THE DETERMINATION OF HEAT-TRANSFER COEFFICIENTS FROM FINNED CYLINDERS IN AN AIR STREAM AT VARYING FIN-PLANE/AIR-STREAM ANGLES, FIN SPACING, AND AIR VELOCITIES

by

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I. INTRODUCTION

Since the turn of the twentieth century, many investigations have been made in the field of heat-transfer from finned cylinders in an air-stream with the fin-plane parallel to the air-stream. Most of these investigations have been made by the National Advisory Committee on Aeronautics (NACA) at Langely Memorial Aeronautical Laboratory, Langely Field, Virginia.

The problem of determining the rate of heat-transfer from finned cylinders is extremely complex due to many variables such as fin space; fin width; fin thickness; cylinder diameter; and cooling air conductivity, viscosity, turbulence, and velocity. In the literature reviewed, there have been no successful theoretical equations for the determination of the rate of heat-transfer. Therefore, all information on the rate of heat-transfer must be based on experimental results or on empirical relationships which closely approximate the experimental values.

The rate of heat-transfer from finned cylinders is a very important factor in the design of air-cooled internal combustion engines and high rate heat-exchangers.

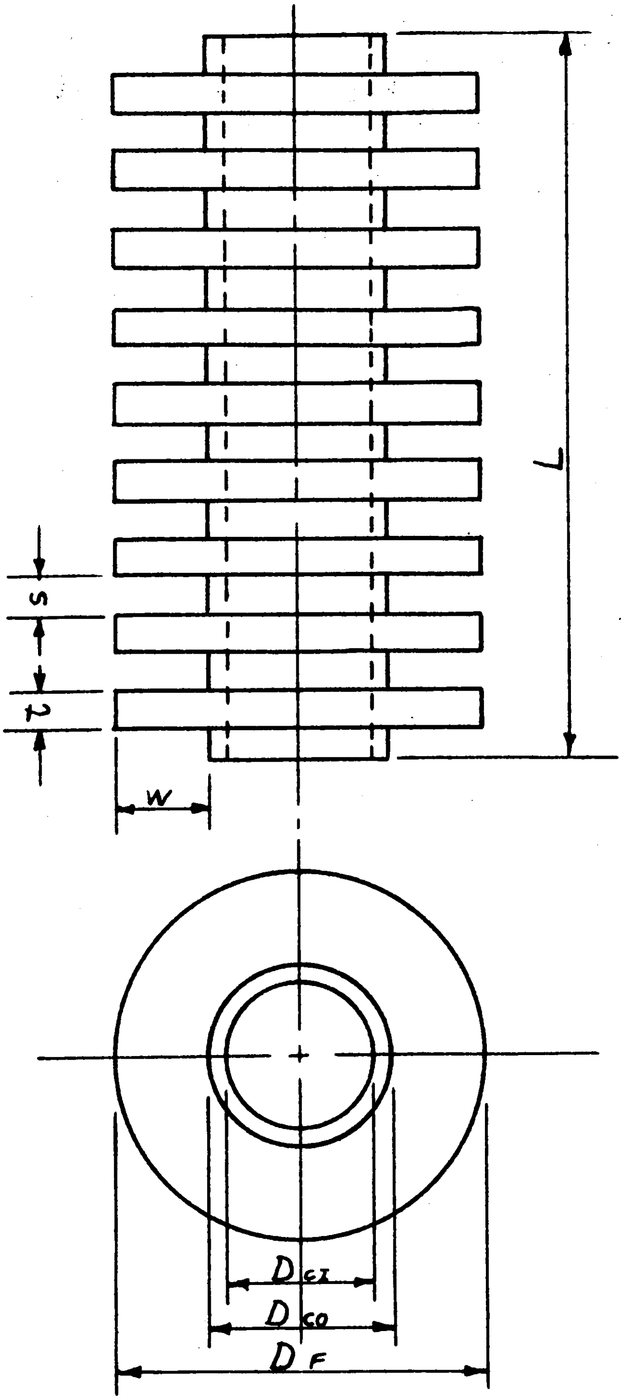
It is known that the rate of heat-transfer for the range of fin-plane/air-stream angles between 30 and 60 degrees is nearly twice that of a zero fin-plane/air-stream angle. Since the subject of heat-transfer from finned cylinders in an air-stream with the fin-plane parallel to the air-stream has been thoroughly investigated by the NACA, the author decided to conduct this investigation on finned cylinders in an air-stream with varying fin-plane/air-stream angles. Due to the limiting size of equipment available, this investigation was conducted on finned cylinders with a cylinder diameter of about one inch, while the test carried on by the NACA covered a range of cylinder diameters from 3.66 to 6.34 inches.[5] The difference in the cylinder diameters may provide a valuable correlation for the variation of the rate of heat-transfer due to cylinder diameter.

II. LITERATURE REVIEW

A. General

A series of investigations to determine and correlate the experimental surface heat-transfer coefficients of finned cylinders with different air-stream cooling arrangements was conducted by NACA during the period of 1932 to 1938. The effects of fin width, fin space, fin thickness, and cylinder diameter (refer to Figure 1 for finned cylinder notation) on the heat-transfer were covered. Tests were made in a free air stream with and without baffles and also with various devices for creating a turbulent air stream. Tests were also made with blower cooling, in which case all the air must flow through the fins of the cylinder since the jacket blocks off the rest of the duct. The investigations were conducted on 58 test cylinders with fins having widths from 0.37 to 3 inches, mean spaces from 0.01 to 0.50 inches, and mean thicknesses from 0.026 to 0.270 inches; with cylinder diameters from 3.66 to 6.34 inches.[5] The fin shape was rectangular for all but nine of these cylinders which had tapered fins. All of the finned cylinders were made of steel except

FINNED CYLINDER NOTATIONS



NOTATIONS

D_{CI}, Inner diameter of cylinder, inches.
D_{CO}, Outer diameter of cylinder, inches.
D_F, Outer diameter of fins, inches.
L, Length of test section, inches.
s, Average distance through air space between adjacent fin surfaces, inches.
t, Average fin thickness, inches.
w, Fin width, inches.

D.G.D. 12-22-54

FIGURE 1

three which were made of copper. The air velocities varied from 30 to 150 mph.[2] The test cylinders were electrically heated, and the axial heat flow was controlled by guard sections.

In 1934, Biermann[2] of the NACA made the following statements about heat-transfer from finned cylinders: "The cooling of hot bodies by means of metal fins exposed to an air stream can be treated as two related problems, one involving the convection of heat from the fin surfaces by the air-stream and the other involving the conduction of heat through the finned surfaces. For complex bodies, such as finned cylinders, the velocity field over the surface of the fins is extremely complicated, especially in the region at the rear half of the cylinder where the flow is vertical. For such bodies experimental methods must be used at present for determining the surface heat-transfer coefficient.* The second problem--the conduction of the heat through the fins--is simpler and the associated differential equation permits of

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* Surface heat-transfer coefficient (q), Btu/sq in.-hr-F, based on the total area of the outer surface of the finned cylinder, and the difference between the average temperature of the outer surface of the finned cylinder and the inlet cooling air temperature.

solution in terms of functions of the fin dimensions and the surface heat-transfer coefficient."

The following conclusions were drawn by Biermann[2] in regard to the surface heat-transfer coefficient (q) with approximately constant heat input and varying air speeds: "Increase in fin width up to about 0.40 inch results in an appreciable reduction in the value of q; whereas for a further increase in width the variation in the value of q is much smaller. As most fins of practical interest have a width greater than 0.40 inch it may be assumed for purposes of calculation that q is independent of fin width. For the range of spacings tested the value of q varies with the 0.322 power of s (fin space)." The fin spacings employed varied from about 0.045 to 0.330 inch. Biermann[2] continued, stating that for a given value of fin spacing, the variation in fin thickness does not have an appreciable effect on the air-flow and is of minor importance in determining the value of q. It was found that, for the range of fin spacings tested, the value of q varies with the 0.796 power of the velocity.[2] This value holds fairly well except for the very close fin spacing where a transition point is indicated at low velocities. A theoretical equation in the report by Biermann[2] shows that q varies inversely as the diameter of the finned cylinder, all other parameters being held constant. (Ellerbrock[5] later found experimentally that q varied inversely as the fourth root of the finned cylinder diameter). Biermann[2] also found that, "The value of the surface heat-transfer coefficient varies mainly with the air velocity and the space between fins. The effect of the other fin dimensions is small."

In 1939, Ellerbrock[5] of the NACA made the following statement about heat-transfer from finned cylinders: "The surface heat-transfer coefficients of finned cylinders can be correlated for any one air-flow arrangement by plotting a factor involving the surface heat-transfer coefficients, the fin space, and the conductivity of the cooling air against a factor involving the velocity, the density, and the viscosity of the cooling air and the fin space, the fin width, and the cylinder diameter." The values of q were determined experimentally under several air-flow conditions: cylinder in free air-stream with no baffles, cylinder in free air-stream with baffles, cylinder in free air-stream with axis 45 deg to air-stream, and cylinder enclosed in jacket with a blower supplying air. Ellerbrock[5] compiled the recent information that had been obtained by the NACA on the heat-transfer coefficient and presented a method of correlating the available data on q for each air-flow arrangement. He[5] stated that, "Three methods of attack have been used to predict the heat-transfer, namely: by mathematical analysis, by analogy between results from heat-transfer and friction, and by dimensional analysis." He[5] found that dimensional analysis was the most successful method of attack, with the constants in the equations being determined experimentally. The empirical equations for the surface heat-transfer coefficient were developed from empirical equations for smooth pipes.[5] For a finned cylinder in a free air-stream with no baffles, Ellerbrock[5] made the following correlation:

$$\frac{q\ s}{k_a} = f\left(\frac{V \rho_1\ g\ s^2}{12\ \mu\ D^{0.25}\ w^{0.45}}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(A)}$$

where

q,	Surface heat-transfer coefficient, Btu/sq in.-hr-F, based on the total area of the outer surface of the finned cylinder, and the difference between the average temperature of the outer surface of the finned cylinder and the inlet cooling air temperature.
s,	Average space between adjacent fin surfaces, in.

k_a,	Thermal conductivity of air, Btu/sq in. thru 1 in.-sec-F.
V,	Velocity of air in tunnel throat, fps.
$\rho_1 g$,	Specific weight of air in tunnel throat in front of cylinder, lbs/cu ft.
μ,	Absolute viscosity of air, lbs/sec-ft.
D,	Cylinder diameter at fin root, in.
w,	Fin width, in.

Similar correlations were presented for the different air-flow arrangements tested.

Another method of determining the value of the surface heat-transfer coefficient by empirical means is described by Lichty[8]. This method was based on information he compiled from work done by Brevoort[29]. According to Lichty[8] q is a function of Reynolds' number and Nusselt's number with a single curve expressing the relationship between the two. This method was for baffled cylinders only, with the hydraulic diameter of the space between fins being included. Lichty[8] confirmed this method of determining q experimentally on a few samples.

Normally, in heat-transfer from pipes the average coefficient of heat-transfer is based on the temperature difference between the average surface temperature of the exposed surface of the pipe and the average fluid temperature. In the case of finned cylinders, Ellerbrock[5] found it more advantageous to base q on the difference between the entering inlet-air temperature and average surface temperature. He[5] found that, "Using the average air temperature greatly complicated the problem since the temperature rise may be difficult to determine." In application of finned cylinders to internal combustion engines he[5] further states, "An additional advantage in using q or U** based on the inlet-air temperature is that the over-all heat-transfer coefficient (U) is proportional to the rate of heat-transfer, which is a function of the (engine) power developed. Thus an increase of U is also an indication as to how much the power can be increased."

The following statements were made by Schmidt[7] in regard to heat-transfer from complex bodies. "Heat transfer of finned surfaces and pipes depends upon too

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** Over-all heat-transfer coefficient (U), Btu/sq in.-hr-F, based on the outer cylinder wall base area, and the difference between the average temperature of the cylinder wall and the inlet cooling air temperature.

many factors for simple calculation of capacities, and the data have been procured so far by experiment only. The importance of each factor thus remained undisclosed, and no generally correct statements were possible on the important question of optimum dimensions for fins under various view points. Test results, however, have been published in such aggregate volume as to permit the investigator to discern some basic inter-relations, but it remains necessary to draw a simplified picture first before devising a method for calculating this complex process. One such simplification is the customary equating of the amount of heat transmitted to the total area of the surface times the difference in the temperatures, times the coefficient of heat-transfer, notwithstanding the well known fact that different parts of the surface contribute differently and that their temperatures vary widely." Schmidt refers to data published in a report by Harper[9].

