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DEPARTMENT OF MECHANICAL ENGINEERING
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TRAILING EDGE OBSERVATIONS OF THE STEAM TUNNEL EXPERIMENT

by

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submitted to

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for M.E. 490

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ABSTRACT

Futher investigation of trailing edge activity of the steam tunnel suggests a large dependence of periodicity of finger shedding, maximum length of fingers, and number of fingers present at any instant on steam velocity and shear force as well as flow rate of the water film.

INTRODUCTION

As steam expands through a turbine, water builds up on the turbine blades in the low and intermediate pressure regions of the turbine, as the steam changes from super-heated vapor to a two phase mixture of water and steam. The water as it is thrown off, can, over a period of time, have a erosive effect on successive blades as droplets with high momentum impinge on these blades in the latter stages of the turbine.

A means of simulating the action of the water as it is thrown off the turbine blade is provided by the steam tunnel experiment.

In this experiment a simulated turbine blade is inserted in a plexiglass test section. Steam, whose velocity may be varied by a throttle valve, enters the text section at one end. At the same time, a water film whose flow rate may also be varied, is allowed to travel over the surface of the blade, being driven by the steam. High speed motion pictures are then taken viewing the blade from above. These films slow the action sufficiently for an analysis to be performed. There are basically three areas of interest: one is the nature of the flow water over the surface of the blade. The second is the activity at the trailing edge of the blade. The third is the motion of the water droplets after they are shed from the blade.

My area of study concerned the activity at the trailing edge of the blade. The action here is basically one of periodic formation of water spikes or fingers and their shedding. To investigate the nature of finger shedding, I relied heavily on data that had been collected previously by S. Blome, E. Trier, and A. Bou-Maroun. This group had defined and recorded two basic parameters of the trailing edge. One is the maximum length (L_{max}) of the fingers present at a certain time for a given steam velocity (V_s) and water film flow rate (Q). The other is the "wave length" (λ) which is the distance between the fingers (see Fig. 1). This data was collected by analyzing the motion picture films every .016 second. The number of fingers present and L_{max} were recorded in tabular form, and frequency plots of L_{max} vs. time were also made.

ANALYSIS

The first procedure was to determine some average maximum finger lengths (L_{mp}). This established some reference finger length for a given V_s and Q. The procedure for finding L_{mp} was the following: for a given V_s and Q the number of L_{max}'s of a particular length were recorded. For example, for a steam velocity of 93 m/sec and Q of 5 cm^3/min., there might be 5 L_{max}'s of 0.5 ± 0.1125 cm in length, 11 L_{max}'s of 1.0 ± 0.1125 cm in length, and so on. The total is then found and L_{max} is then categorized by percent. Using the same example, if 76 L_{max}'s were counted, L_{max} of 0.5 cm constituted 5/76 times 100 = 3.95% or 4% of the total. L_{max} of 1.0 cm constituted 11/76 times 100 = 6.5% of the total. After these percentages were compiled, a histogram was made plotting the percent of total vs. L_{max}. L_{max} was divided into intervals of 0.225 cm. L_{mp} was then found by summing the percents times each interval and dividing by 100% (see Fig. 2).

The next parameter sought was that of a time interval between appearances of large fingers of T_{mp}. The value of L_{mp} was plotted on the frequency plots of L_{max} vs. time then the peaks were counted which were above L_{mp}. A peak was counted if a point was 3 cm above the previous point and/or L_{mp} (see Fig. 3). T_{mp} is then the total time divided by the number of peaks.

Two large tables were made of trailing edge parameters. One was based on most probable values, and the other based on average values of L_{max}, with time between peaks (T_{avg}) found in previous analysis by A. Bou-Maroun et al. The parameters defined are as follows:

V_s - velocity steam

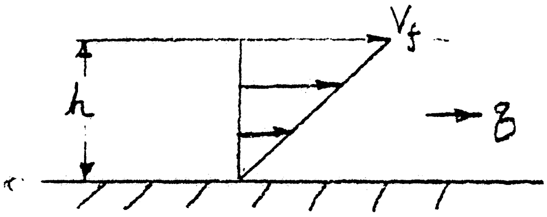
q - specific flow rate

h - height of film, thickness

T - most probable or average time between finger peaks

V_f Velocity of Film

was found in the following manner: $q = \frac{V_f}{2} h$; $V_f = \frac{2q}{h}$



h is found from the graph of film thickness vs. V_S

$$V_f = \frac{2Q}{8(60)\,2.54 \times 10^{-3}\, h} \quad , \quad V_f = 1.64 \frac{Q}{h}$$

L_{MAX} most probable or average finger length

Re_f	Film Reynold's No.	$\frac{V_f h}{\nu_w}$
Re_S	Steam Reynold's No.	$\frac{V_S D_H}{\nu_S}$
S_1	Most Probable Film Strouhal No.	$\frac{L_{mp}}{T_{mp} V_f}$
S_2	Most Probable Steam Strouhal No.	$\frac{L_{mp}}{T_{mp} V_S}$
S_3	Average Film Strouhal No.	$\frac{L_{AVG}}{T_{AVG} V_f}$
S_4	Average Steam Strouhal No.	$\frac{L_{AVG}}{T_{AVG} V_S}$

S_5 $\frac{\lambda}{T_{mp} V_f}$

S_6 $\frac{\lambda}{T_{AVG} V_f}$

S_7 $\frac{\lambda}{T_{mp} V_S}$

S_8 $\frac{\lambda}{T_{mp} V_S}$

Y_1 (cm) Reference Length Based on Steam $\left(\frac{2\sigma h}{\rho_s V_s^2}\right)^{1/2}$

$$Y_1 = \left(\frac{2\,(72.8)\,2.54\times10^{-3}}{1.1\times10^{-4}}\frac{h}{V_s^2}\right)^{1/2} = \left(3362\frac{h}{V_s^2}\right)^{1/2}$$

Y_2 (cm) Reference Length Based on Film $\left(\frac{2\sigma h}{\rho_w V_f^2}\right)^{1/2}$

$$Y_2 = \left(\frac{2\,(72.8)\,2.54\times10^{-3}}{1}\frac{h}{V_f^2}\right)^{1/2} = \left(.37\frac{h}{V_f^2}\right)^{1/2}$$

$$L^*_{mp} = \frac{\lambda}{L_{mp}}$$

$$L^*_{AVG} = \frac{\lambda}{L_{AVG}}$$

From these tables, plots were made of the following parameters so that some trends in the finger shedding could hopefully be obtained. These plots are:

1. L_{mp} vs. V_s — Q is used as the governing parameter
2. T_{mp} vs. V_s — Q is the governing parameter
3. λ vs. V_s — with Q governing.
4. Strouhal numbers vs. Steam Reynold's number (S vs. Re_s)
5. L^* vs. Re_s — using Re_f as governing parameter
6. $\frac{L_{mp}}{Y_1}$, $\frac{L_{mp}}{Y_2}$, $\frac{\lambda}{Y_1}$, $\frac{\lambda}{Y_2}$, $\frac{L_{AVG}}{Y_1}$, $\frac{L_{AVG}}{Y_2}$

   Re_f is the governing parameter

RESULTS AND CONCLUSIONS

Overall there appears to be a good correlation between the frequency of finger shedding, the most probable length of fingers, and wave length with steam velocity. Flow rate also appears to have some influence on these trends. There is little difference between the dimensionless plots using most probable values and those using average values for L_{max}, T, and L^*. It should be noted that an anomally in the data appears to exist for steam velocity 975 $\frac{ft}{sec}$ (297 $\frac{m}{sec}$) or Re_s of 170,000. This is also found in previous analysis by A. Bou-Maroun and I believe it to be error in the data rather than a "transition" point in the behavior of finger shedding. Detailed results plots are as follows:

1) L_{mp} vs. V_s

We find in this plot that L_{mp} is generally converging toward some intermediate value of L_{mp} around 0.3 cm at the high steam velocities Further, the lower flow rates seem to tend toward lower L_{mp}'s, and higher flow rates yield higher L_{mp}'s. We might expect this since the shear force of the steam is lower at low velocities and the water, at high flow rates, has sufficient momentum to produce more stable and longer fingers. When the steam velocity is increased the stability of the fingers reduces, and, as well, their length. For low flow rates the momentum of the water is lower, thus stable fingers tend to be shorter. But, as steam velocity (thus the shear force) increases, this tends to support longer fingers

2) T_{mp} vs. V_s

We find that the time between finger peaks seems to be increasing with higher steam velocities. Also the lower flow rates seem to have the highest (longest) period between peaks. One explanation for this is that the shear force, due to the steam, as it increases, is sweeping out larger volumes of water. For low flow rates it takes more time for this water to be replaced and thus fingers to be formed again. This, as well, may account for the trend as a whole.

3) λ vs. V_s.

This plot shows that the number of fingers is decreasing with higher steam velocities, the low flow rates seem to have more fingers than higher flow rates though this is questionable. In this case the higher shear forces seem to be driving the water off in large sheets The stability of individual fingers decreases.

4) S vs. Re_s

The Strouhal number gives some indication of the frequency of an event. With these plots we can support further what has been established for T_{mp}. That is, in all cases, the frequency between finger formation is decreasing with higher shear stresses, due to increasing steam velocity. The magnitude of S depends on whether V_f or V_s is used. Flow rate does not appear to have a definite influence on this trend. Strouhal numbers using λ also are decreasing

5) L^* vs. Re_s

The ratio of λ to L_{mp} is decreasing with higher Reynolds numbers. This is understandable since both L_{mp} and λ decrease (or tend to) with higher steam velocities. We do find that λ / L_{avg} orders with increasing flow rate. That is, the ratio is higher for lower flow rates and lower for higher flow rates. This trend is not so obvious for λ / L_{mp}. We do know that λ is greater for low flow rates than for high flow rates and that finger length is smaller at low flow rates than for high so this trend should be observable in our data.

6) $\frac{L_{mp}}{Y_1}$, $\frac{L_{mp}}{Y_2}$, $\frac{\lambda}{Y_1}$, $\frac{\lambda}{Y_2}$, $\frac{L_{AVG}}{Y_1}$, $\frac{L_{AVG}}{Y_2}$ vs. Re_s

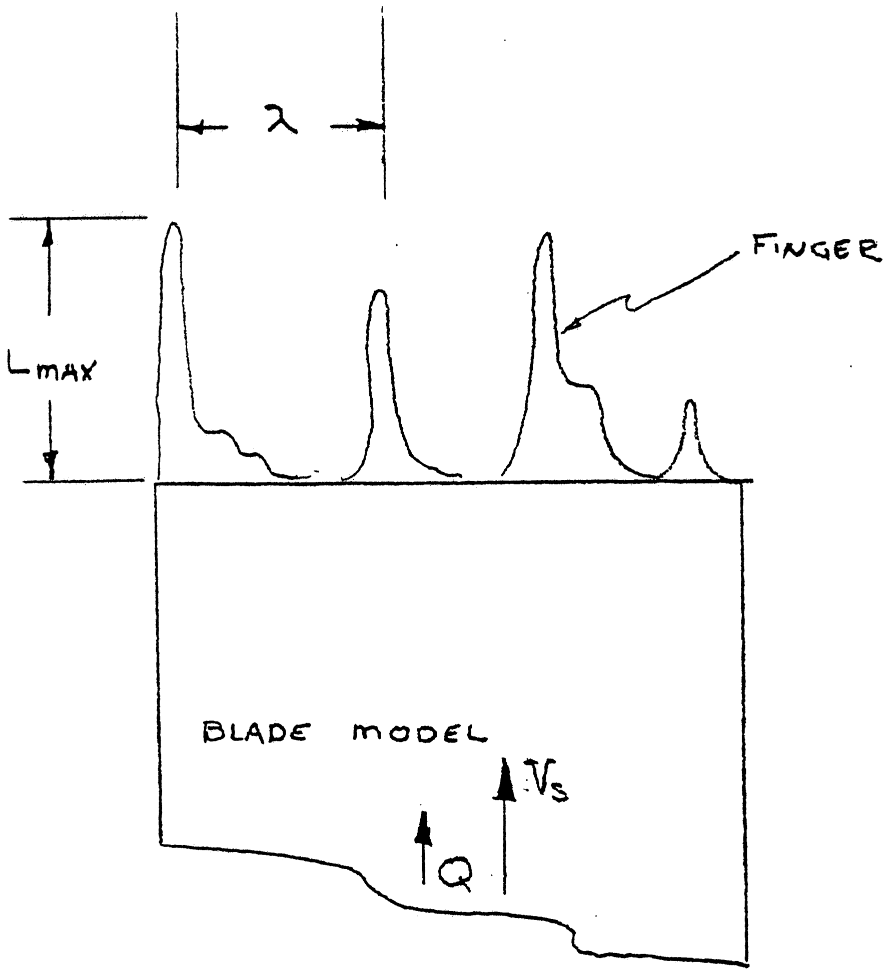
These ratios are always increasing with increasing Reynolds numbers. The plots seem to order with flow rate for these ratios using L_{avg}, but this trend is not so clear for the ratios using L_{mp}. Since Y_1 and Y_2 are fixed for a given Re_s, but L_{avg} and L_{mp} depend on flow rate the reason for this trend then becomes apparent. Note in the plots of L/Y that at Re_s of 170,000 the points are very disimilar from the overall trend, for this reason I regard the data at this point as erroneous rather than regarding this point as some transition.

