TESTS OF AXIAL FLOW FANS DESIGNED BY LATTICE THEORY

THESIS

by

William H. Bowen

In Partial Fulfillment of the Requirements for the

Degree of

MASTER OF SCIENCE

California Institute of Technology

Pasadena, California

1938

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Dr. Theodor von Karman for his interest and helpful suggestions.

He wishes to thank Dr. Clark B. Millikan for suggestions and criticisms.

He wishes to thank Mr. A. M. O. Smith for his assistance in making the tests.

REFERENCES

I. Aerodynamic Theory ----------Durand Vol. II P. 91

II. Axial Flow Fans ----------Kellar-Marks

III. Axial Flow Fan Design by Lattice Theory
C. Wood--Thesis Calif. Inst. of Tech. 1935

IV. Luftfahrtforschung -------- -20-9-37

DISCUSSION

This paper presents the tests and calibrations which were made on three axial flow fan units of the G.A.L.C.I.T. Boundary Layer Removal Model. in order that operating parameters might be developed from the data. The tests serve also as a check on the success achieved in the design of fans using the Lattice Theory.(cf. Theoretical Aerodynamics Lecture Notes of Dr. Clark B. Millikan).

When embarking on a program of research on the problem of increasing the lift on airplane wings by removal of the boundary layer, it became necessary to provide some suitable means of air removal. After consideration of numerous methods, the following elements were decided upon for an investigation of the problem;

(1.) A motor driven fan enclosed in a normal fuselage shape, connecting to a ducted wing and exhausting at the tail of the fuselage.

(2.) Three fan units with different values of blade pitch, giving different pressure volume relations.

(3.) Fan units to be driven from either end, so that the boundary layer could be removed by either suction or pressure.

The design and construction of the fan units are covered in the paper "Axial Flow Fan Design by Lattice Theory", Master of Science Thesis, Calif. Inst. of Technology, by Carlos Wood, 1935. A description of the design characteristics will be found in Appendix I. Figure 1 shows the normal fan arrangement for suction at the wing.

The principal experimental values investigated were:

(1.) Quantity of air passing through the fan.

(2.) Power input to the fan.

(3.) Pressure rise through the fan.

From the above parameters, the fan efficiencies were dtermined for all operating conditions under which the fans were likely to be used. It was also necessary to determine the validity with which the averaging pitot bar in the exit section measured the average velocity.

The independent variables were:

(1.) Fan # A, B, or C.

(2.) Fan speed.

(3.) Amount of throttling.

(4.) Throttling ahead of or behind the fans.

The blade angles and guide vane angles were fixed.

It was assumed that fan operation should be the same, regardless of which end was throttled, and since previous reports tend to show much better results by removing the boundary layer by suction, it was decided to test the fan by throttling only the inlet. Appendix II and photos show the experimental set up for calibration purposes.

Fans A,B,C, were throttled in six arbitrary steps of 0%, 50%, 65%, 80%, 87%, and 95%. Six values of speed, 5000, 7500, 10000, 12500, 15000,and 17500 R.P.M. were used. At each of these points the following measurements were made:KW. input, torque to fan, pressures ahead of and behind the fan, averaging pitot reading ($\bar{P}_T$), and static pressure at the exit. A 19 point pitot traverse was also taken across the exit. Appendix II gives a discussion of variables and parameters, appendix IV contains data reduction sheets and pages 23,24 present a sample data sheet and sample velocity distributions in the fan exit.

From an operating standpoint, it was found to be much more desirable to run through a series of motor speeds with a constant percentage of throttling, than to operate with constant speed or constant pressure rise through the fan. Constant speed lines on the Quantity-Head diagrams (see page 30) are therefore faired lines. For the same reason, the efficiency curves for constant values of blocking (see page 27) were cross plotted with the Quantity-

Head diagrams to obtain the curves of Efficiency as a function of Quantity for various values of pressure rise through the fan (pages 33-35).

Both the Quantity-Head diagrams and the Efficiency-Quantity curves show stalling for low quantities, particularly for fans 1A and 1B, which have the largest angles of attack. These fans were designed for larger capacities than was fanC, this fact being borne out. A comparison of the curves (fig.30-32) shows that this was achieved, but at the expense of some efficiency. Mr. Wood's calculations show fan C to be designed for a minimum loss and of the fans tested, it has the highest efficiency. Whether further decrease of the angle of attack of the fans would adversely affect the efficiency is not known.

The curve of Quantity of air, as a function of the multiple pitot reading,(fig.7) contains the points from all 98 runs and shows little consistent variation from fan to fan, indicating that conditions in the exit section, which is common to all fans,are independent of the fan installed within very few percent. The variation of actual Quantity with the theoretical Quantity indicated by the multiple pitot ($\bar{P}$) has been determined for each fan by plotting the dimensionless ratio $\frac{Q\ \text{actual}}{Q\ \text{theoretical}} = C$ (A,B,C) as a function of average velocity for each fan.(See pages 36-38).

Specific values will be found in the family of curves giving Quantity coefficients as a function of indicated average jet velocity for a series of wind tunnel air speeds. (fig. 8) This coefficient, developed on page 22, Appendix III, contains the wing area of the existing Boundary Layer Model wing and the ratios of tunnel air density to model air density and should be useful in applying the results of the present investigation to future researches with the complete model.

CONCLUSIONS

1. The design of axial flow fans by lattice theory gives very favorable results, as indicated by the relatively high efficiencies found in this investigation.

2. Efficiency increases result from increase in the number of stages, over the range covered by the present tests.

3. Fan 1 A- Maximum efficiency of 54% at o.35 M/sec and a pressure rise of 30 cm. of water.

   Maximum quantity of 0.77 M /sec with 30 cm. pressure rise and 39% efficiency.

4. Fan 1B - Maximum efficiency of 49% at 0.30 to 0.50 M /sec with a pressure rise of 25 to 40 cm. of water.

   Maximum quantity of 0.825 M /sec. with 36 cm. pressure rise and 40% efficiency.

5. Fan 1C - Maximum efficiency of 71.5% with 0.33 M /sec. and 82 cm. pressure rise.

   Maximum quantity of 0.59 M /sec. at 18 cm. pressure rise and 22% efficiency.

6. The operating parameters of average jet velocity as indicated by the multiple pitot seems quite reliable.

APPENDIX I

FAN DESCRIPTION

The fan is made up of four parts (see fig. 2).

Motor unit

Wing mounting unit

Fan units (3)

Exhaust section

The motor unit contains a 10 H.P., 17500 R.P.M. Electric motor; G.E. 3 phase induction, Type KT38, 34.5 Amps. at 165 Volts and 300 cycles. The rotor and field are directly housed by the duralumin outer casting which makes up part of the fuselage. Cooling is effected by a cowl and air ducts only.

The wing mounting unit is a cylindrical section with a cutout for mounting the wing in either a high or low wing configuration. Air from the wing is normally drawn through this section into the fan. The drive shaft passes axially through this section in an enclosed housing.

The fan units, three in number, are identical in construction except for the number of stages and the blade setting. The following table is a compilation of design data taken from the thesis of Carlos Wood.

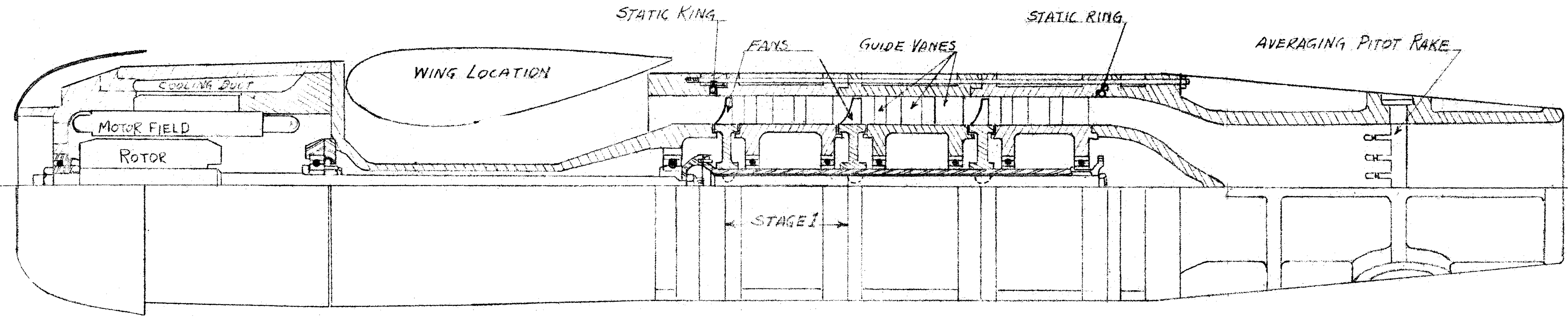
COMPILED FAN DESIGN DATA

	Fan 1A		Fan 1B(2 stage)		Fan 1C(3stage)	
	r_{inner}	r_{outer}	r_{inner}	r_{outer}	r_{inner}	r_{outer}
r inches	2.45	3.50	2.45	3.50	2.45	3.50
$90^\circ-(\beta)^\circ$					29.95	22.60
γ° chord setting to		26.3°		31.7°	28.25	20.90
λ or t/h					.691	.303
h(inches					1.925	2.750
t(inches					1.330	.832
ΔP (no swirl)					92.9 lbs./ft^2	
ΔP (swirl)					43.9 lbs./ft^2	
Quantity					15.17 ft^3/sec.	

In each fan stage, there are ten vane sets arranged radially around the periphery of the annular channel behind each fan section. Each vane set is composed of five vanes of a chord of 0.9 inches arranged at angles from 49.4° to the axis to parallel with the axis. Thus, there are fifty guide vanes behind each fan section to convert the rotational component of the velocity into pressure.

The fan units are designed to be driven from either end. In this way, either suction or pressure may be applied to a wing for boundary layer removal.

The exhaust section contains a transition section from annular to circular cross-section. The cross-sectional area is constant. Installed in this exhaust section is a bar carrying six Prandtl type pitots, manifolded together and mounted along a diameter. This set of averaging pitots gives an operating parameter for the quantity of air passing through the fans.



ARRANGEMENT FOR SUCTION AT THE WING
1/4 SCALE

MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER
			Bowen			

TOLERANCES ± .010 OR $\frac{1}{64}$ UNLESS OTHERWISE NOTED

GUGGENHEIM AERONAUTICAL LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY	BOUNDARY LAYER MODEL 3 STAGE FAN NAME.	DRAWING NO.

APPENDIX II

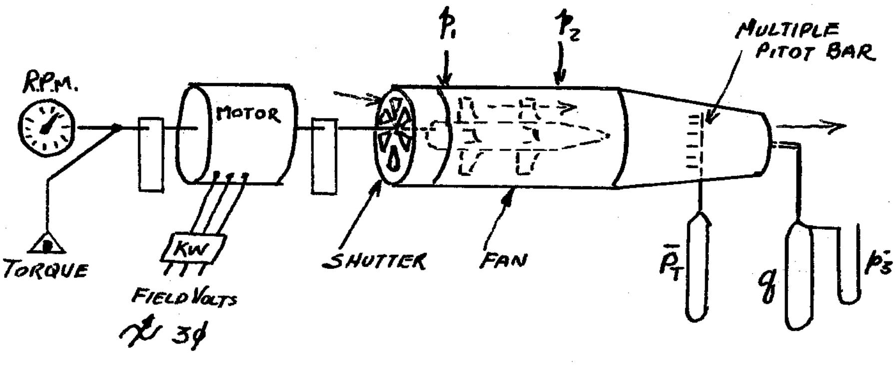
DESCRIPTION OF EXPERIMENTAL SETUP

To determine the torque applied to the fans, the motor and fan units were separated. The fan was placed in a fixed support, while the motor unit was mounted as a dynamometer, with provisions made for reading torque and speed.(see fig.2)

The dynamometer cradle was constructed of structural steel frames; a pedestal in front carried the nose of the motor frame in a single central self aligning ball bearing.The rear of the motor (driving end) was carried in a cradle of three ball bearing rollers,5 inches in diameter. These rollers were adjustable to provide motor alignment. The fan units were held in position, coaxial with the motor, in front and rear A frames, with setscrews 120 apart in each frame.

A drive shaft extension 6" long was bolted to the fan section to provide a gap for the installation of a shutter for fan throttling.The shutter was made of two pieces of $\frac{1}{4}$ inch plywood, with radial vents. One of the plywood layers could be rotated and locked to close the vents in any desired degree.

VARIABLES AND PARAMETERS



q Measured at the jet outlet in a point by point traverse, using a small Prandtl type pitot, alcohol manometer, millimeter divisions on scale. Fluid density precision ± .001 gr/cc.

p_3 Static pressure at outlet; same precision as q.

$\bar{p}_T$ Averaged pressure of 6 pitots across a diameter. This parameter, though empirical, is expected to be used with a calibration curve to measure quantity of air moved during boundary layer tests.

p_2 Static pressure behind fan unit; static ring buried in wall of fan housing with 6 orifices in periphery; alcohol manometer; mm precision.

p_1 Static pressure ahead of fan; same type of ring as p_2; same precision.

Air temp.
Humidity
Barometric press.
} Not measured.

Torque Measured at constant lever arm of 40 cm. by application of known weights to balance the torque beam; precision= 200 gr.cm.

Power Input to Motor

Measured by polyphase wattmeter G.E. #871239 25- 125 cycle; precision 0.1 kw.

Herein lies one of the worst errors in the measurements. The frequency of the power applied to the motor varied from 50 to 300 cycles. This precluded the use of ammeters entirely. Power factor varied from 17% to 85% with load. Attempts to compute motor efficiency were, therefore, unsuccessful.

R.P.M. The first attempts at speed measurement was by use of a stroboscope. This was rather complicated and had other limitations. A 10 to 1 worm reduction gear was designed and built, which engaged the motor drive shaft to drive a Kollsman Precision Tachometer with a guaranteed precision of 0.1%.