Investigations were made to determine the effects of various conditions that may take place in a wind tunnel test or in an actual case. Tests were conducted to determine the effect of turbulence on the heat-transfer coefficient. Ellerbrock[5] found that for the range tested the initial turbulence in the wind tunnel air-stream had very little effect on the surface heat-transfer coefficient. In a NACA Report written in 1938 by Pinkel[4] the following statements which are somewhat contradictory were made: "The cooling of the front of the cylinder depends upon the degree of turbulence of the air. The turbulence devices in front of the cylinder provided an increase in the heat-transfer coefficient of the order of 30 percent for the same pressure drop." Ellerbrock[5] found that the heat lost from an air-cooled engine cylinder by direct radiation is generally considered negligible as compared with the heat lost by convection, a black enamel thickness of 0.002 in. showed greatest heat-transfer, and an oil film on the surface has no measurable effect on the heat-transfer.

Investigations were made to determine the effects of various modifications of the finned cylinders. Biermann[6] made the following statement: "Of several available methods of securing uniform temperatures around the cylinder, two methods are of particular interest. One method is to distribute the effective fin area as to achieve the desired temperature distribution. The other is to control the air velocities around the cylinder by means of baffles surrounding the cylinder. In general, either of the foregoing methods will result in some loss in the maximum over-all heat-transfer otherwise obtained for the same fin weight." According to Brevoort[3] the cooling can be increased by using several baffles. Brevoort[3] also found by test that some improvement of cooling may be achieved by streamlining the cylinder and thus increasing the mass flow of air for a given pressure drop.

E. Varying Fin-Plane/Air-Stream Angle

The information found on the heat-transfer from finned cylinders at various fin-plane/air-stream angles has been limited to two NACA publications. In 1932 Schey[1] stated that to his knowledge no work had been done to determine the effect on cylinder temperatures by directing the cooling air at different angles with respect to the fins.

Some of the conclusions drawn from Schey's[1] report are as follows: "The tests show the best angle for cooling at all air speeds to be about 45 deg. With the same temperature for the two conditions and with an air speed of 76 miles per hour, the heat input to the cylinder can be increased fifty percent at 45 deg. fin-plane/air-stream angle over that at zero deg. At the low air speeds the range of the angle that gives the best cooling is from 40 to 55 deg and at the high velocities it is from 30 to 80 deg." The range of air speeds was from 30 to 150 mph. Since the rear temperatures are the highest, the range of the angles were based on the rear-cylinder temperatures.

According to Schey[1] the cause of the increased heat-transfer rates has been somewhat limited to two theories, which are as follows:

1. Air is an excellent heat insulator, consequently, it is necessary that the boundary layer be reduced to the minimum thickness to obtain the best cooling.

2. The cooling may also be improved because the cylinder forms an elliptical section at angles between 0 and 90 deg with respect to the air stream, resulting in more of the cooling area coming in contact with the air stream.

An empirical equation was found by Ellerbrock[5] to determine the coefficient of surface heat-transfer for a finned cylinder at 45 deg fin-plane/air-stream angle. This correlation was similar to equation A.

III. INVESTIGATION

A. Object of Investigation

The object of this investigation was to obtain experimental values for the outer surface heat-transfer coefficient for a variety of conditions of fin spacing and fin-plane/air-stream angles over a wide range of air speeds.

These values were compared with the values of similar test by the NACA. An attempt was made to determine if there is any difference in the value of the surface heat-transfer coefficient caused by the air flowing upward or downward as it passes over the fins of the cylinder.

B. Table of Symbols

The symbols used in this report are defined as follows:

A,	Area of the outer surface of the finned cylinder, sq in.
A_c,	Area of the outer surface of the cylinder assuming no fins, sq in.
D_{ci},	Inner diameter of cylinder, in.
D_{co},	Outer diameter of cylinder, in.
D_f,	Outer diameter of fins, in.

g,	Acceleration of gravity, (32.2 ft/sec-sec).
L,	Length of test section, in.
N,	Number of fins on test section.
P_s,	Static pressure of upstream air, in. H_2O abs (Barometer + pitot tube average).
P_t,	Total pressure of upstream air, in. H_2O abs (Barometer + pitot tube average).
q,	Surface heat-transfer coefficient, Btu/sq in. outer surface area-hr-F temperature difference between average cylinder surface temperature and upstream cooling air temperature.
Q,	Heat input to test section, Btu/hr (Volts x Amps x 3.42).
R,	Specific gas constant for air, (53.3 ft/R).
s,	Average distance through air space between adjacent fin surfaces, in.
t,	Average fin thickness, in.
T_a,	Average temperature of upstream cooling air, F.
T_c,	Average temperature of the test cylinder surface, F.
T_f,	Average temperature of fins, F.
T_{fc},	Average temperature of the outer surface of the finned cylinder, F.
$\triangle T$,	Temperature difference between the average test cylinder surface and the upstream air, F $(T_c - T_a)$.

T_1, T_2, etc.	Temperature at point as determined by thermocouple at location of number, F.
T'_x,	Temperature of subscript notation, R.
U,	Over-all heat-transfer coefficient, Btu/sq in. outside surface area of cylinder assuming no fins-hr-F temperature difference between average cylinder surface temperature and upstream cooling air temperature.
V_a,	Average upstream air velocity, mph.
V_s,	Upstream air velocity at standard air conditions, fps and mph.
V_t,	Upstream air velocity at test conditions, fps and mph.
V_{var}(mph),	Maximum variation of air velocity.
V_{var}(%),	Maximum variation of air velocity.
w,	Fin width, in.

C. Apparatus

1. Description of Apparatus

The test apparatus was divided into the following five major groups: (a) Wind Tunnel; (b) Finned Cylinder, Heating Element, Stand, and Holder Assembly;

(c) Apparatus for Air Velocity and Temperature Measurement; (d) Apparatus for Test Section Temperature and Heat Supply Measure; and (e) Electric Power Supply and Apparatus for Control of Test Specimen Temperatures. (For reference to underlined letters, see Figures 2, 3, 4 and 5).

(a). Wind Tunnel

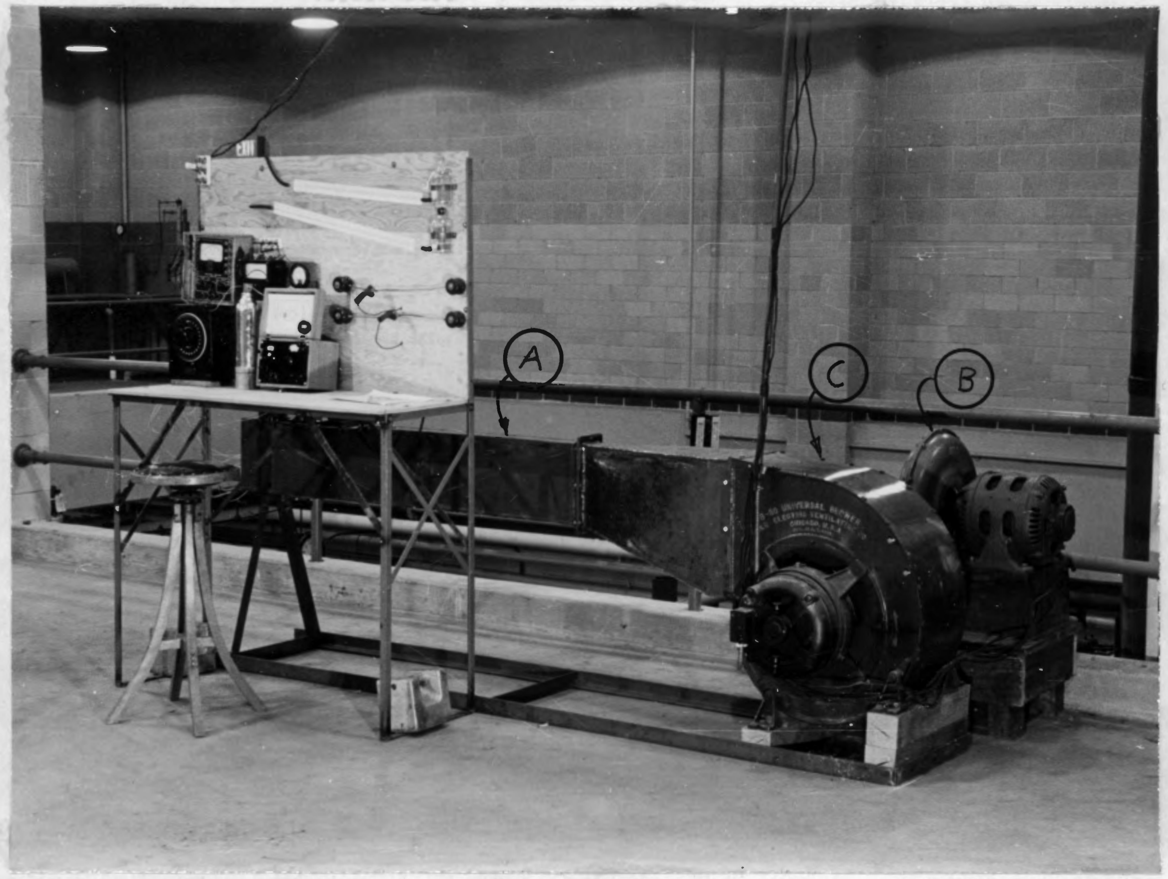
The wind tunnel consisted of two centrifugal blowers connected in series, with the outlet of the second blower connected to a 3 1/8" x 10 3/16" duct (A) five feet long. The two blowers were the primary blower (B), and the secondary blower (C). For the details of the wind tunnel, see Figure 6.

(b). Finned Cylinder, Heating Element Stand, and Holder Assembly

The five specimens of the finned cylinder that were used in the test had the following fin spacings:

1. 0.11"
2. 0.16"
3. 0.26"
4. 0.36"
5. 0.56"

For the specifications of the finned cylinder, see Figure 7. The finned cylinders were divided into three parts which are consecutively: front guard section (D), test section (E), and rear



OVER-ALL VIEW OF TEST APPARATUS

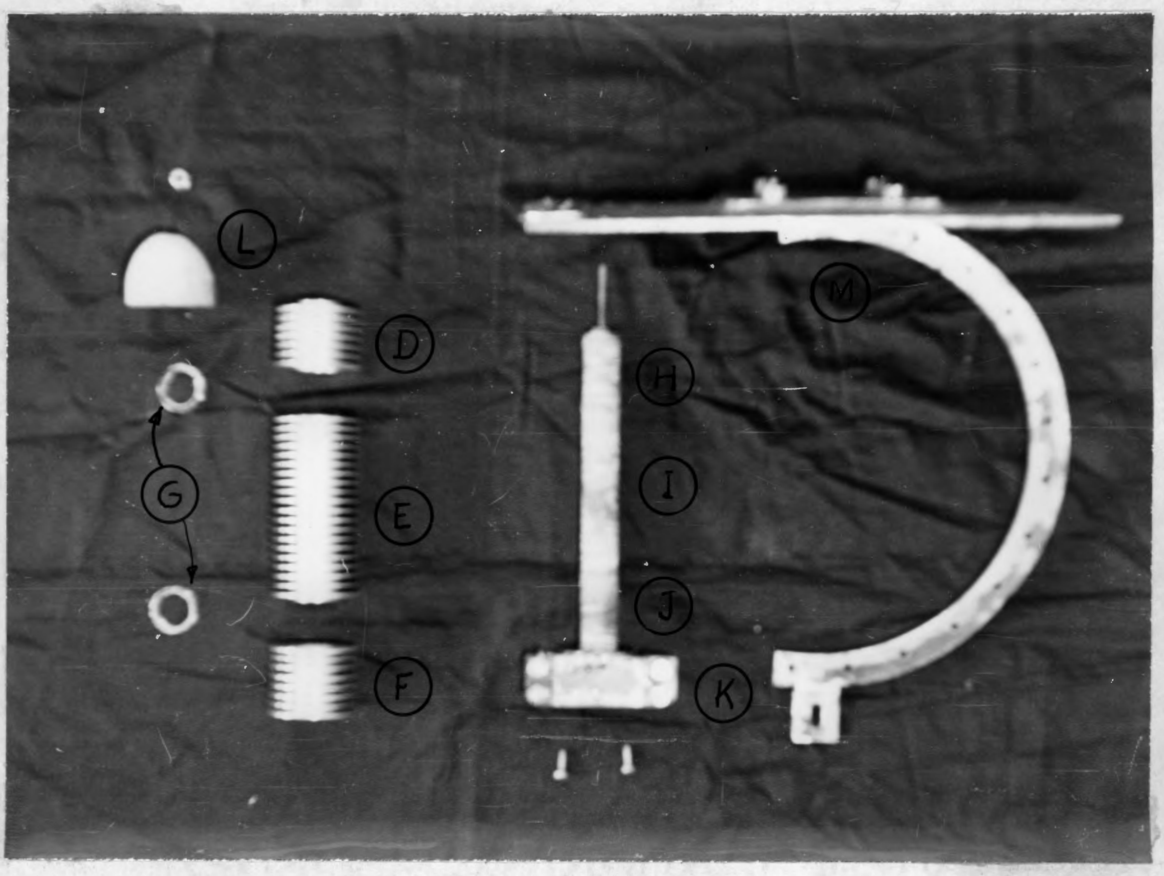
Key:

A, Wind tunnel

B, Primary blower

C, Secondary blower

FIGURE 2

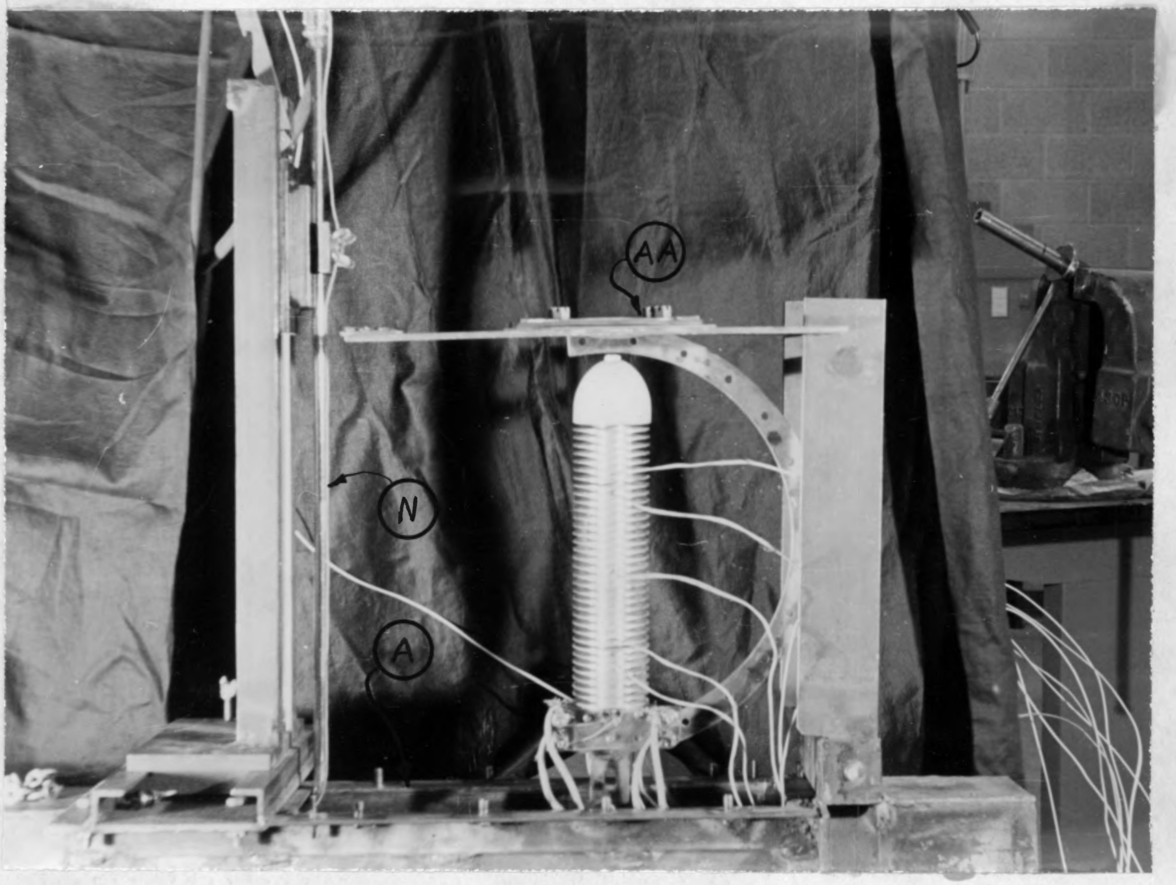


FINNED CYLINDER, HEATING ELEMENT, STAND, AND HOLDER EXPLODED

Key:

D,	Finned cylinder, front guard section
E,	Finned cylinder, test section
F,	Finned cylinder, rear guard section
G,	Sheet mica insulators
H,	Heating element, front guard section
I,	Heating element, test section
J,	Heating element, rear guard section
K,	Stand
L,	Nose block
M,	Holder

FIGURE 3



FINNED CYLINDER WITHDRAWN FROM WIND TUNNEL

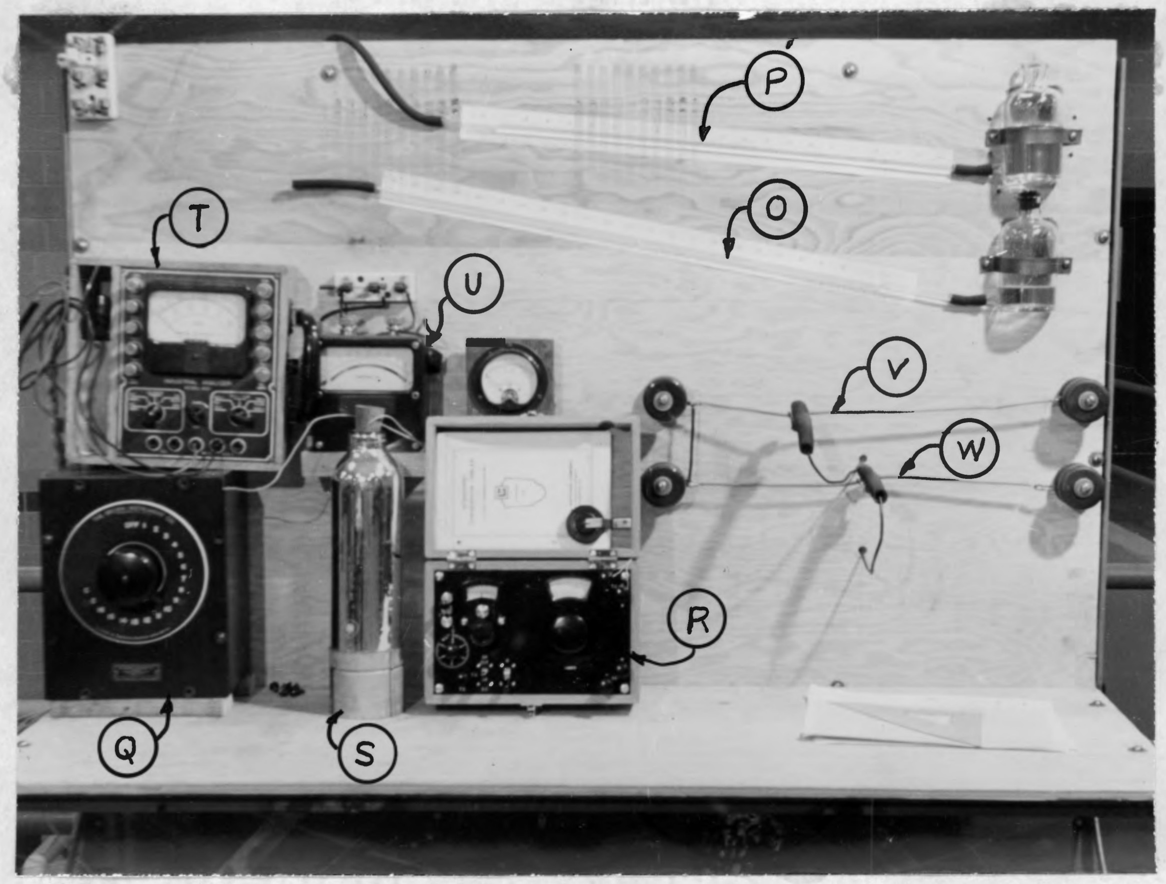
Key:

N, Pitot tube

AA, Finned cylinder, heating element, stand, and holder

A, Wind Tunnel

FIGURE 4

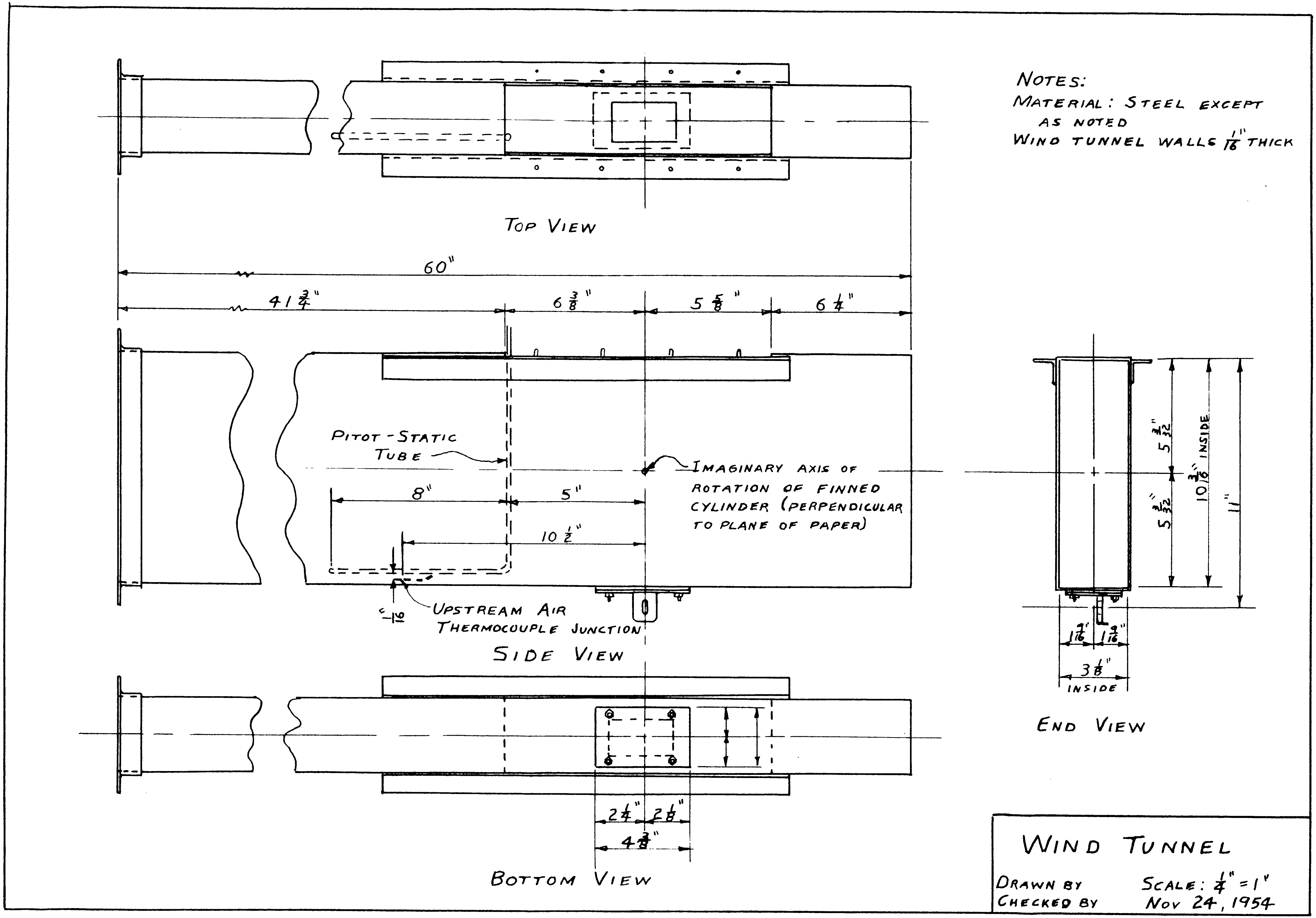


INSTRUMENT BOARD

Key:

O,	Total pressure manometer
P,	Static pressure manometer
Q,	Thermocouple selector switch
R,	Potentiometer
S,	Ice bath
T,	D C voltmeter
U,	D C ammeter
V,	Front guard section rheostat
W,	Rear guard section rheostat

FIGURE 5

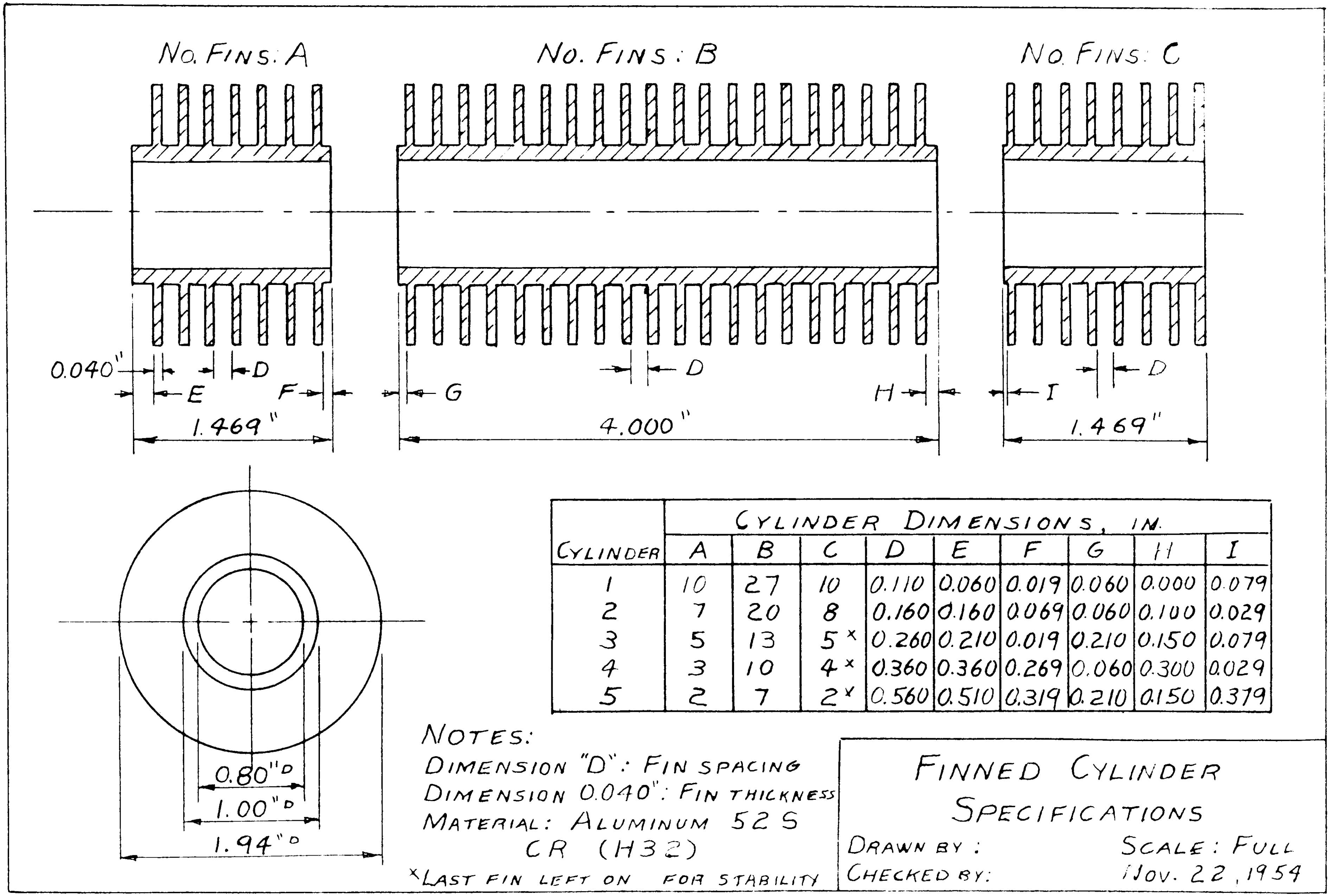


WIND TUNNEL

DRAWN BY
CHECKED BY

SCALE: 1/4" = 1"
NOV 24, 1954

FIGURE 6



Cylinder	Cylinder Dimensions, in.								
	A	B	C	D	E	F	G	H	I
1	10	27	10	0.110	0.060	0.019	0.060	0.000	0.079
2	7	20	8	0.160	0.160	0.069	0.060	0.100	0.029
3	5	13	5 x	0.260	0.210	0.019	0.210	0.150	0.079
4	3	10	4 x	0.360	0.360	0.269	0.060	0.300	0.029
5	2	7	2 x	0.560	0.510	0.319	0.210	0.150	0.379

NOTES:
DIMENSION "D": FIN SPACING
DIMENSION 0.040": FIN THICKNESS
MATERIAL: ALUMINUM 52 S
CR (H32)
x LAST FIN LEFT ON FOR STABILITY

FINNED CYLINDER
SPECIFICATIONS

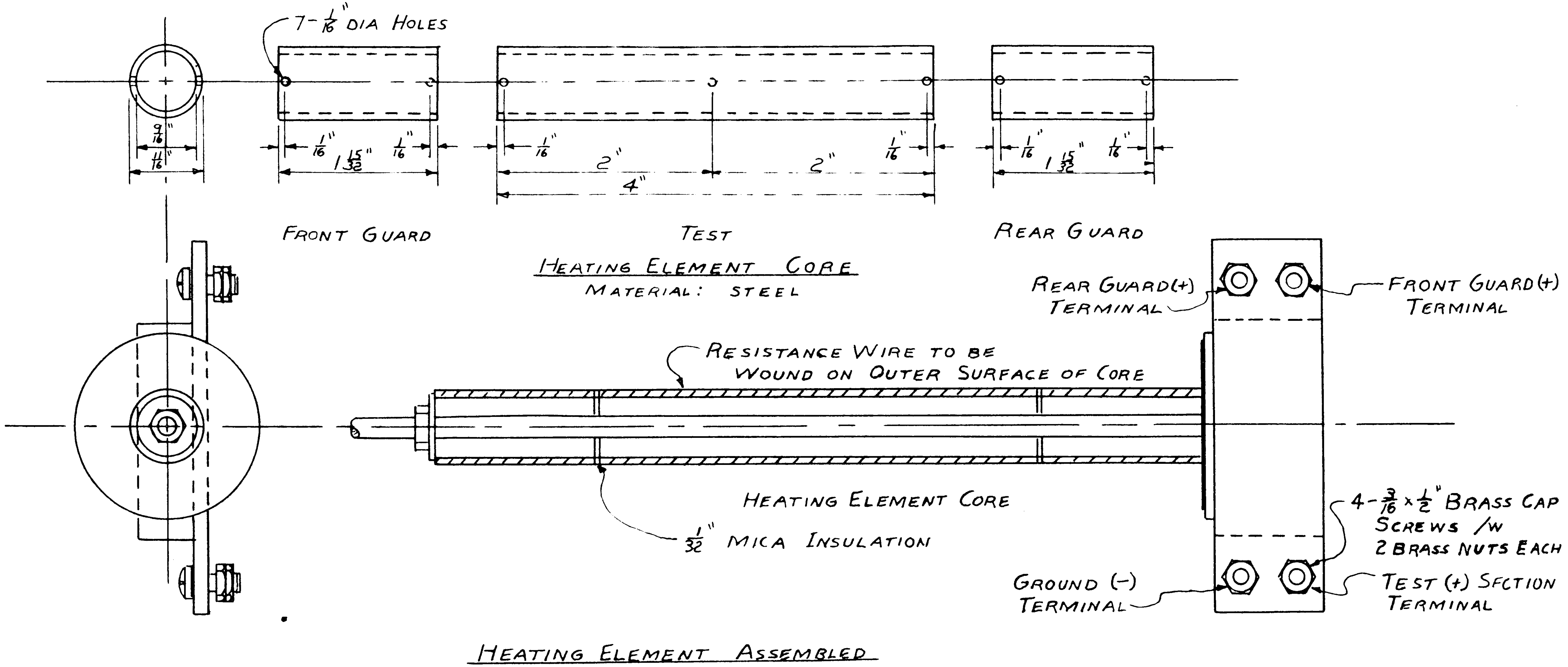
DRAWN BY:
CHECKED BY:
SCALE: FULL
NOV. 22, 1954

FIGURE 7

guard section (F). These sections were separated by sheet mica insulators 1/32" thick (G). The heating element was also divided into the front guard section (H), test section (I), and rear guard section (J). The heating element and the stand (K) were left assembled during the investigation except for the nose block (L), which was removed to facilitate the removal of the test cylinder. For the details and wire specifications of the heating unit, see Figure 8, and for the stand details, see Figure 9. For the details of the holder (M), see Figure 10.

(c). Apparatus for Air Velocity and Temperature Measurement

The air velocity and temperature were measured approximately 12" upstream of the mid-point of the test specimen. A pitot tube (N) was used in conjunction with two inclined manometers for measuring the total pressure (O) and static pressure (P). The temperature was measured by a thermocouple attached to the pitot tube with the junction 2 1/2" from the tip of the pitot tube and 1/16" away from the tube on the underside. The thermocouple leads were attached to the



NOTES:

WIRE SPECIFICATIONS:

MATERIAL: CHROMEL A, 24 GAGE, ASBESTOS INST.

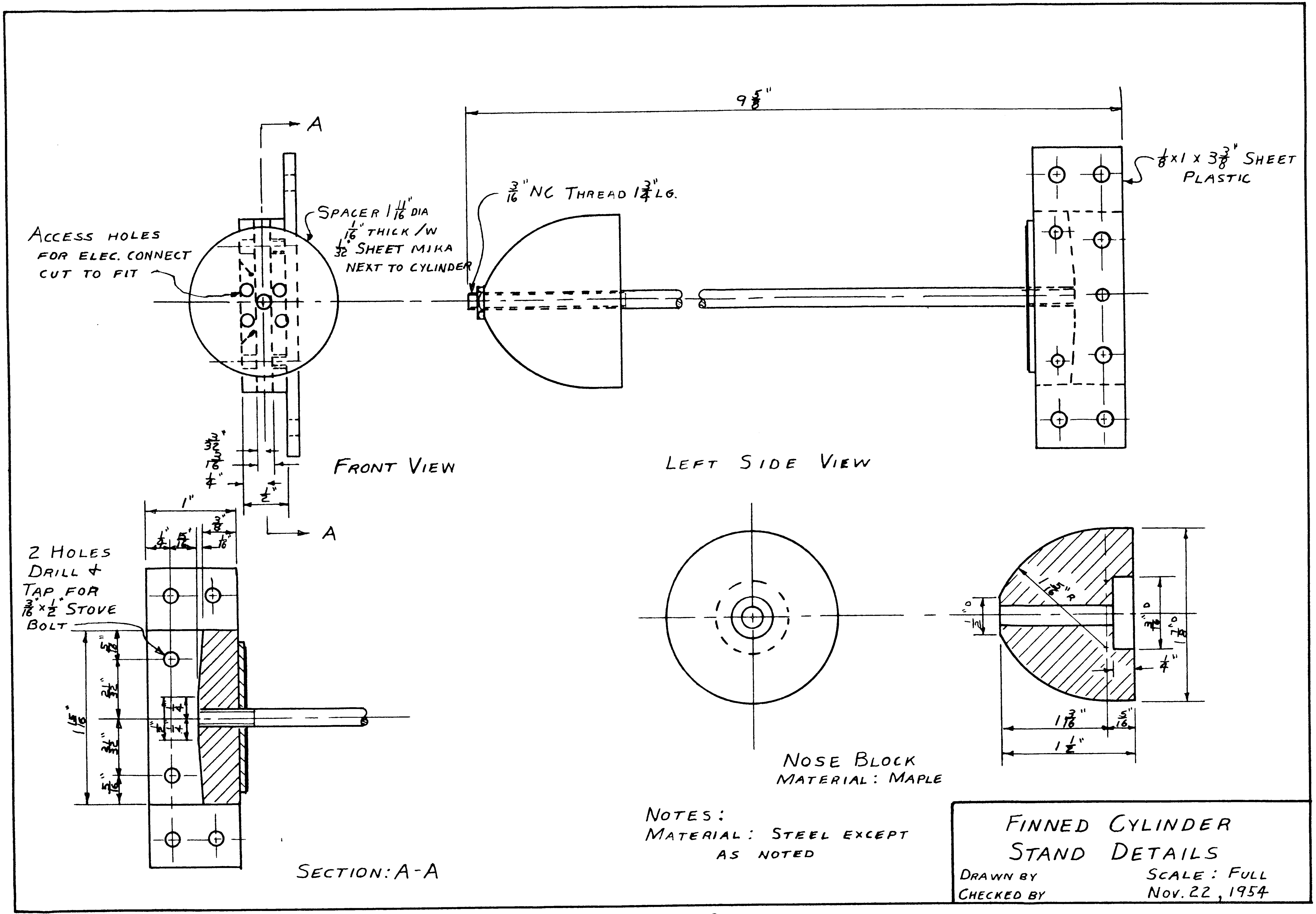
LENGTH: FRONT GUARD 65 IN.
TEST: FRONT COIL 89 IN.
REAR COIL 89 IN.
REAR GUARD 65 IN.
TOTAL 308 IN.