In conclusion I find that with increasing steam velocity and thus shear stress on the fingers that: The length of the fingers will generally decrease for high flow rates but increase, somewhat, for low flow rates. That is, that the stability of fingers for lower steam velocities and higher flow rates decreases, but the stability of fingers at low flow rates increases at higher steam velocities. Second, the time period between finger formation generally increases with increasing steam velocity as larger volumes of water get swept out and increased time is needed to replace a sufficient volume upon which the shear forces can act. Lower flow rates will take more time than higher flow rates. Third, individual fingers are less stable at higher steam velocities and the higher shear forces act to sweep the water out in large sheets.

Footnote

In this report I have provided all tables and graphs used to find L_{mp}, as well as a comparison of L_{avg} found by A Bou-Maroun (Report No. Umich 014571-9-I) and L_{mp}. T_{avg} was also obtained from this report. All the plots mentioned and parameter tables are also included.

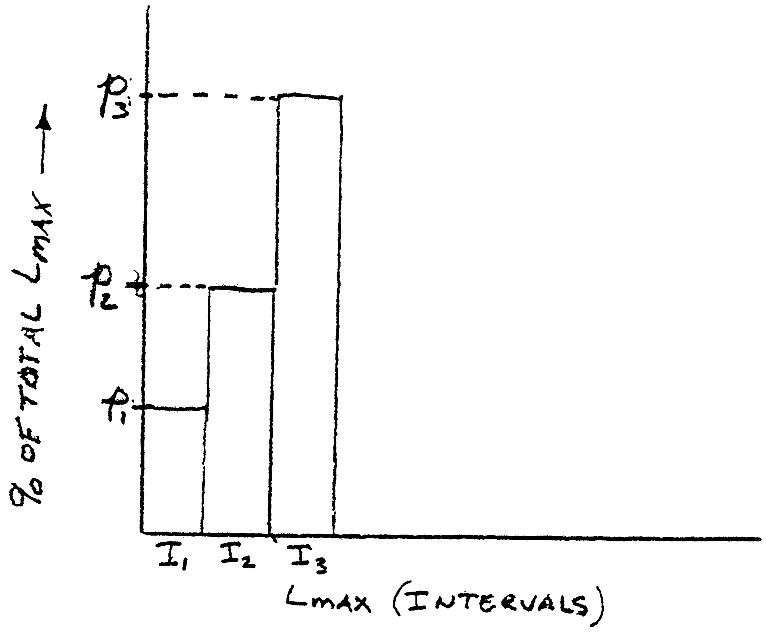
FIG. 1



$$\lambda = \frac{\text{WIDTH BLADE}}{\text{NUMBER OF FINGERS}}$$

FIG. 2

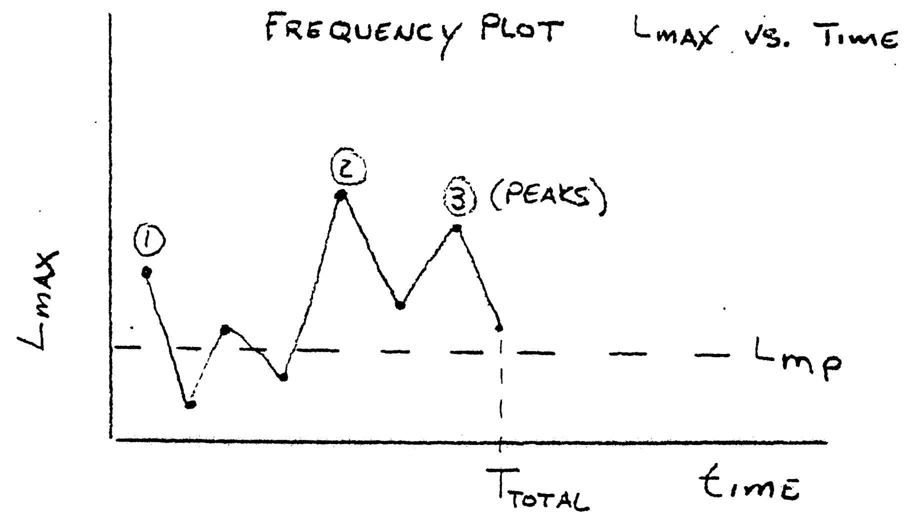
HISTOGRAM FOR Lmp DETERMINATION



$$L_{mp} = \frac{P_1 I_1 + P_2 I_2 + P_3 I_3 + P_N I_N}{100}$$

FIG. 3

Tmp DETERMINATION



PEAK CRITERION: 1) POINT IS 3CM ABOVE PREVIOUS POINT

2) POINT IS ABOVE Lmp

$$T_{mp} = \frac{T_{TOTAL}}{\text{NUMBER OF PEAKS}}$$

TRAILING EDGE PARAMETERS USING L^*, t, S MOST PROBABLE (mp)

V_0 m/s	q cm^2/s	V_f cm/s	h mils	λ cm	$L_{MAX}^{(mp)}$ cm	Re_f	Re_s $\times 10^{-3}$	t_{mp} s	Y_1 $\times 10^{+2}$	Y_2	S_1	S_2 $\times 10^{+5}$	S_5	S_7 $\times 10^{+4}$	S	L^*_{mp}
93	.010	9.45	1.1	1.25	.1125	2.8	53.3	.098	.65	.09	.154	12.2	1.71	13.7		11.11
	.021	10.93	1.5	1.09	.1125	5.6		.068	.76	.07	.151	17.6	1.47	17.2		9.69
	.031					8.4										
	.043	16.4	2	.93	.675	11.26		.061	.88	.052	.675	11.8.9	.93	16.4		1.38
	.063					16.9										
	.104					28.2										
158.5	.010	13.67	0.6	.74	.1125	2.8	90.9	.087	.28	.034	.092	7.9	.61	5.2		6.58
	.021	18.22	0.9	.65	.1125	5.6		.072	.35	.032	.086	9.7	.50	5.7		5.78
	.031	2236	1.1	.59	.1125	8.4		.056	.38	.029	.09	12.7	.47	6.6		5.24
	.043	25.23	1.3	.66	.3375	11.26		.067	.42	.027	.20	31.8	.39	6.2		1.96
	.063	30.75	1.6	.66	.5625	16.9		.057	.46	.025	.321	62.3	.38	7.3		1.17
	.104	39.1	2.1	.66	.1125	28.2		.073	.53	.023	.04	9.7	.23	5.7		5.87
252	.010	16.4	0.5	.34	.125	2.8	144	.30	.16	.026	.025	16.5	.07	.45		2.72
	.021	27.33	0.6	.41	.20	5.6		.245	.18	.017	.03	3.2	.06	.66		2.05
	.031	35.14	0.7	.41	.25	8.4		.103	.19	.014	.07	9.6	.11	1.6		1.64
	.043	36.4	0.9	.40	.375	11.26		.118	.22	.016	.087	12.6	.09	1.3		1.07
	.063	49.2	1.0	.43	.20	16.9		.087	.23	.012	.047	9.1	.1	2.0		2.15
	.104	58.6	1.4	.37	.375	28.2		.067	.27	.012	.096	22.2	.09	2.2		.987

TRAILING EDGE PARAMETERS USING $L^*_{,} t, S$ MOST PROBABLE (mp)

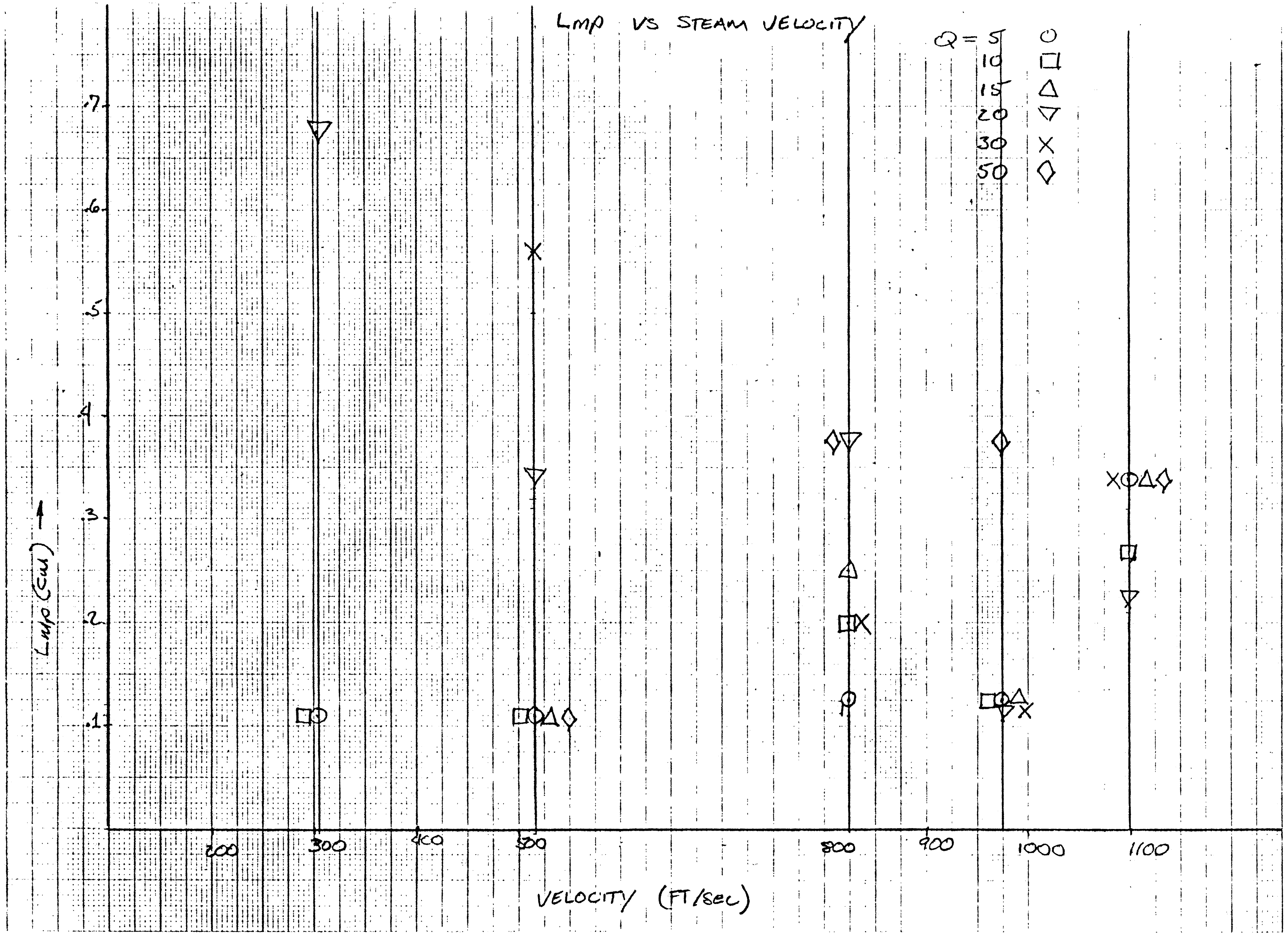
V_0 m/s	q cm²/s	V_f cm/s	h mils	λ cm	$L_{MAX}^{(mp)}$ cm	Re_f	Re_s $\times 10^{-3}$	t_{mp} s	Y_1 $\times 10^{+2}$	Y_2	S_1	S_2 $\times 10^{+5}$	S_5	S_7 $\times 10^{+4}$	S	L^*_{mp}
297	.010	20.5	0.4	.83	.125	2.8	170	.393	.12	.019	.016	1.1	.10	.71		6.64
	.021	32.8	0.5	.425	.125	5.6		.188	.14	.013	.02	7.6	.07	.76		3.4
	.031	41.0	0.6	.44	.125	8.4		.157	.15	.011	.019	2.7	.07	.94		3.52
	.043	46.9	0.7	.50	.125	11.26		.109	.16	.011	.024	3.9	.10	1.5		4.0
	.063	61.5	0.8	.50	.125	16.9		.131	.17	.009	.016	3.2	.06	1.3		4.0
	.104			.46	.375	28.2										1.23
335	.010	27.3	0.3	.64	.3375	2.8	192	.506	.095	.012	.024	2.0	.05	.38		1.90
	.021	32.8	0.5	.55	.27	5.6		.152	.12	.013	.054	5.3	.11	.11		2.04
	.031	41.0	0.6	.46	.3375	8.4		.152	.13	.011	.054	66.3	.09	.90		1.36
	.041	46.9	0.7	.37	.225	11.26		.288	.145	.011	.017	2.3	.03	.38		1.64
	.063	61.5	0.8	.46	.3375	16.9		.20	.155	.009	.027	5.0	.04	.69		1.36
	.104	82.0	1.0	.45	.3375	28.2		.22	.17	.007	.019	4.6	.02	.61		1.33

