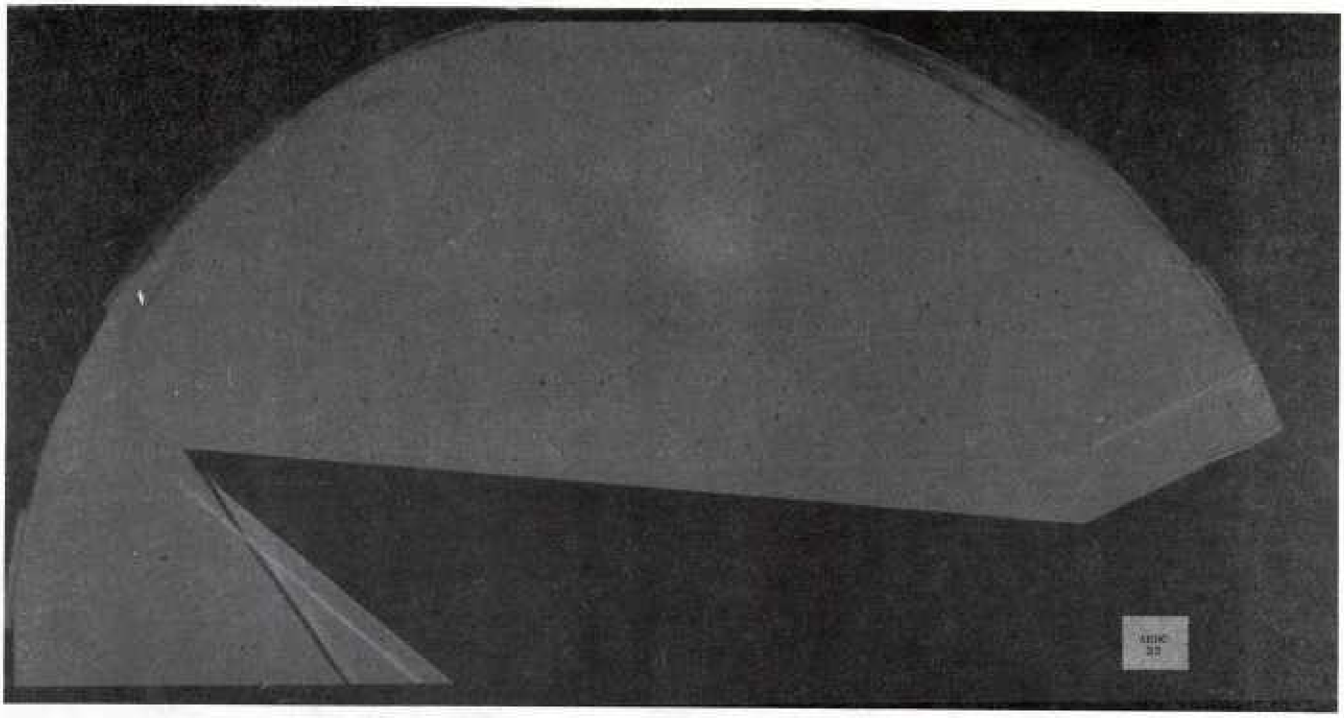


Fig. 53 Shadowgraph Flow Photograph; Ramp On, No Coolant Flow, $\alpha = +5^{\circ}$, $Re_{\infty}/ft = 1,100,000$

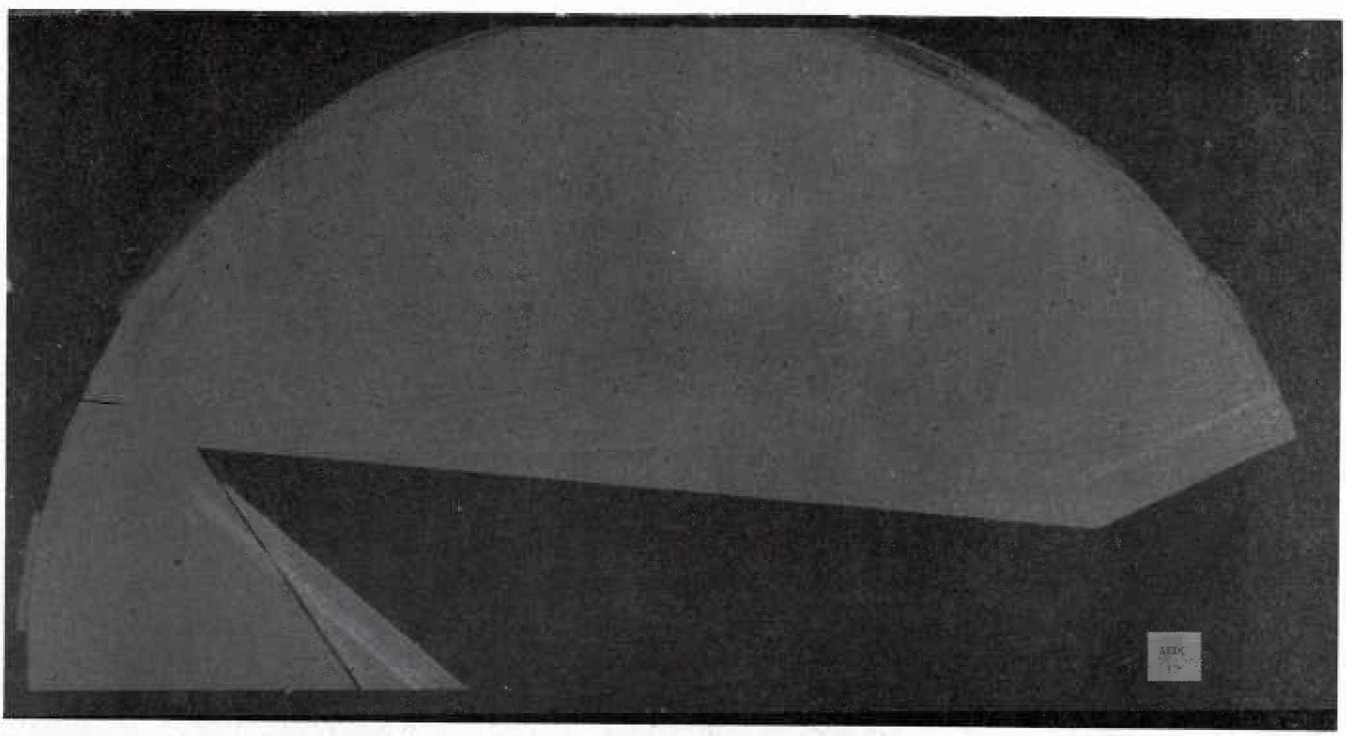


Fig. 54 Shadowgraph Flow Photograph; Ramp On, Maximum Coolant Flow Rate, $\alpha = +5^{\circ}$, $Re_{\infty}/ft = 1,100,000$

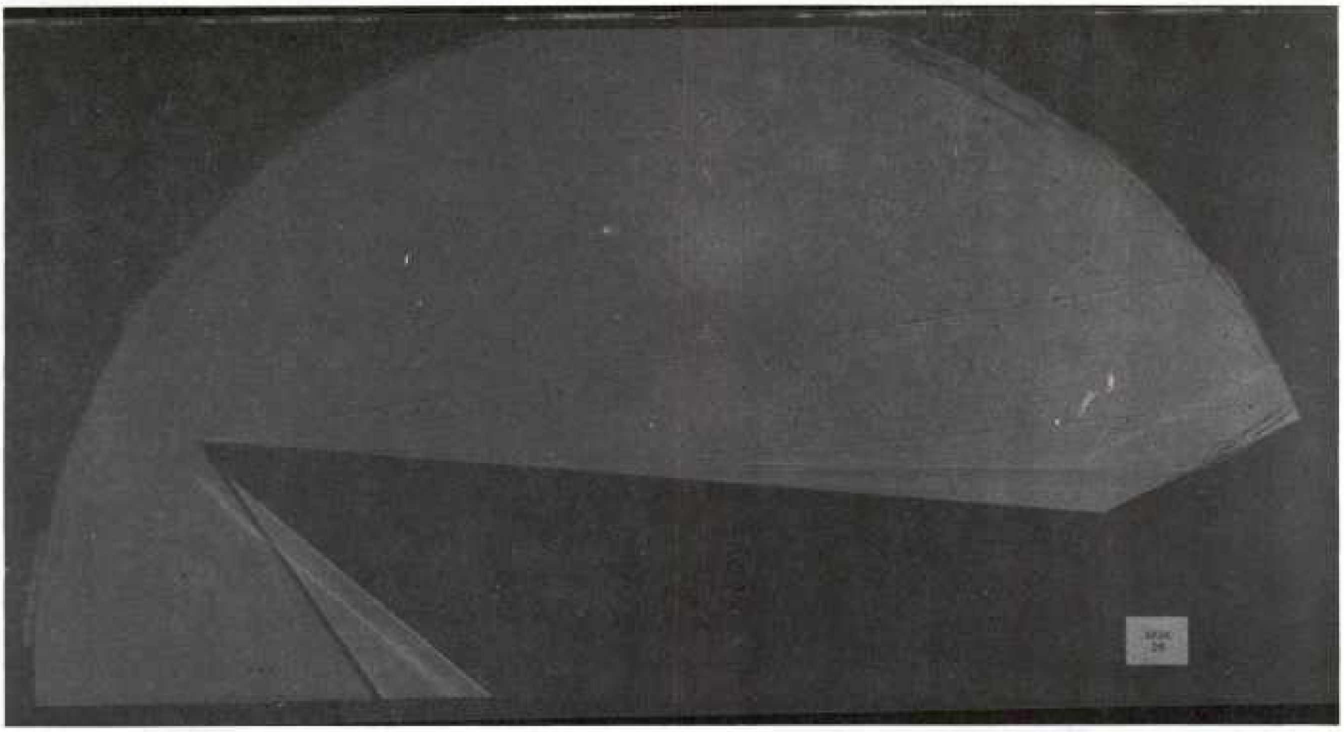


Fig. 55 Shadowgraph Flow Photograph; Ramp On, No Coolant Flow, $\alpha = +5^{o}$, Re_{∞}/ft = 3,300,000

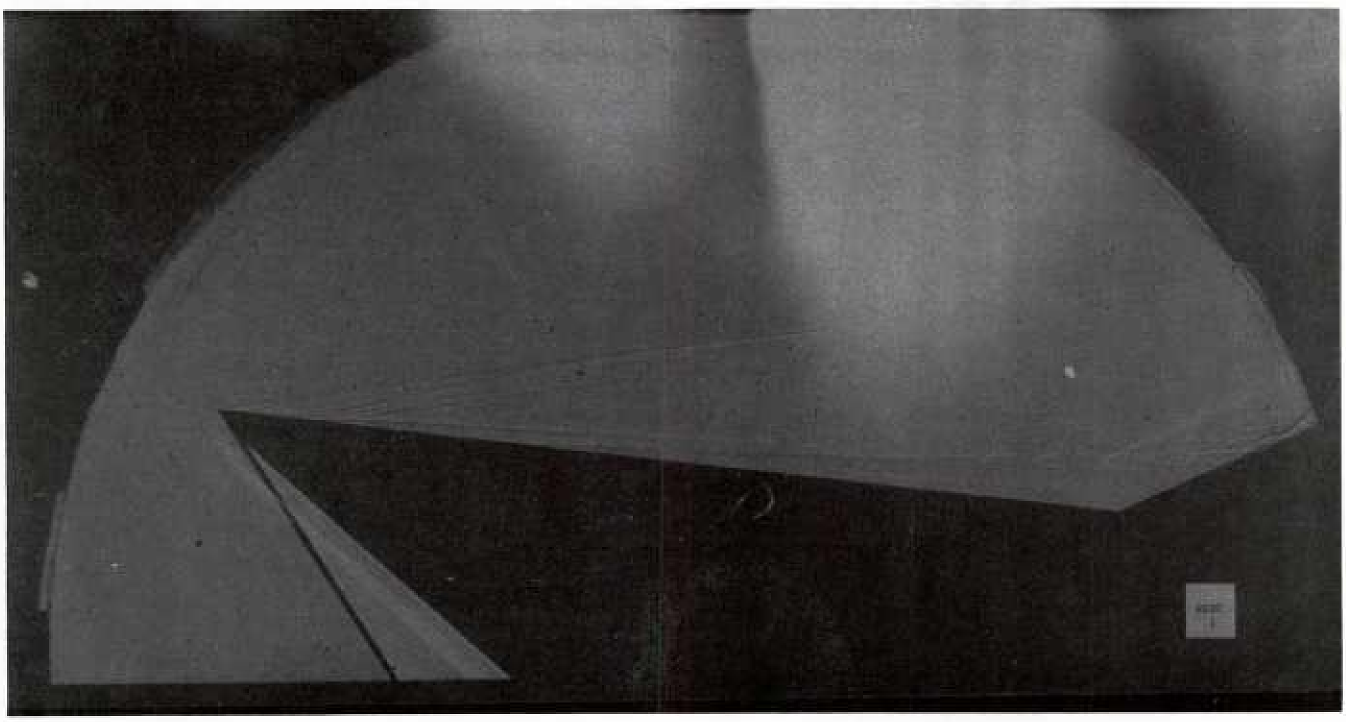


Fig. 56 Shadowgraph Flow Photograph; Ramp On, Maximum Coolant Flow Rate, $\alpha = +5^{o}$, Re_{∞}/ft = 3,300,000

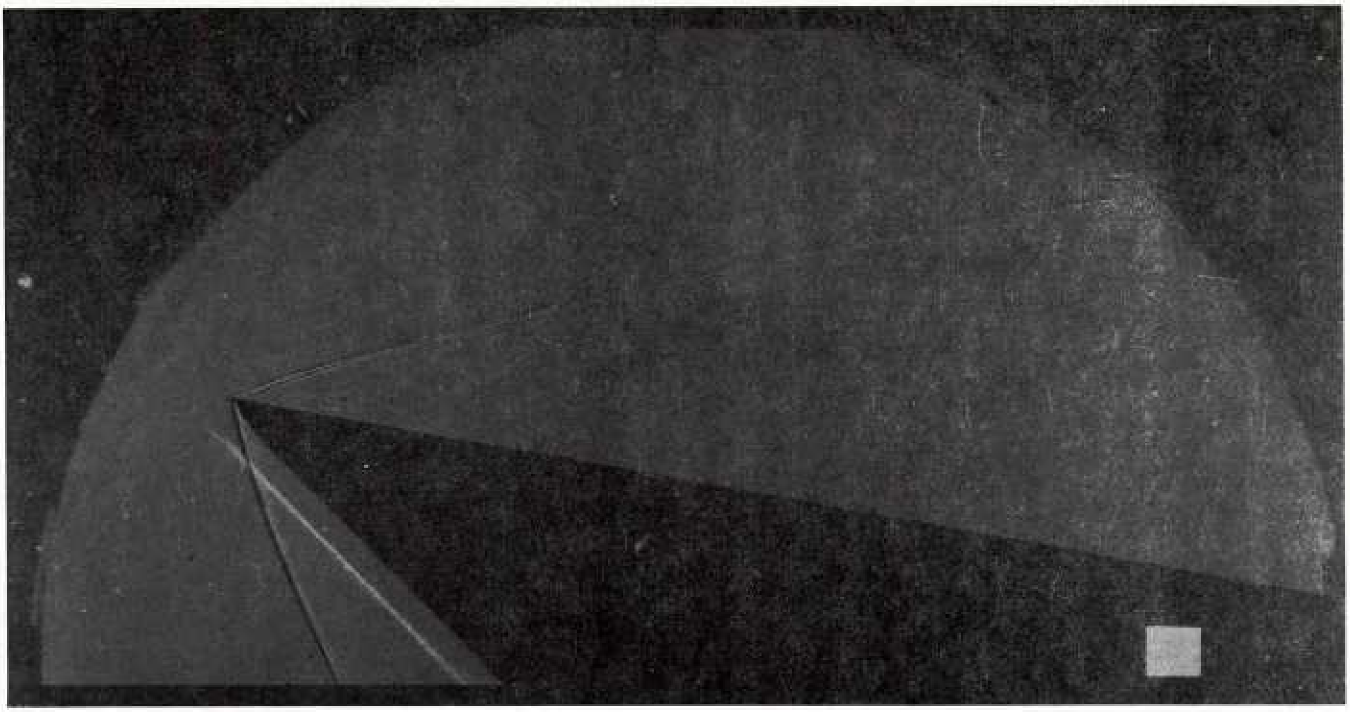


Fig. 57 Shadowgraph Flow Photograph; Ramp Off, No Coolant Flow, $\alpha = +10^{\circ}$, $Re_{\infty}/ft = 1,100,000$

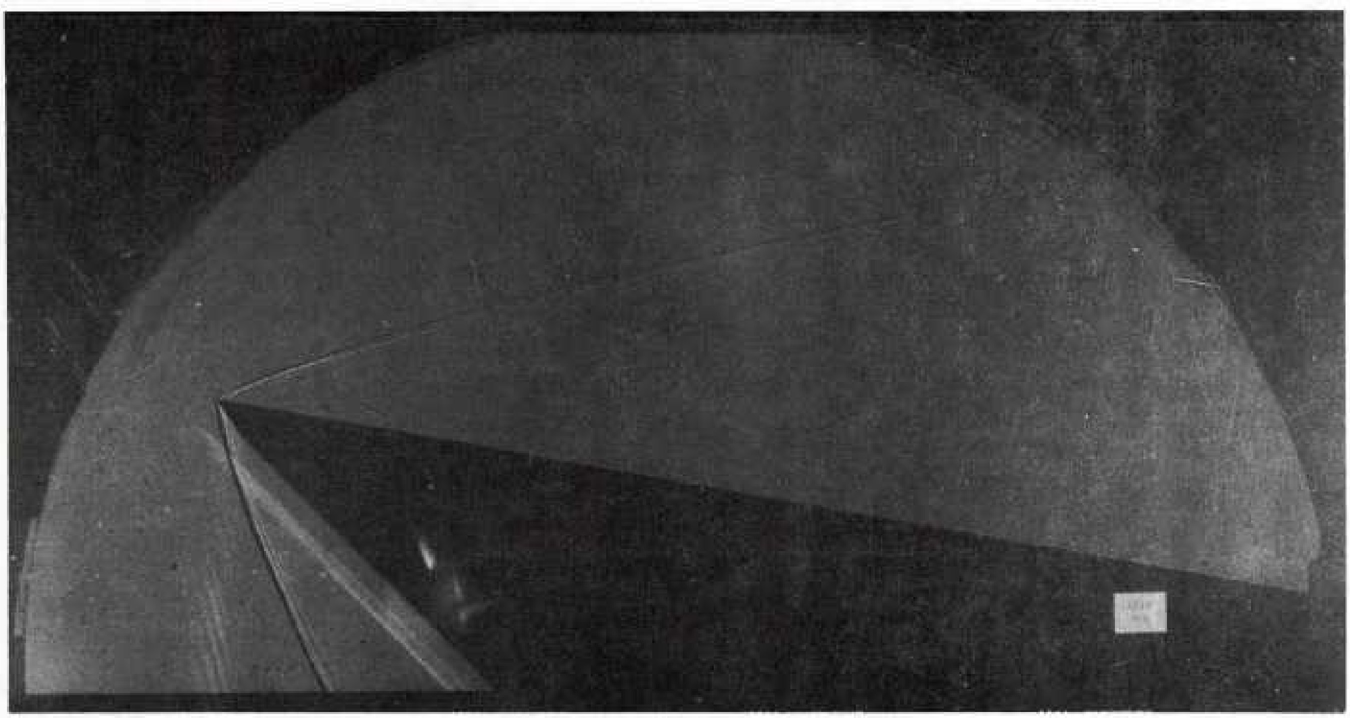


Fig. 58 Shadowgraph Flow Photograph; Ramp Off, Maximum Coolant Flow Rate, $\alpha = +10^{\circ}$, $Re_{\infty}/ft = 1,100,000$

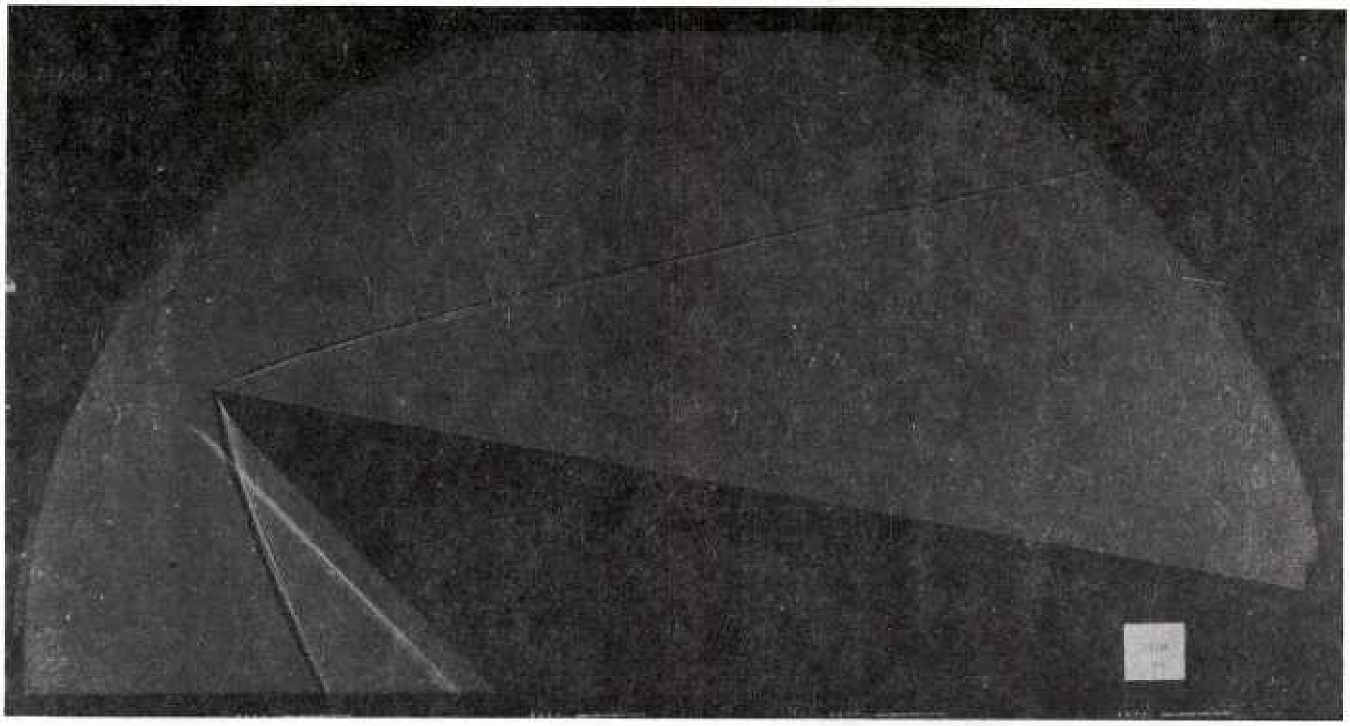


Fig. 59 Shadowgraph Flow Photograph; Ramp Off, No Coolant Flow, $\alpha = +10^{\circ}$, $Re_{\infty}/ft = 2,200,000$

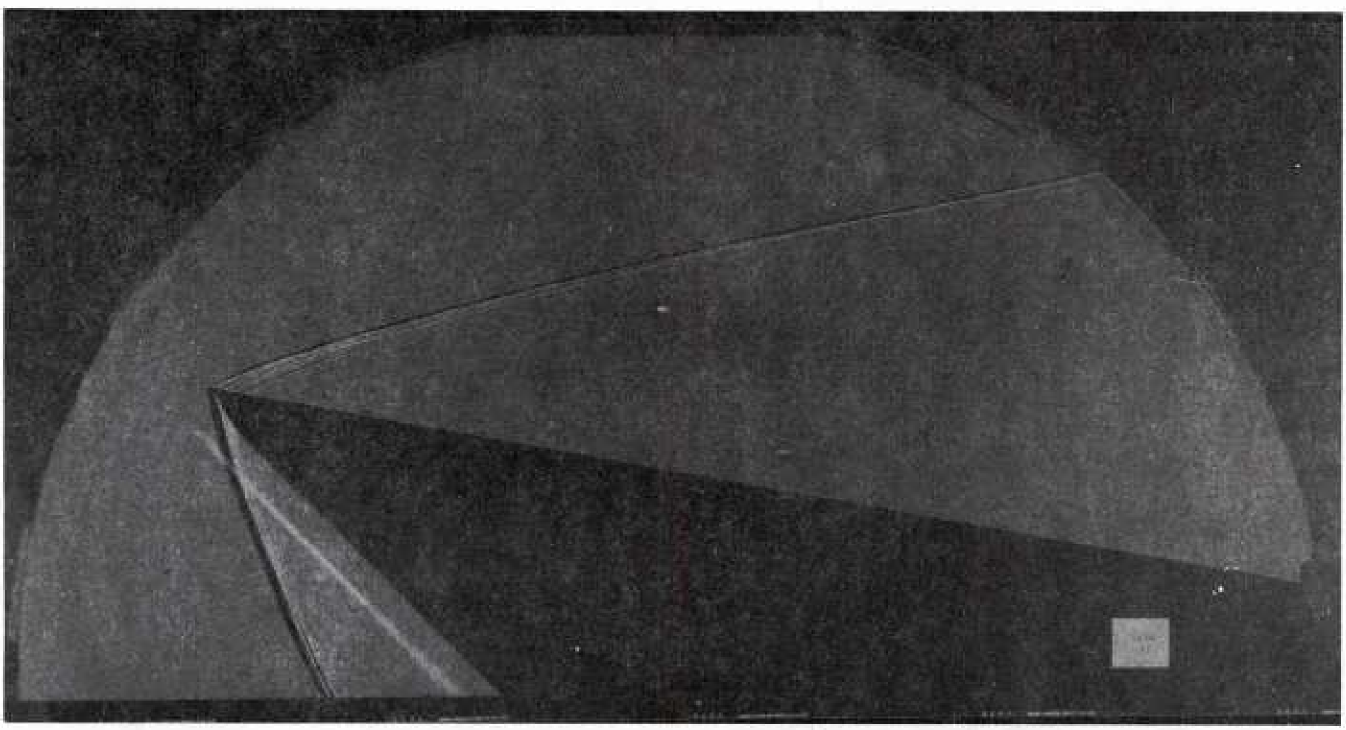


Fig. 60 Shadowgraph Flow Photograph; Ramp Off, No Coolant Flow, $\alpha = +10^{\circ}$, $Re_{\infty}/ft = 3,300,000$

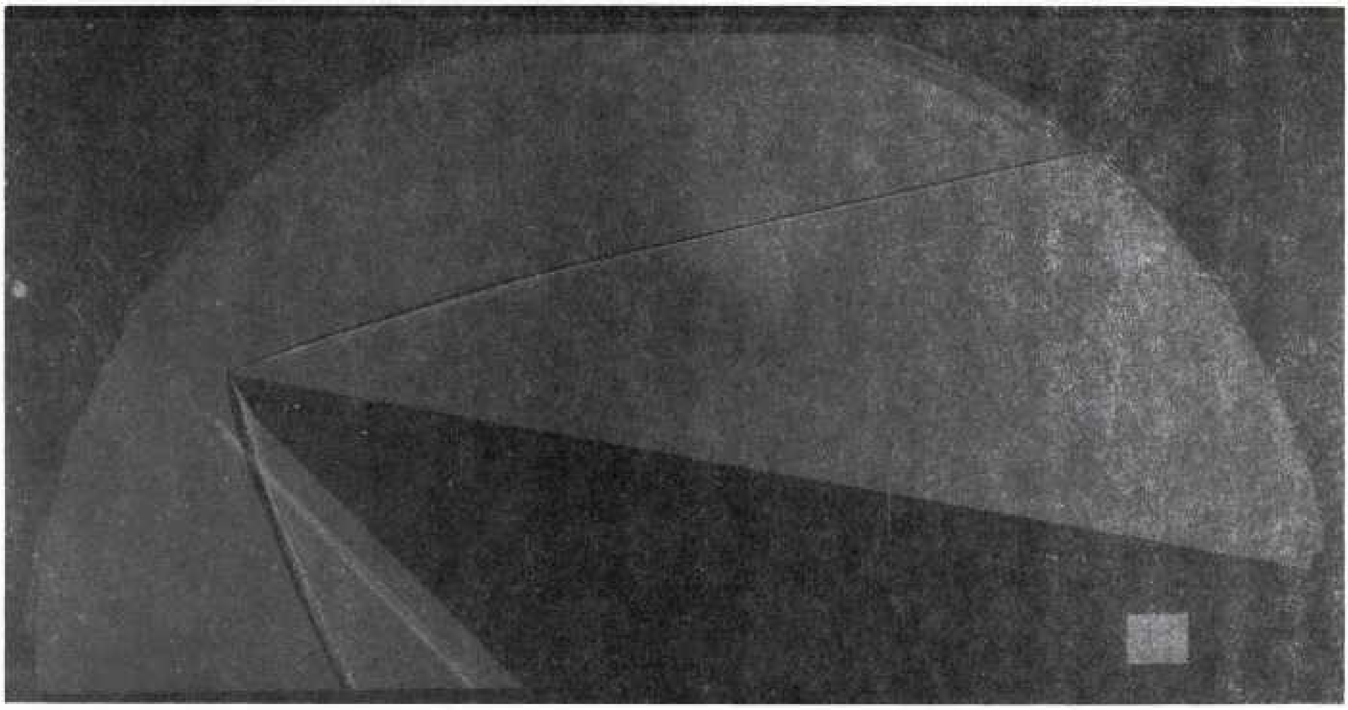


Fig. 61 Shadowgraph Flow Photograph; Ramp Off, Medium Coolant Flow Rate, $\alpha = +10^{o}$, $Re_{\infty}/ft = 3{,}300{,}000$

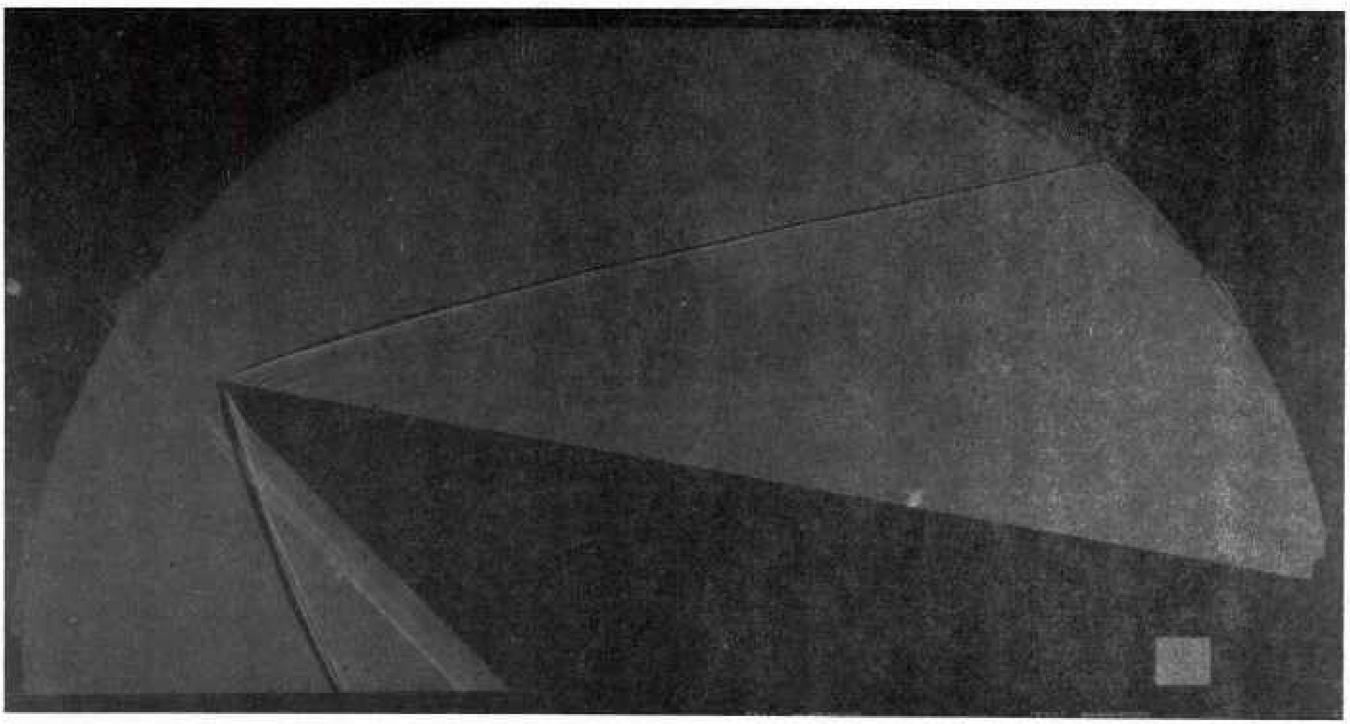


Fig. 62 Shadowgraph Flow Photograph; Ramp Off, Maximum Coolant Flow Rate, $\alpha = +10^{o}$, $Re_{\infty}/ft = 3{,}300{,}000$

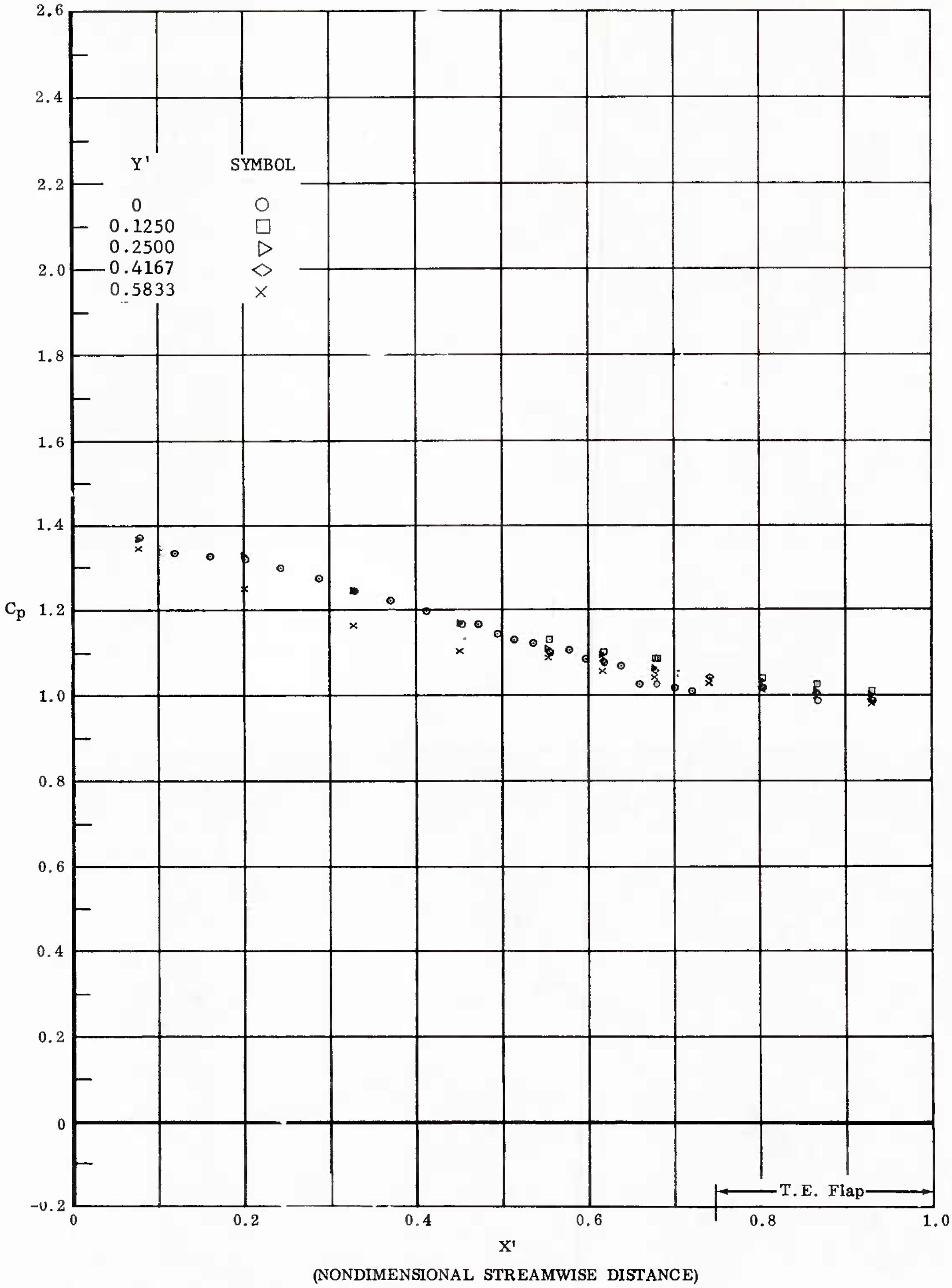


Fig. 63 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -43°$, $Re_\infty/ft = 1,100,000$.

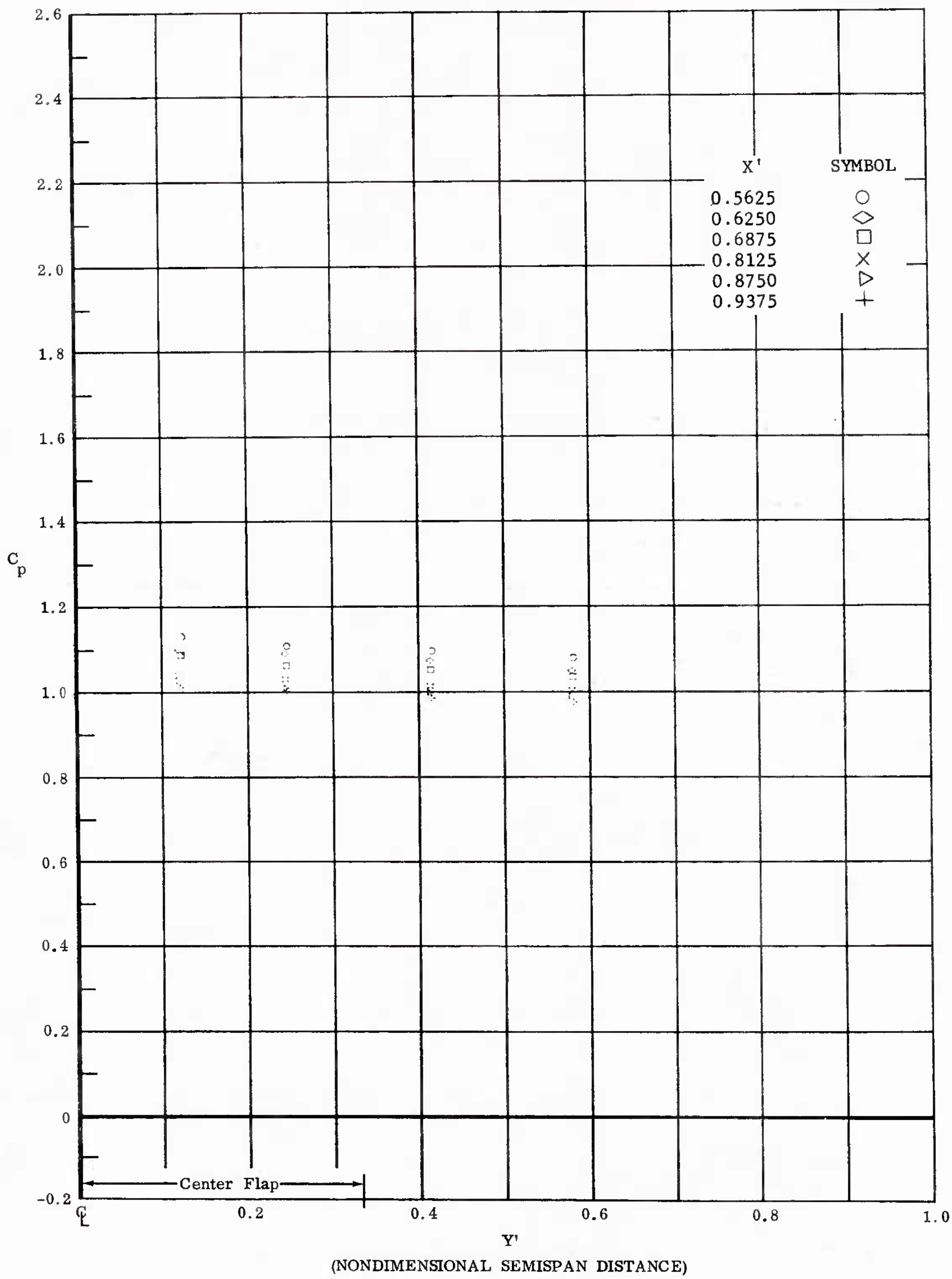


Fig. 63 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -43°$, $Re_{\infty}/ft = 1,100,000$.

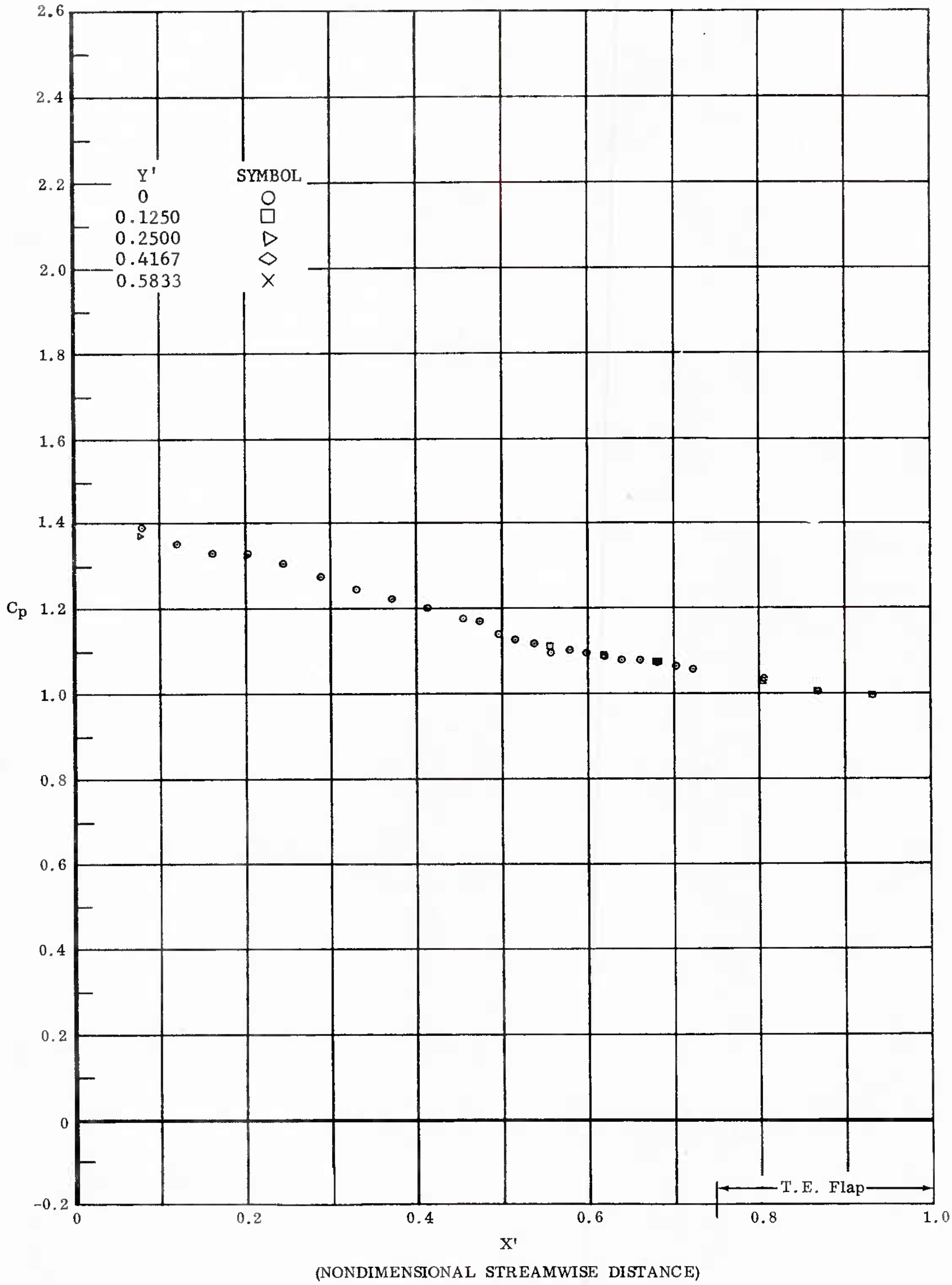


Fig. 64 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -43°$, $Re_\infty/ft = 2,200,000$.

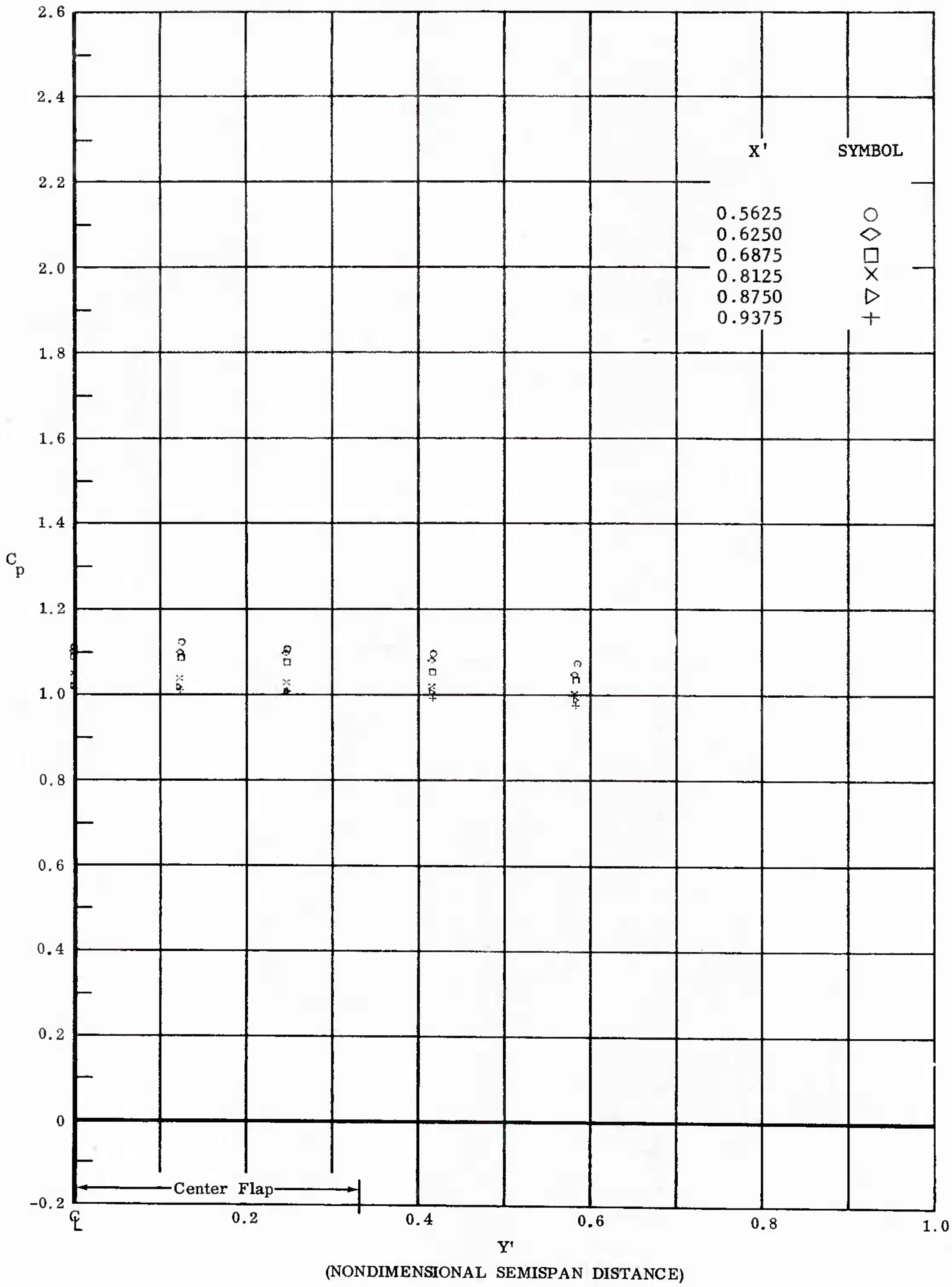


Fig. 64 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, α = -43°, Re_∞/ft = 2,200,000.

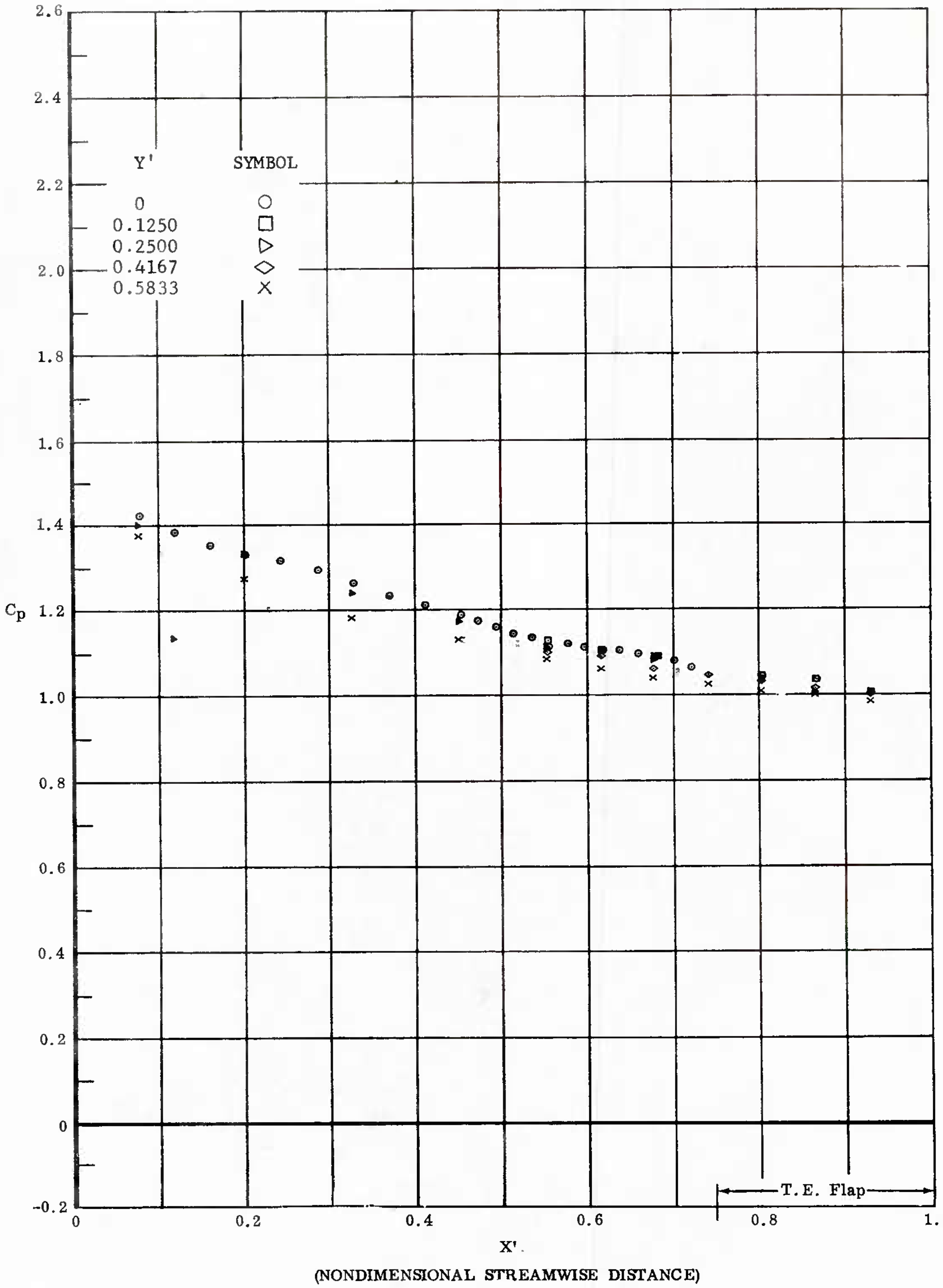


Fig. 65 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -43°$, $Re_\infty/ft = 3,300,000$.

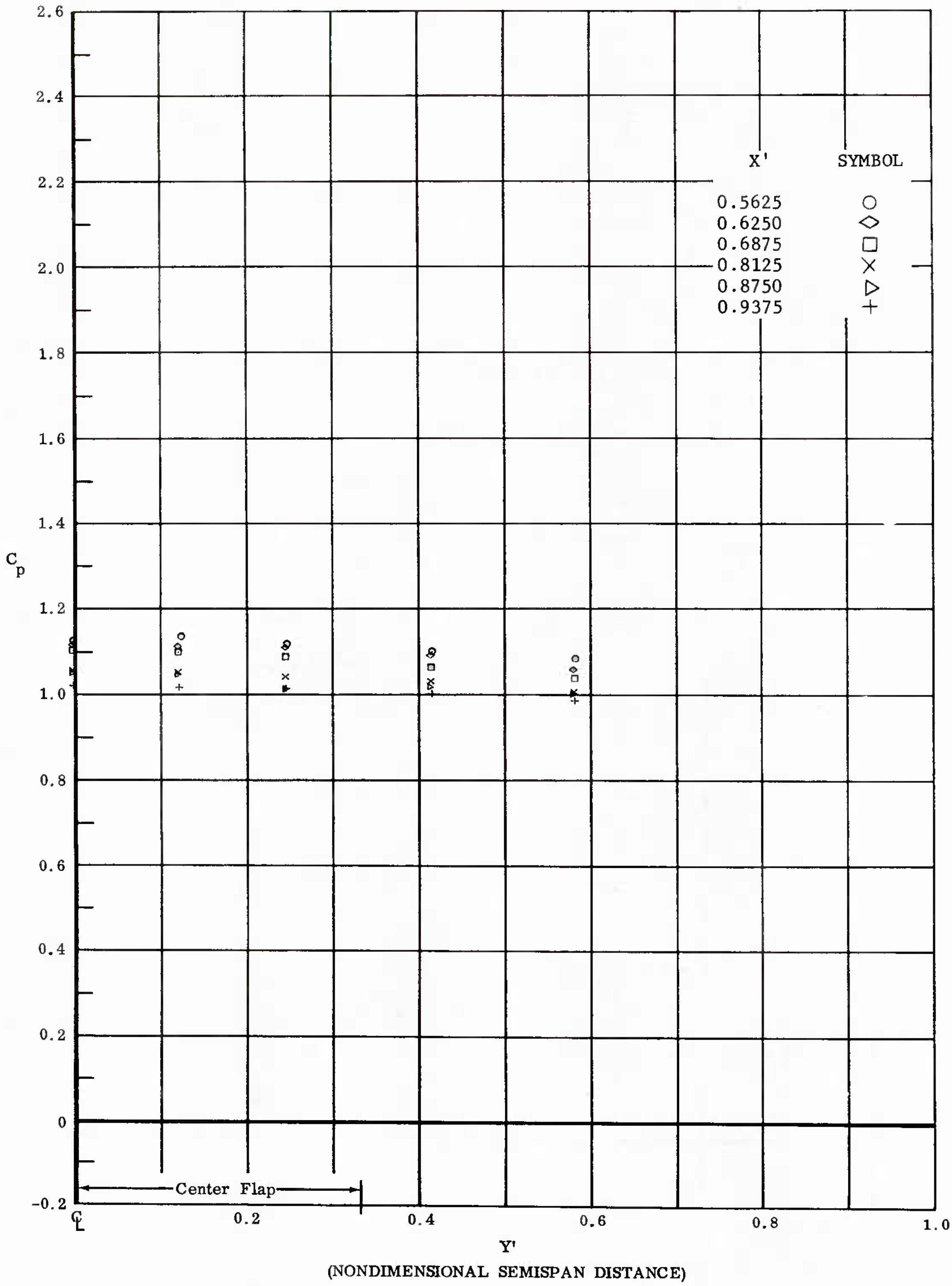


Fig. 65 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -43°$, $Re_\infty/ft = 3,300,000$.

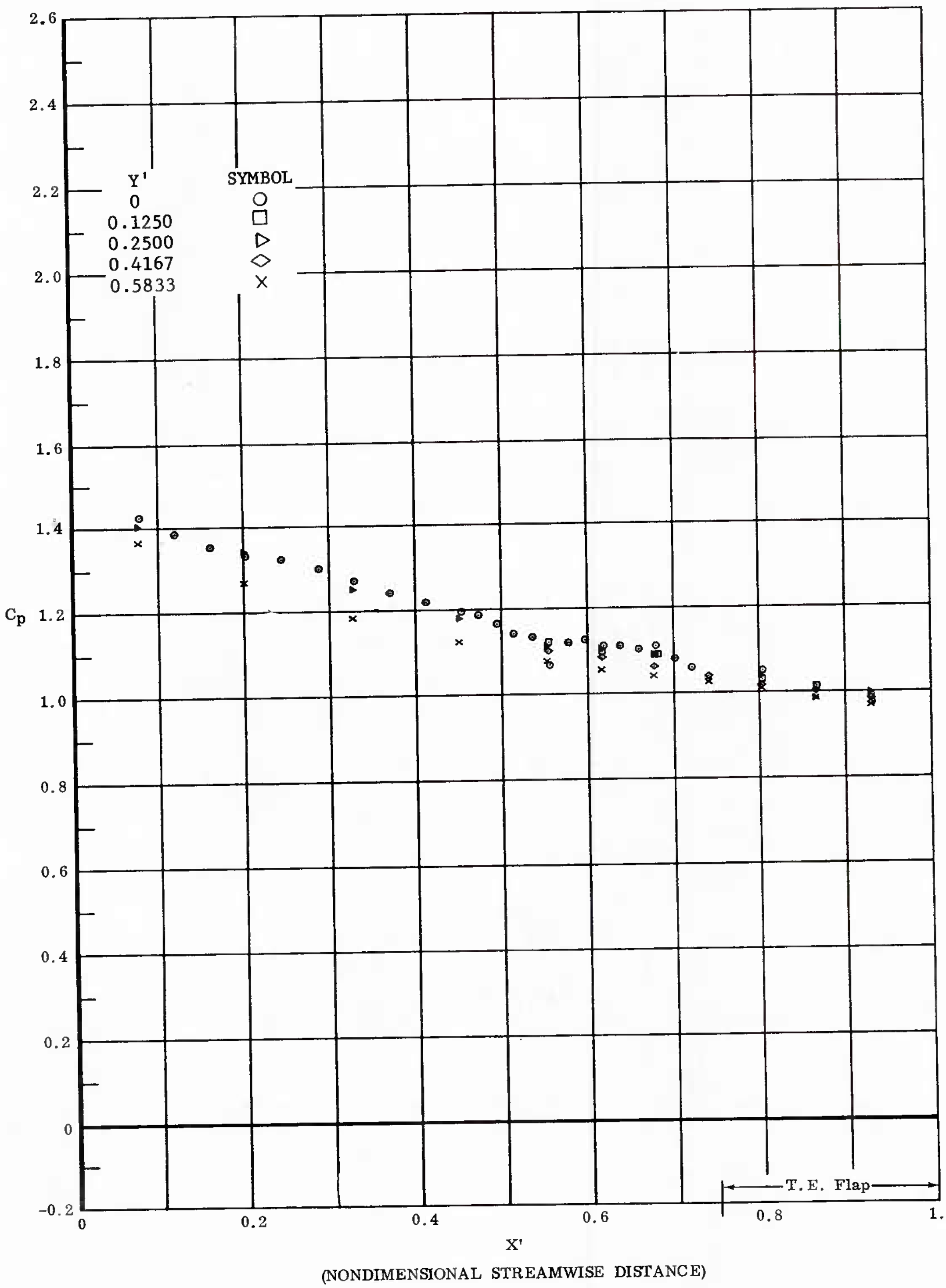


Fig. 66 Streamwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, $\alpha = -43°$, $Re_\infty/ft = 3,300,000$.

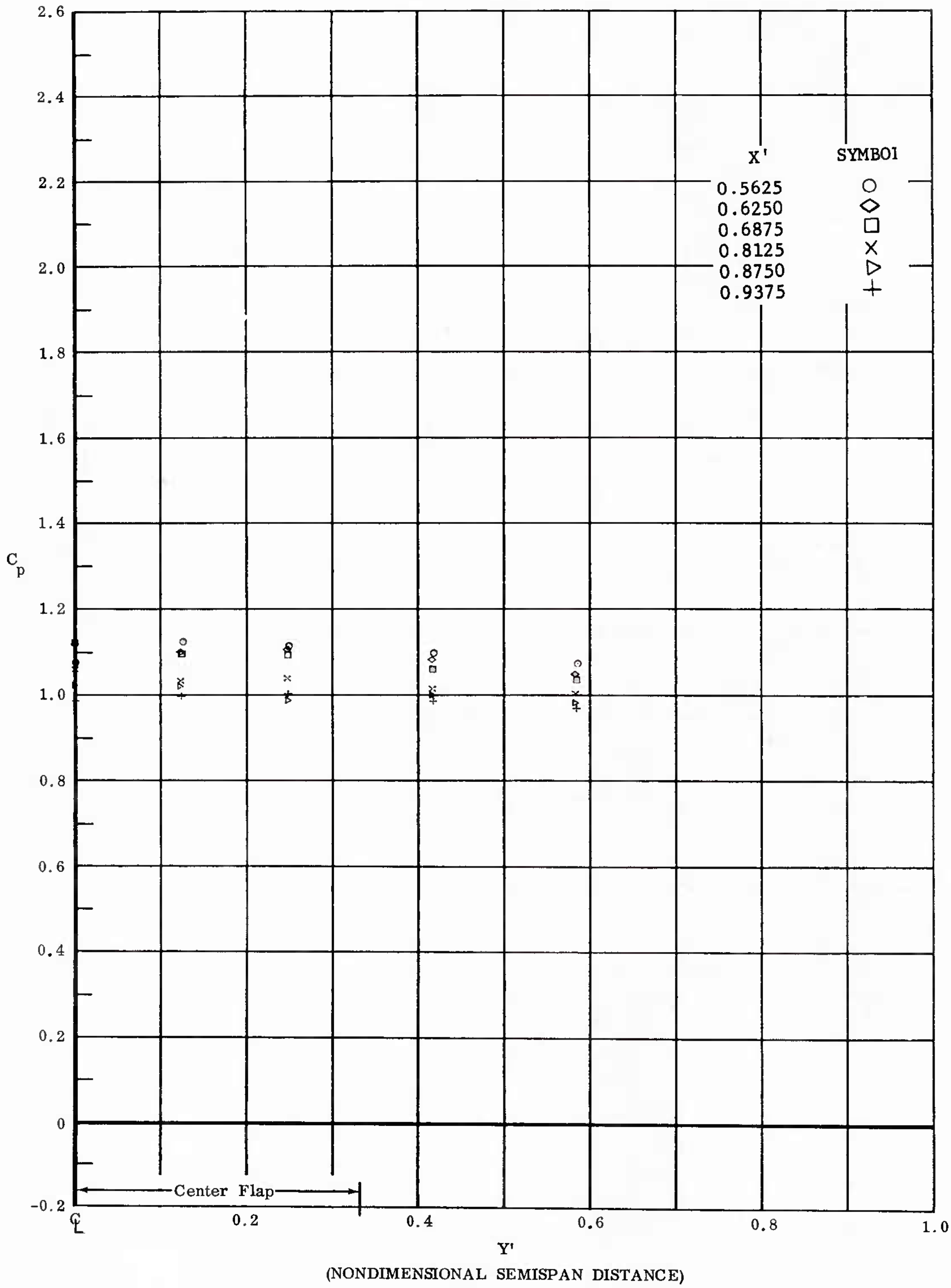


Fig. 66 Spanwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, $\alpha = -43°$, $Re_\infty/ft = 3,300,000$.

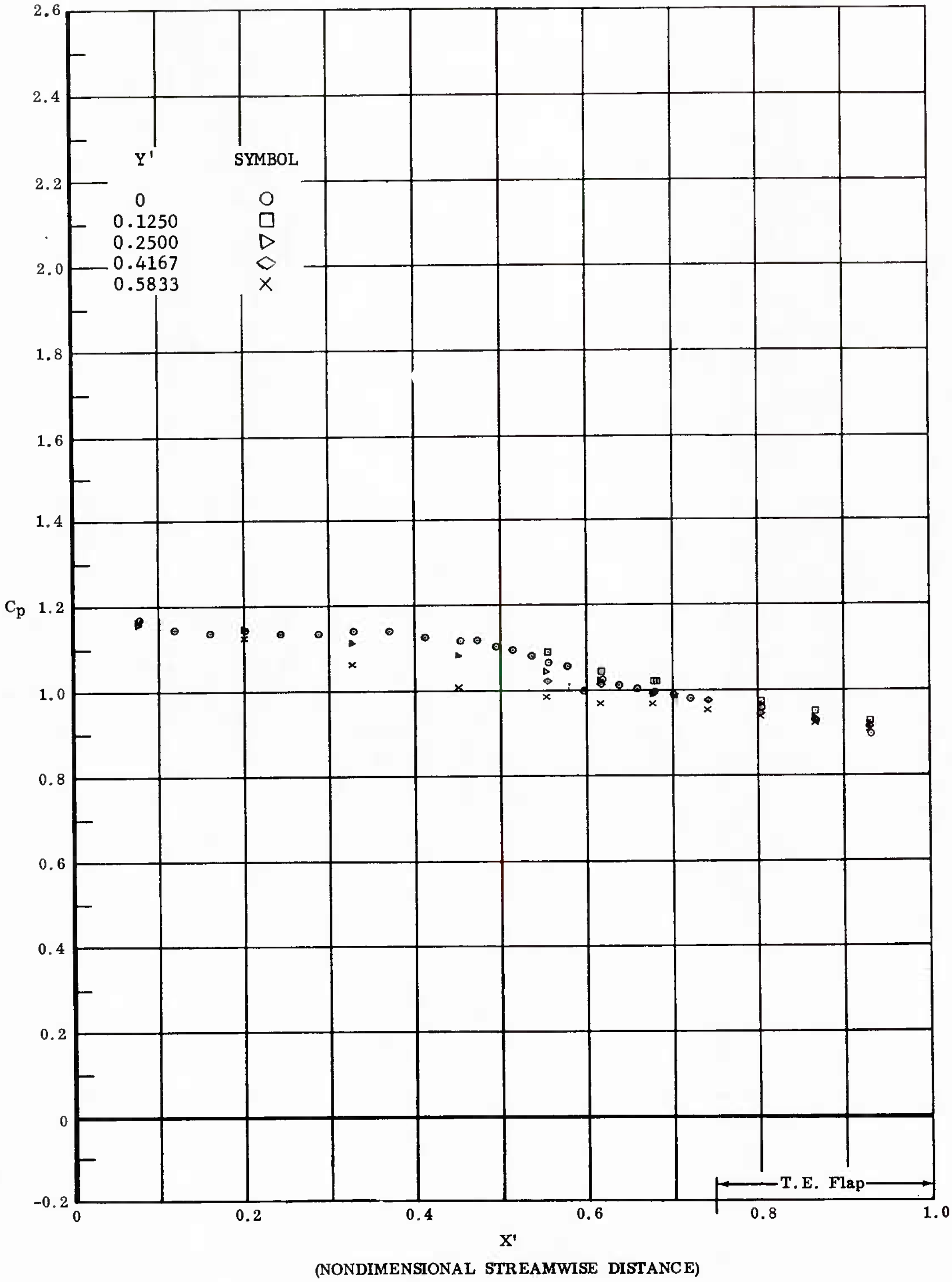


Fig. 67 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -40°$, $Re_\infty/ft = 1,100,000$.