WOUND COUNTER-CLOCKWISE, EVENLY SPACED

LEADS: FRONT GUARD AND TEST:
14 GAGE IN 2 MM I.D. PYREX TUBE
REAR GUARD: COIL WIRE EXTENDED TO TERMINALS
RUN LEAD WIRES INSIDE CORE FROM RESISTANCE WIRE TO TERMINALS
ALL CONNECTIONS SILVER SOLDERED

HEATING ELEMENT SPECIFICATIONS
DRAWN BY
CHECKED BY
SCALE: FULL
NOV 23, 1954

FIGURE 8



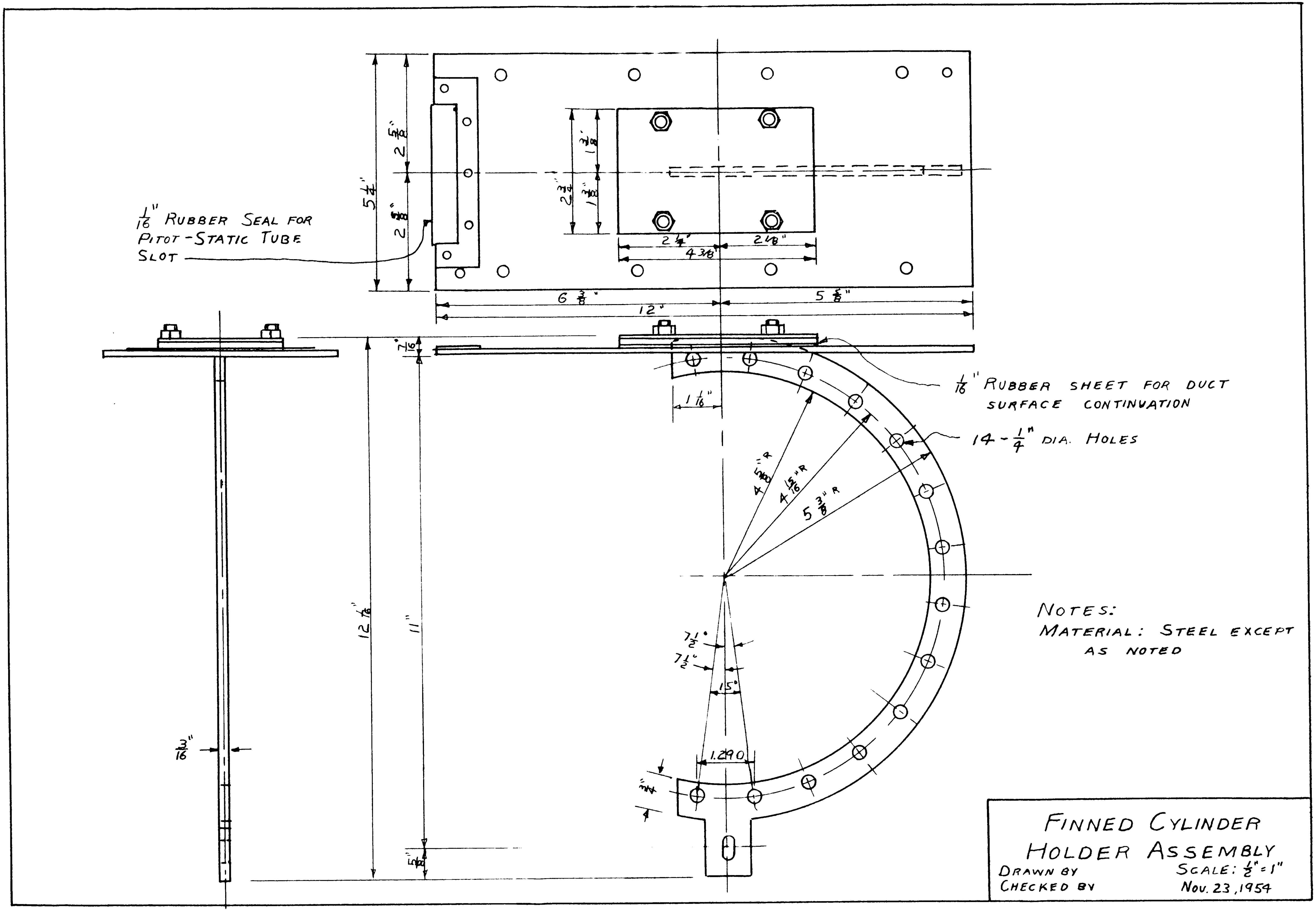
NOTES:
MATERIAL: STEEL EXCEPT
AS NOTED

FINNED CYLINDER
STAND DETAILS

DRAWN BY
CHECKED BY

SCALE: FULL
NOV. 22, 1954

FIGURE 9



Notes:
Material: Steel except as noted

Finned Cylinder
Holder Assembly
Drawn by
Checked by
Scale: 1/2" = 1"
Nov. 23, 1954

Figure 10

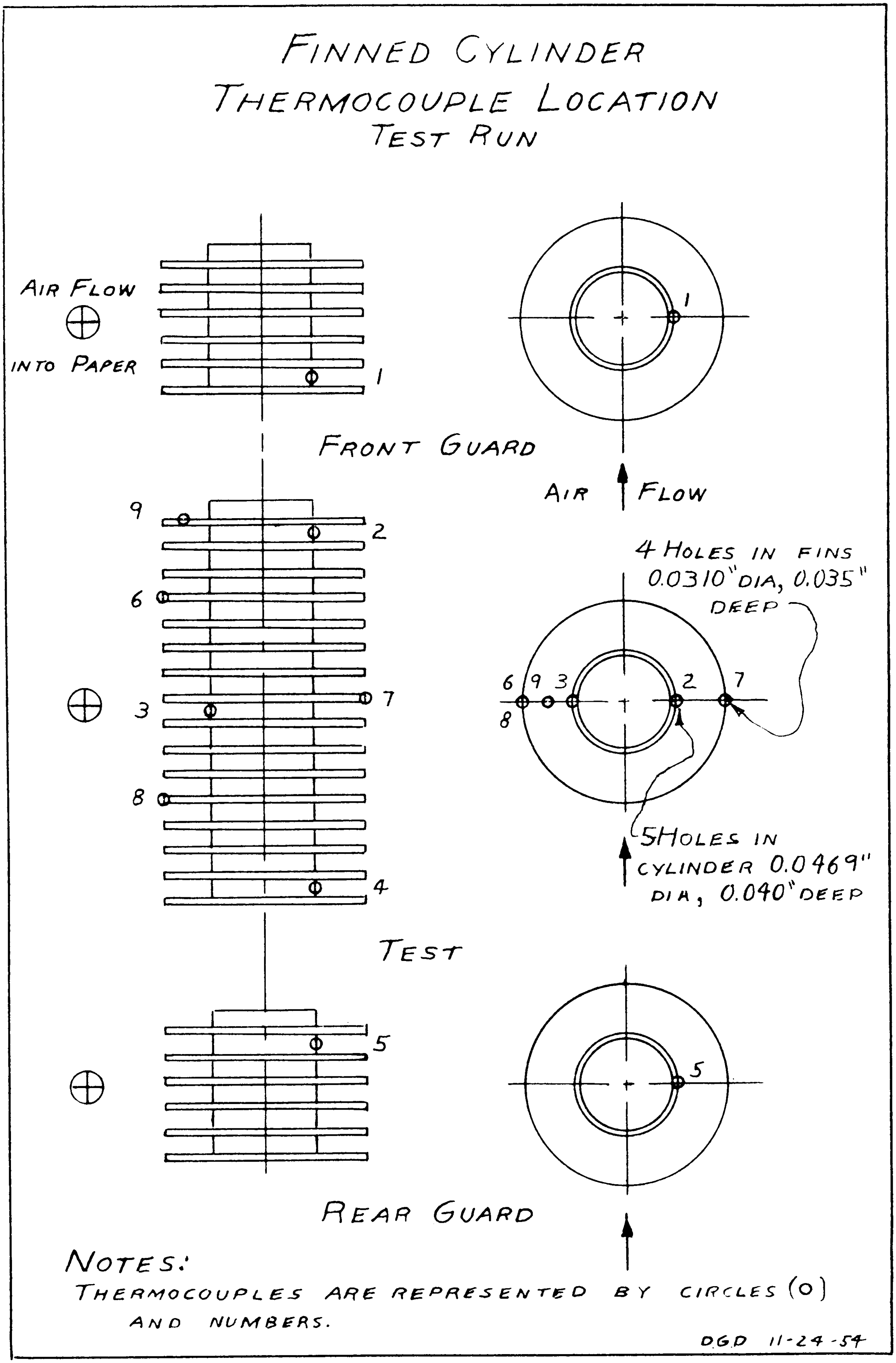
temperature measuring apparatus as described in Part (d).

(d). Apparatus for Test Section Temperature and Heat Supply Measurement

The temperatures of the necessary points on the test section of the finned cylinder were determined by the use of 24 gage iron-constantan thermocouples. The location and specifications of the holes for the thermocouple hot junctions are shown in Figure 11. All the leads of the thermocouples were connected to a selector switch (Q) as shown in Figure 12. The potential difference between the hot and cold junction was measured by a potentiometer (R). An ice bath (S) was used to insure constant temperature of the cold junction. The electrical power supplied to the test section was measured by a D C voltmeter (T) and D C ammeter (U).

(e). Electric Power Supply and Apparatus for Control of Test Specimen Temperature

Electric power was supplied by a 60 volt D C generator. The potential impressed on the entire test specimen was controlled by a field rheostat on the generator. The temperatures of



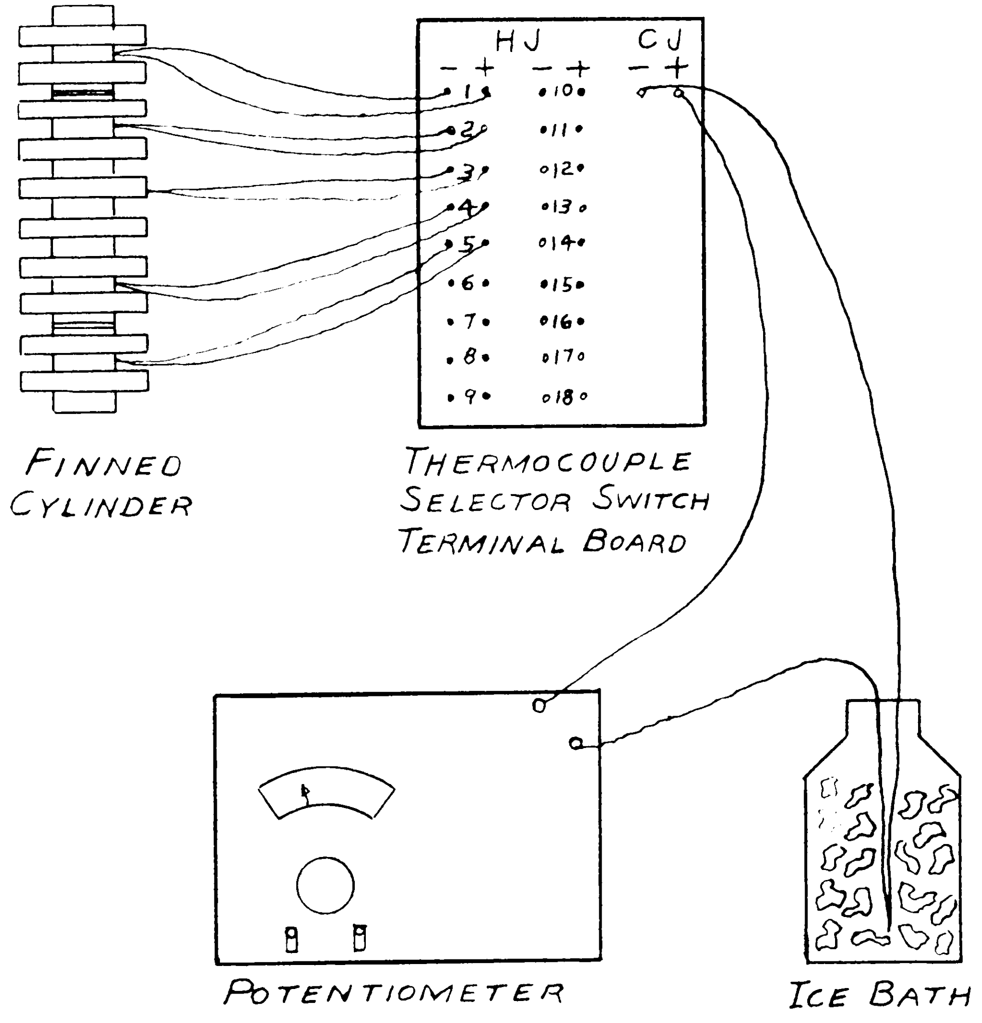
FINNED CYLINDER THERMOCOUPLE LOCATION TEST RUN

NOTES:
THERMOCOUPLES ARE REPRESENTED BY CIRCLES (O) AND NUMBERS.