TRAILING EDGE PARAM('ERS USING L^*, t, S AVERAGE (AVG(

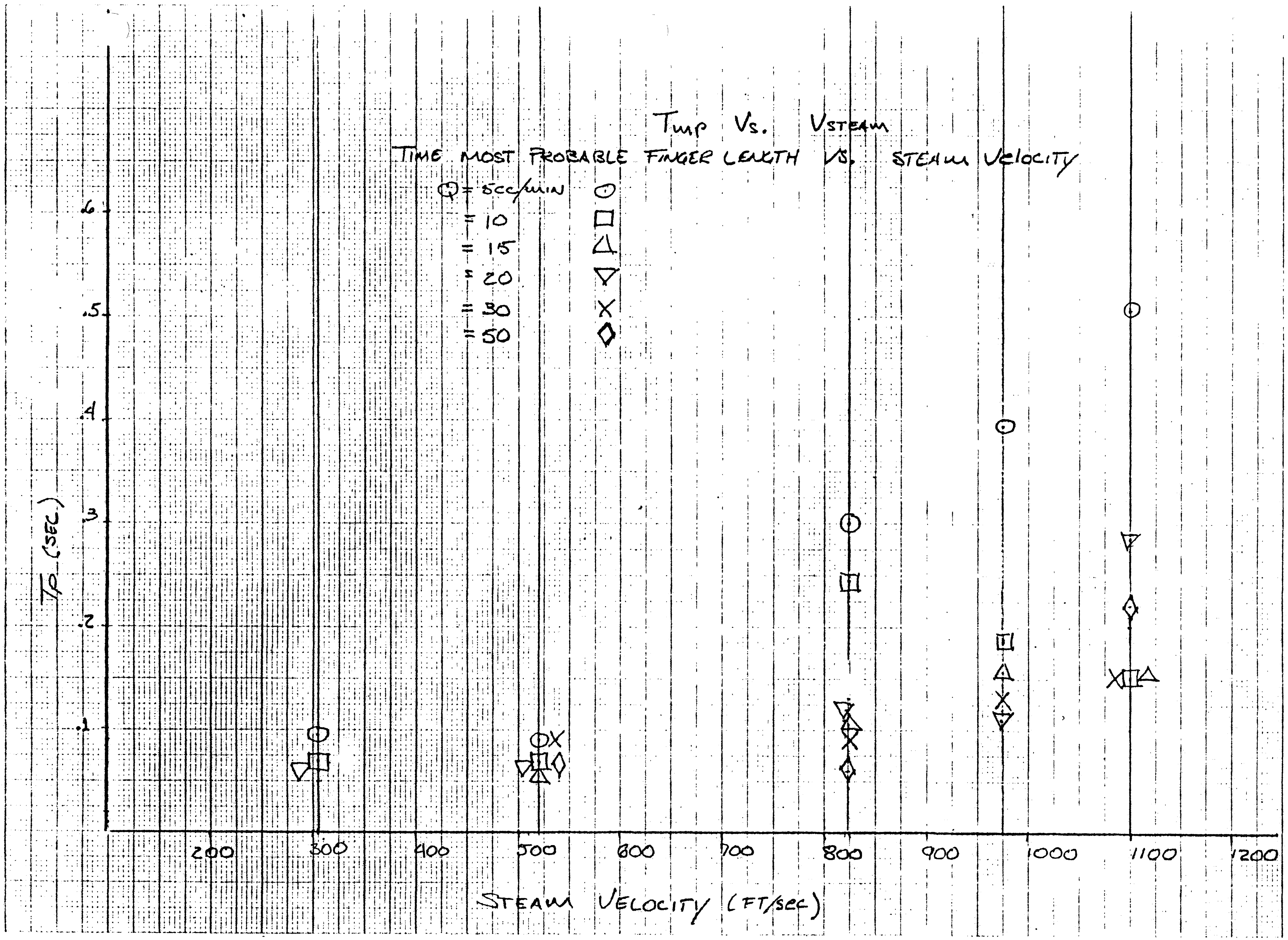
V_0 m/s	q cm²/s	V_f cm/s	h mils	λ cm	$L_{max}^{(AVG)}$ cm	Re_f	Re_s $\times 10^{-3}$	t_{AVG} s	Y_1 $\times 10^{+2}$	Y_2	S_3	S_4 $\times 10^{+4}$	S_6	S_8 $\times 10^{+4}$	S	L^*_{AVG}
93	.010	7.45	1.1	1.25	.458	2.8	53.3	.10	.65	.09	.61	4.9	1.68	13.4		2.9
	.021	10.93	1.5	1.09	.73	5.6		.068	.76	.07	.98	11.5	1.47	17.2		1.38
	.031					8.4										
	.043	16.4	2	0.93	.86	11.26		.074	.88	.052	.71	12.5	.77	13.5		1.08
	.063					16.9										
	.104					28.2										
158.5	.010	13.67	0.6	0.74	.347	2.8	90.9	.08	.28	.034	.32	2.7	.68	5.8		2.13
	.021	18.22	0.9	0.65	.459	5.6		.062	.35	.032	.41	4.7	.58	6.6		1.42
	.031	22.36	1.1	0.59	.51	8.4		.064	.38	.029	.36	5.0	.41	5.9		1.16
	.043	25.23	1.3	0.66	.51	11.26		.073	.42	.027	.28	4.4	.36	5.7		1.29
	.063	30.75	1.6	0.66	.65	16.9		.062	.46	.025	.34	6.6	.35	6.7		1.02
	.104	39.1	2.1	0.66	.83	28.2		.092	.53	.023	.23	5.7	.18	4.5		.80
252	.010	16.4	0.5	0.34	.346	2.8	144	.12	.16	.026	.18	1.1	.17	1.1		.98
	.021	27.33	0.6	0.41	.44	5.6		.071	.18	.017	.23	2.5	.21	2.3		.93
	.031	35.14	0.7	0.41	.49	8.4		.069	.19	.014	.20	2.8	.17	2.4		.84
	.043	36.4	0.9	0.40	.59	11.26		.140	.22	.016	.12	1.7	.08	1.1		.68
	.063	49.2	1.0	0.43	.62	16.9		.073	.23	.012	.14	2.6	.09	1.8		.69
	.104	58.6	1.4	0.37	.869	28.2		.098	.27	.012	.15	3.5	.06	1.5		.43

TRAILING EDGE PARAMETERS USING L^*, t, S AVERAGE (AVG)

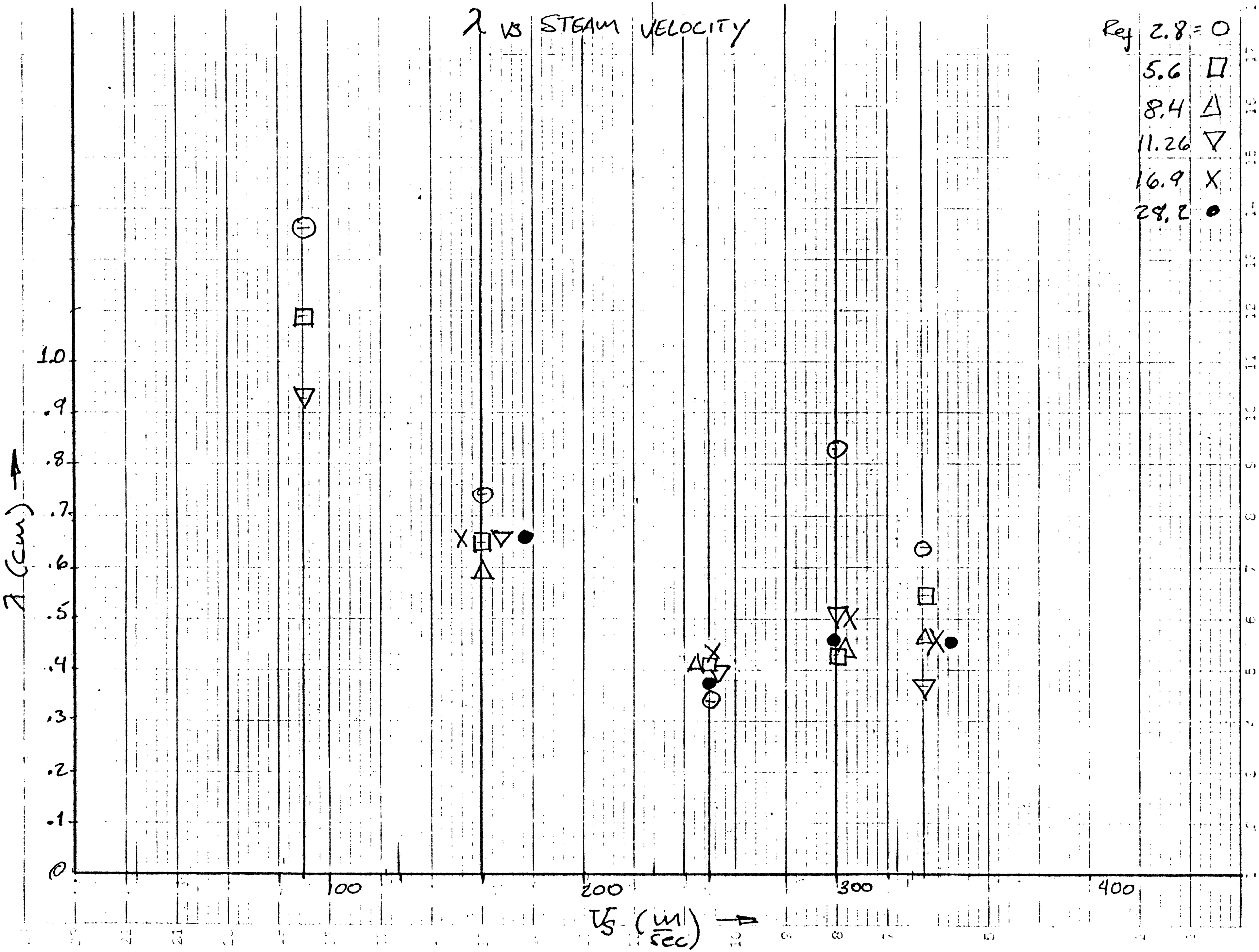
V_0 m/s	q cm²/s	V_f cm/s	h mils	λ cm	$L_{MAX}^{(AVG)}$ cm	Re_f	Re_s $\times 10^{-3}$	t_{AVG} s	Y_1 $\times 10^{+2}$	Y_2	S_3	S_4 $\times 10^{+4}$	S_6	S_8 $\times 10^{+4}$	S	L^*_{AVG}
297	.010	20.5	0.4	0.83	.253	2.8	170	.11	.12	.019	.11	.77	.37	2.5		3.3
	.021	32.8	0.5	0.425	.286	5.6		.06	.14	.013	.15	1.6	.22	2.4		1.49
	.031	41.0	0.6	0.44	.398	8.4		.054	.15	.011	.18	2.5	.20	2.7		1.11
	.043	46.9	0.7	0.50	.416	11.26		.09	.16	.011	.10	1.6	.12	1.9		1.2
	.063	61.5	0.8	0.50	.428	16.9		.08	.17	.009	.09	1.8	.10	2.1		1.17
	.104			0.46	.734	28.2		.07								.63
335	.010	27.3	0.3	0.64	.384	2.8	192	.09	.095	.012	.16	1.3	.26	2.1		1.67
	.021	32.8	0.5	0.55	.445	5.6		.076	.12	.013	.18	1.7	.22	2.2		1.24
	.031	41.0	0.6	0.46	.47	8.4		.063	.13	.011	.18	2.2	.18	2.2		.98
	.043	46.9	0.7	0.37	.425	11.26		.103	.145	.011	.09	1.2	.08	1.1		.87
	.063	61.5	0.8	0.46	.61	16.9		.107	.155	.009	.09	1.7	.07	1.3		.75
	.104	82.0	1.0	0.45	.65	28.2		.126	.17	.007	.06	1.5	.04	1.1		.69