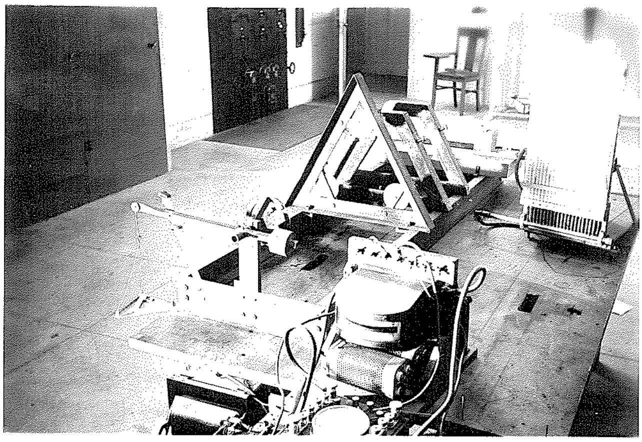


Fig. 3 Fan Test Stand, motor end.

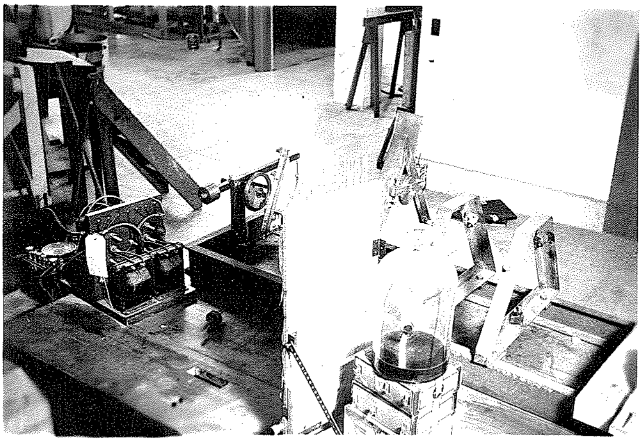


Fig. 4 Fan Test Stand, fan end.

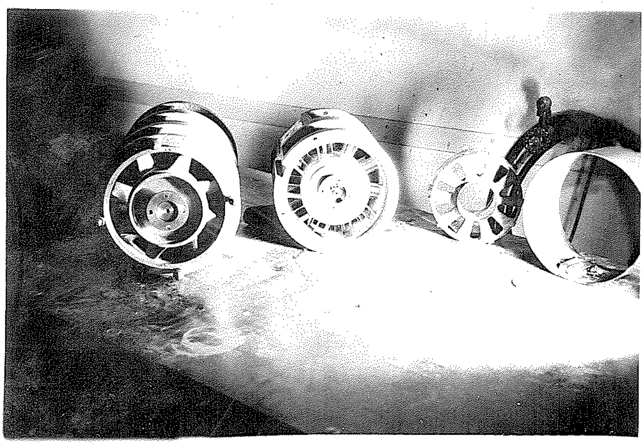


Fig. 5 Fan Units, Shutter

APPENDIX III

COMPUTATIONS

Power output of Motor

The power output of the motor in HP. is,

$$HP. = \frac{2\pi nlw}{550}$$

where n = R.P.S., l = lever arm (ft.), w = wt (lbs.)

In the C.G.S. system,

$$HP. = 33.0 \times 10^{-6} nw$$

where w = wt. in grams; l = constant of 40 cm., is included in the general constant.

As input to the fan,

$$W_i = 2\pi lnw$$

$$251.3 \text{ nw gram cm./sec.}$$

Motor Efficiency

$$Eff. = \frac{33.0 \times 10^{-6} nw \times 100}{1.341 \times KW.}$$

$$= \frac{2425 \times 10^{-6} nw}{KW.}$$

Useful Work

The useful work of the fan is, in this problem, defined as the quantity of air passing through the fan times the pressure rise, The purpose of the fan being, to remove the boundary layer from the wing, there is no further use for the air once it has passed through the fan. It is most econ--omical to retain the kinetic energy of the jet as such, to facilitate in exhausting this air from the fan. The power utilized therefore is,

$$W_o = Q(p_2 - p_1)$$

where $Q = cm.^3/sec.$; p_1, the pressure ahead of and p_2, the pressure behind the fan. But,

$$Q = AV$$
$$= A\sqrt{\frac{2q}{\rho}}$$
$$1.414A\,\rho^{-\frac{1}{2}}q^{\frac{1}{2}}$$

If it is assumed, $\rho = F(r)$ = constant--1.194×10^{-6} then,

$$Q = 1.414\int 2\pi r\,\rho^{-\frac{1}{2}}q^{\frac{1}{2}}dr$$
$$= 8120\int_0^{6.3} rq^{\frac{1}{2}}dr$$

The function $rq^{\frac{1}{2}}$ is obtained by a pitot traverse of 19 points taken across the jet. (see sample data sheet, page 24 ,and velocity distribution curves, page 25). Due to the non-uniform velocity distribution, graphical integration was resorted to for the solution of equation . The values of $rq^{\frac{1}{2}}$ plotted against r, give Q as the area under the curve. (see quantity curves, pages 25-26). These areas were measured with a planimeter.

Fan Efficiency

$$\text{Eff.} = \frac{W_i \times 100}{W_o}$$

$$\frac{Q\,\Delta P \times 100}{2\pi \text{lnw}}$$

where Q = quantity (cm^3/sec.)

$P = (p_2 - p_1)$ in cm. of water.

Development of C_Q Equation

$$Q = KA\sqrt{\frac{2\overline{P_T}}{\rho}}$$

Where A = jet area = 125.6 cm^2.

K = fan constant

$\overline{P_T}$ = reading of multiple pitot.

By definition,

$$C_Q = \frac{Q}{VS}$$

V = wind tunnel air speed
S = wing area 6841.4 cm^2.

but

$$V = \sqrt{\frac{2q}{\rho}}$$

Substituting in

$$C_Q = \frac{Q}{S\sqrt{\frac{2q}{\rho}}}$$

$$= \frac{C_x\ A\sqrt{\frac{2\overline{P_T}}{\rho\ (\text{model air})}}}{S\sqrt{\frac{2q}{\rho\ (\text{tunnel air})}}}$$

$$= \frac{C_x A}{S}\left(\frac{\rho_m}{\rho_t}\right)^{\frac{1}{2}}\left(\frac{\overline{P_T}}{q}\right)^{1/2}$$

$$C_Q = 0.01836\ C_x\left(\frac{\rho_m}{\rho_t}\right)^{\frac{1}{2}}\left(\frac{\overline{P_T}}{q}\right)^{\frac{1}{2}}$$

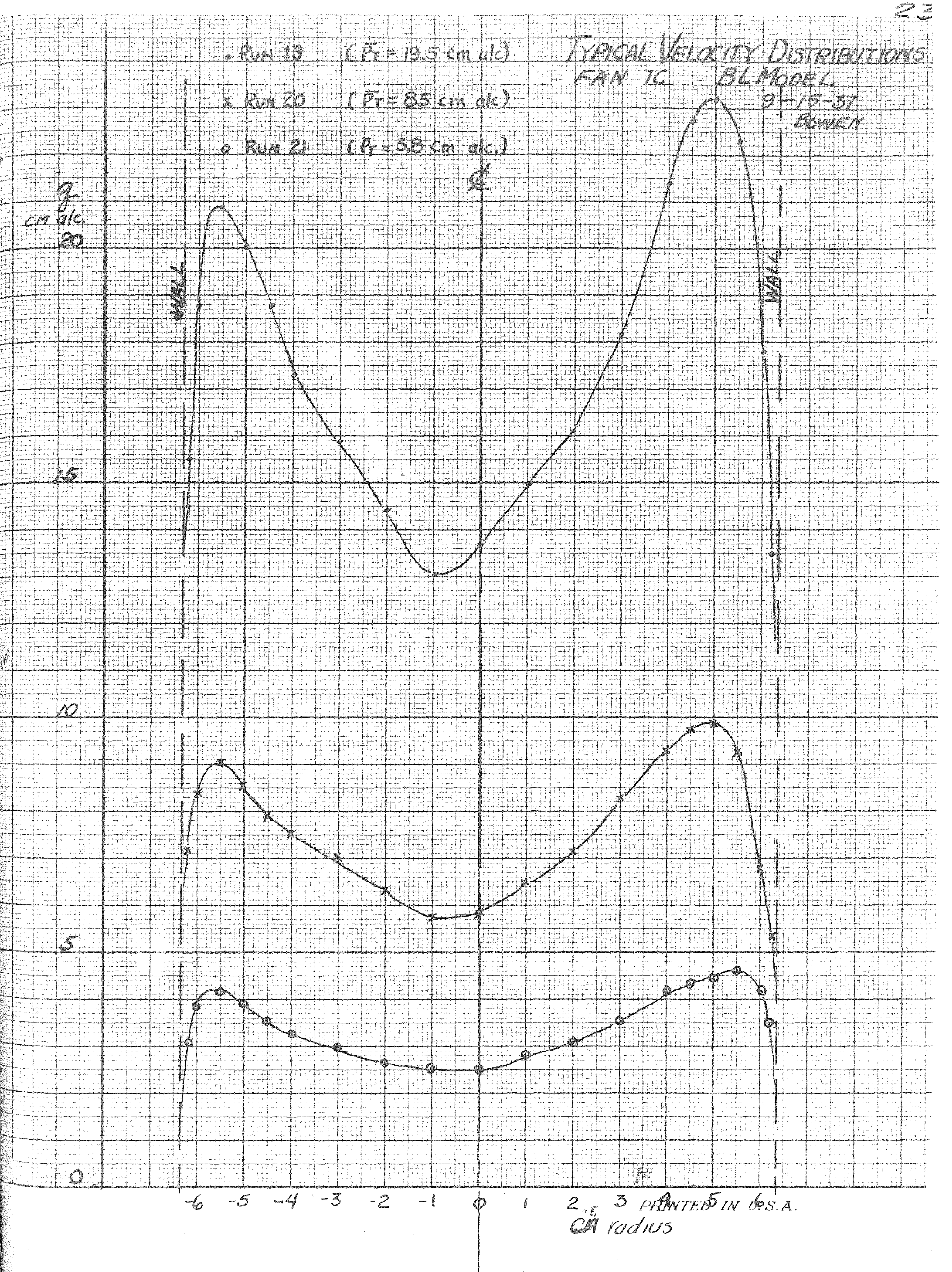
or,

$$\overline{P_T} = \frac{q\ C_Q^2}{.000337 C_x^2}\ \frac{\rho_t}{\rho_m}$$

$$= \frac{2970\ q\ C_Q^2}{C_X^2}\ \frac{\rho_t}{\rho_m}$$

Equation has been plotted for a family of values of tunnel air speeds (see fig. 8)

PAGE 40


TYPICAL VELOCITY DISTRIBUTIONS
FAN 1C BL MODEL
9-15-37
BOWEN
• RUN 19 ($\bar{P}_T$ = 19.5 cm alc)
x RUN 20 ($\bar{P}_T$ = 8.5 cm alc)
o RUN 21 ($\bar{P}_T$ = 3.8 cm alc.)
q
cm alc.
20
15
10
5
0
WALL
WALL
℄
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6
cm radius

CALIFORNIA INSTITUTE OF TEC OLOGY

SAMPLE DATA SHEET

GUGGENHEIM AERONAUTICS LABORATORY ....TUNNEL

Rep.	Exp.	Run	Page
BLM CALIB		64	640

Experiment FAN 1B Test FAN CHARACTERISTICS

Setup DYNAMOMETER Date 10-14-37

Observers: BOWEN W.H. ; SMITH, A.M.O. Computers: —

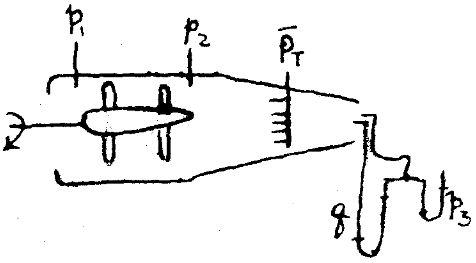
Model Data: q .... R.P.M. ....