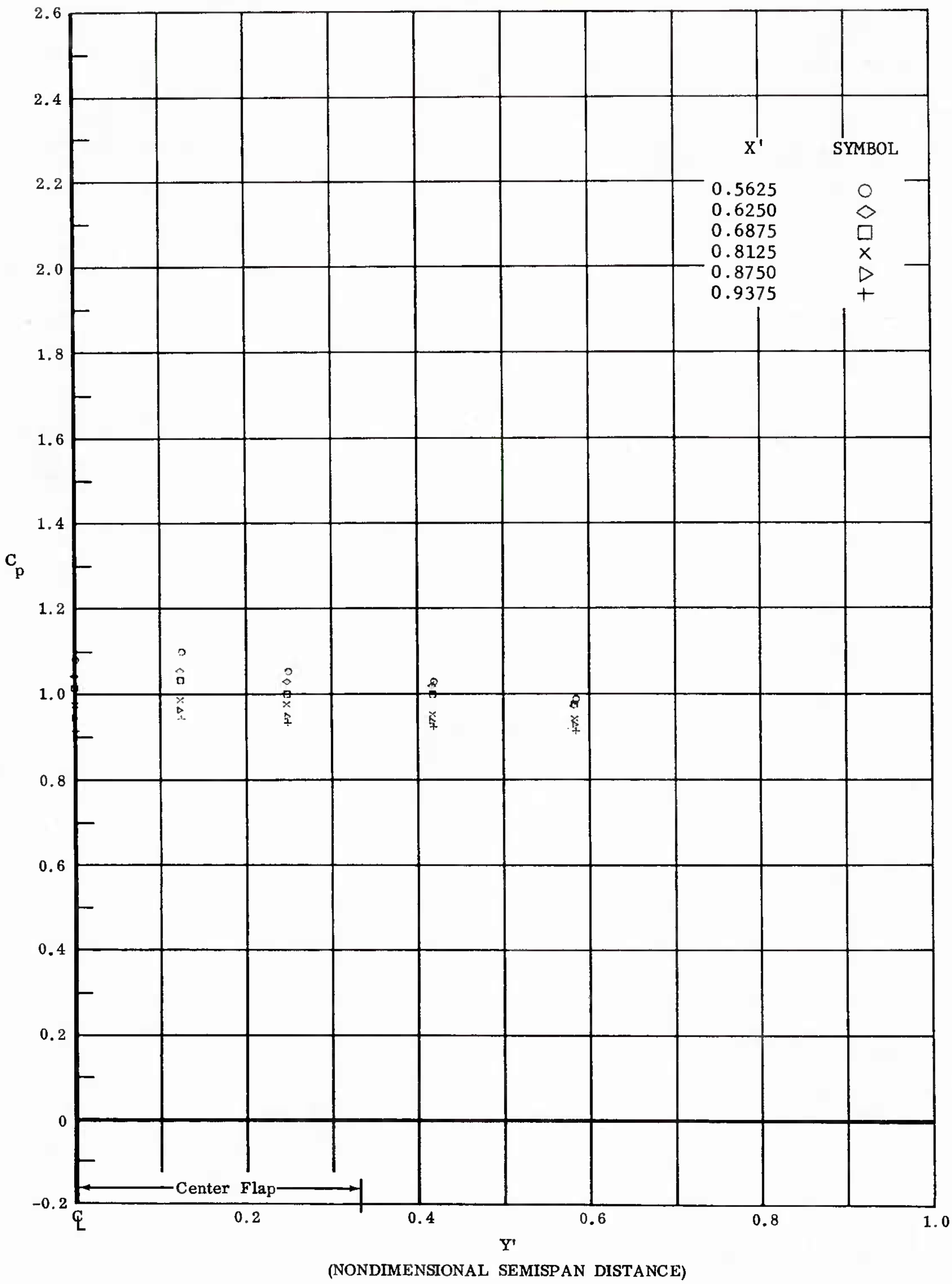


Fig. 67 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -40°$, $Re_\infty/ft = 1,100,000$.

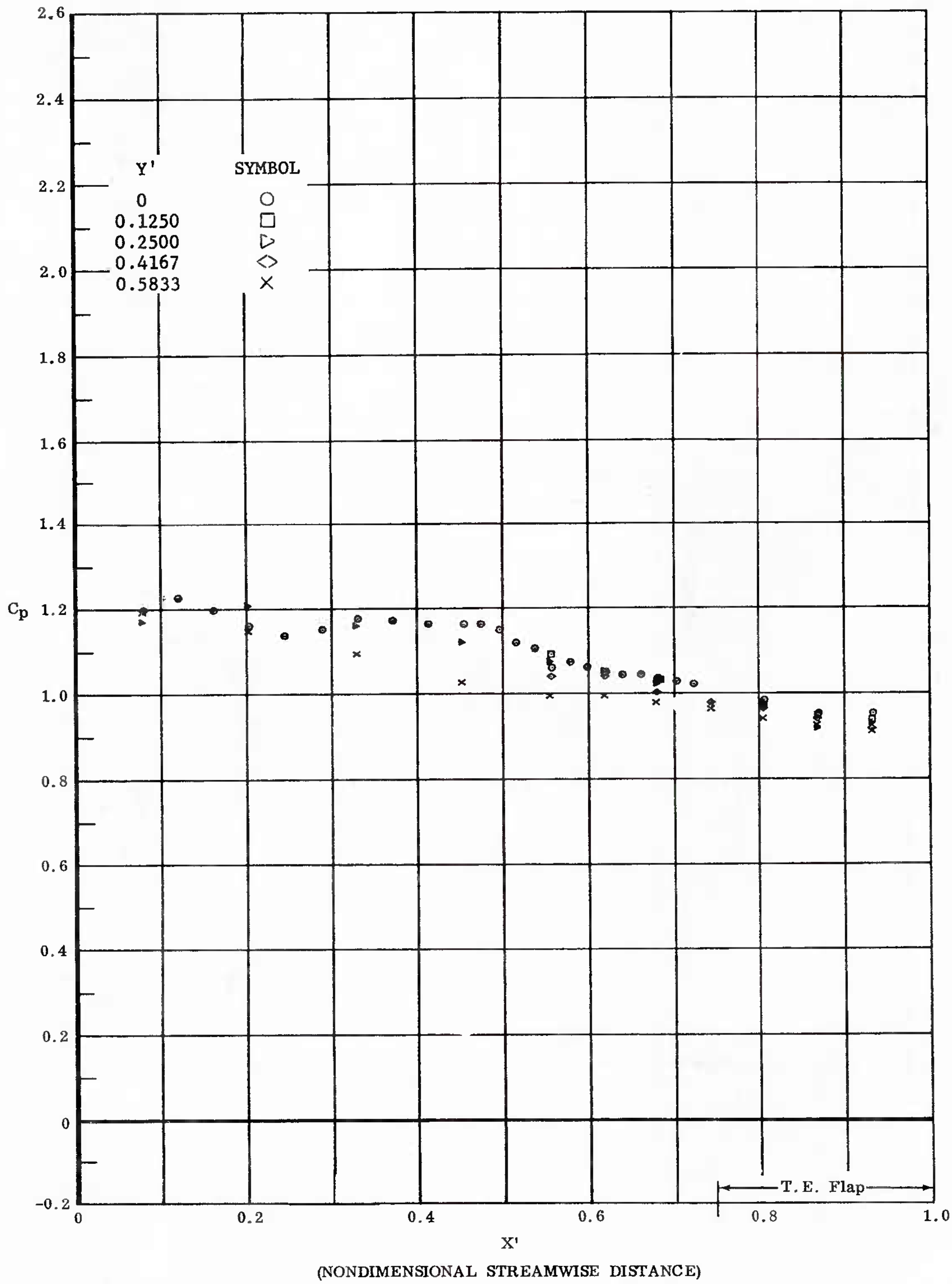


Fig. 68 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, α = -40°, Re_∞/ft = 3,300,000.

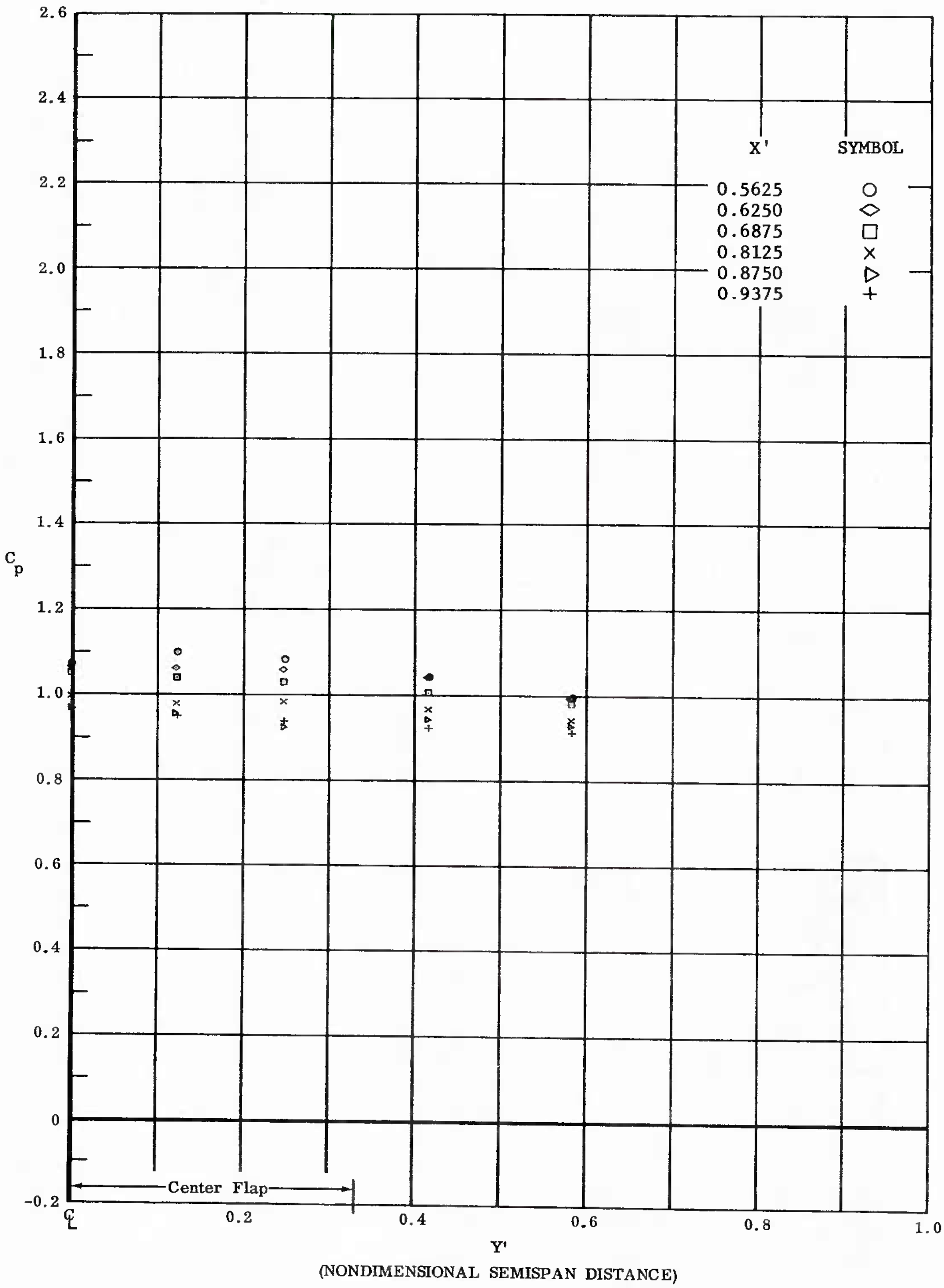


Fig. 68 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -40°$, $Re_\infty/ft = 3,300,000$.

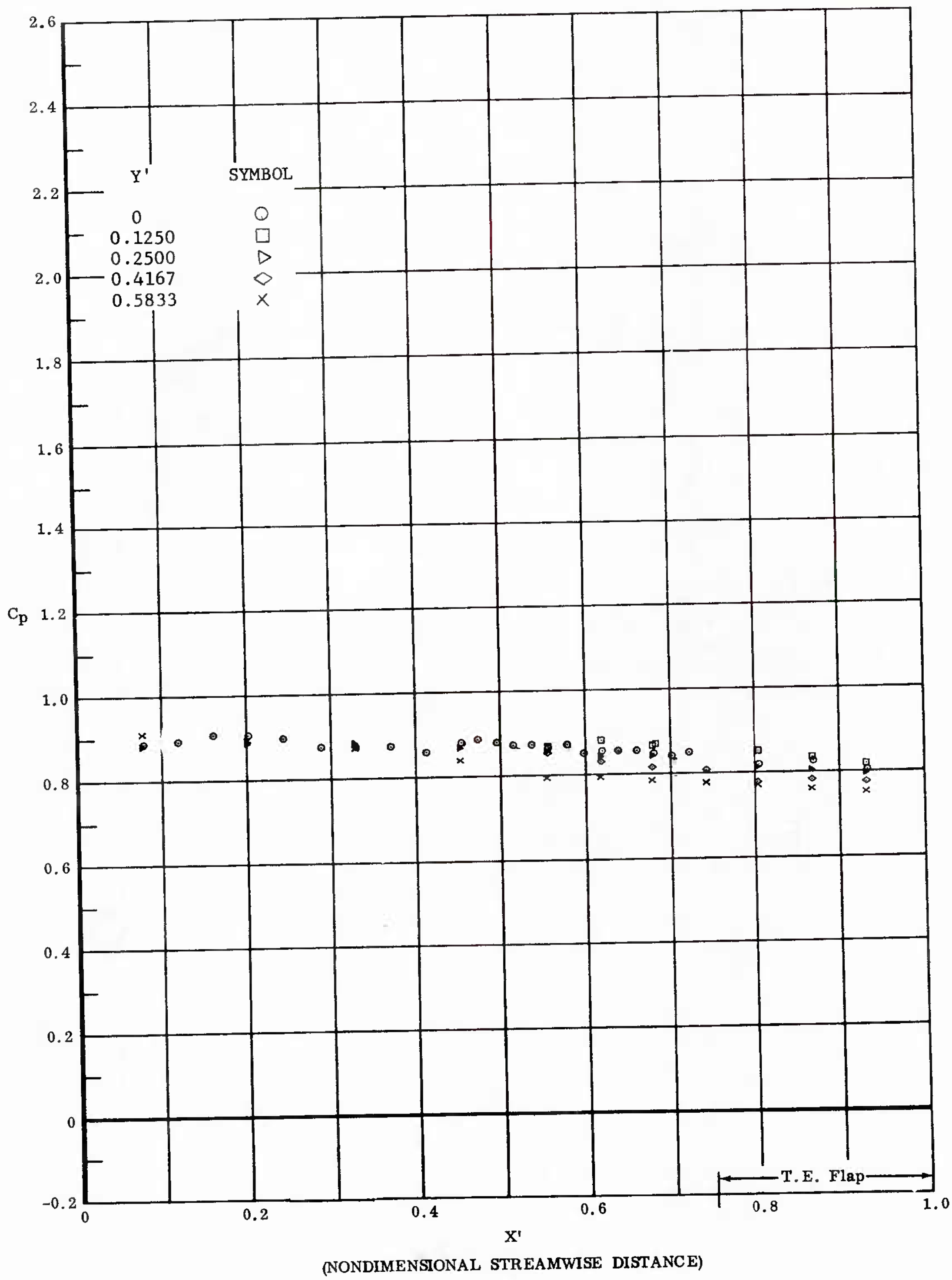


Fig. 69 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -35°$, $Re_\infty/ft = 1,100,000$.

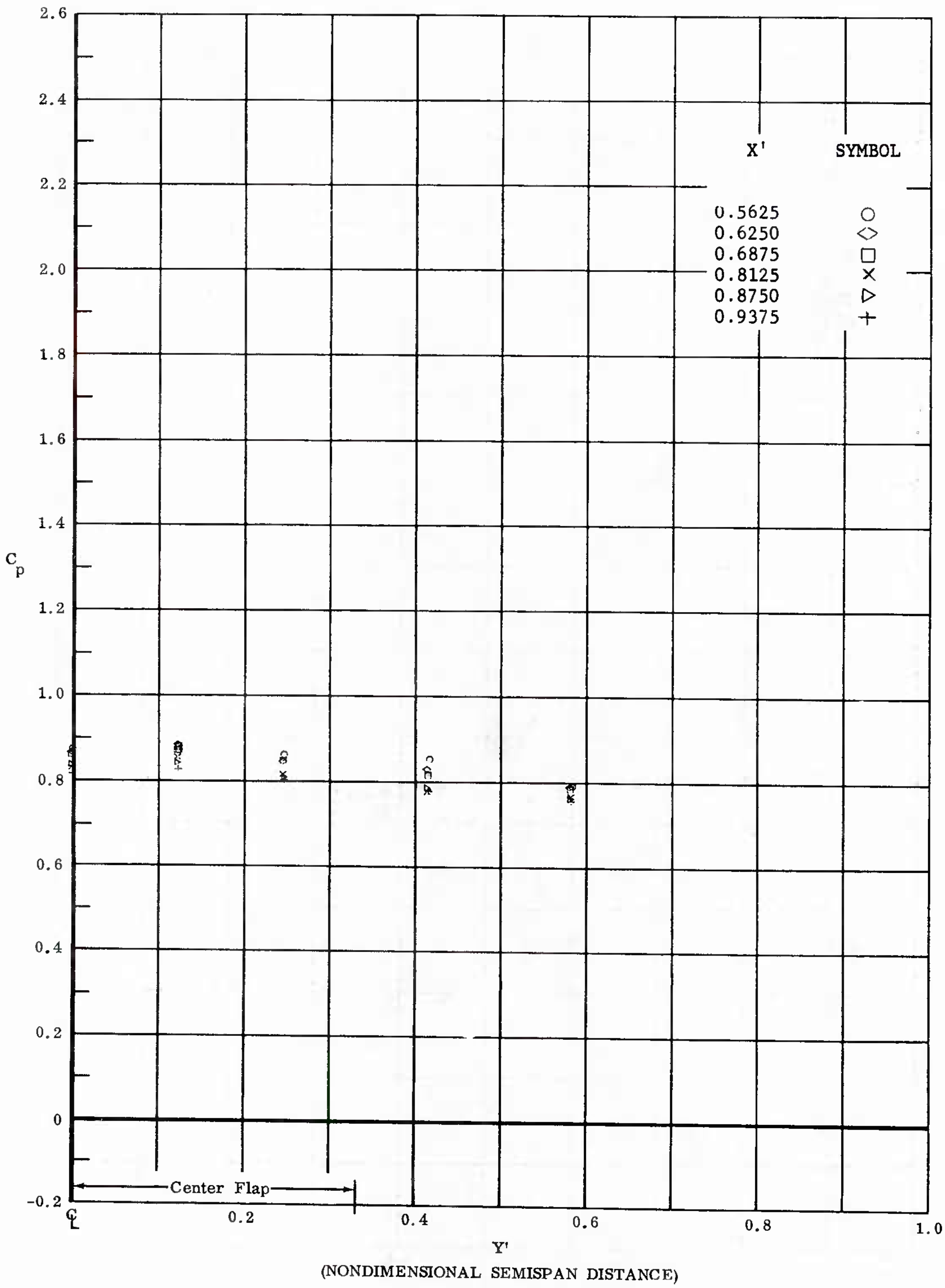


Fig. 69 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -35°$, $Re_\infty/ft = 1,100,000$.

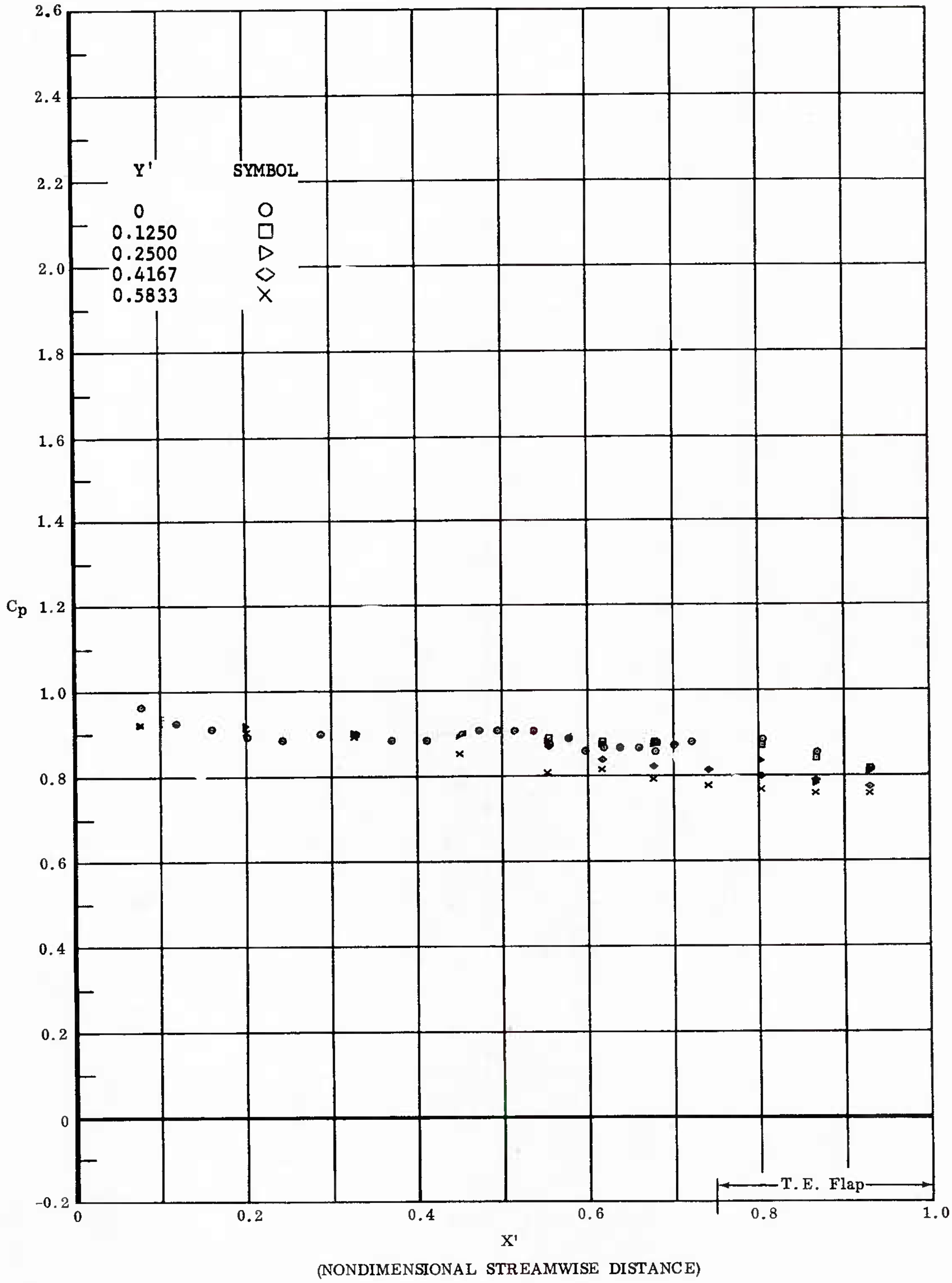


Fig. 70 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -35°$, $Re_\infty/ft = 3,300,000$.

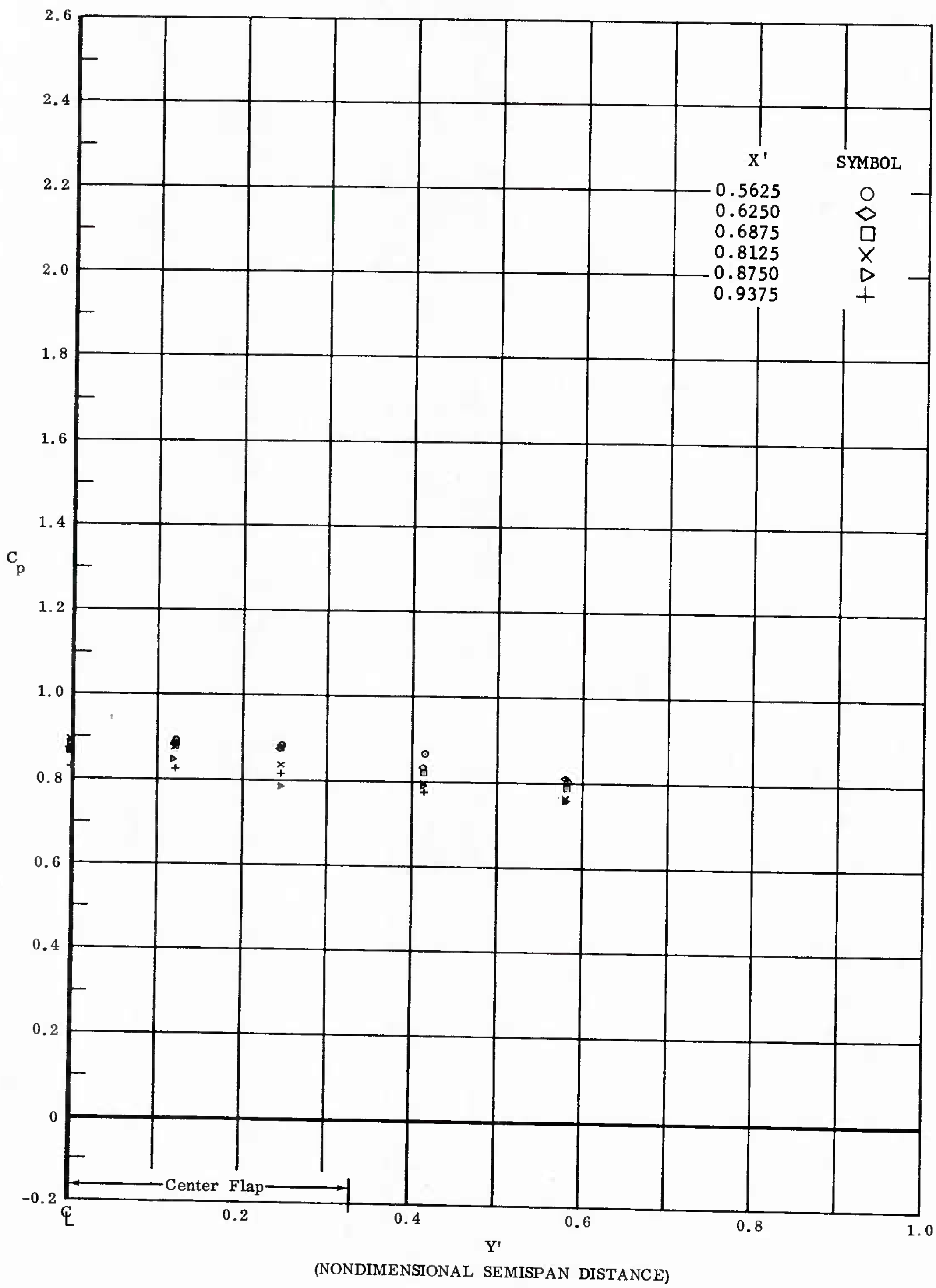


Fig. 70 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, α = -35°, Re_{∞}/ft = 3,300,000.

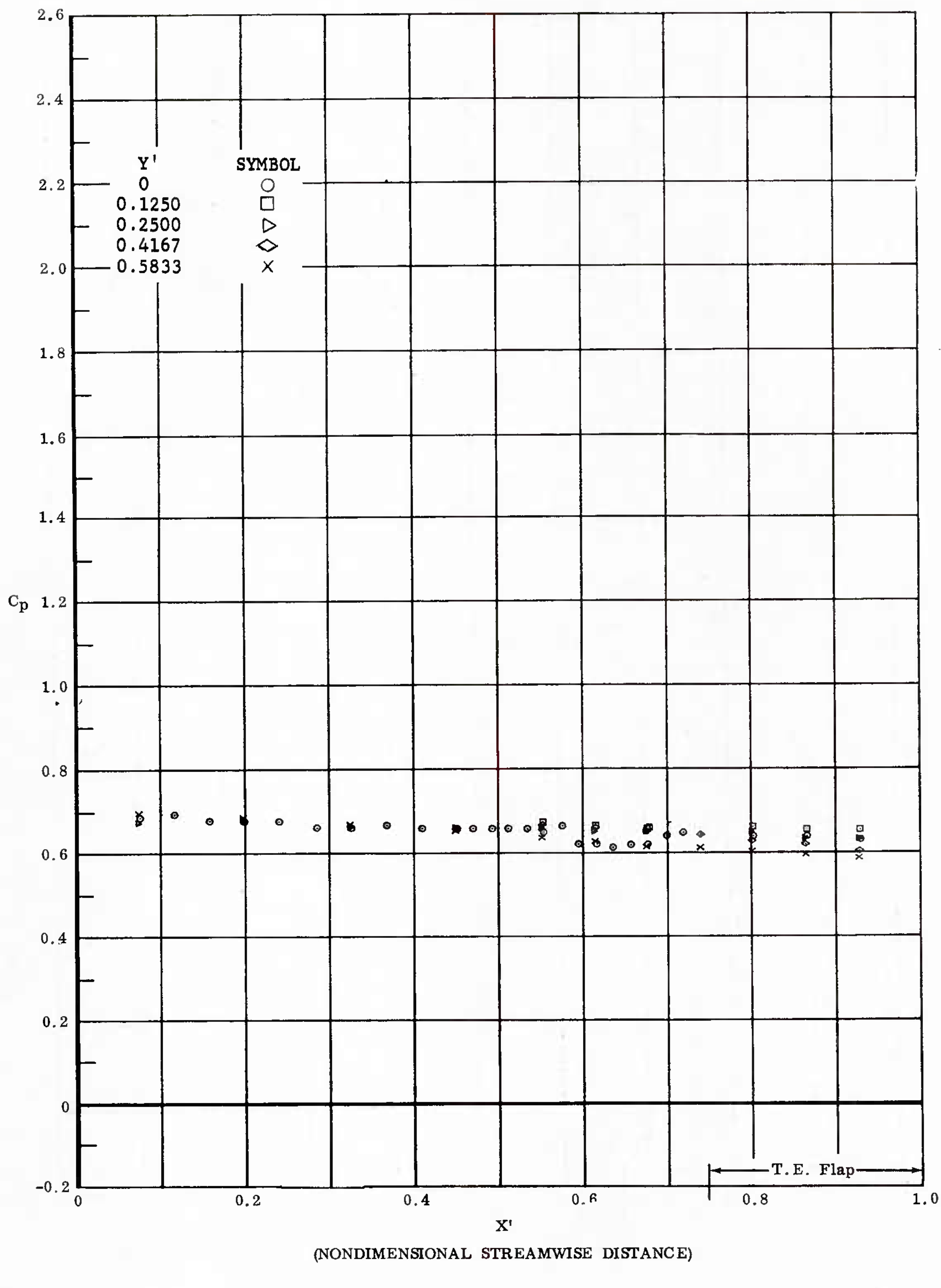


Fig. 71 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -30°$, $Re_\infty/ft = 1,100,000$.

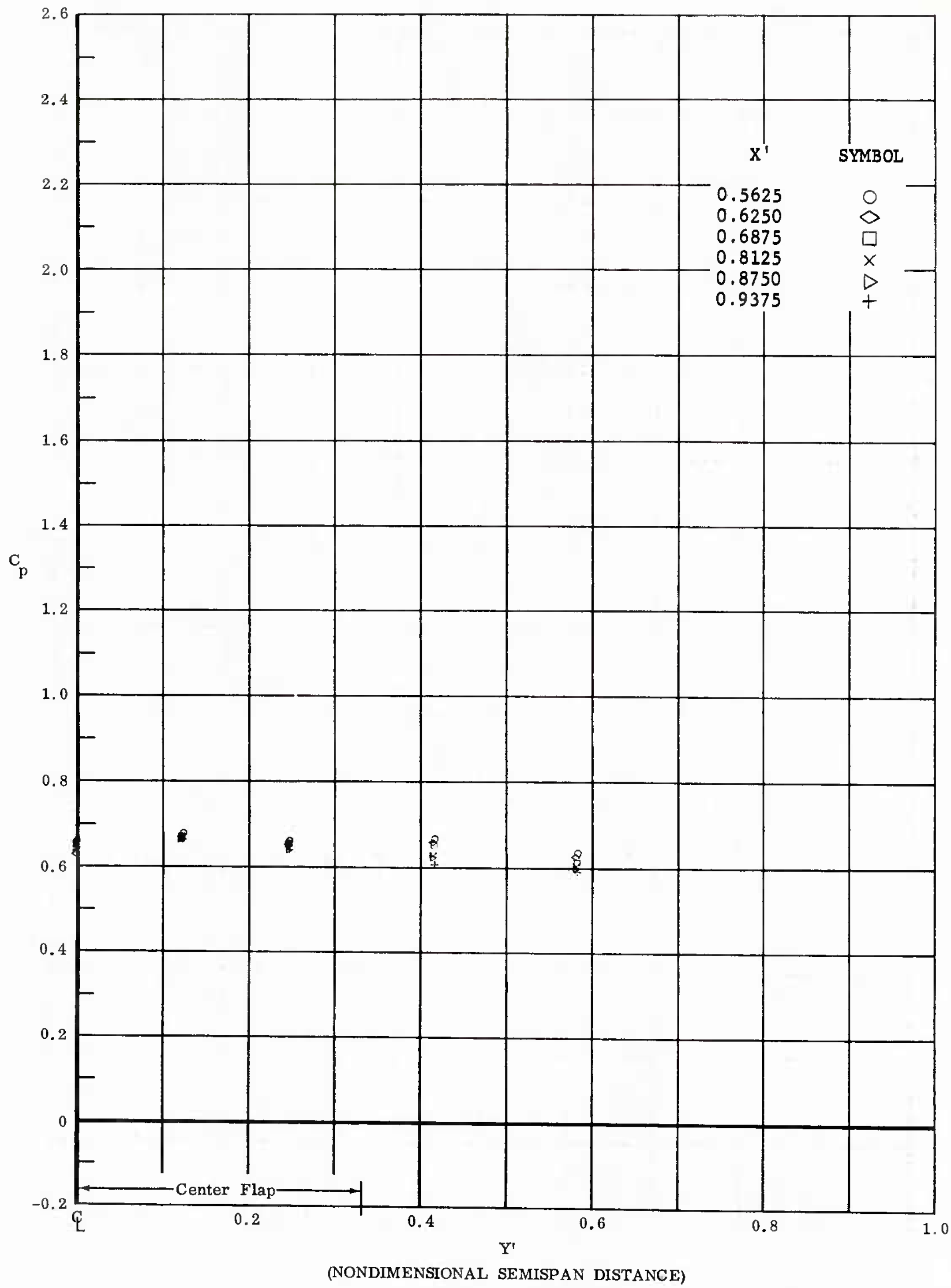


Fig. 71 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -30°$, $Re_\infty/ft = 1,100,000$.

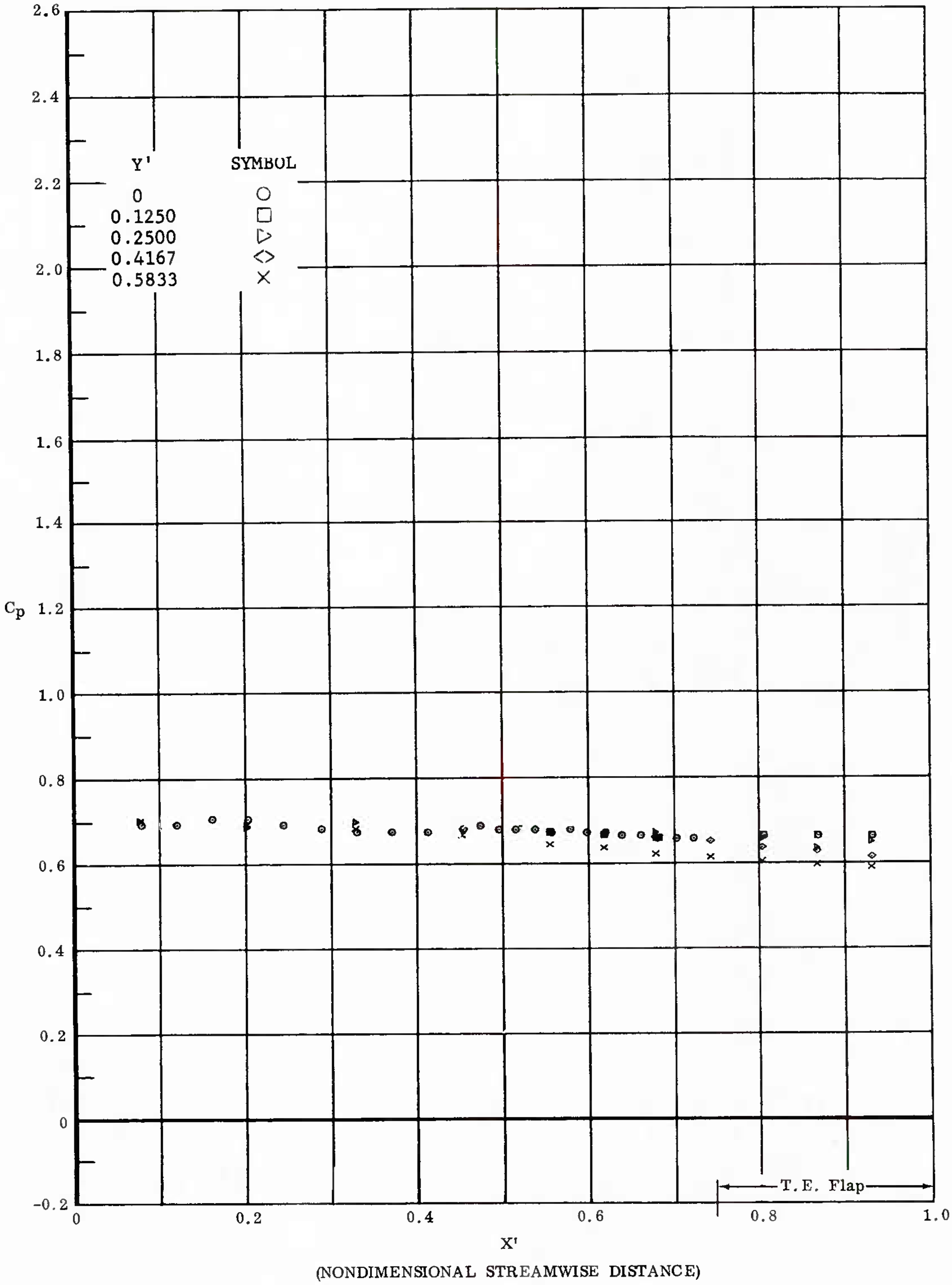


Fig. 72 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, α = -30°, Re_∞/ft = 2,200,000.

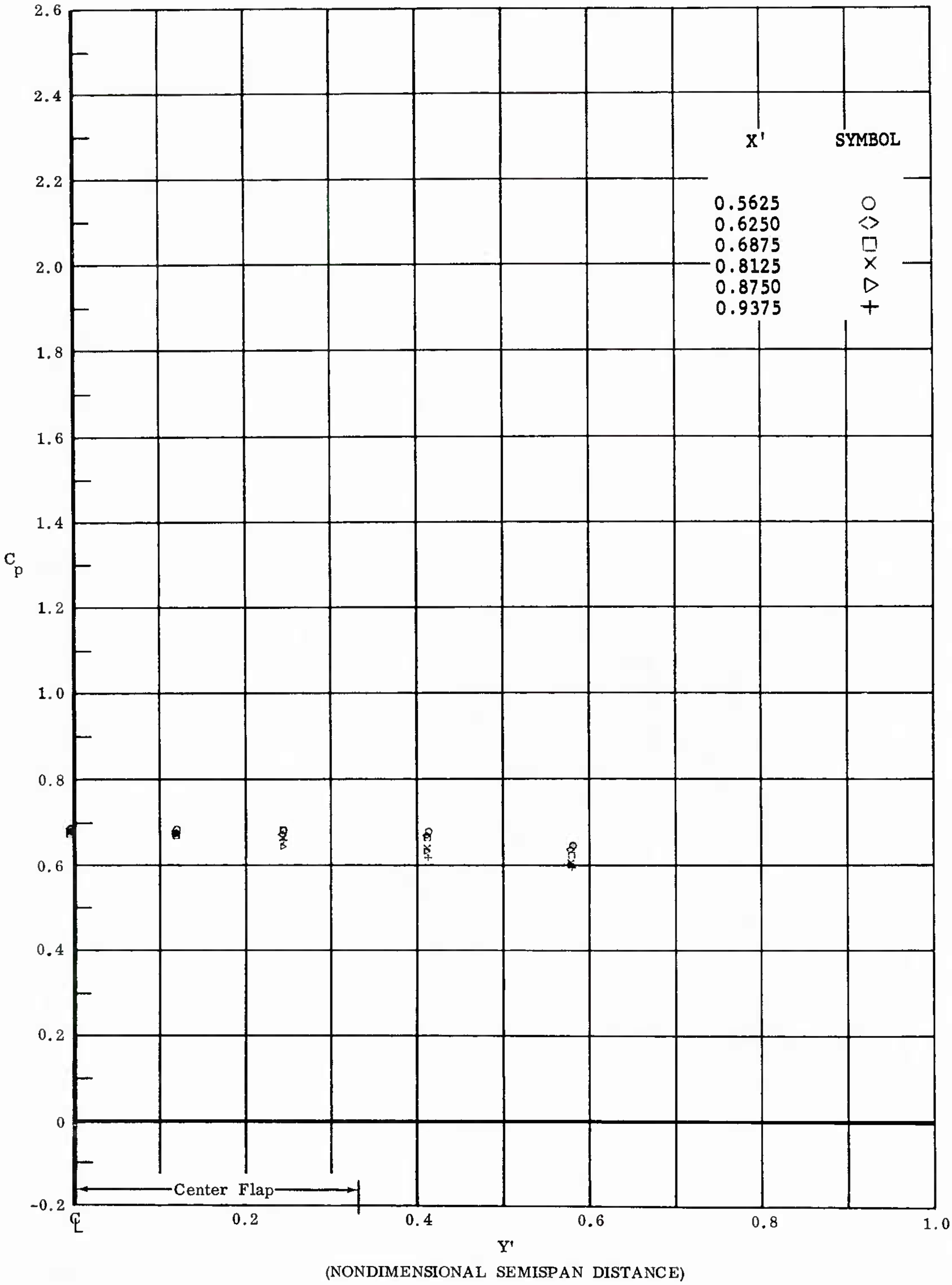


Fig. 72 Spanwise Pressure Distribution; Ramp Off, No Coolant Flow, $\alpha = -30°$, $Re_\infty/ft = 2{,}200{,}000$.

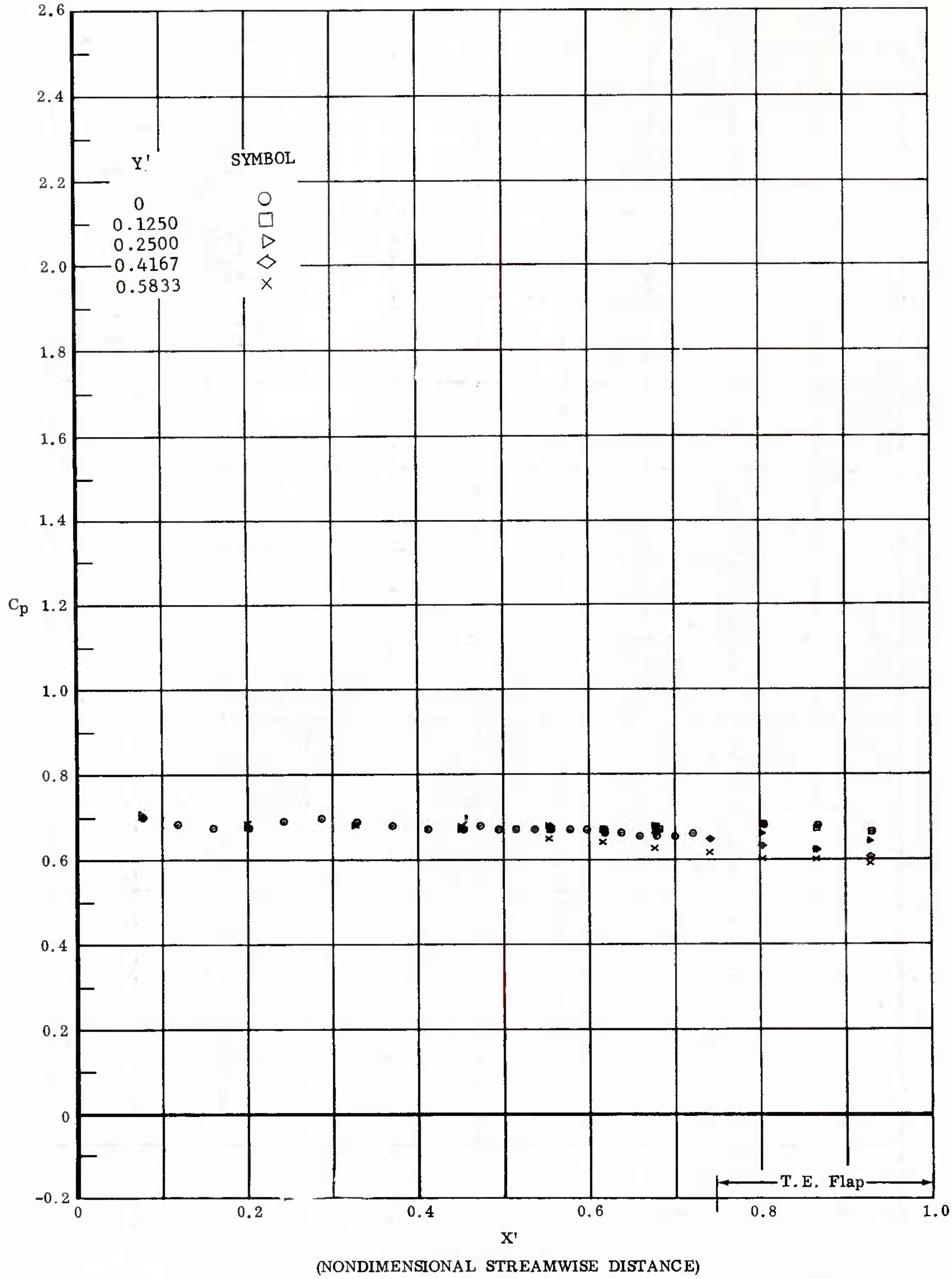


Fig. 73 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -30°$, $Re_\infty/ft = 3,300,000$.

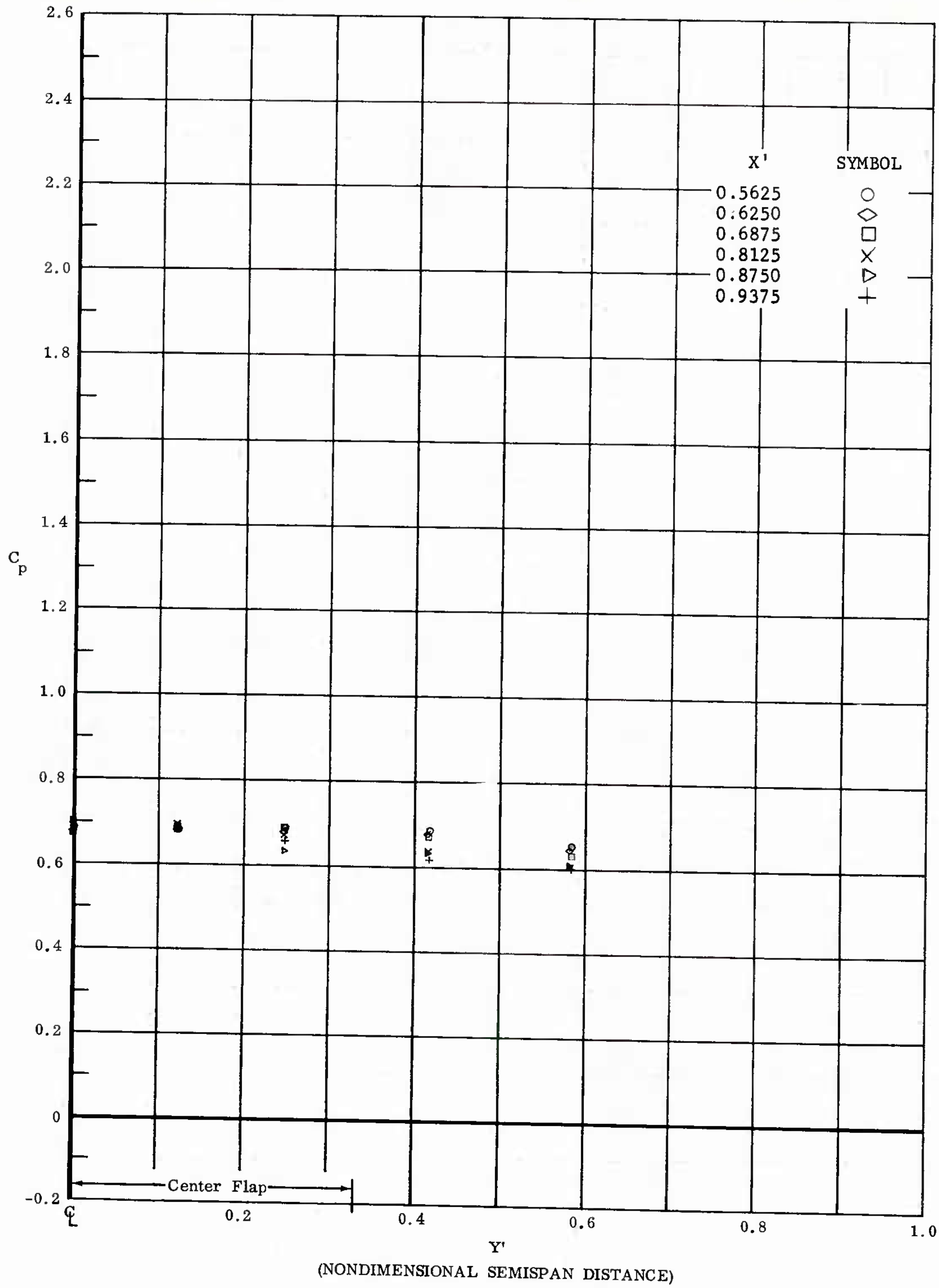


Fig. 73 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -30°$, $Re_{\infty}/ft = 3,300,000$.

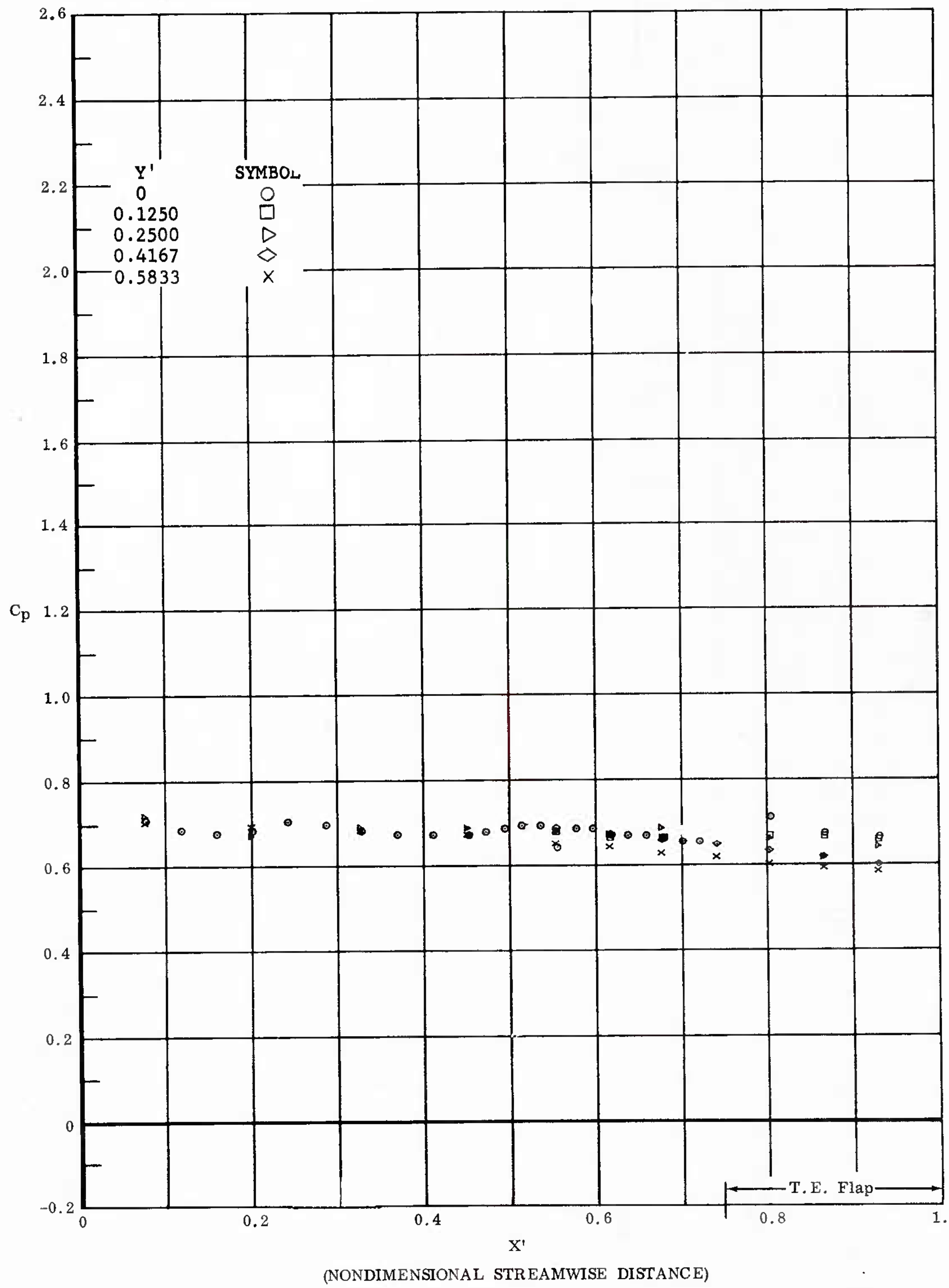


Fig. 74 Streamwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, α = -30°, Re_{∞}/ft = 3,300,000.

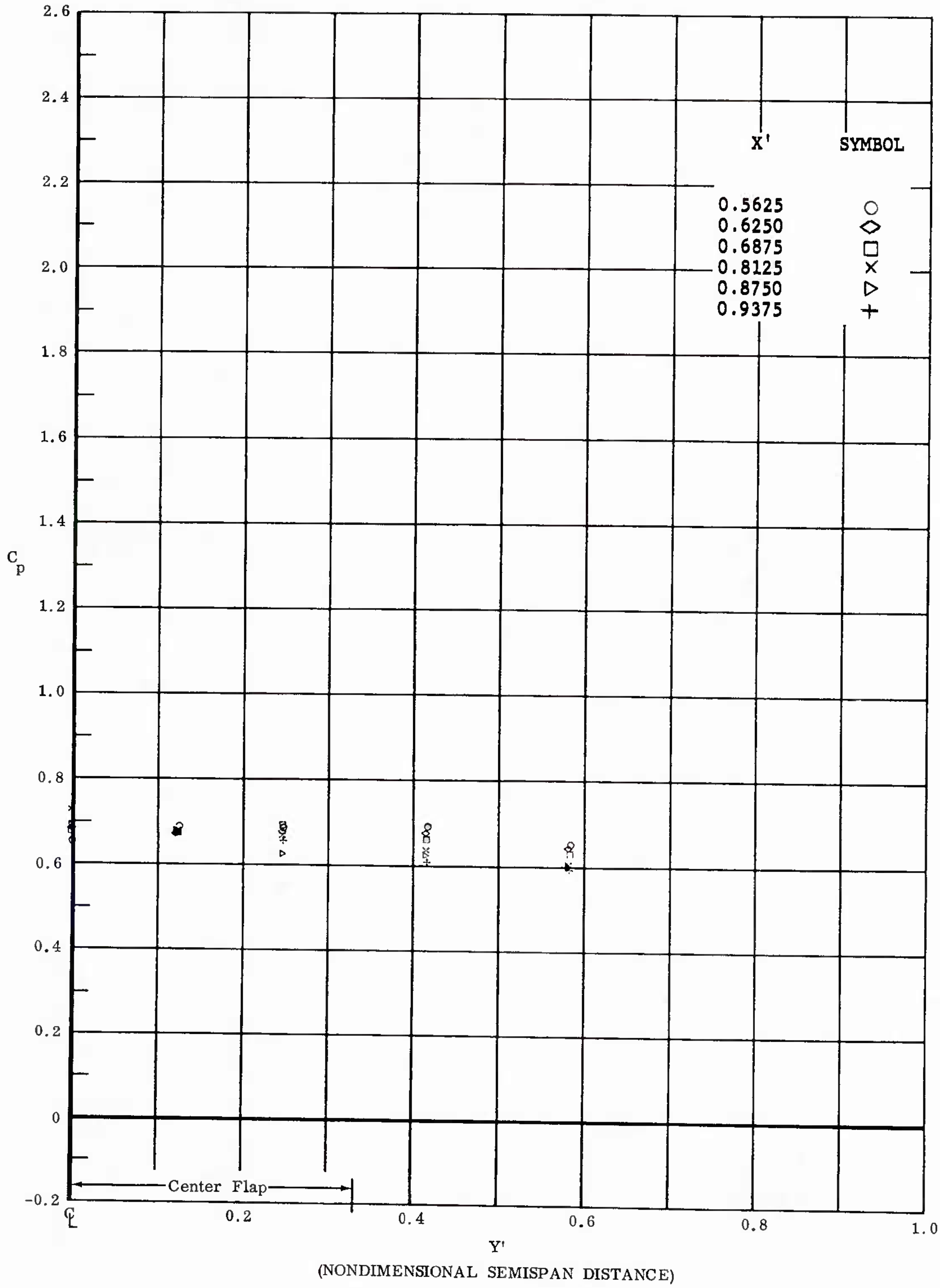


Fig. 74 Spanwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, α = -30°, Re_∞/ft = 3,300,000.

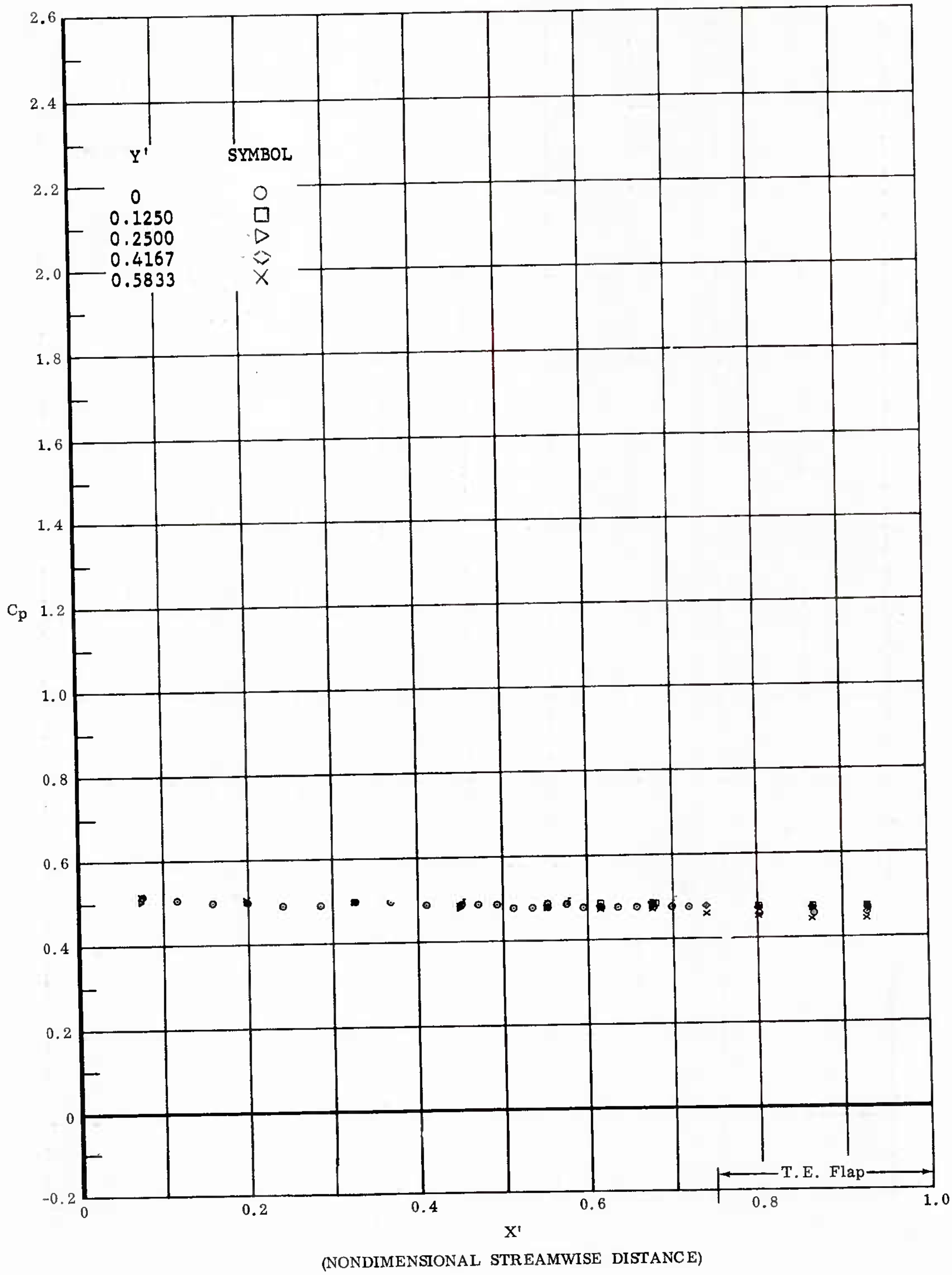


Fig. 75 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -25°$, $Re_\infty/ft = 1,100,000$.

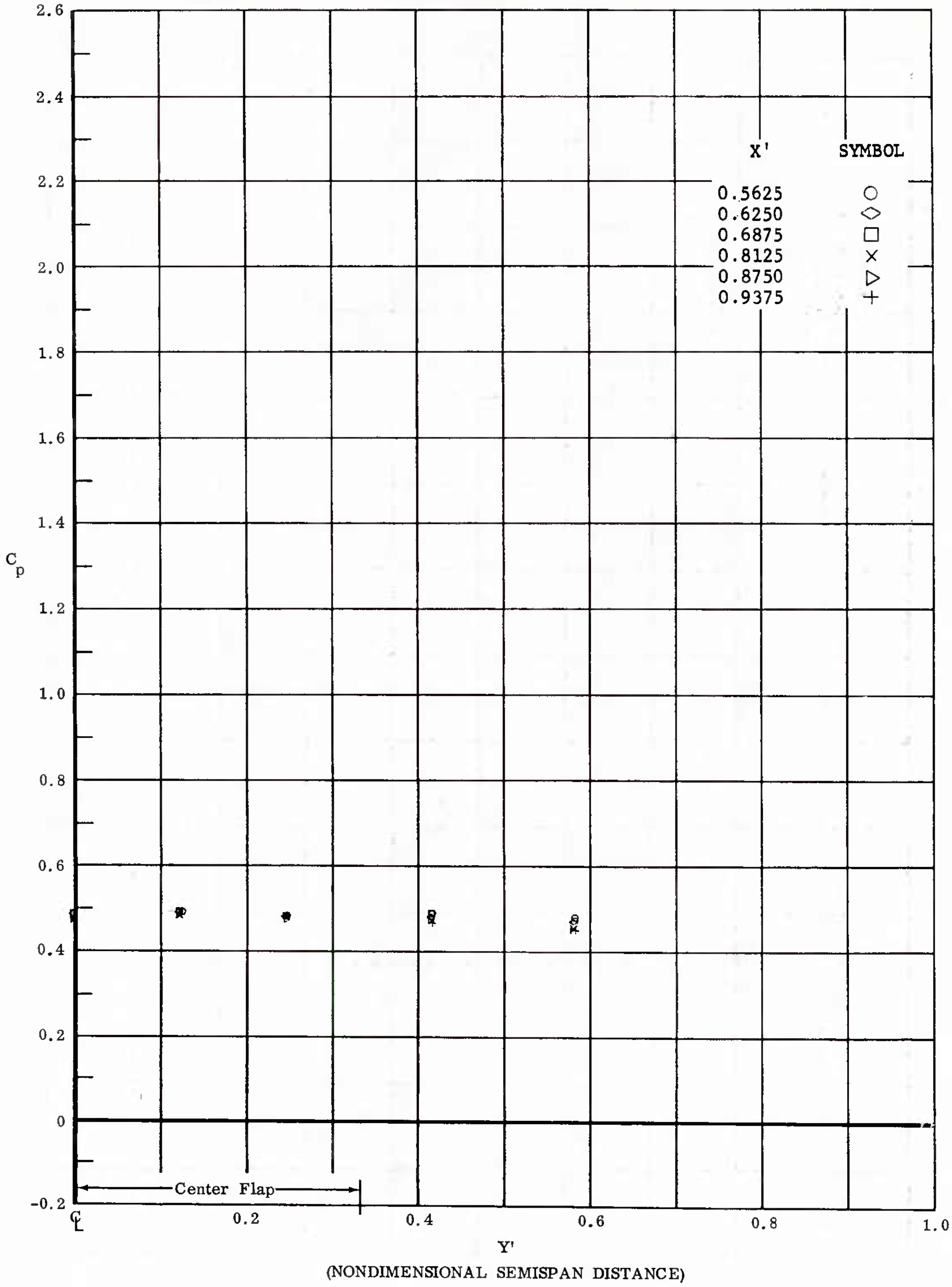


Fig. 75 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -25°$, $Re_\infty/ft = 1,100,000$.

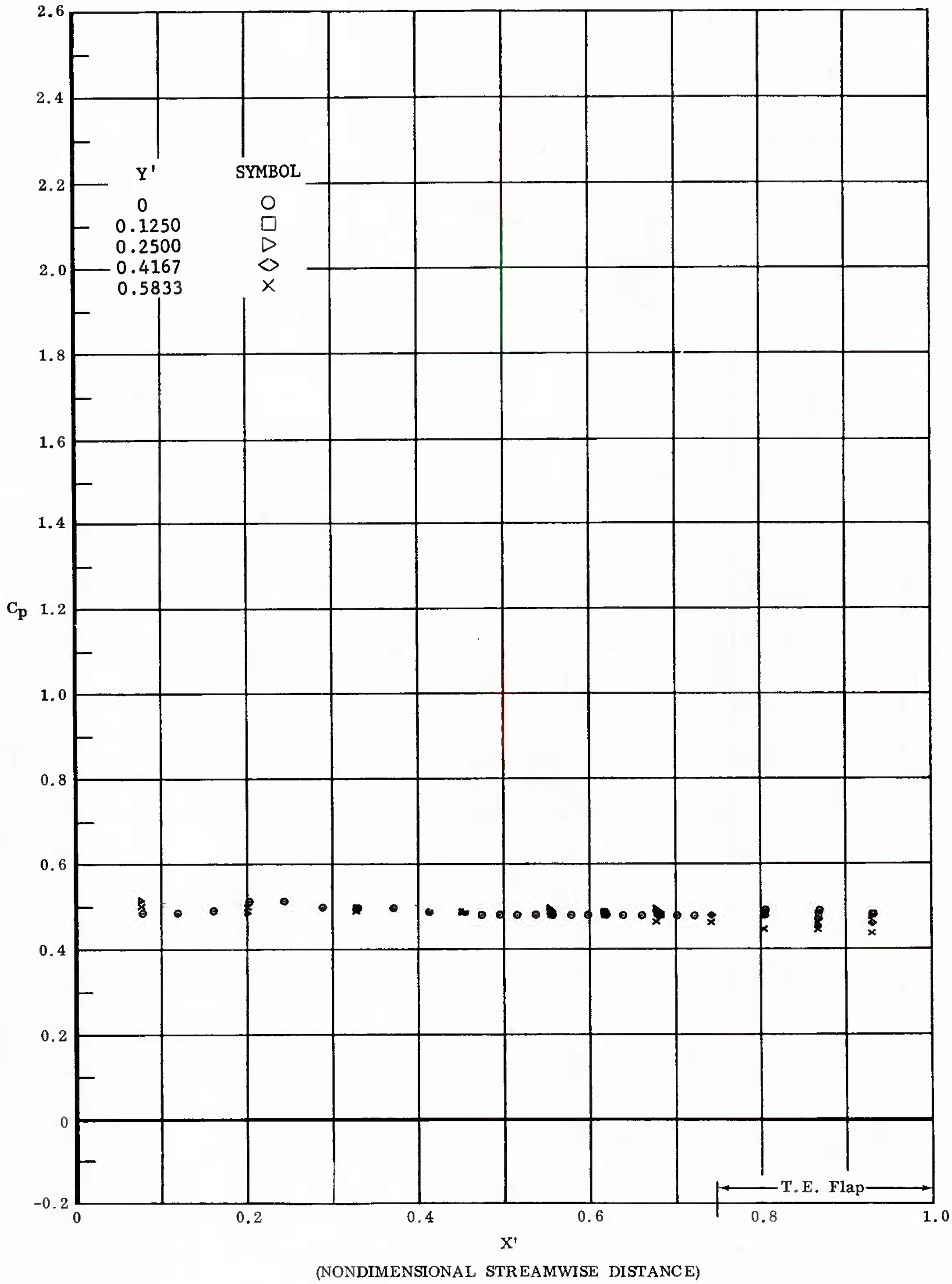


Fig. 76 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -25°$, $Re_\infty/ft = 3{,}300{,}000$.