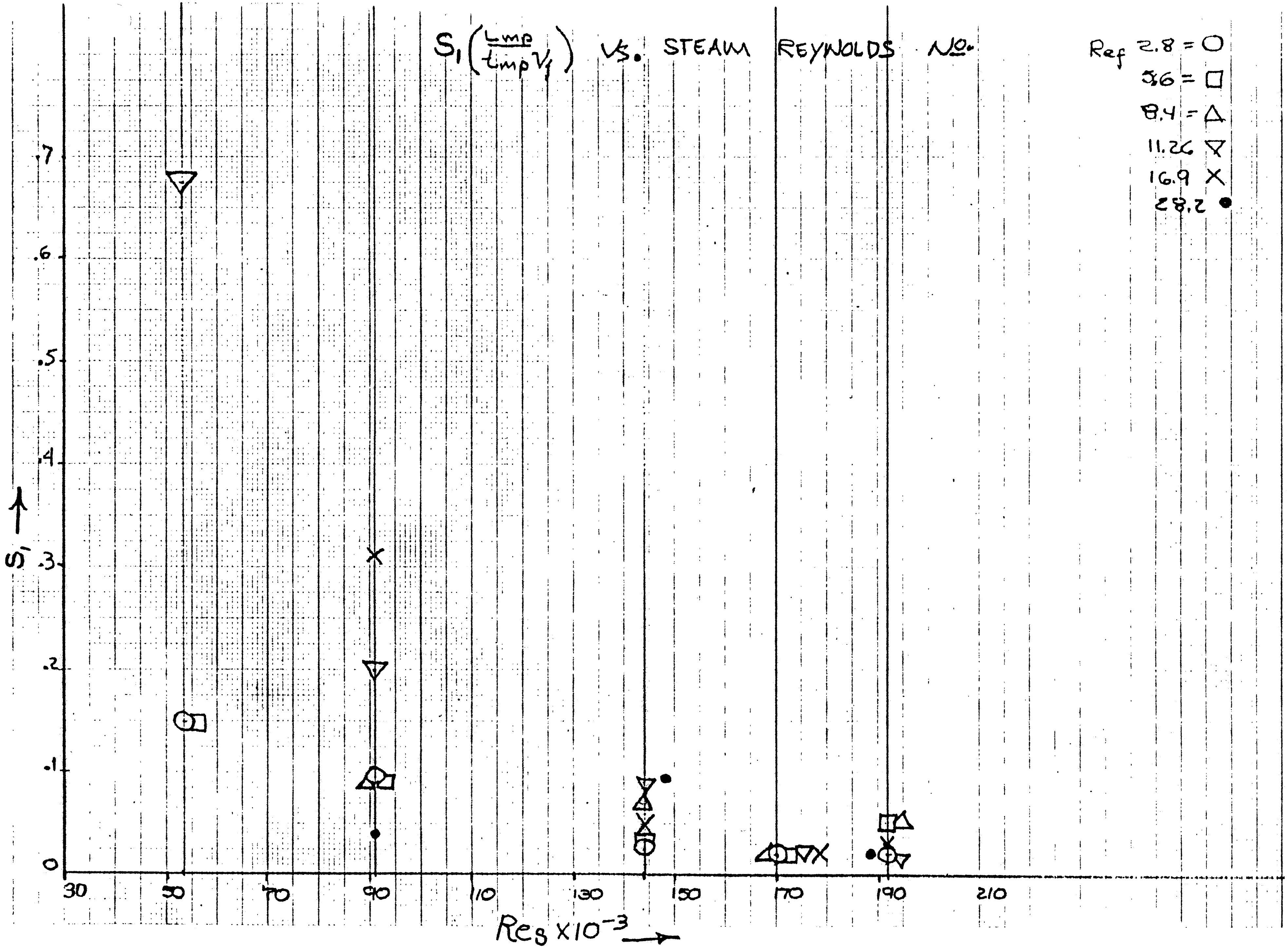
LMP VS STEAM VELOCITY
Q = 5
10
15
20
30
50
LMP (CM)
.1
.2
.3
.4
.5
.6
.7
200
300
400
500
800
900
1000
1100
VELOCITY (FT/SEC)



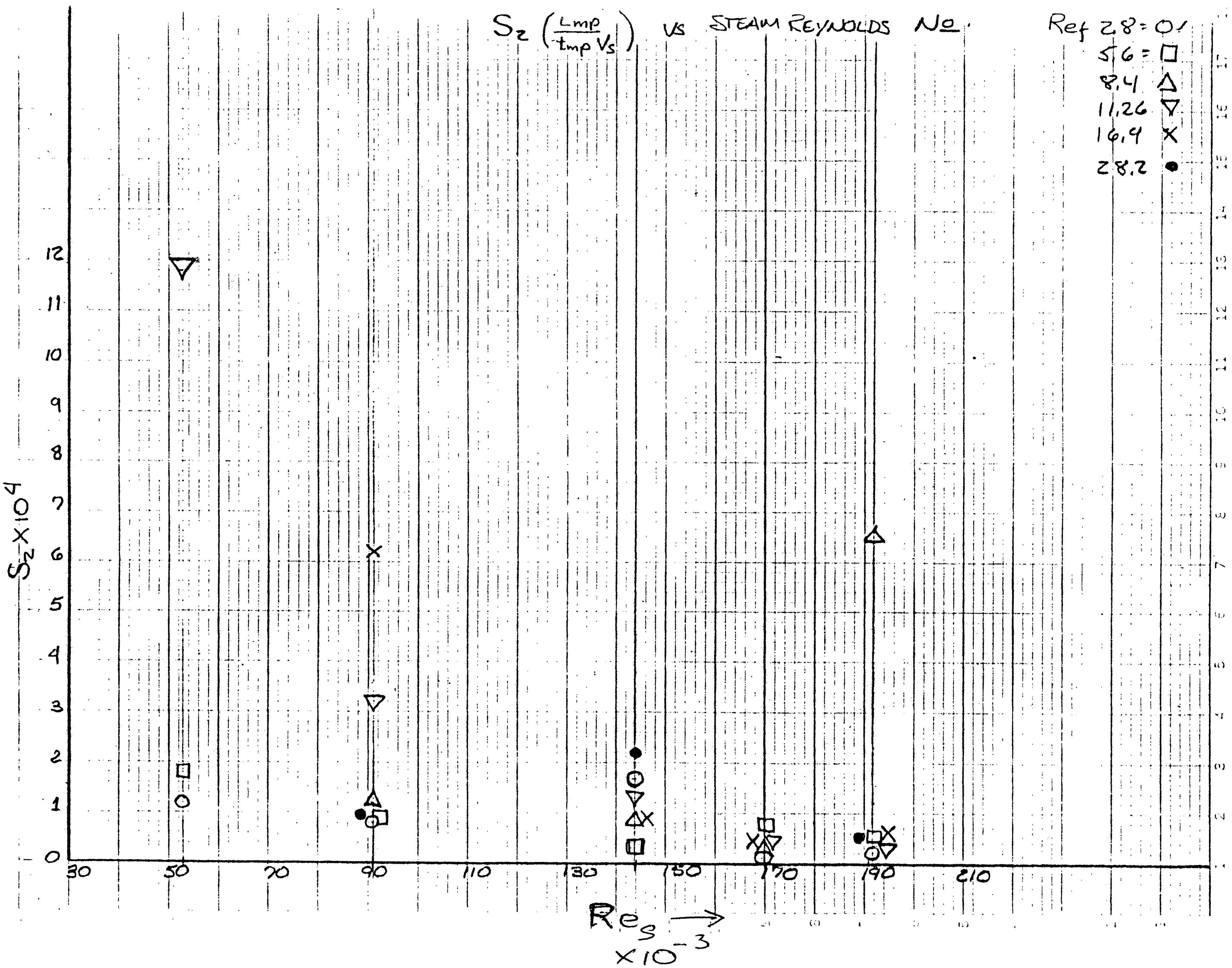
Tmp Vs. Vsteam
Time most probable finger length Vs. steam velocity
Q = scc/min ⊙
= 10 □
= 15 △
= 20 ▽
= 30 X
= 50 ◇
Tp (sec.)
.1
.2
.3
.4
.5
.6
200
300
400
500
600
700
800
900
1000
1100
1200
Steam Velocity (ft/sec)



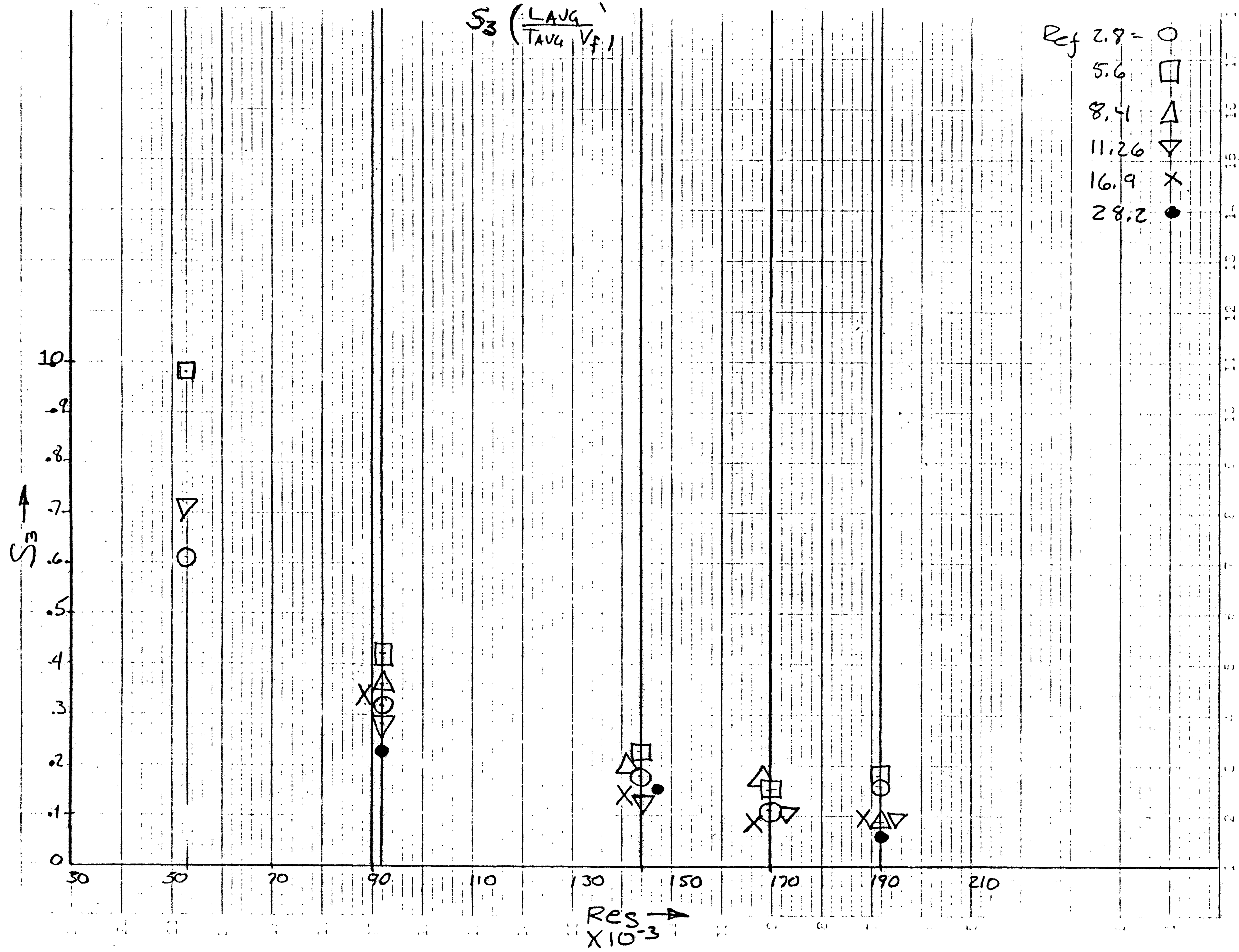
λ vs STEAM VELOCITY
Ref 2.8 = ○
5.6 □
8.4 △
11.26 ▽
16.9 X
28.2 ●
λ (cm) →
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Us (m/sec) →
100
200
300
400