SHUTTER REMOVED

γ_f = 1.108 for p_1

= .822 for other pressures

12,500 RPM



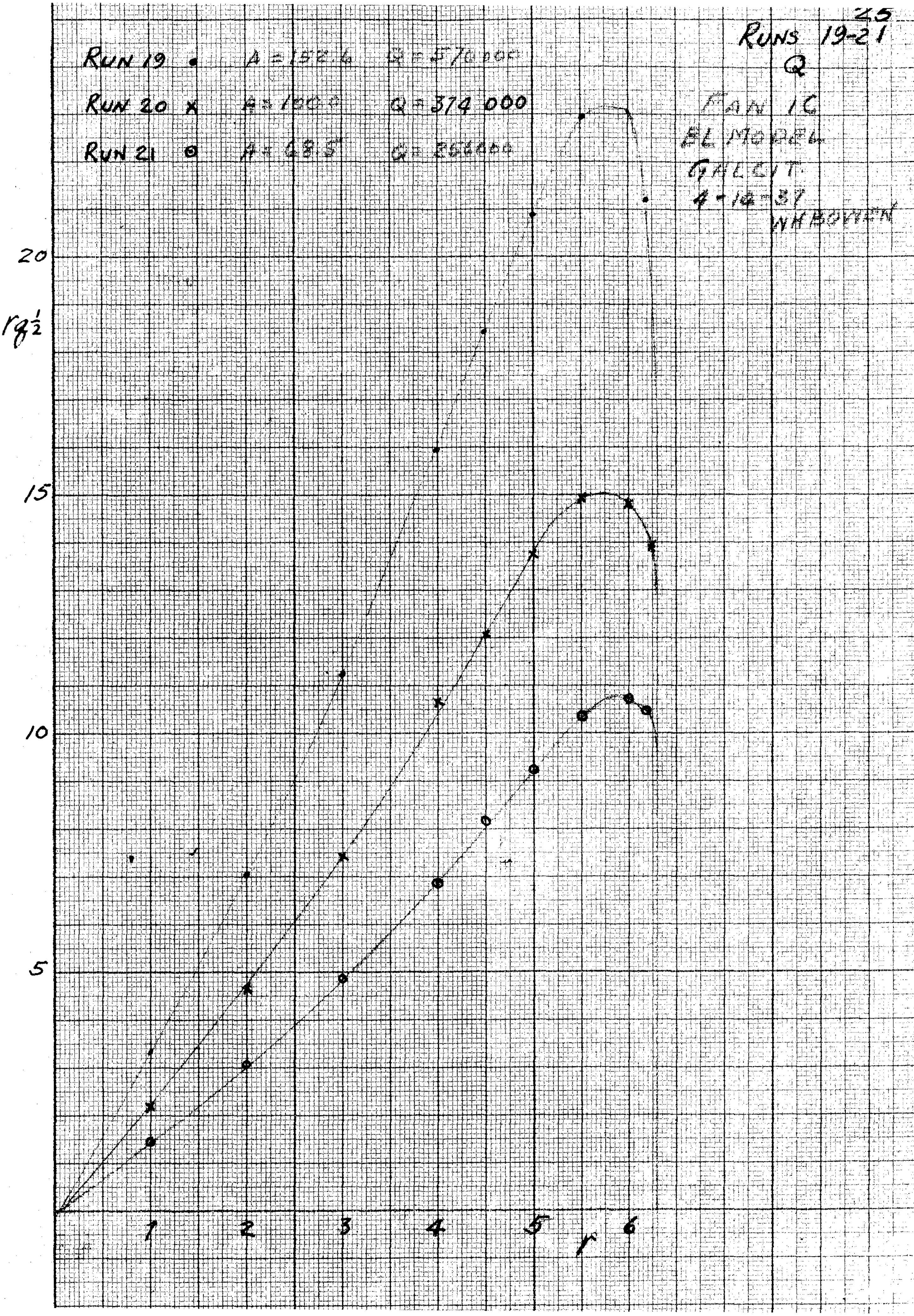
PITOT TRAVERSE OF JET

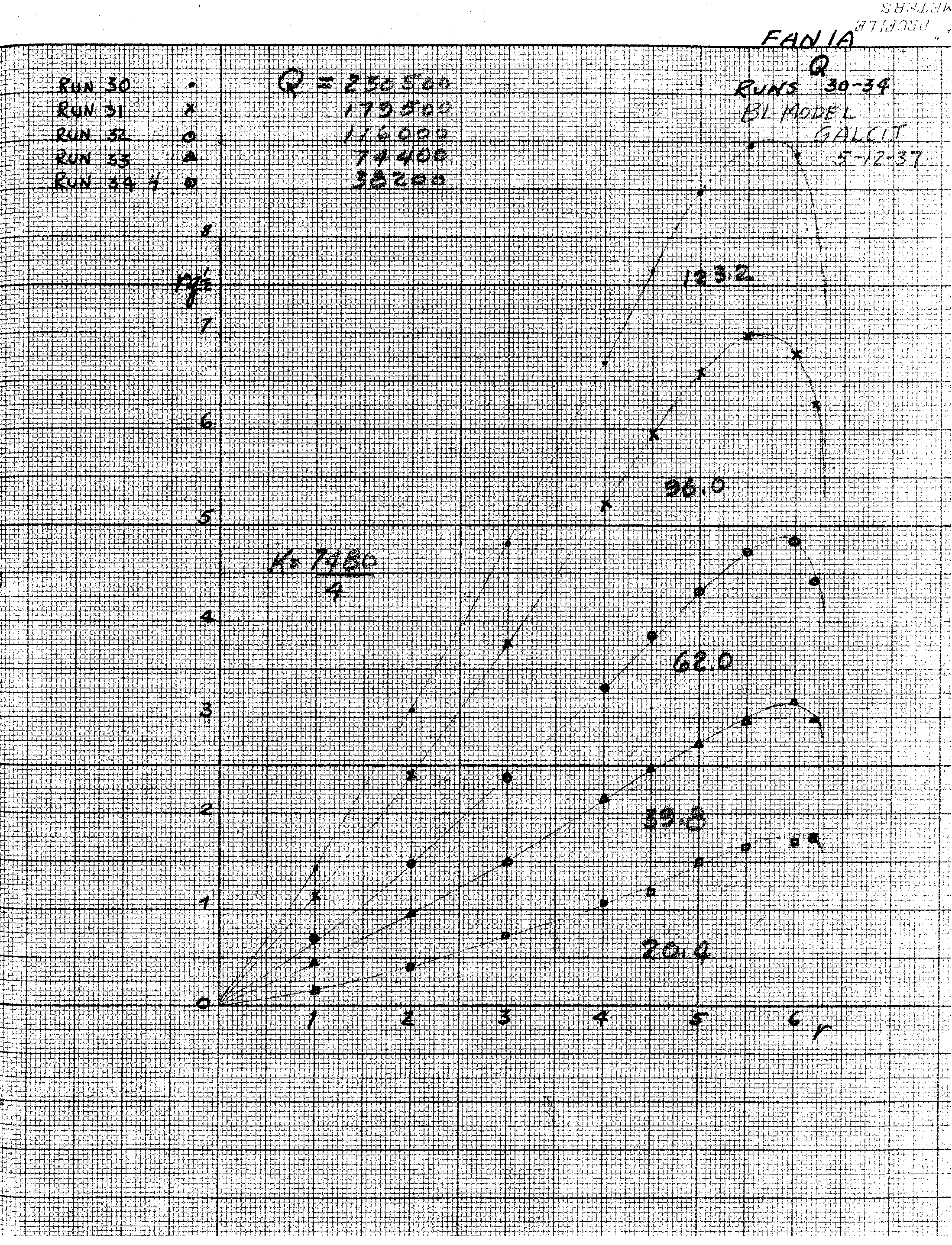
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
							Radius cms	q alc cm	Average q alc	Average q water	$r q_w^{1/2}$				
		CONTROL HEAD VOLTS	104				6.2	11.60	12.00	9.85	19.50				
		RPM	12500				6.0	15.35	15.73	12.80	21.50				
		K.W. INPUT	3.00				5.5	17.05	18.10	14.90	21.20				
		MOTOR TORQUE	525gr.				5.0	16.95	18.70	15.40	19.60				
		p_1	47.8-62.3				4.5	16.50	18.50	15.20	17.55				
		p_2	31.4 cm				4.0	16.00	17.93	14.70	15.34				
		p_3	33.8				3.0	15.65	16.23	13.30	10.95				
		$\bar{P}_T$	33.7-18.1				2.0	14.95	14.23	11.70	6.84				
		Pressure ATMOS.	34.45				1.0	12.35	11.40	9.35	3.06				
							0	10.05	10.05	8.25	0				
							-1.0	10.45							
							-2.0	13.50							
							-3.0	16.80							
							-4.0	19.85							
							-4.5	20.50							
							-5.0	20.45							
							-5.5	19.15							
							-6.0	16.10							
							-6.2	12.40							

NOTE COLUMN 12 IS GRAPHICALLY INTEGRATED TO GET QUANTITY OF AIR THROUGH THE FAN

$$Q = 7480 \int_{-6.2}^{6.2} r q^{1/2} dr$$

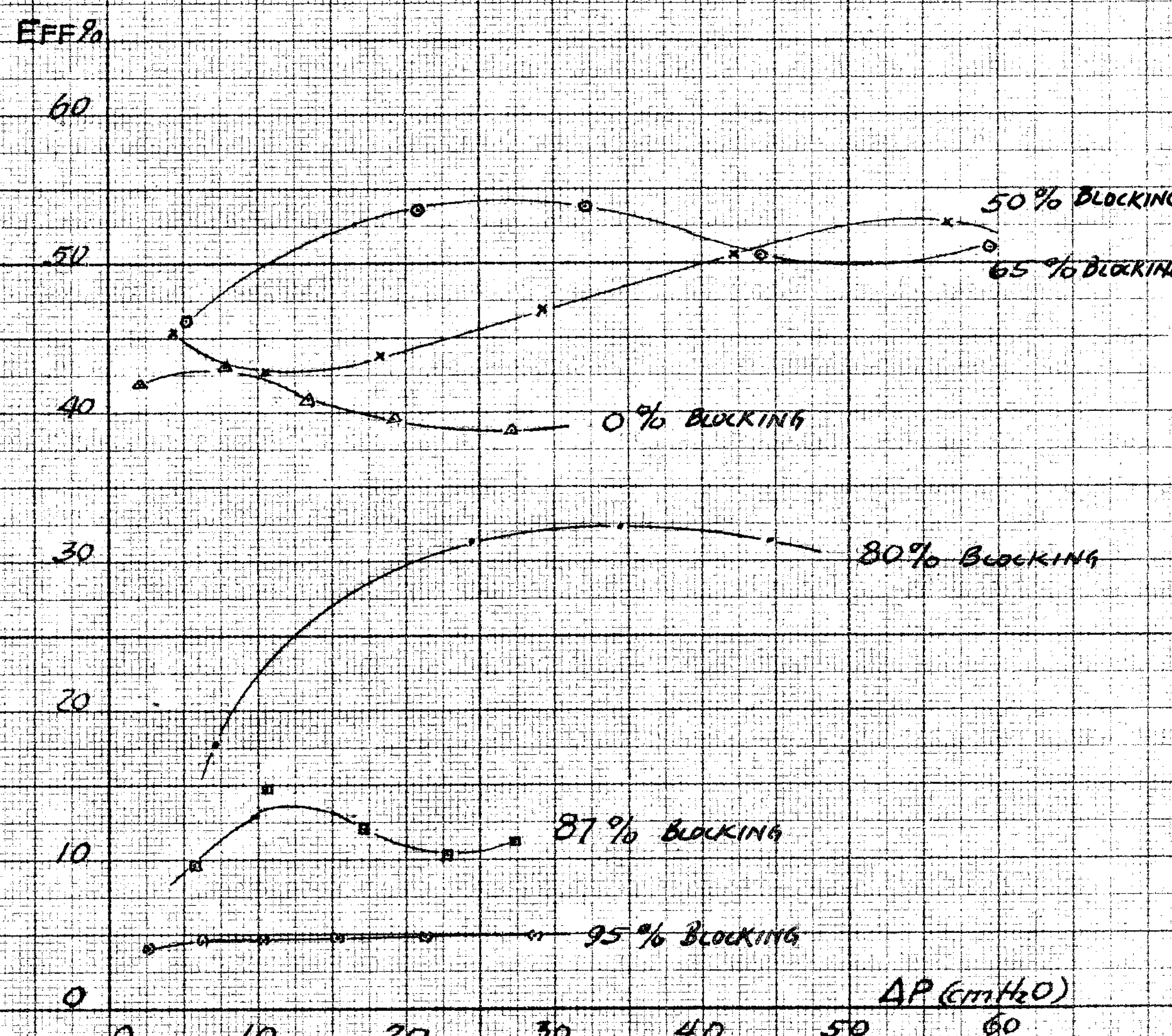
FORM AL-1 10M-2-30

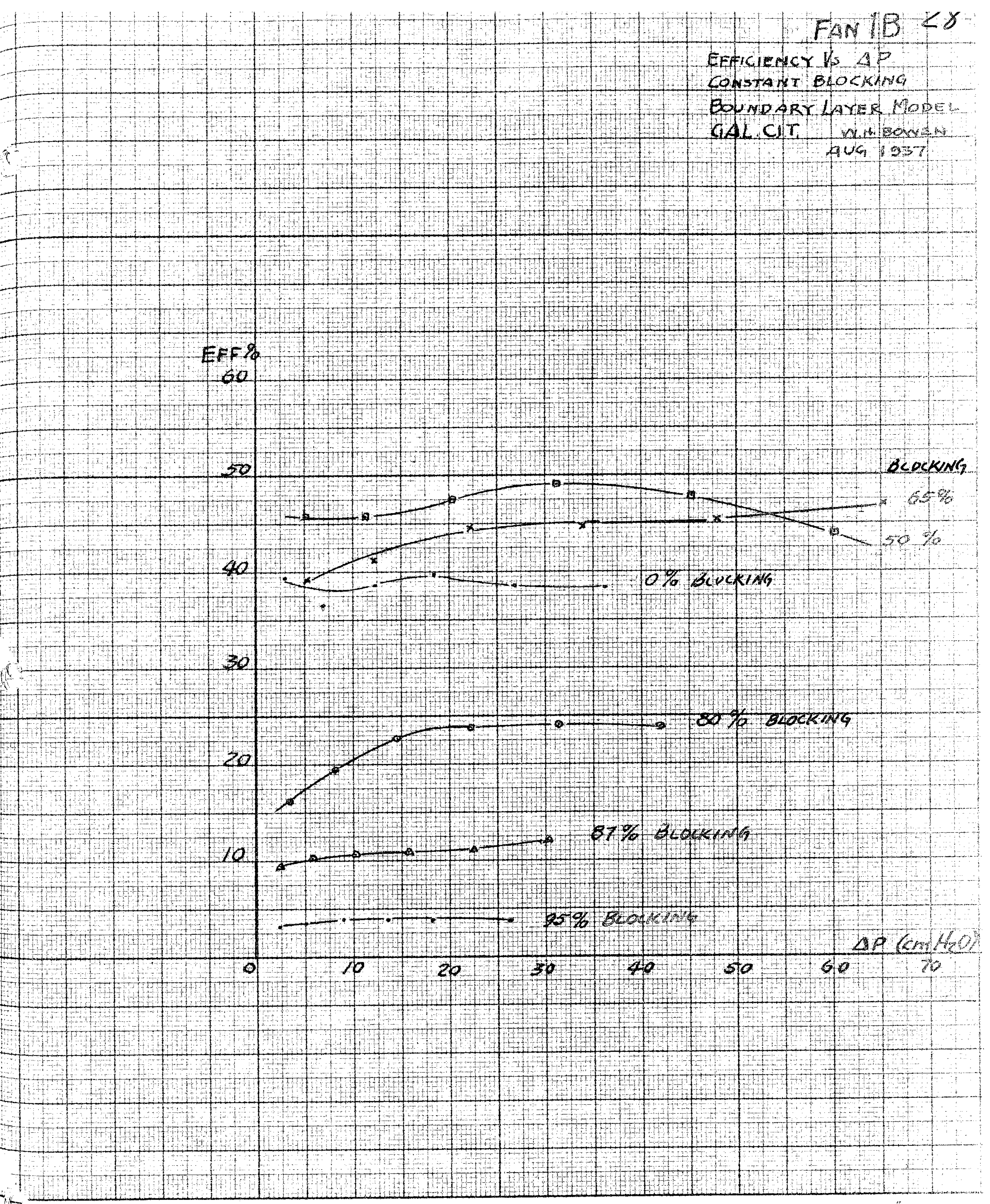

25
RUNS 19-21
Q
FAN 1C
BL MODEL
GALCIT
WH BOWEN
RUN 19 •
A = 152.6
RUN 20 x
Q = 374 000
RUN 21 ⊙
20
15
10
5
1
2
3
4
5
6
r