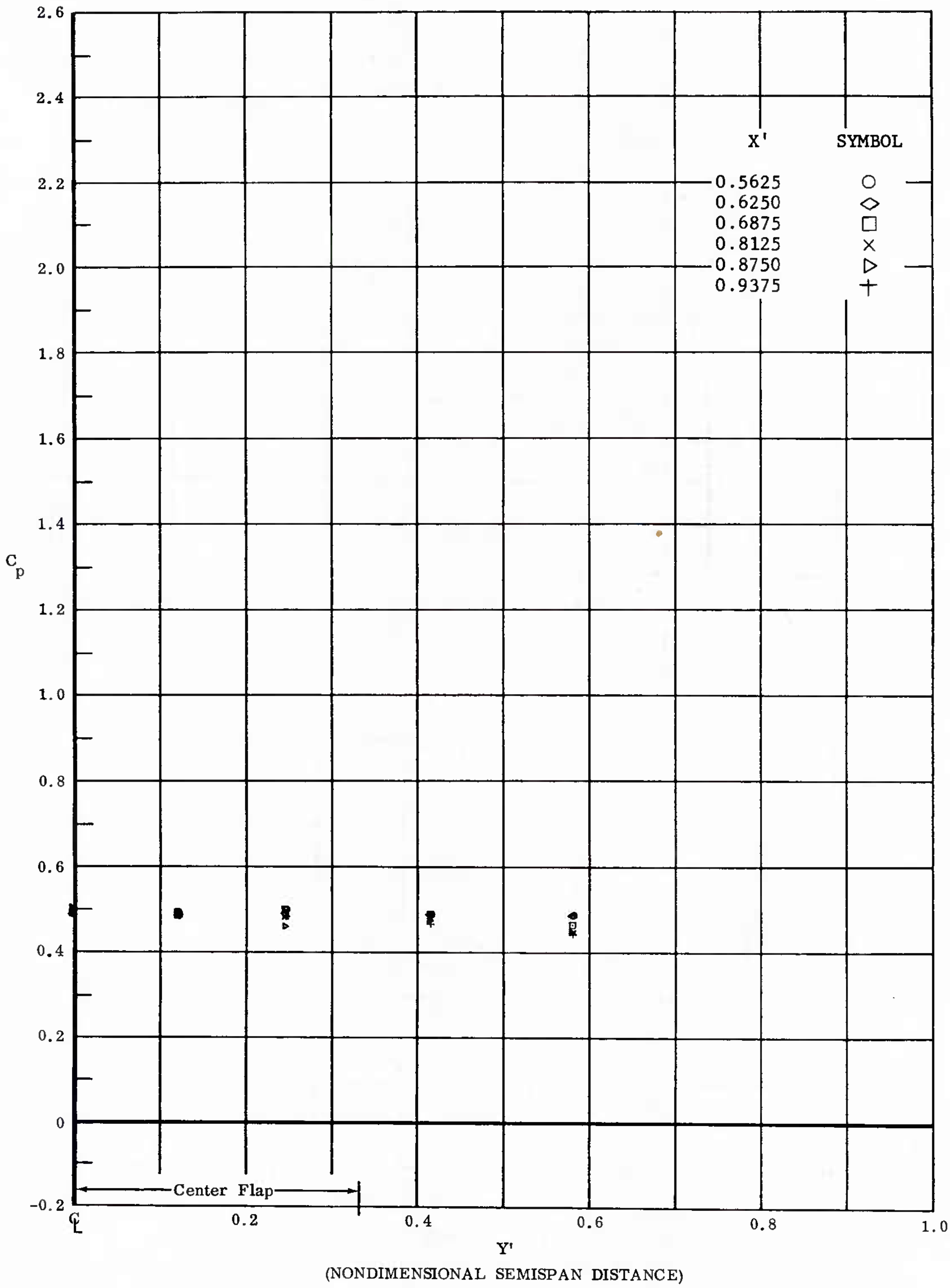


Fig. 76 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -25°$, $Re_\infty/ft = 3,300,000$.

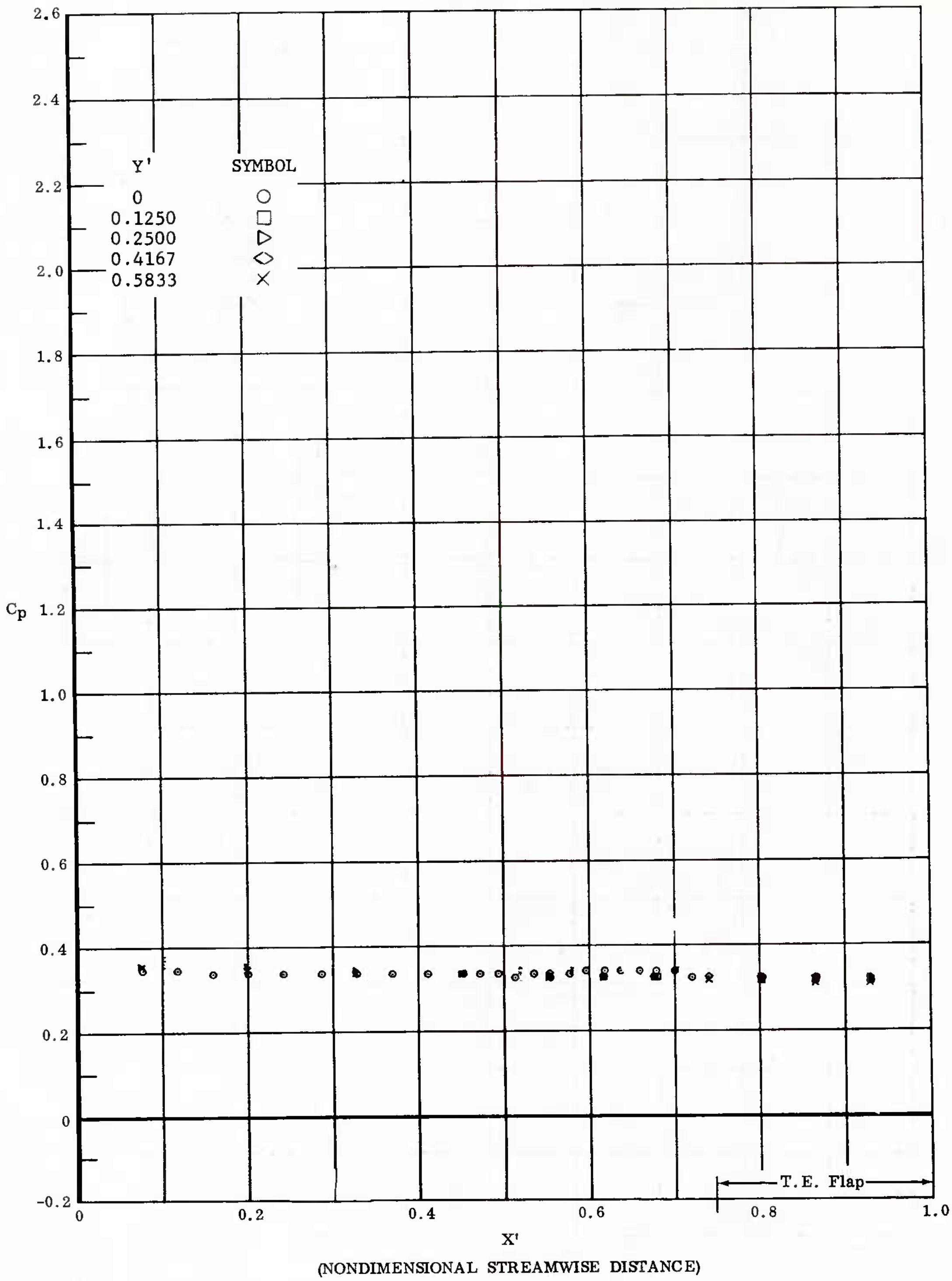


Fig. 77 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -20°$, $Re_\infty/ft = 1,100,000$.

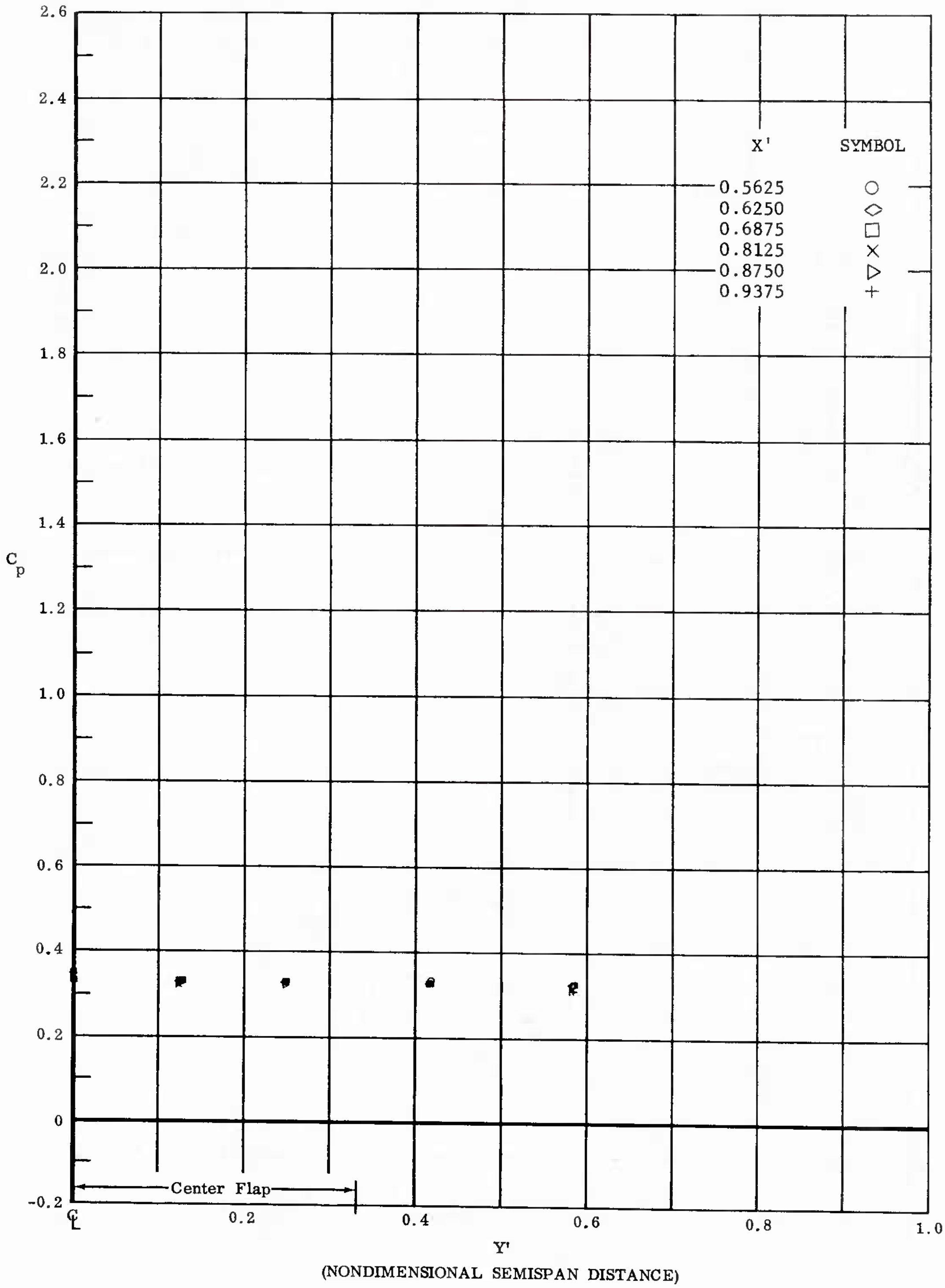


Fig. 77 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -20°$, $Re_\infty/ft = 1,100,000$.

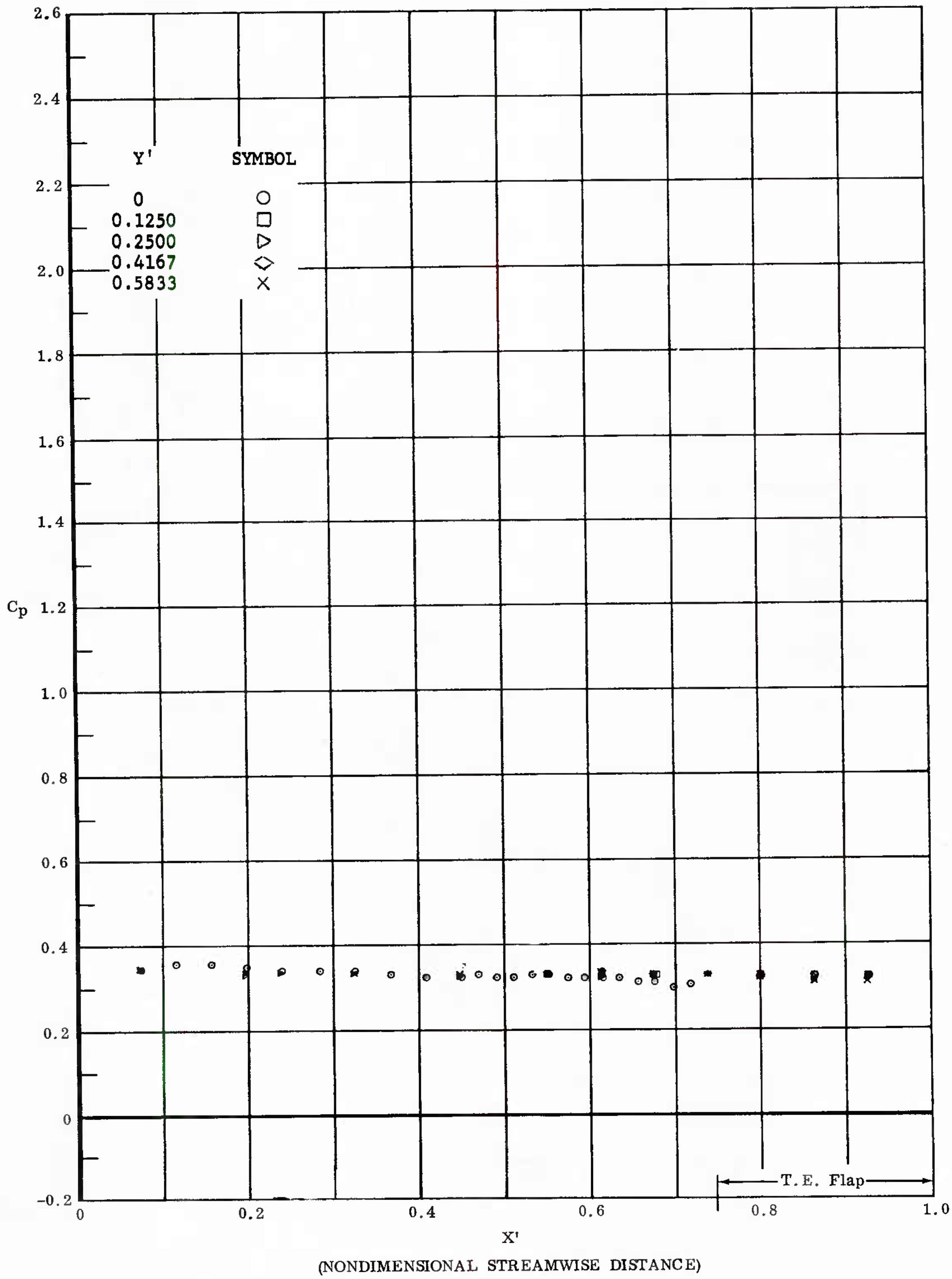


Fig. 78 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, α = -20°, Re_{∞}/ft = 3,300,000.

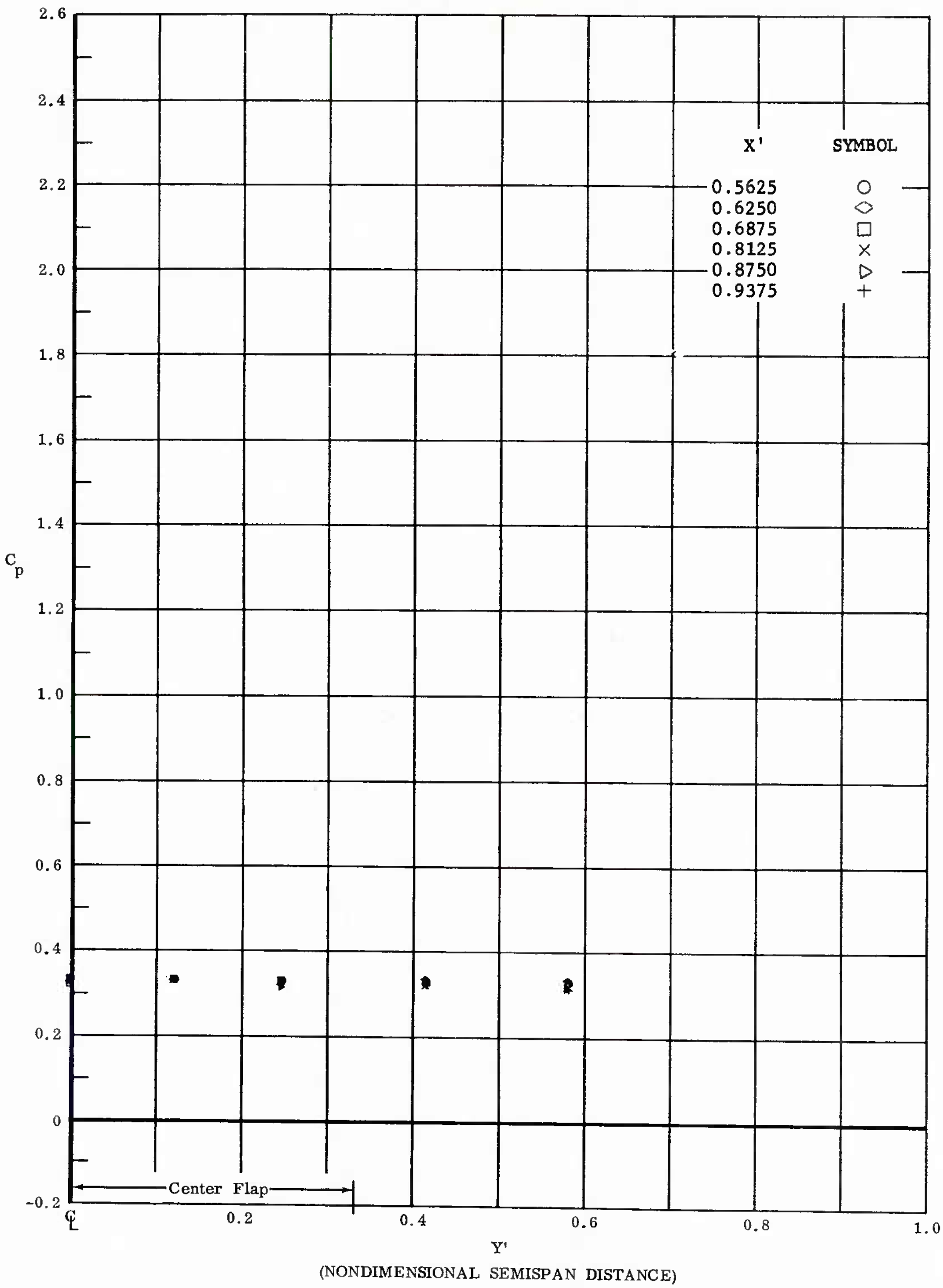


Fig. 78 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -20°$, $Re_\infty/ft = 3,300,000$.

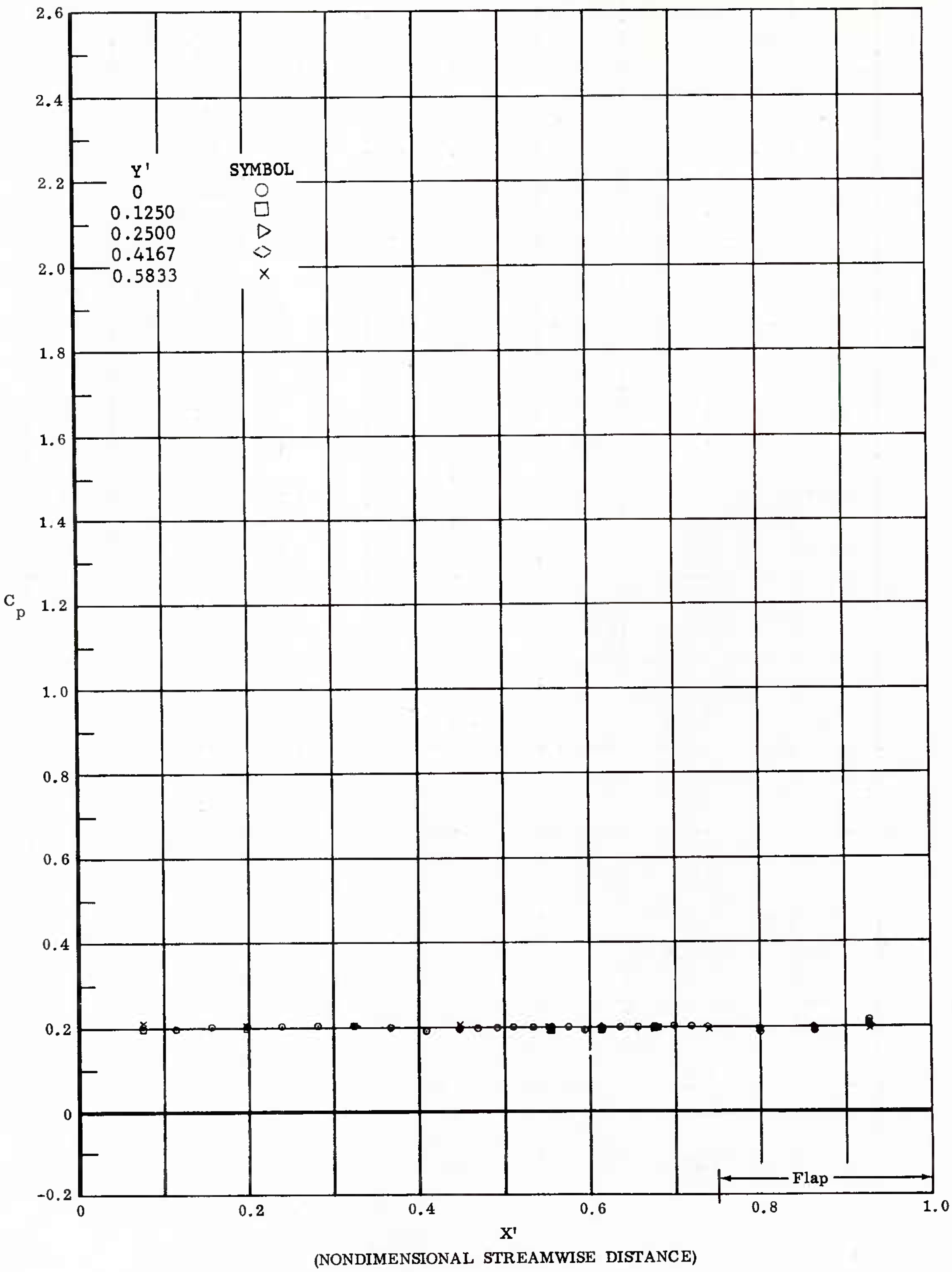


Fig. 79 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -15°$, $Re_\infty/ft = 1,100,000$.

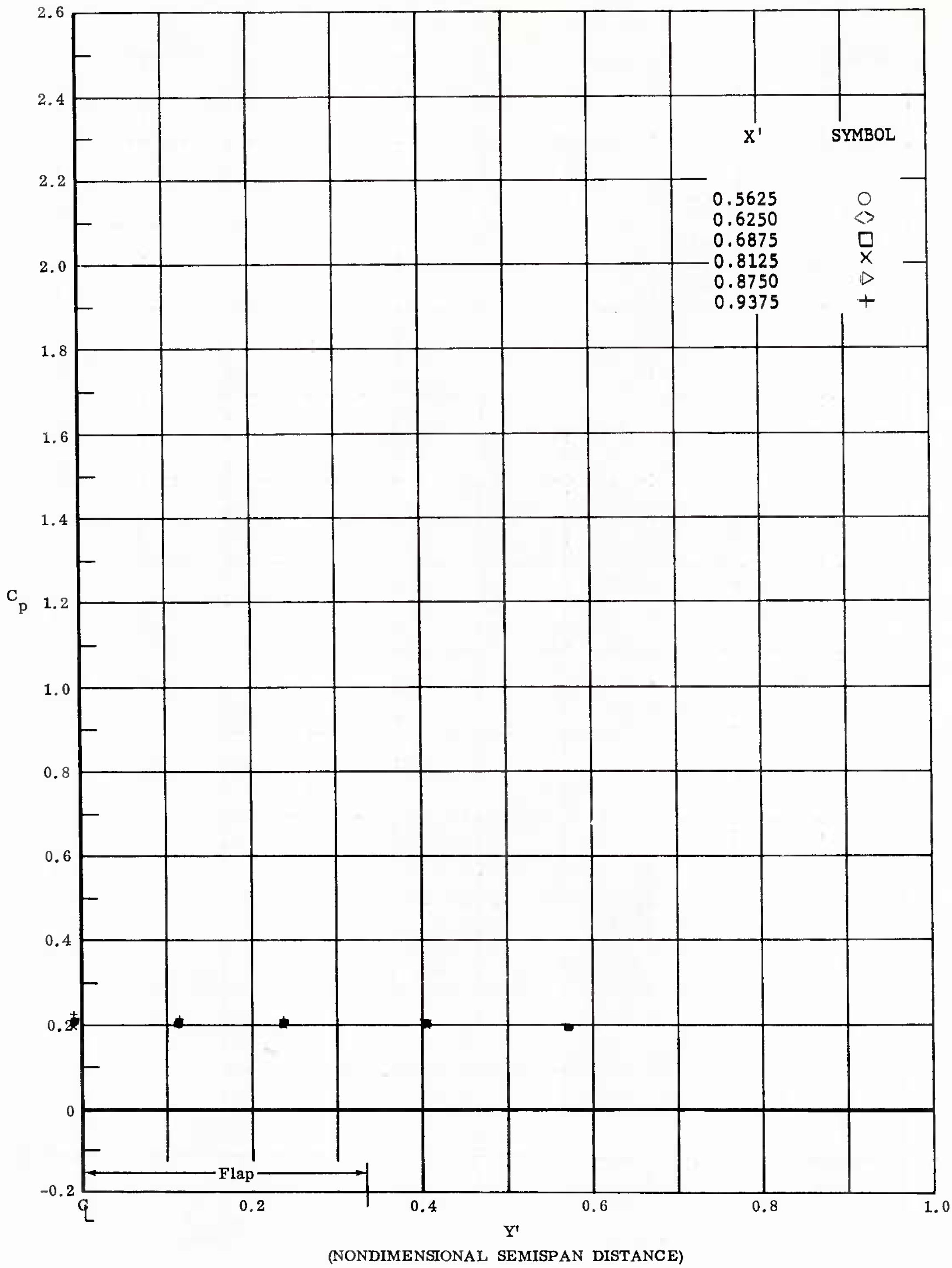


Fig. 79 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -15°$, $Re_\infty/ft = 1,100,000$.

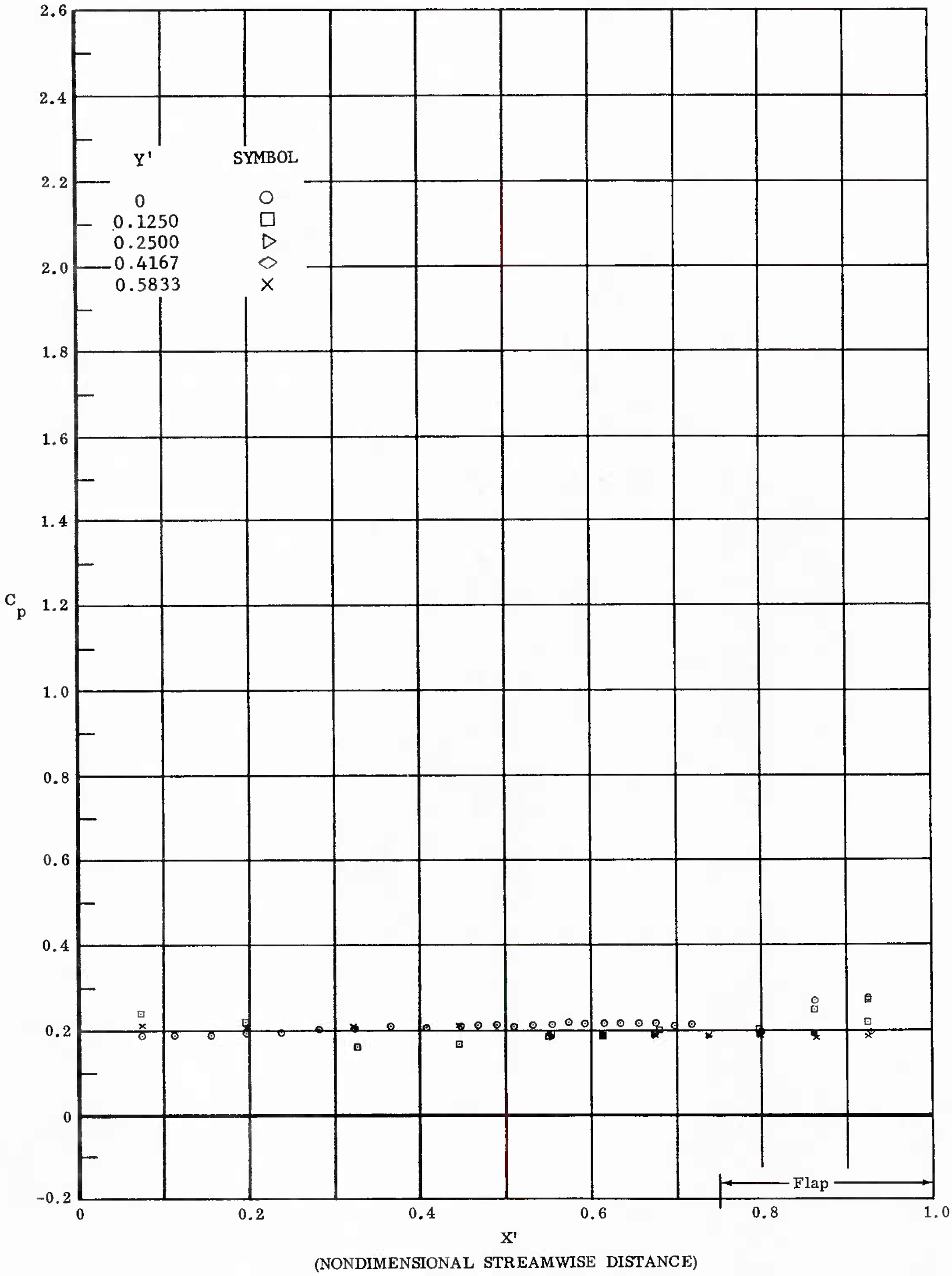


Fig. 80 Streamwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, $\alpha = -15°$, $Re_\infty/ft = 1{,}100{,}000$.

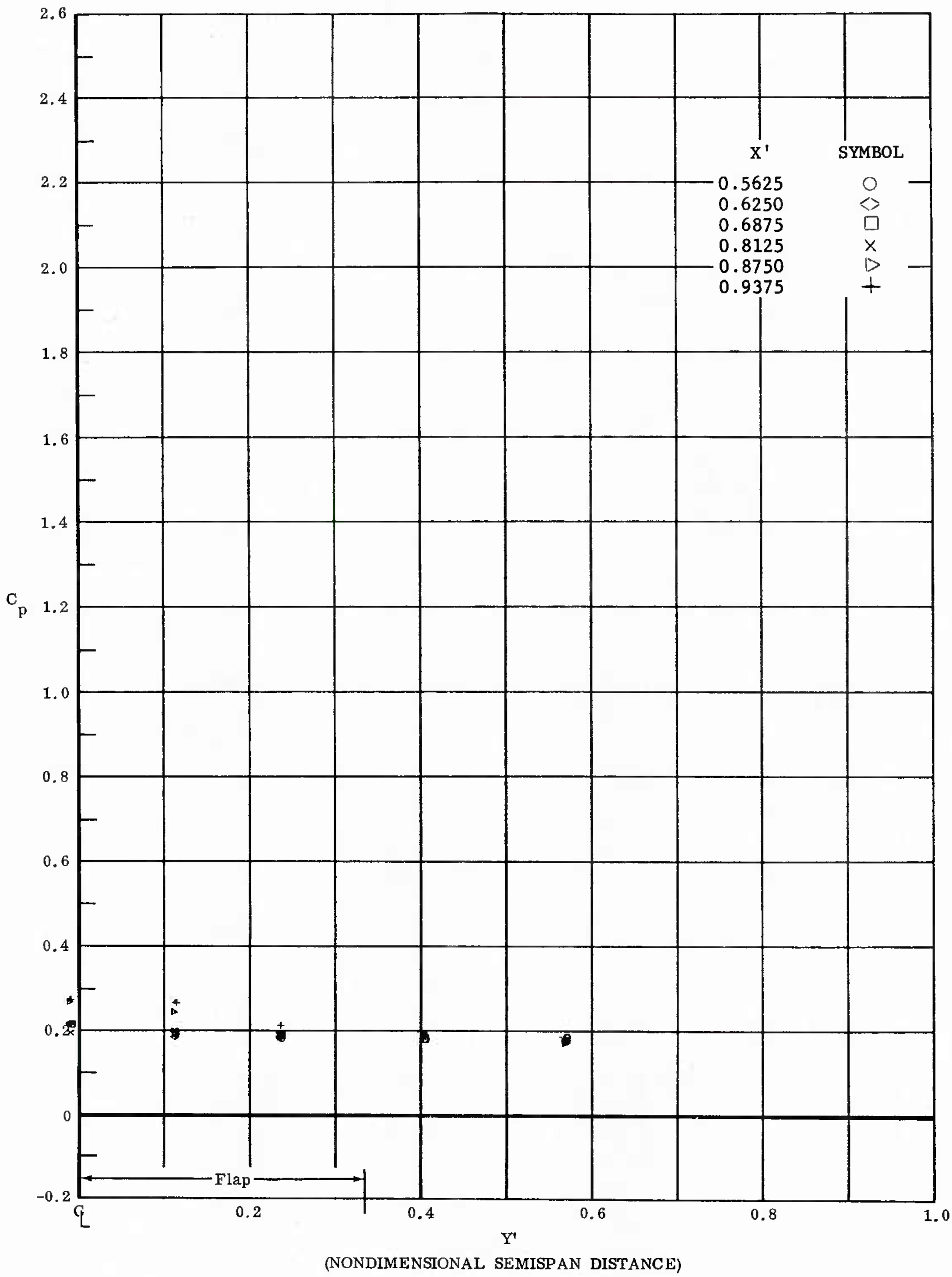


Fig. 80 Spanwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, α = -15°, Re_∞/ft = 1,100,000.

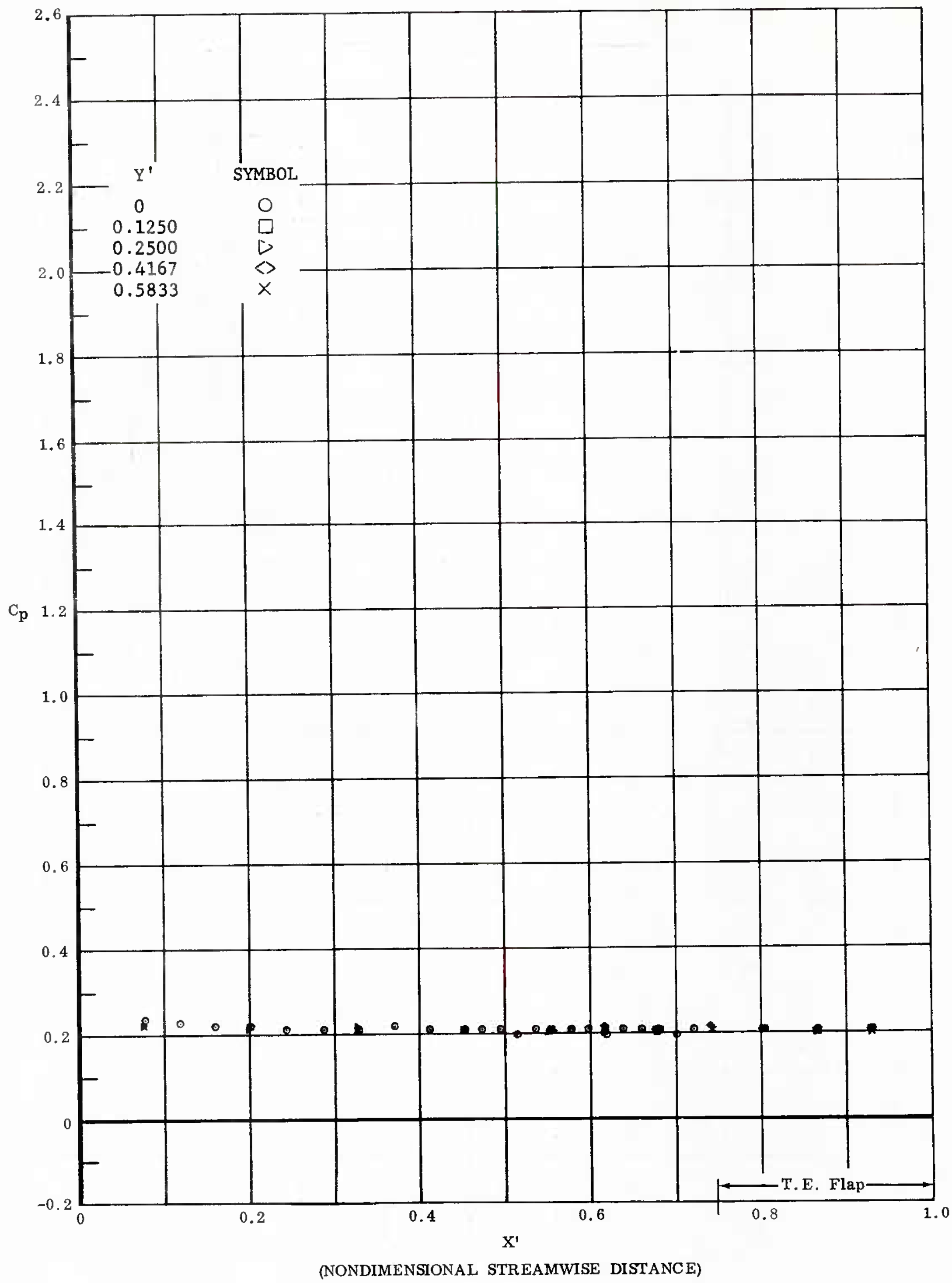


Fig. 81 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -15°$, $Re_\infty/ft = 3,300,000$.

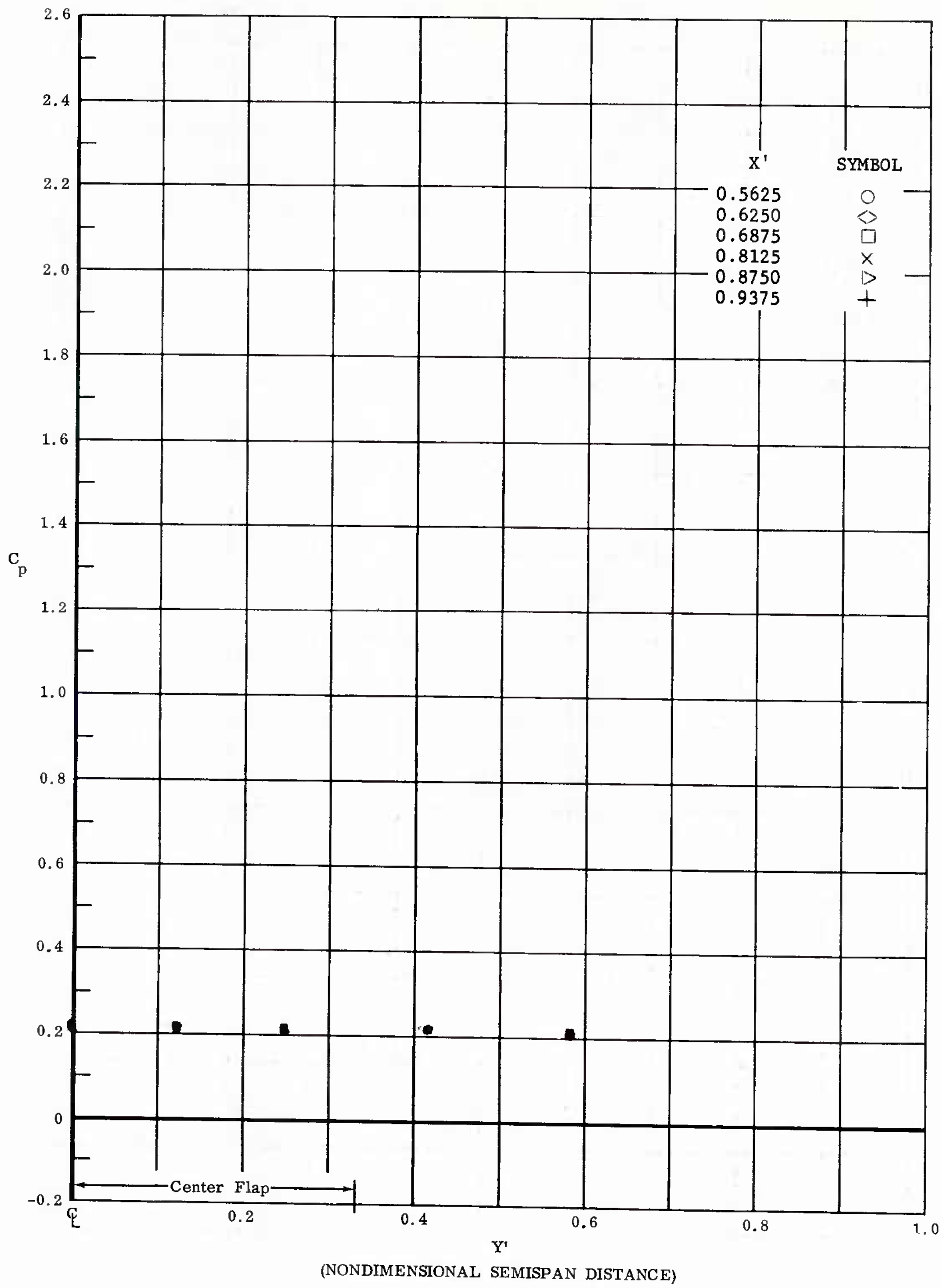


Fig. 81 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -15°$, $Re_\infty/ft = 3,300,000$.

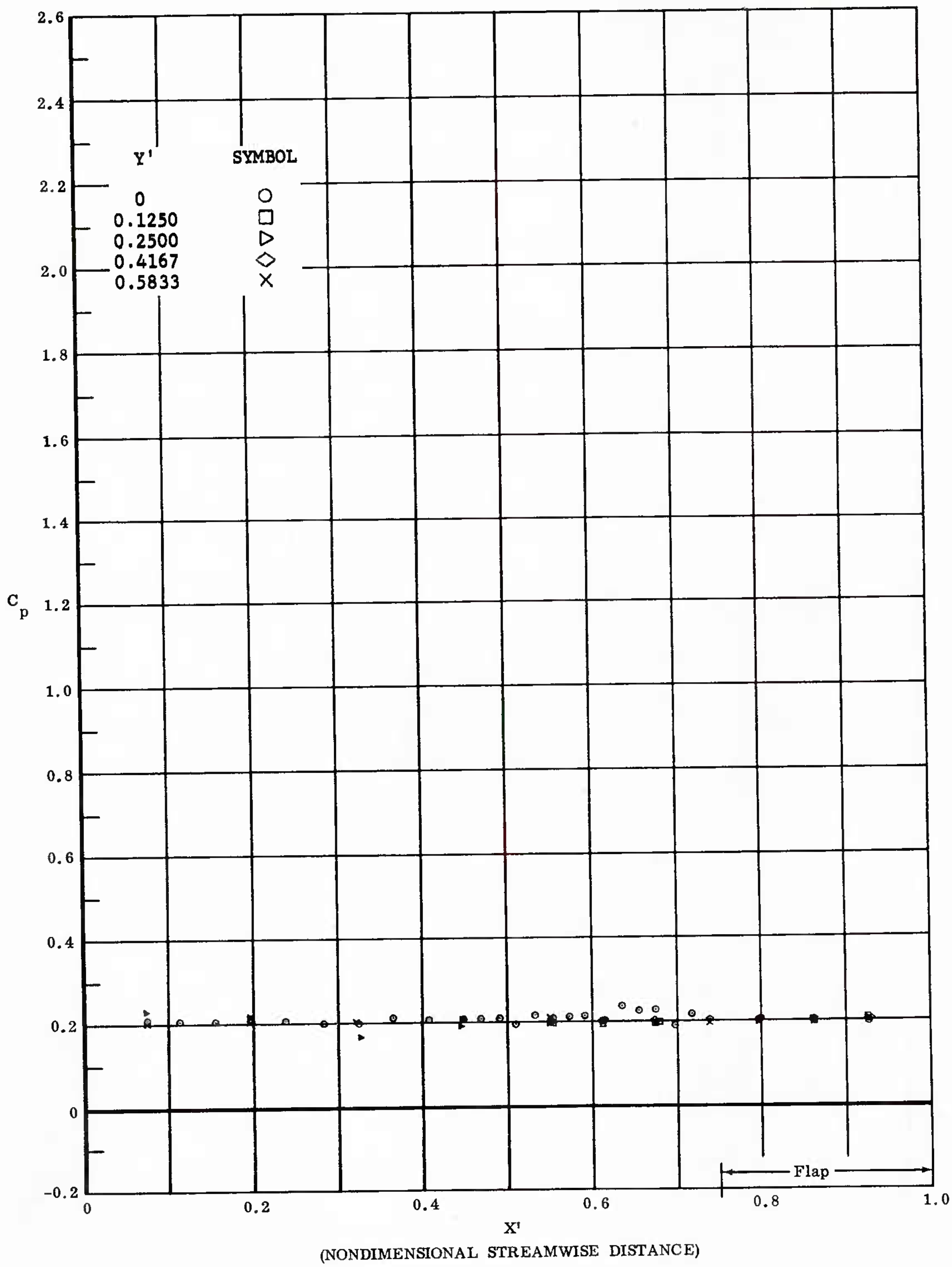


Fig. 82 Streamwise Pressure Distributions; Ramp Off, Medium Coolant Flow Rate, $\alpha = -15°$, $Re_\infty/ft = 3,300,000$.

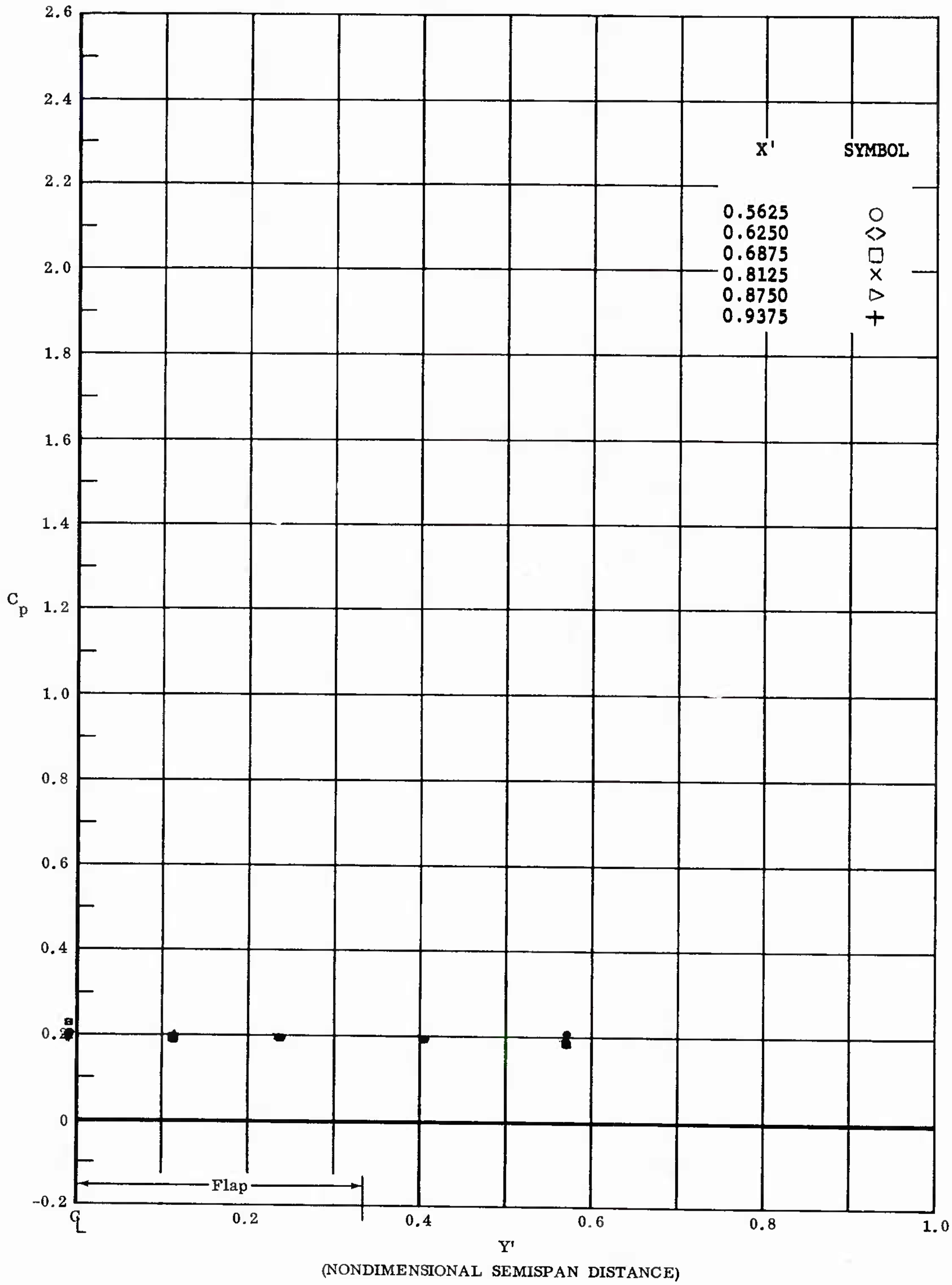


Fig. 82 Spanwise Pressure Distributions; Ramp Off, Medium Coolant Flow Rate, α = -15°, Re_∞/ft = 3,300,000.

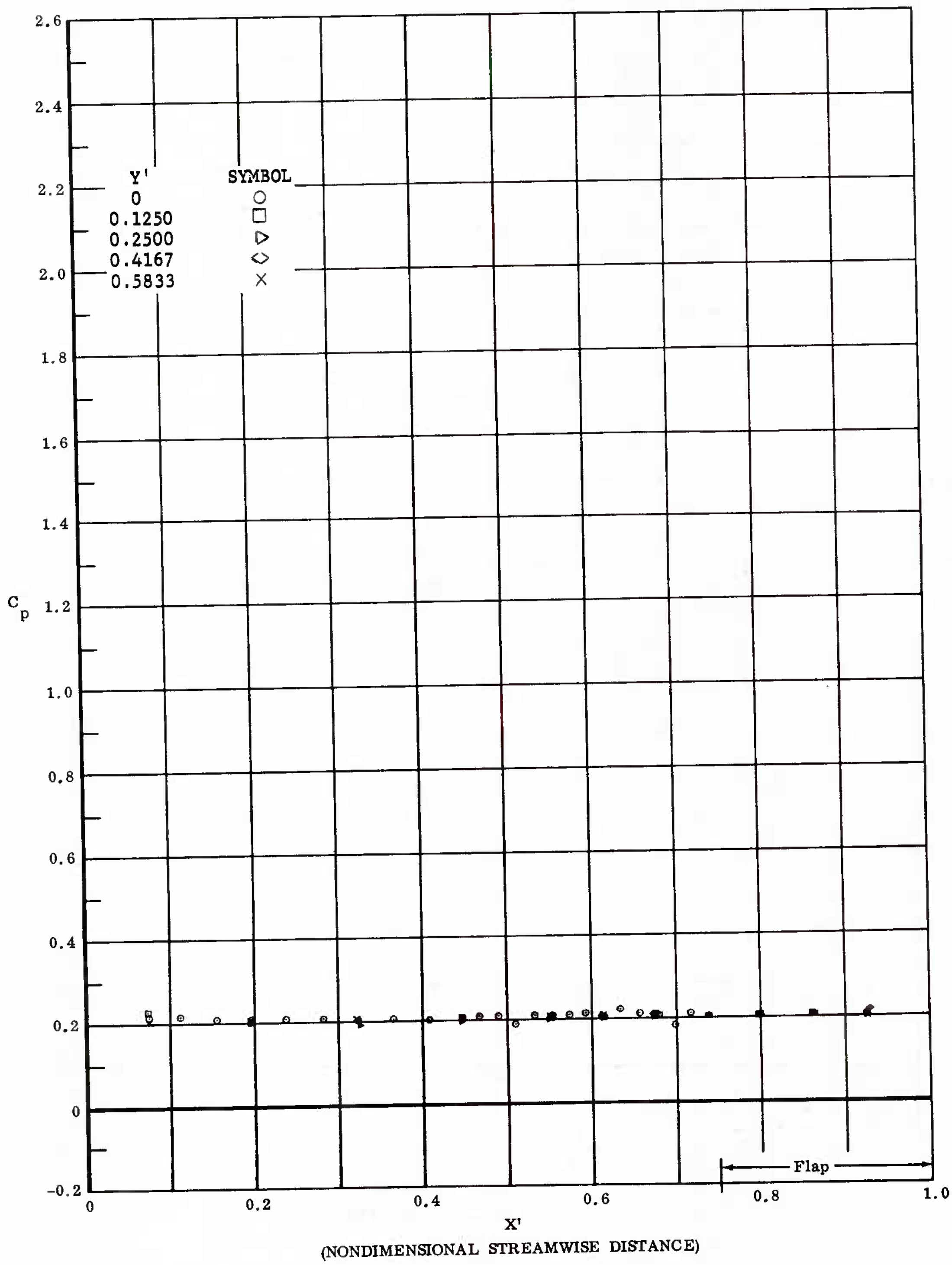


Fig. 83 Streamwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, $\alpha = -15°$, $Re_{\infty}/ft = 3,300,000$.

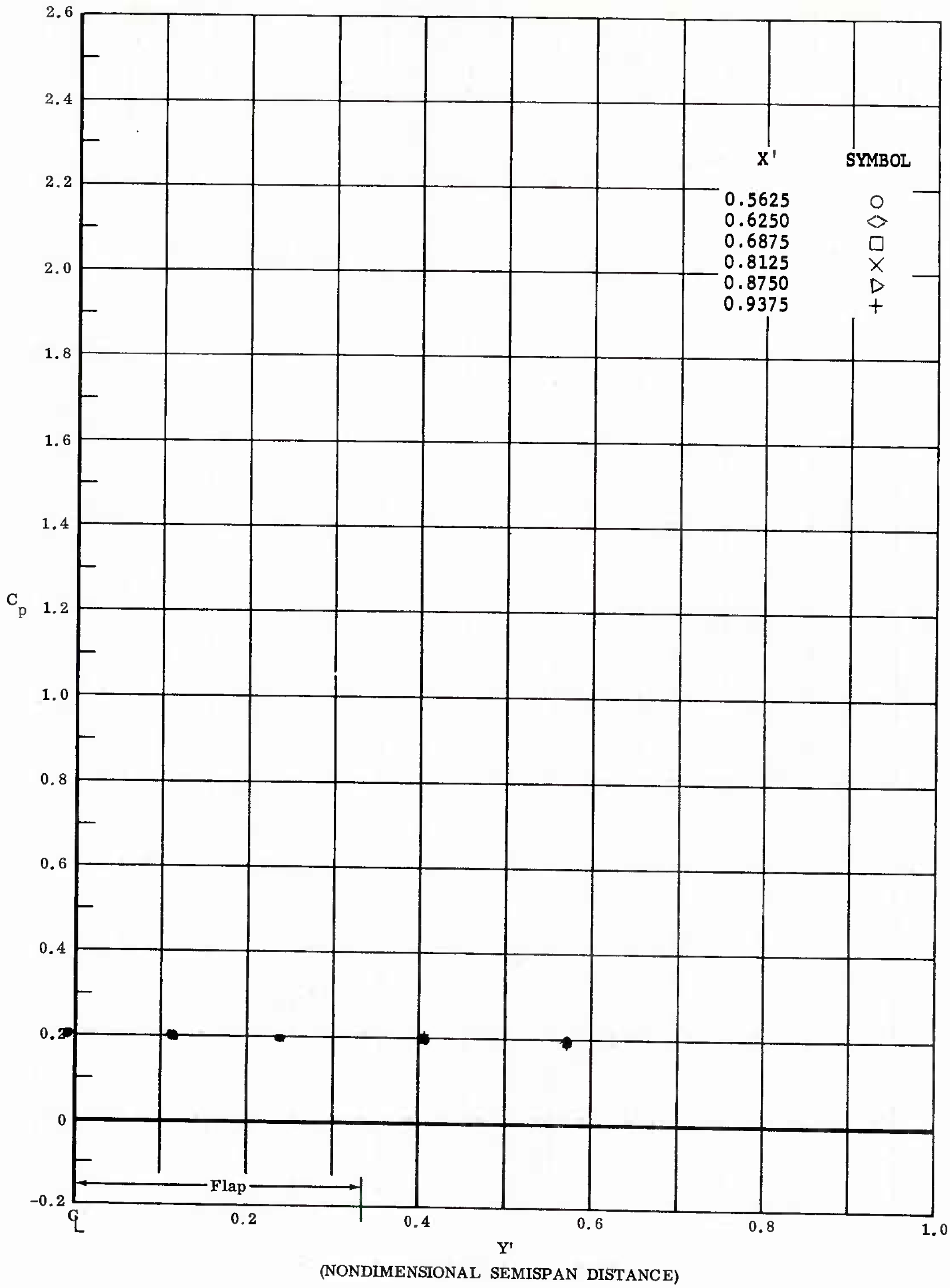


Fig. 83 Spanwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, α = -15°, Re_∞/ft = 3,300,000.

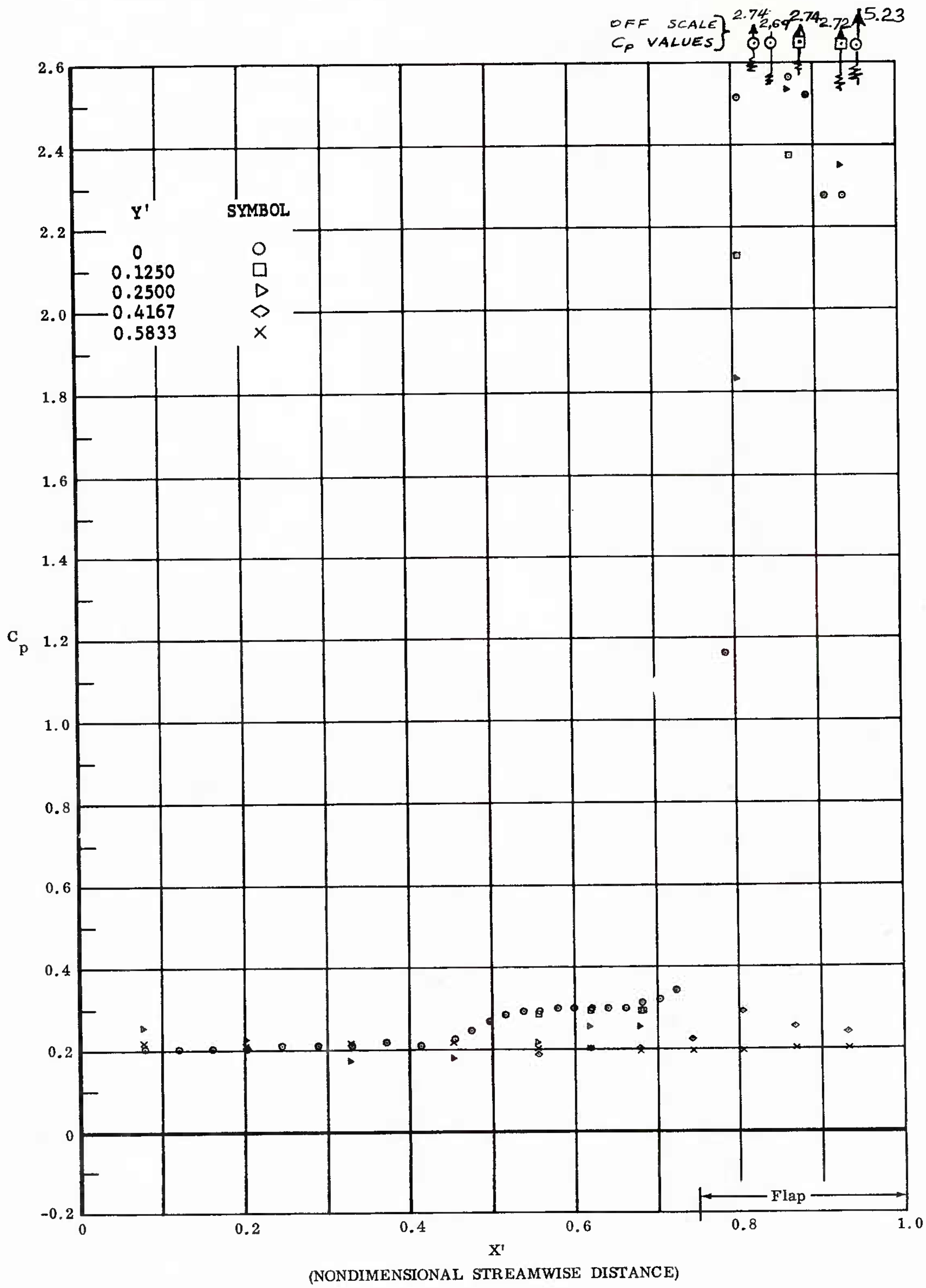


Fig. 84 Streamwise Pressure Distributions; Ramp On, Maximum Coolant Flow Rate, $\alpha = -15°$, $Re_{\infty}/ft = 1,100,000$.

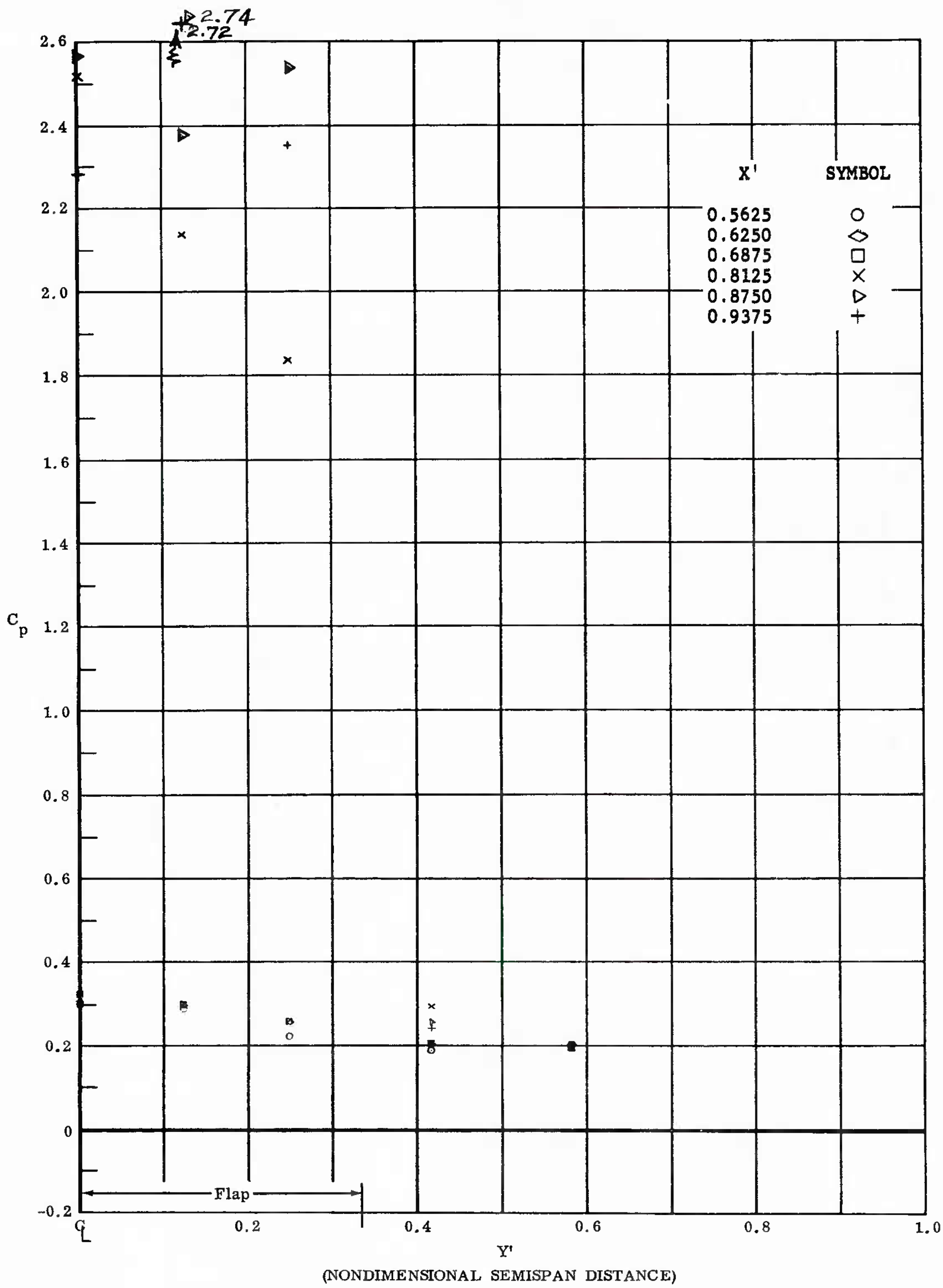


Fig. 84 Spanwise Pressure Distributions; Ramp On, Maximum Coolant Flow Rate, $\alpha = -15°$, $Re_\infty/ft = 1,100,000$.

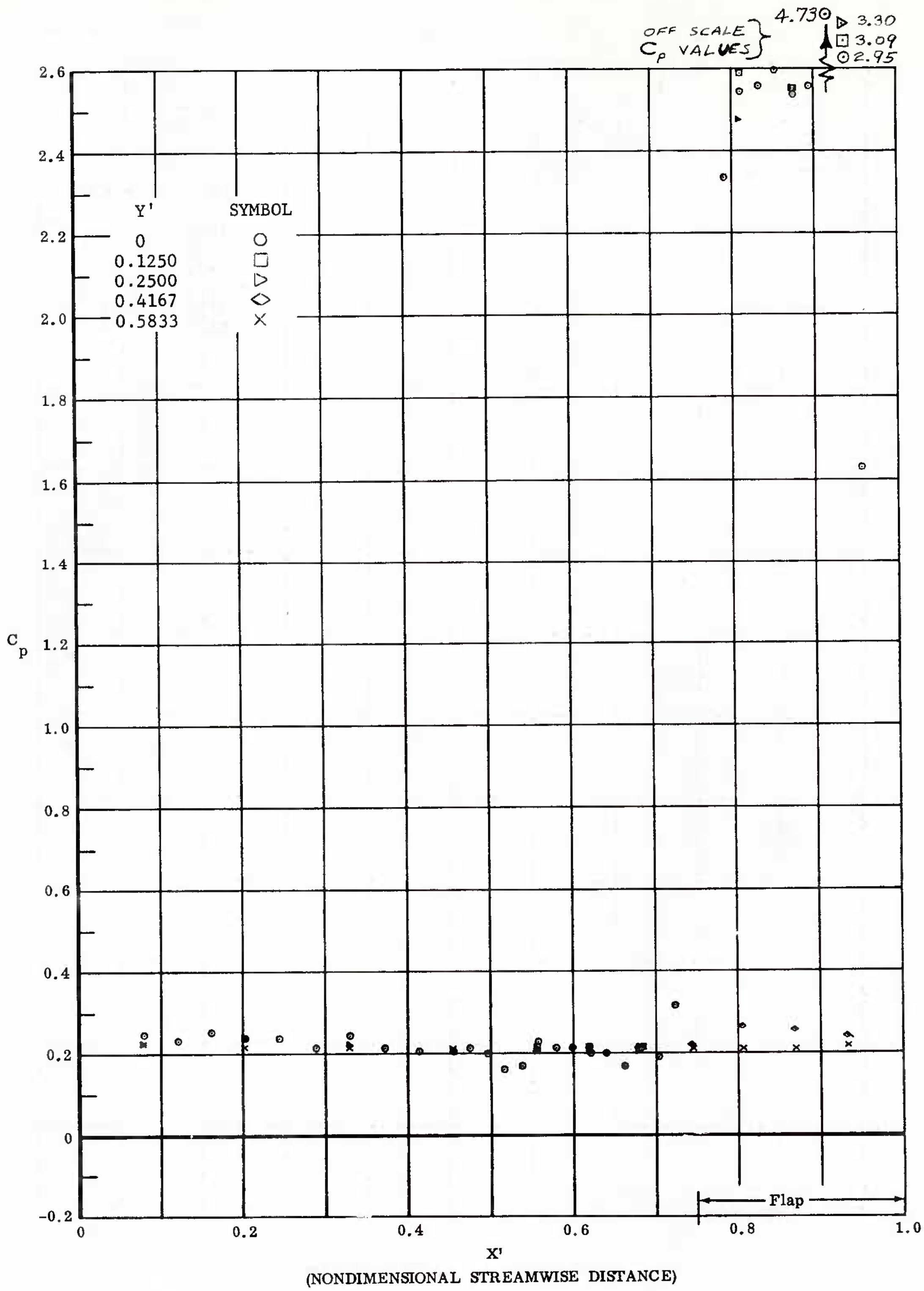


Fig. 85 Streamwise Pressure Distributions; Ramp On, No Coolant Flow, $\alpha = -15°$, $Re_\infty/ft = 3{,}300{,}000$.