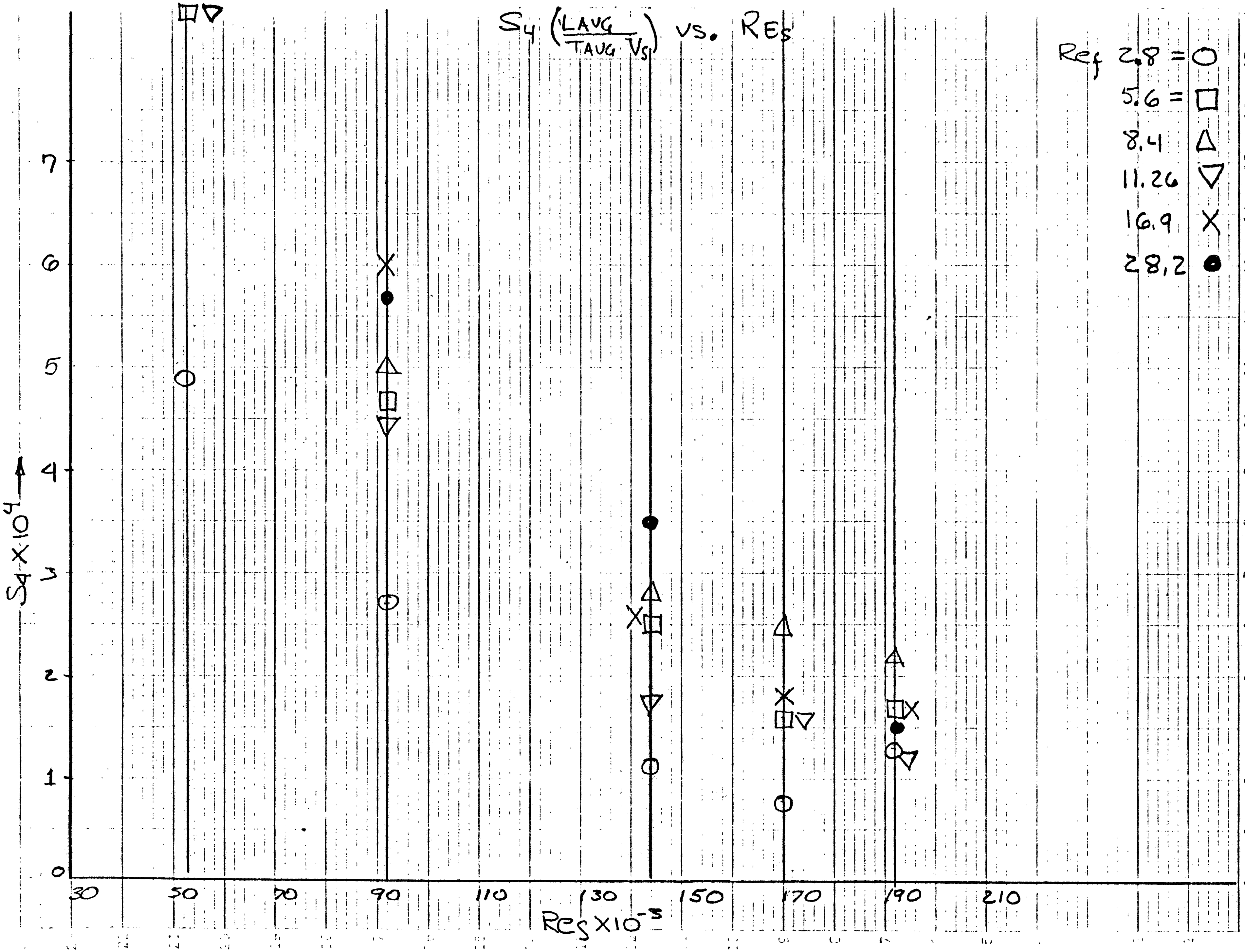


S1 (Lmp / Lmp Vf) VS. STEAM REYNOLDS No.
Ref 2.8 = ○
5.6 = □
8.4 = △
11.26 ▽
16.9 ×
28.2 ●
S1
.7
.6
.5
.4
.3
.2
.1
0
30
50
70
90
110
130
150
170
190
210
Res × 10⁻³

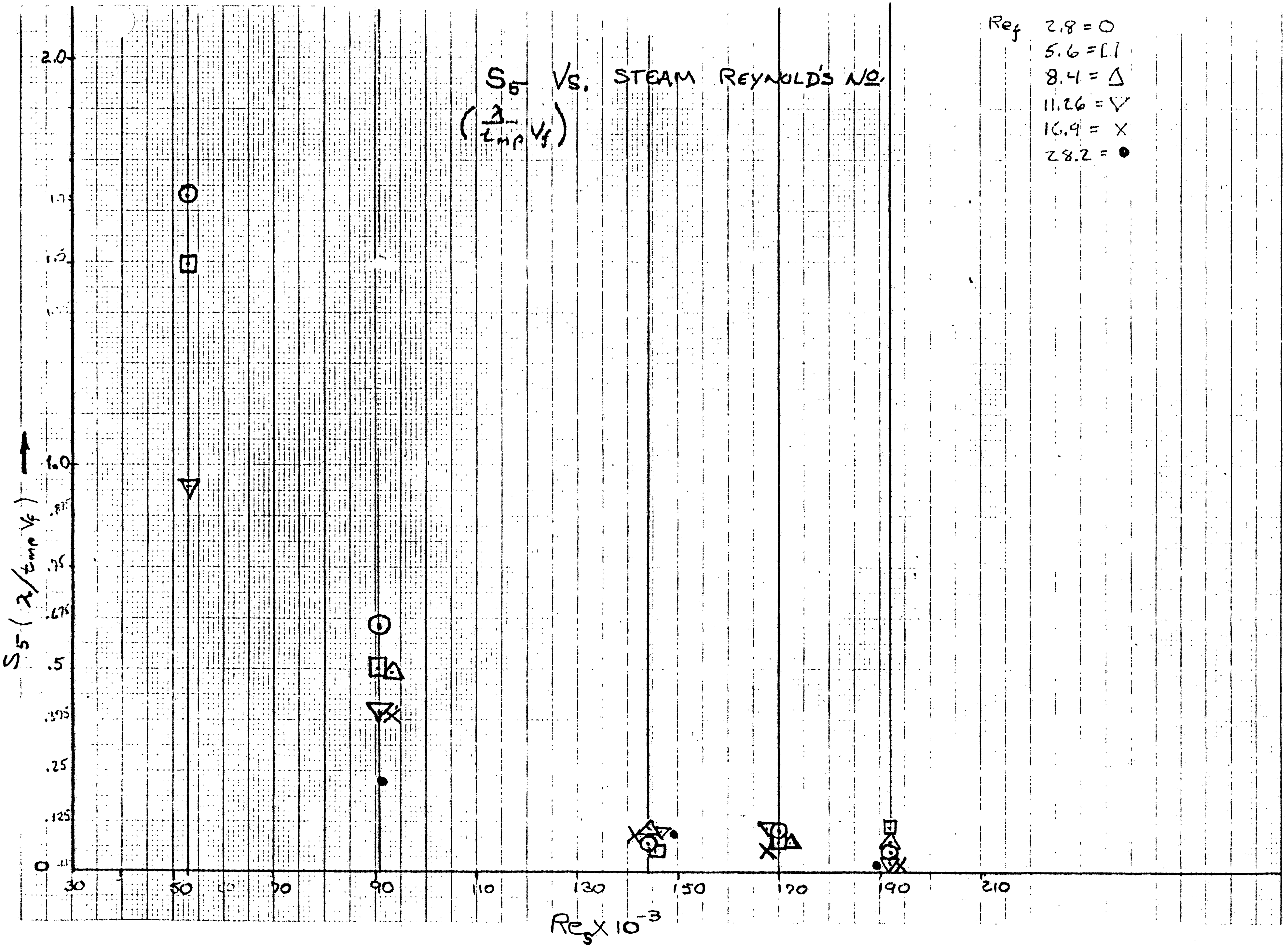


$S_2 \left(\frac{Lmp}{tmp V_s}\right)$ vs STEAM REYNOLDS No.
Ref 2.8 = O
5.6 = □
8.4 △
11.26 ▽
16.4 X
28.2 ●
$S_2 \times 10^4$
0
1
2
3
4
5
6
7
8
9
10
11
12
30
50
70
90
110
130
150
170
190
210
$Re_s \rightarrow$
$\times 10^{-3}$

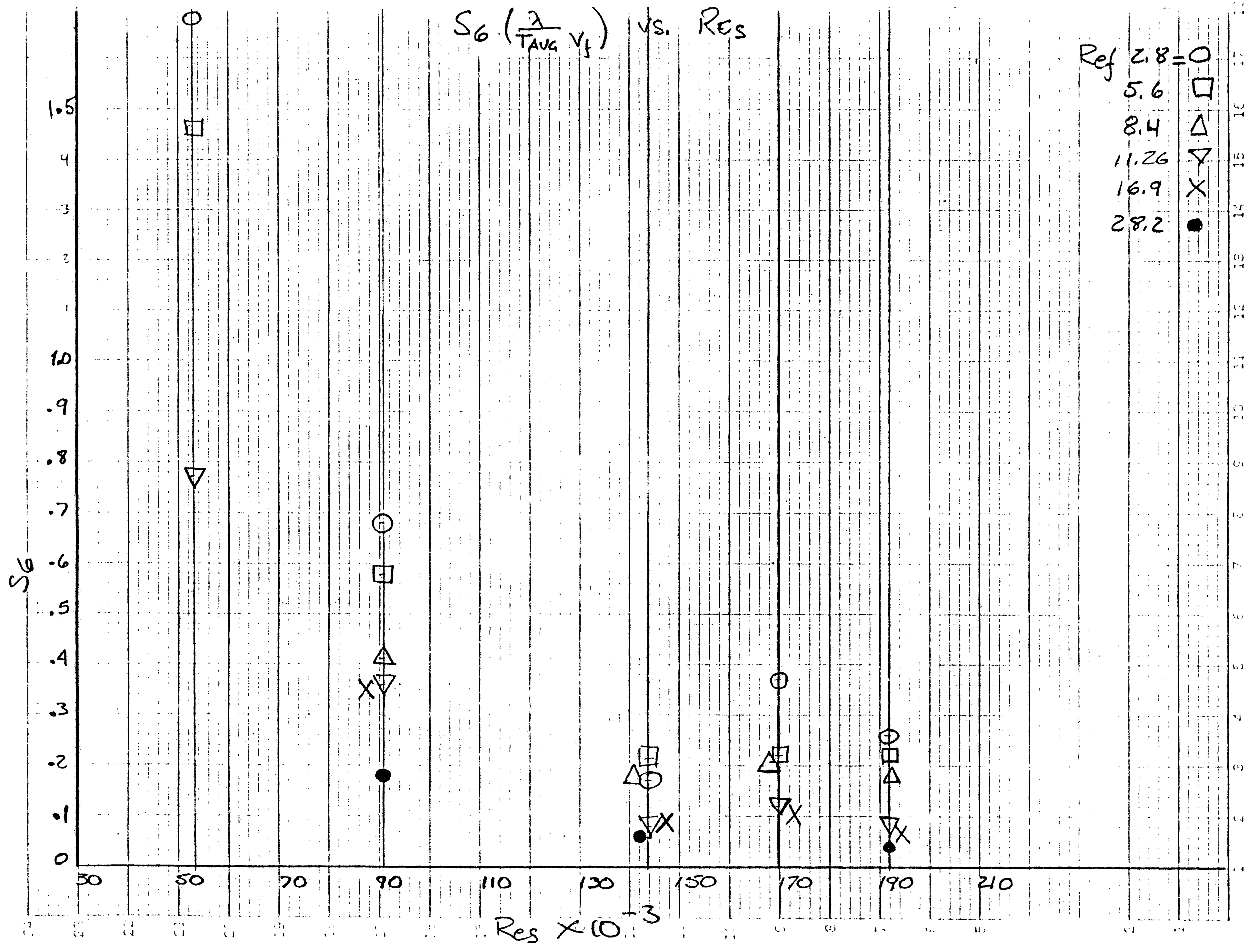

S3 (LAVG / TAVG Vf)
Ref 2.8 ○
5.6 □
8.41 △
11.26 ▽
16.9 X
28.2 ●
S3 ↑
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
10
30
50
70
90
110
130
150
170
190
210
Res →
X10-3



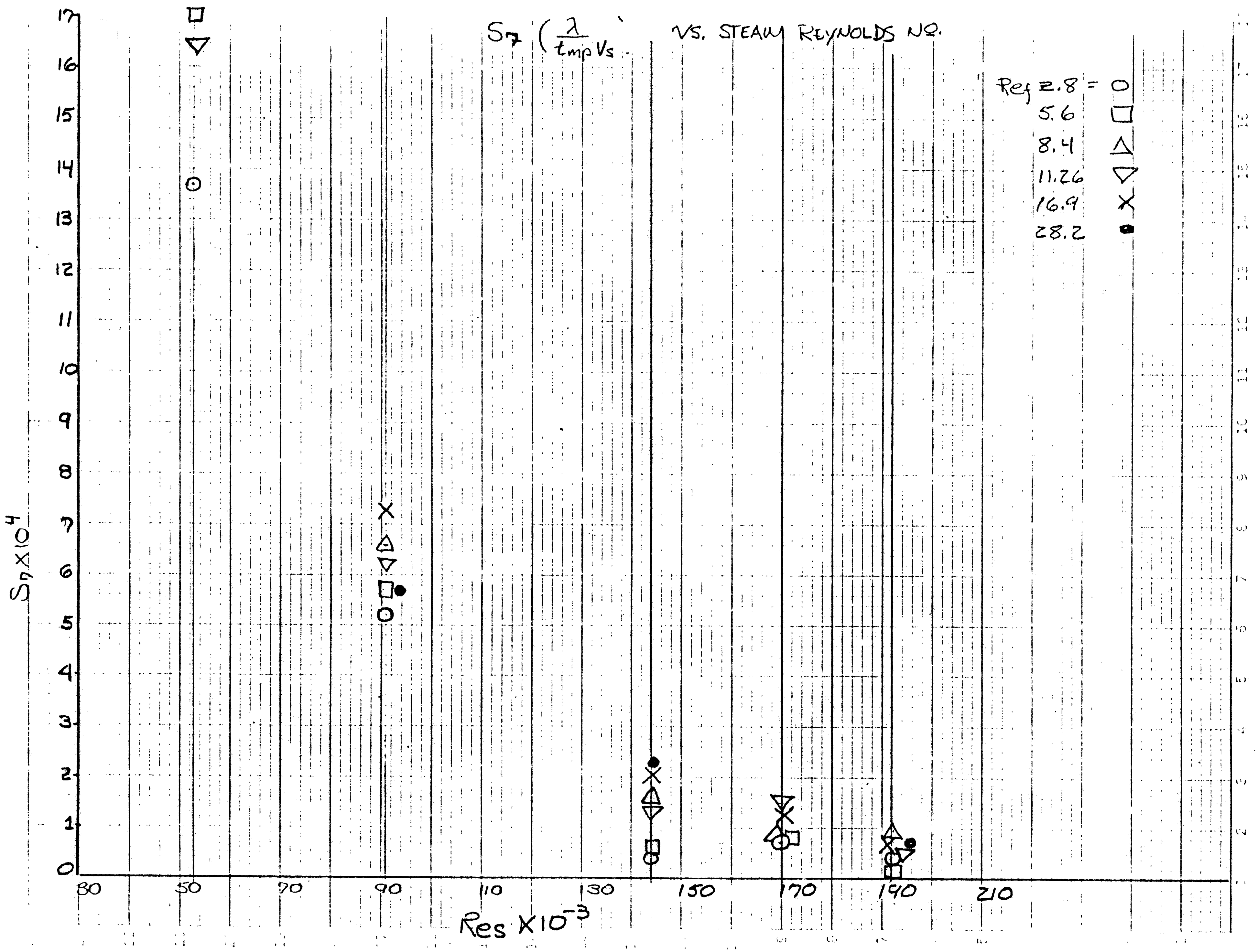
$S_4 \left(\frac{L_{AVG}}{T_{AVG} V_S}\right)$ vs. Re_S
Ref 2.8 = ○
5.6 = □
8.4 △
11.26 ▽
16.9 ×
28.2 ●
$S_4 \times 10^4$
0
1
2
3
4
5
6
7
30
50
70
90
110
130
150
170
190
210
$Re_S \times 10^{-3}$