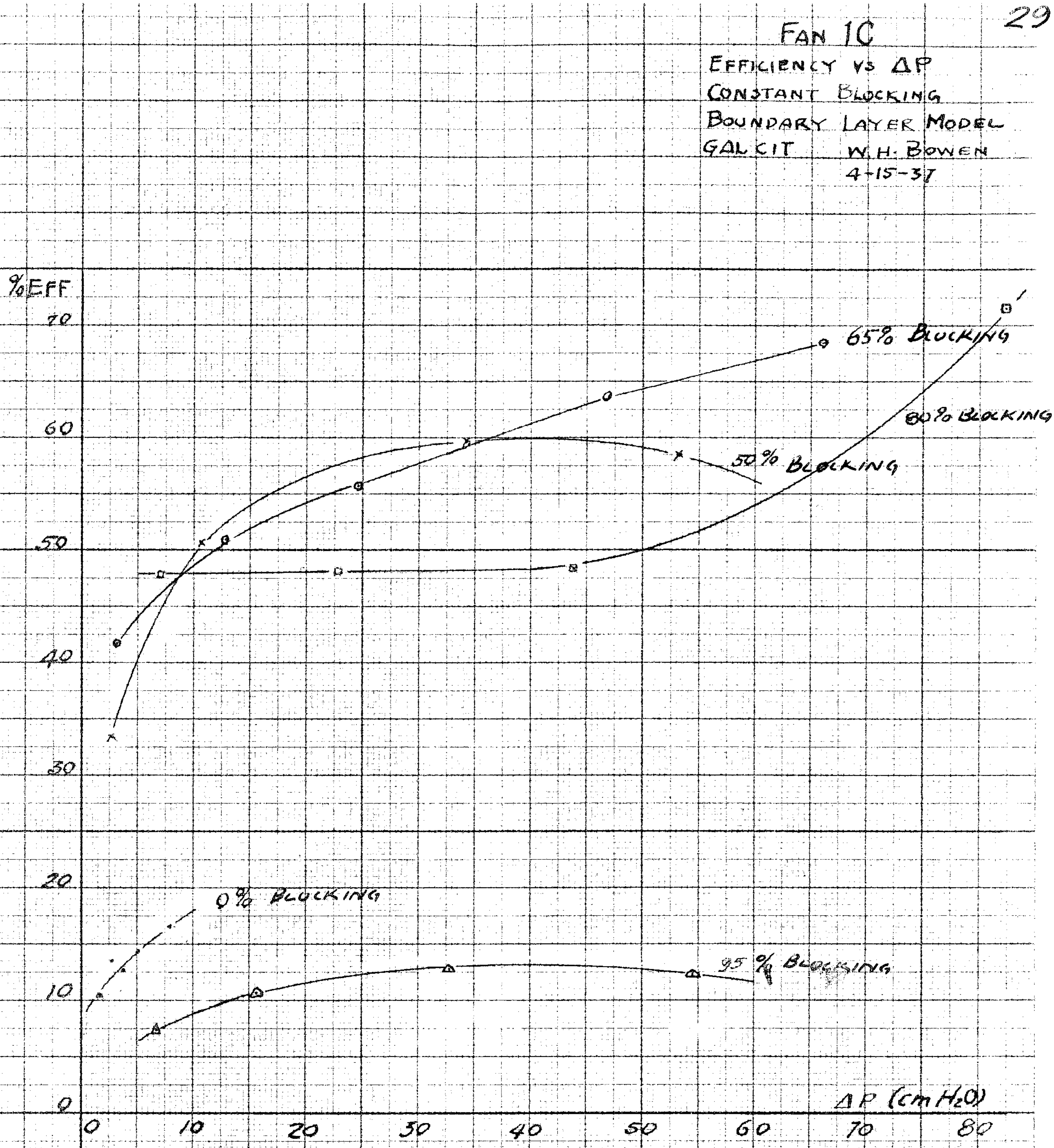

FAN 1A
Q
RUNS 30-34
BL MODEL
GALCIT
5-12-37
RUN 30 •
RUN 31 x
RUN 32 o
RUN 33 ▲
RUN 34 ■
Q = 250500
179500
116000
74400
38200
K = 7480/4
123.2
96.0
62.0
39.8
20.4
0
1
2
3
4
5
6
7
8
r

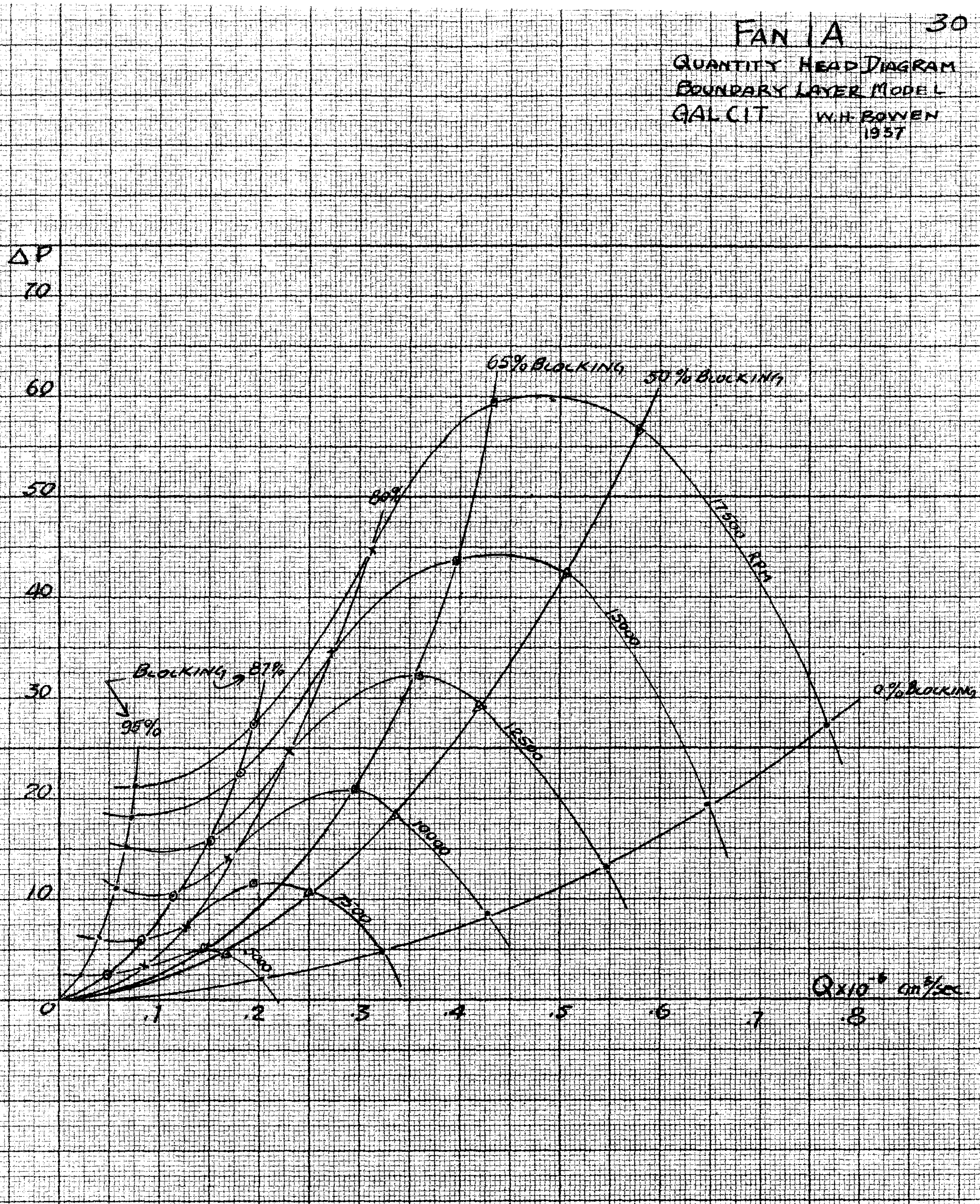
FAN 1A

EFFICIENCY VS ΔP
CONSTANT BLOCKING
BOUNDARY LAYER MODEL
GAL. CIT. W.H. BOWEN
FEB 1937

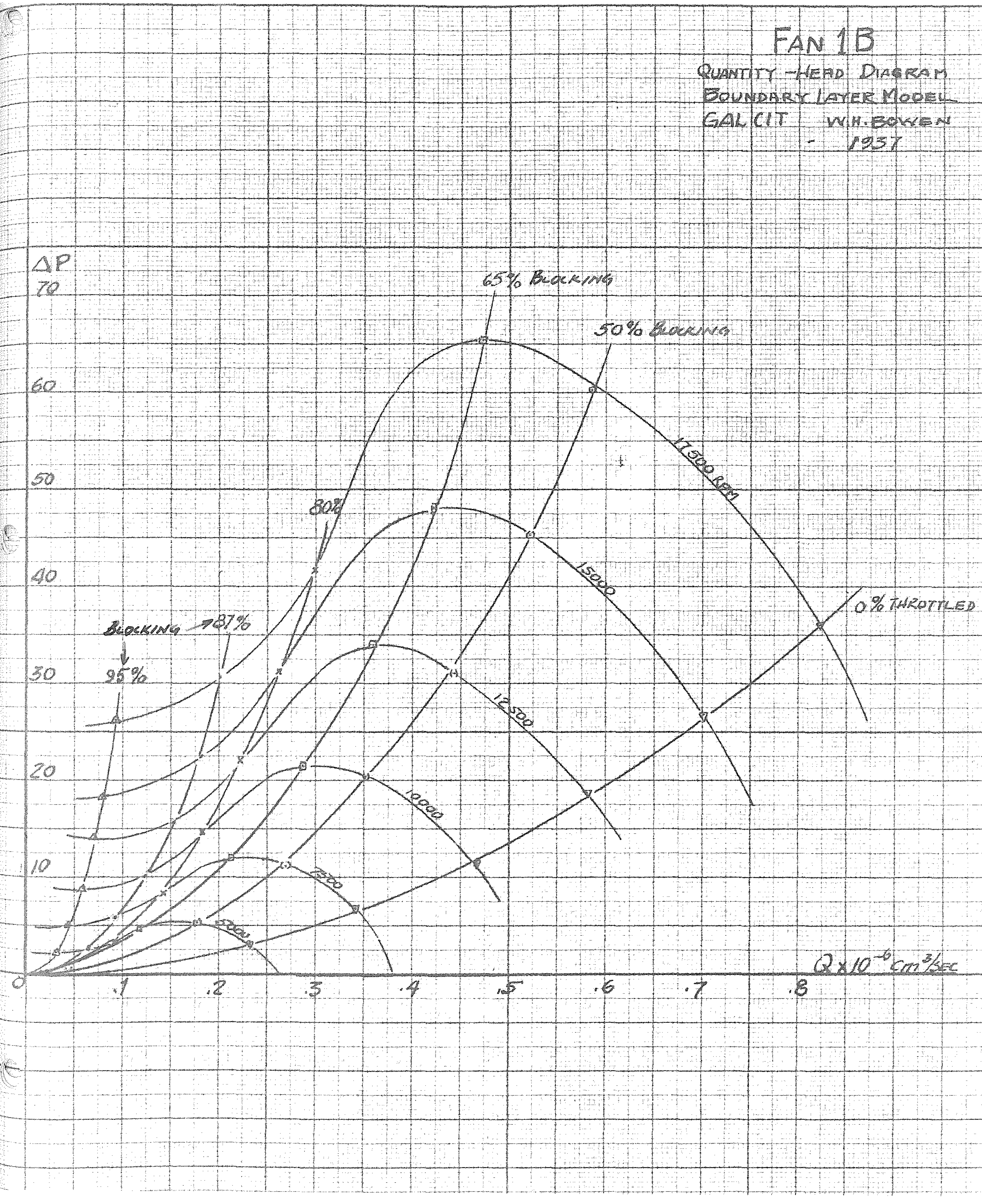



FAN 1B
EFFICIENCY Vs ΔP
CONSTANT BLOCKING
BOUNDARY LAYER MODEL
GAL. CIT.
W.H. BOWEN
AUG 1937
EFF %
60
50
40
30
20
10
0
10
20
30
40
50
60
70
ΔP (cm H₂O)
BLOCKING
65%
50 %
0% BLOCKING
80% BLOCKING
87% BLOCKING
95% BLOCKING