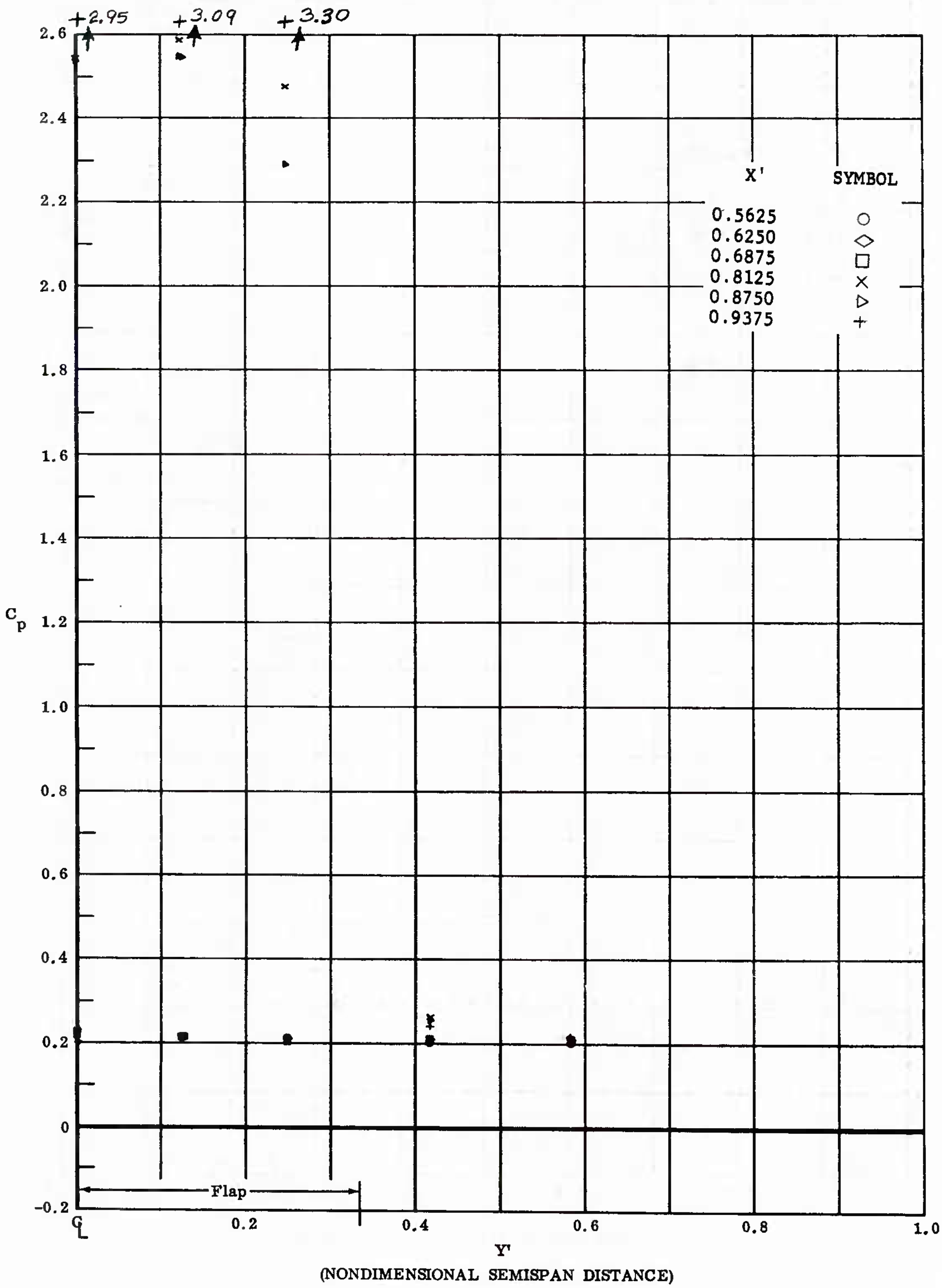


Fig. 85 Spanwise Pressure Distributions; Ramp On, No Coolant Flow, α = -15°, Re_∞/ft = 3,300,000.

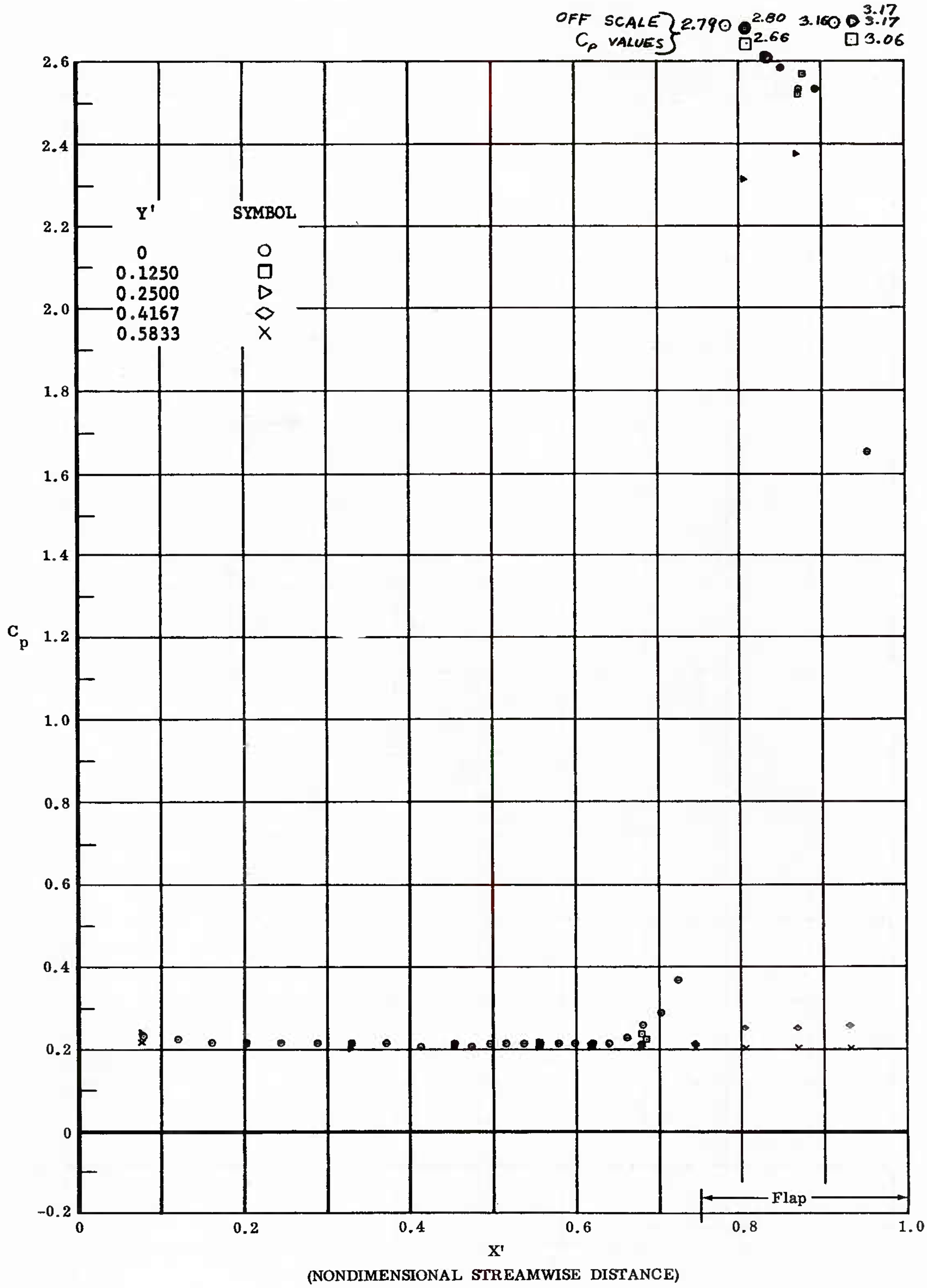


Fig. 86 Streamwise Pressure Distributions; Ramp On, Maximum Coolant Flow Rate, $\alpha = -15°$, $Re_\infty/ft = 3,300,000$.

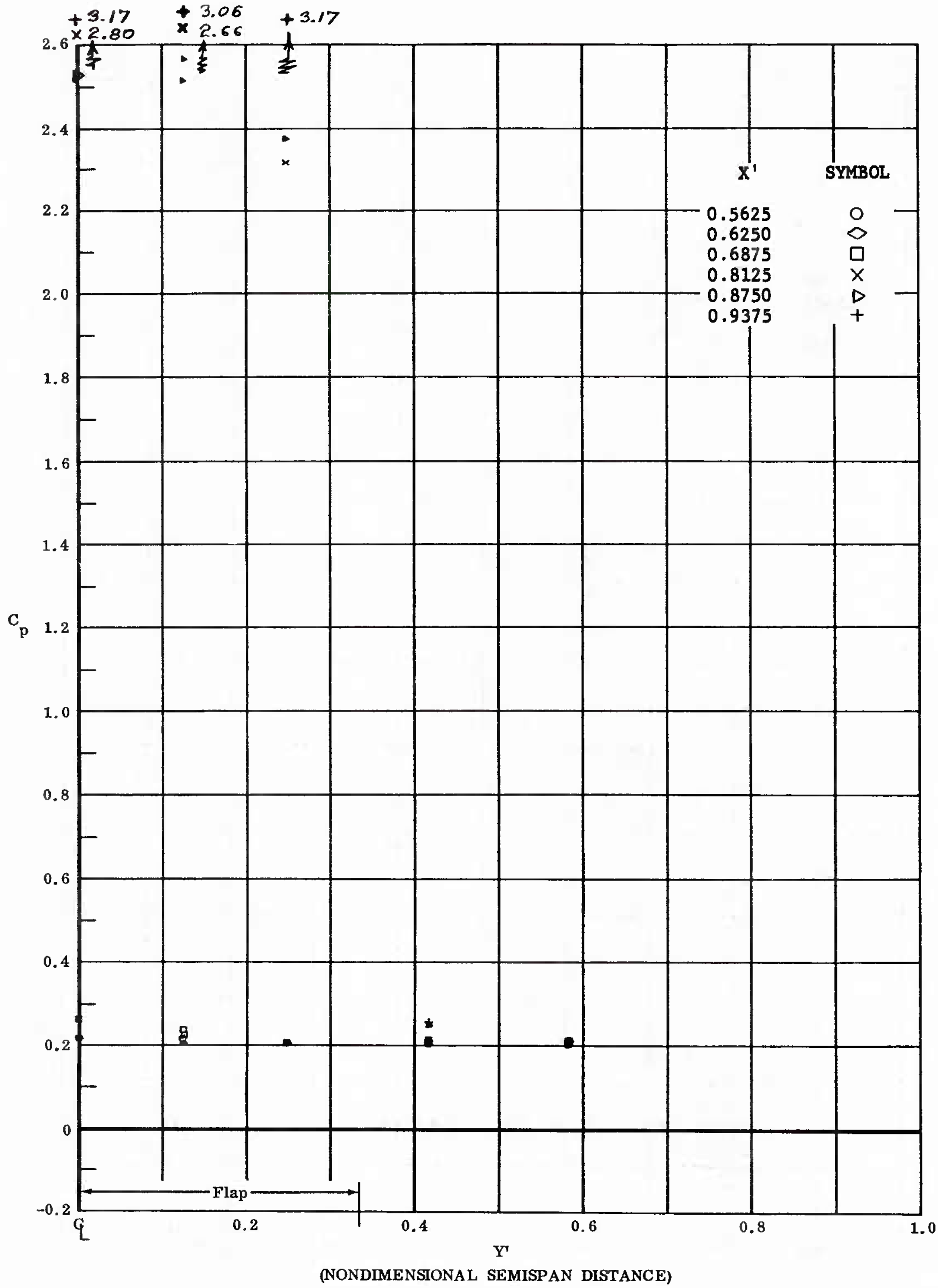


Fig. 86 Spanwise Pressure Distributions; Ramp On, Maximum Coolant Flow Rate, $\alpha = -15°$, $Re_\infty/ft = 3,300,000$.

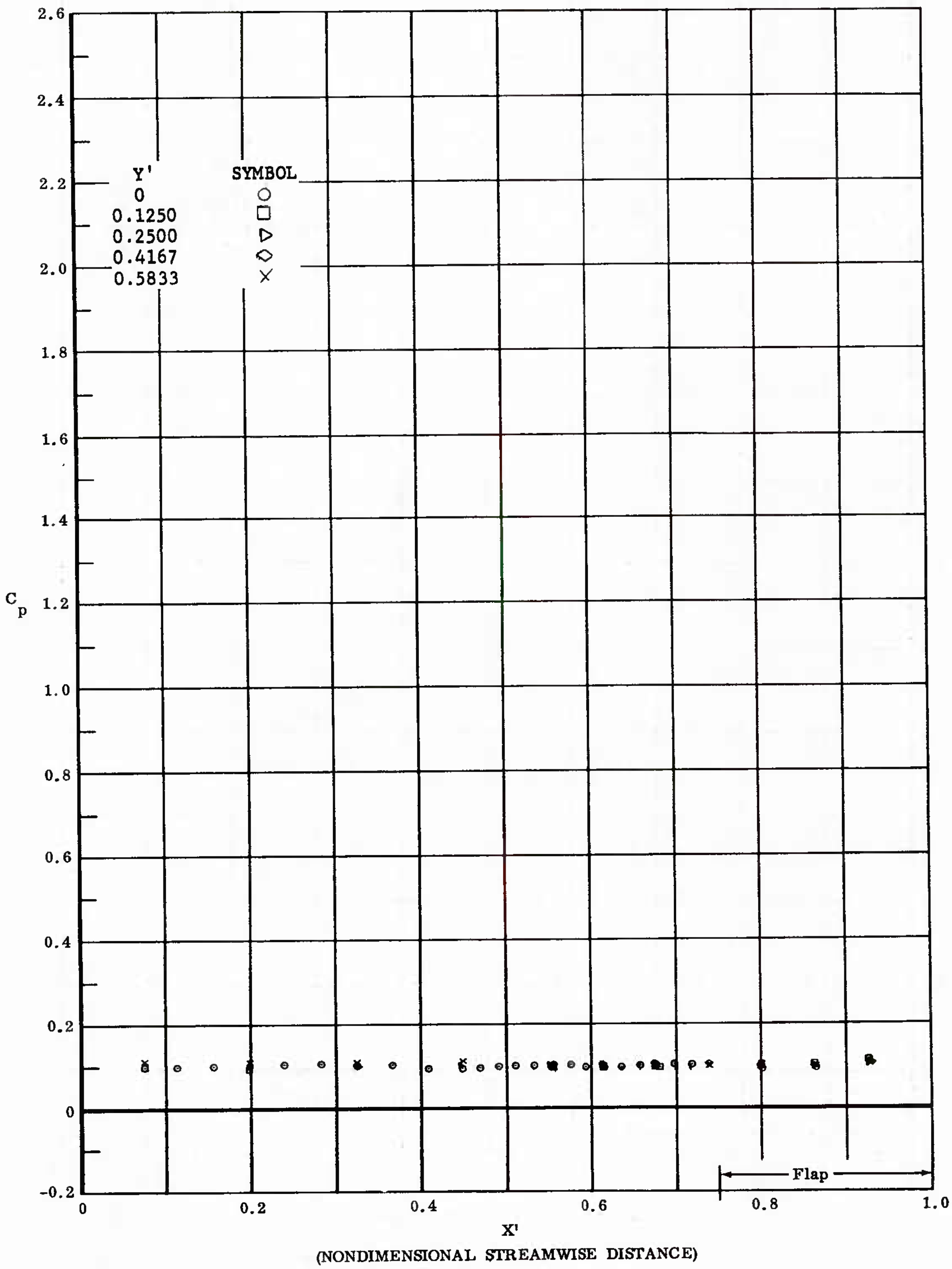


Fig. 87 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -10°$, $Re_\infty/ft = 1,100,000$.

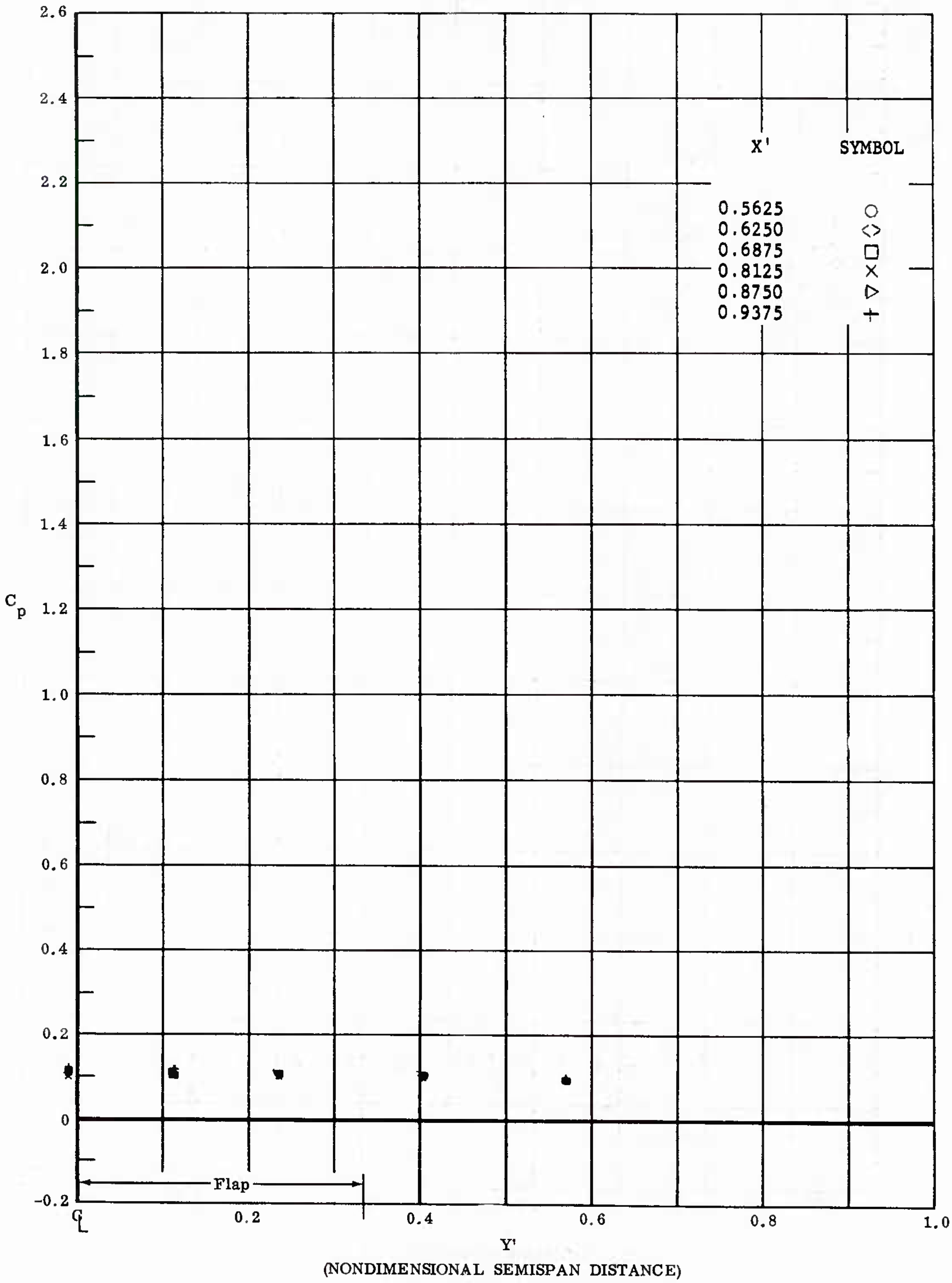


Fig. 87 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, α = -10°, Re_∞/ft = 1,100,000.

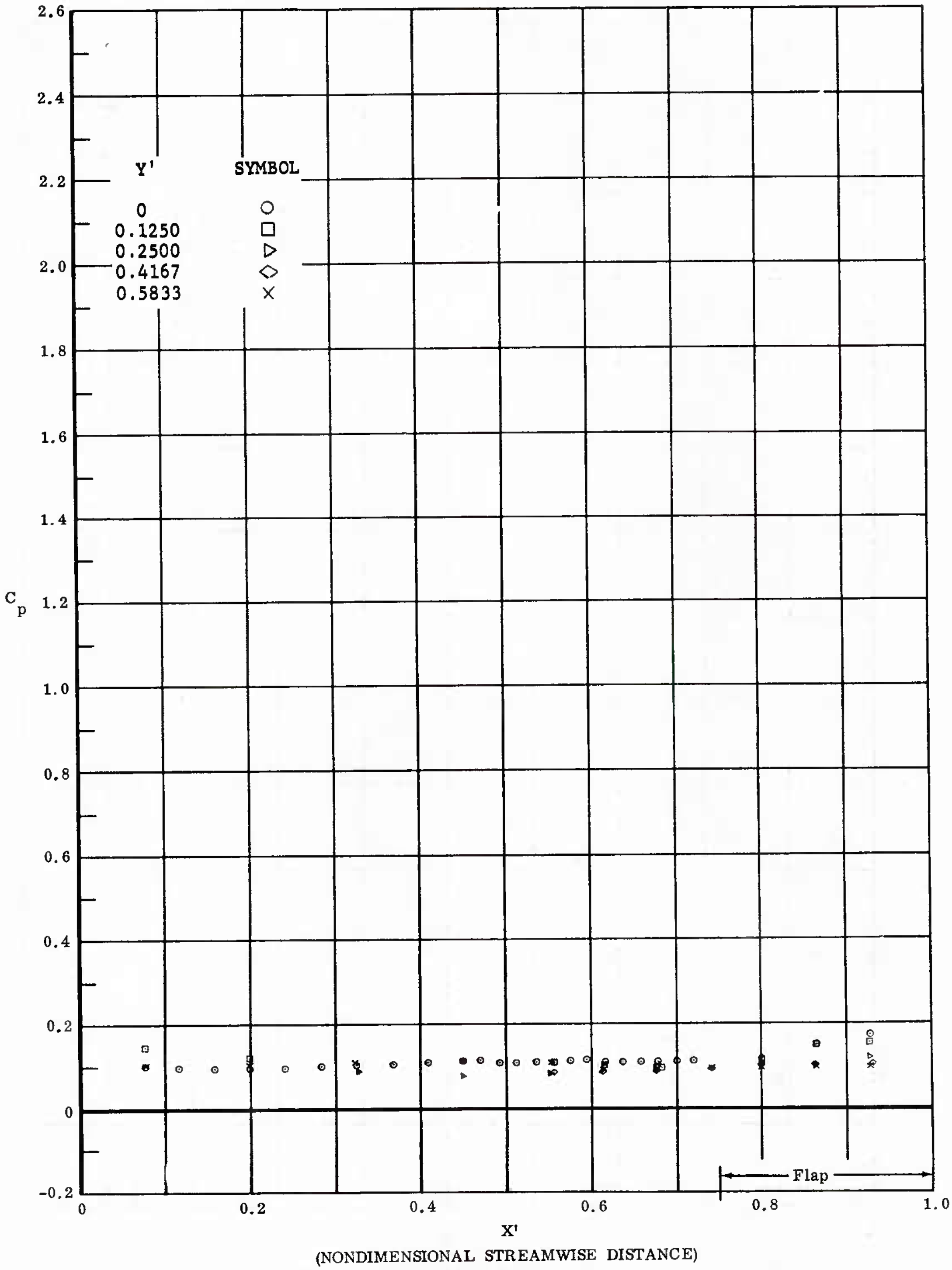


Fig. 88 Streamwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, α = -10°, Re_{∞}/ft = 1,100,000.

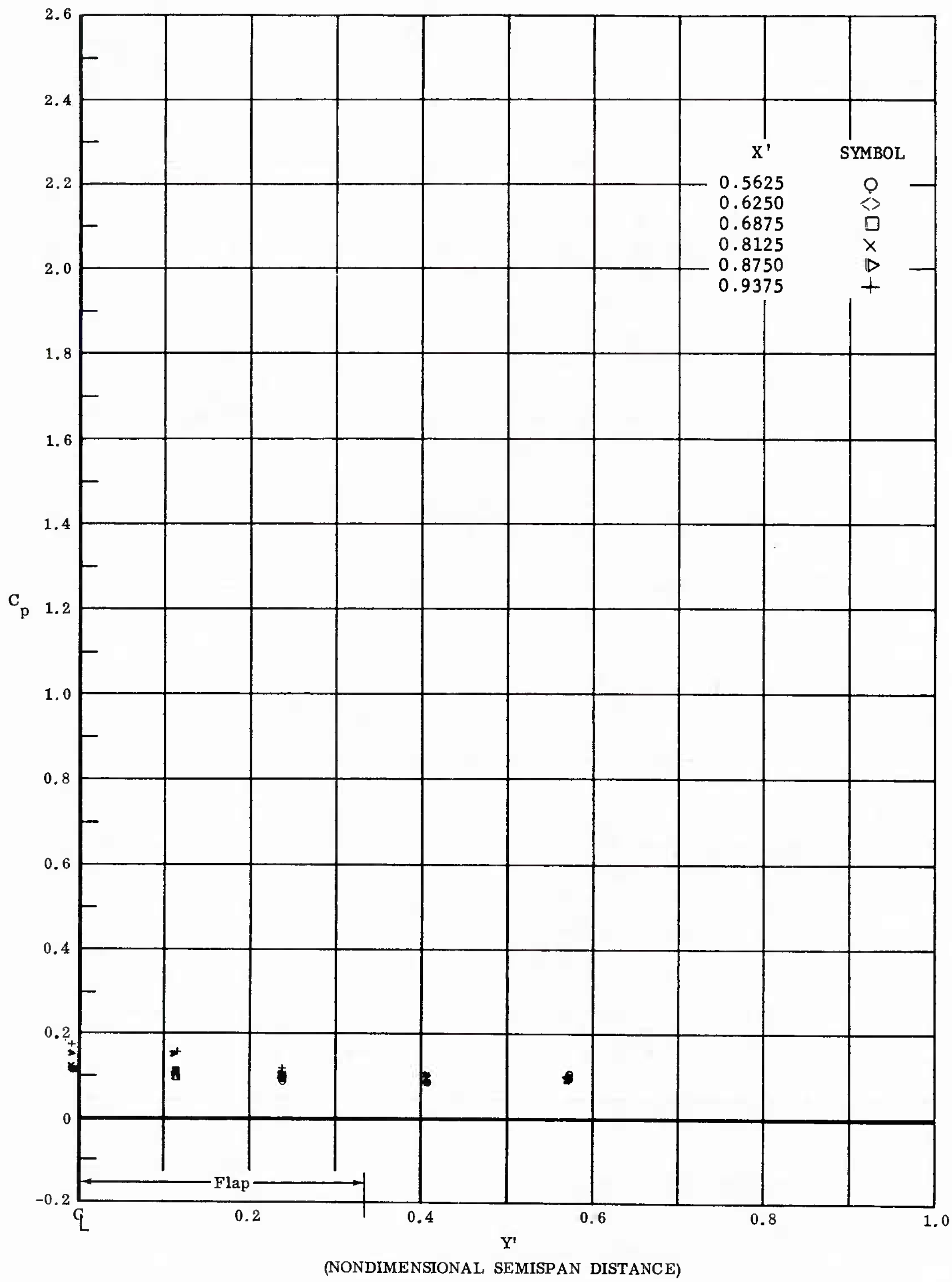


Fig. 88 Spanwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, $\alpha = -10°$, $Re_\infty/ft = 1,100,000$.

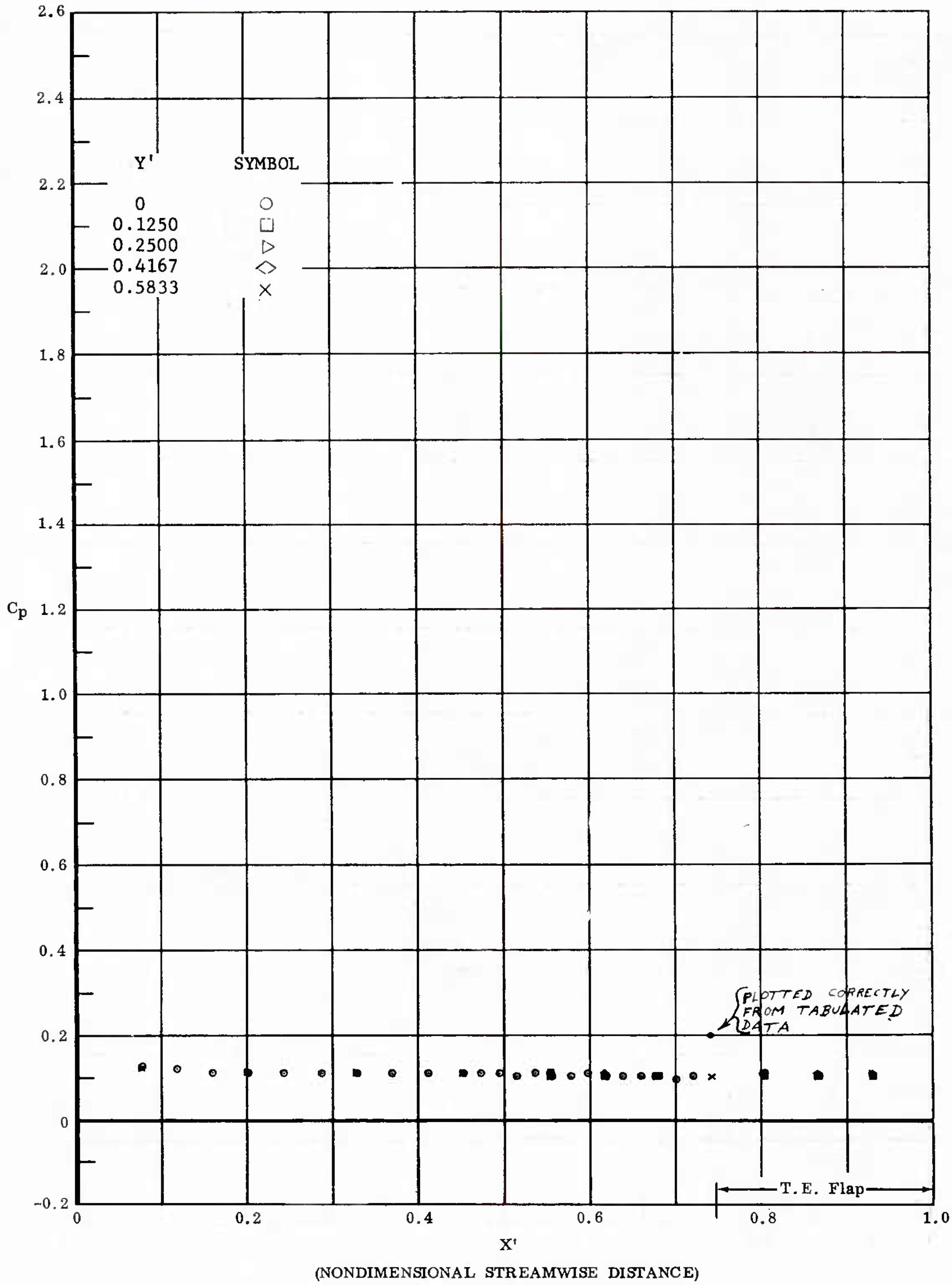


Fig. 89 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -10°$, $Re_\infty/ft = 3,300,000$.

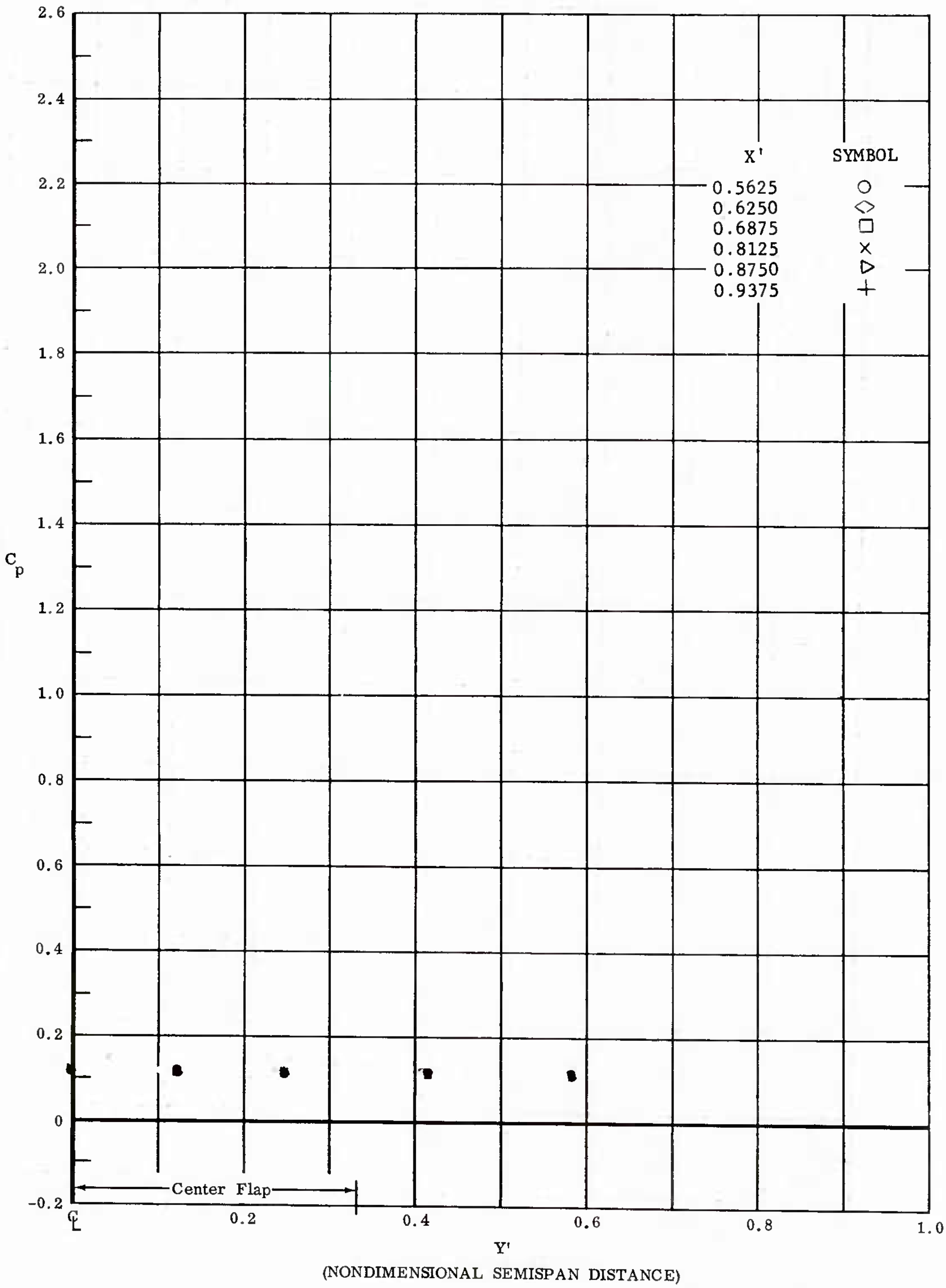


Fig. 89 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -10°$, $Re_\infty/ft = 3,300,000$.

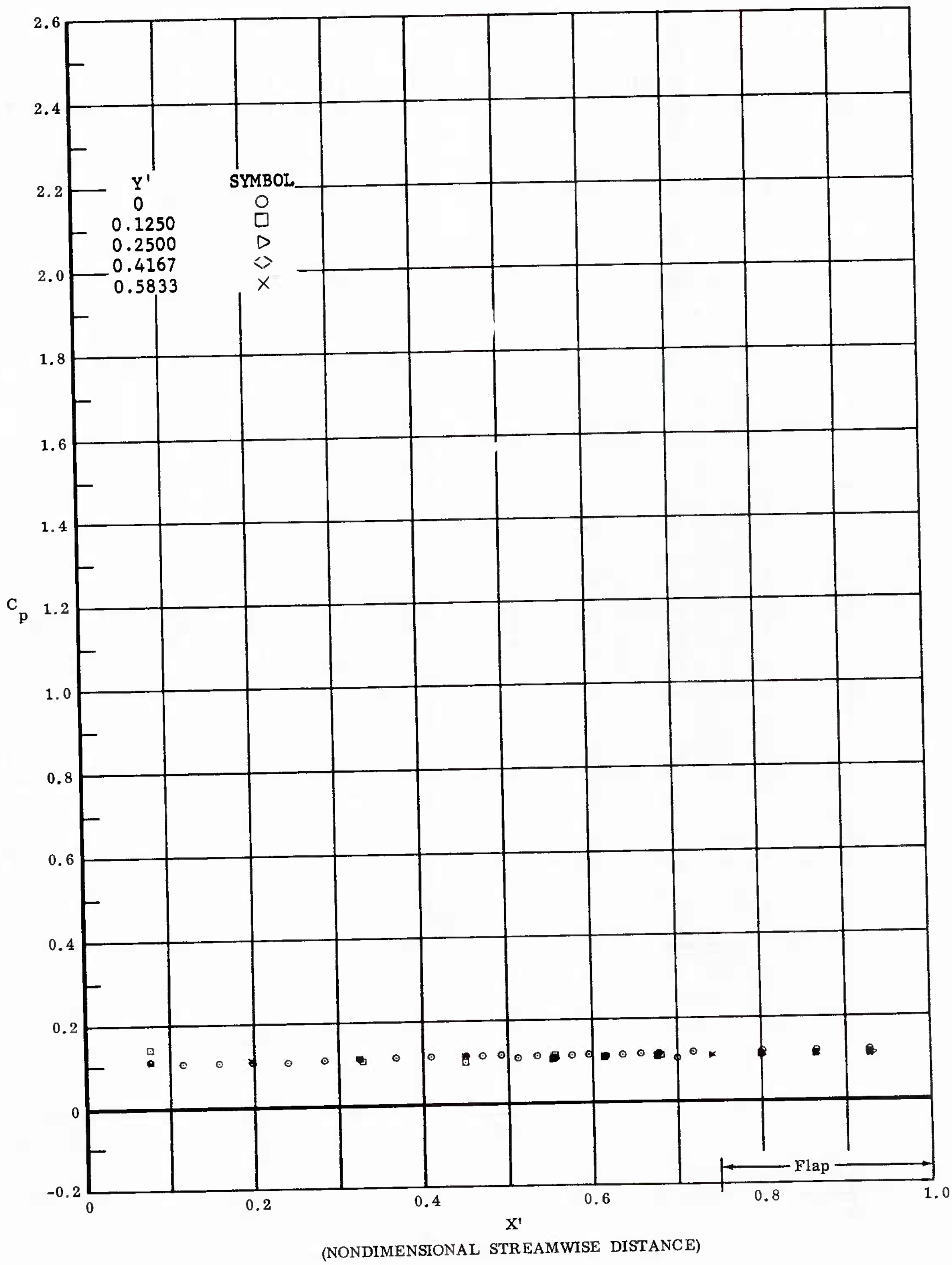


Fig. 90 Streamwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, $\alpha = -10°$, $Re_\infty/ft = 3,300,000$.

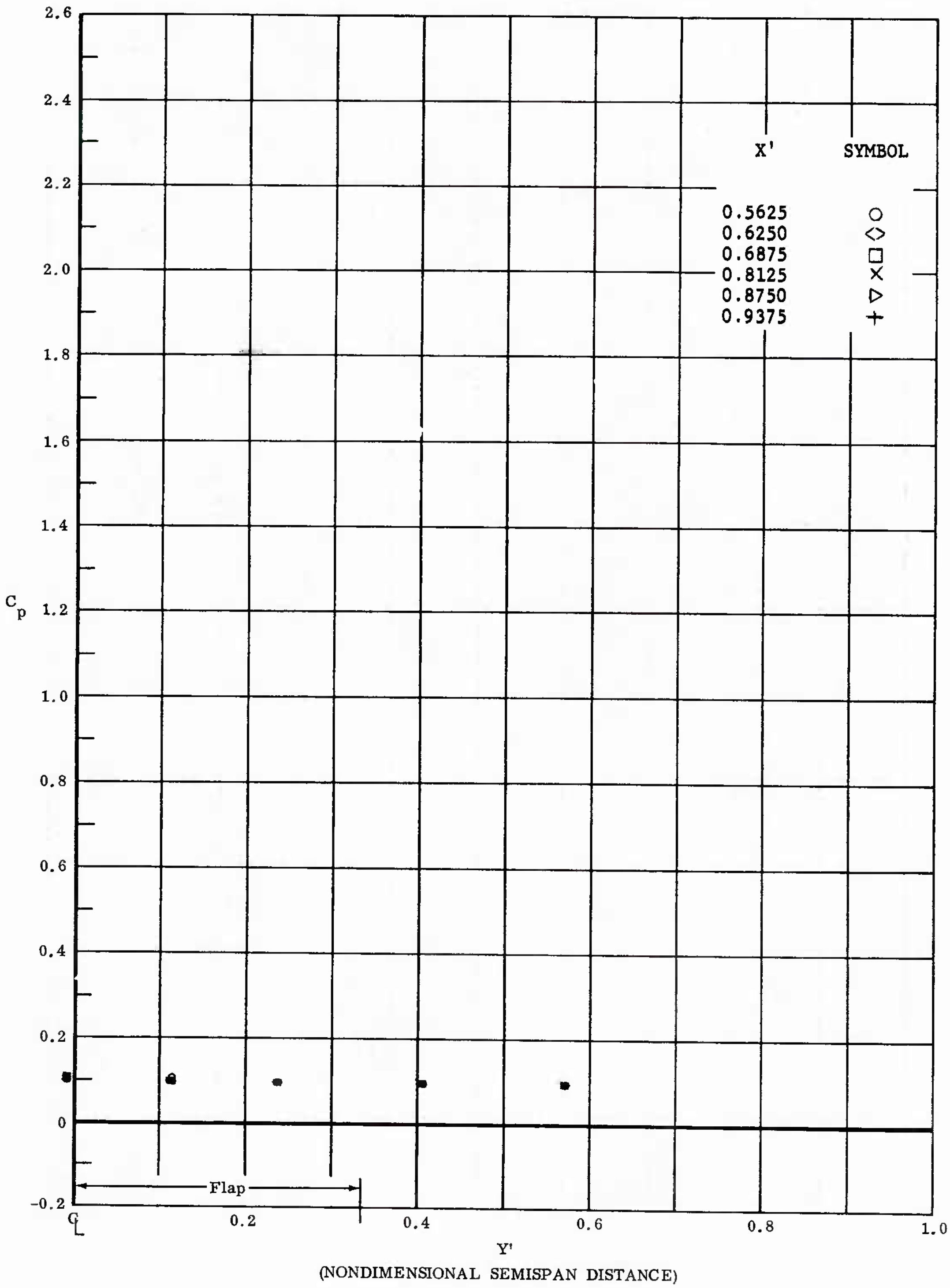


Fig. 90 Spanwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, $\alpha = -10°$, $Re_\infty/ft = 3,300,000$.

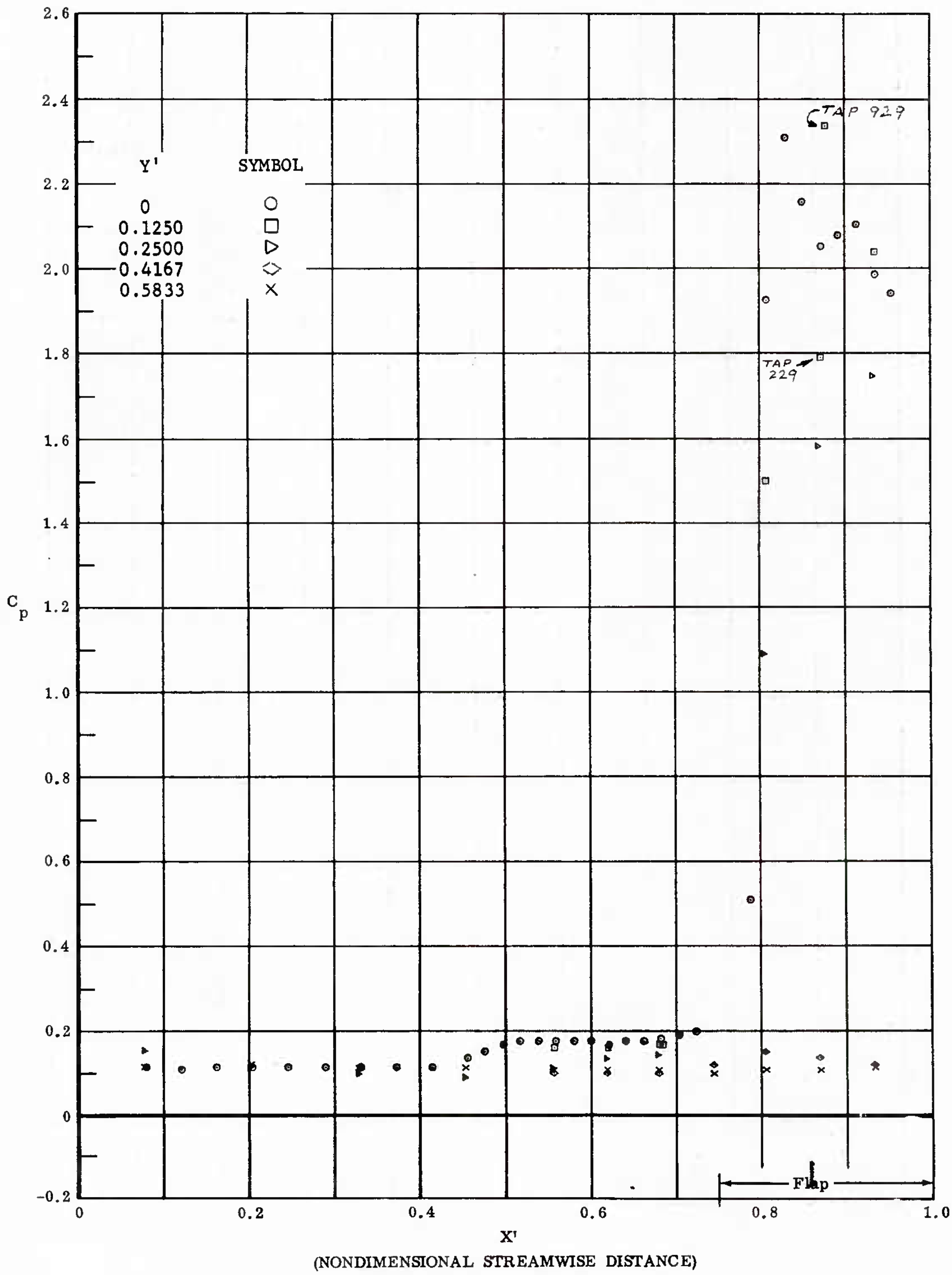


Fig. 91 Streamwise Pressure Distributions; Ramp On, Maximum Coolant Flow Rate, $\alpha = -10°$, $Re_\infty/ft = 1,100,000$.

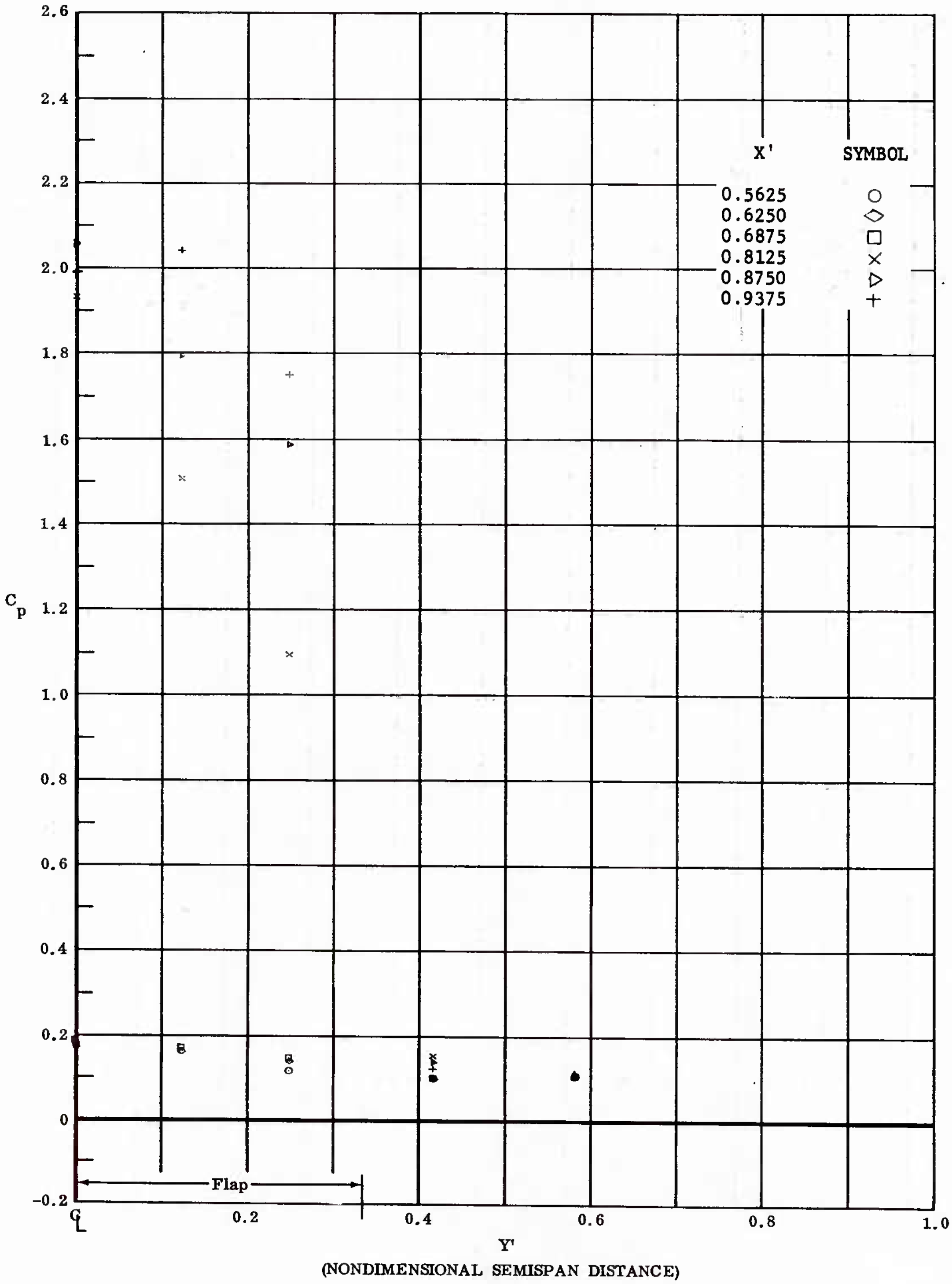


Fig. 91 Spanwise Pressure Distributions; Ramp On, Maximum Coolant Flow Rate, $\alpha = -10°$, $Re_\infty/ft = 1,100,000$.

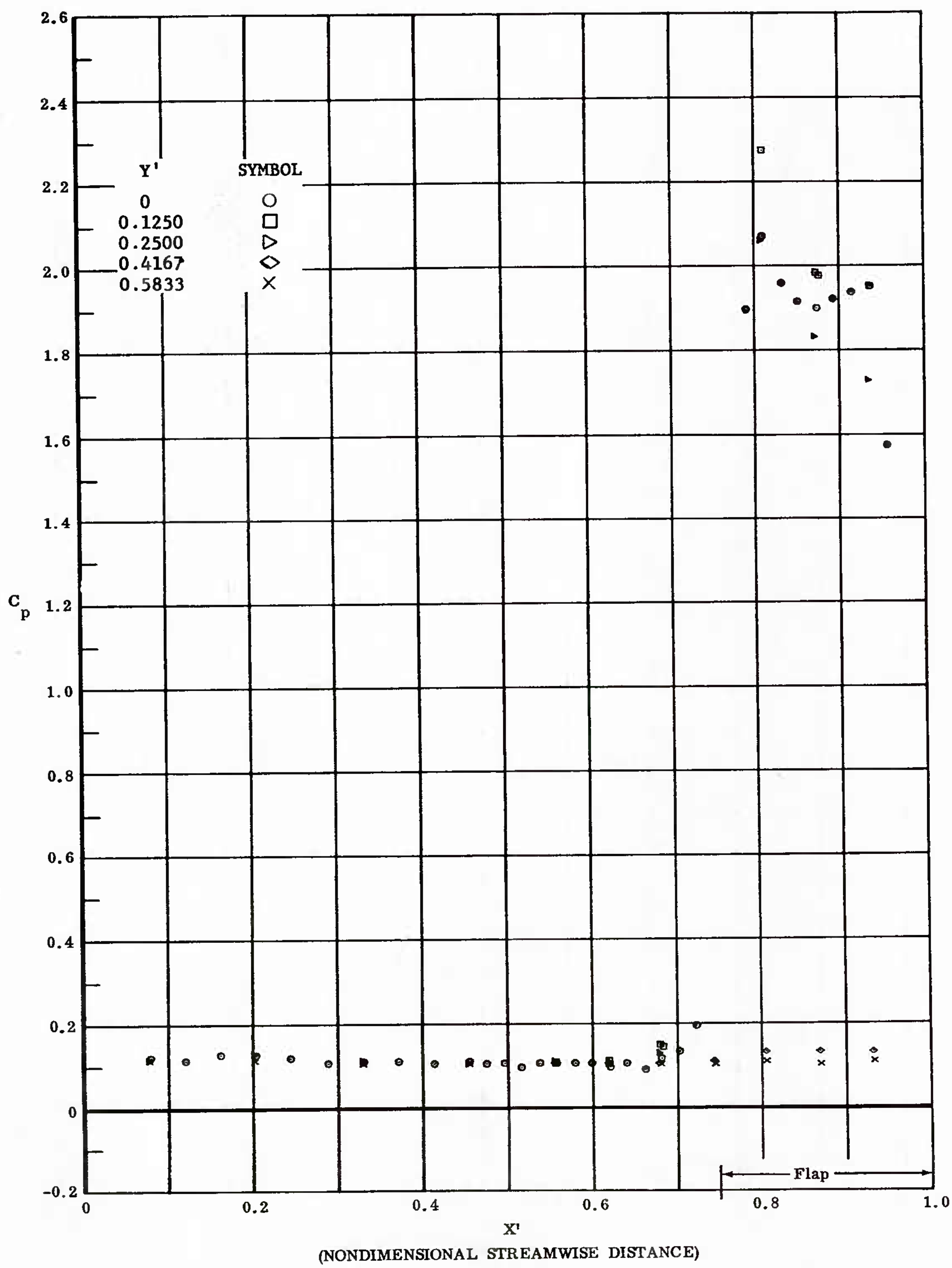


Fig. 92 Streamwise Pressure Distributions; Ramp On, No Coolant Flow, $\alpha = -10°$, $Re_\infty/ft = 3,300,000$.

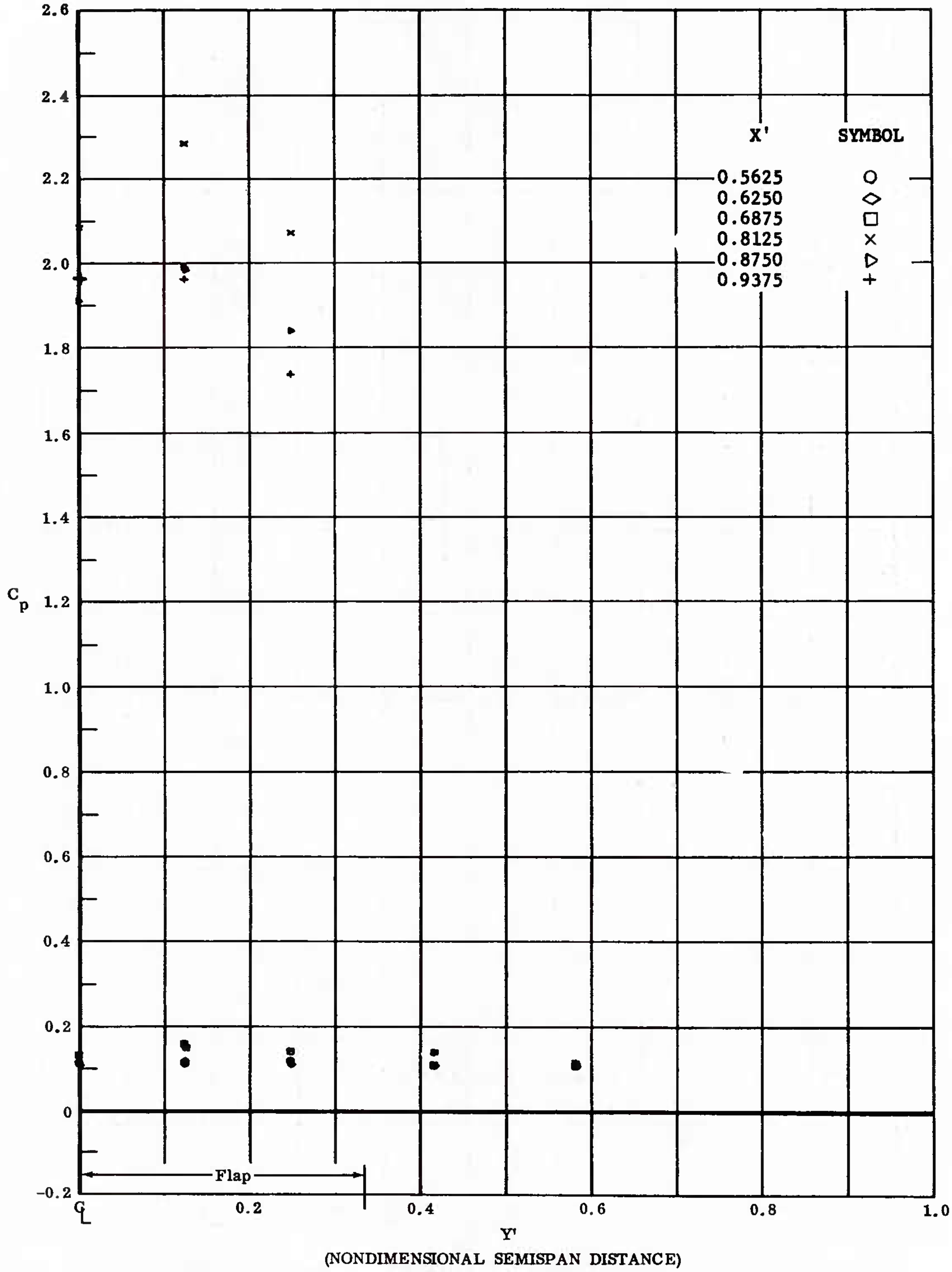


Fig. 92 Spanwise Pressure Distributions; Ramp On, No Coolant Flow, α = -10°, Re_∞/ft = 3,300,000.

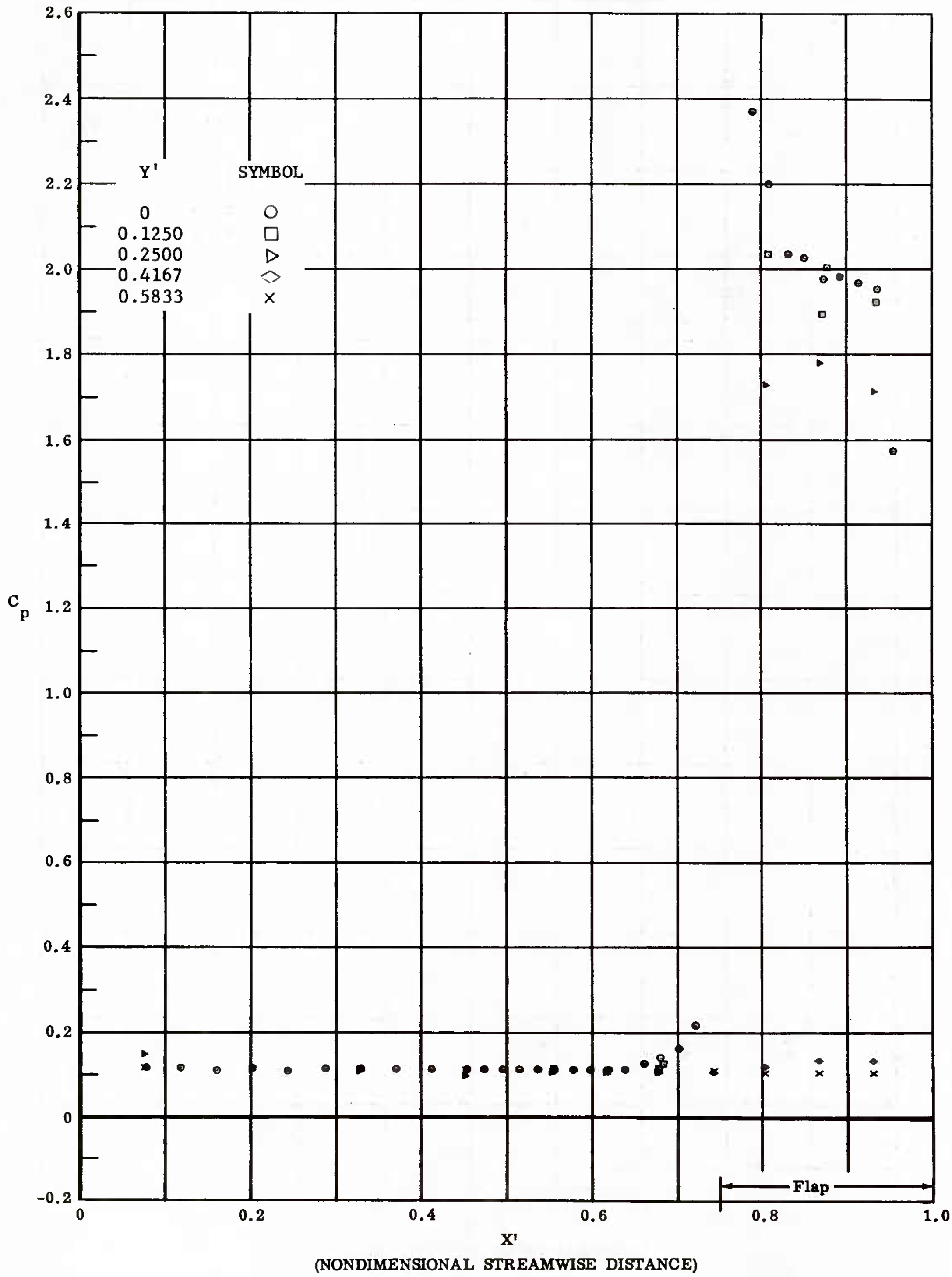


Fig. 93 Streamwise Pressure Distributions; Ramp On, Maximum Coolant Flow Rate, $\alpha = -10°$, $Re_\infty/ft = 3,300,000$.

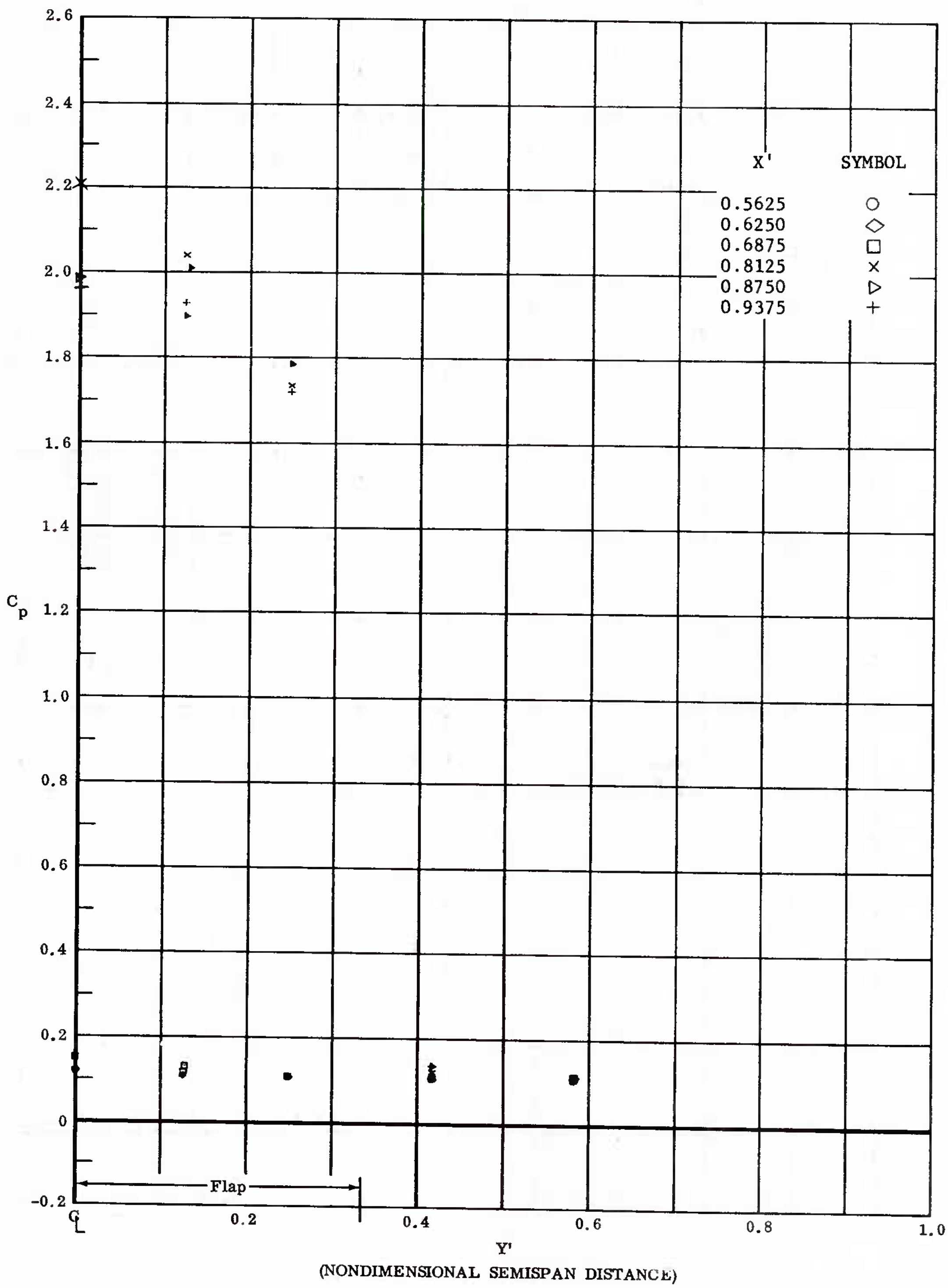


Fig. 93 Spanwise Pressure Distributions; Ramp On, Maximum Coolant Flow Rate, α = -10°, Re_∞/ft = 3,300,000.