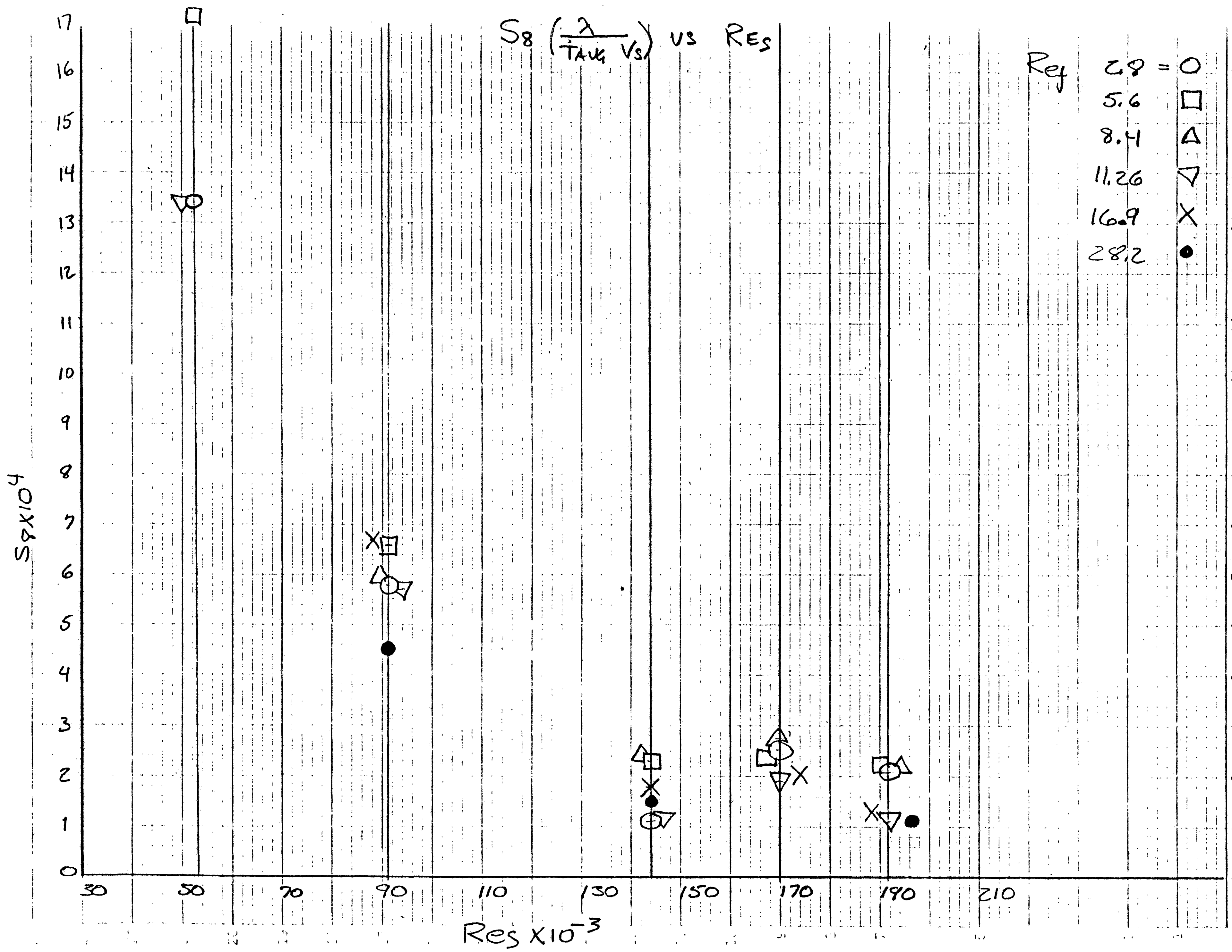
S5 Vs. STEAM REYNOLD'S NO.
(λ / t_mp V_f)
Re_f
2.8 = ○
5.6 = □
8.4 = △
11.26 = ▽
16.4 = X
28.2 = ●
S5 (λ/t_mp V_f)
2.0
1.0
.5
.25
.125
0
30
50
90
110
130
150
170
190
210
Re_s X 10^-3



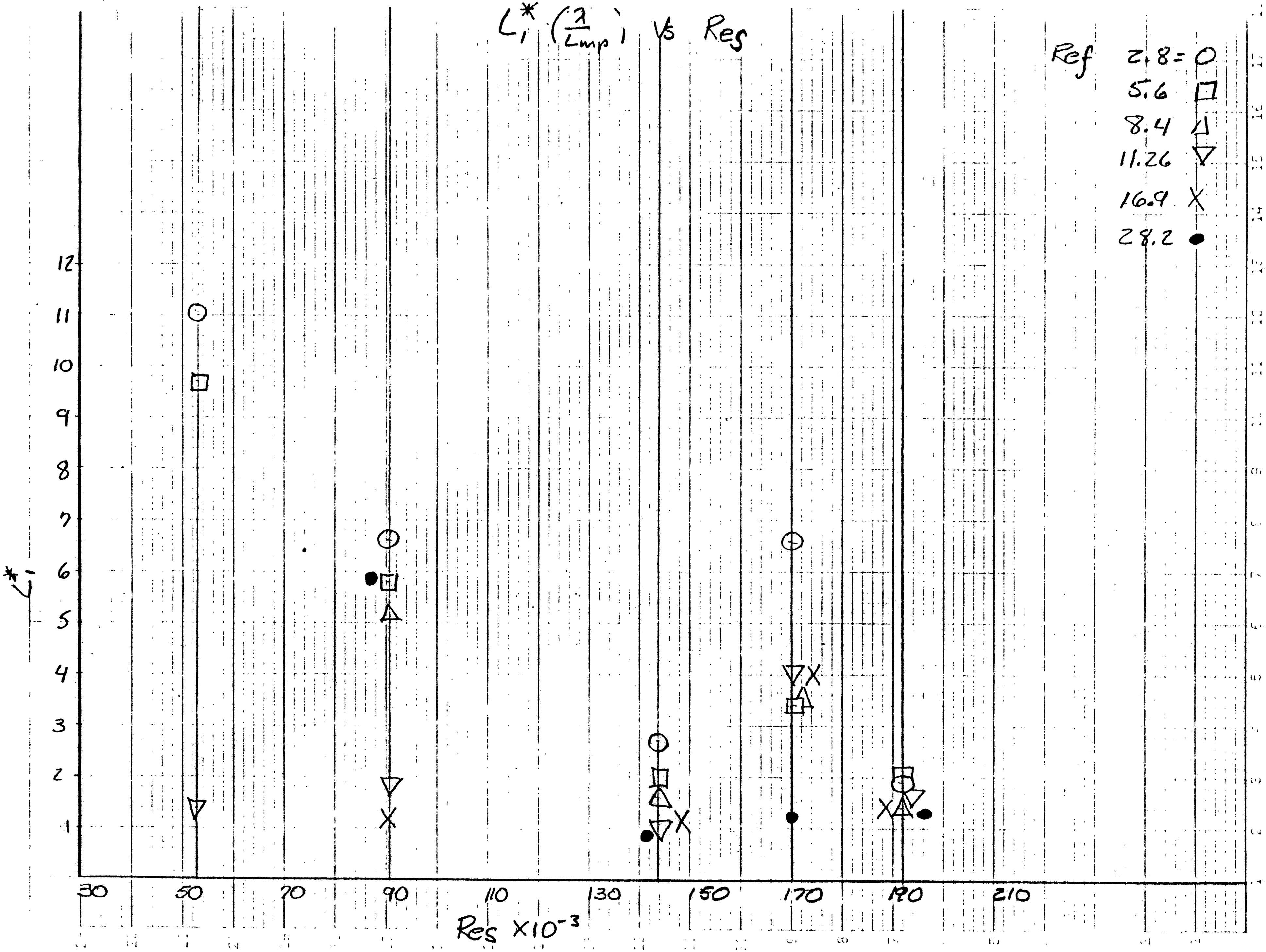
S6 (λ / T_AVG Y_f) vs. Res
Ref 2.8 = ○
5.6 □
8.4 △
11.26 ▽
16.9 ×
28.2 ●
S6
Res × 10^-3

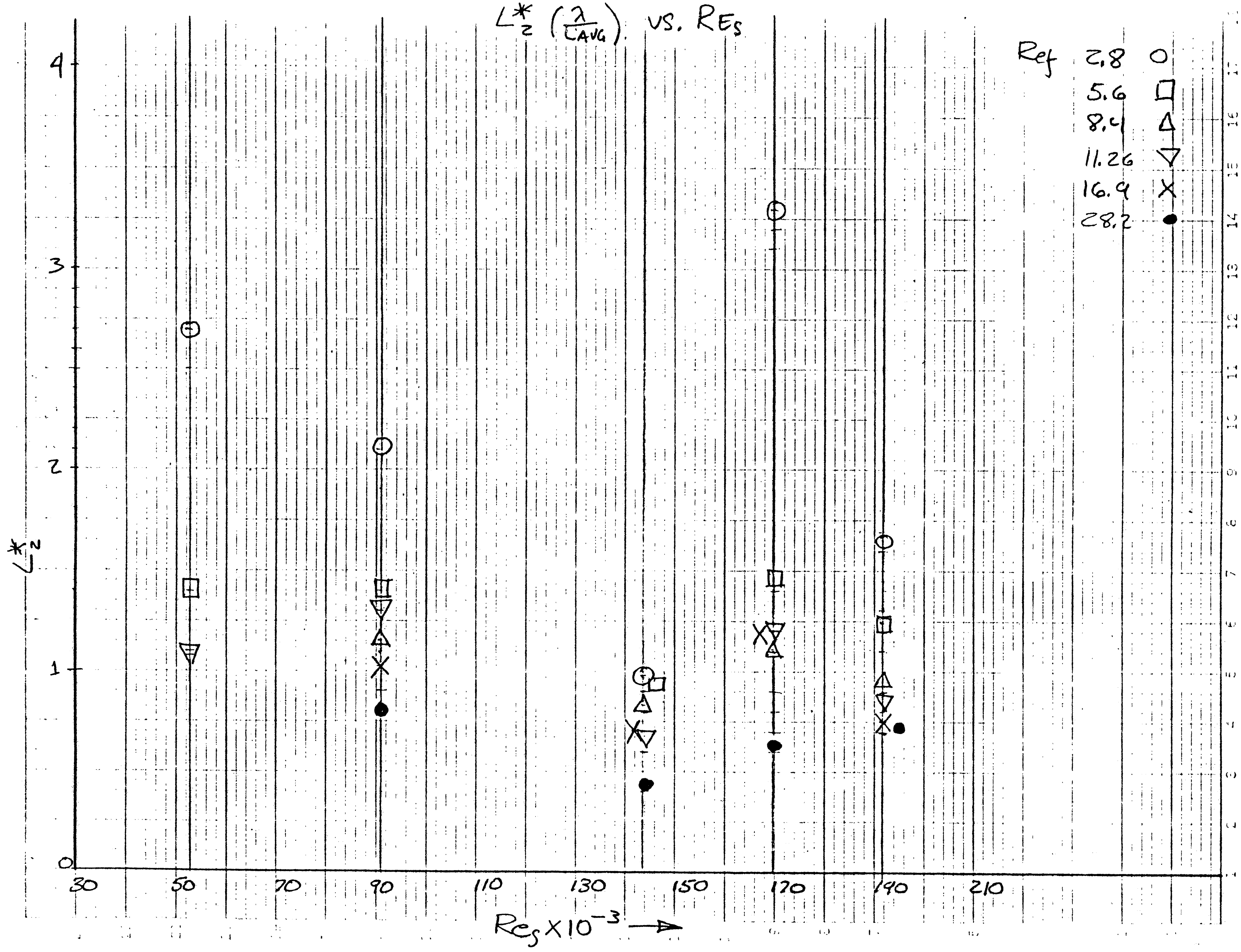


$S_7 \left(\frac{\lambda}{t_{mp} V_s}\right)$ VS. STEAM REYNOLDS NO.
Ref 2.8 = ○
5.6 □
8.4 △
11.26 ▽
16.9 ×
28.2 ●
$S_7 \times 10^4$
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
$Re_s \times 10^{-3}$
80 50 70 90 110 130 150 170 190 210