DGD 11-24-54

FIGURE 11

SCHEMATIC DIAGRAM OF THERMOCOUPLE WIRING



NOTES:
HJ, HOT JUNCTION THERMOCOUPLE TERMINALS.
CJ, COLD JUNCTION THERMOCOUPLE TERMINALS.
HOT JUNCTION THERMOCOUPLES CONNECTED TO
TERMINALS OF RESPECTIVE NUMBER.
ALL IRON LEADS CONNECTED TO POSITIVE (+) TERMINALS.
ALL CONSTANTAN LEADS CONNECTED TO NEGATIVE
(−) TERMINALS.

DGD 12-25-54

FIGURE 12

the guard sections were adjusted until equal to the temperature of the adjacent edge of the test section by separate rheostats for the front guard section (V), and the rear guard section (W). See Figure 13 for the electrical power wiring diagram. The temperature differential between the guard and test sections was indicated by the thermocouples as shown in Figure 11.

2. Lists of Apparatus

(a). Wind Tunnel Apparatus

Primary Blower - Steel pressure blower.
Des 2, Size 2, No. 2933; Sturtevant Co., Boston, Mass.
Driven by: Watson Induction Motor.
Type KH, Frame 5, Form A, 5 hp, 3 phase, 60 cycles, 220 volts, 14 amps, 3400 rpm, No. 54452; Mechanical Appliance Co., Milwaukee, Wis.

Secondary Blower - B-30 Universal Blower.
ILG Electric Ventilating Co., Chicago, Ill.
Driven by: ILG Self Cooled Motor Fan.
Frame 103, 7/8 hp, 3 phase, 60 cycles, 220 volts, 5.5 amps, 685 rpm, No. 70366; ILG Electric Ventilating Co., Chicago, Ill.

Duct - Fabricated in the Mechanical Engineering Laboratory as shown in Figure 6.

(b). Finned Cylinder, Heating Unit, Stand, and Holder Assembly

Finned Cylinders - Five each fabricated in the Mechanical Engineering Laboratory as shown in Figure 7.

SCHEMATIC DIAGRAM OF POWER WIRING

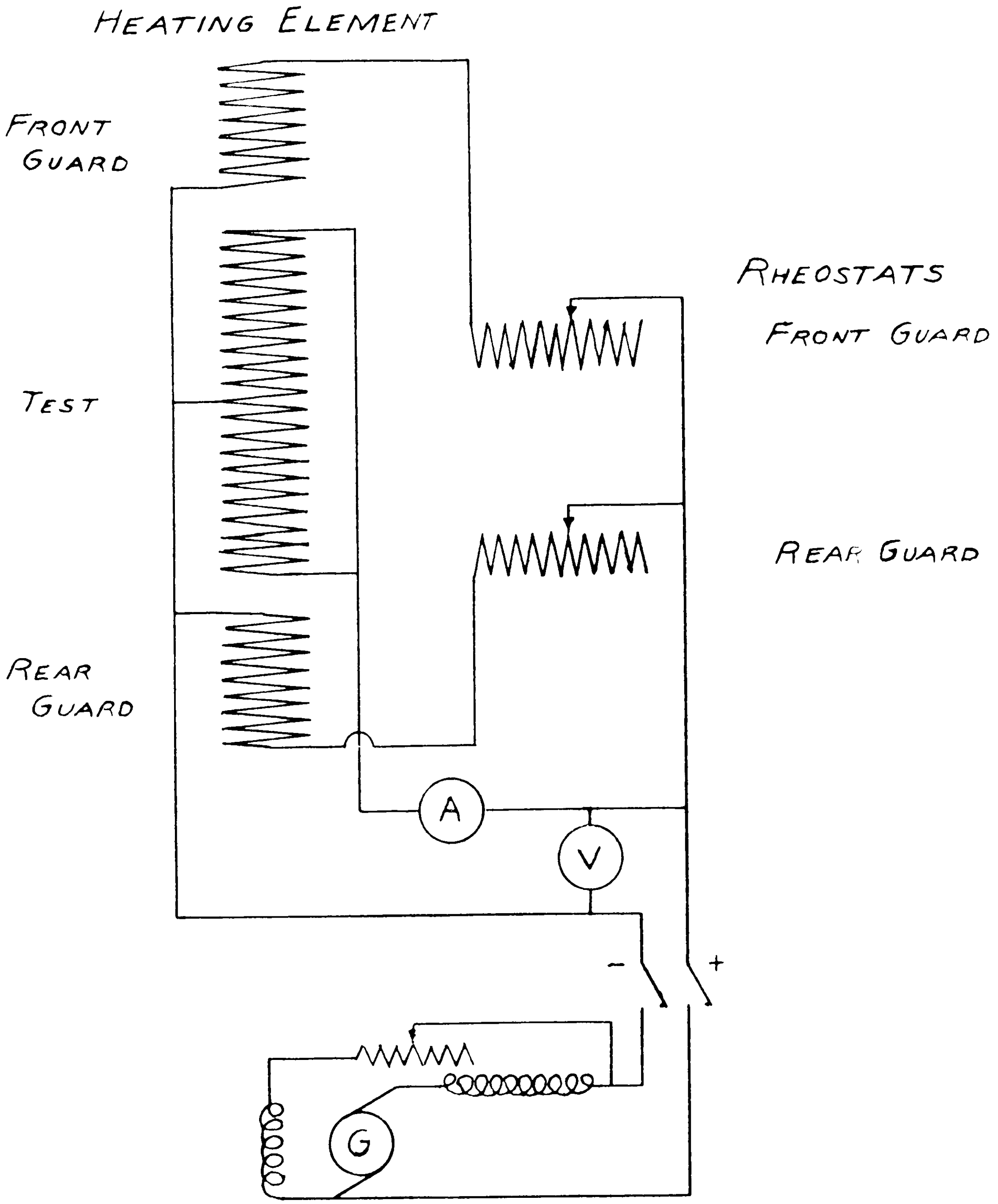


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FIGURE 13

Heating Element - Fabricated in the Mechanical Engineering Laboratory as shown in Figure 8.

Stand - Fabricated in the Mechanical Engineering Laboratory as shown in Figure 9.

Holder - Fabricated in the Mechanical Engineering Laboratory as shown in Figure 10.

(c). Air Velocity and Temperature Measurement

Pitot Tube - Dia 3/16", Unknown manufacturer.

Manometers - Two each fabricated in the Mechanical Engineering Laboratory using 8 mm glass tubing, and 2.358" ID bottle.

Thermocouple - Iron-Constantan, Duplex Wire, 24 gage, asbestos and glass insulation; fabricated in the Mechanical Engineering Laboratory.

Barometer - Mercury; Henry J. Green Scientific Instruments, Brooklyn, N. Y.

Room Air Temperature - Wet and Dry Bulb; Taylor Instrument Co., Rochester, N. Y.

(d). Test Section Temperature and Heat Supply Measurement

Thermocouples - Iron-Constantan Duplex Wire, 24 gage, asbestos and glass insulation; fabricated in the Mechanical Engineering Laboratory.

Selector Switch, Thermocouple - 16 point; The Brown Instrument Co., Philadelphia, Pa.

Potentiometer - Double Range Potentiometer Indicator. No. 8657-C, Std 41149, Issue 2, Sln No. 1134674; Leeds and Northrup, Philadelphia, Pa.

Ice Bath - Thermos one quart bottle; The American Thermos Bottle Co., Norwich, Conn.

D C Ammeter - Model 430, 0 - 50 amps, No. 19991; Weston Electric Instrument Corp., Newark, N. J.

D C Voltmeter - Industrial Analyzer. Model 630, 0 - 75 and 0 - 150 volt D C scales; Superior Instruments Co., New York, N. Y.

(e). Electrical Power and Control of Test Specimen Temperatures

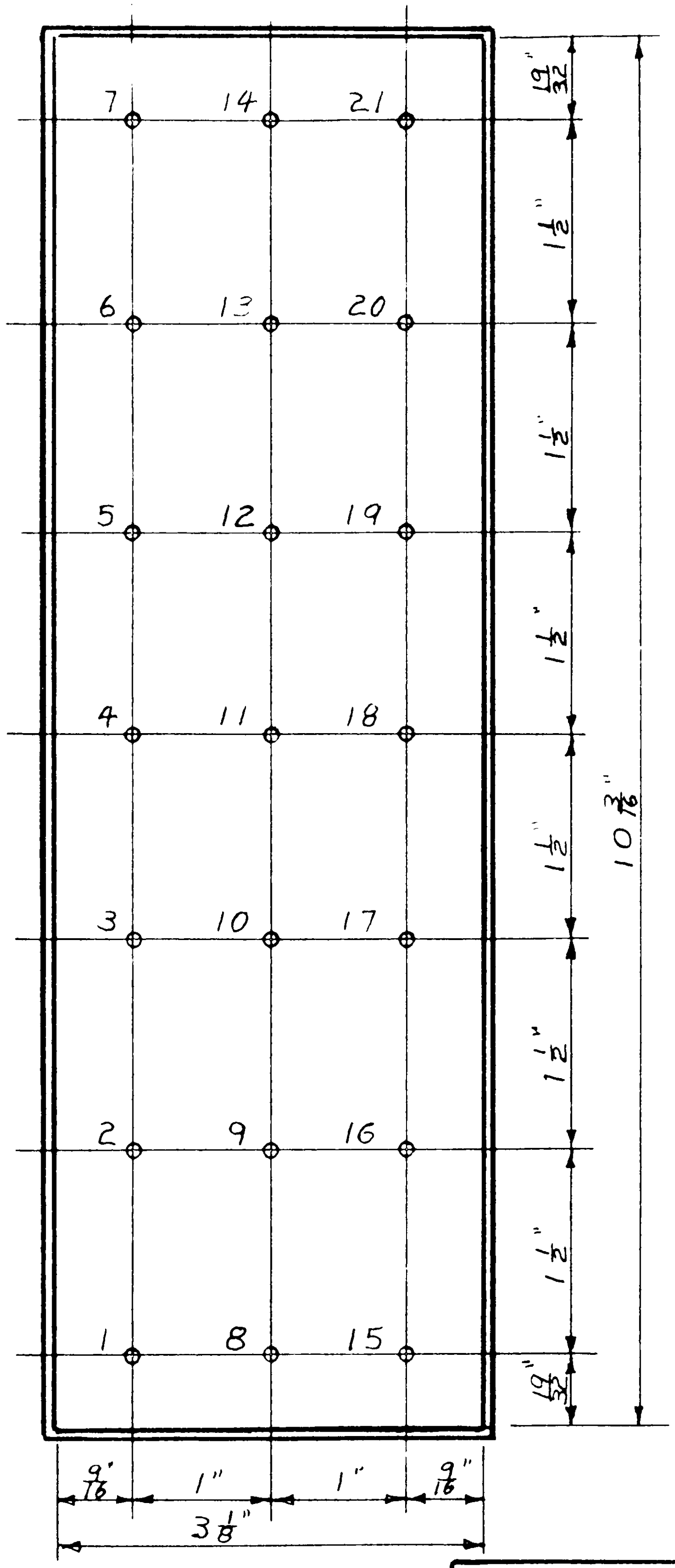
D C Generator - Compound wound, Type SCNDG, Frame 2844, 60 volts, 50 - 100 amp, 1750 rpm, Spec No. 6347, Serial No. 5W14749; Century Electric Co., St. Louis, Mo.
/w Field Rheostat of unknown specifications and manufacture.