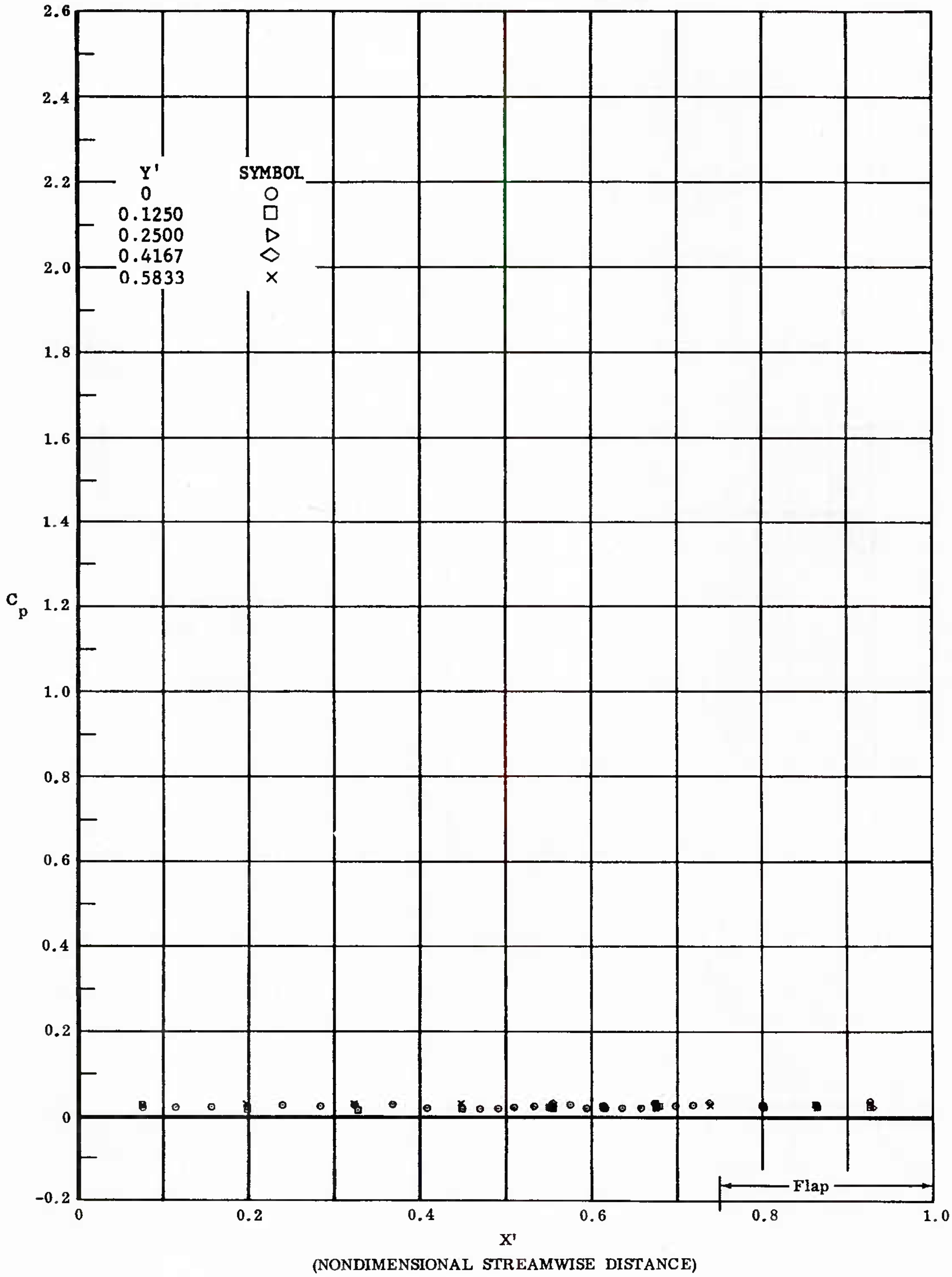


Fig. 94 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -5°$, $Re_\infty/ft = 1,100,000$.

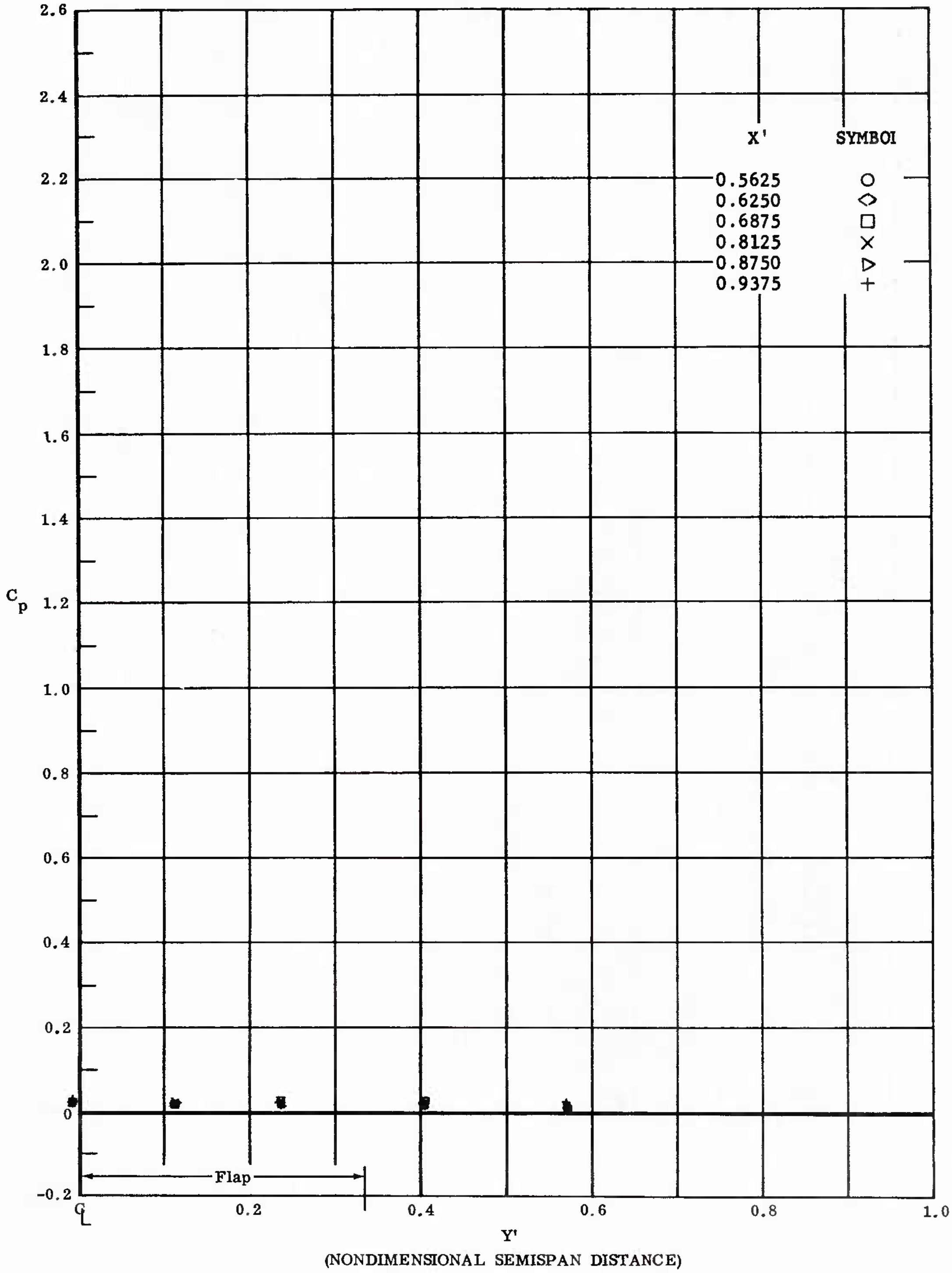


Fig. 94 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -5°$, $Re_\infty/ft = 1{,}100{,}000$.

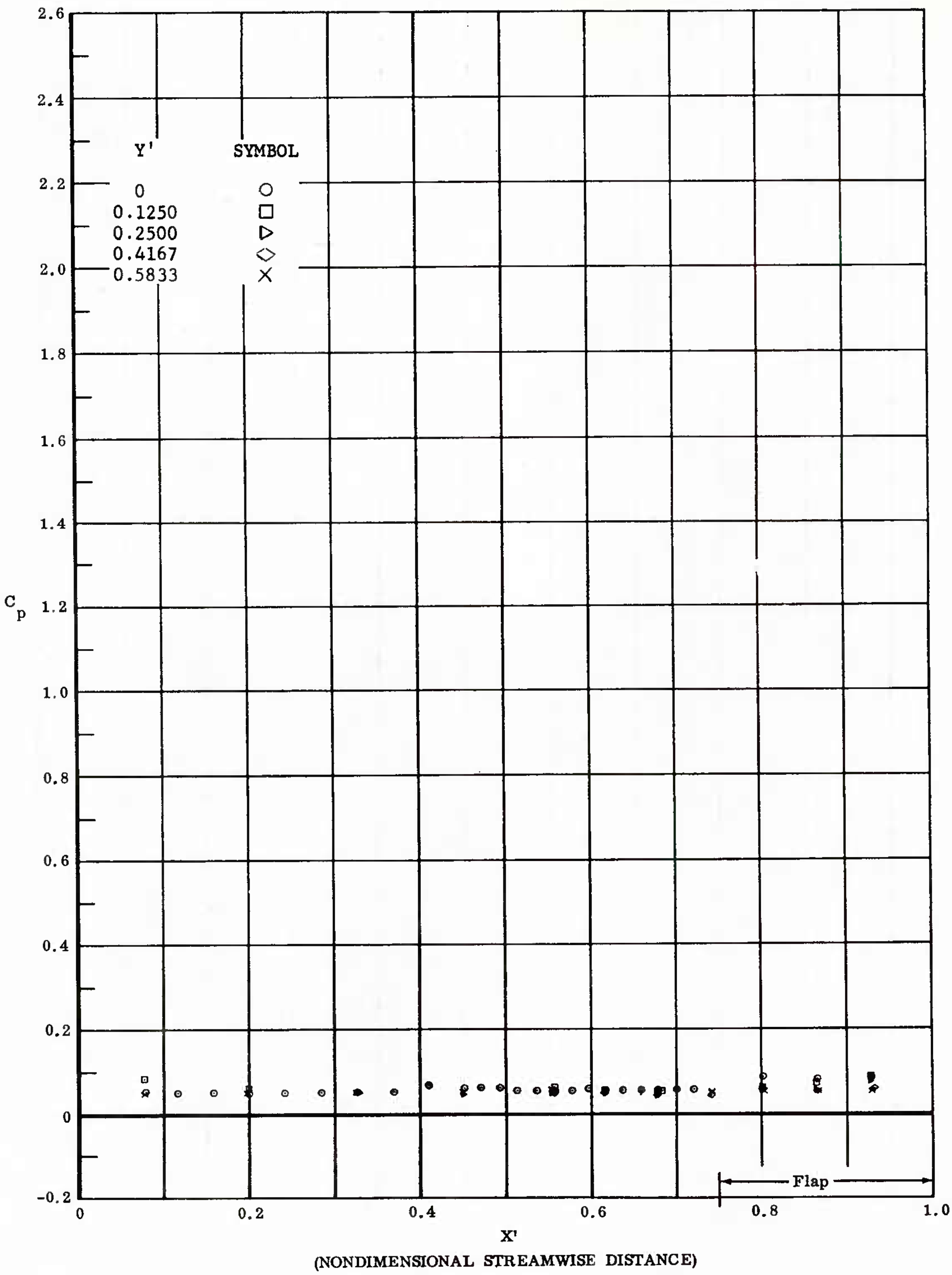


Fig. 95 Streamwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, $\alpha = -5°$, $Re_\infty/ft = 1,100,000$.

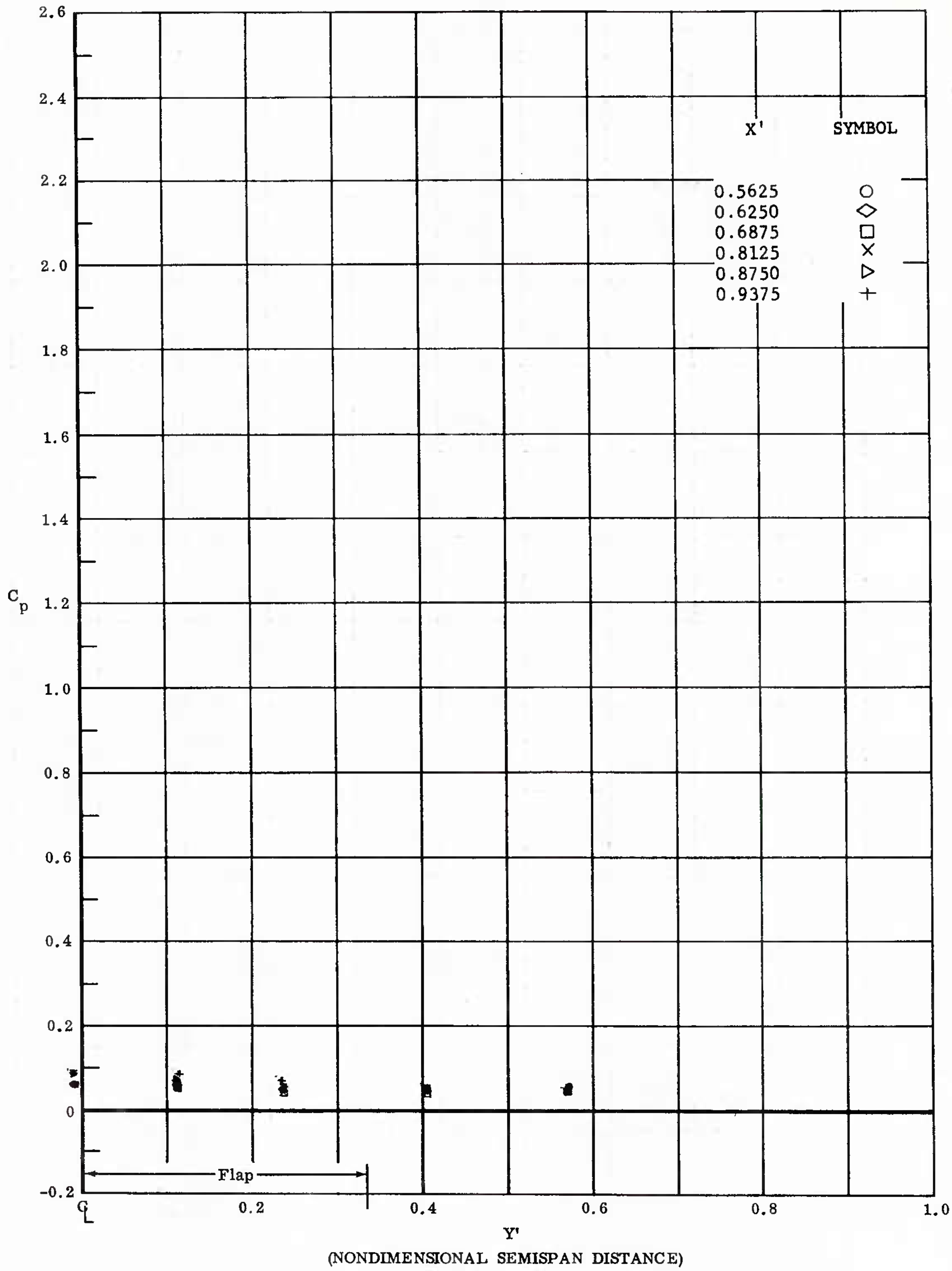


Fig. 95 Spanwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, $\alpha = -5°$, $Re_\infty/ft = 1,100,000$.

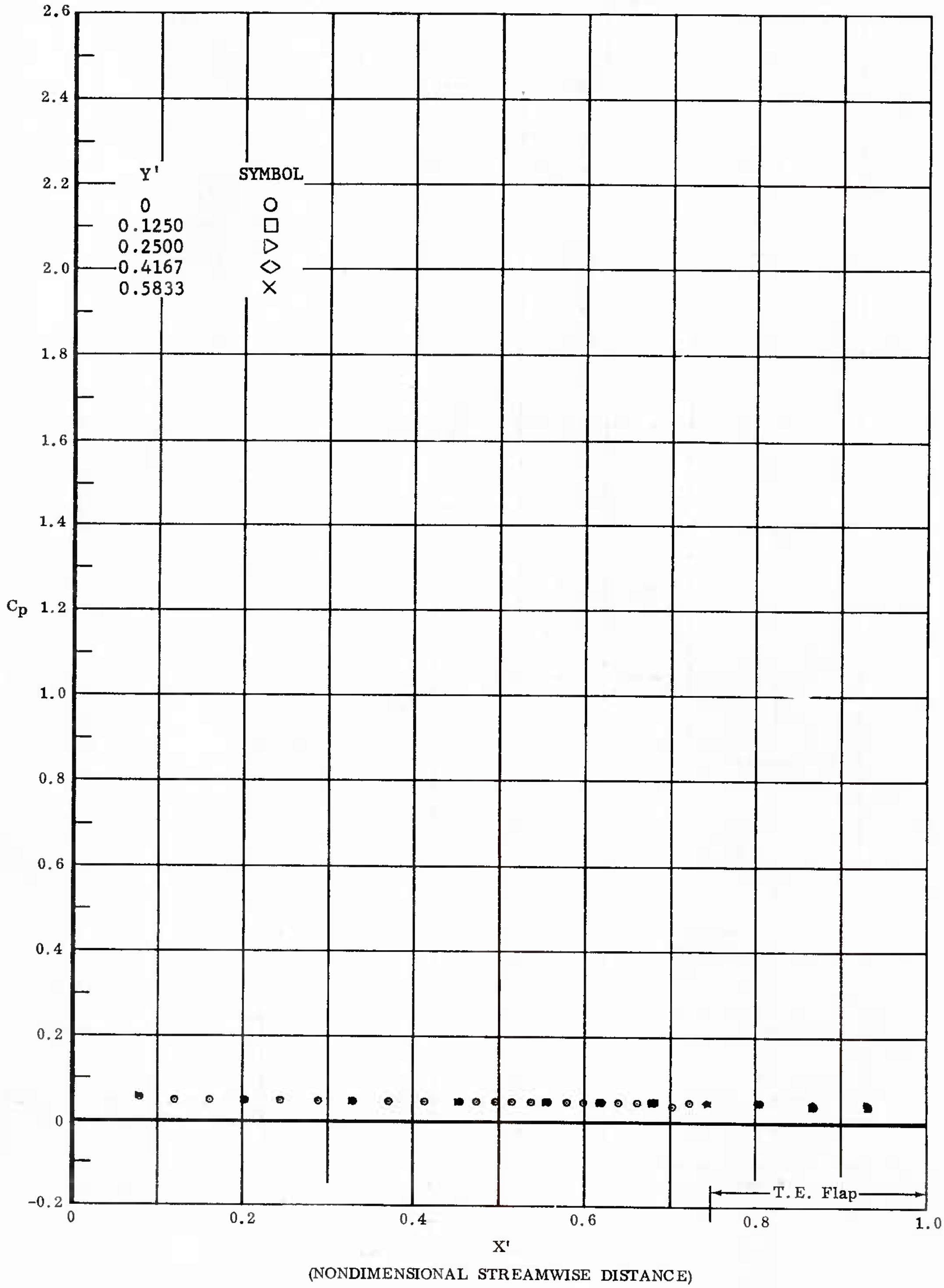


Fig. 96 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -5°$, $Re_\infty/ft = 3,300,000$.

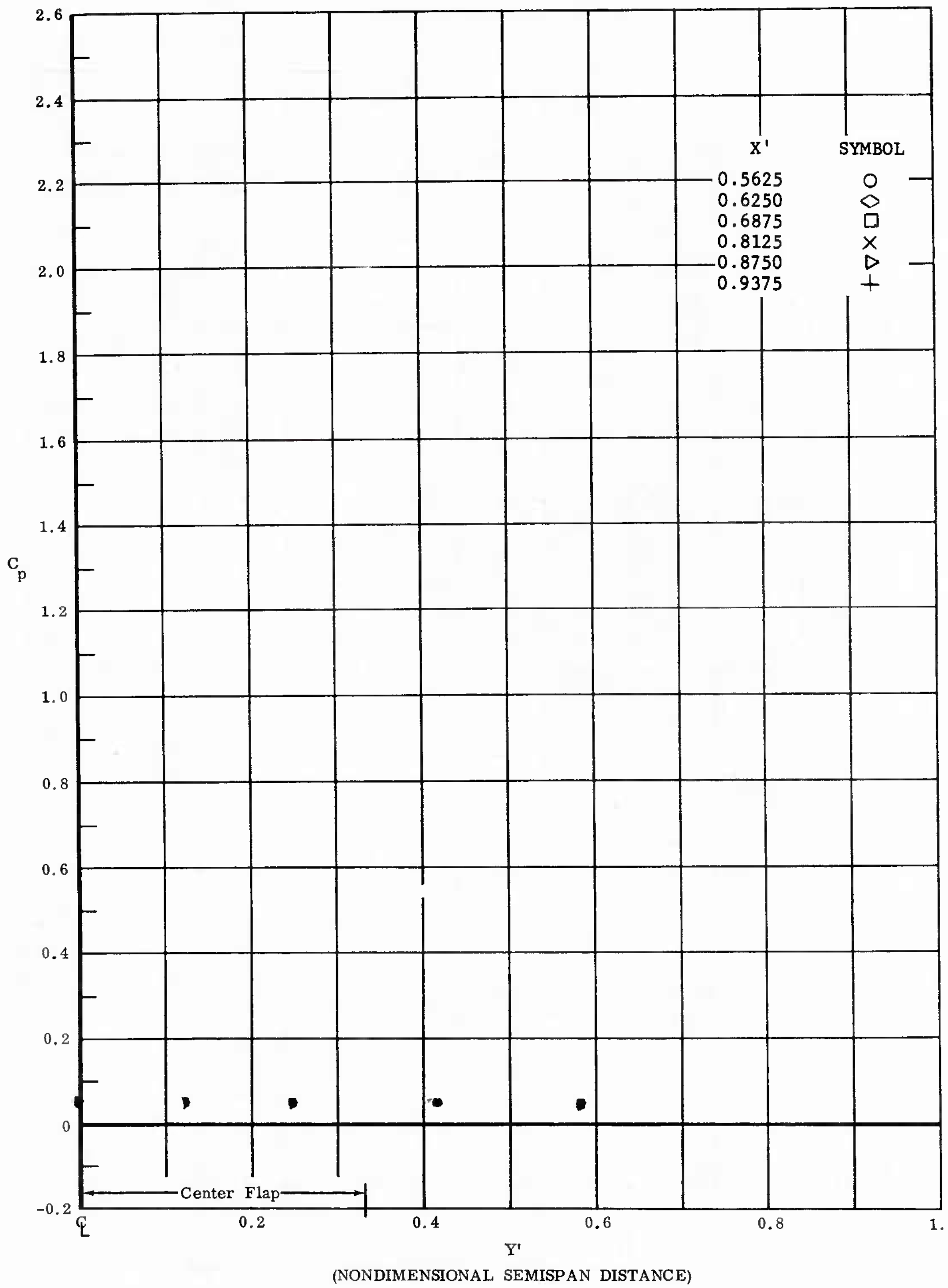


Fig. 96 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = -5°$, $Re_\infty/ft = 3{,}300{,}000$.

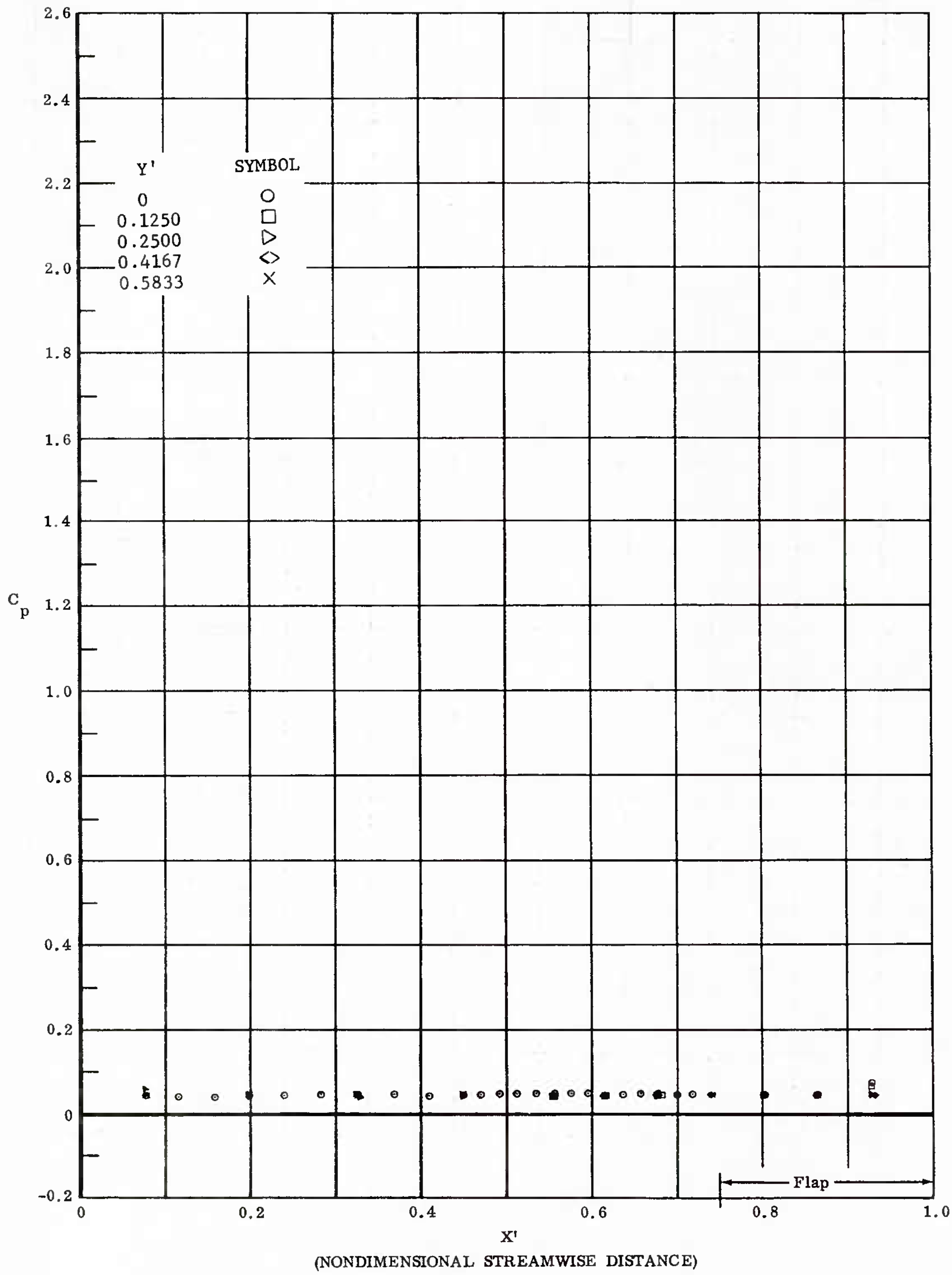


Fig. 97 Streamwise Pressure Distributions; Ramp Off, Medium Coolant Flow Rate, $\alpha = -5°$, $Re_{\infty}/ft = 3,300,000$.

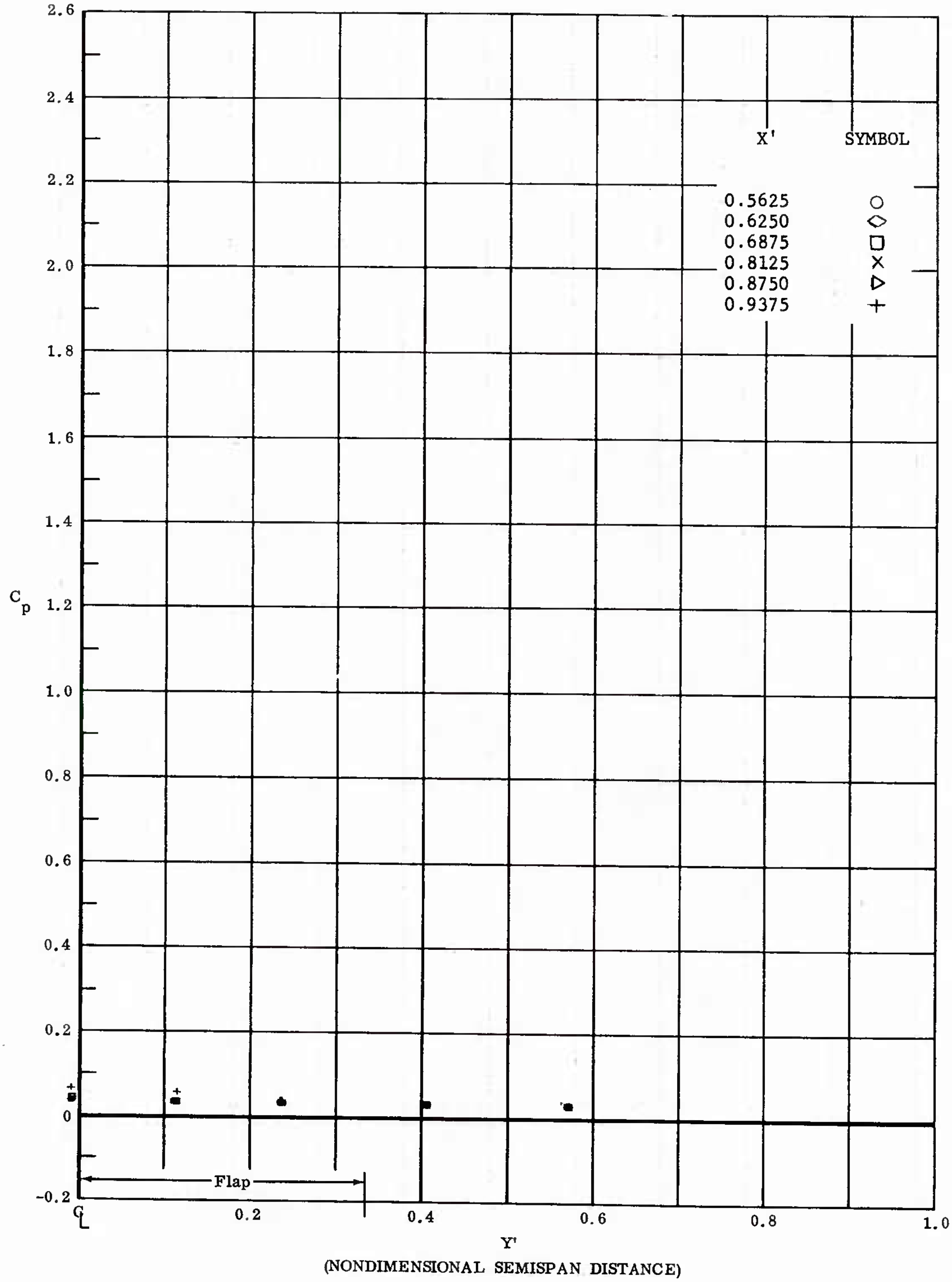


Fig. 97 Spanwise Pressure Distributions; Ramp Off, Medium Coolant Flow Rate, α = -5°, Re_∞/ft = 3,300,000.

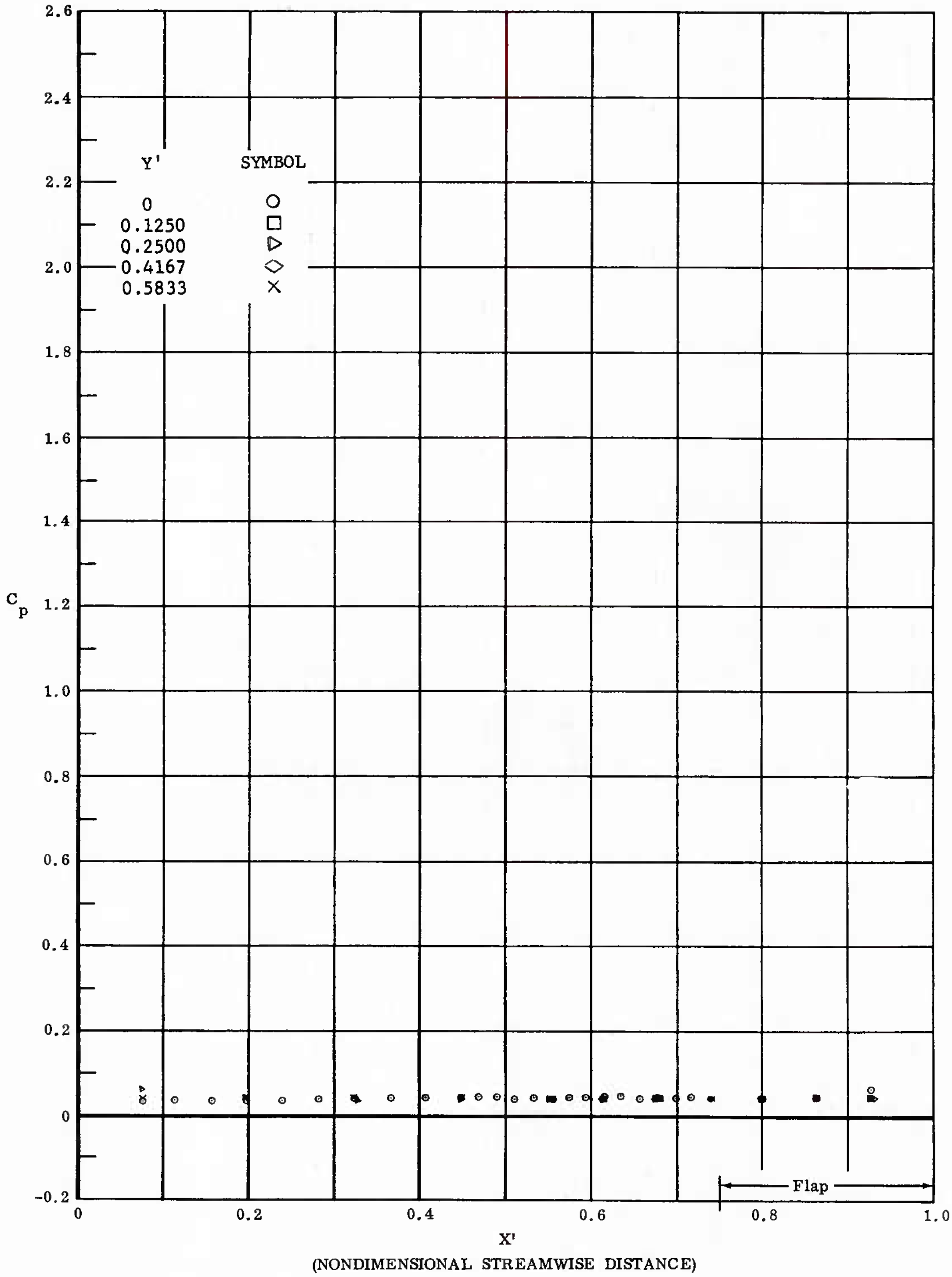


Fig. 98 Streamwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, $\alpha = -5°$, $Re_\infty/ft = 3,300,000$.

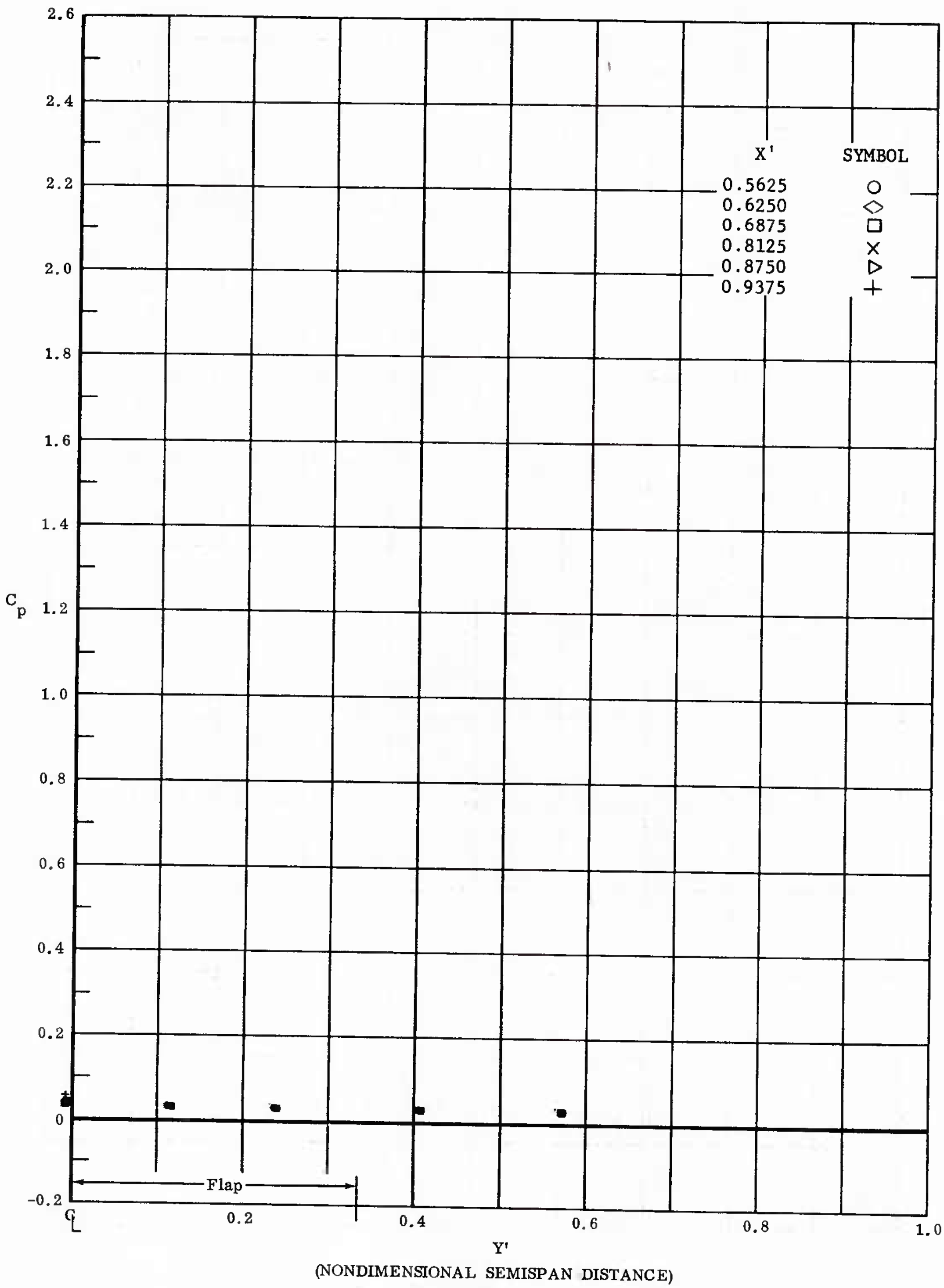


Fig. 98 Spanwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, $\alpha = -5°$, $Re_\infty/ft = 3,300,000$.

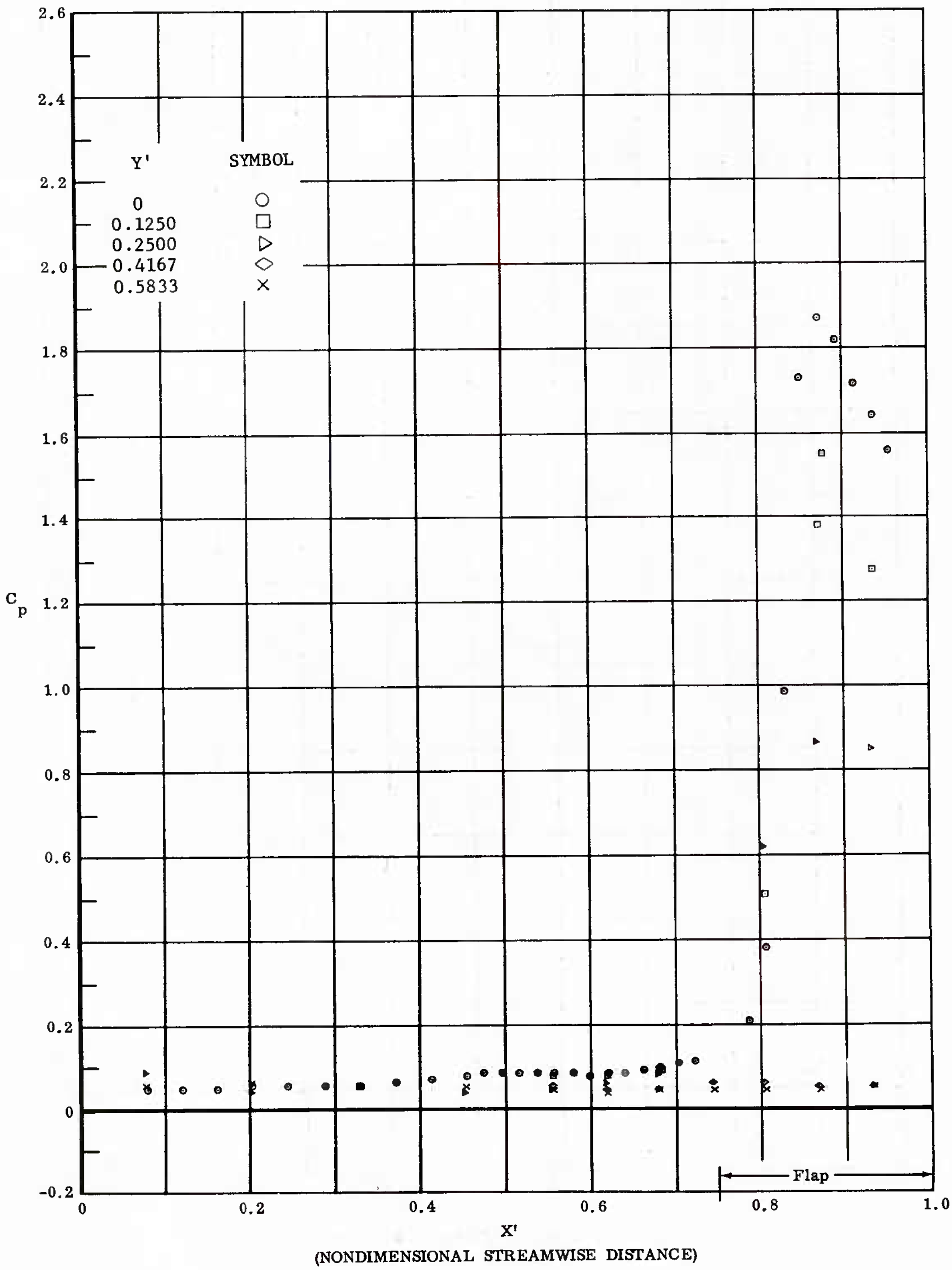


Fig. 99 Streamwise Pressure Distributions; Ramp On, Maximum Coolant Flow Rate, $\alpha = -5°$, $Re_\infty/ft = 1,100,000$.

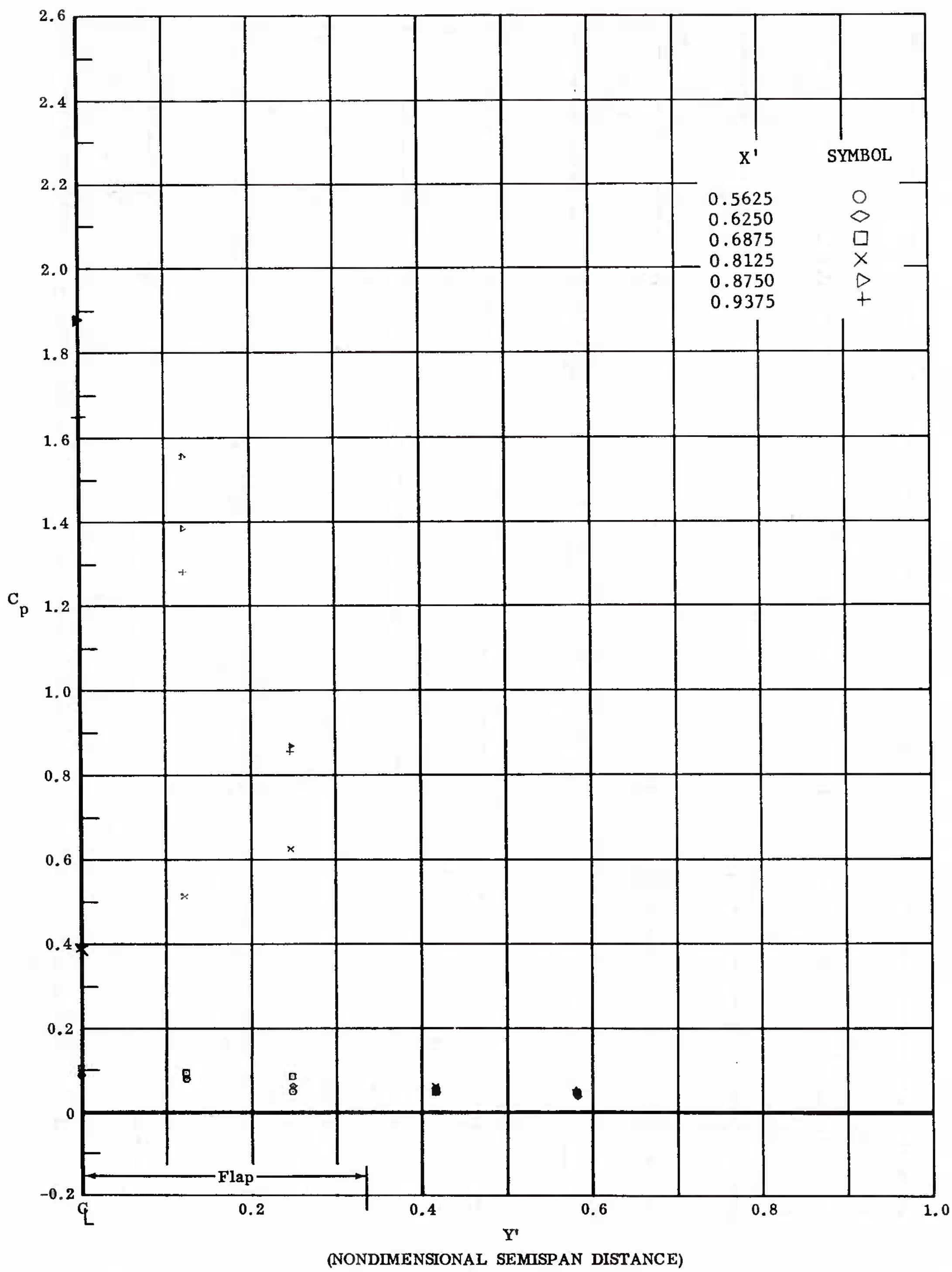


Fig. 99 Spanwise Pressure Distributions; Ramp On, Maximum Coolant Flow Rate, $\alpha = -5°$, $Re_\infty/ft = 1,100,000$.

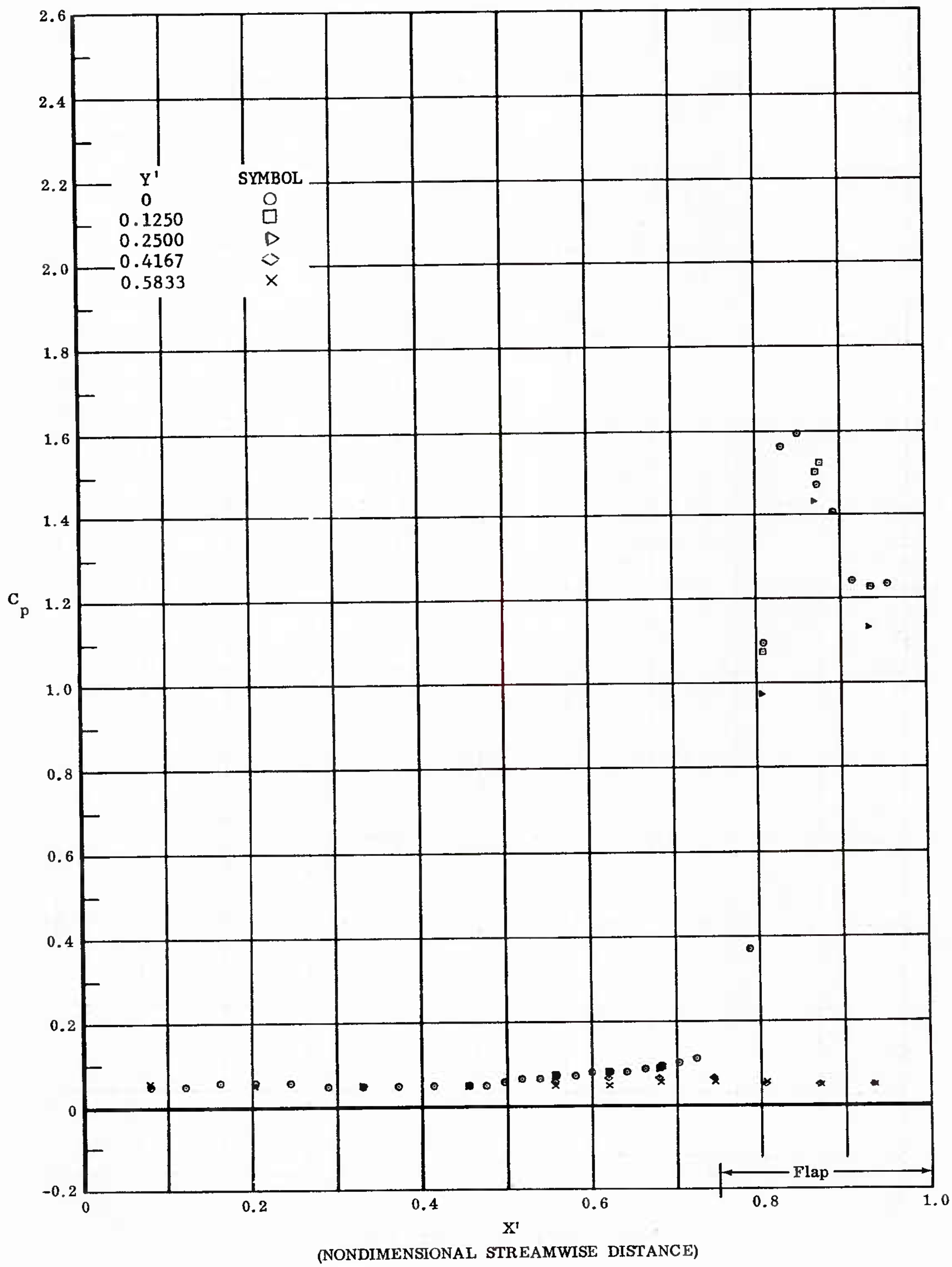


Fig. 100 Streamwise Pressure Distributions; Ramp On, No Coolant Flow, $\alpha = -5°$, $Re_\infty/ft = 3,300,000$.

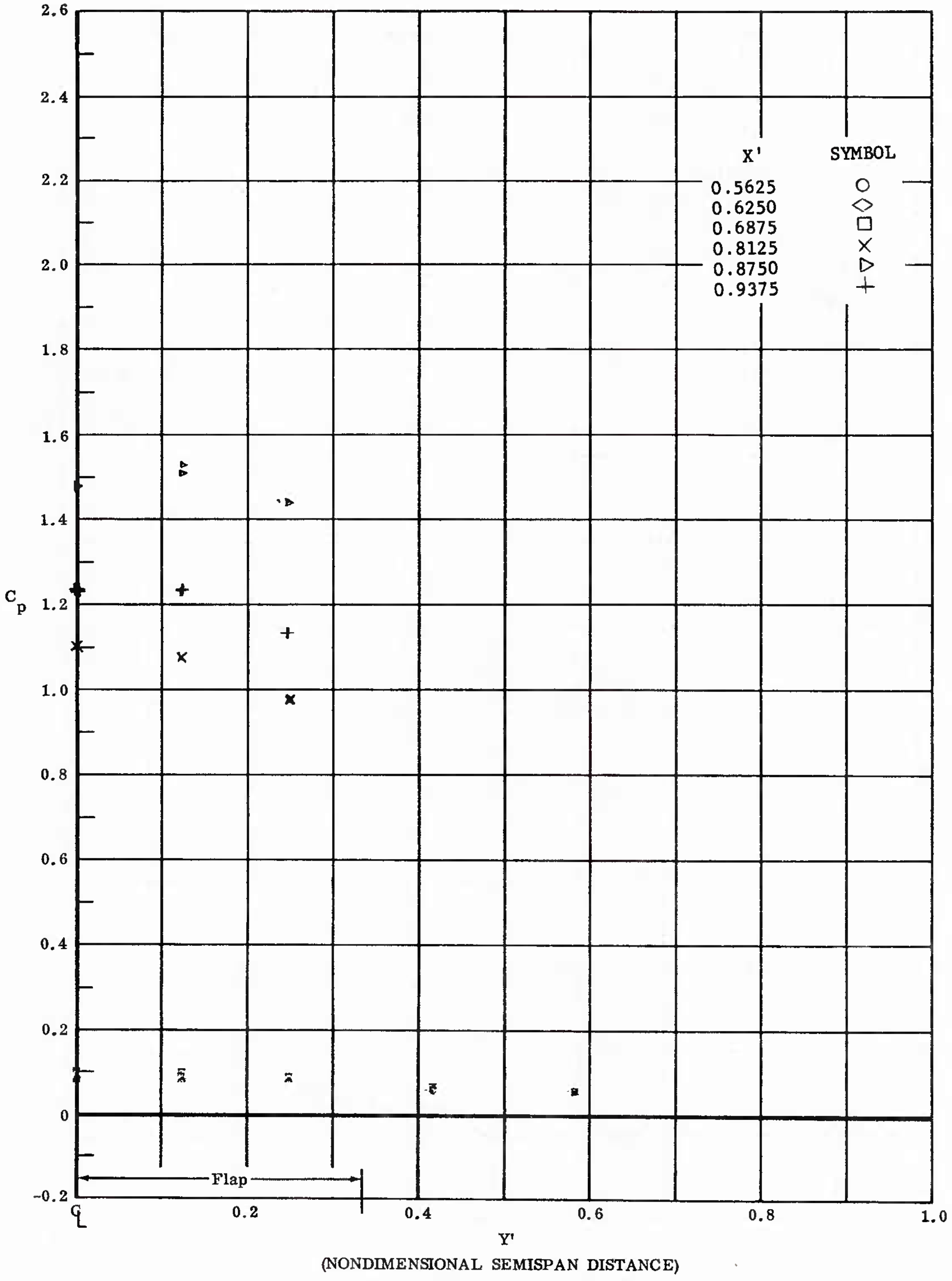


Fig. 100 Spanwise Pressure Distributions; Ramp On, No Coolant Flow, α = -5°, Re_∞/ft = 3,300,000.

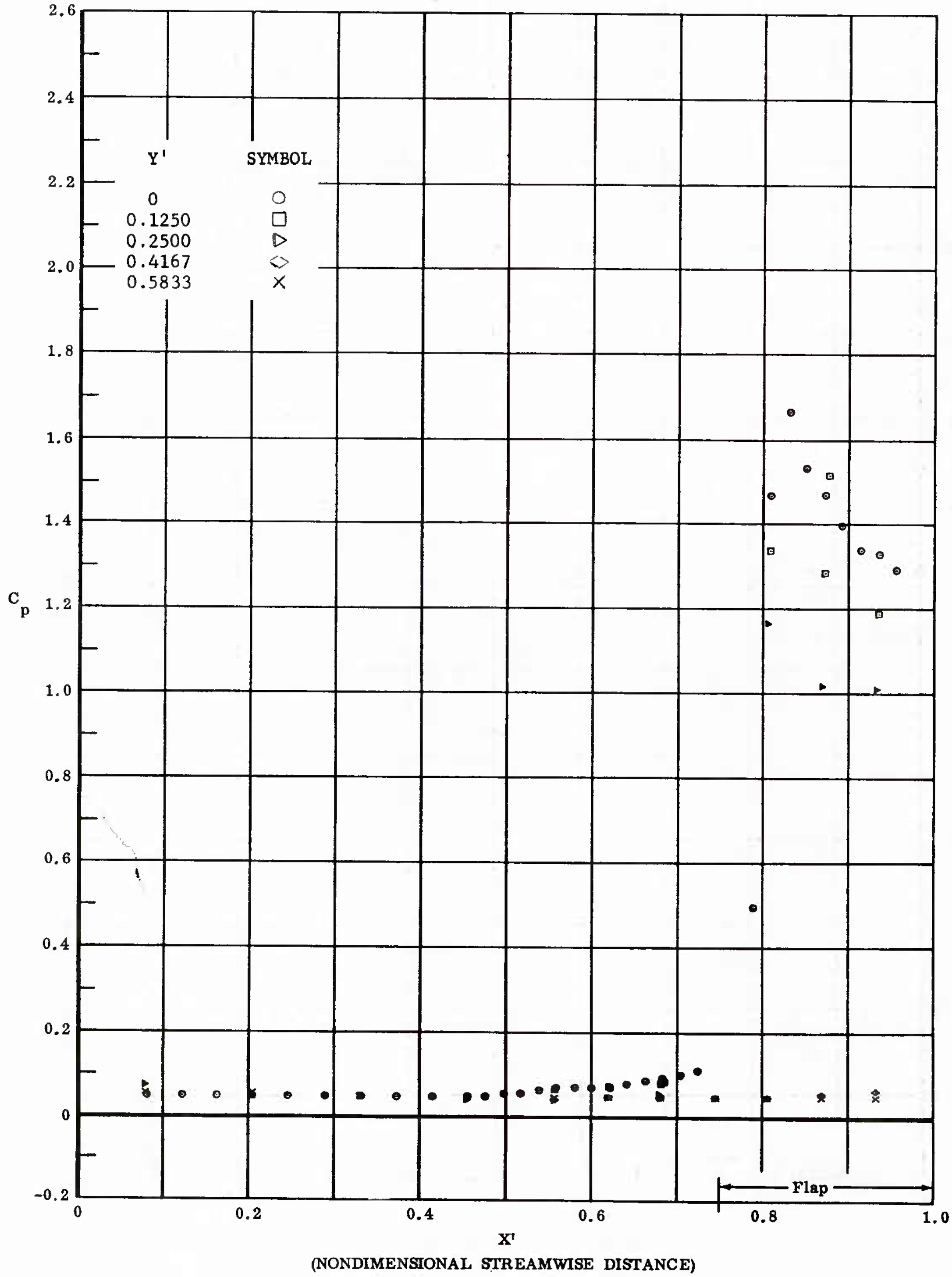


Fig. 101 Streamwise Pressure Distributions; Ramp On, Maximum Coolant Flow Rate, $\alpha = -5°$, $Re_\infty/ft = 3,300,000$.

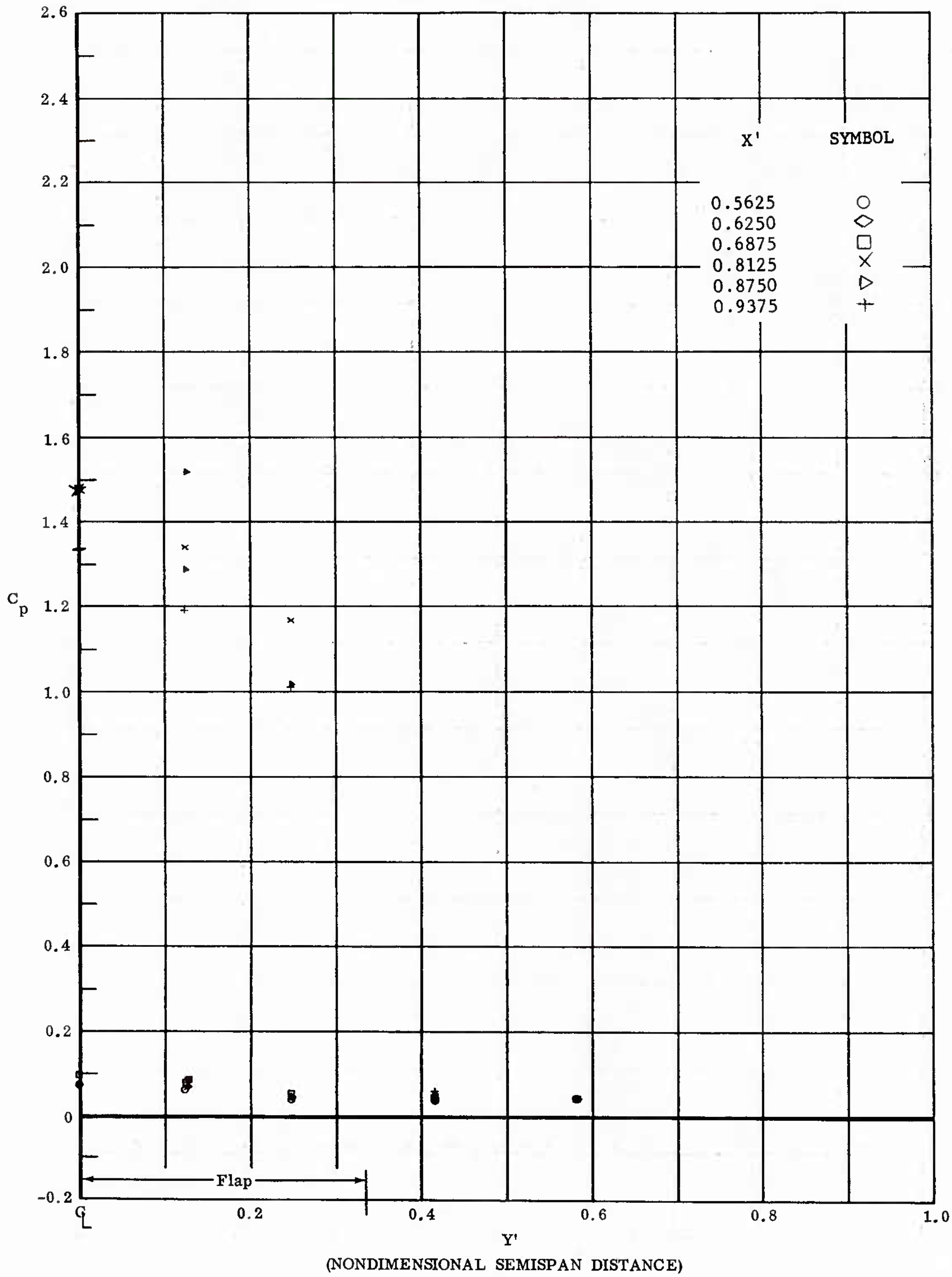


Fig. 101 Spanwise Pressure Distributions; Ramp On, Maximum Coolant Flow Rate, $\alpha = -5°$, $Re_\infty/ft = 3{,}300{,}000$.

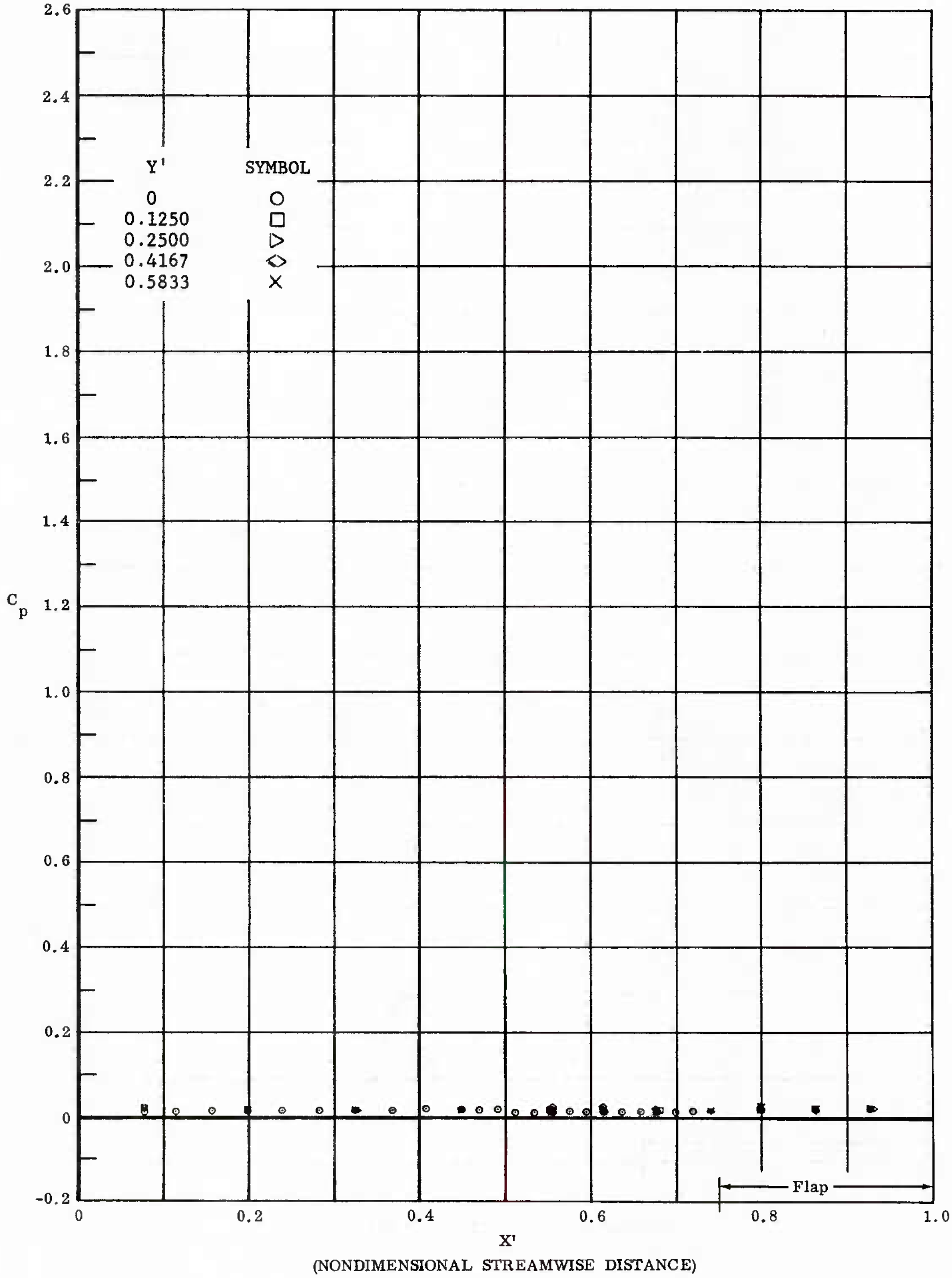


Fig. 102 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = 0°$, $Re_\infty/ft = 1,100,000$.

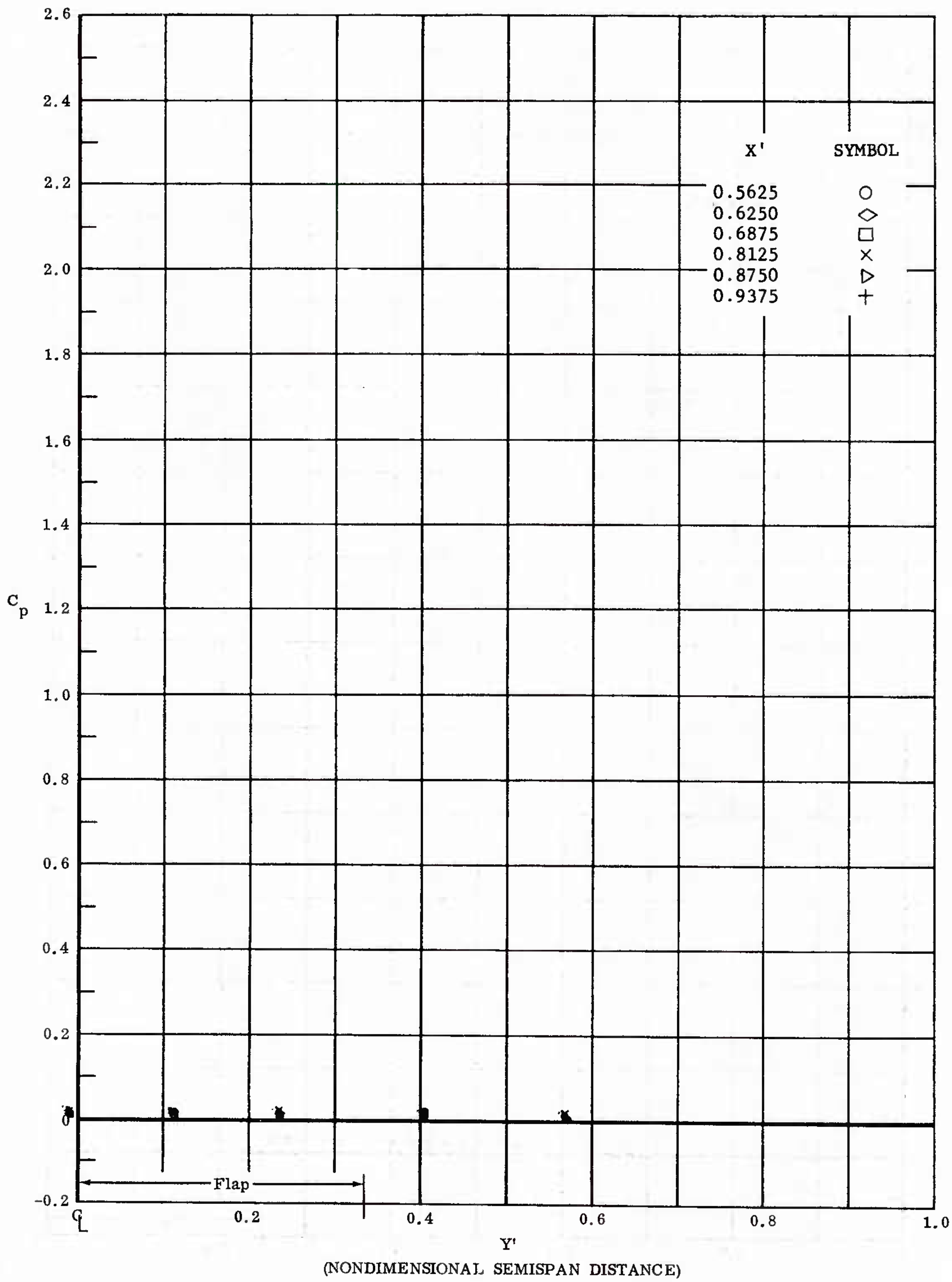


Fig. 102 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = 0°$, $Re_\infty/ft = 1,100,000$.