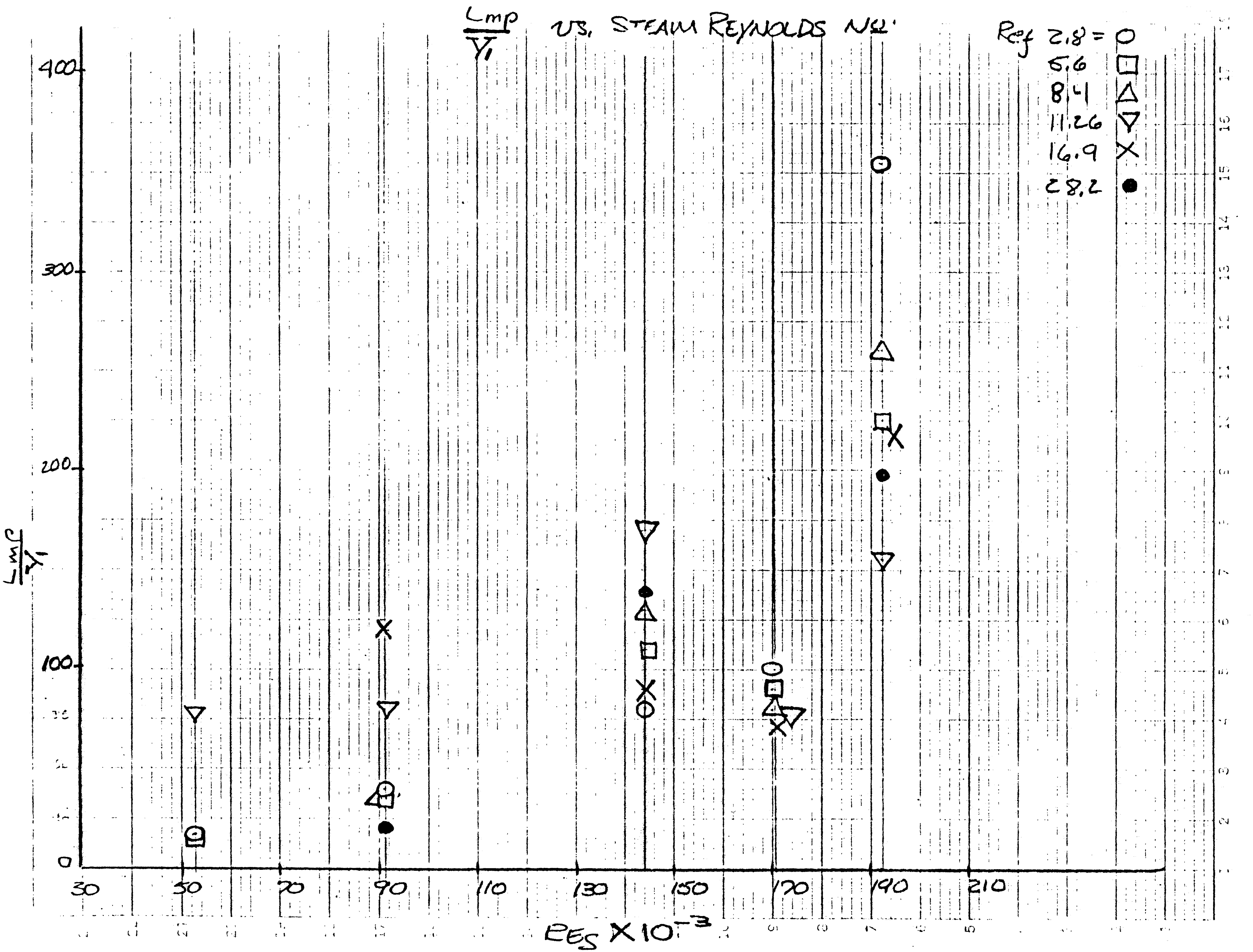


S8 (λ / TAVG Vs) vs Res
Ref
2.8 = ○
5.6 □
8.4 △
11.26 ▽
16.9 X
28.2 ●
S8 X10^4
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
30
50
70
90
110
130
150
170
190
210
Res X10^-3

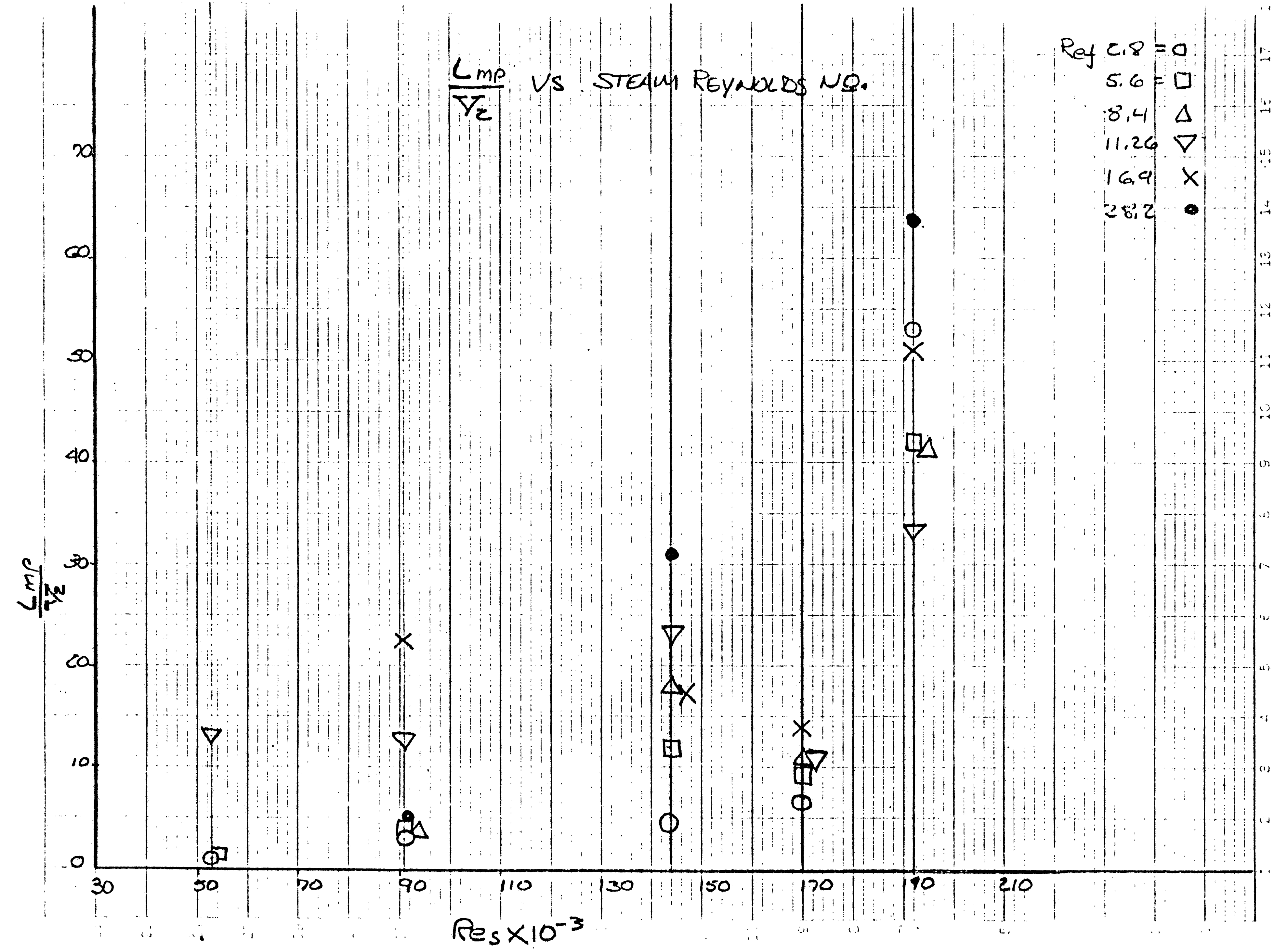

$L_1^* (\frac{\lambda}{L_{mp}})$ Vs Res
Ref
2.8 = ○
5.6 □
8.4 △
11.26 ▽
16.9 X
28.2 ●
L_1^*
1
2
3
4
5
6
7
8
9
10
11
12
30
50
70
90
110
130
150
170
190
210
Res $\times 10^{-3}$

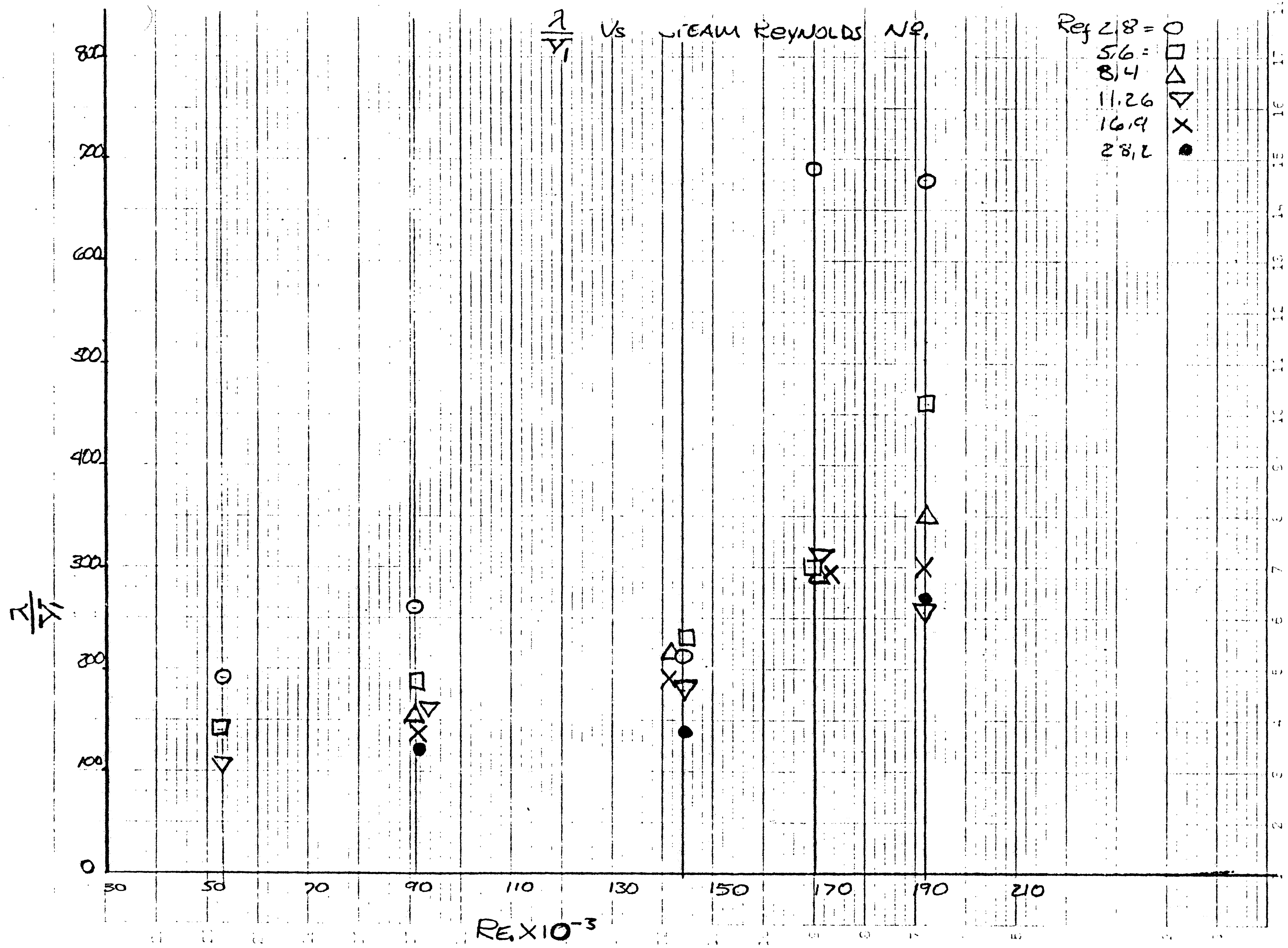


$L_z^* \left(\frac{\lambda}{\ell_{AVG}}\right)$ VS. Re_s
Ref 2.8 ○
5.6 □
8.4 △
11.26 ▽
16.9 X
28.2 ●
L_z^*
0
1
2
3
4
30
50
70
90
110
130
150
170
190
210
$Re_s \times 10^{-3}$ →