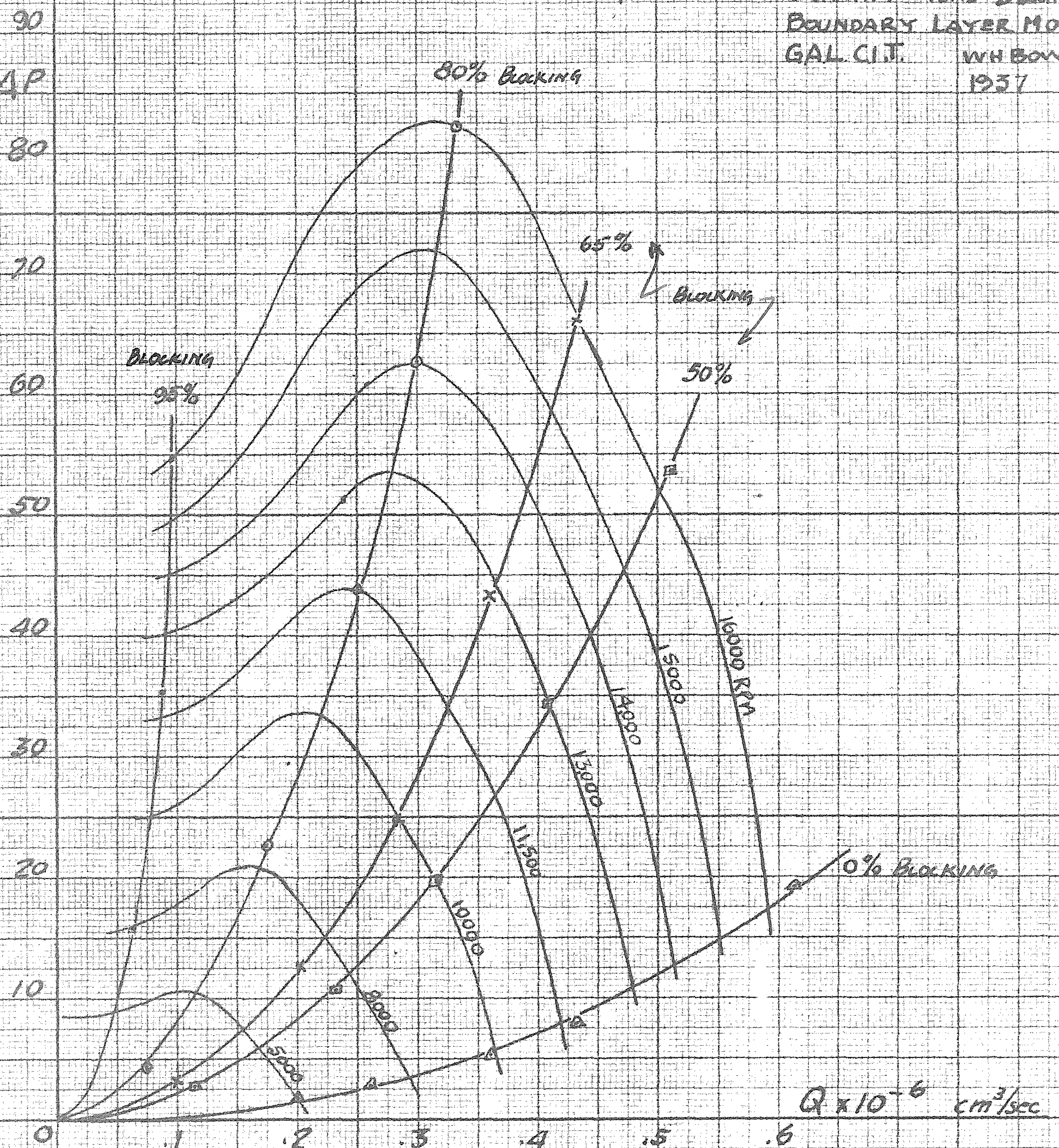

FAN 1C
EFFICIENCY vs ΔP
CONSTANT BLOCKING
BOUNDARY LAYER MODEL
GALCIT W. H. BOWEN
4-15-37
%EFF
70
60
50
40
30
20
10
0
65% BLOCKING
80% BLOCKING
50% BLOCKING
0% BLOCKING
95% BLOCKING
ΔP (cm H_2O)
0
10
20
30
40
50
60
70
80



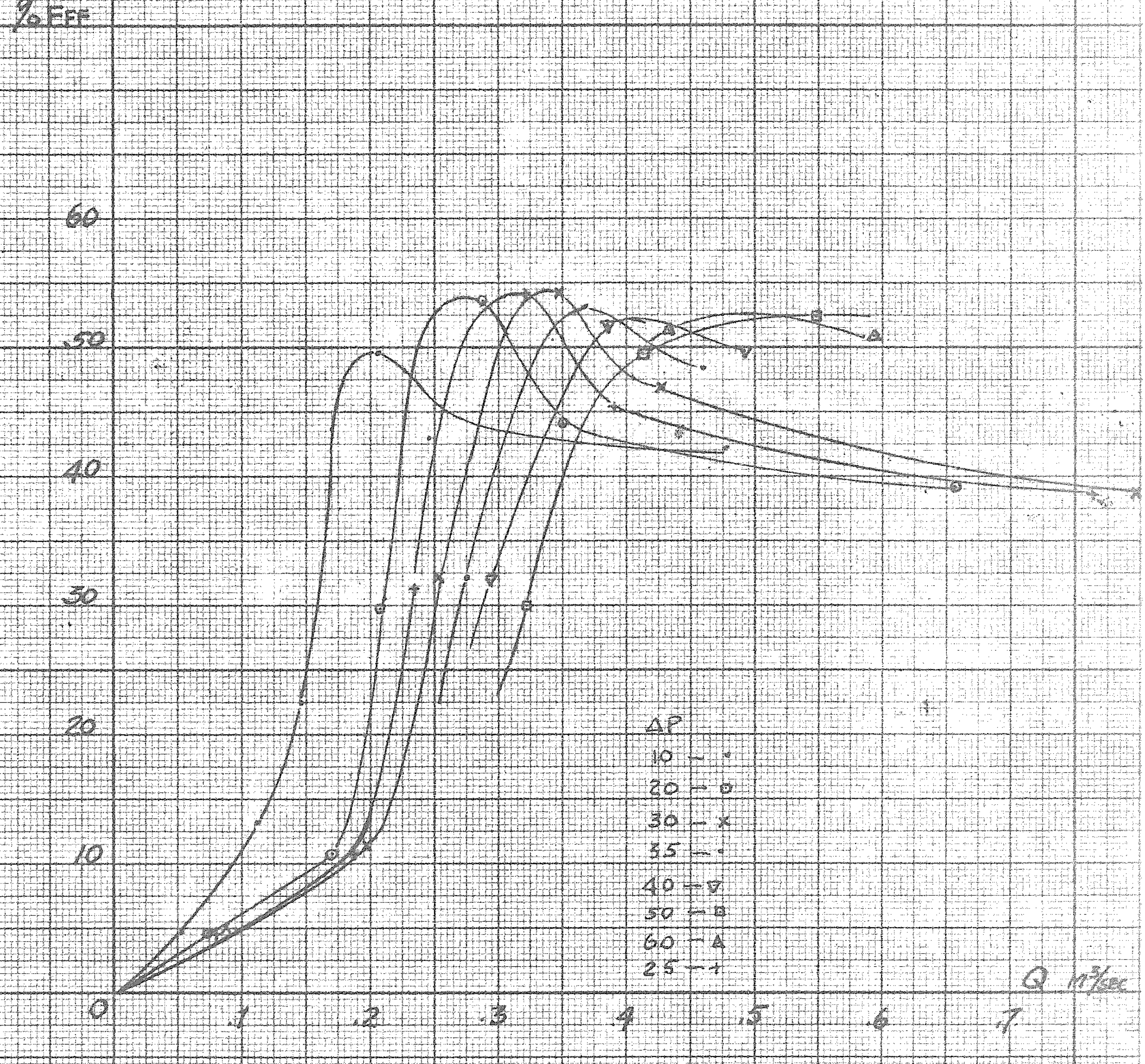
"Perfect" PROFILE
MILLIMETERS
EUGENE DIETZGEN Co.

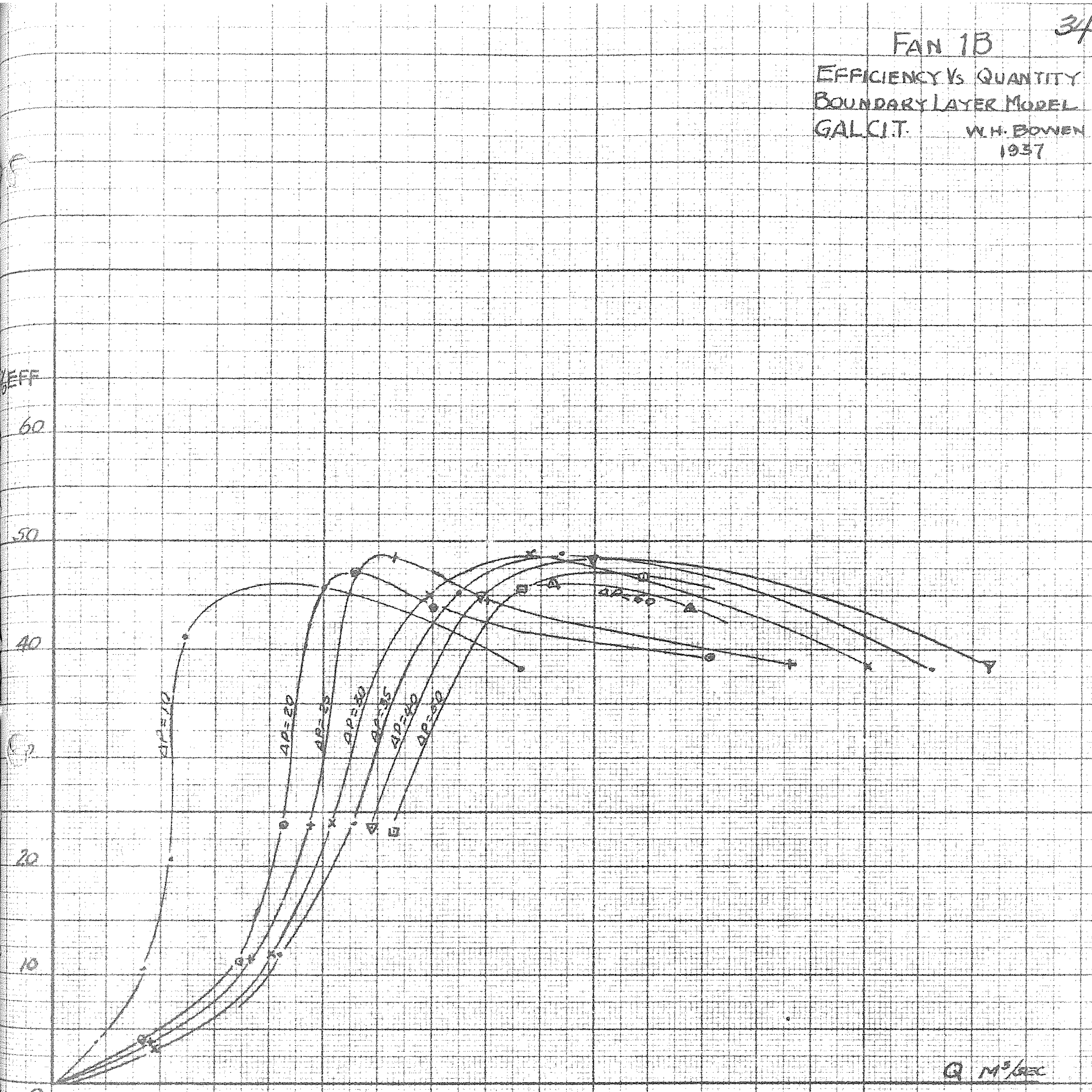

FAN 1B
QUANTITY - HEAD DIAGRAM
BOUNDARY LAYER MODEL
GALCIT W.H. BOWEN
1937
ΔP
70
60
50
40
30
20
10
0
.1
.2
.3
.4
.5
.6
.7
.8
Q x 10^-6 cm^3/sec
65% BLOCKING
50% BLOCKING
80%
BLOCKING 87%
95%
17500 RPM
15000
12500
10000
7500
5000
0% THROTTLED