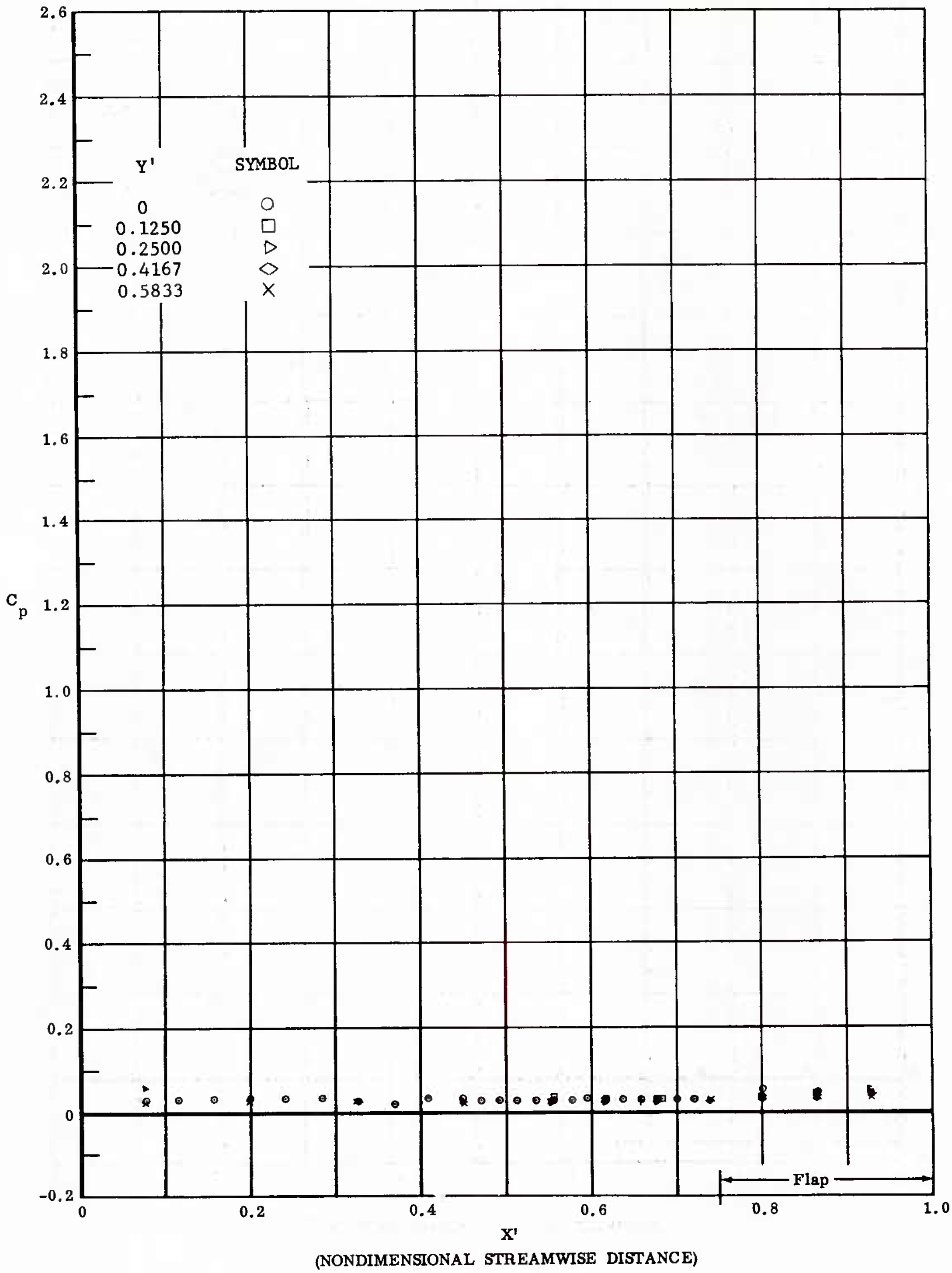


Fig. 103 Streamwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, $\alpha = 0°$, $Re_\infty/ft = 1,100,000$.

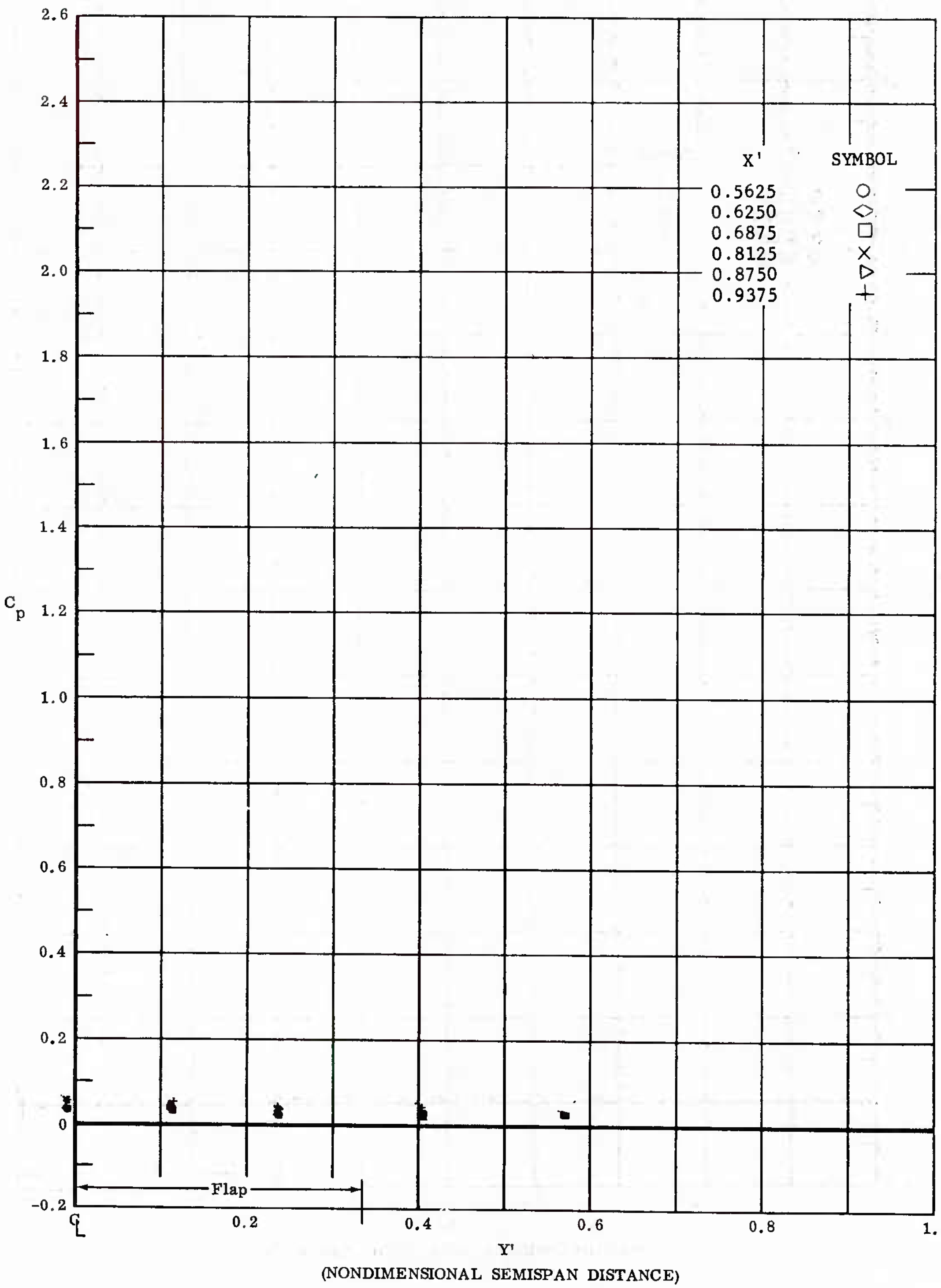


Fig. 103 Spanwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, $\alpha = 0°$, $Re_\infty/ft = 1,100,000$.

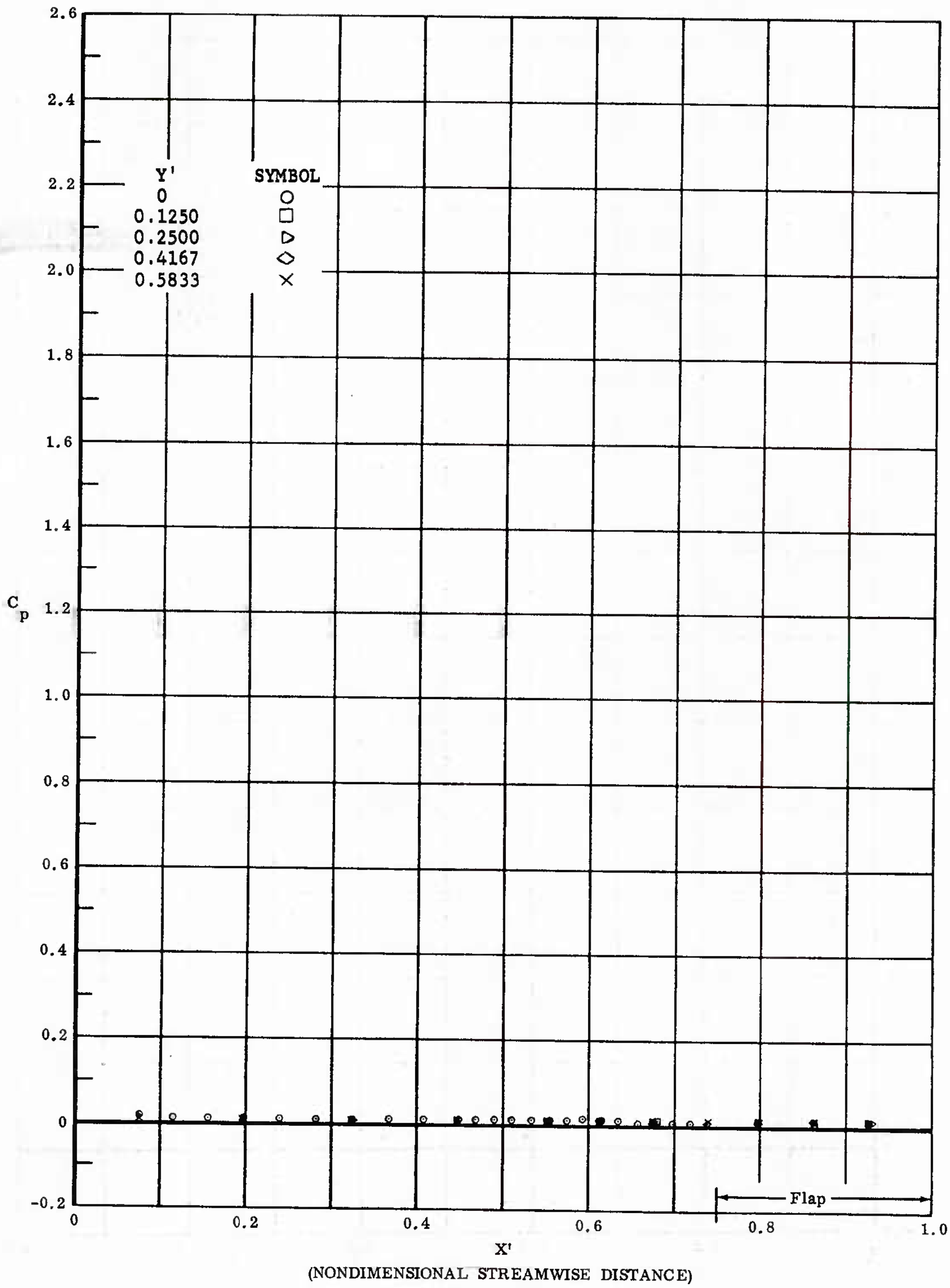


Fig. 104 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = 0°$, $Re_\infty/ft = 2{,}200{,}000$.

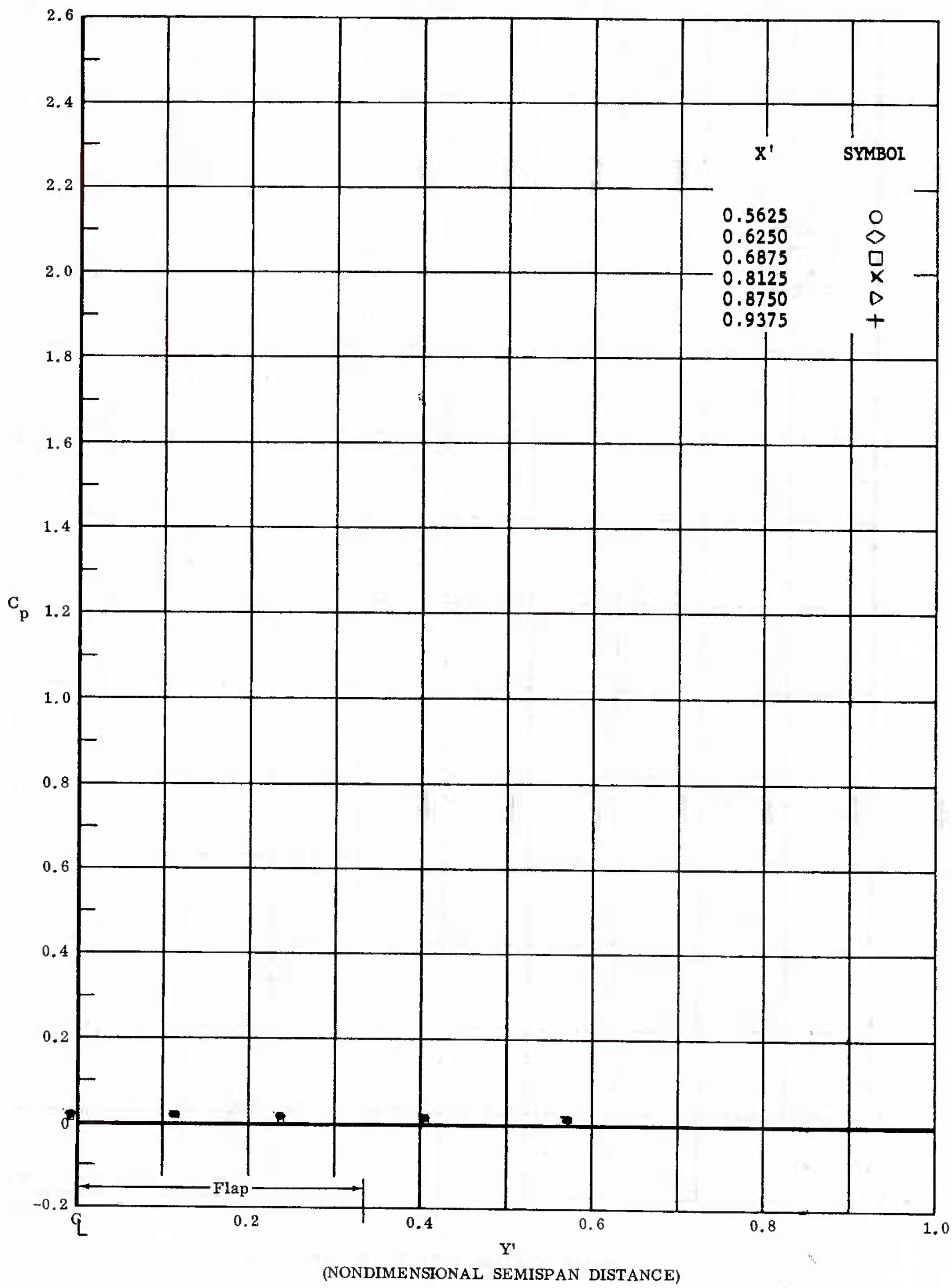


Fig. 104 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = 0°$, $Re_\infty/ft = 2{,}200{,}000$.

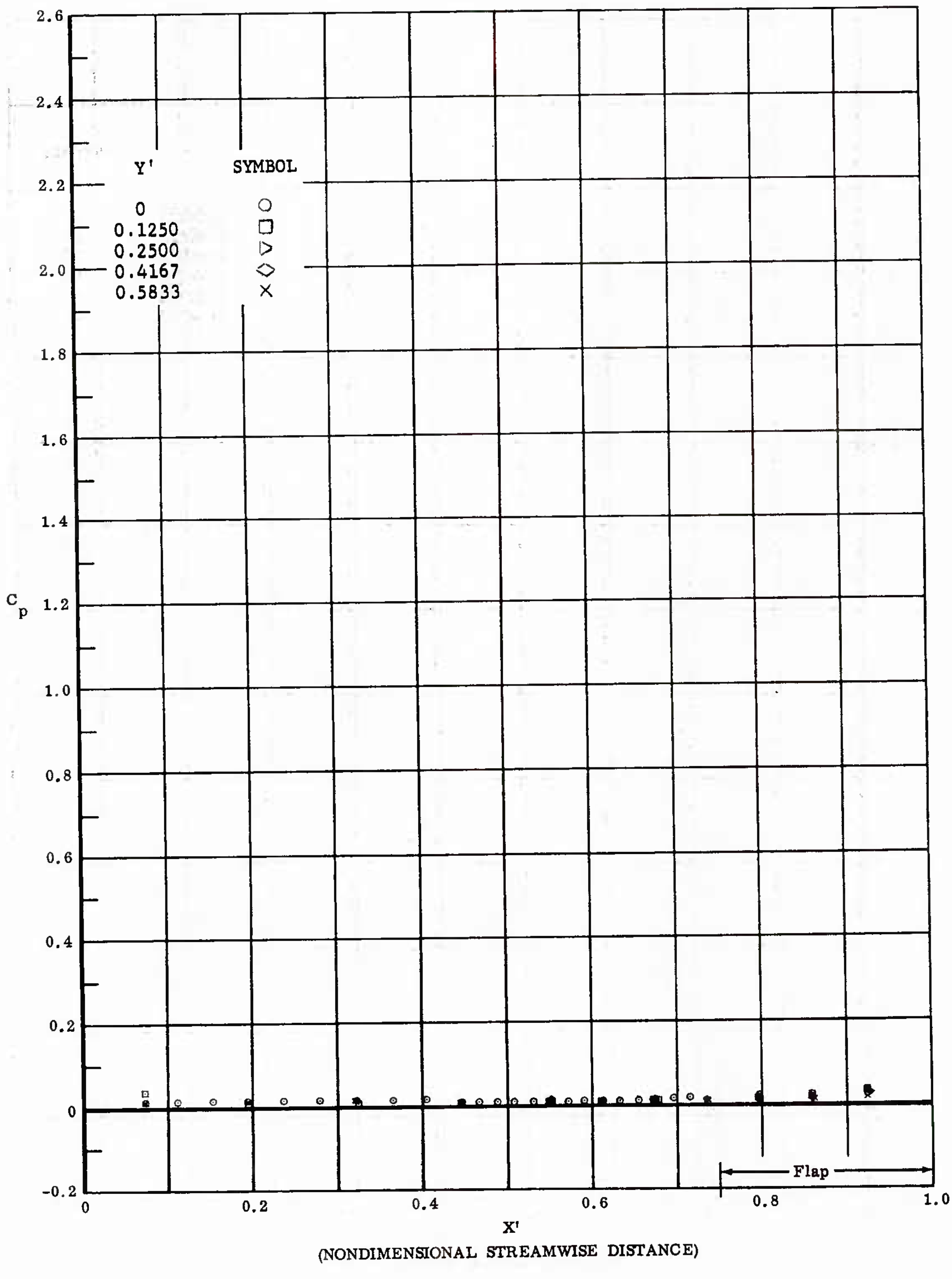


Fig. 105 Streamwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, $\alpha = 0°$, $Re_\infty/ft = 2{,}200{,}000$.

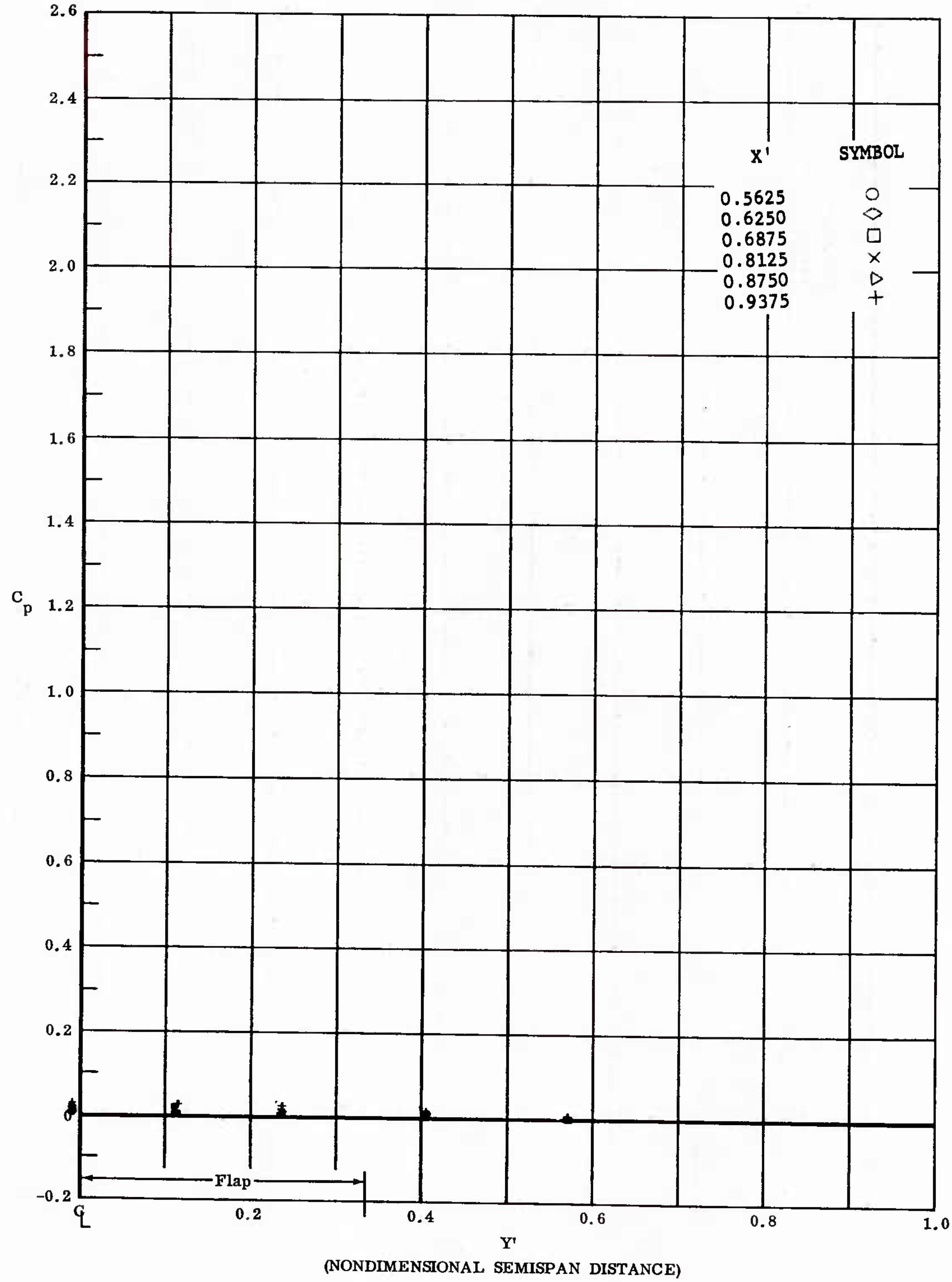


Fig. 105 Spanwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, $\alpha = 0°$, $Re_{\infty}/ft = 2,200,000$.

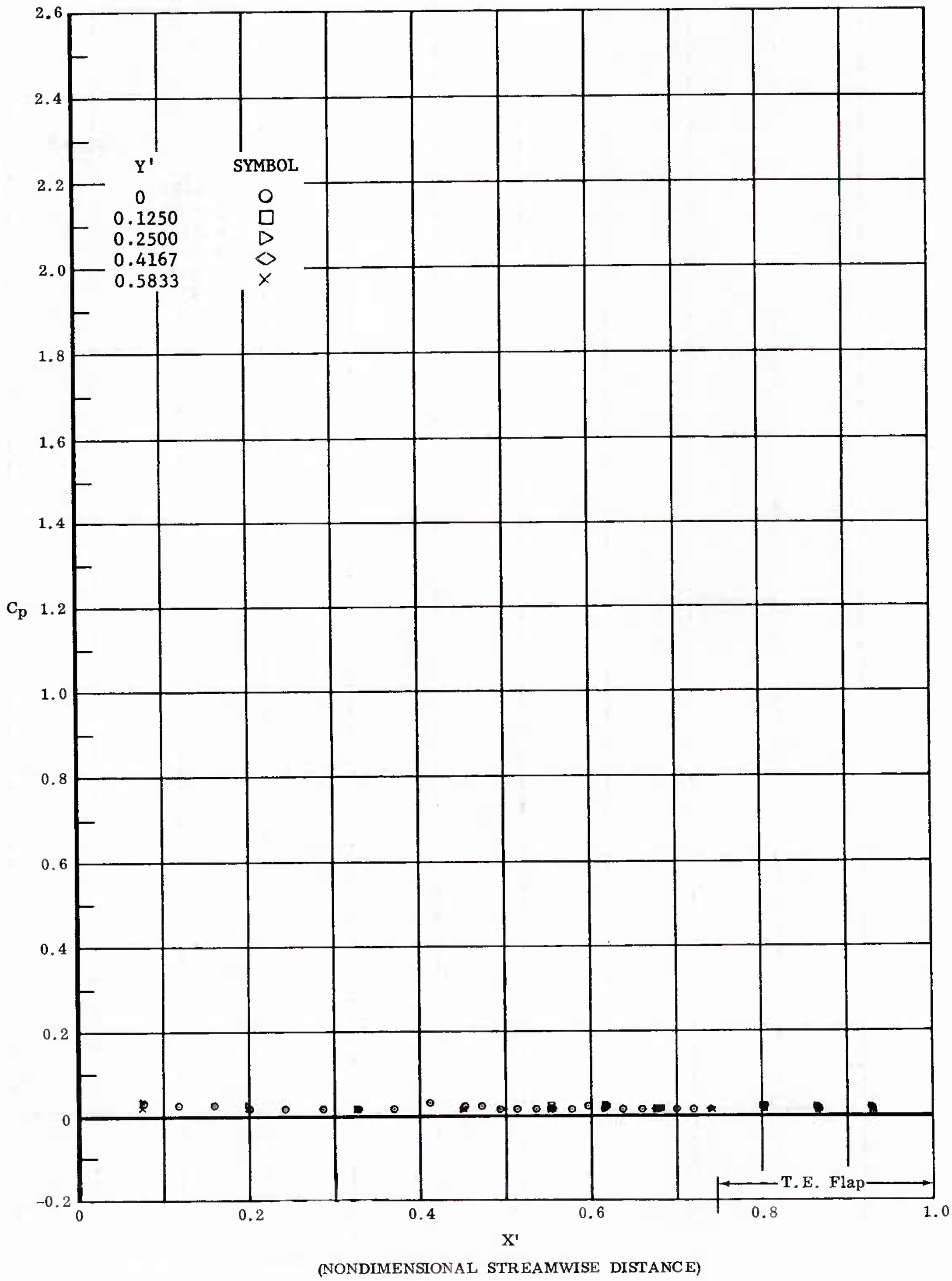


Fig. 106 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = 0°$, $Re_\infty/ft = 3,300,000$.

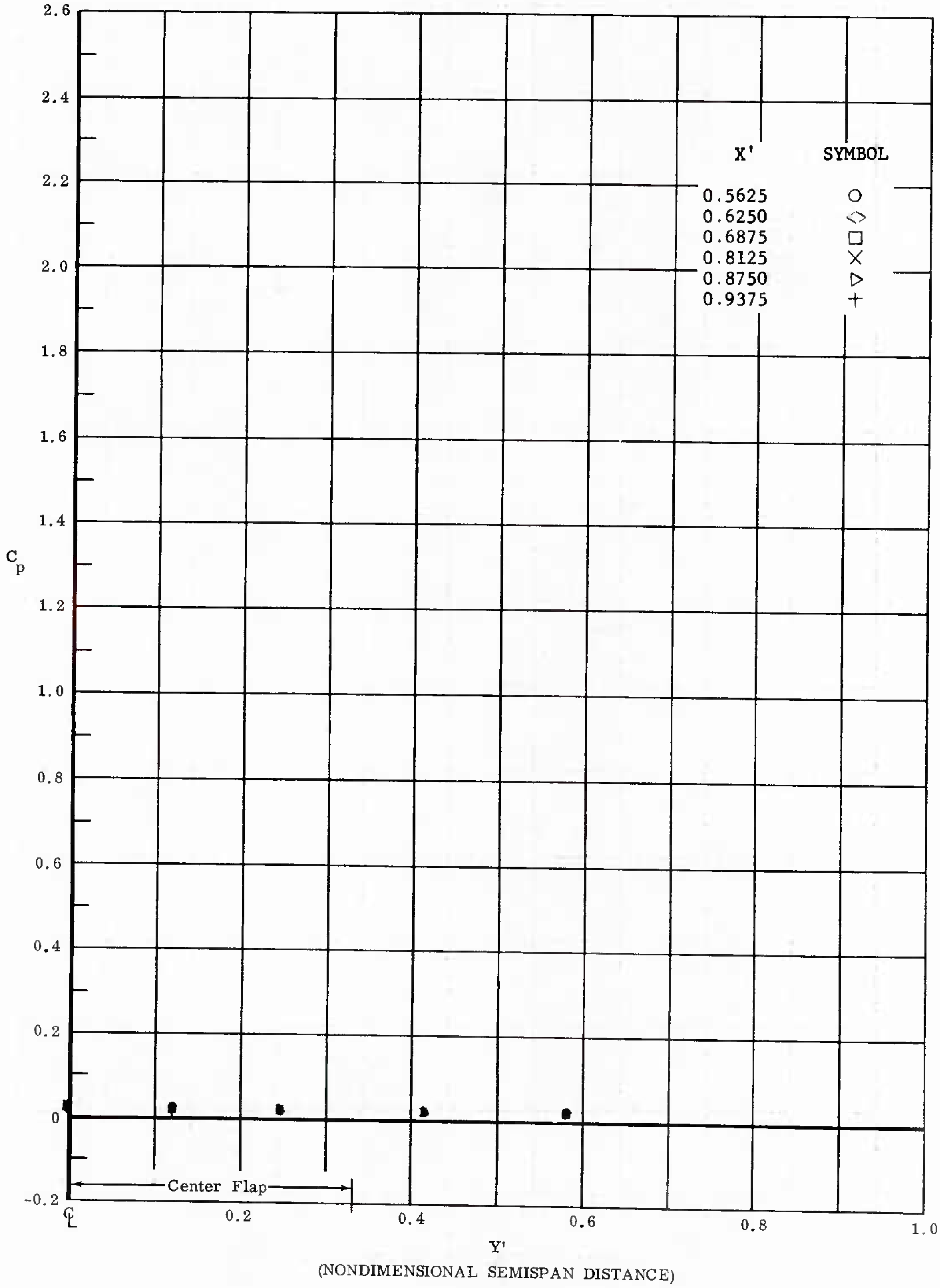


Fig. 106 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = 0°$, $Re_\infty/ft = 3,300,000$.

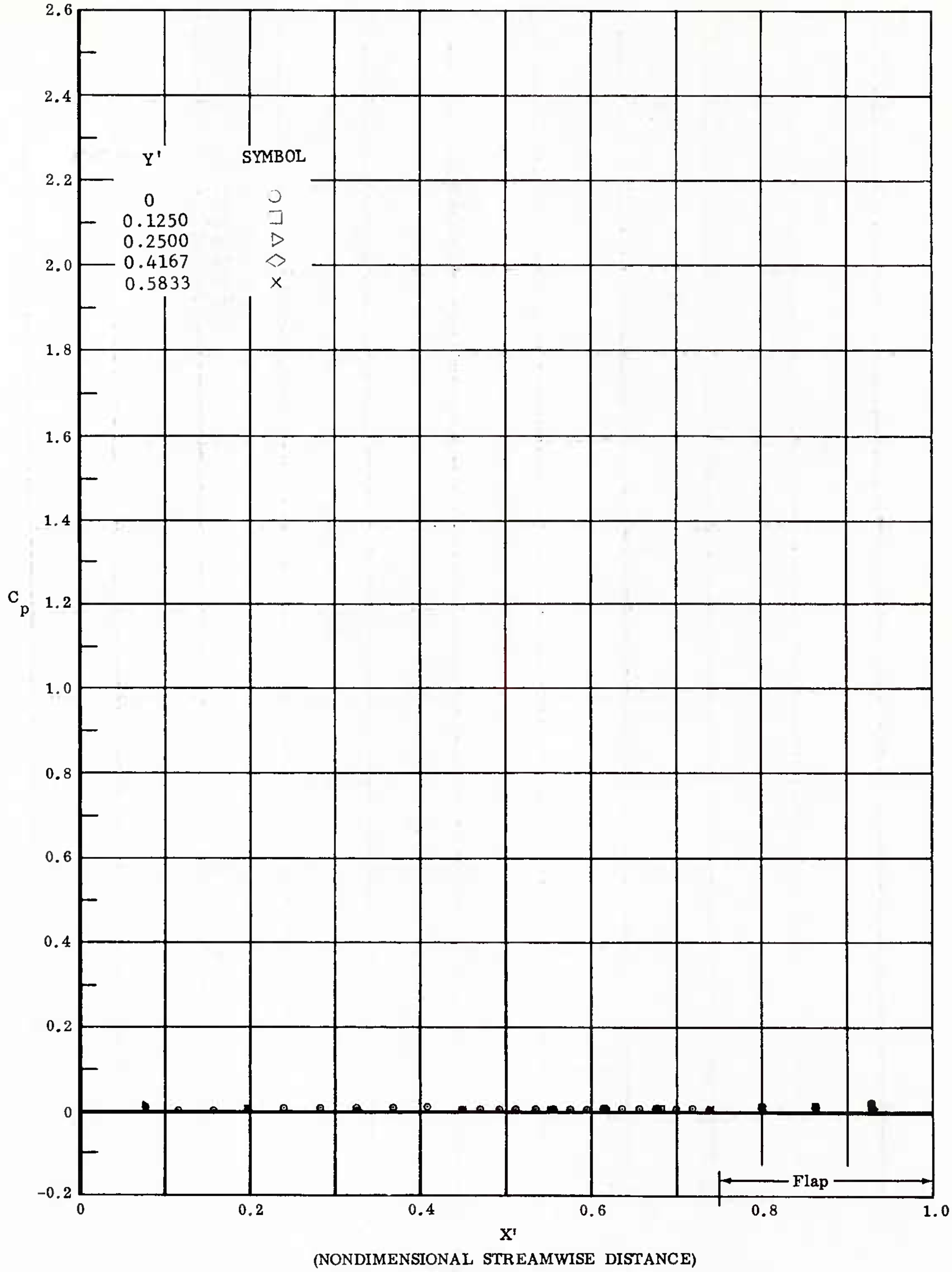


Fig. 107 Streamwise Pressure Distributions, Ramp Off, Medium Coolant Flow Rate, $\alpha = 0°$, $Re_\infty/ft = 3,300,000$.

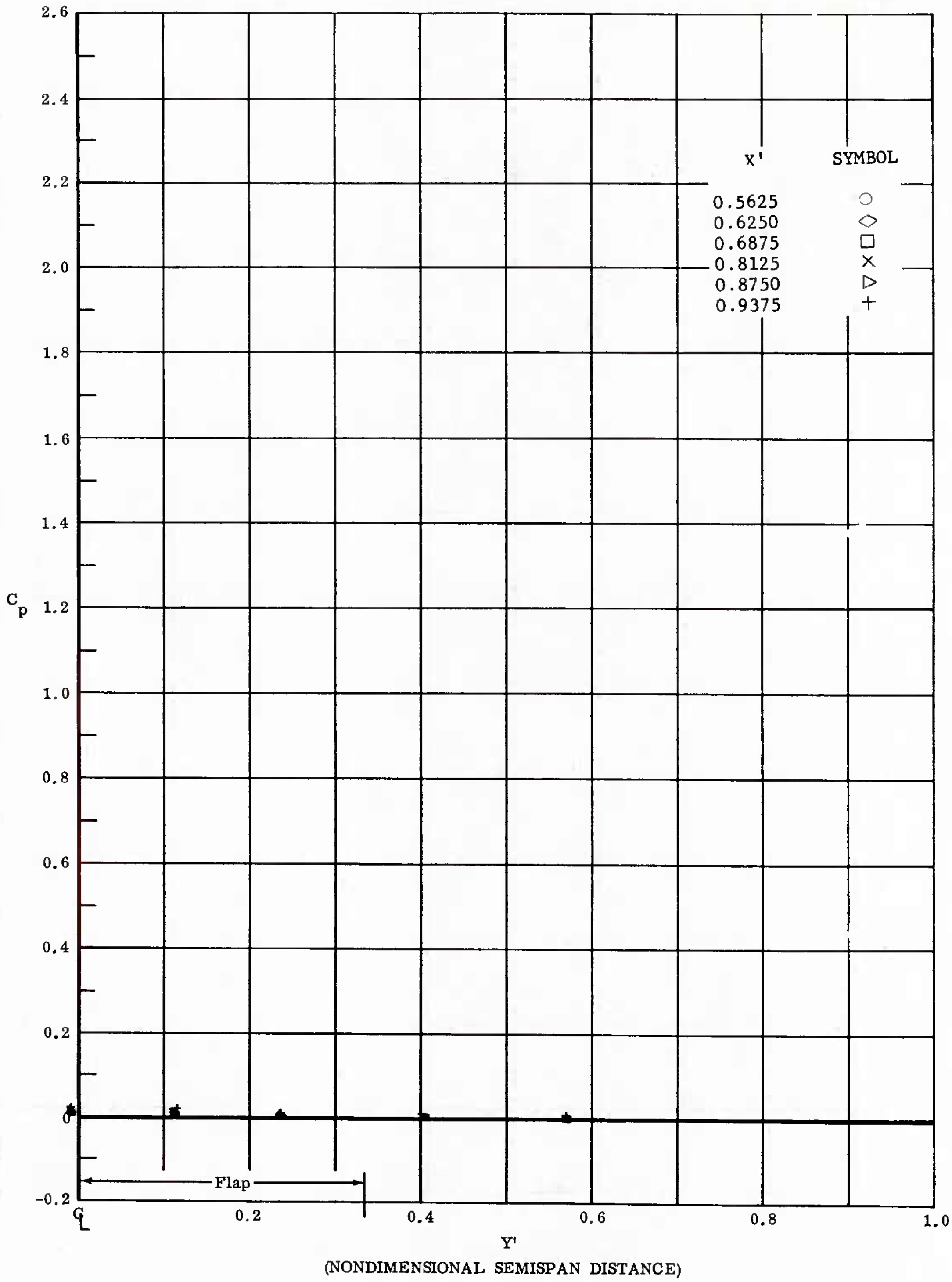


Fig. 107 Spanwise Pressure Distributions, Ramp Off, Medium Coolant Flow Rate, $\alpha = 0°$, $Re_\infty/ft = 3,300,000$.

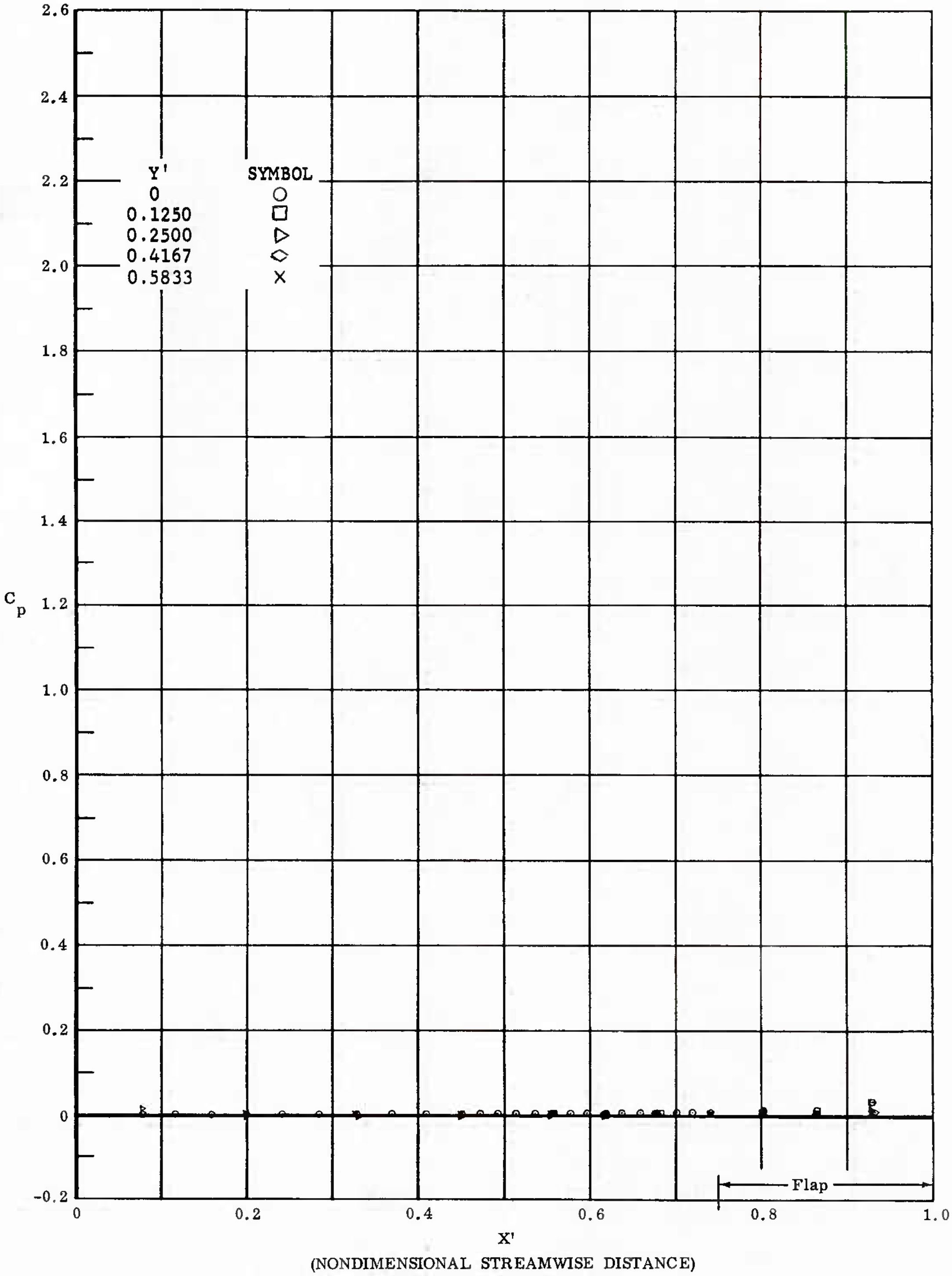


Fig. 108 Streamwise Pressure Distributions, Ramp Off, Maximum Coolant Flow Rate, $\alpha = 0°$, $Re_\infty/ft = 3,300,000$.

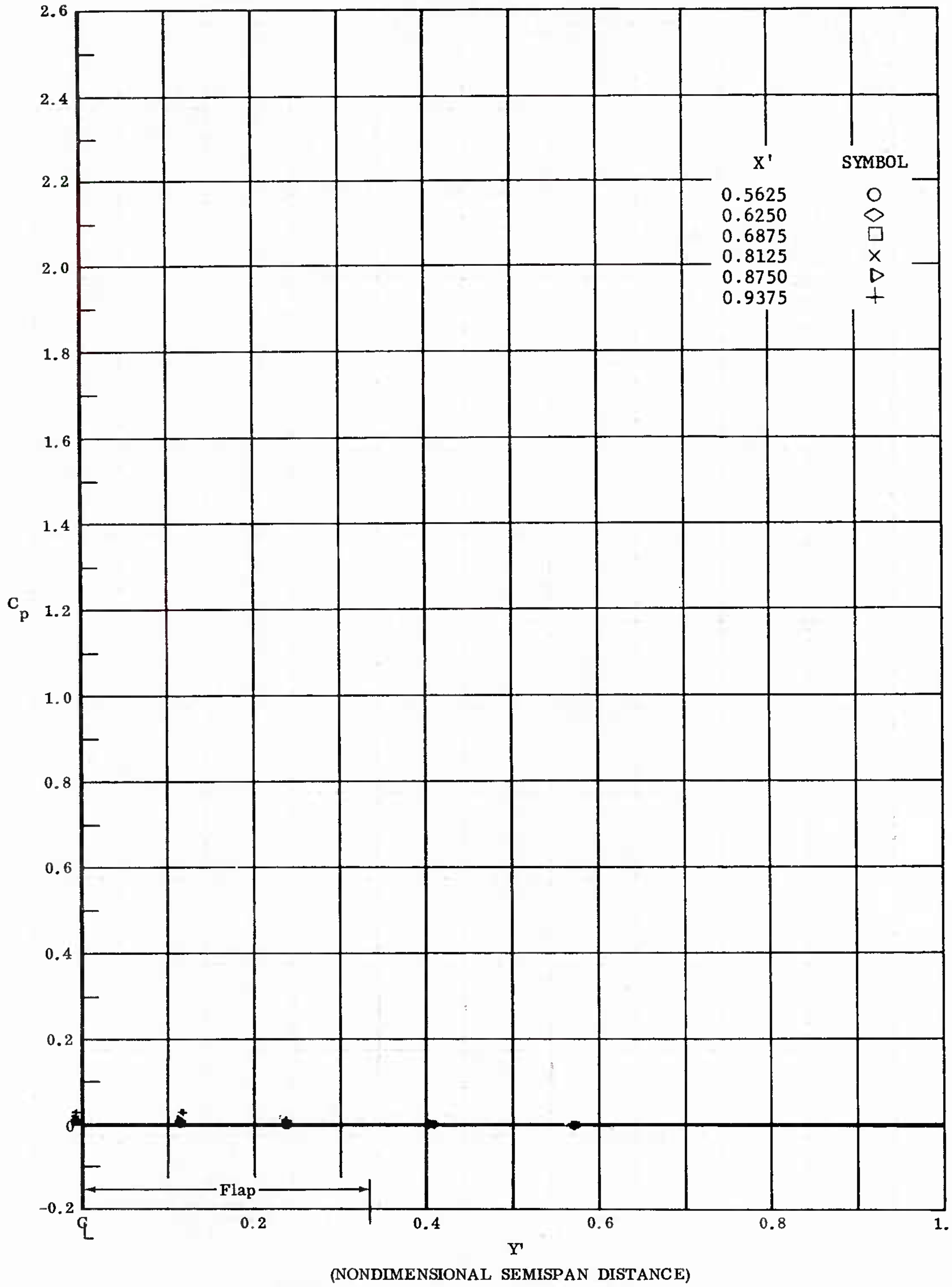


Fig. 108 Spanwise Pressure Distributions, Ramp Off, Maximum Coolant Flow Rate, $\alpha = 0°$, $Re_\infty/ft = 3,300,000$.

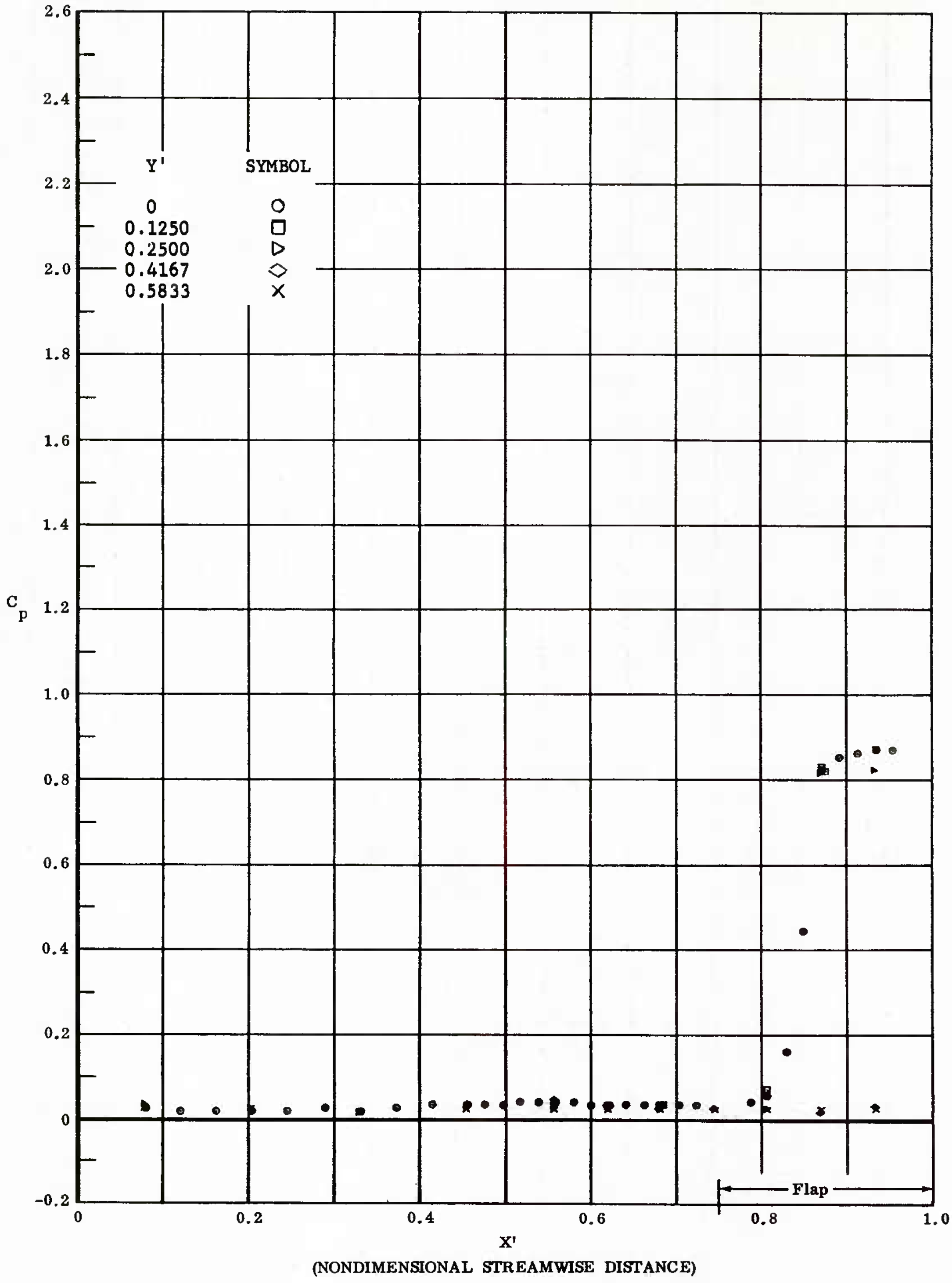


Fig. 109 Streamwise Pressure Distributions; Ramp On, No Coolant Flow, $\alpha = 0°$, $Re_\infty/ft = 1,100,000$.

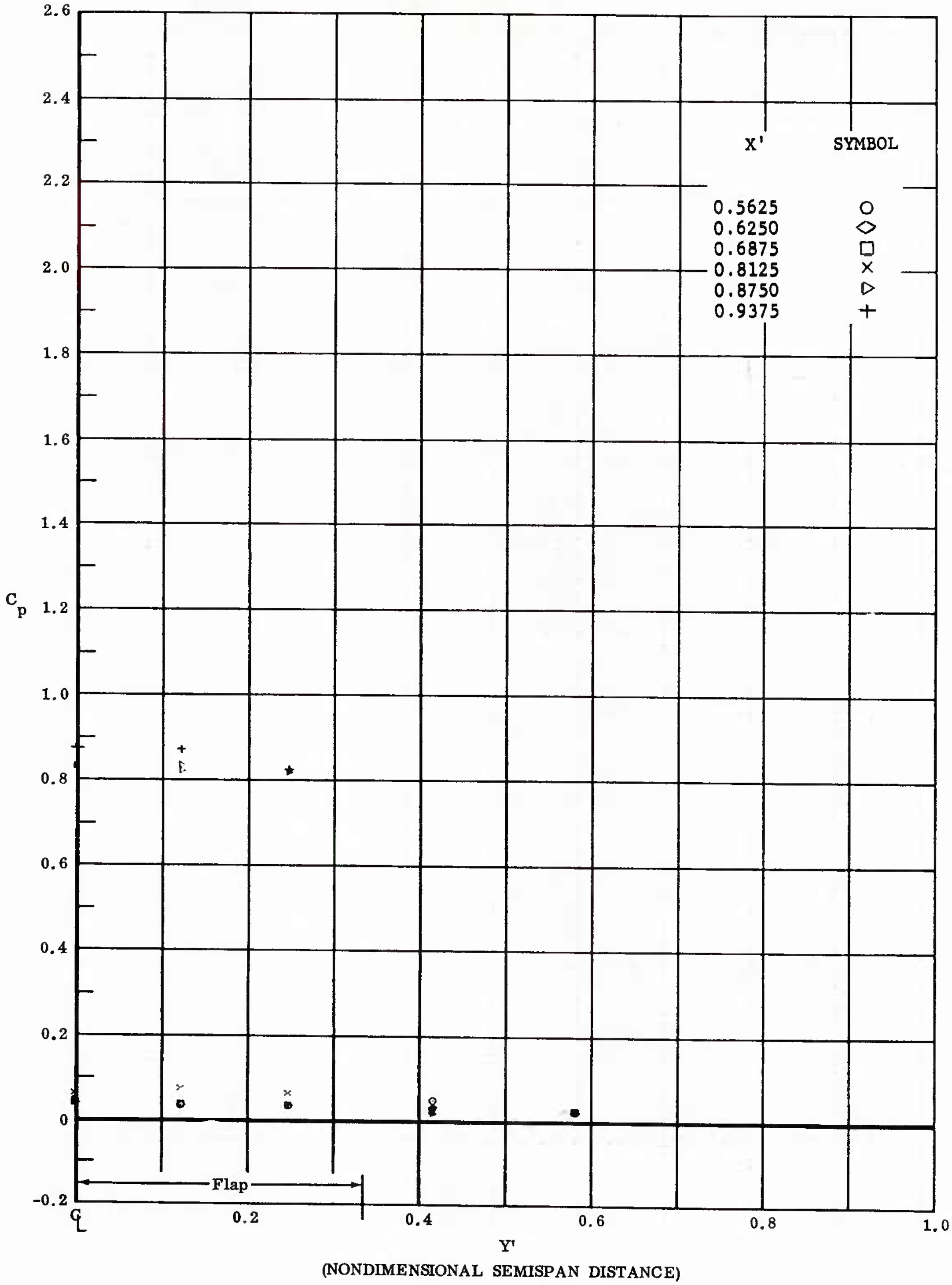


Fig. 109 Spanwise Pressure Distributions; Ramp On, No Coolant Flow, $\alpha = 0°$, $Re_\infty/ft = 1,100,000$.

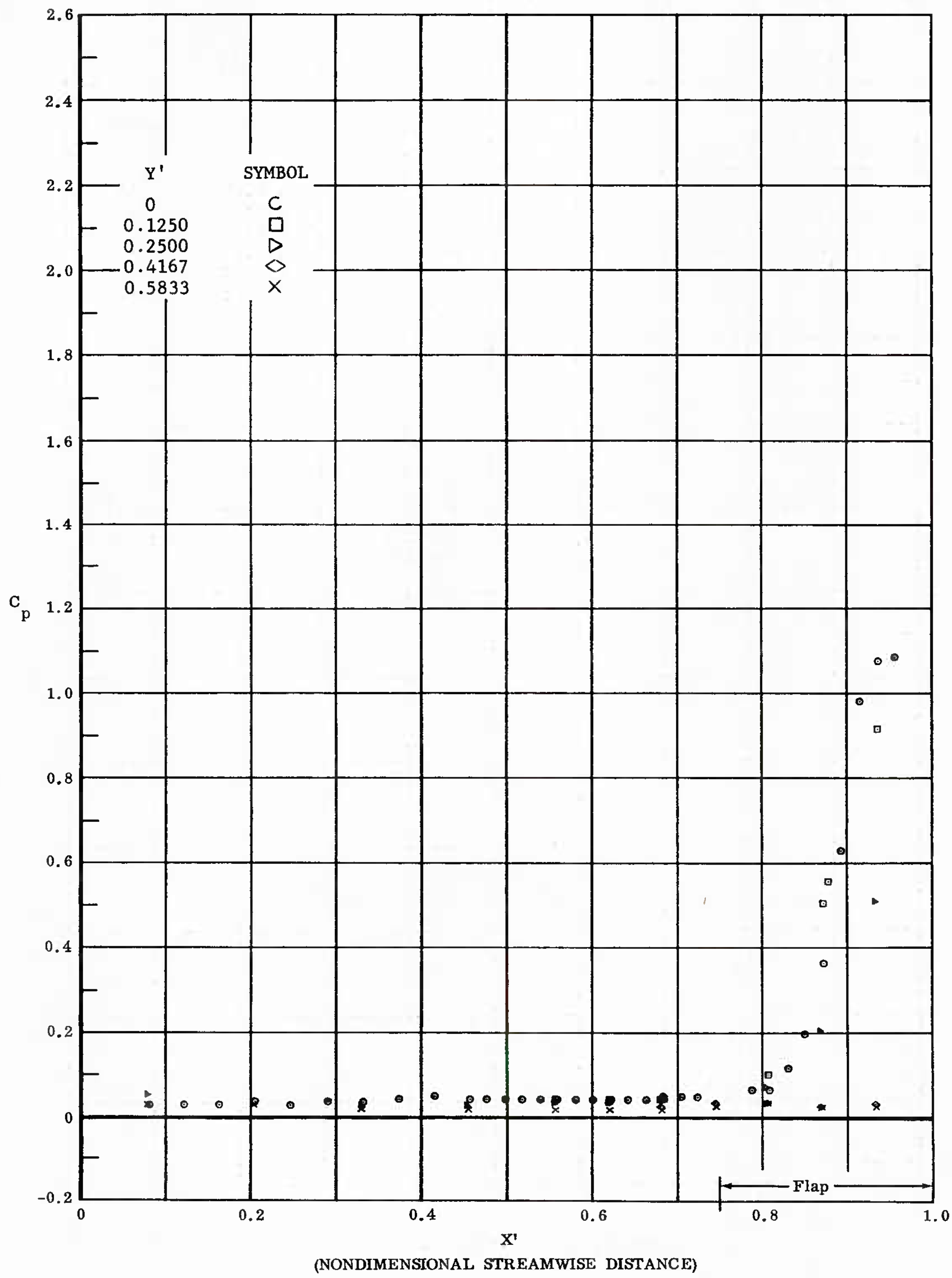


Fig. 110 Streamwise Pressure Distributions; Ramp On, Maximum Coolant Flow Rate, $\alpha = 0°$, $Re_\infty/ft = 1,100,000$.

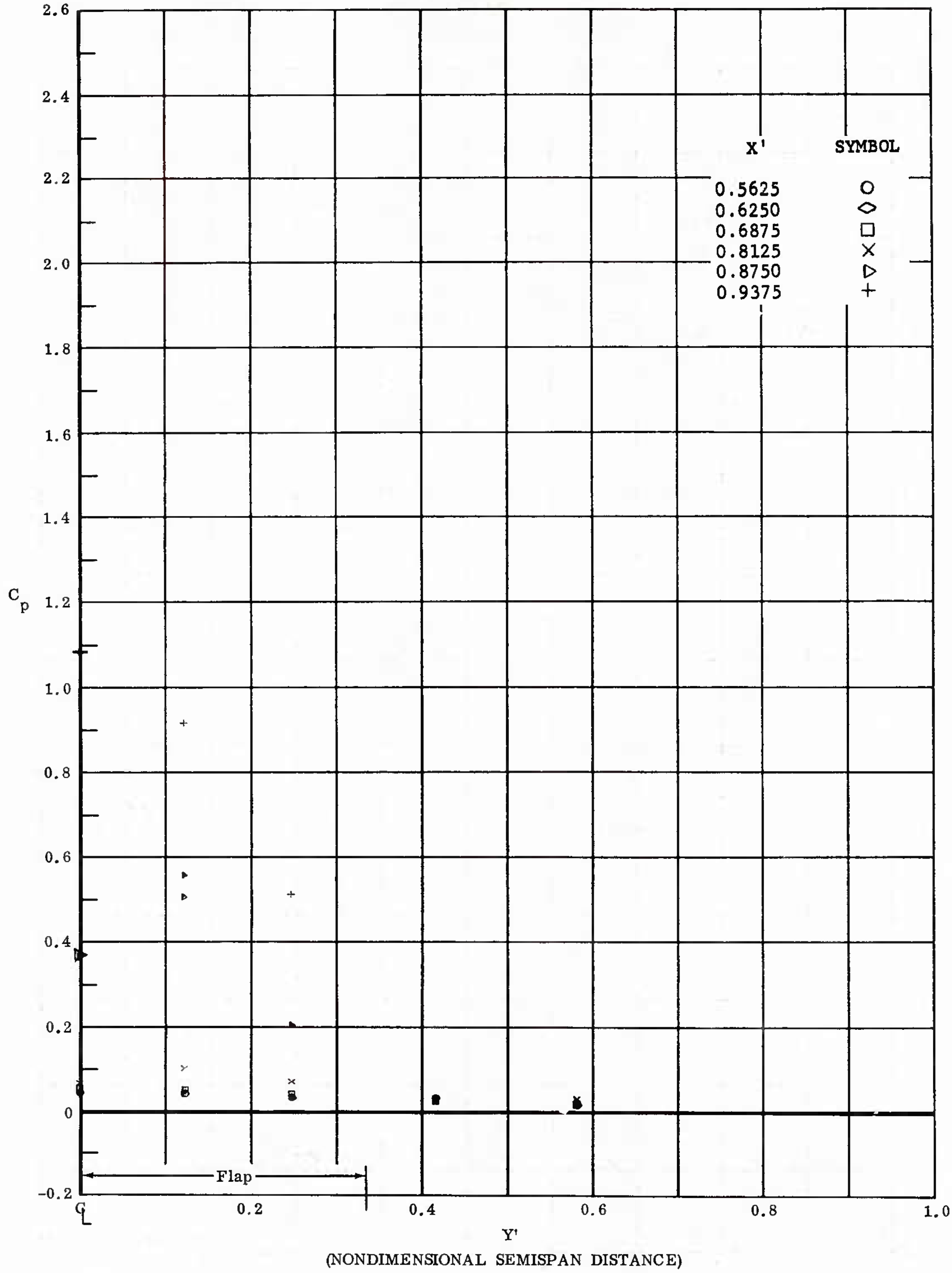


Fig. 110 Spanwise Pressure Distributions; Ramp On, Maximum Coolant Flow Rate, $\alpha = 0°$, $Re_\infty/ft = 1,100,000$.

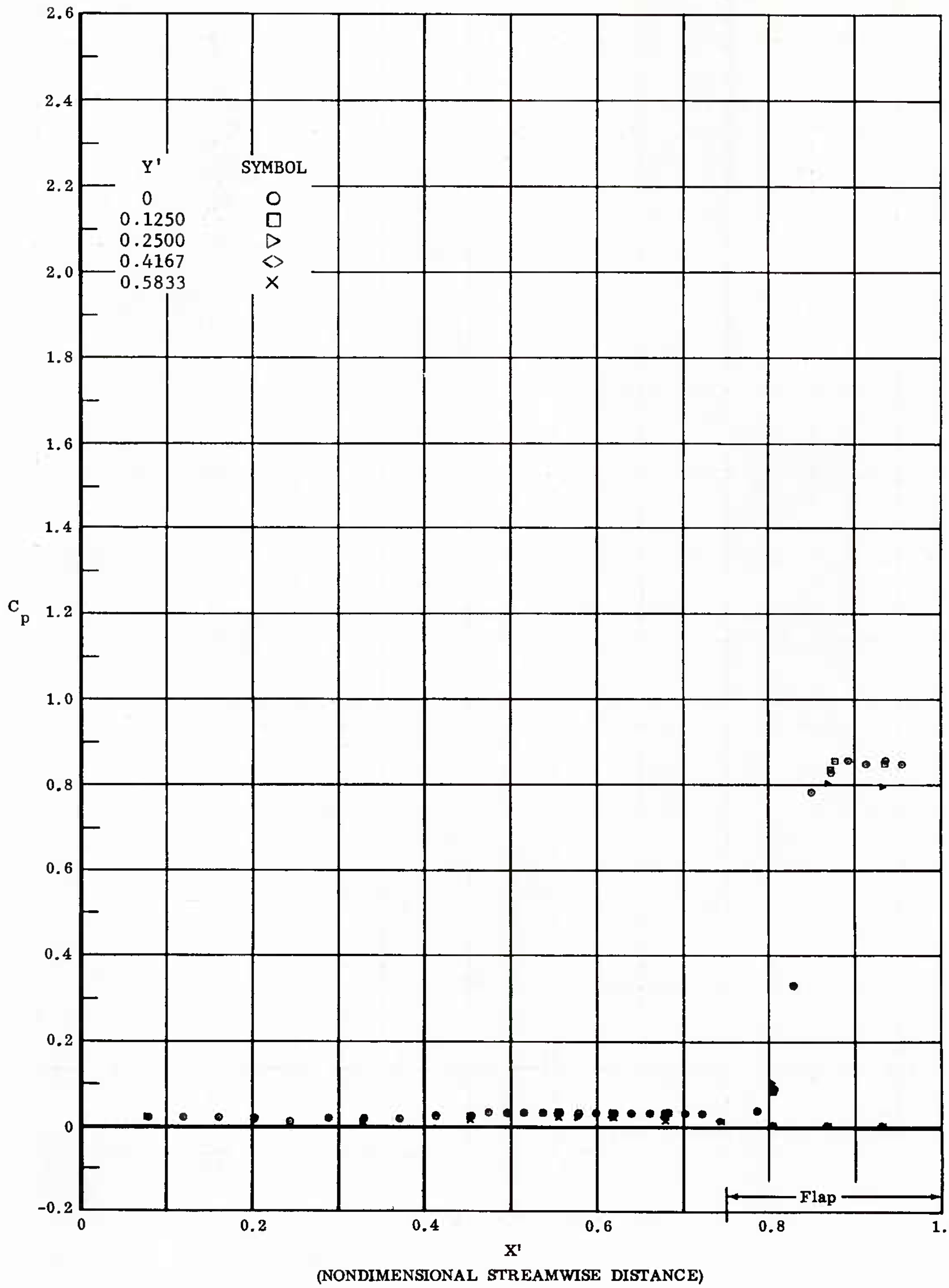


Fig. 111 Streamwise Pressure Distributions; Ramp On, No Coolant Flow, $\alpha = 0°$, $Re_\infty/ft = 2{,}200{,}000$.