Guard Section Rheostats - Two each 4 ohm, fabricated in the Mechanical Engineering Laboratory.

D. Preliminary Investigations

1. Velocity and Temperature Traverse of Tunnel

A preliminary study of the variation of velocity and temperature across the cross section of the tunnel was made to determine if the variations of the velocity and temperature were excessive and to locate a position in the profile which would give an average velocity and temperature of the air-stream. It was decided to use twenty-one points for a traverse as shown in Figure 14. Traverses, indicated by an (X),



NOTES

TRAVERSE POSITIONS
AS VIEWED LOOKING
UPSTREAM

NUMBERS REPRESENT
TRAVERSE POSITIONS

VELOCITY & TEMPERATURE
TRAVERSE POSITIONS
OF WIND TUNNEL

DRAWN BY
CHECKED BY

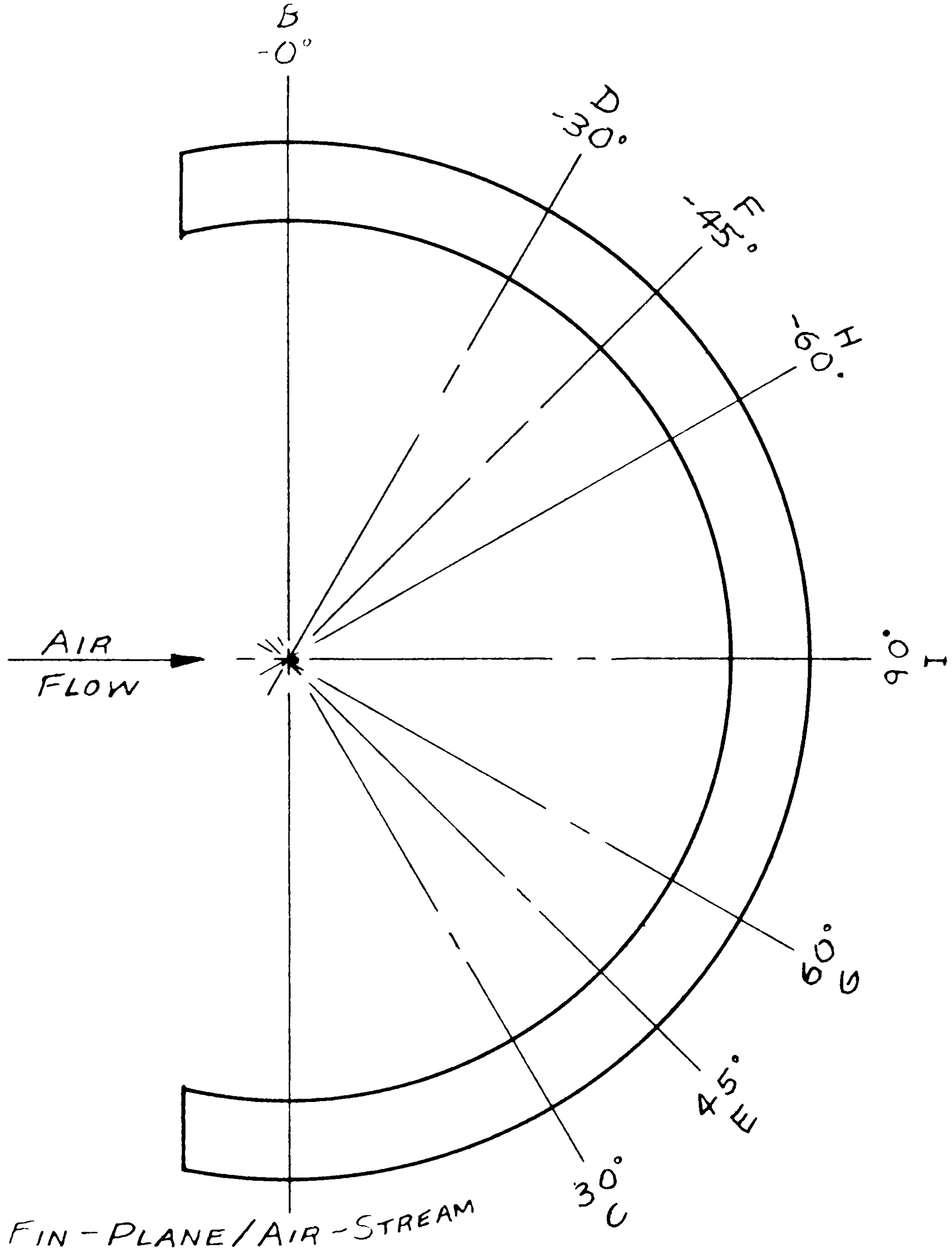
SCALE: 3/4" = 1"
NOV. 22, 1954

FIGURE 14

were made for the following conditions:

Approx Upstream Air Vel, mph.	Fin-Plane/ Air-Stream Position (See Figure 15)	Velocity Traverse	Temperature Traverse
65	A	X	X
	B	X	X
	C	X	X
	D	X	X
	E	X	X
	F	X	X
	G	X	X
	H	X	X
	I	X	X
55	A	X	
	F	X	
	G	X	
45	C	X	
	D	X	
	I	X	
35	B	X	
	E	X	
	H	X	

The data and results of the velocity and temperature traverse of the tunnel are shown in Figures 18-a and b. The maximum velocity variation, which occurred at Cylinder Position F, Traverse Position 2, was found to be 3.7 mph or 5.3% for the 65 mph run (actual average 69.5 mph). The maximum velocity variation occurred in the corners of the duct. The value and location of the maximum velocity variation were considered to be satisfactory. The temperature of the air remained constant across the duct for the 65 mph run and it was thus assumed to remain uniform



FIN-PLANE/AIR-STREAM
ANGLE: 0°
POSITION: A

NOTES:
FINNED CYLINDER
STAND BASE LOCATED
AT LETTERED POSITION

FIN-PLANE/AIR-STREAM
ANGLES & POSITIONS

DRAWN BY
CHECKED BY

SCALE: NONE
NOV. 22, 1954

FIGURE 15

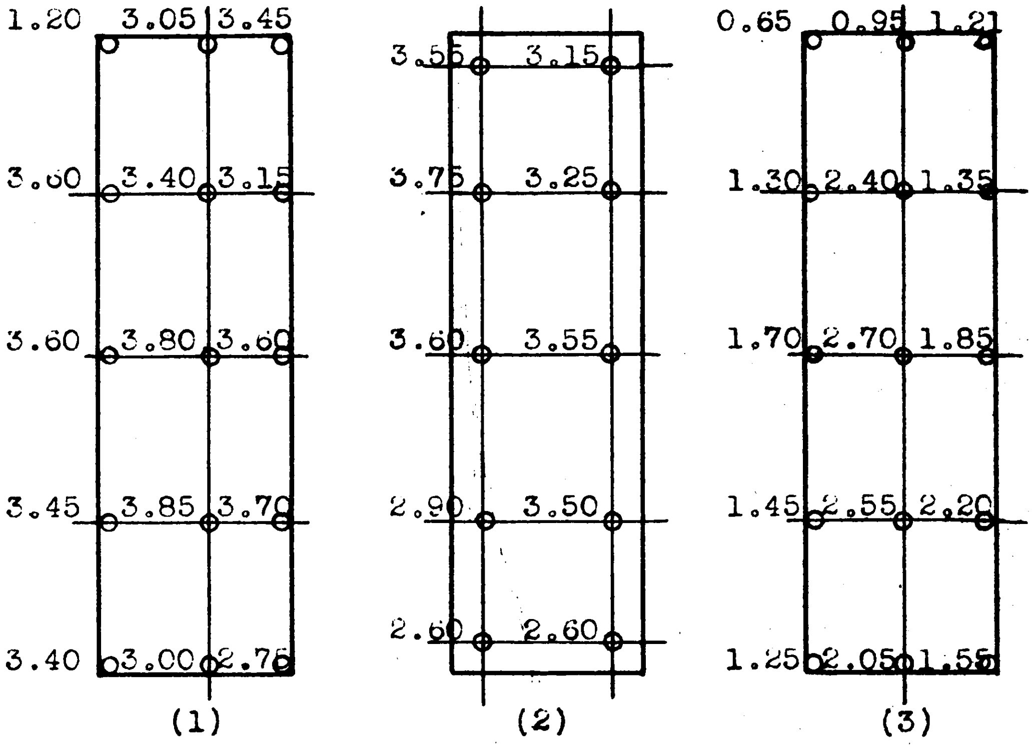
throughout all runs. Traverse Position 19 was found to be the position at which the velocity head most closely approximated the average for the positions and velocities tested.

A total pressure traverse was taken with a 1/8" diameter impact tube; the locations and results are shown in Figure 16. The location and value of the maximum variation in total pressure indicated satisfactory uniformity of the air-stream flow.

2. Finned Cylinder Temperature Distribution

A preliminary investigation was made to determine the number and location of the thermocouples required on the test cylinder. The location and the specifications of the holes in which the thermocouples were peened are shown in Figure 17. The finned cylinder temperature distribution investigation was made on the cylinder with the 0.11" fin spacing at the following fin-plane/air-stream positions as noted in Figure 15; A, C, E, G, and I. A repeat was run on position A with thermocouples 2, 4, 5, 6, 10, 11, and 16 left on the cylinder. Thermocouples 2, 4, 10, 11, and 16 were rotated 180 degrees radially to determine if there was any effect due to difference in air flow for positions A and B.

TOTAL PRESSURE TRAVERSE
OF WIND TUNNEL
WITH 1/8 IN. COPPER TUBE



(1). Readings taken 3 in. infront of finned cylinder, against walls and slightly to right of vertical center line.

(2). Readings taken beside finned cylinder and 1/2 in. off walls.

(3). Readings taken at finned cylinder position without finned cylinder in place against walls and on vertical center line.