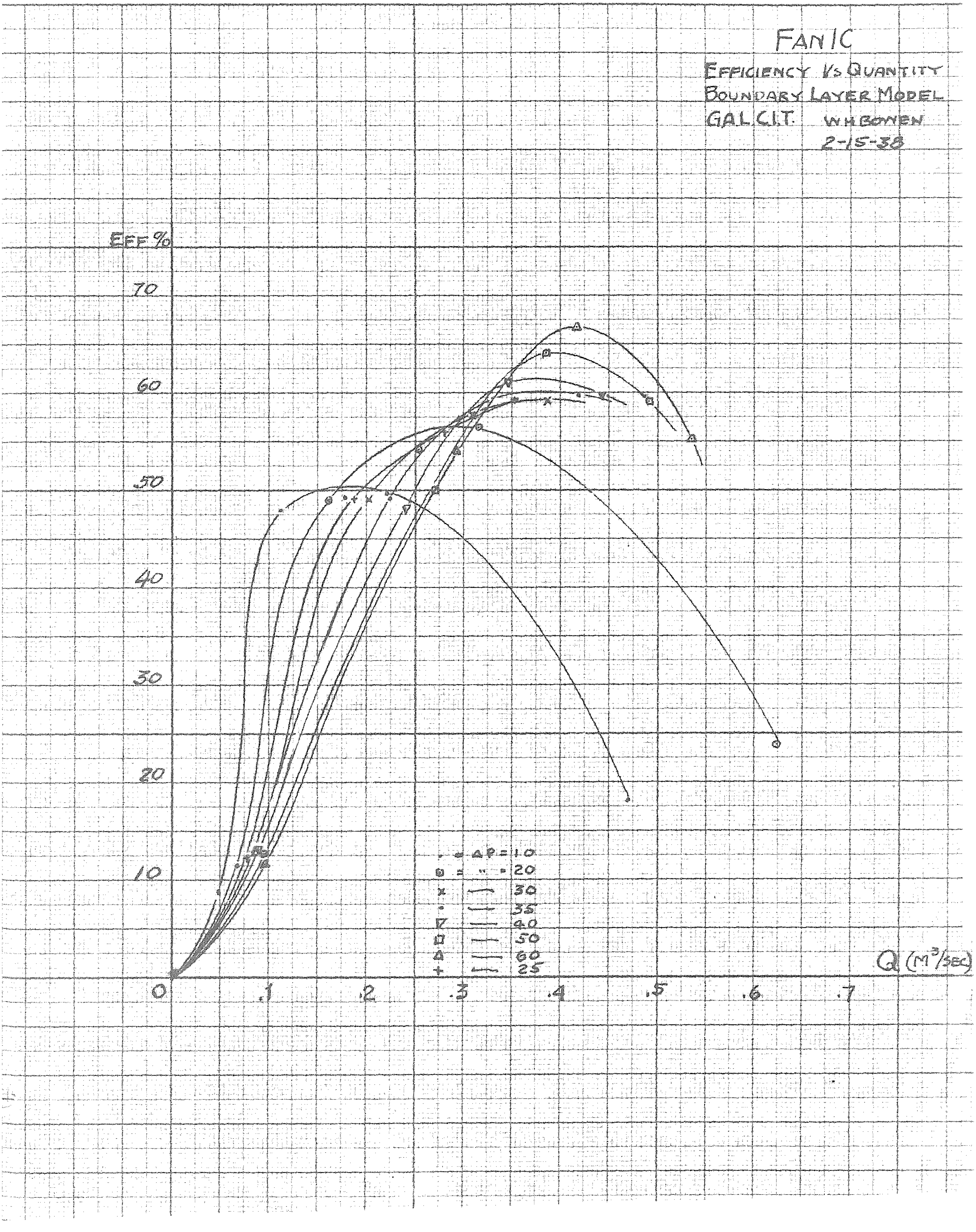
QUANTITY HEAD DIAGRAM
BOUNDARY LAYER MODEL
GAL. CIT. W.H. BOWEN
1937

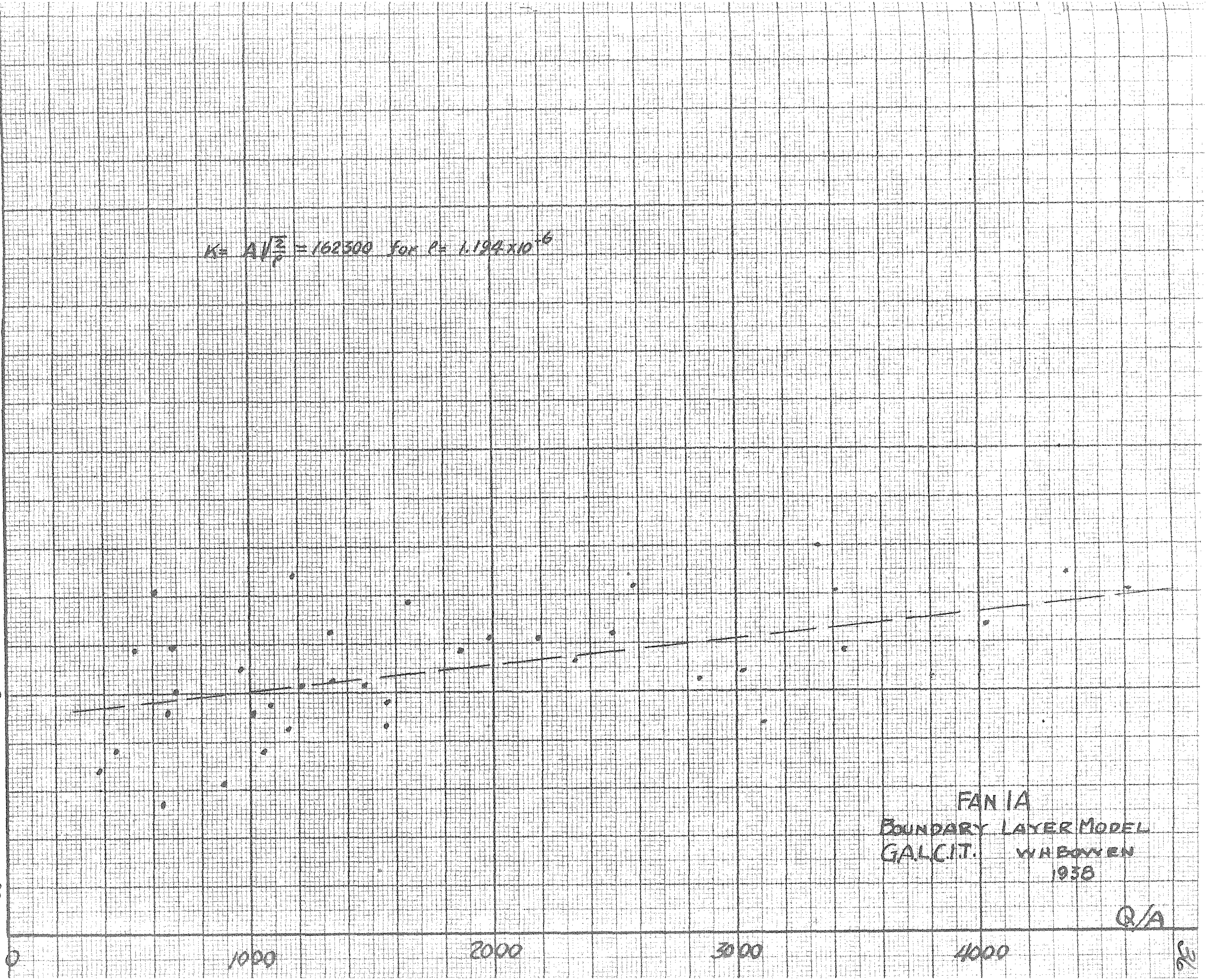


FAN 1A
EFFICIENCY VS QUANTITY
BOUNDARY LAYER MODEL
GAL CIT W.H. BOWEN
1938

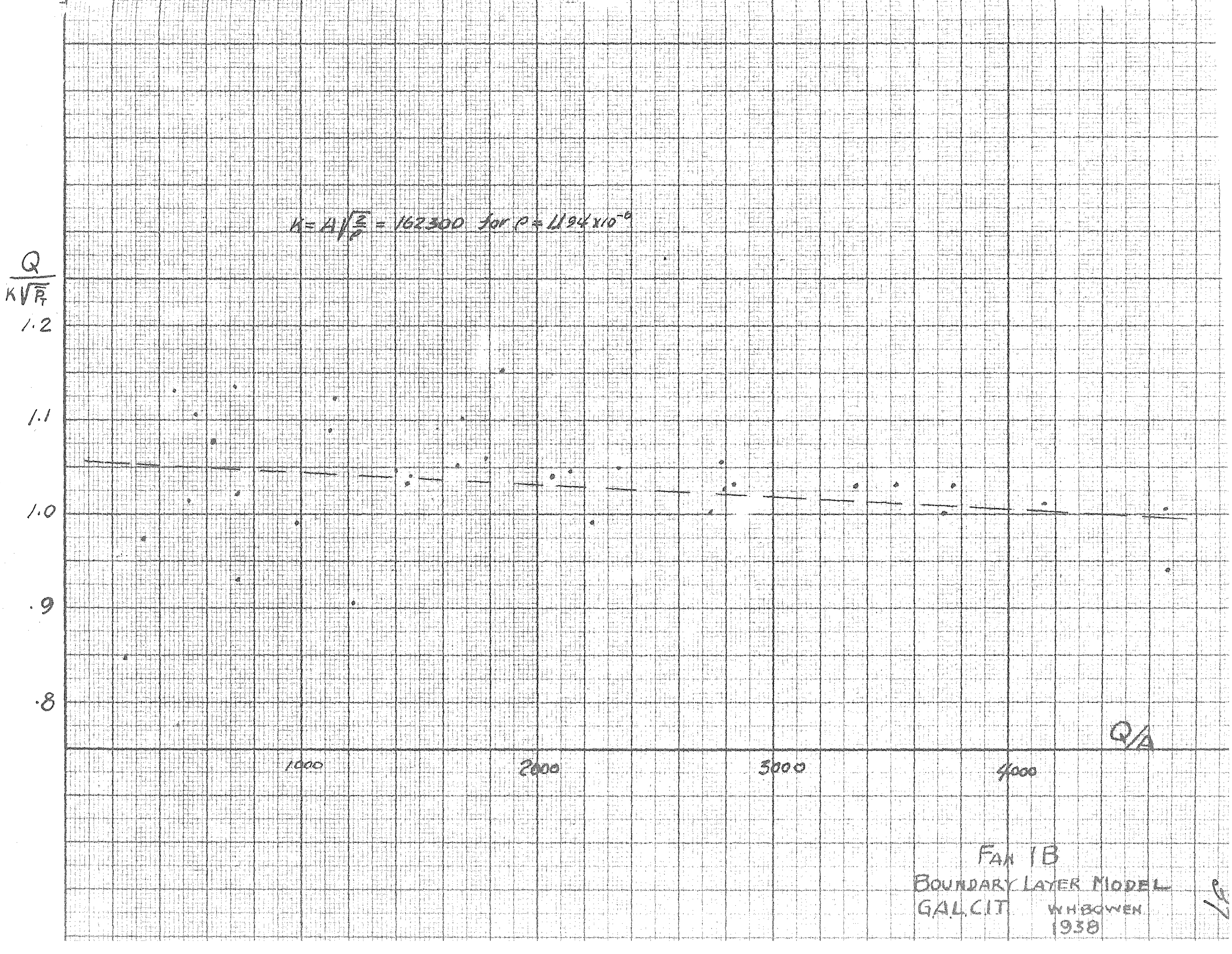


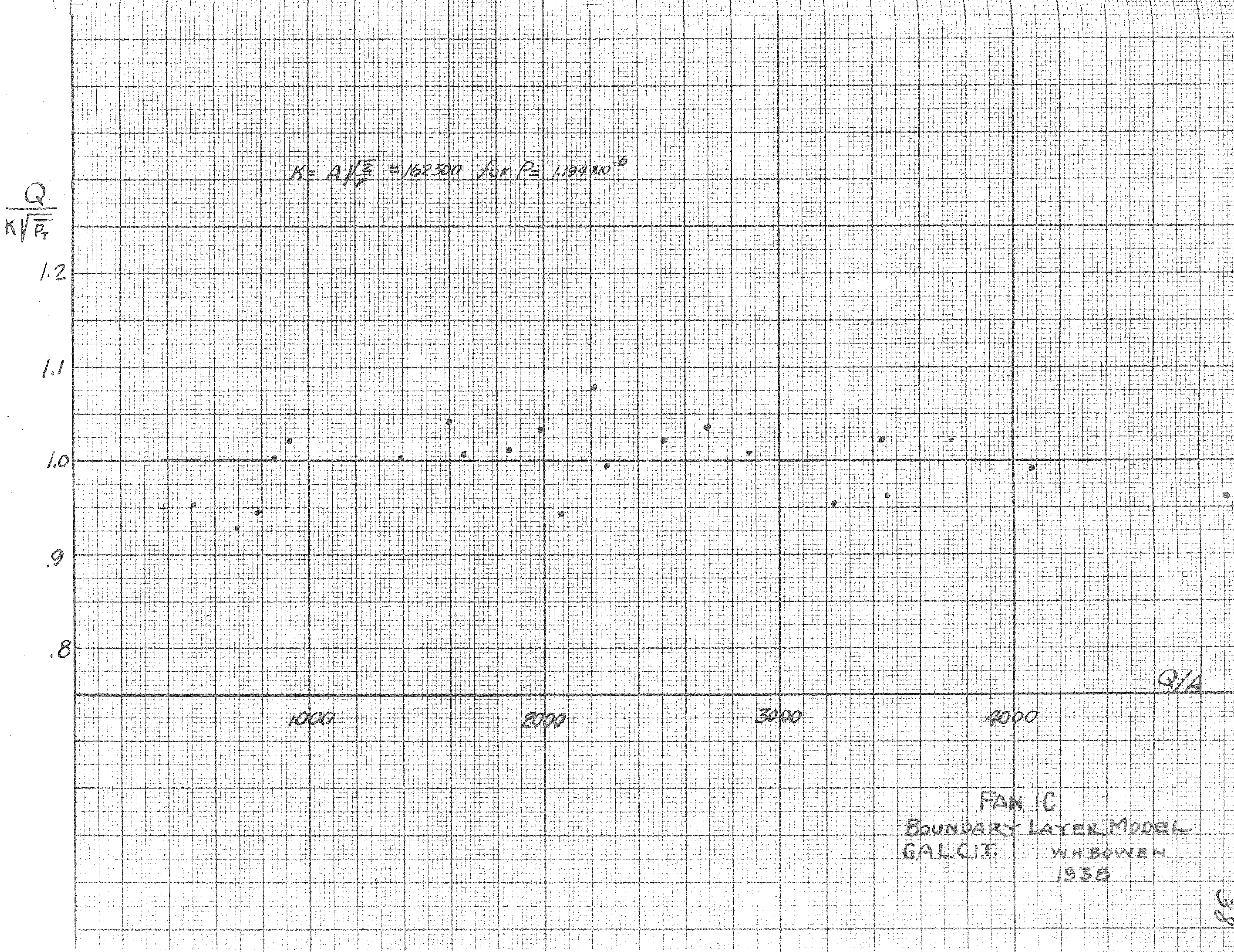

FAN 1B
EFFICIENCY VS QUANTITY
BOUNDARY LAYER MODEL
GALCIT
W.H. BOWEN
1937
%EFF
60
50
40
20
10
0
.1
.2
.3
.4
.5
.6
.7
.8
Q M³/SEC
ΔP=10
ΔP=20
ΔP=25
ΔP=30
ΔP=35
ΔP=40
ΔP=50
ΔP=60


FAN 1C
EFFICIENCY Vs QUANTITY
BOUNDARY LAYER MODEL
GALCIT
W.H.BOWEN
2-15-38
EFF %
70
60
50
40
30
20
10
0
.1
.2
.3
.4
.5
.6
.7
Q (M³/SEC)
ΔP = 10
20
30
35
40
50
60
25



"Perfect" PROFILE
MILLIMETERS
EUGENE DIETZGEN Co.


$K = A\sqrt{\frac{2}{\rho}} = 162300$ for $\rho = 1194 \times 10^{-6}$
$\frac{Q}{K\sqrt{P_T}}$
1.2
1.1
1.0
.9
.8
Q/A
1000
2000
3000
4000
FAN 1B
BOUNDARY LAYER MODEL
GALCIT
W.H. BOWEN
1938
37



K= A√(2/ρ) =162300 for ρ= 1.194×10^-6
Q / K√(P_T)
1.2
1.1
1.0
.9
.8
Q/A
1000
2000
3000
4000
FAN IC
BOUNDARY LAYER MODEL
GAL.C.I.T.
W.H. BOWEN
1938

APPENDIX IV

REDUCED DATA

CALIFORNIA INSTITUTE OF TECHNOLOGY

GUGGENHEIM AERONAUTICS LABORATORY ....TUNNEL

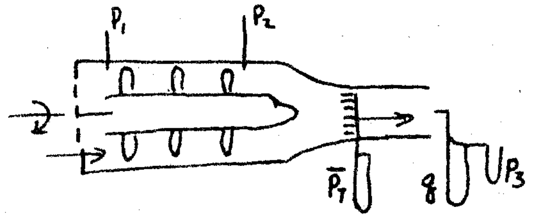
Rep.	Exp.	Run	Page
BLM		B	B1

Experiment FAN CALIBRATION Test FAN 1C 3 STAGE

Setup DATA REDUCTION Date

Observers: Computers:

Model Data: q R.P.M.