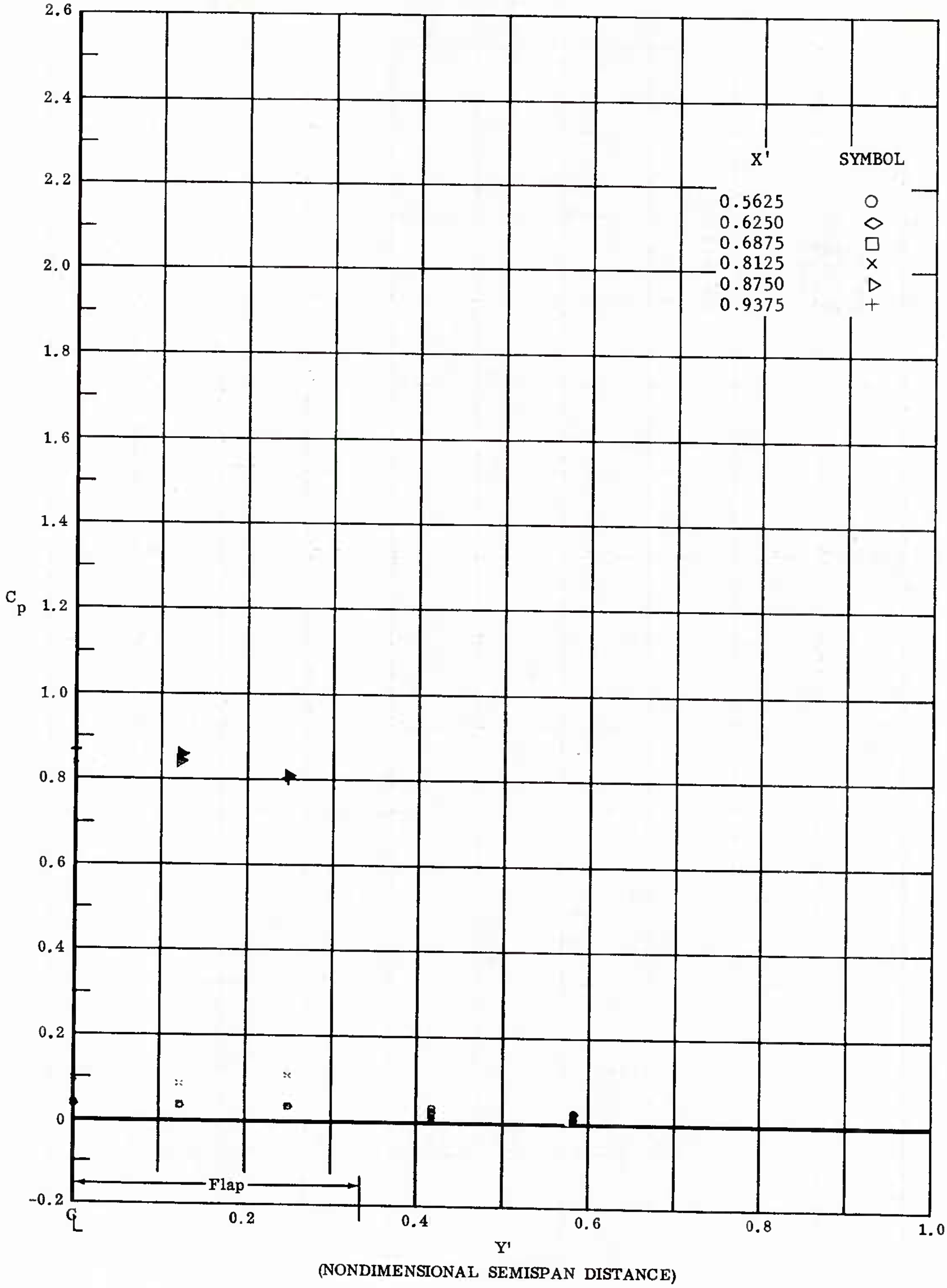


Fig. 111 Spanwise Pressure Distributions; Ramp On, No Coolant Flow, $\alpha = 0°$, $Re_\infty/ft = 2,200,000$.

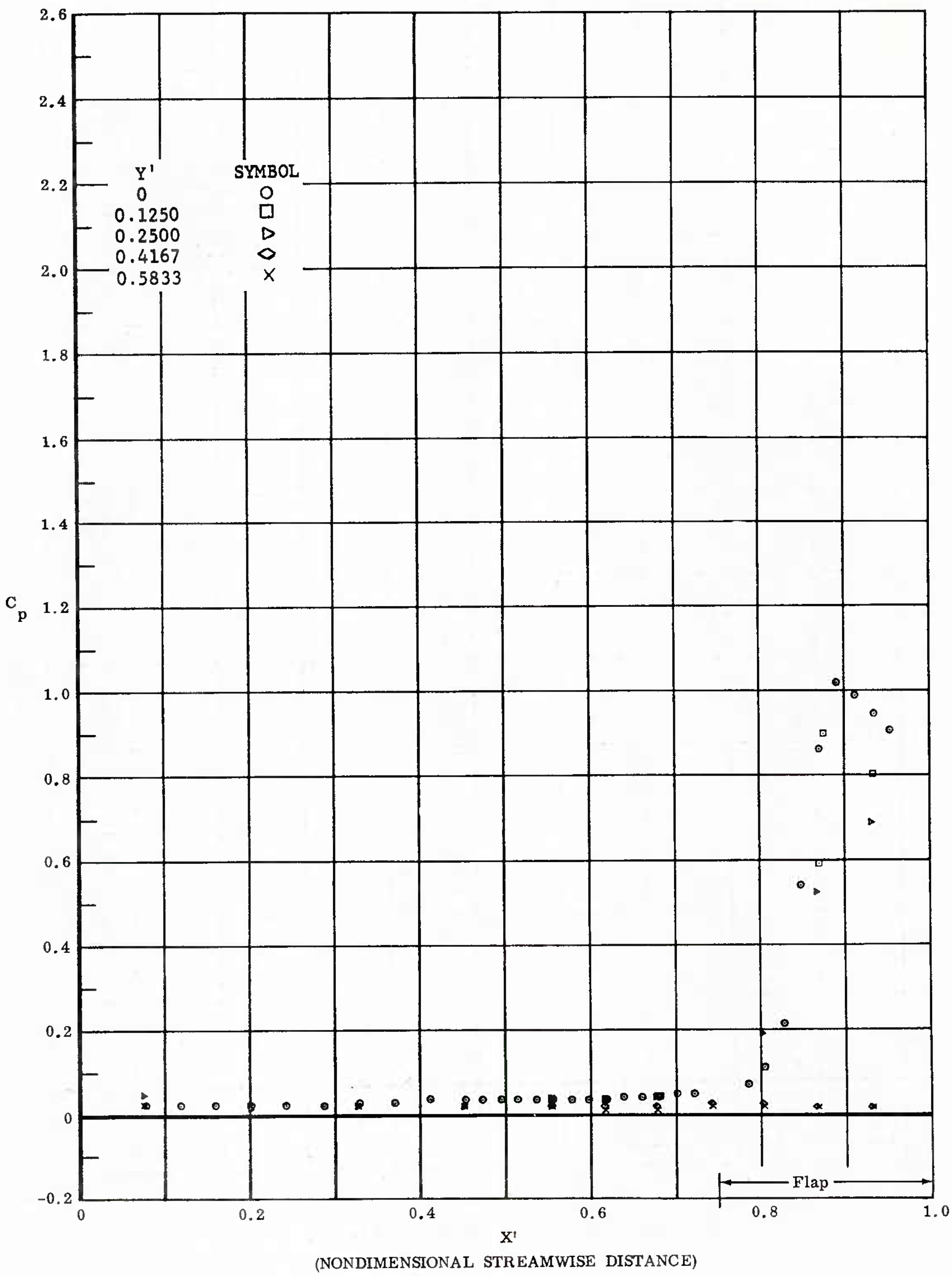


Fig. 112 Streamwise Pressure Distributions; Ramp On, Maximum Coolant Flow Rate, $\alpha = 0°$, $Re_\infty/ft = 2,200,000$.

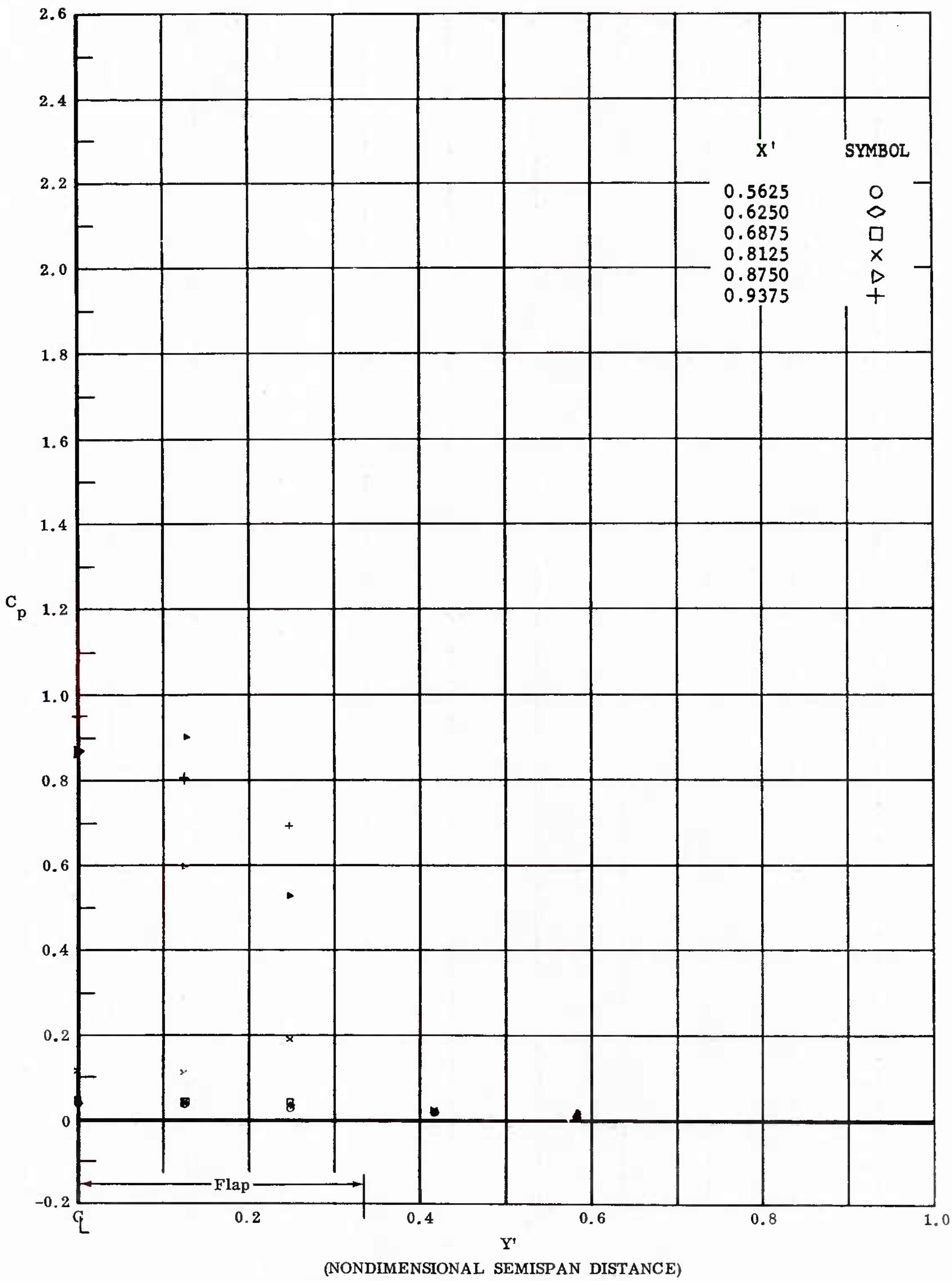


Fig. 112 Spanwise Pressure Distributions; Ramp On, Maximum Coolant Flow Rate, $\alpha = 0°$, $Re_\infty/ft = 2{,}200{,}000$.

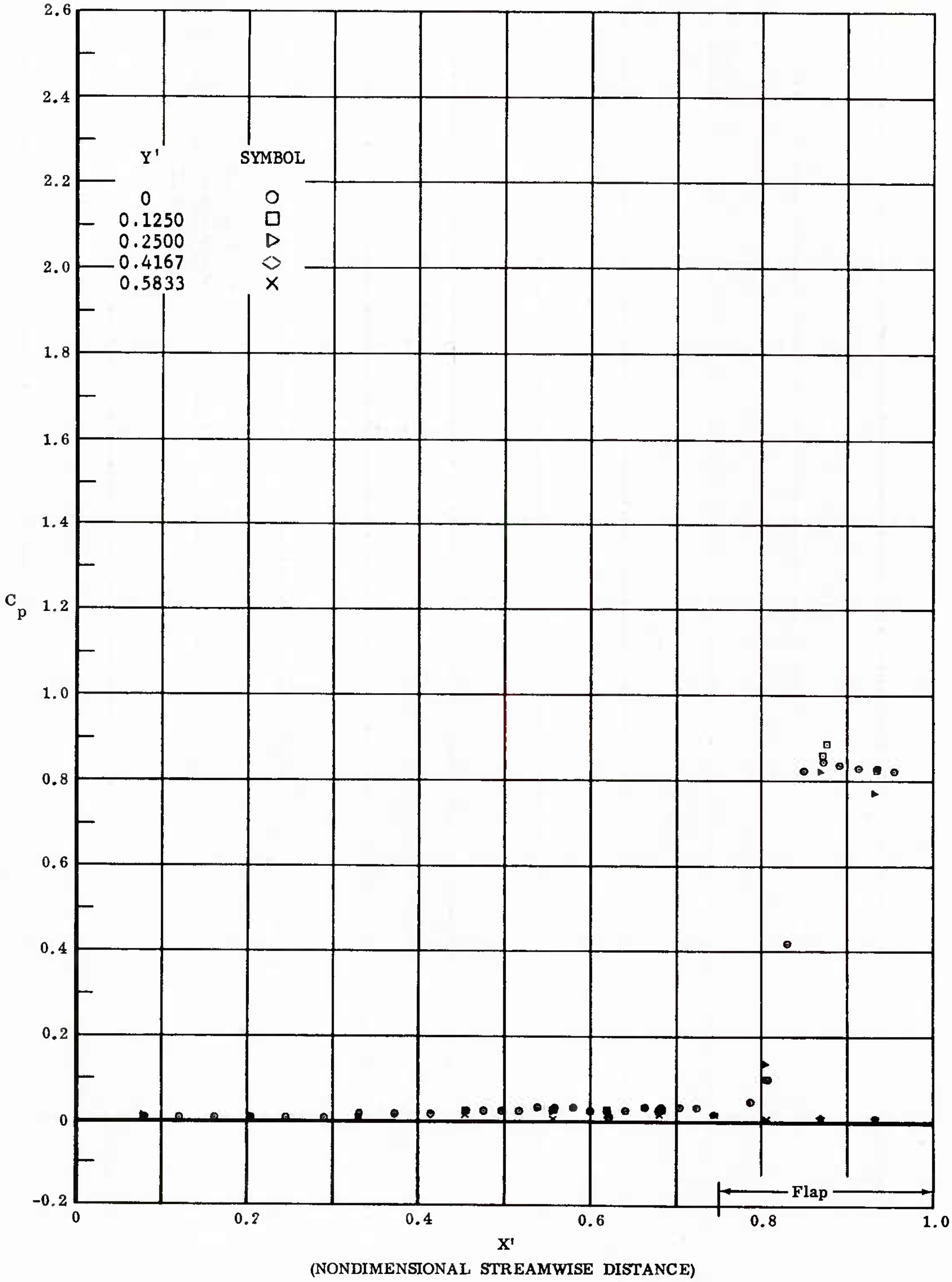


Fig. 113 Streamwise Pressure Distributions; Ramp On, No Coolant Flow, $\alpha = 0°$, $Re_\infty/ft = 3,300,000$.

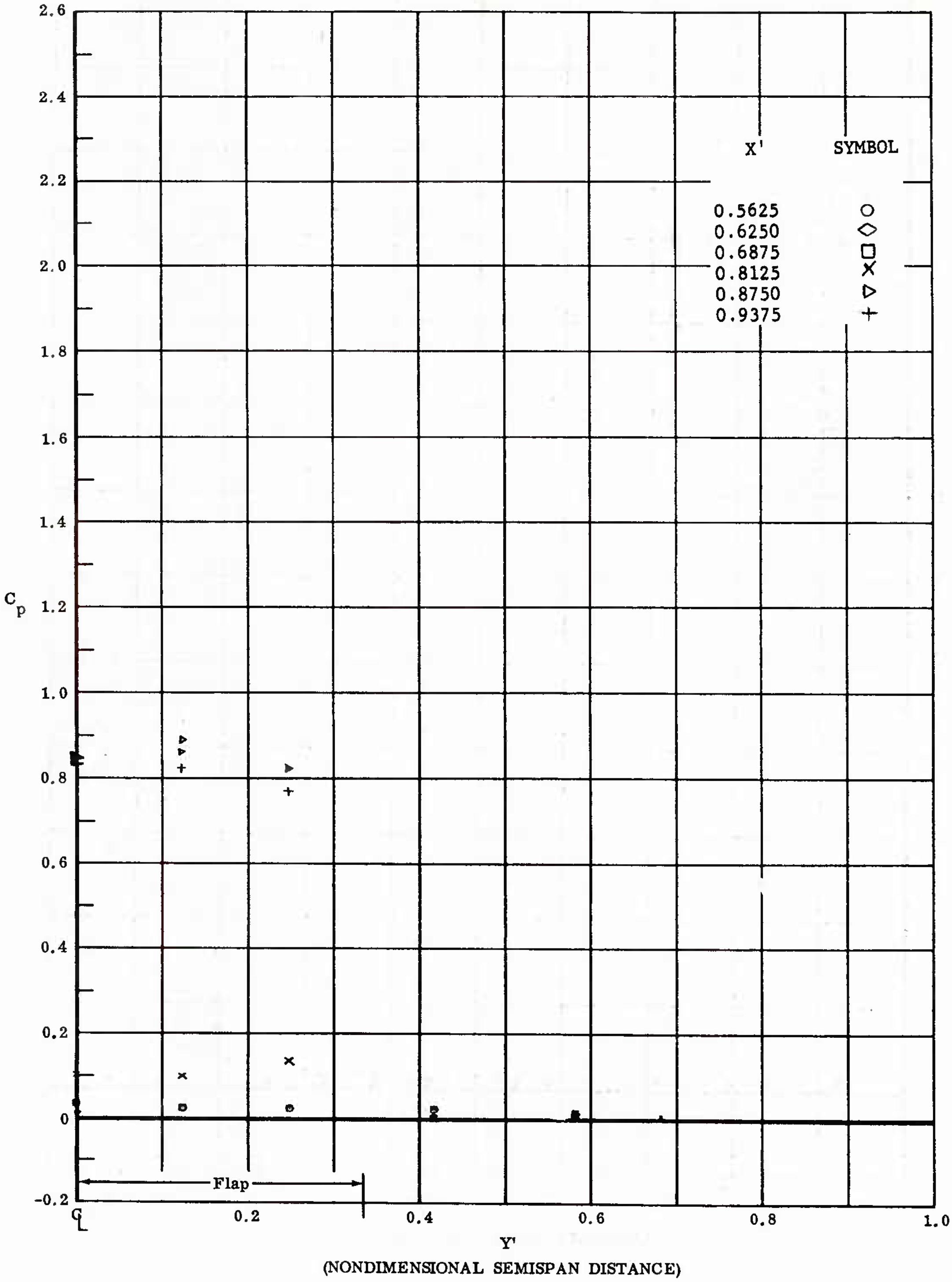


Fig. 113 Spanwise Pressure Distributions; Ramp On, No Coolant Flow, $\alpha = 0°$, $Re_\infty/ft = 3,300,000$.

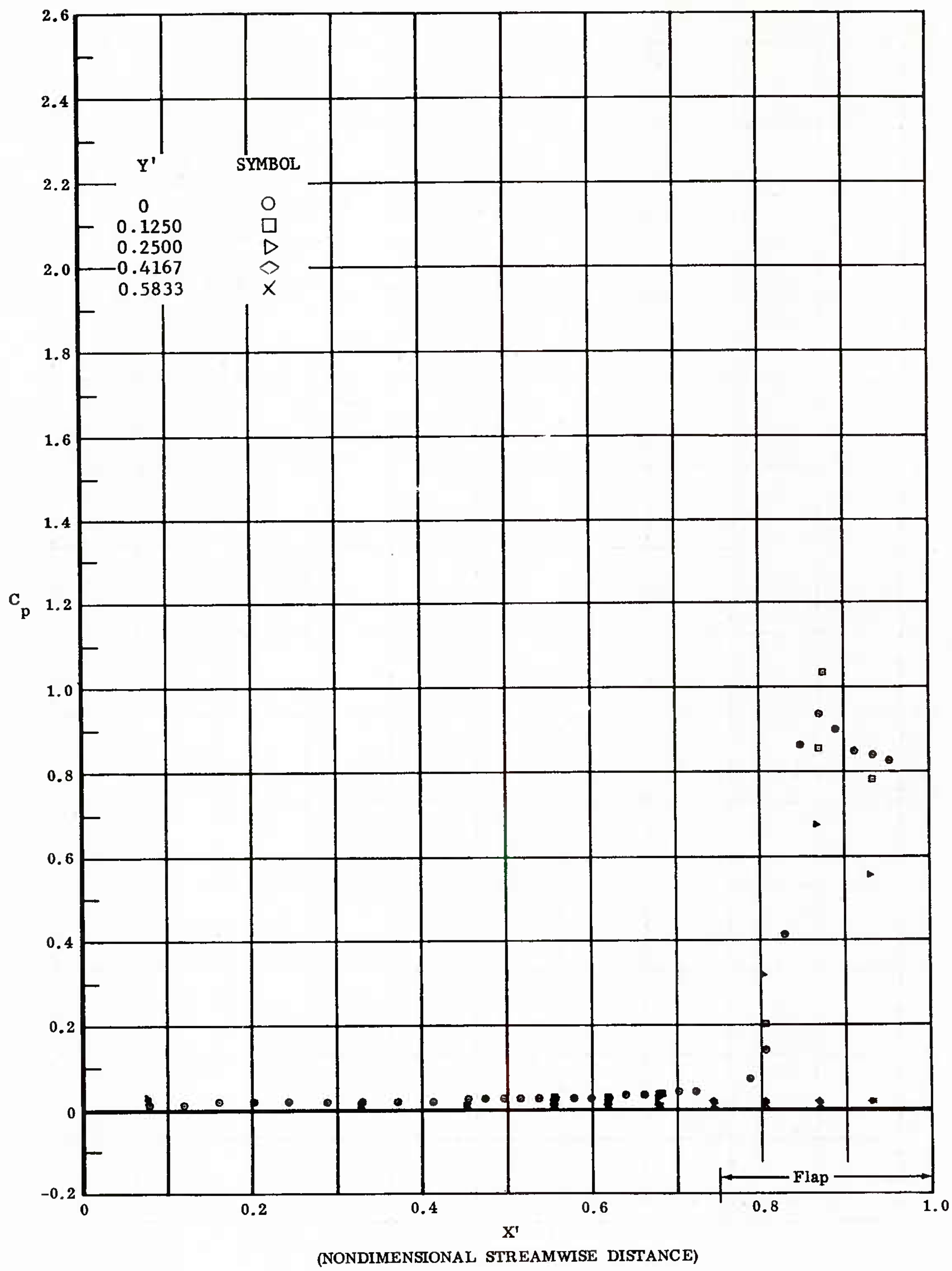


Fig. 114 Streamwise Pressure Distributions; Ramp On, Maximum Coolant Flow Rate, $\alpha = 0°$, $Re_\infty/ft = 3,300,000$.

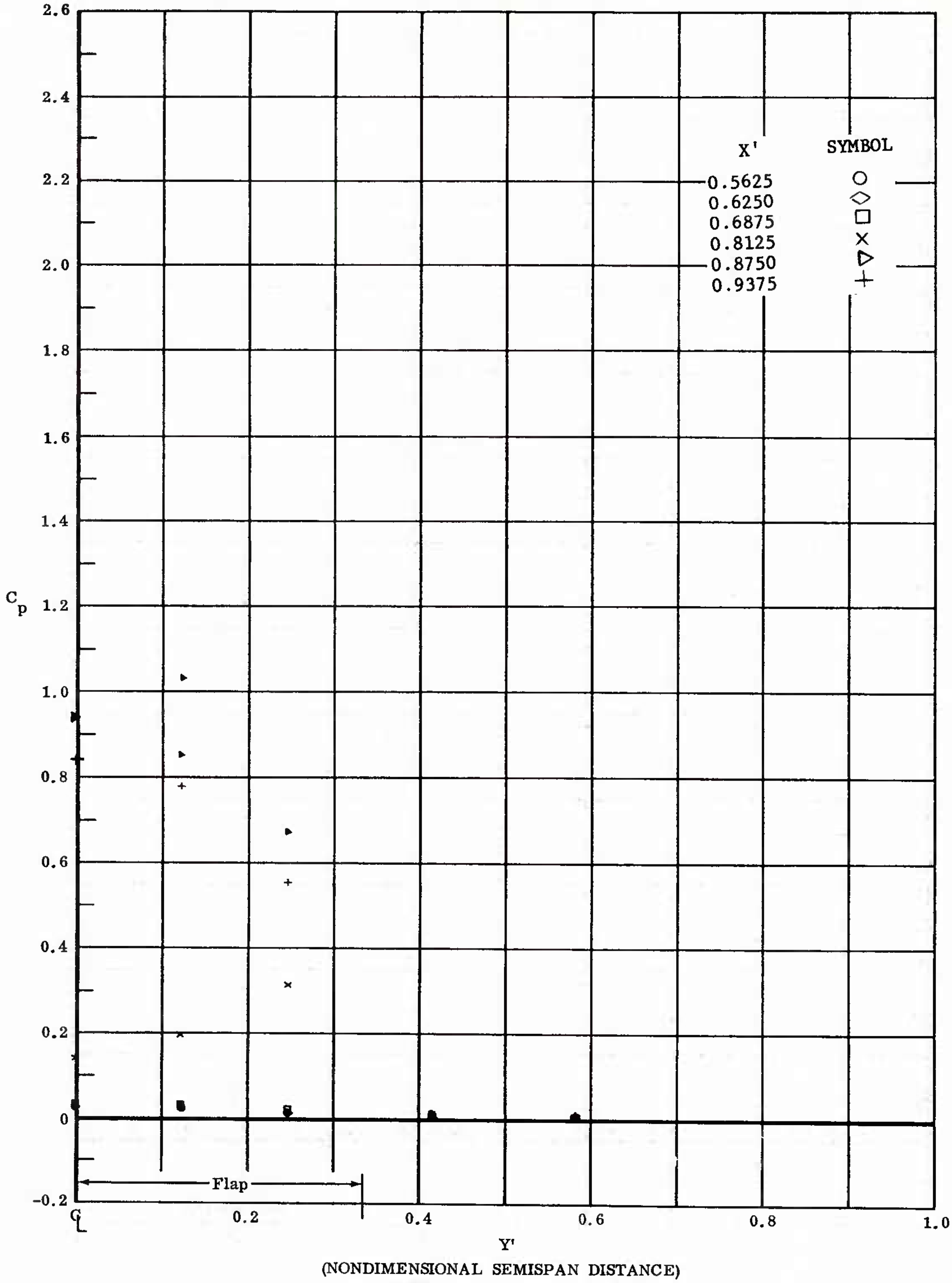


Fig. 114 Spanwise Pressure Distributions; Ramp On, Maximum Coolant Flow Rate, $\alpha = 0°$, $Re_\infty/ft = 3,300,000$.

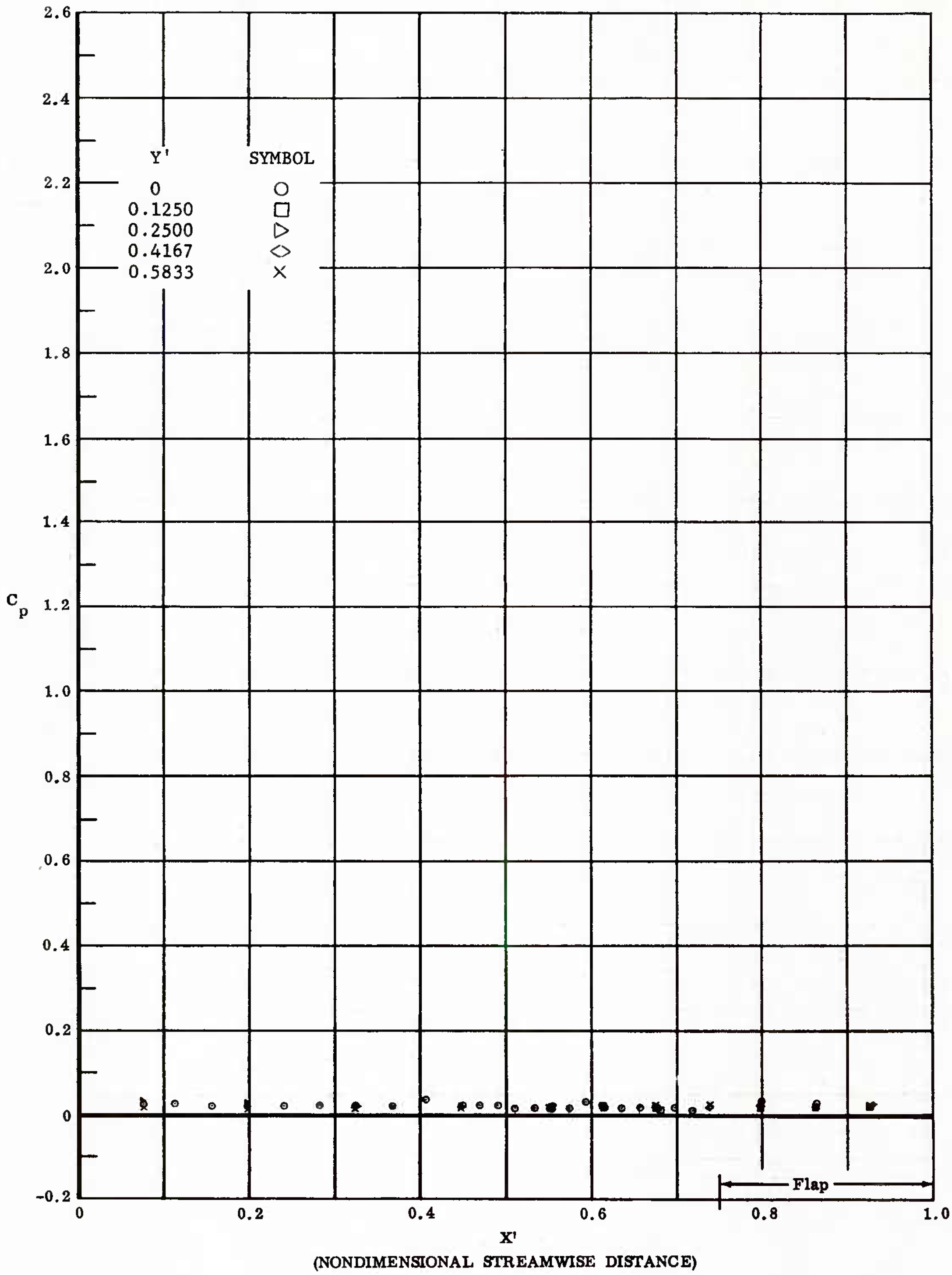


Fig. 115 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = +5°$, $Re_\infty/ft = 1,100,000$.

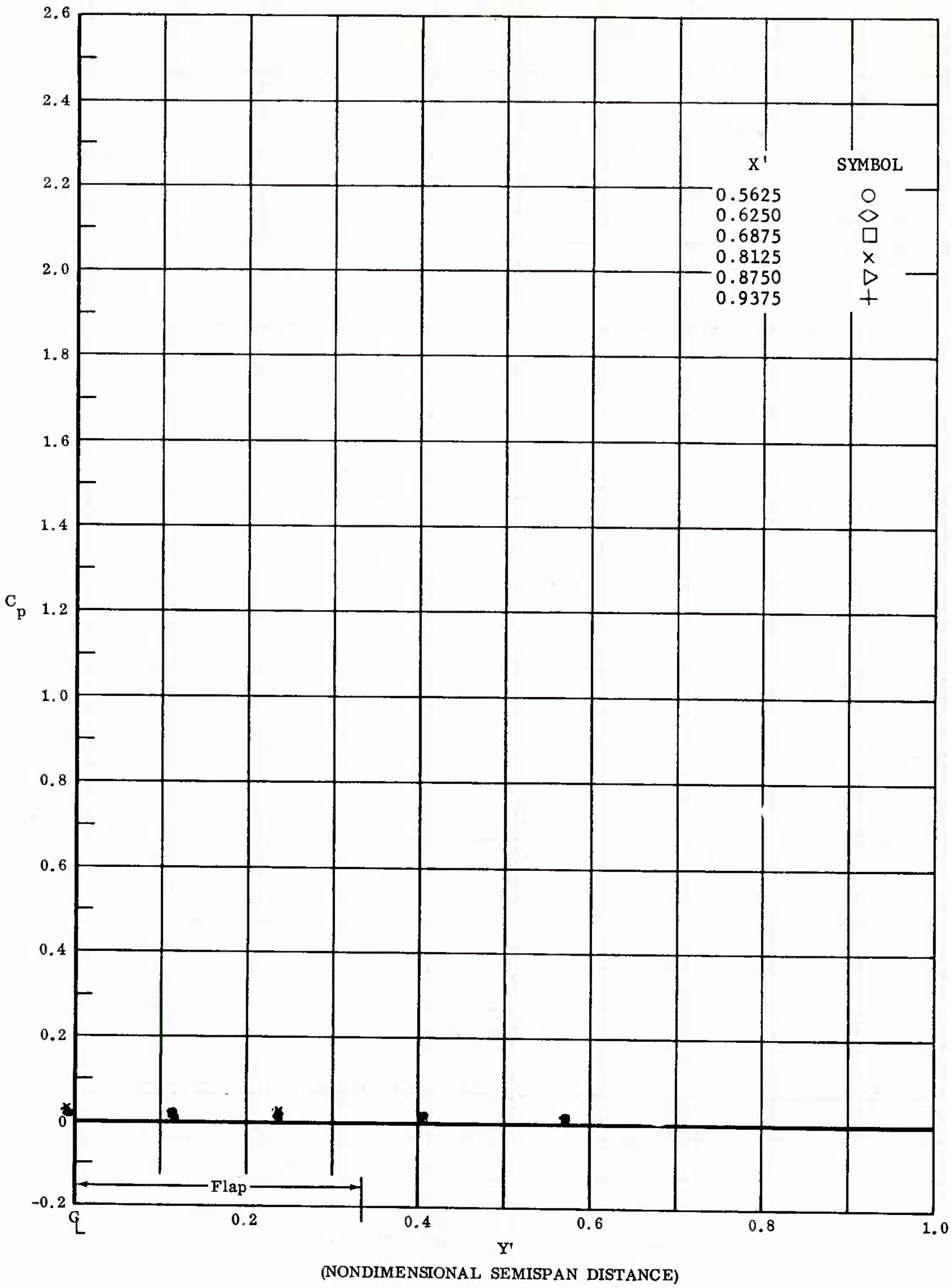


Fig. 115 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = +5°$, $Re_\infty/ft = 1,100,000$.

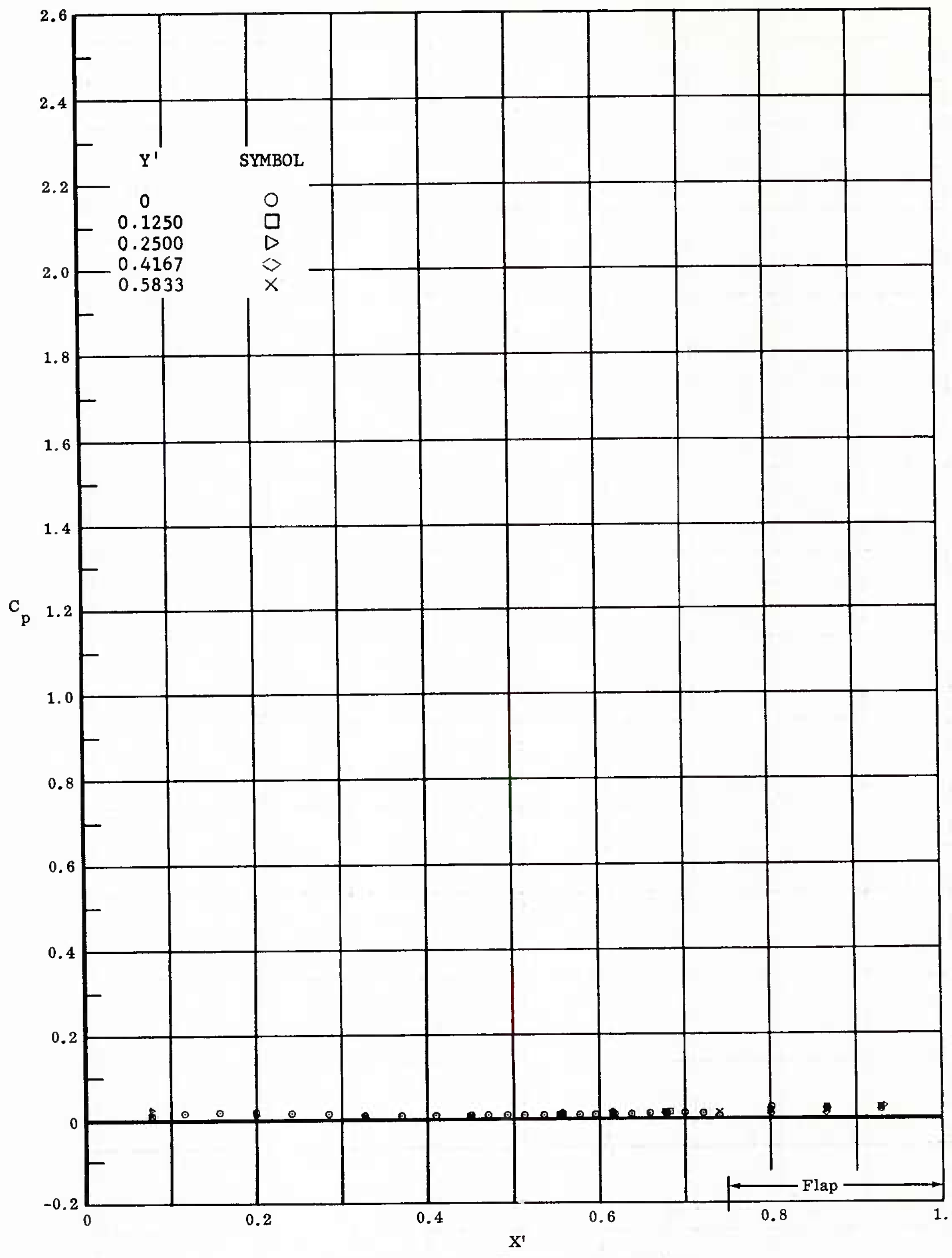


Fig. 116 Streamwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, $\alpha = +5°$, $Re_{\infty}/ft = 1,100,000$.

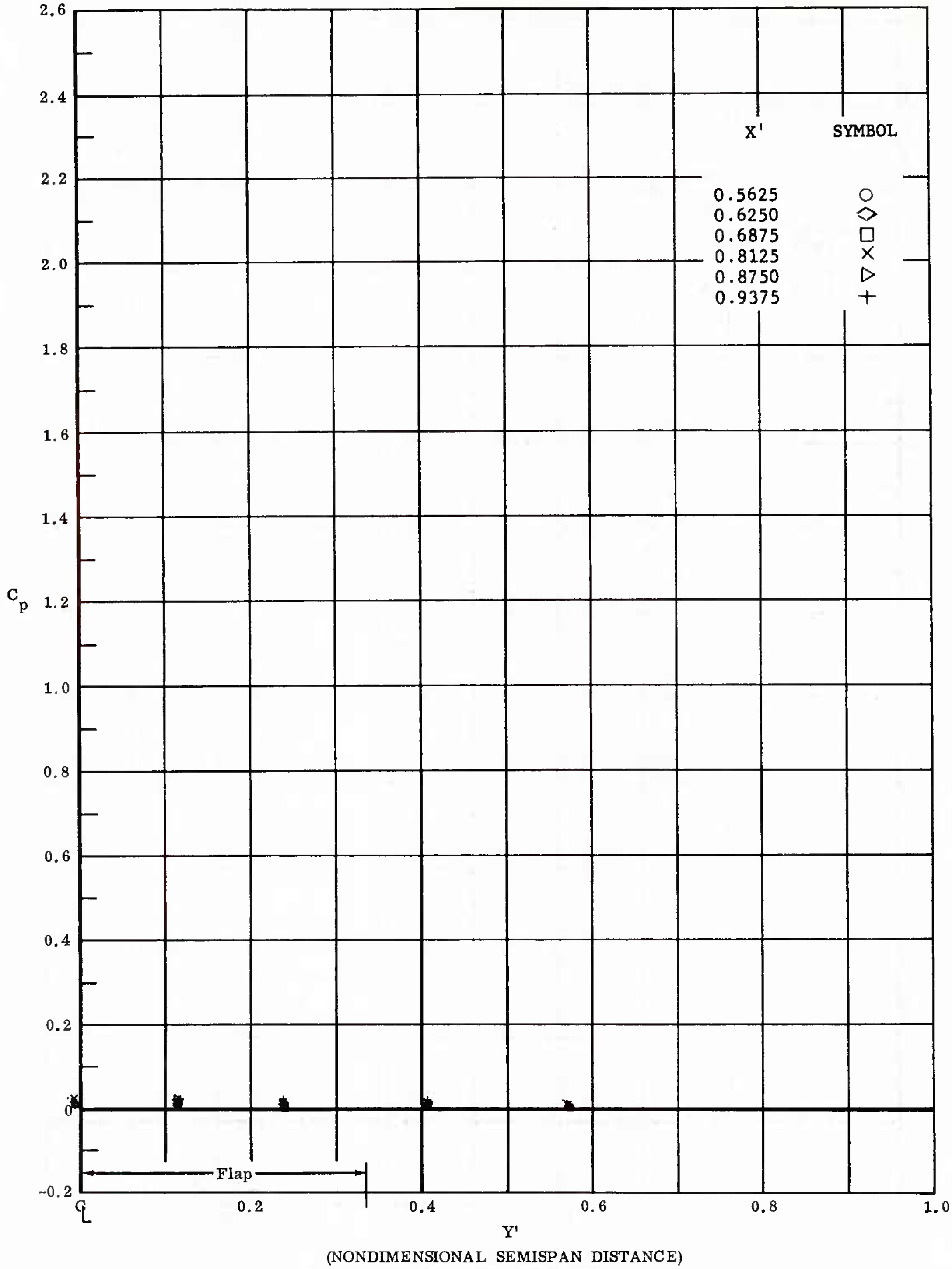


Fig. 116 Spanwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, $\alpha = +5°$, $Re_{\infty}/ft = 1{,}100{,}000$.

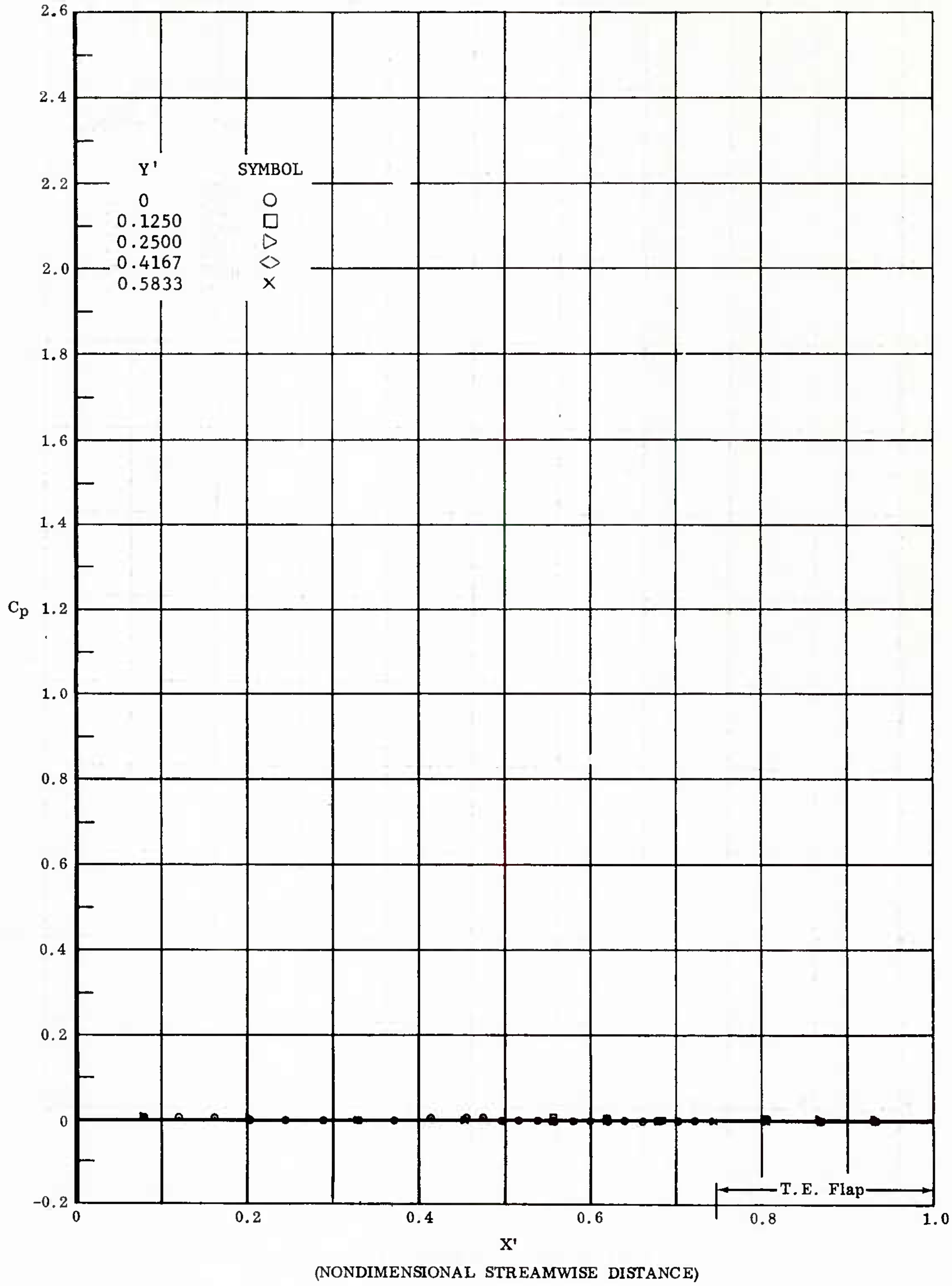


Fig. 117 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = +5°$, $Re_\infty/ft = 3{,}300{,}000$.

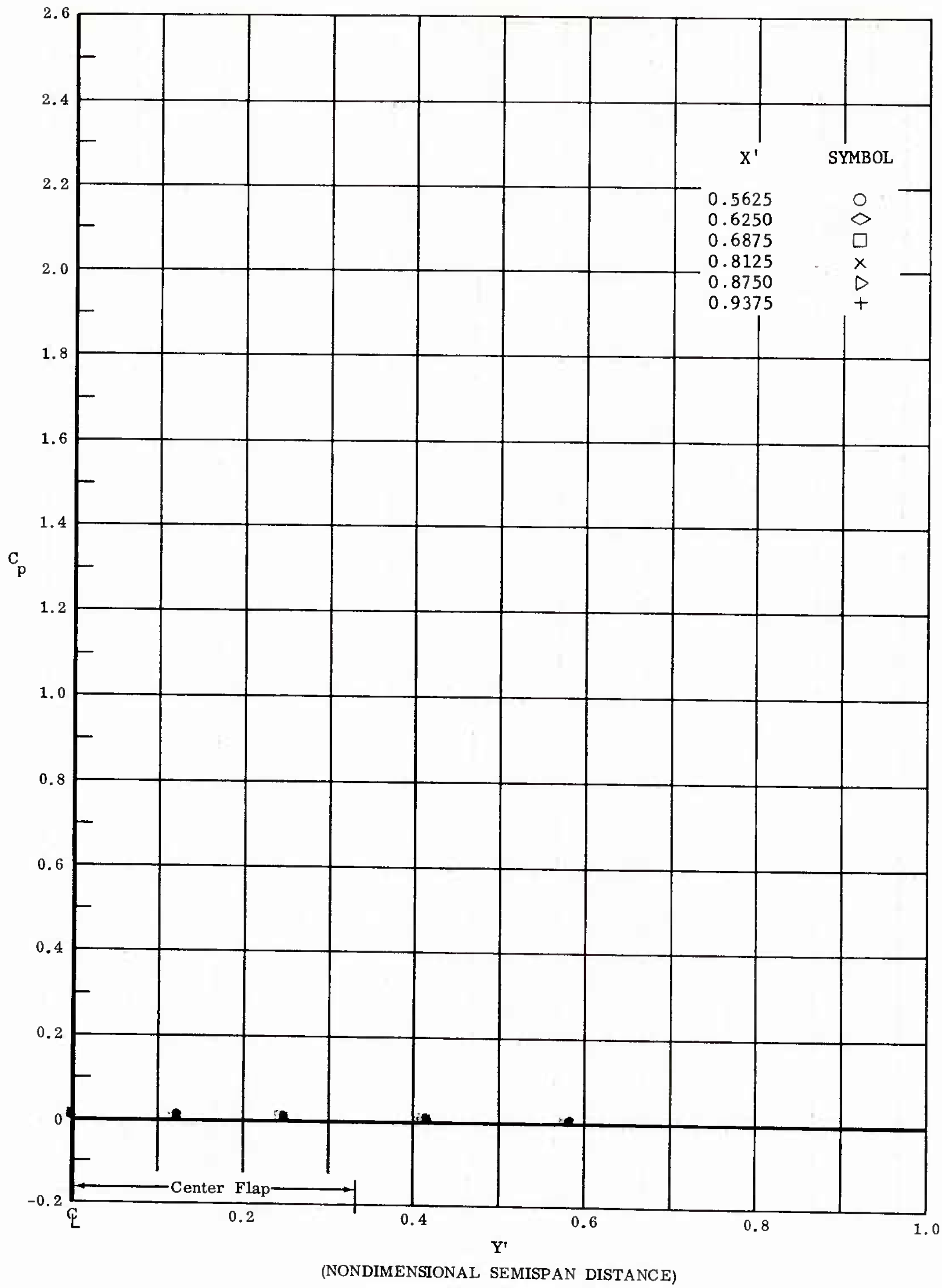


Fig. 117 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = +5°$, $Re_\infty/ft = 3,300,000$.

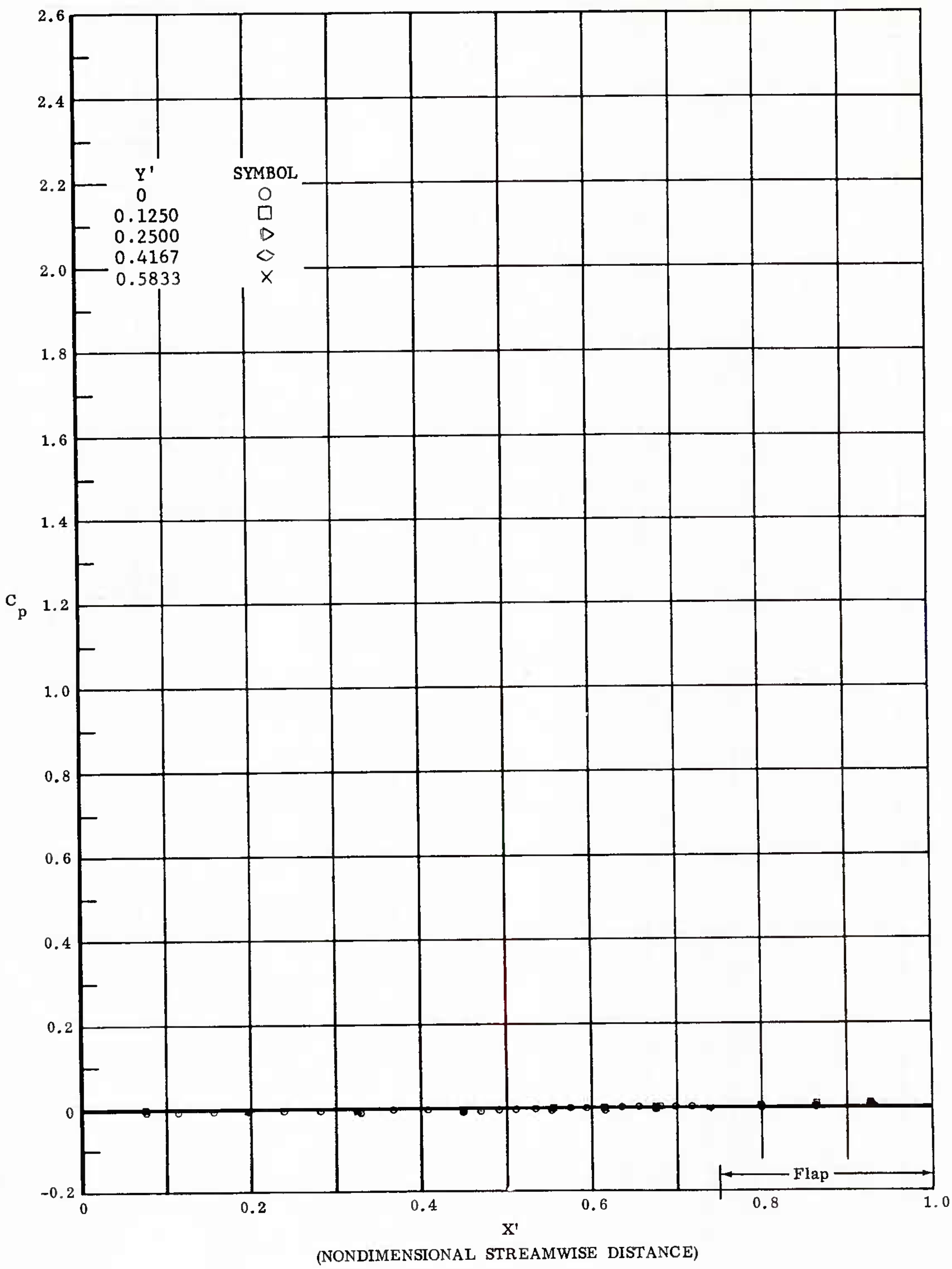


Fig. 118 Streamwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, $\alpha = +5°$, $Re_\infty/ft = 3,300,000$.

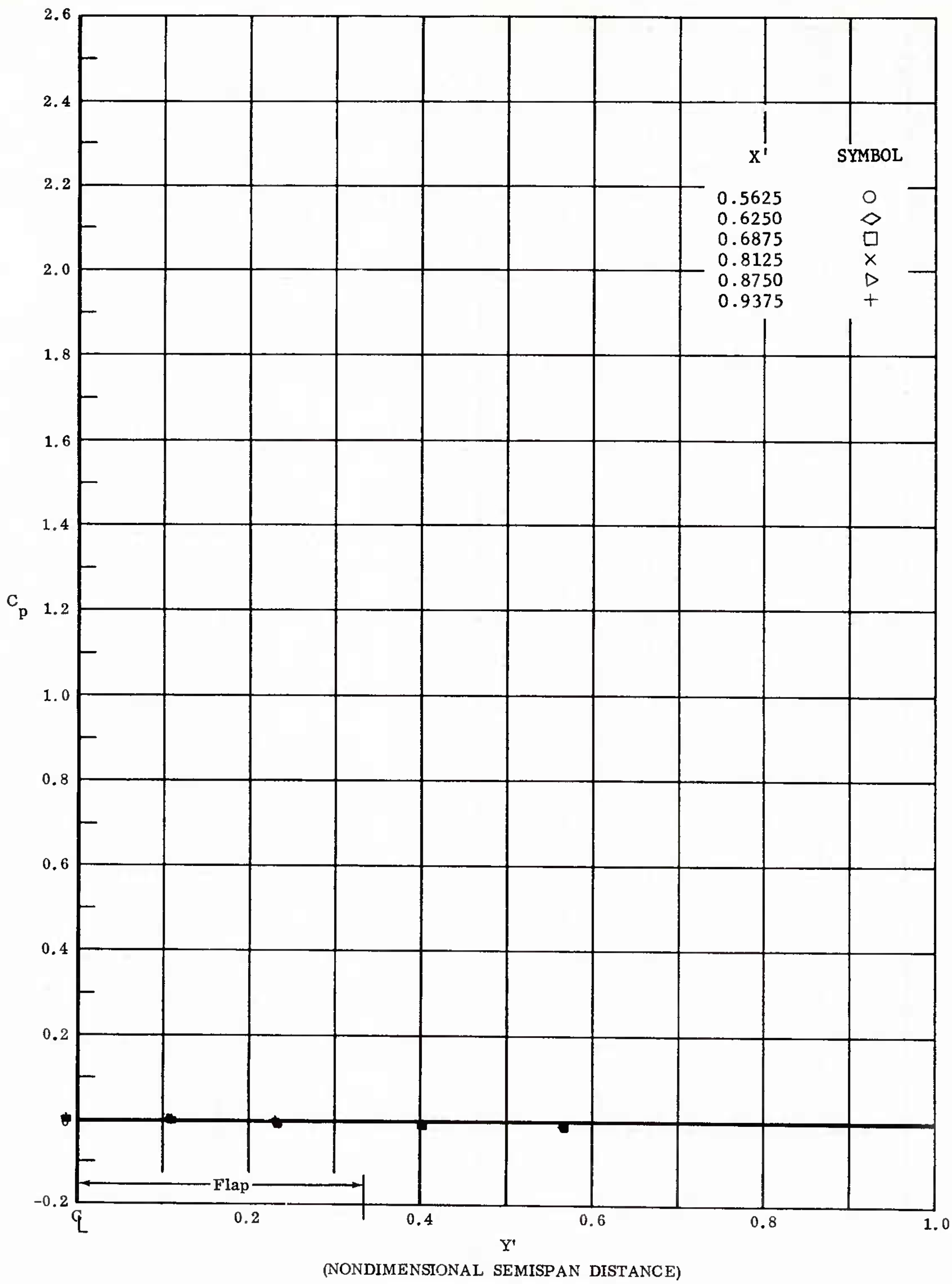


Fig. 118 Spanwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, $\alpha = +5°$, $Re_\infty/ft = 3,300,000$.

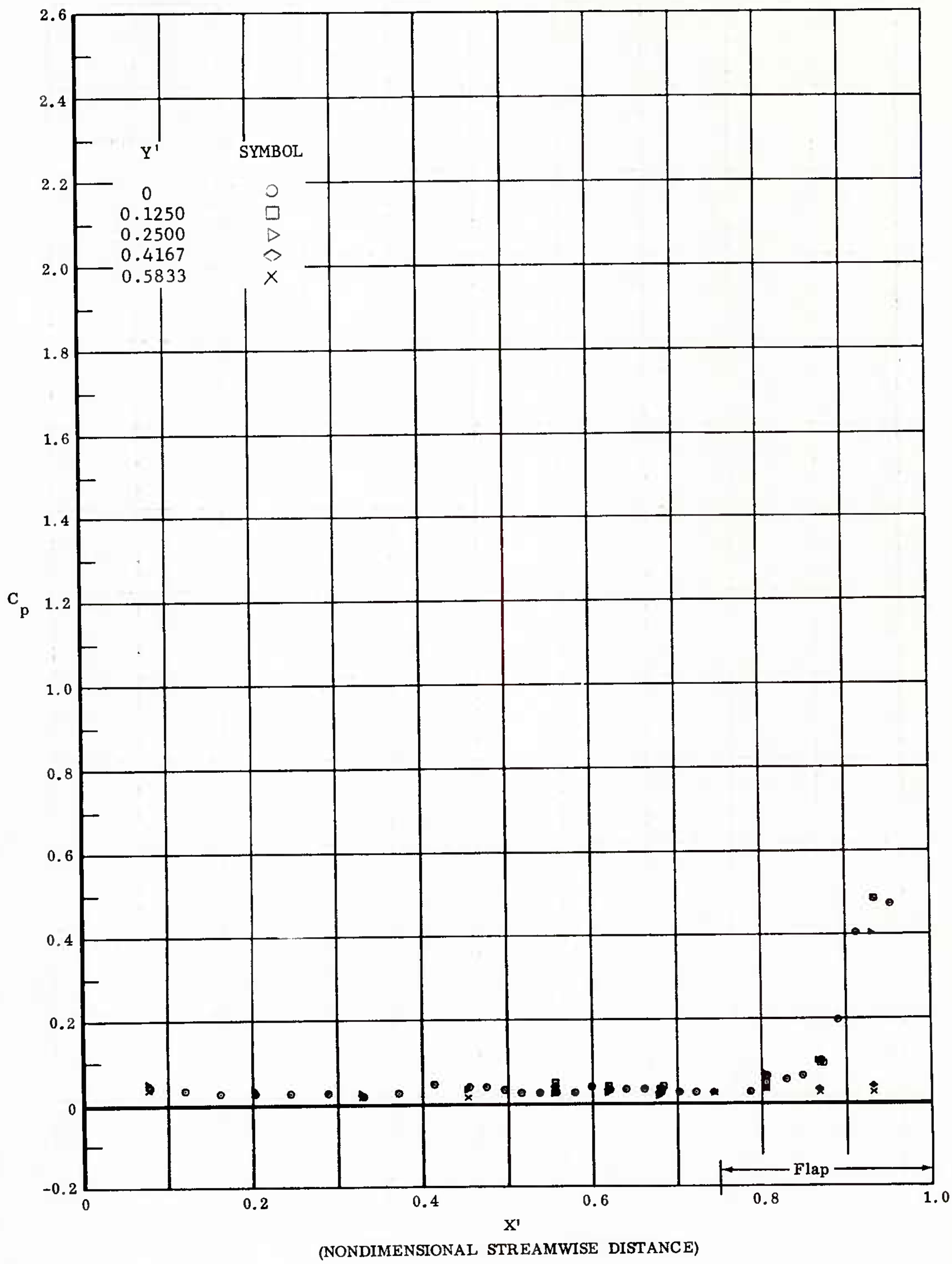


Fig. 119 Streamwise Pressure Distributions; Ramp On, No Coolant Flow, $\alpha = +5°$, $Re_\infty/ft = 1{,}100{,}000$.

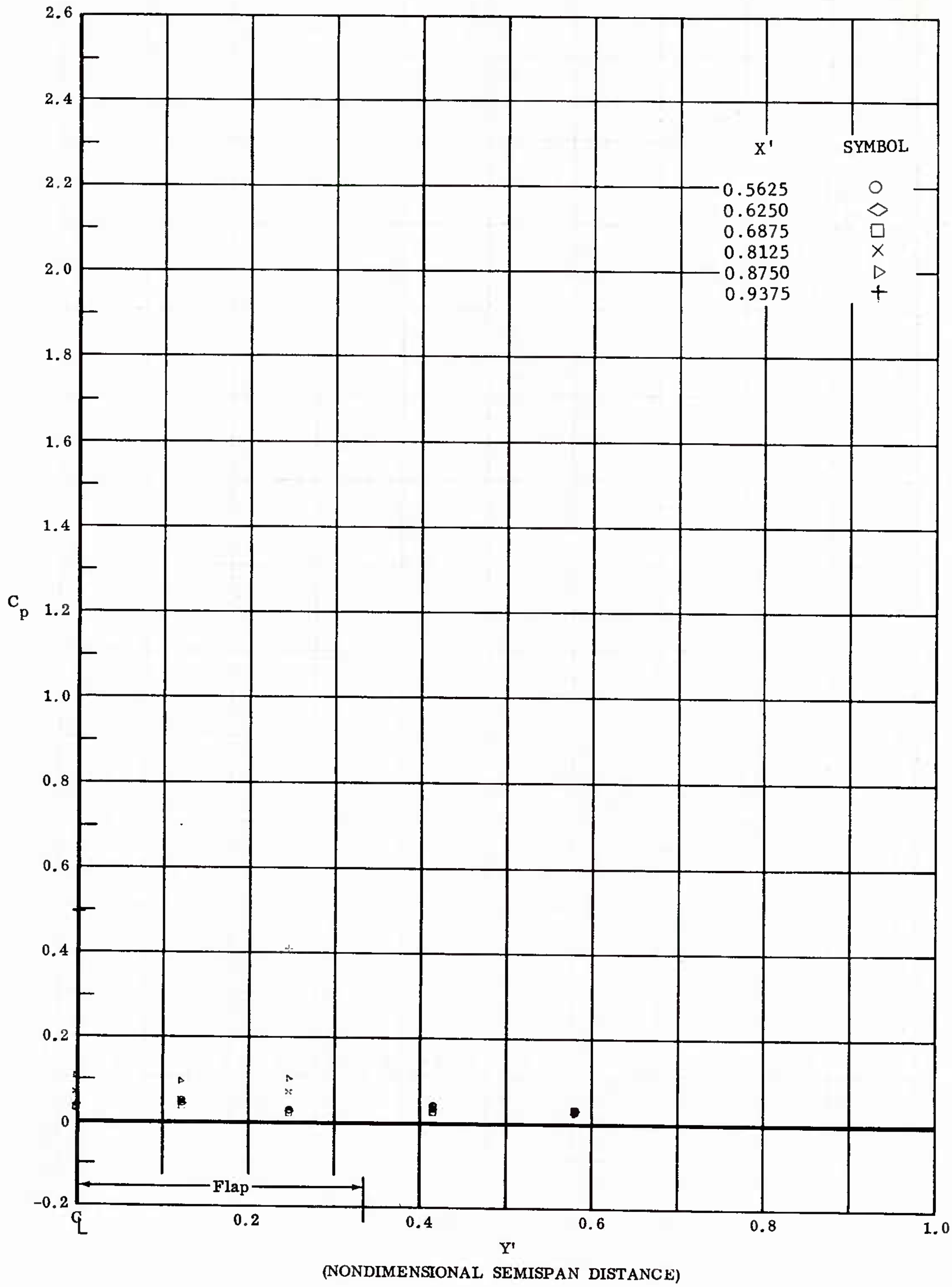


Fig. 119 Spanwise Pressure Distributions; Ramp On, No Coolant Flow, $\alpha = +5°$, $Re_\infty/ft = 1{,}100{,}000$.

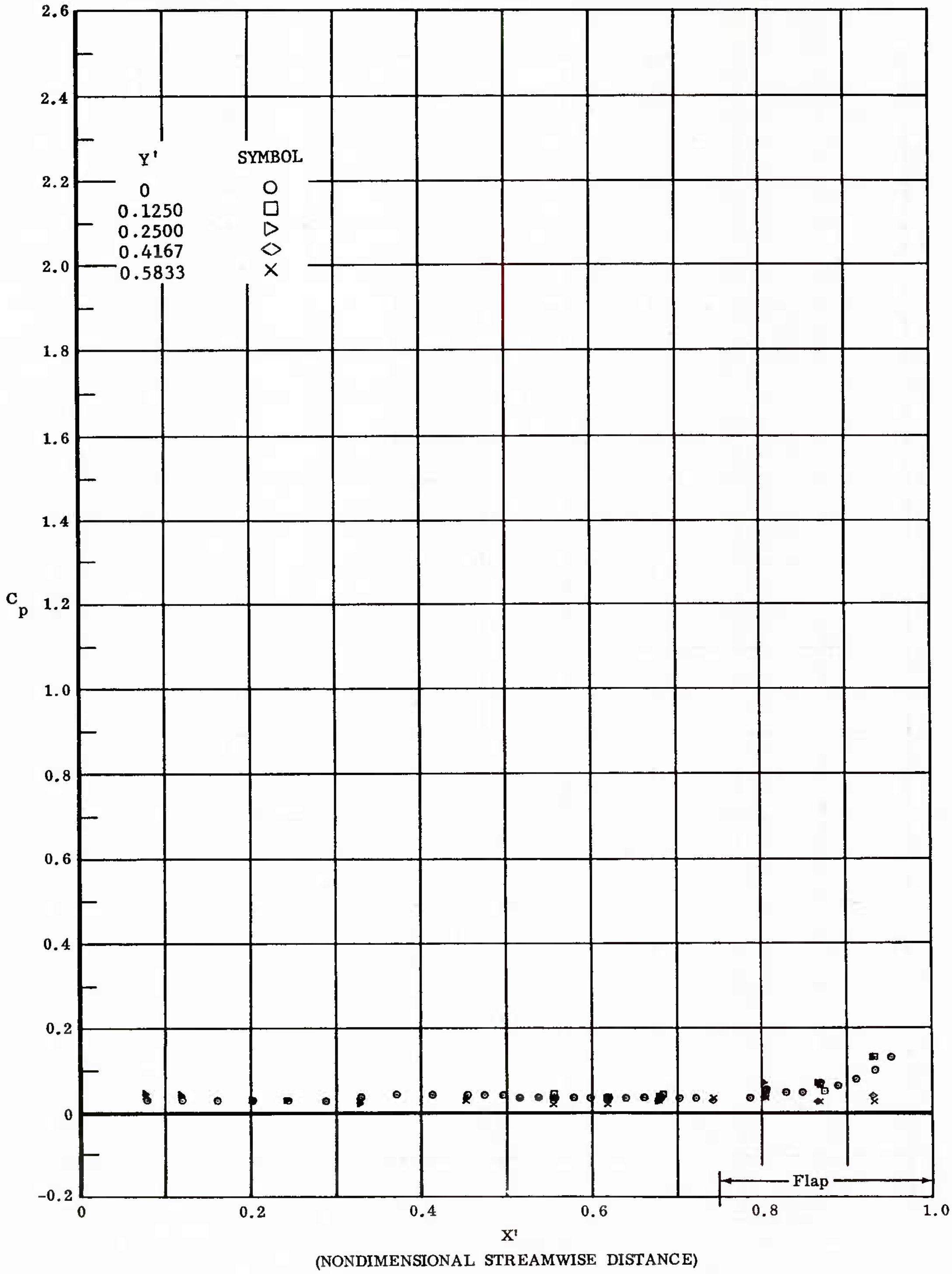


Fig. 120 Streamwise Pressure Distributions; Ramp On, Maximum Coolant Flow Rate, $\alpha = +5°$, $Re_\infty/ft = 1,100,000$.