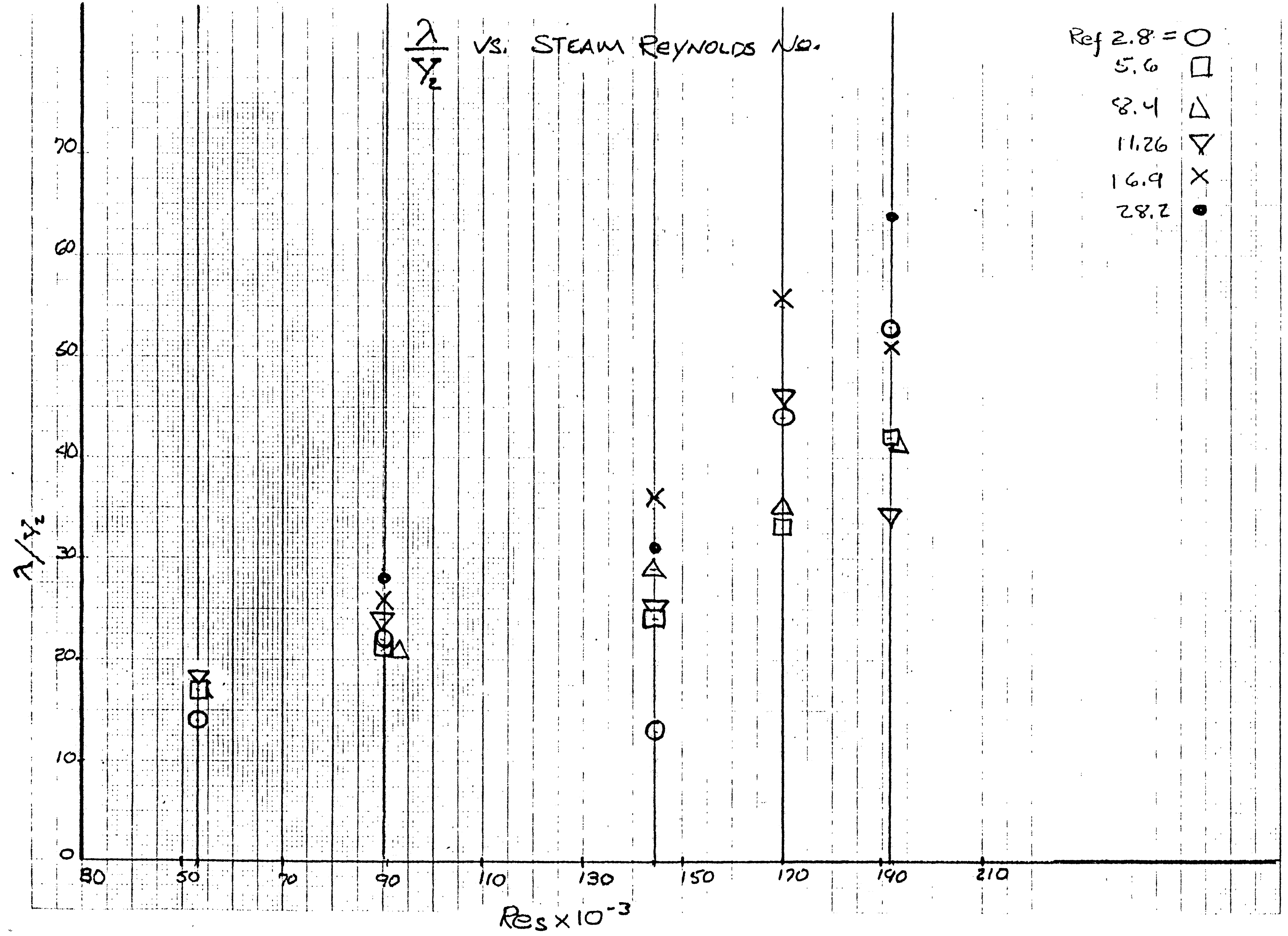


Lmp/Y1 VS. STEAM REYNOLDS NO.
Ref 2.8 = ○
5.6 □
8.4 △
11.26 ▽
16.9 X
28.2 ●
Lmp/Y1
0
100
200
300
400
30
50
70
90
110
130
150
170
190
210
Res X 10^-3

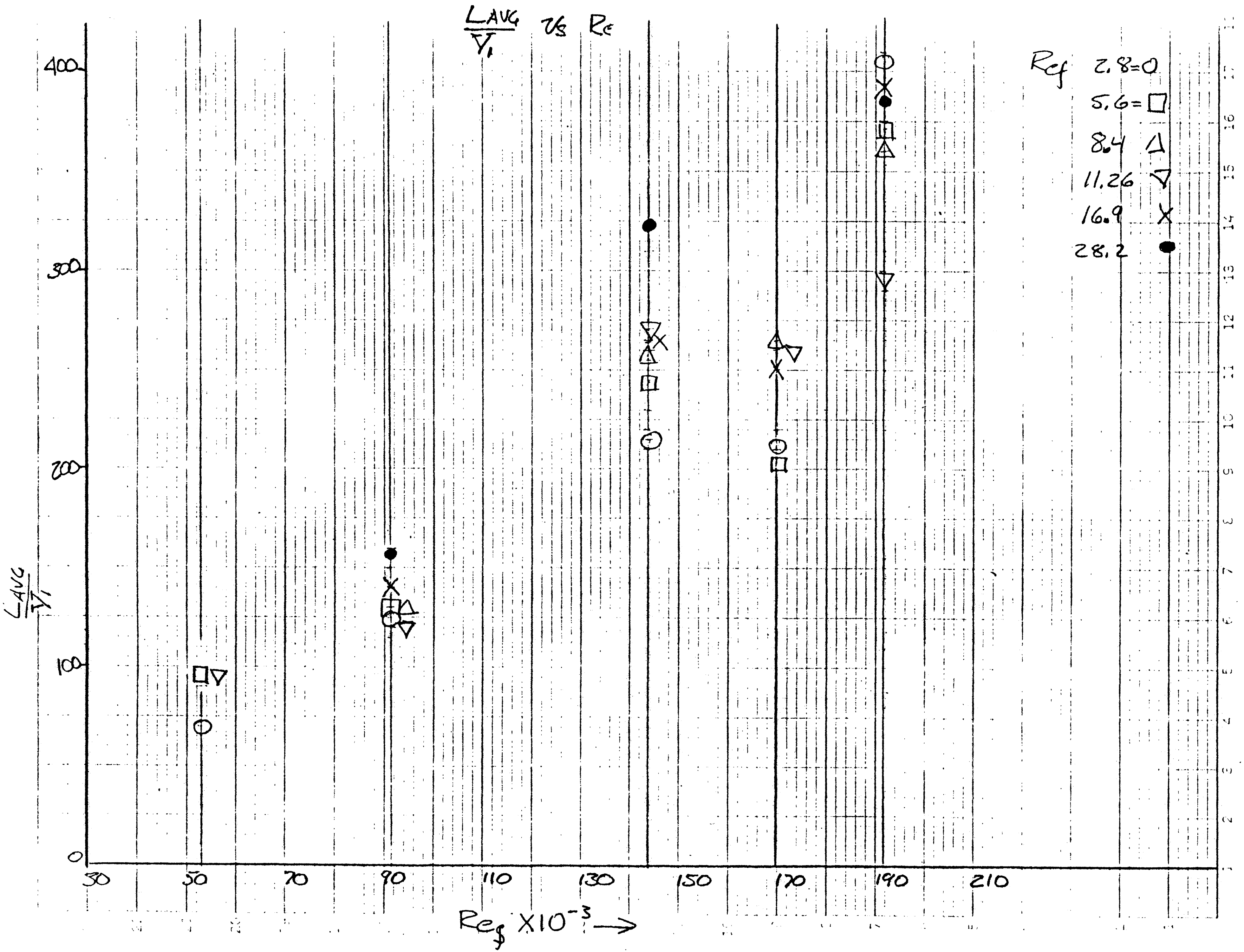

Lmp/V/2 VS STEAM REYNOLDS NO.
Ref 2.8 = ○
5.6 = □
8.4 △
11.26 ▽
16.9 ×
28.2 ●
Lmp/V/2
0
10
20
30
40
50
60
70
30
50
70
90
110
130
150
170
190
210
Res X10^-3



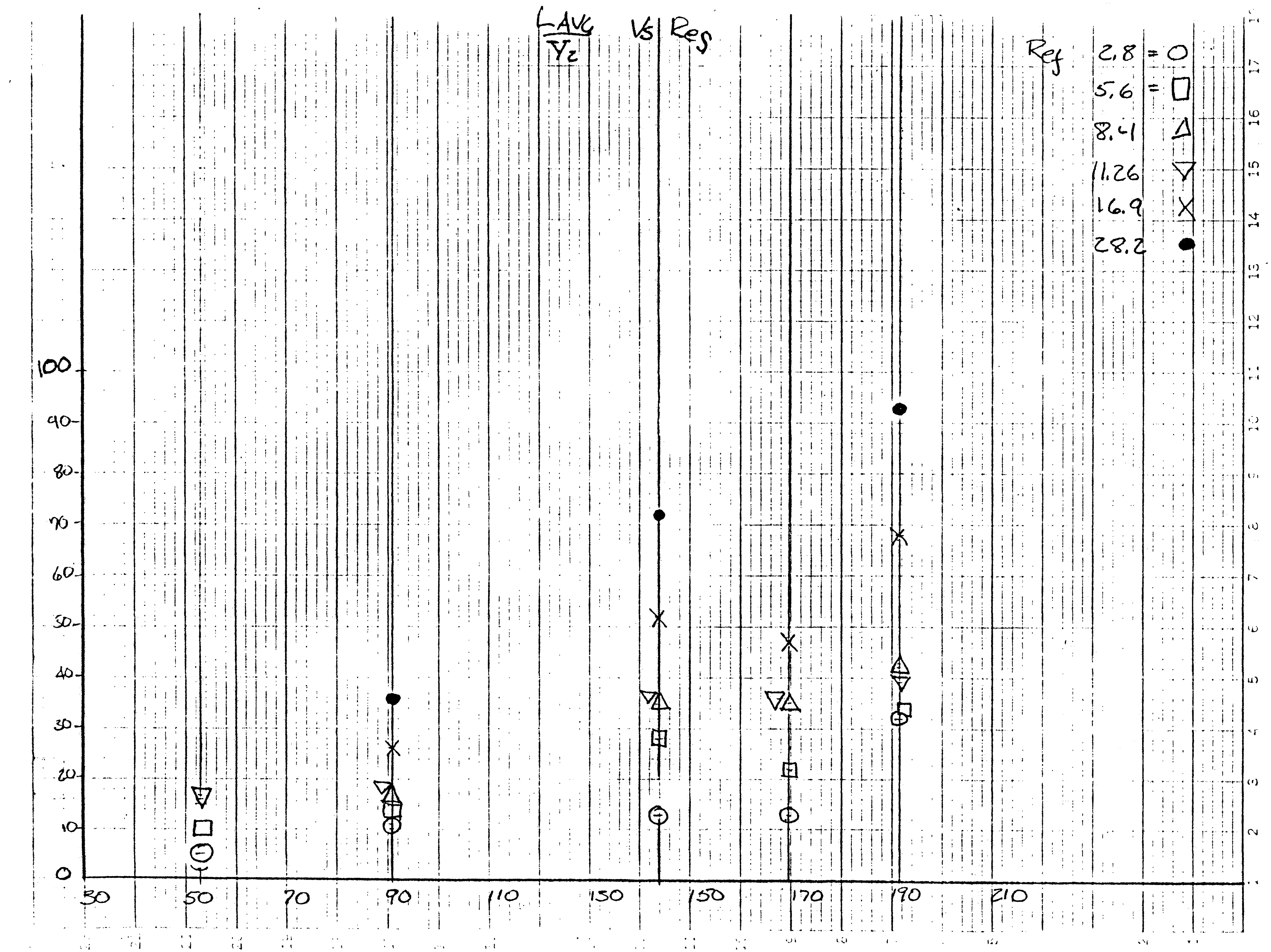
λ/Y1 Vs STEAM REYNOLDS NO.
Ref 2.8 = ○
5.6 = □
8.4 △
11.26 ▽
16.9 ×
28.2 ●
λ/Y1
0
100
200
300
400
500
600
700
800
RE × 10^-3
30
50
70
90
110
130
150
170
190
210



λ / Y2 VS. STEAM REYNOLDS No.
Ref 2.8 = ○
5.6 □
8.4 △
11.26 ▽
16.9 ×
28.2 ●
λ/Y2
0
10
20
30
40
50
60
70
80
50
70
90
110
130
150
170
190
210
Res × 10^-3



LAVG/V1 vs Re
Ref 2.8=○
5.6=□
8.4 △
11.26 ▽
16.9 ×
28.2 ●
400
300
200
100
0
LAVG/V1
30
50
70
90
110
130
150
170
190
210
Re$ X10^-3 →



L AVG / Y2 Vs Res
Ref
2.8 = ○
5.6 = □
8.41 △
11.26 ▽
16.9 X
28.2 ●
0
10
20
30
40
50
60
70
80
90
100
30
50
70
90
110
130
150
170
190
210