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	RUN #	BLOCKING %	RPM	CYCLES RPS	TORQUE GRAMS	MOTOR VOLTS	KW INPUT	P_1	P_2	P_3	$\bar{P}_T$	$Q \times 10^{-6}$ CM³/SEC	INPUT TO FAN GRCM/SEC $\times 10^{-6}$	ΔP	EFF. %
	2	0	7309	123.8	170	60	.68	-2.71	.072	.182	2.88	.23936	5.35	2.782	12.4
	3A	0	5000	82.3	150	40	.40	-1.656	.052	.029	1.402	.18438	3.321	1.708	9.5
	3B	0	9520	158.5	325	80	1.20	-5.01	.081	.118	4.856	.33248	12.93	5.091	13.1
	3C	0	11,700	195	420	99	1.85	-7.81	.092	.193	6.70	.3083	20.53	7.907	15.5
	4	50	7375	123	160	60.5	.67	-10.45	.32	0	1.98	.21393	4.94	10.77	46.6
	5	50	10000	166.7	310	86.5	1.40	-19.2	.68	-.09	3.56	.29022	12.98	19.88	44.5
	6	50	16100	268	700	140	5.32	-51.2	2.54	-.05	10.0	.4715	47.1	53.74	53.7
	7	50	13050	217.5	420	113.9	2.84	-32.95	1.13	.02	6.02	.3750	23.0	34.08	55.0
	8	50	3750	62.5	60	20	.18	-2.60	.12	.04	.48	.1062	9.43	2.72	50.7
	9	65	3800	63.9	50	20	.20	-3.15	.12	.04	.42	.0996	.797	3.25	38.6
	10	65	7300	121.8	170	61	.55	-12.4	.31	.02	1.62	.1910	5.20	12.71	46.7
	11	65	9975	166.2	300	86	1.36	-24.3	.57	0	3.06	.2603	12.55	24.87	51.5
	12	65	16075	257.5	650	138	5.13	-65.7	.65	.04	7.64	.4010	42.1	66.35	63.2
	13	80	7975	133	250	67	.67	-20.6	.23	.09	1.16	.1616	8.35	22.83	44.2
	14	80	16025	267	580	135.5	4.95	-81.5	.808	.02	4.94	.3120	38.95	82.31	65.8
	15	80	11550	192.5	470	98	1.90	-43.3	.48	.02	2.21	.2303	22.74	43.78	44.4
	16	95	16000	267	650	135	5.41	-55.0	-.16	0	.41	.0902	43.7	54.89	11.3
	17	95	11550	192.5	470	95.5	2.11	-33.4	-.16	.20	.38	.0809	22.15	33.24	11.8
	18	95	8000	133.2	270	66.5	.68	-15.9	-.06	.09	.17	.0586	9.02	15.89	9.8
	19	0	17600	293.5	680	151	5.41	-17.8	1.21	.42	15.75	.5700	50.2	19.01	21.7
	20	0	11800	197	420	100	1.86	-7.73	.685	.49	6.86	.3740	20.8	8.42	15.2
	21	0	7850	130.8	280	66	.56	-3.33	.28	.16	3.07	.2960	9.20	3.61	10.0

CALIFORNIA INSTITUTE OF TECHNOLOGY

GUGGENHEIM AERONAUTICS LABORATORY ....TUNNEL

Rep.	Exp.	Run	Page
			B_2

Experiment: FAN CALIBRATION Test: FAN 1C 3 STAGE

Setup: DATA REDUCTION Date:

Observers: Computers:

Model Data: q R.P.M.

$$K = A\sqrt{\frac{2}{\rho}} = 162313 \text{ for } \rho = 1.194 \times 10^{-6}$$

2	3	4	5	6	7	8	9	10
Run #	$\bar{P}_T$	$Q \times 10^{-6}$	Fan input GrCM/10^{-6}	ΔP cm H_2O	% Eff.	$10^{-6} K\sqrt{P_T}$	$\frac{Q}{K\sqrt{P_T}}$	Q/A
2	2.88	.2600	5.350	2.782	13.5	.2760	.942	2070
3A	1.402	.2010	3.321	1.708	10.3	.1925	1.044	1600
3B	4.856	.3605	12.93	5.091	14.2	.3580	1.006	2870
3C	6.700	.4320	20.53	7.907	16.6	.4210	1.026	3430
4	1.980	.2320	4.940	10.770	50.6	.2285	1.016	1846
5	3.560	.3150	12.980	19.880	48.3	.3060	1.029	2505
6	10.00	.5115	47.100	53.740	58.4	.5130	.997	4070
7	6.02	.4070	23000	34.080	59.7	.3980	1.022	3735
8	.480	.1152	9430	2.720	33.3	.1128	1.022	915
9	.420	.1056	.797	3.250	41.8	.1052	1.003	845
10	1.620	.2075	5.200	12.710	50.7	.2060	1.007	1655
11	3.060	.2828	12.550	24.870	55.9	.2840	.996	2250
12	7.640	.4345	42.100	66.350	68.6	.4510	.962	3460
13	1.160	.1754	8.350	22.830	48.0	.1750	1.002	1397
14	4.040	.3385	38.950	82310	71.5	.3265	1.036	2692
15	2.210	.2500	22.740	43.780	48.2	.2415	1.035	1990
16	.410	.0978	43.700	54.840	12.3	.1038	.945	777
17	.380	.0878	22.750	33.240	12.8	.1000	.930	695
18	.170	.0636	9.020	15.840	10.6	.0668	.952	506
19	15.750	.6180	50.200	19.010	23.6	.6400	.966	4920
20	6.86	.4060	20.800	8.420	16.5	.4250	.958	3225
21	3.07	.2775	9.200	3.610	10.8	.2840	1.081	2205

CALIFORNIA INSTITUTE OF TECHNOLOGY

GUGGENHEIM AERONAUTICS LABORATORY ....TUNNEL

Rep.	Exp.	Run	Page
		C	C₁

Experiment FAN CALIBRATION Test FAN 1A 2 STAGE BLM

Setup DATA REDUCTION Date

Observers: Computers:

Model Data: q R.P.M.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	RUN #	% BLOCKING	RPM	RPS	TORQUE GRAMS	MOTOR VOLTS	KW INPUT	P_1	P_2	P_3	$\bar{P}_T$	$Q \times 10^{-6}$ CM^3/SEC	INPUT TO FAN $\frac{GR \cdot CM}{SEC} \times 10^{-6}$	ΔP	EFF %
	26	80	5000	83.3	65	33	.19	-3.15	.04	.02	.285	.0800	1.360	3.17	18.7
	27	95	5000	83.3	75	36	.20	-2.56	.04	.01	.049	.0232	1.568	2.57	3.8
	28	65	5000	83.3	75-80	38	.29	-5.16	.05	.03	.88	.1345	1.620	5.18	4[illegible].8
	29	50	5000	83.3	80	38	.20	-4.88	.18	.08	.935	.1537	1.672	4.56	41.8
	30	50	7500	125	199	61	.65	-10.10	.32	-.07	2.125	.2305	6.250	10.63	33.2
	31	65	7500	125	164	61	.56	-11.61	.23	.02	1.535	.1795	5.650	11.63	37.0
	32′	80	7500	125	165	61	.60	-7.25	.08	.04	.621	.1160	5.180	7.33	16.5
	33′	87	7475	124.3	160	61	.57	-5.98	0	.06	.258	.0744	5.090	5.98	8.8
	34′	95	7500	125	180	61	.68	-6.08	0	.02	.08	.0382	5.660	6.08	4.1
	35′	50	10000	166.7	340	84	1.55	-18.09	.57	.08	3.43	.3090	14.27	18.11	49.3
	36′	50	12500	208	500	105	2.73	-28.35	.89	.13	5.03	.3865	26.18	29.24	43.2
	37′	50	15000	250	610	128	4.50	-41.05	1.305	.16	8.48	.4670	42.70	42.35	46.4
	38′	50	17500	292	850	150	6.38	-54.7	1.94	.18	11.30	.5330	62.50	56.64	48.3
	39′	87	17500	292	650	150	4.91	-27.4	0	0	2.095	.1762	47.10	27.50	10.1
	40	87	15000	250	480	129	3.40	-22.44	-.18	.06	.840	.1245	30.15	22.60	9.2
	41	87	12500	208.2	399	109	2.90	-17.46	-.16	0	.81	.136	20.85	17.30	11.26
	42	87	10000	166.7	255	88	1.35	-11.16	-.08	-.01	.52	.111	8.03	11.08	15.3
	43	80	10000	166.7	157	88	1.22	-14.13	.08	-.04	1.033	.155	6.57	14.21	33.5
	44	80	12500	208.2	354	105	1.92	-24.5	.23	.06	1.89	.215	18.71	24.13	28.8
	45	80	15000	250	465	128	3.12	-34.5	.20	.08	2.54	.253	29.20	34.70	29.6
	46	80	17500	292	610	140	4.85	-44.2	.49	.08	3.30	.288	44.80	44.69	28.8
	47	95	10000	166.7	295	82.5	1.37	-11.2	-.06	.01	.131	.0512	12.34	11.14	4.2
	48	95	12500	208.2	405	104	2.25	-15.4	-.05	.02	.148	.0605	21.15	15.35	4.4
	49	95	15000	250	545	125	3.675	-21.4	-.16	-.04	.181	.0705	34.25	21.24	4.4
	50	95	17450	291	735	140	5.615	-29.1	-.16	.02	.263	.0805	53.8	28.94	4.3

CALIFORNIA INSTITUTE OF TECHNOLOGY

GUGGENHEIM AERONAUTICS LABORATORY .... TUNNEL

Rep.	Exp.	Run	Page
			C_2

Experiment FAN CALIBRATION Test FAN 1A 2STAGE

Setup DATA REDUCTION Date

Observers: Computers:

Model Data: q R.P.M.

2	3	4	5	6	7	8	9	10
RUN#	$\bar{P}_T$	$Q \times 10^{-6}$	INPUT TO FAN	ΔP	EFF%	$K \times 10^{-3} \sqrt{\bar{P}_T}$	$\frac{Q}{10^{-6} K \sqrt{\bar{P}_T}}$	Q/A
26	.285	.0808	1.360	3.17	20.3	.0867	1.001	692
27	.049	.0252	1.568	2.57	4.1	.0359	.703	202.5
28	.88	.1460	1.620	5.18	46.5	.1523	.961	1162
29	.935	.1668	1.672	4.56	45.5	.1570	1.062	1328
30	2.125	.2500	6.250	10.63	42.5	.2365	1.059	1992
31	1.535	.1948	5.650	11.63	40.2	.2010	.968	1552
32'	.627	.1259	5.180	7.33	17.7	.1285	.980	1002
33'	.258	.0807	5.090	5.98	9.6	.0824	.980	643
34'	.08	.0414	5.660	6.08	4.5	.0450	.921	380
35'	3.43	.3355	14.27	18.11	43.8	.304	1.110	2572
36'	5.03	.4190	26.18	29.24	46.9	.364	1.150	3340
37'	8.48	.5070	42.70	42.35	50.3	.472	1.074	4035
38'	11.30	.5780	62.50	56.64	52.5	.521	1.108	4610
39'	2.095	.1912	47.70	27.50	11.0	.235	.814	1524
40	.840	.1350	30.15	22.60	10.0	.1366	.989	1077
41	.810	.1475	20.85	17.30	12.2	.1317	1.121	1175
42	.520	.1204	8.03	11.08	16.6	.1170	1.028	959
43	1.033	.1681	6.57	14.21	36.4	.1650	1.018	1339
44	1.890	.233	18.51	24.73	31.2	.2235	1.043	1859
45	2.540	.2747	29.20	34.70	32.2	.259	1.058	2191
46	3.300	.3125	44.80	44.69	31.2	.295	1.060	2492
47	.1310	.0566	12.34	11.14	4.6	.0587	.947	443
48	.1480	.0656	21.15	15.35	4.8	.0626	1.048	523
49	.181	.0765	34.25	21.24	4.8	.0691	1.108	604
50	.263	.0873	53.8	28.94	4.7	.0832	1.048	686

CALIFORNIA INSTITUTE OF TECHNOLOGY

GUGGENHEIM AERONAUTICS LABORATORY .... TUNNEL

Rep.	Exp.	Run	Page
BLM		D	D1

Experiment FAN CALIBRATION Test FAN 1A

Setup DATA REDUCTION Date

Observers: Computers:

Model Data: q R.P.M.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	RUN #	% BLOCKING	RPM	RPS	GRAMS TORQUE	MOTOR VOLTS	KW MOTOR INPUT	P_1	P_2	P_3	$\overline{P}_T$	CM³/SEC Q×10⁻⁶	GR.CM/SEC ×10⁻⁶ INPUT TO FAN	ΔP	EFF %
	51	65	10000	1667	275	82.5	1.25	-20.4	.51	.10	3.04	.271	11.51	20.91	49.3
	52	65	12500	208.2	410	104	2.22	-32.15	-.08	.14	4.68	.330	21.41	32.09	49.4
	53	65	15000	250	540	126	3.41	-42.80	.94	.12	6.07	.361	33.30	43.74	46.6
	54	65	17500	292	690	147	5.15	-58.30	1.19	.16	6.45	.398	50.40	59.49	47.0
	43′	80	10000	166.7	220	83	1.00	-13.97	.12	.04	—	.110	9.21	14.09	27.0
	41′	87	12500	208.2	330	103	1.95	-15.7	-.12	0	.86	.139	17.3	15.58	12.5
	42′	87	10000	166.7	200	83	1.05	-10.1	-.07	0	.55	.103	8.4	10.03	12.3
	26′	80	5000	83.3	45	30	—	-3.3	.07	.01	.32	.074	.943	3.37	26.5
	32′	80	7500	125	105	60	—	-8.0	.13	.07	.74	.122	3.30	8.13	30.0
	31′	65	7500	125	130	60	—	-10.4	.25	.08	1.46	.182	4.08	10.65	47.5
	53′	65	15000	250	530	126	3.55	-45.0	.82	.21	5.15	.350	33.3	45.82	48.2
	55	0	5000	83.3	50	30	.18	-1.99	.12	.02	1.36	.191	1.044	2.11	38.6
	56	0	17500	292	730	146	5.72	-25.22	1.81	1.36	17.2	.707	53.4	27.03	35.8
	57	0	15000	250	500	126	3.60	-18.1	1.11	.86	12.34	.594	31.4	19.21	36.4
	58	0	12500	208.2	340	104	2.13	-12.62	.74	.60	8.91	.503	17.8	13.36	37.1
	59	0	10000	166.7	200	83	1.20	-8.22	.37	.35	5.62	.395	8.38	8.59	40.4
	60	0	7500	125	95	60	.48	-4.54	.25	.20	3.10	.290	2.98	4.79	47.7

CALIFORNIA INSTITUTE OF TECHNOLOGY

GUGGENHEIM AERONAUTICS LABORATORY ....TUNNEL

Rep.	Exp.	Run	Page
BLM			D2

Experiment: FAN CALIBRATION Test: FAN 1A 2STAGE

Setup: DATA REDUCTION Date:

Observers: Computers:

Model Data: q R.P.M.