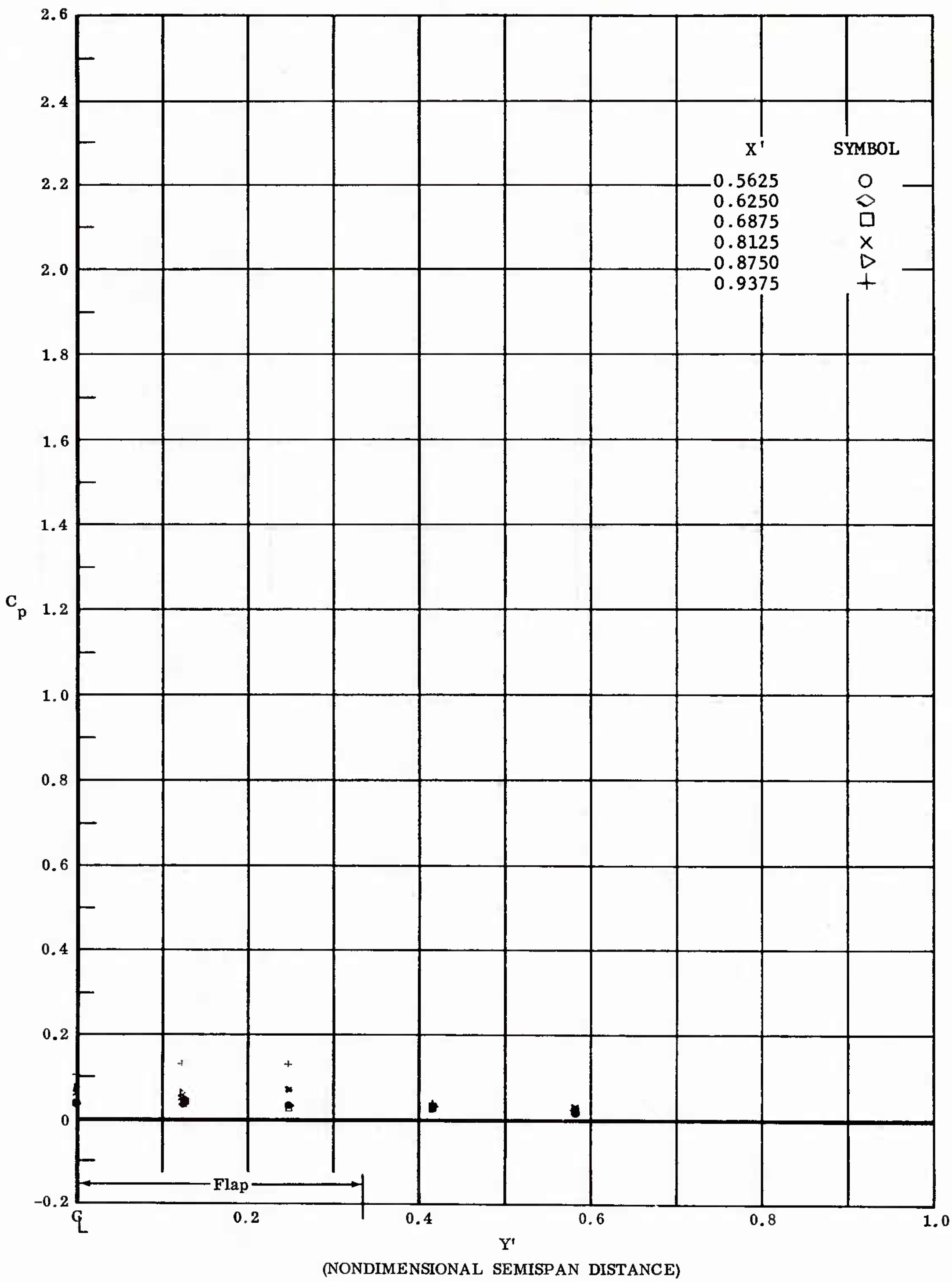


Fig. 120 Spanwise Pressure Distributions; Ramp On, Maximum Coolant Flow Rate, $\alpha = +5°$, $Re_\infty/ft = 1,100,000$.

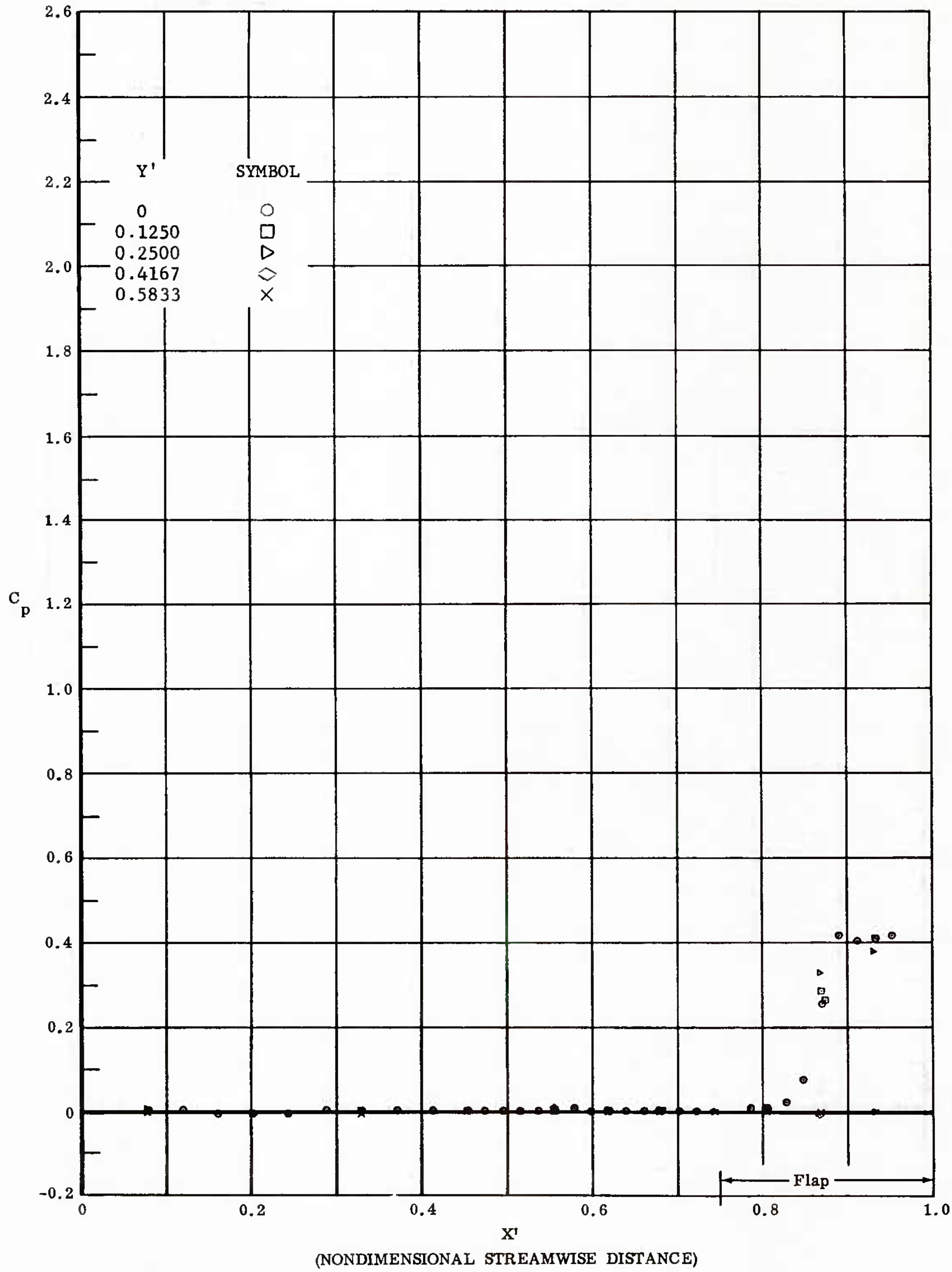


Fig. 121 Streamwise Pressure Distributions; Ramp On, No Coolant Flow, $\alpha = +5°$, $Re_{\infty}/ft = 3{,}300{,}000$.

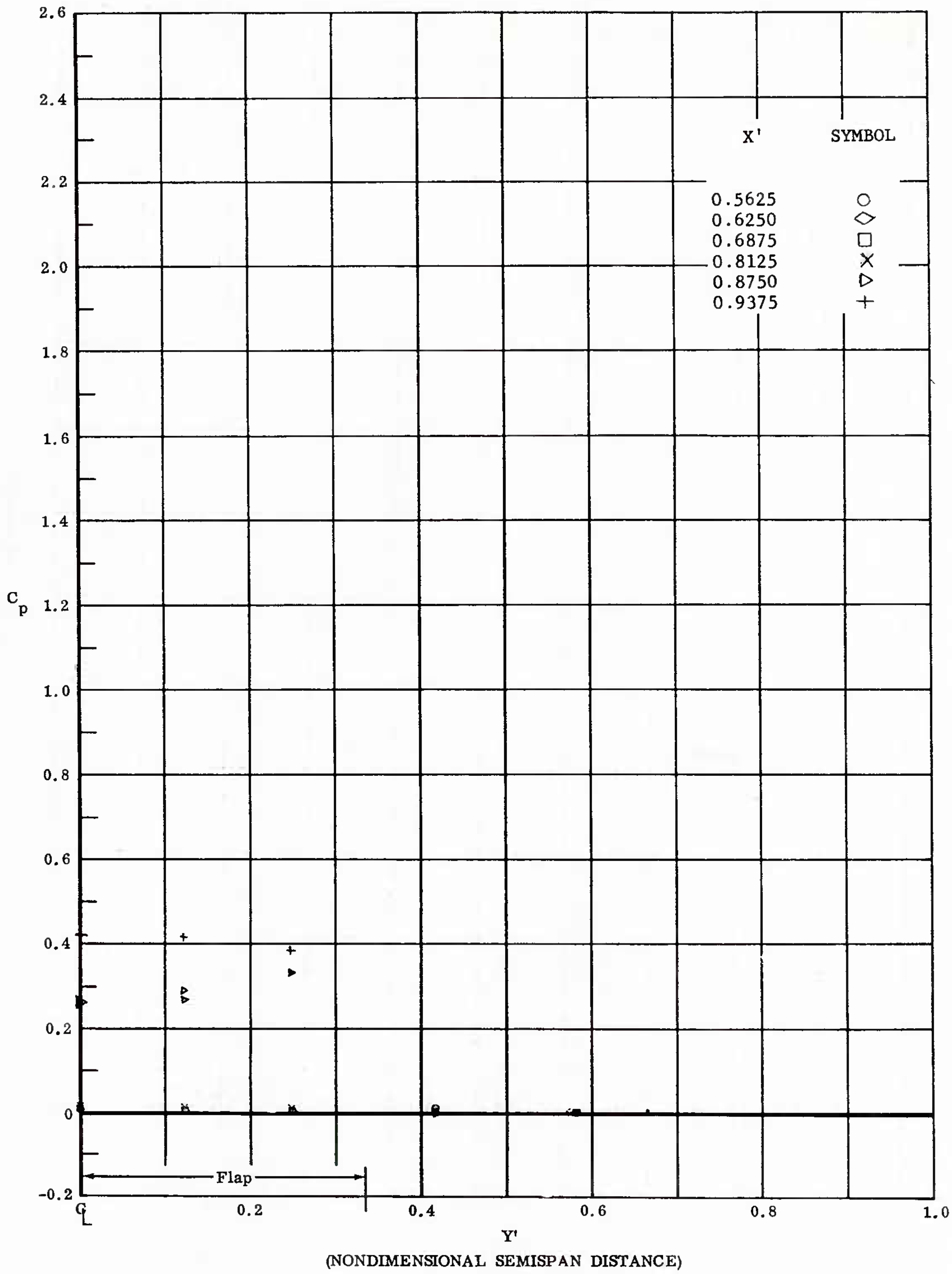


Fig. 121 Spanwise Pressure Distributions; Ramp On, No Coolant Flow, $\alpha = +5°$, $Re_\infty/ft = 3{,}300{,}000$.

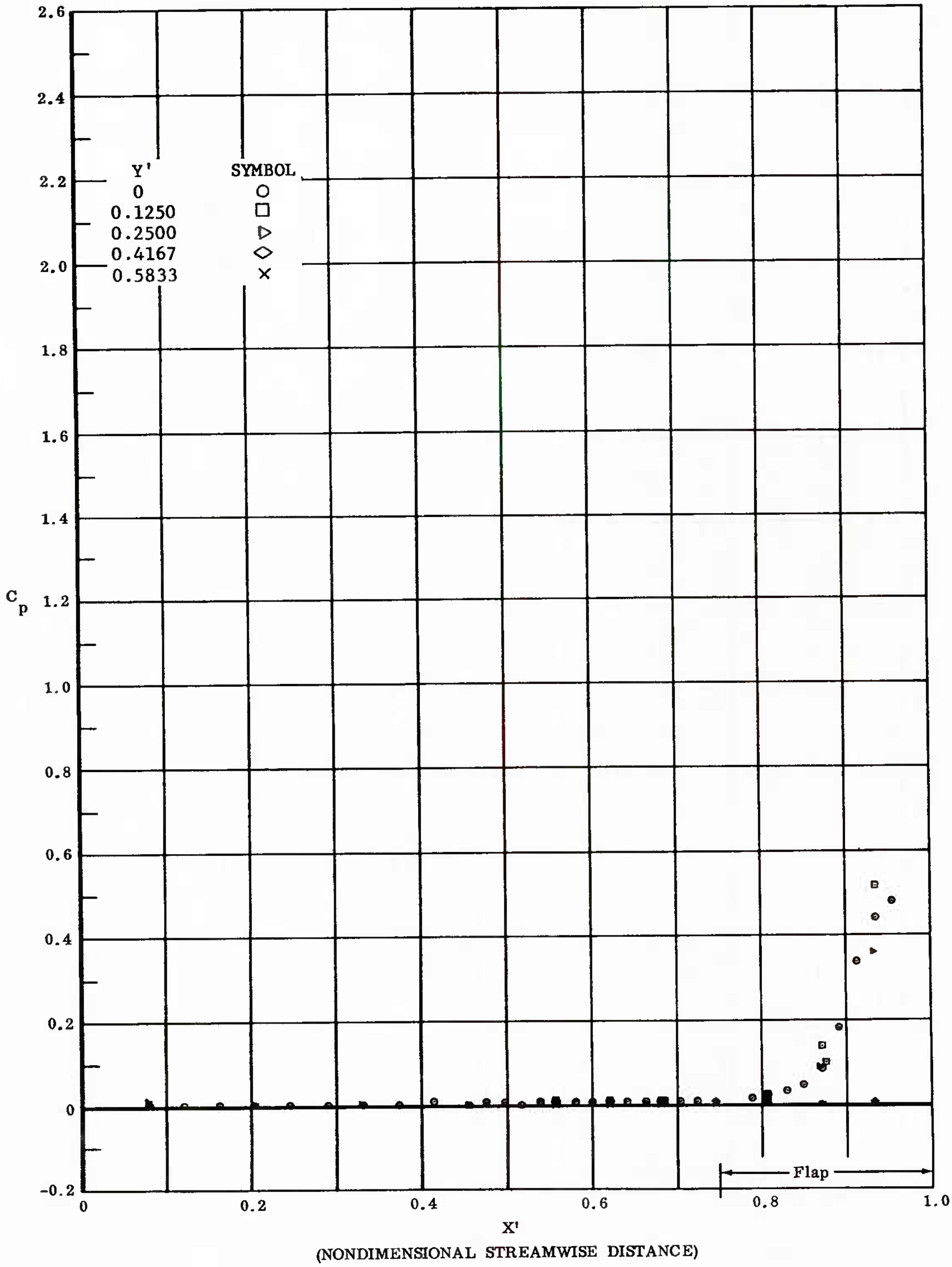


Fig. 122 Streamwise Pressure Distributions; Ramp On, Maximum Coolant Flow Rate, $\alpha = +5°$, $Re_\infty/ft = 3,300,000$.

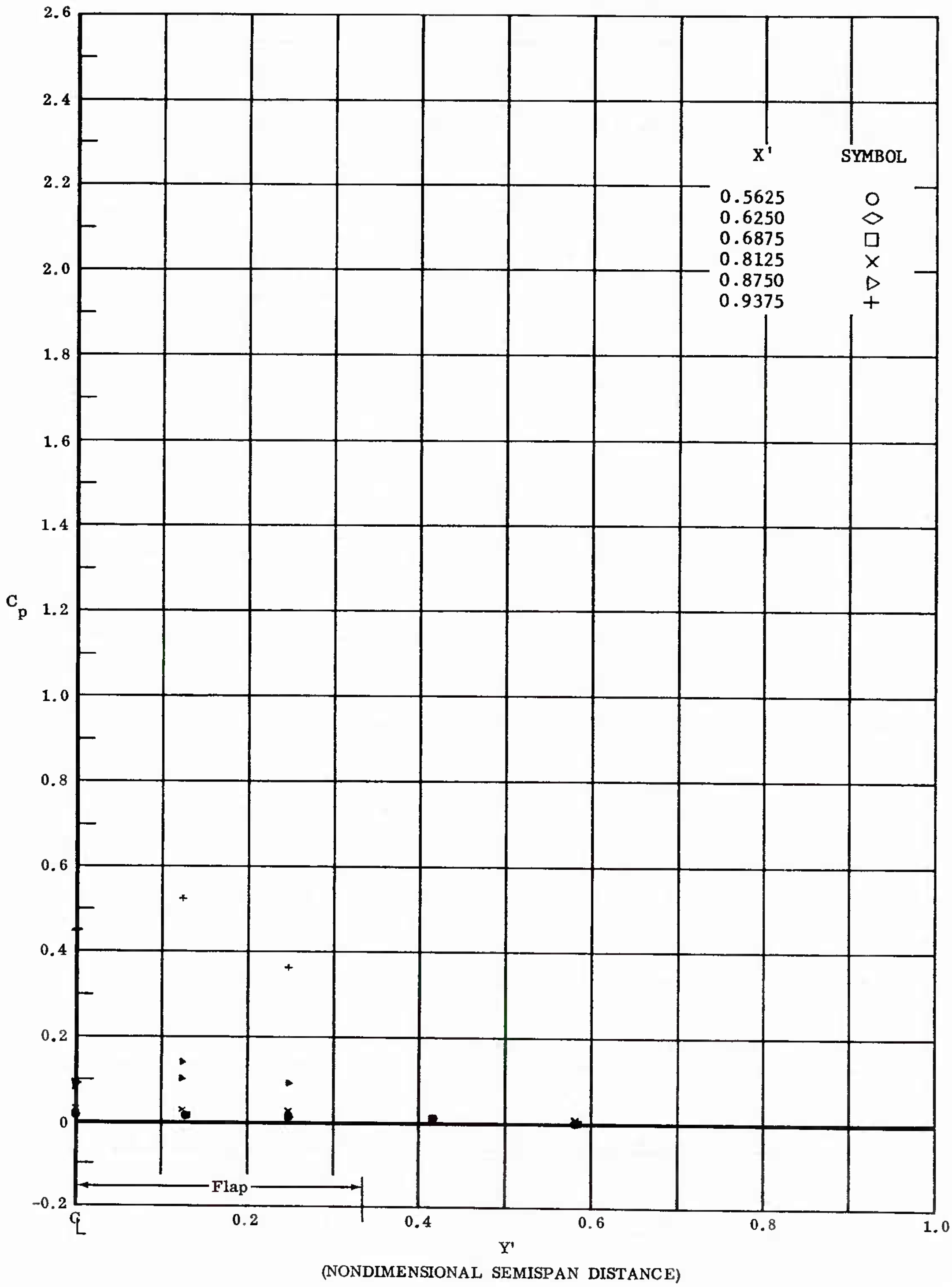


Fig. 122 Spanwise Pressure Distributions; Ramp On, Maximum Coolant Flow Rate, $\alpha = +5°$, $Re_\infty/ft = 3,300,000$.

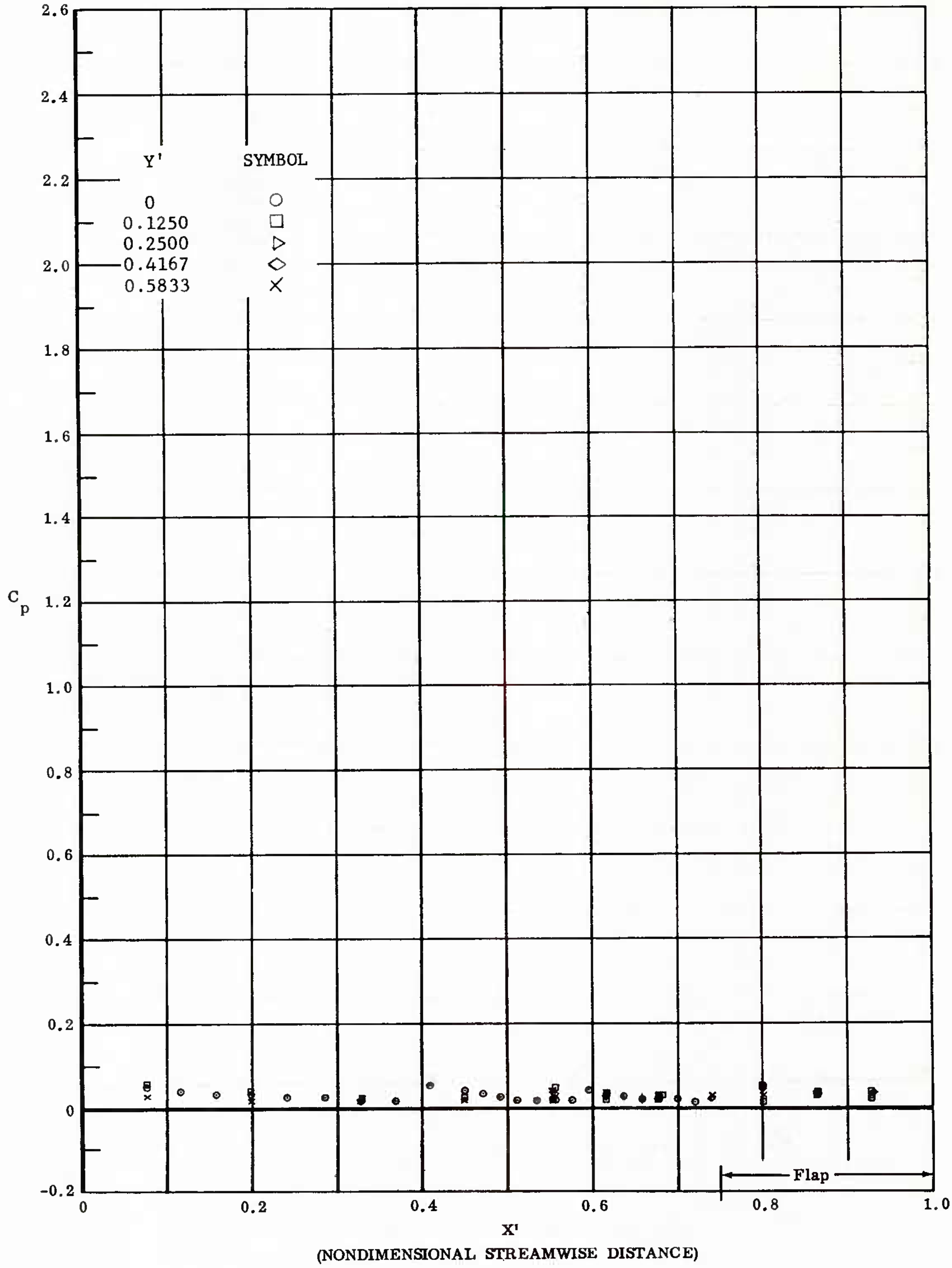


Fig. 123 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = +10°$, $Re_\infty/ft = 1,100,000$.

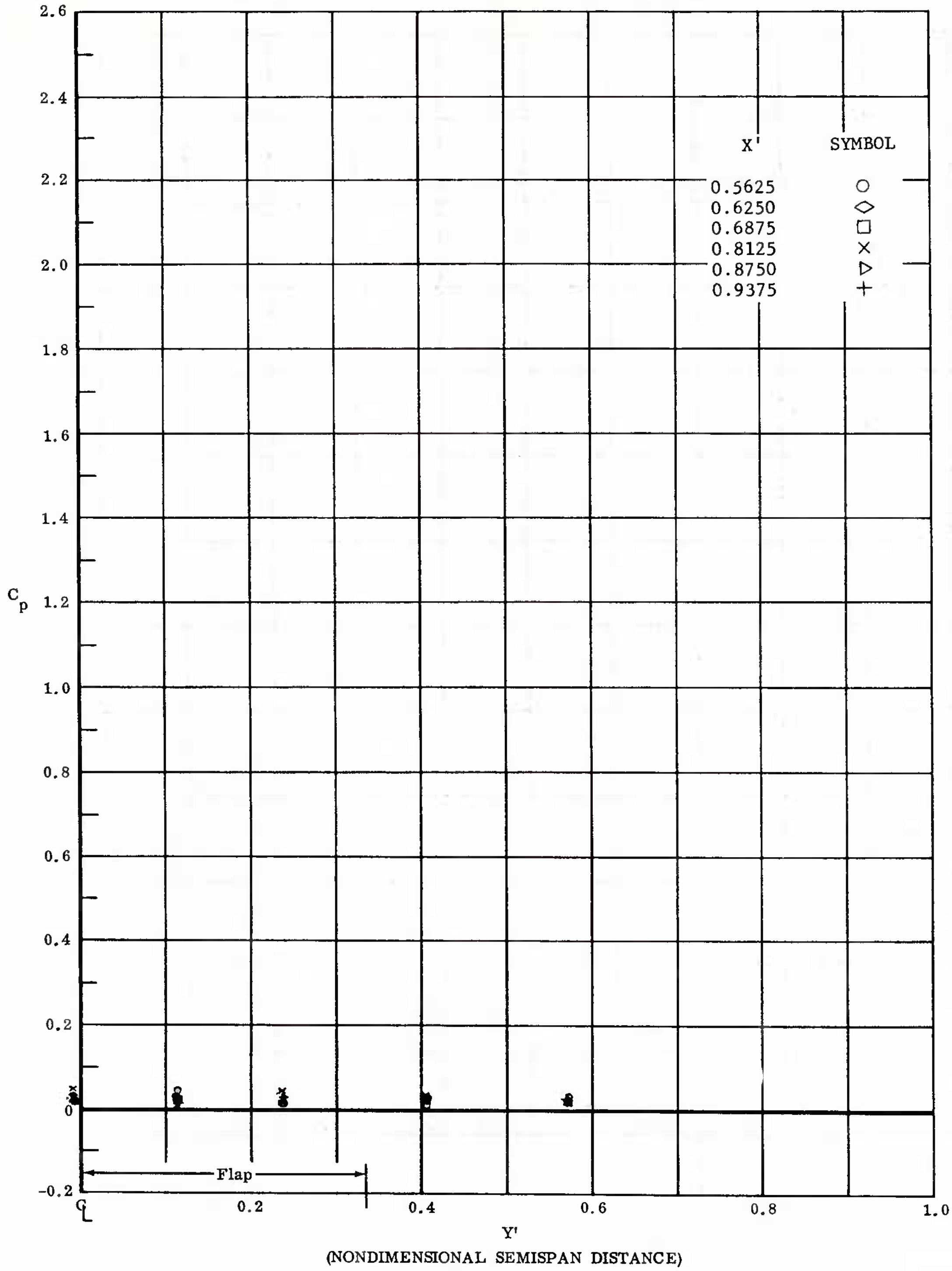


Fig. 123 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = +10^\circ$, $Re_\infty/ft = 1,100,000$.

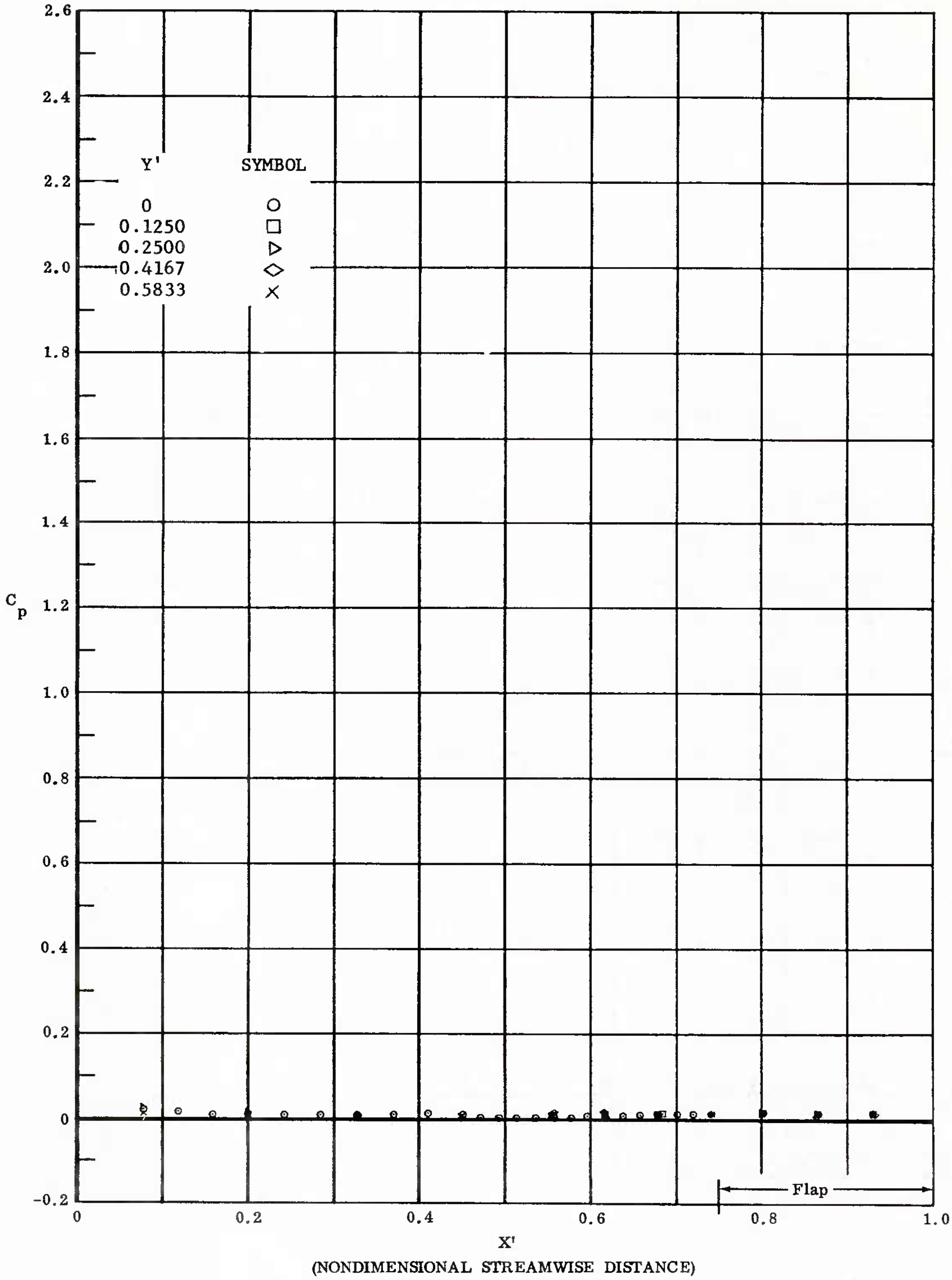


Fig. 124 Streamwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, $\alpha = +10°$, $Re_\infty/ft = 1,100,000$.

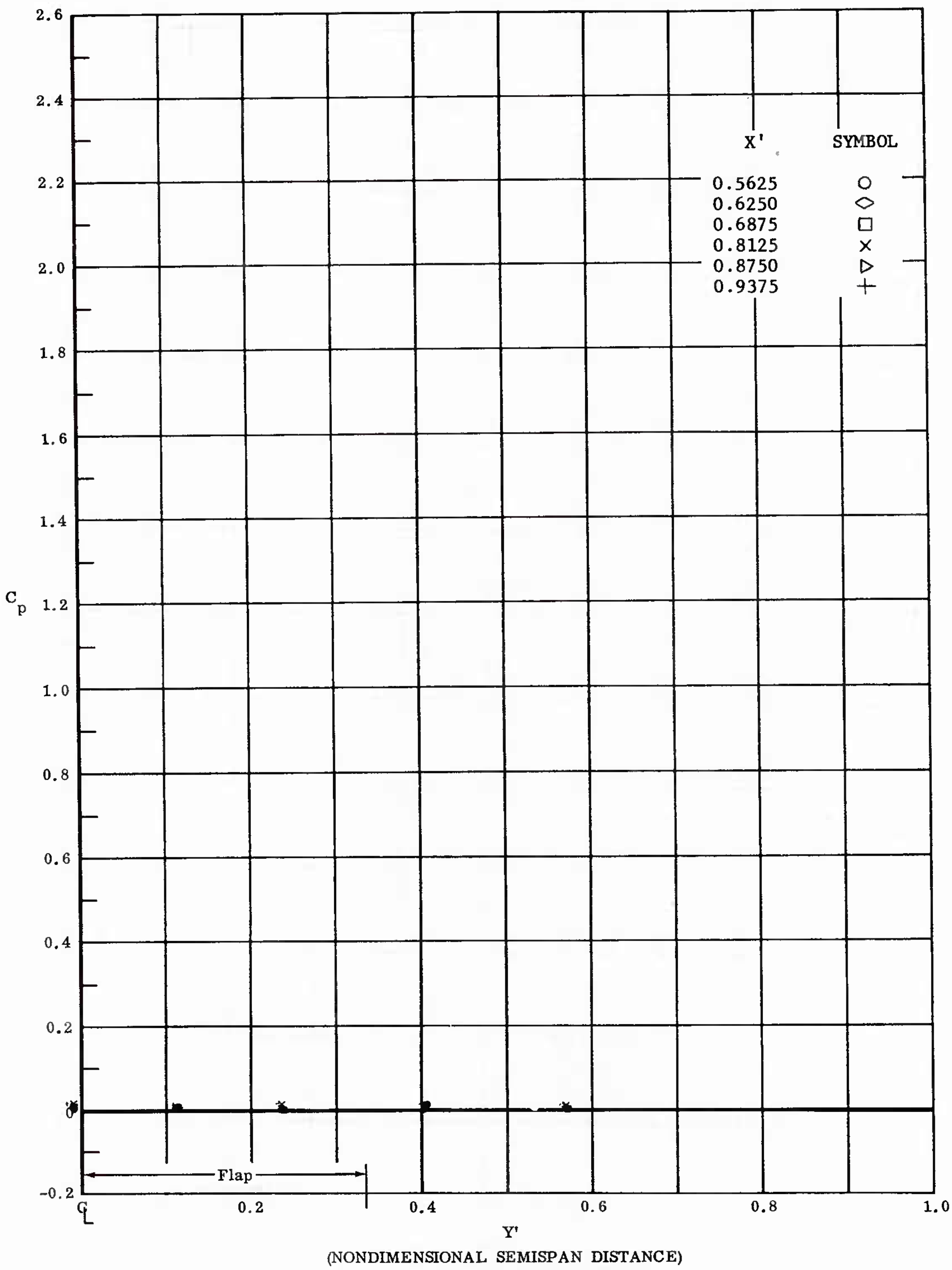


Fig. 124 Spanwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, $\alpha = +10°$, $Re_\infty/ft = 1,100,000$.

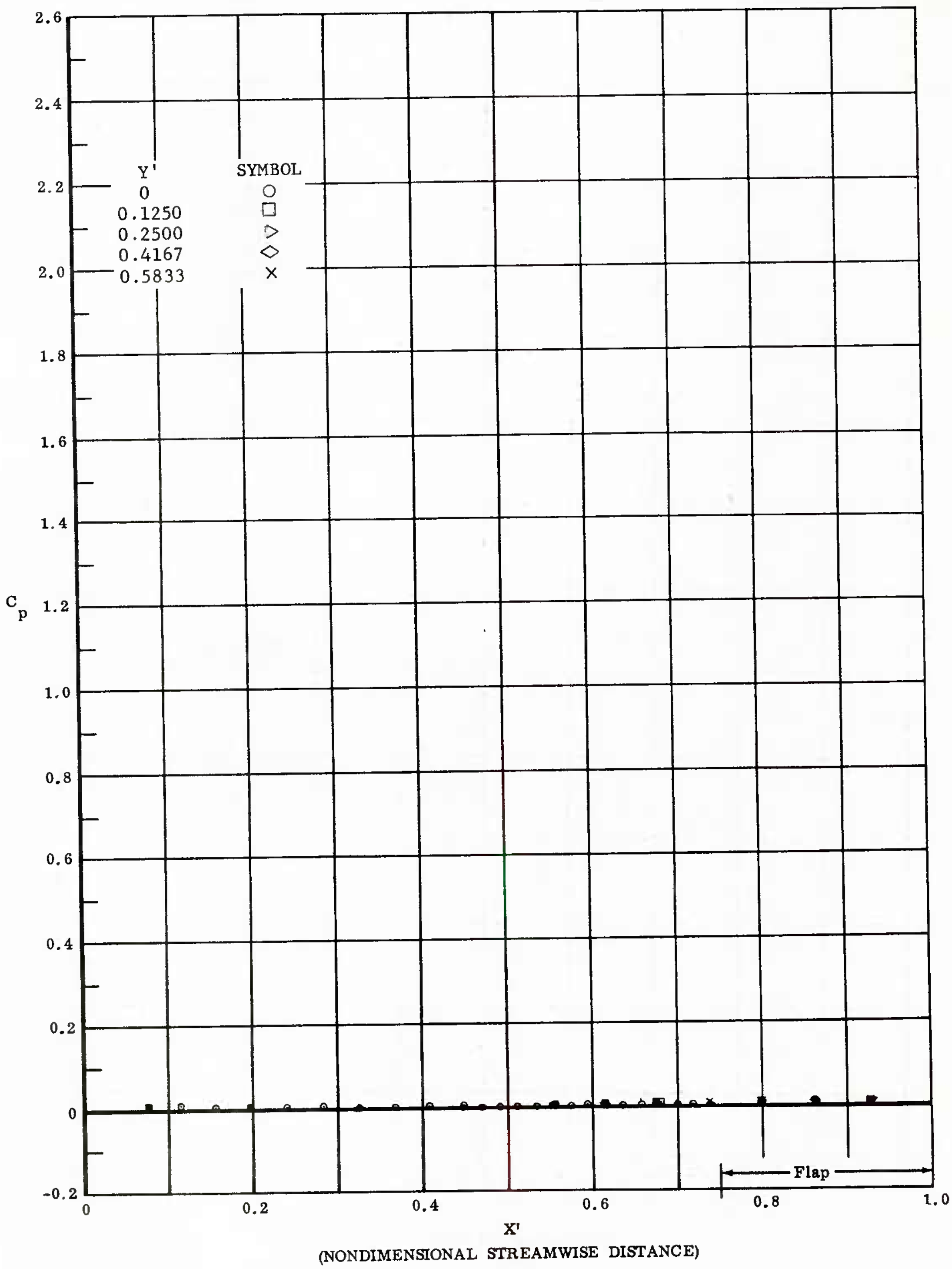


Fig. 125 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = +10°$, $Re_\infty/ft = 2,200,000$.

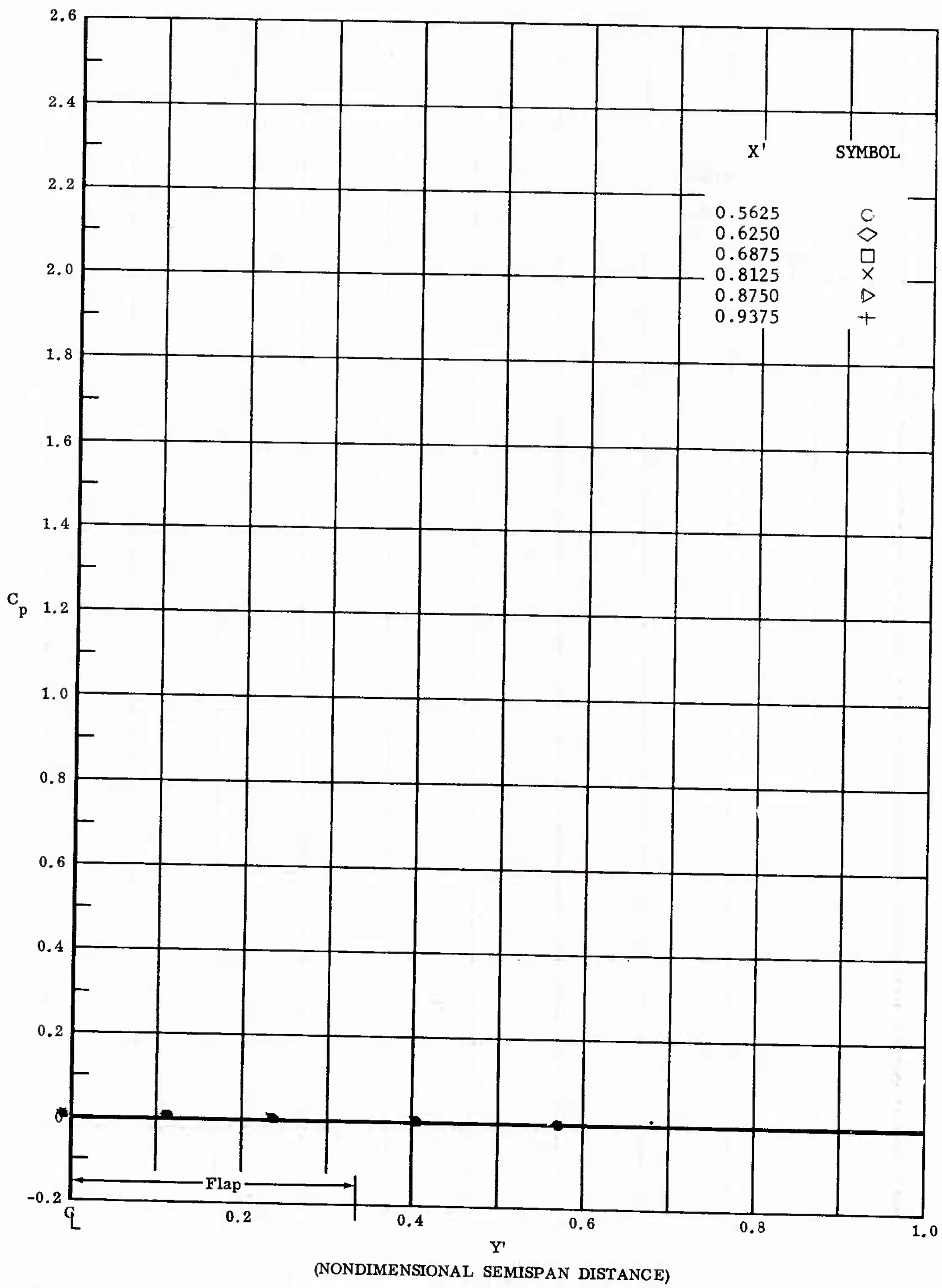


Fig. 125 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = +10°$, $Re_\infty/ft = 2,200,000$.

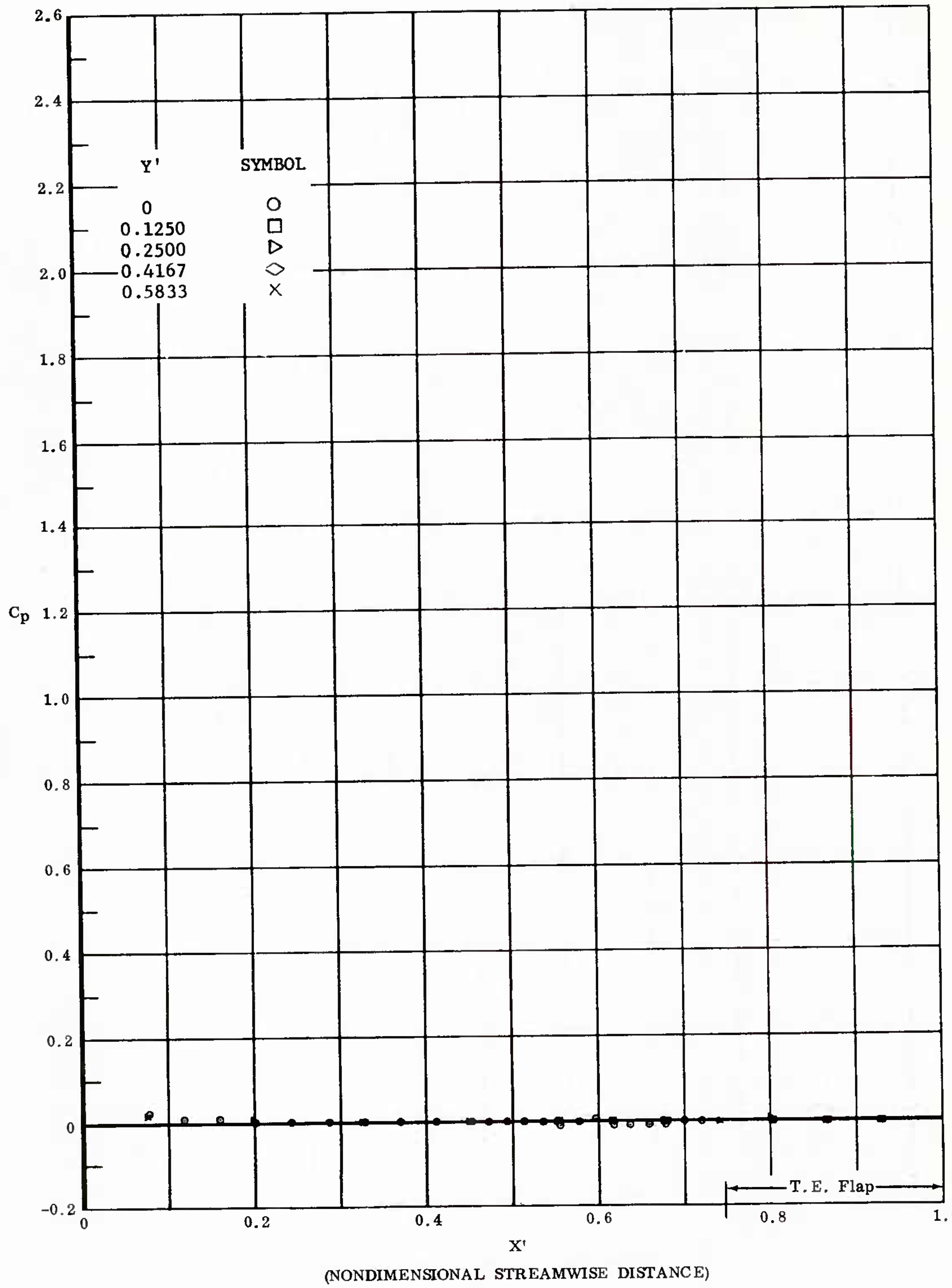


Fig. 126 Streamwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = +10°$, $Re_{\infty}/ft = 3,300,000$.

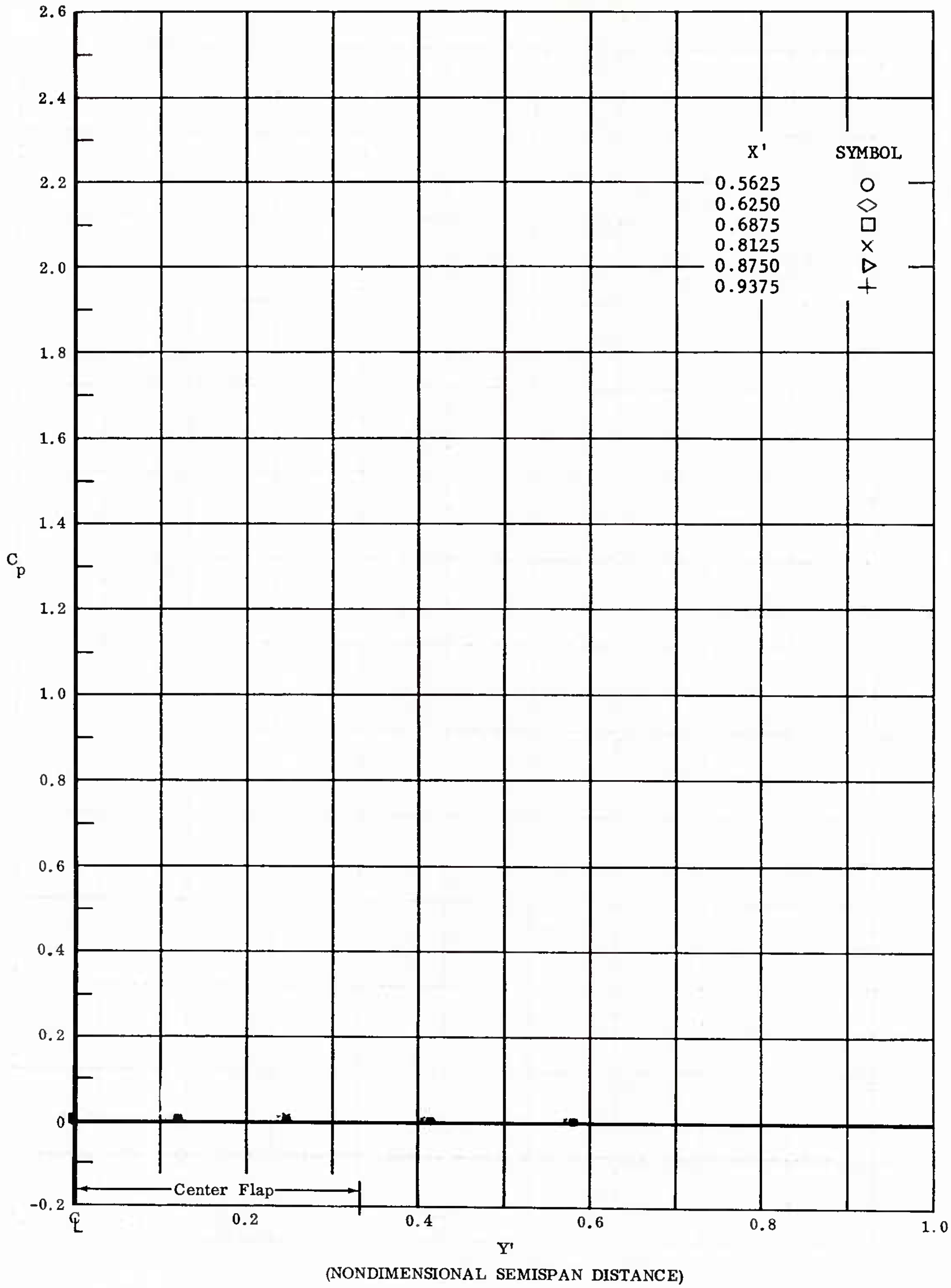


Fig. 126 Spanwise Pressure Distributions; Ramp Off, No Coolant Flow, $\alpha = +10°$, $Re_\infty/ft = 3,300,000$.

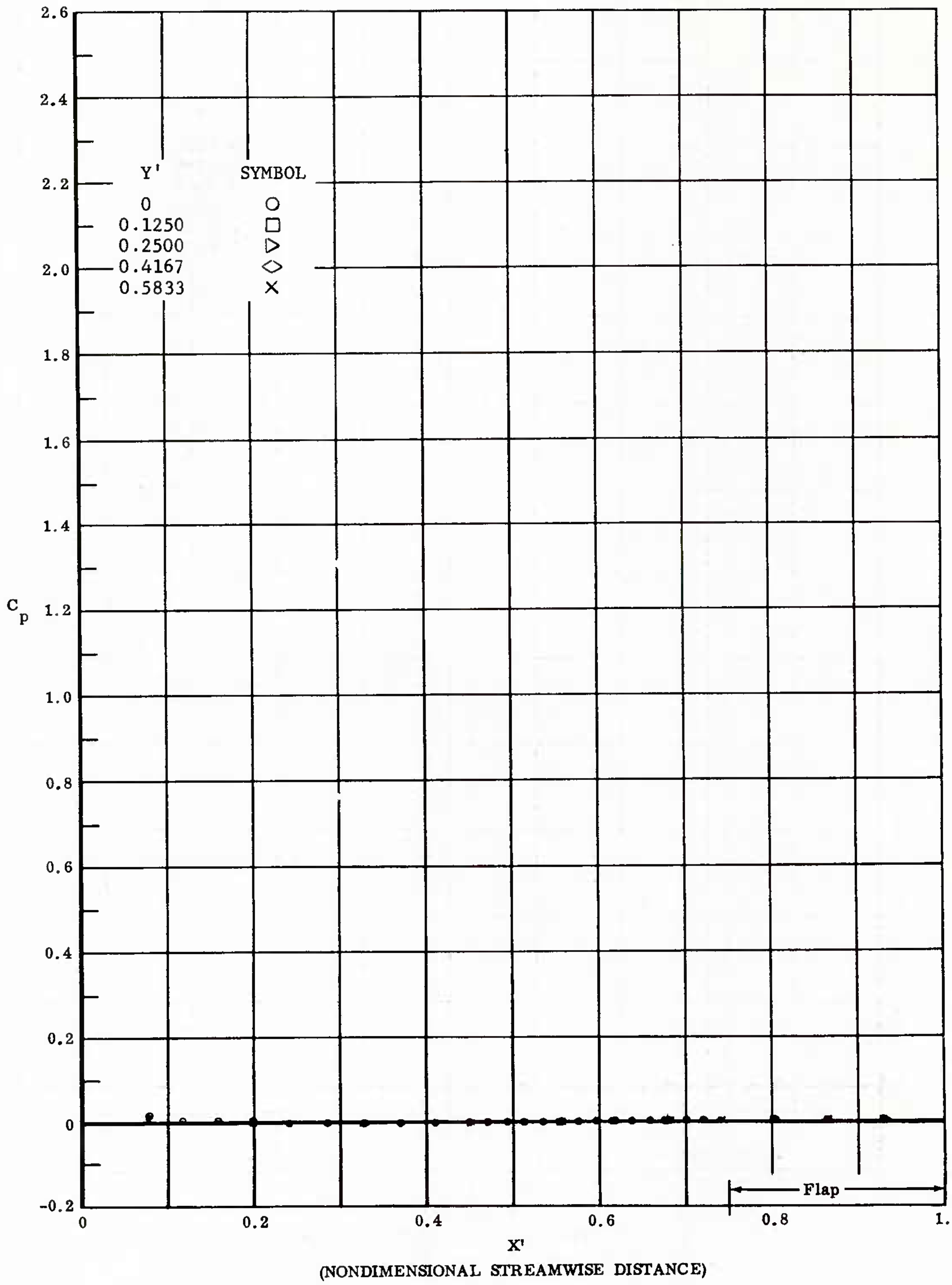


Fig. 127 Streamwise Pressure Distributions; Ramp Off, Medium Coolant Flow Rate, $\alpha = +10°$, $Re_\infty/ft = 3,300,000$.

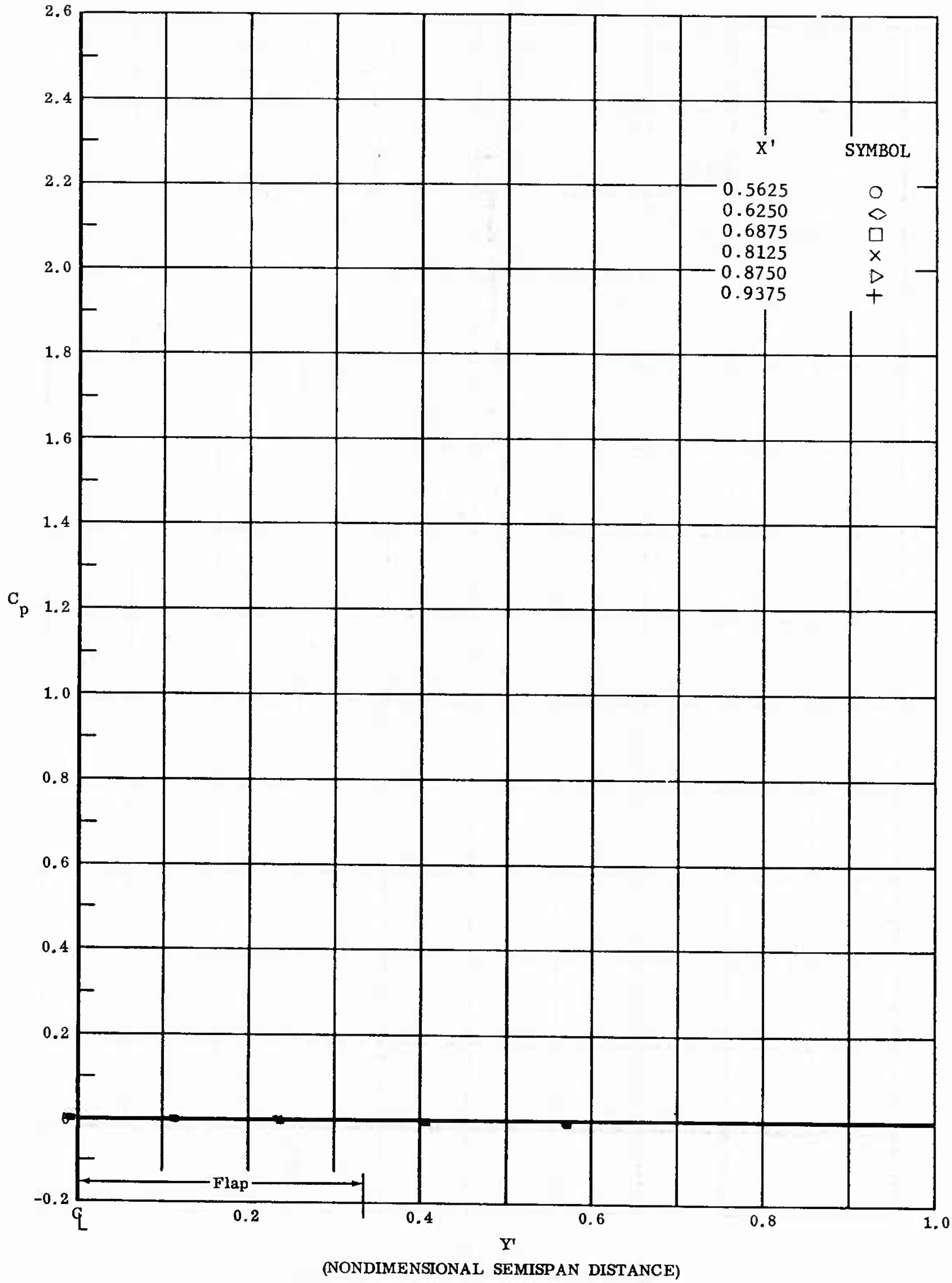


Fig. 127 Spanwise Pressure Distributions; Ramp Off, Medium Coolant Flow Rate, $\alpha = +10°$, $Re_\infty/ft = 3,300,000$.

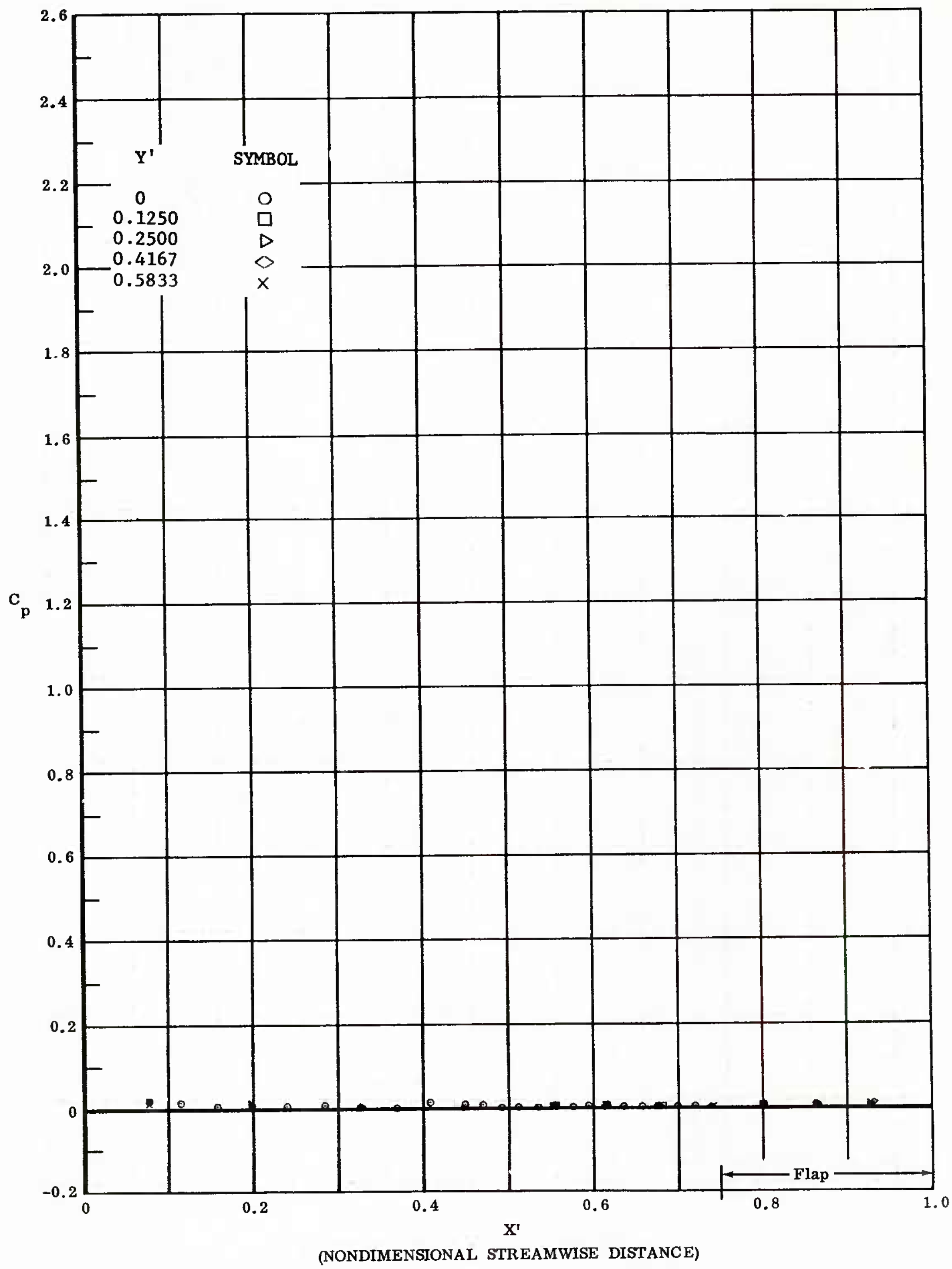


Fig. 128 Streamwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, $\alpha = +10°$, $Re_\infty/ft = 3,300,000$.

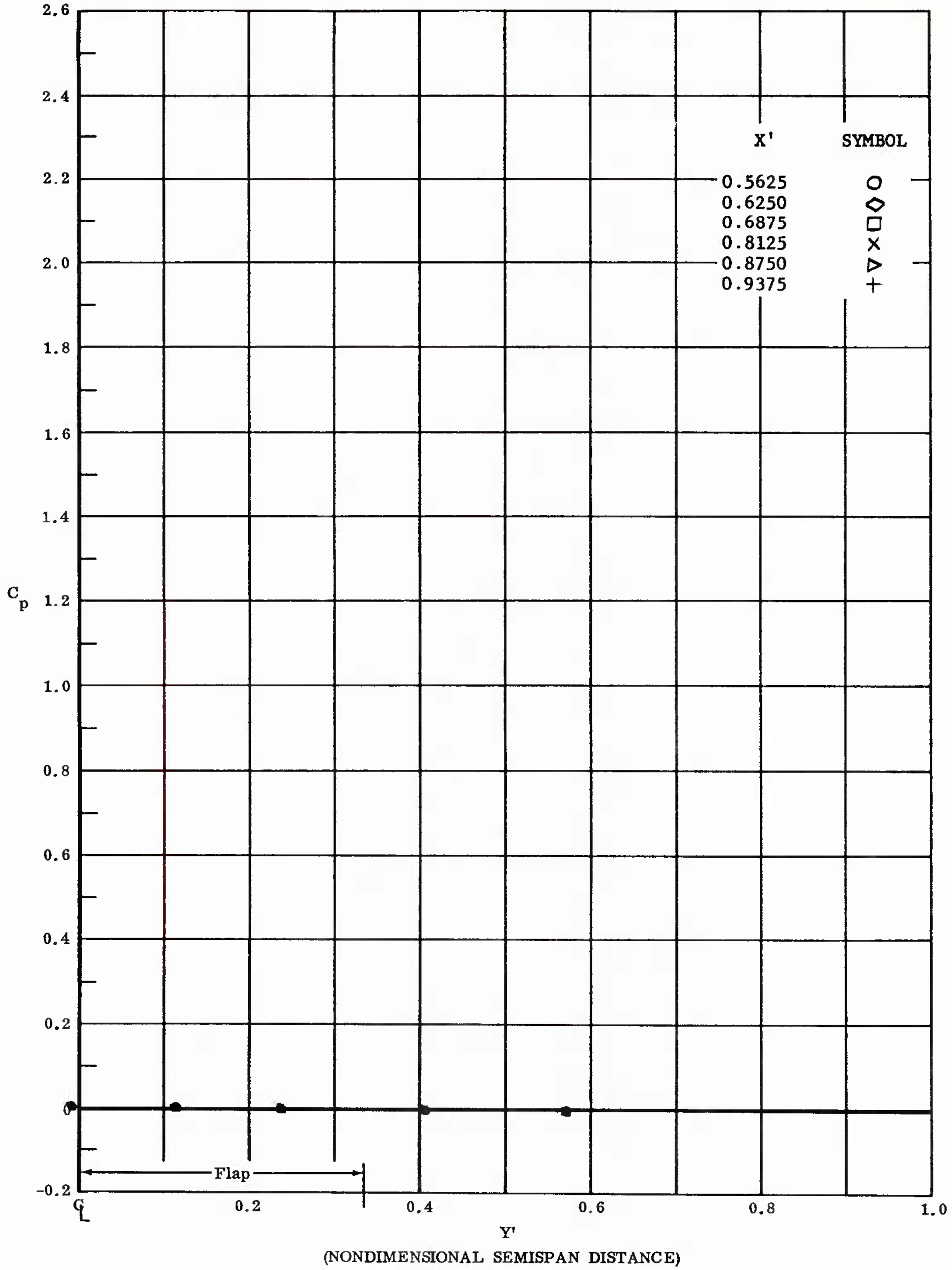


Fig. 128 Spanwise Pressure Distributions; Ramp Off, Maximum Coolant Flow Rate, $\alpha = +10°$, $Re_\infty/ft = 3,300,000$.