RUN #	$\bar{P}_T$	$Q \times 10^{-6}$	INPUT TO FAN $GrCR/10^{-6}$	ΔP	% EFF.	$\frac{Q}{K\sqrt{P_T}}$	Q/A	$10^{-6} K\sqrt{P_T}$
51	3.04	.2942	11.51	20.91	53.6	1.038	2345	.283
52	4.68	.3585	21.41	32.09	53.7	1.019	2855	.351
53	6.07	.3920	3390	43.74	50.6	.970	3120	.400
54	6.45	.4325	5040	59.49	51.0	1.048	3440	.412
43'	1.26	.1845	9.21	14.09	29.3	1.012	1470	.182
41'	.86	.1508	17.30	15.58	13.5	1.007	1202	.152
42'	.55	.1118	8.40	10.03	13.3	.908	890	.123
26'	.32	.0803	.94	3.37	28.8	.887	639	.092
32'	.74	.1324	3.30	8.13	32.6	.947	1054	.140
31'	1.46	.1973	4.08	10.65	51.6	.997	1572	.196
53'	5.15	.3800	3.33	42.85	52.3	1.022	3025	.388
55	1.36	.2075	1.04	2.11	41.9	1.092	1652	.189
56	17.20	.7670	53.40	27.03	38.9	1.071	6110	.713
57	12.94	.6450	31.40	19.21	39.5	1.106	5140	.583
58	8.91	.5460	17.80	13.36	40.9	1.126	4350	.485
59	5.62	.4280	8.38	8.59	43.8	1.106	3410	.384
60	3.10	.3210	2.98	4.79	51.7	1.123	2558	.286

CALIFORNIA INSTITUTE OF TECHNOLOGY

GUGGENHEIM AERONAUTICS LABORATORY ....TUNNEL

Rep.	Exp.	Run	Page
BLM		E	E,

Experiment FAN CALIBRATION Test FAN 1B 2 STAGE

Setup DATA REDUCTION Date

Observers: Computers:

Model Data: q R.P.M.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	RUN #	BLOCKING %	RPM	RPS	GRAMS TORQUE	MOTOR VOLTS	KW INPUT	P_1	P_2	P_3	$\bar{P}_T$	$Q \times 10^{-6}$ CM^3/SEC	INPUT TO FAN $\frac{GR \cdot CM}{SEC} \times 10^{-6}$	ΔP	EFF %
	62	0	17325	289	1065	143	8.25	-31.9	4.23	1.27	25.13	.755	772	36.13	35.4
	63	0	15000	250	780	125	5.15	-23.3	3.62	.95	18.5	.648	49.1	26.92	35.5
	64	0	12500	208.2	525	104	3.00	-16.1	2.51	.53	12.8	.540	27.4	18.61	36.7
	65	0	10000	166.7	385	84	1.77	-10.63	1.68	.53	8.25	.430	16.1	12.31	35.5
	66	0	7500	125	145	60	.72	-5.98	.86	.21	4.43	.316	4.55	6.84	33.3
	67	0	5000	83.3	83	30	.20	-2.66	.37	.15	1.54	.215	1.78	3.03	36.5
	68	65	5000	83.3	90	30	.23	-4.99	.21	.04	.74	.132	1.89	5.20	36.2
	69	65	7500	125	200	60	.78	-11.63	.48	.08	1.69	.196	6.28	12.11	37.9
	70	65	10000	166.7	345	85	1.72	-21.4	.85	.16	3.08	.268	14.50	22.25	41.1
	71	65	12500	208.2	520	106	2.87	-32.7	1.27	.21	4.52	.328	27.20	33.97	40.9
	72	65	15000	250	710	128	4.64	-46.5	1.78	.26	6.32	.387	44.70	48.28	41.9
	73	65	17500	292	900	150	6.92	-62.9	2.59	.37	8.09	.436	66.0	65.49	43.2
	74	80	5000	833	90	31	.22	-3.32	.08	.02	.29	.0836	1.89	3.40	15.0
	75	80	7500	125.0	185	61	.60	-7.97	.12	.01	.63	.130	5.81	8.19	18.2
	76	80	10000	166.7	285	86	1.35	-14.4	.26	.07	1.11	.170	11.9	14.66	20.9
	77	80	12500	208.2	400	107	2.27	-21.9	.39	.08	1.68	.206	20.9	22.29	21.9
	78	80	15000	250	545	129	3.65	-30.9	.53	.10	2.35	.2403	34.3	31.43	22.2
	79	80	17500	292	700	152	5.55	-40.7	1.04	.06	3.09	.216	51.3	41.74	22.0

CALIFORNIA INSTITUTE OF TECHNOLOGY

GUGGENHEIM AERONAUTICS LABORATORY ....TUNNEL

Rep.	Exp.	Run	Page
			E_2

Experiment: FAN CALIBRATION Test: FAN 1B 2 STAGE

Setup: DATA REDUCTION Date:

Observers: Computers:

Model Data: q R.P.M.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	RUN#	$\bar{P}_T$	$Q \times 10^{-6}$	INPUT TO FAN	ΔP	EFF%	$10^{-6} K \sqrt{P_T}$	$Q / 10^{-6} K \sqrt{P_T}$	$\frac{Q}{A}$						
	62	25.13	.821	77.2	36.13	38.4	.816	1005	6540						
	63	18.5	.704	49.1	26.92	386	.698	1.007	5600						
	64	12.8	.586	274	18.61	39.8	.581	1.008	4670						
	65	8.25	.467	16.1	12.31	38.6	.466	1.001	3720						
	66	4.43	.343	4.55	6.84	36.2	.342	1.001	2730						
	67	1.54	.2335	1.78	3.03	39.6	.2020	1.159	1855						
	68	.74	.1432	1.89	5.20	39.3	.140	1.027	1140						
	69	1.69	.2115	6.28	12.11	41.2	.2107	1.002	1683						
	70	3.08	.281	14.50	22.25	44.6	.2845	.991	2235						
	71	4.52	.356	27.20	33.97	444	.345	1.031	2835						
	72	6.32	.421	44.70	48.28	45.5	.408	1.030	3350						
	73	8.09	.473	66.0	65.49	46.8	.461	1.030	3762						
	74	.29	.0908	1.89	3.40	16.3	.089	1.020	723						
	75	.63	.1411	5.81	8.19	19.7	.129	1.092	1122						
	76	1.17	.1835	11.9	14.66	22.7	.1755	1.042	1460						
	77	1.68	.2235	20.9	22.29	238	.2105	1.061	1778						
	78	2.35	.2605	34.3	31.43	24.1	.249	1.042	2072						
	79	3.09	.2995	57.3	41.74	23.9	.285	1.050	2345						

CALIFORNIA INSTITUTE OF TECHNOLOGY

GUGGENHEIM AERONAUTICS LABORATORY ....TUNNEL

Rep.	Exp.	Run	Page
BLM		F	F_1

Experiment FAN CALIBRATION Test FAN 1B 2 STAGE

Setup DATA REDUCTION Date

Observers: Computers:

Model Data: q R.P.M.

1	2	3	4	5	6	7	8	9	10	11	12	13	14 ($\frac{GR \cdot CM}{SEC} \times 10^{-6}$)	15	16
	RUN #	BLOCKING %	RPM	RPS	GRAMS TORQUE	VOLTS MOTOR	KW INPUT	P_1	P_2	P_3	$\bar{P}_T$	$Q \times 10^{-6}$ GMS/SEC	INPUT TO FAN	ΔP	EFF %
	80	87	5000	83.3	90	31	.21	¯2.66	.02	.10	.16	.0607	1.89	2.68	8.62
	81	87	7500	125	165	61	.58	¯5.76	.02	.06	.32	.0845	5.18	5.78	9.44
	82	87	10000	166.7	280	85	1.30	¯10.1	0	.02	.57	.1140	11.7	10.1	9.83
	83	87	12500	208.2	420	107	2.37	¯15.7	04	.02	1.09	.141	22.0	15.14	10.1
	84	87	15000	250	590	130	3.82	¯22.5	¯.02	0	1.17	.168	31.1	22.48	10.2
	85	87	17500	292	720	151	5.80	¯29.8	.47	.01	1.50	.193	52.8	30.27	11.1
	86	95	17500	292	845	151	6.72	¯26.5	¯.19	¯.02	.25	.085	62.0	26.31	3.61
	87	95	15000	250	645	129	4.22	¯18.5	¯.11	.07	.10	.073	40.6	18.39	3.31
	88	95	12500	208.2	470	106	2.57	¯13.5	¯.04	02	.15	.0636	24.6	13.46	3.47
	89	95	10000	166.7	320	85	1.45	¯8.97	¯.04	0	.10	.0535	13.4	8.93	3.57
	90	95	7500	125	195	61	.63	¯5.10	¯.04	03	.07	.0386	6.12	5.06	3.19
	91	95	5000	83.3	100	33	.22	¯2.32	0	0	.05	.0284	2.10	2.32	3.13
	92	50	17500	292	1090	150	8.30	¯56.2	3.89	.70	14.80	.540	80.00	60.10	40.1
	93	50	15000	208.2	790	129	5.28	¯42.6	2.75	.30	10.00	.480	49.50	45.35	44.1
	94	50	12500	208.2	540	106	3.23	¯29.8	1.43	¯.03	6.99	.408	28.30	31.23	45.2
	95	50	10000	166.7	360	86	1.70	¯19.5	.93	¯.04	4.46	.329	15.10	20.43	43.8
	96	50	7500	125	210	61	.70	¯10.6	.65	.12	2.44	.248	6.60	11.25	42.2
	97	50	5000	83.3	95	32	.23	¯4.91	.28	.07	1.06	.162	1.99	5.19	42.2
	98	50	10000	166.7	360	86	1.70	¯19.2	0	1.15	4.46	.322	15.10	19.2	42.2

CALIFORNIA INSTITUTE OF TECHNOLOGY

GUGGENHEIM AERONAUTICS LABORATORY ....TUNNEL

Rep.	Exp.	Run	Page
			F_2

Experiment: FAN CALIBRATION Test: FAN 1B 2STAGE

Setup: DATA REDUCTION Date:

Observers: Computers:

Model Data: q R.P.M.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	RUN #	$\bar{P}_T$	$Q \times 10^{-6}$	INPUT TO FAN	ΔP	EFF %	$10^{-6} K \sqrt{\bar{P}_T}$	$\frac{Q}{10^{-6} K \sqrt{\bar{P}_T}}$	$\frac{Q}{A}$						
	80	.16	.0659	1.89	2.68	9.36	.0648	1.016	524						
	81	.32	.0917	5.18	5.78	10.25	.0987	.930	730						
	82	.57	.1238	11.7	10.1	10.68	.1250	.991	984						
	83	1.09	.1530	22.0	15.74	11.0	.1698	.905	1218						
	84	1.17	.1822	371	22.48	11.1	.1756	1.038	1450						
	85	1.50	.2092	528	30.27	12.0	.1988	1.052	1663						
	86	.25	.0923	62.9	26.31	3.9	.0811	1.138	734						
	87	.28	.0782	40.6	18.39	3.6	.0728	1.078	622						
	88	.15	.0691	24.6	13.46	3.8	.0628	1.101	549						
	89	.10	.0581	13.4	8.93	3.9	.0514	1.132	462						
	90	.07	.0418	6.12	5.06	3.5	.0429	.976	333						
	91	.05	.0308	2.10	2.32	3.4	.0363	.848	245						
	92	14.80	.5865	8000	60.10	44.2	.6230	.942	4670						
	93	10.00	.5220	4950	45.35	47.8	.5140	1.015	4150						
	94	6.99	.4430	2830	31.23	49.1	.428	1.032	3530						
	95	4.46	.352	1510	20.43	475	.343	1.028	2800						
	96	2.44	.2685	660	11.25	45.8	.259	1.048	2135						
	97	1.06	.1758	1.99	5.19	458	.167	1.048	1400						
	98	4.46	.3495	1510	19.2	45.8	.343	1.056	2780						

APPENDIX V

THREE PHASE VARIABLE FREQUENCY POWER SUPPLY

THREE PHASE VARIABLE FREQUENCY POWER SUPPLY

Attention might be directed to the installation which furnishes a power supply of great flexibility for the Guggenheim Aeronautical Laboratory.

The attached schematic and detail wiring diagrams are, in themselves, largely self explanatory.

A 20 H.P. shunt wound D.C. motor drives the rotor of the 3 phase frequency changer. The field of the frequency changer is 60 cycle, 3 phase, 220 volt and in the low frequency range is rotating in the same direction as the rotor. The low frequency range covers frequencies from 40 to 180 cycles.

For operation in the high frequency range, the 3 phase field is reversed so that it turns in the opposite direction to the rotor. This gives frequencies from 160 to 300 cycles.

The output voltage varies from 30 to 165 volts. The power factor variation runs from 17% at no load and 80 cycles to 90% at full load and 300 cycles. This power factor determination was made with a polyphase wattmeter calibrated for 60 cycles, and may be somewhat in error.

The control of frequency is effected by resistors in the D.C. shunt field. These are mounted with the necessary resistors and meters, in a convenient portable stand, which allows the operator complete freedom in choosing the operating station. The precision of speed regulation is of the order of 0.1 cycle at 300 cycles and the operation is very steady, assuming constant voltage on the D.C. power supply. The D.C. power supply is generated in the laboratory and close check can be kept on the line voltage.

The method of operation is to start the frequency changer at its lowest value of frequency with the load or motor to be driven on the line. Then the frequency is brought up to the desired value by adjusting the D.C. motor field rheostats. In this way, the shock of heavy starting is avoided. High frequency operation is a continuation through the low frequency range. At the highest value on the low frequency range the circuit breakers are opened, the frequency changer field reversed, the D.C. motor field rheostat run down to the starting position, and the frequency changer started again while the load or driven motor is still coasting. This eliminates the shock and overload of trying to start the machines from a dead stop at 160 cycles.

Two pole Induction motors of 12 H.P. rating (17500 R.P.M.) are available which are only 6½" in diameter by 9" long, and where space limitation is strict, as in airplane models and small tunnels, this type of powersupply offers many advantages. The G.A.L.C.I.T. Installation has been in constant operation for about seven years.