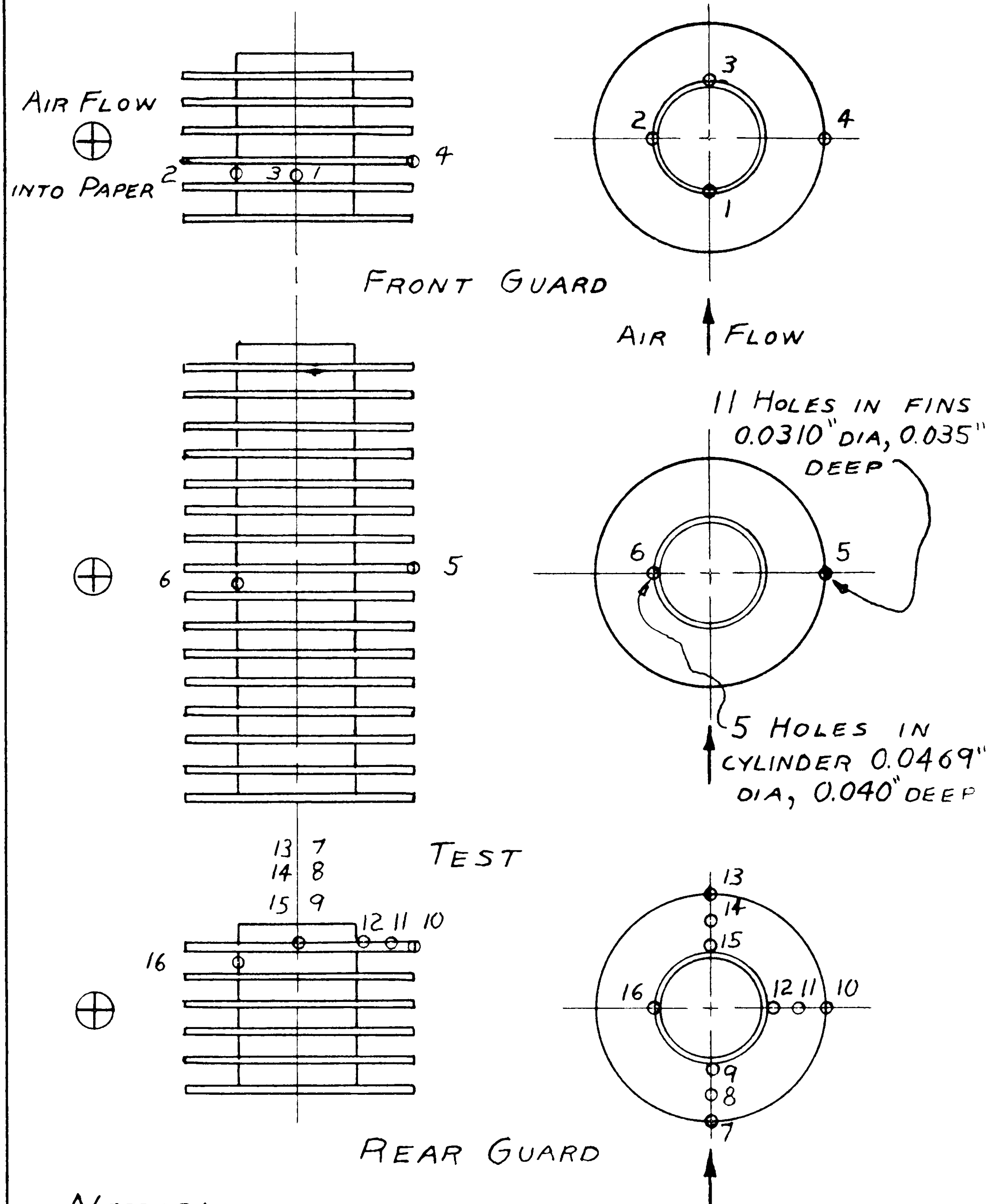
NOTE:

Numbers in figures represent total pressure of position to right of number in in. water.

DGD 11-24-54

FIGURE 16

FINNED CYLINDER
THERMOCOUPLE LOCATION
TEMPERATURE DISTRIBUTION



NOTES:
THERMOCOUPLES ARE REPRESENTED BY CIRCLES (O) AND NUMBERS.

D.G.D. 12-1-54

FIGURE 17

The data and results of the finned cylinder temperature distribution investigation are shown in Figure 19. It was found that the maximum variation in using the thermocouple position number 2 as the average cylinder temperature was 6 F, which gave a variation of 2.3% for Cylinder Position I at the air speed range of 55 mph. The average fin surface temperature was determined by a weighted area method as shown in Sample Calculations, Equation Number 8. The average surface temperature for the fins appeared to be at thermocouple number 11 with a maximum variation of 4 F which gave a variation of 2.4% for Cylinder Position G at the air speed range of 55 mph.

Although the value of q (see Table of Symbols) as used in this study was not based on the average temperature of the extended outer surface, the average temperature of the extended outer surface was held approximately constant during the experimental test to prevent changes in thermal properties of the air. With an average fin surface temperature and an average cylinder surface temperature, the average temperature of the outer surface can be estimated by Equation Number 11 of the Sample Calculations. Run A* (Figure 19) indicated that the temperature measurements were reasonably repeatable. Runs A** and B** (Figure 19) indicated that the effect of the non uniform air flow on the finned cylinder temperature distribution was negligible.

Since it was difficult to place a thermocouple at position 11 (refer to Figure 17 for thermocouple positions), the difference in temperature between position 10 and the average fin surface temperature was determined for the positions tested. There seemed to be no significant temperature variation between position 10 and average fin surface temperature. The temperature at position 10 was 10 F (± 2 F) lower than the average fin surface temperature. It was assumed that for the experimental test of the cylinder with the 0.11" fin spacing, the average fin surface temperature would be 10 F above the average of the thermocouples 6, 7, and 8 as shown in Figure 11. The thermocouples at positions 2, 3, and 4 (Figure 11) were used to determine the average cylinder temperature.

E. Procedure

1. General

Data for all air speeds and fin-plane/air-stream angles were taken for each fin spacing, starting with the smallest fin spacing. The approximate air velocities for the test were: 65, 55, 45, and 35 mph; and the fin-plane/air-stream angles were those shown in Figure 15 (page 45). The cylinder was tested at each fin-plane/air-stream position for the four air speeds in alphabetical order of positions. Baffle plates were used on the intake to the primary blower to vary the air velocity.

2. Preliminary

The iron-constantan thermocouples were made, using the mercury-arc method. The thermocouples were filed as necessary and peened into small holes drilled into the finned cylinder at the locations shown in Figure 11 (page 37). Where necessary, a small amount of Insalute cement was added after peening. The thermocouple leads were connected to the measuring apparatus as shown in Figure 12 (page 38). The sections of the finned cylinder, separated by mica sheets, were slipped over the heating element with the front guard section away from the base of the stand. The nose block was then placed over the end of the cylinder and the nose nut screwed down tight to hold the sections in alignment so the thermocouples would remain in proper position during the test.

3. Test

The assembled test specimen and stand were attached to the holder in the proper position by the two screws in the base of the stand. The entire assembly was then lowered into the wind tunnel and screwed down tightly. All connections were then checked for possible shorts or looseness. The two manometers were zeroed by adding or removing water as required to correct the zero reading. The blowers and the DC generator were then started. The field rheostat was adjusted until the voltmeter indicated approximately 15 volts so that the gages and the test specimen could be checked for proper functioning. After the specimen had heated up slightly, the field rheostat was adjusted until the average temperature of the outer surface of the finned test cylinder was 132 F. This temperature was estimated by the use of Equation 11 (page 58). In Equation 11, the average cylinder surface temperature (T_c) was determined by averaging the temperatures (T_2, T_3, T_4). Since the average fin surface temperature (T_f) was difficult to determine, the average of the fin tip temperatures (T_6, T_7, T_8) was subtracted from the average fin surface temperature attainable (T_9). This differential was used to estimate the average fin surface temperature. In the case of the 0.11 inch fin spacing, a 10 F temperature differential was used since this temperature was determined in the Preliminary Investigation, Finned Cylinder Temperature Distribution.

The cylinder temperatures of the guard sections (front - T_1 and rear - T_5) were adjusted to equal the temperature of the adjacent thermocouples on the test section (T_2 and T_4 respectively) by the rheostats located on the right portion of the instrument board.

After sufficient time for the temperatures of the finned cylinder to become balanced and steady, the pitot tube was lowered into position 19 (Figure 14) and the water in each of the two manometers was oscillated by applying suction or pressure to the open end of the manometer with the fingers to reduce the effects of surface tension in the tubes. After the inlet air readings were taken, the pitot tube was withdrawn to the upper right corner of the tunnel, looking upstream. The following readings were taken:

1. Static pressure.
2. Total pressure.
3. Upstream air temperature.
4. Current to test section.
5. Voltage on test section.
6. Temperatures of the test section by thermocouples 1 thru 9.

During the test on the finned cylinder with the 0.11" fin spacing, readings of thermocouple number 9 (T_9) were omitted. The average temperature of the outer surface was determined by making a trial run with the

0.11" fin spaced cylinder at the approximate position of maximum heat-transfer (Position E) and at full power input.

After completion of test with the highest air velocity, the above procedure was repeated for each of the reduced air velocities. The series of constant air velocities was obtained by the use of four different baffle plates.

After the completion of all the runs at a given fin-plane/air-stream angle, the power to the specimen was cut and the blowers stopped. It should be noted that the power to the finned cylinder should be cut and the un-throttled blowers allowed to run until the finned cylinder is cool. The finned cylinder and holder assembly was then unfastened and lifted out of the tunnel to facilitate the changing of the fin-plane/air-stream angle to the next position. The foregoing test procedure was then repeated for the next fin-plane/air-stream angle.

During each period of operation, the atmospheric pressure and the room wet and dry bulb temperatures were determined. These conditions were recorded for possible use in this investigation or in future investigations. The preliminary and test procedures were repeated for each of the fin spacings.

F. Sample Calculations

1. Preliminary Investigation of Velocity and Temperature Traverse of Tunnel

The sample calculations shown below were for 0.11" fin spacing, position A, 65 mph air velocity range.

Average Upstream Air Temperature

$$T_a = (\Sigma T_1 \text{ thru } T_{21})/21 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$T_a = (79 + 79 + \cdots 79 + 79)/21$$

$$T_a = 79 \text{ F}$$

Average Velocity Head

$$VH_a = \left[(\Sigma \sqrt{VH_1} \text{ thru } \sqrt{VH_{21}})/21\right]^2 \quad \ldots\ldots\ldots\ldots\ldots (2)$$

$$\sqrt{VH_1} = \sqrt{TP_1 - SP_1} = \sqrt{3.77"H_2O - 1.89"H_2O}$$

$$= 1.37$$

Same for VH for rest of readings

$$VH_a = \left[(1.37 + 1.37 + \cdots 1.35 + 1.35)/21\right]^2$$

$$VH_a = 2.10"H_2O$$

Average Upstream Air Velocity

$$V_a = \left[2\ g\ R\ T \left(\frac{VH_a}{P_t}\right)\right]^{1/2} \times 0.682 \text{ mph/fps} \quad \ldots . (3)$$

$$P_t = (28.2 \times 13.6) + 3.87 = 386.87"H_2O$$

$$V_a = \left[2 \times 32.2 \times 53.3 \times 539 \left(\frac{2.10}{386.87}\right)\right]^{1/2} \times 0.682$$

$$V_a = 68.3 \text{ mph}$$

Maximum Variation of Air Velocity from Average

V_{var} (mph) = Air speed of max var - V_a ....(4)

For Position 18, V = 71.6 mph

= 71.6 - 68.3

= 3.3 mph

V_{var} (%) = V_{var} (mph) x 100%/ V_a ....(5)

= 3.3 x 100 / 68.3

= 4.8%

2. Preliminary Investigation of Finned Cylinder Temperature Distribution

The sample calculations shown below were for 0.11" fin spacing, position A, 65 mph air speed range.

Average Cylinder Surface Temperature

$T_c = (T_1 + 2T_2 + T_3)/4$ ....(6)

$T_c = (172 + 2 \times 177 + 196)/4$

$T_c = 181$ F

Variation of T_2 from T_c (%)

$= (T_c - T_2) \times 100\%/ T$ ....(7)

$= (181 - 177) \times 100/ 181$

= 2.2%

Average Fin Surface Temperature

$$T_f = \left[\frac{(1.96)^2 - (1.75)^2}{(1.96)^2 - (1.00)^2}\right]\left[\frac{T_7 + 2T_{10} + T_{13}}{4}\right] + \left[\frac{(1.75)^2 - (1.25)^2}{(1.96)^2 - (1.00)^2}\right]$$

$$\times \left[\frac{T_g + 2T_{11} + T_{14}}{4}\right] + \left[\frac{(1.25)^2 - (1.00)^2}{(1.96)^2 - (1.00)^2}\right]$$

$$\times \left[\frac{T_9 + 2T_{12} + T_{15}}{4}\right]$$

(Based on weighted area method of temperature distribution).........(8)

$$T_f = \left[\frac{(1.96)^2 - (1.75)^2}{(1.96)^2 - (1.00)^2}\right] \left[\frac{145 + 2 \times 151 + 172}{4}\right]$$

$$+ \left[\frac{(1.75)^2 - (1.25)^2}{(1.96)^2 - (1.00)^2}\right]$$

$$\times \left[\frac{152 + 2 \times 158 + 178}{4}\right] + \left[\frac{(1.25)^2 - (1.00)^2}{(1.96)^2 - (1.00)^2}\right]$$

$$\times \left[\frac{157 + 2 \times 173 + 187}{4}\right]$$

T_f = 161 F

Variation of T_{11} from T_f (%)

= $(T_f - T_{11}) \times 100\% / T_f$ ....(9)

= (161 - 158) x 100/ 161

= 1.9%

Variation of T_{10} from T_f

= $T_f - T_{10}$ ....(10)

= 161 - 151

= 10 F

Average Temperature of the Outer Surface

$$T_{fc} = T_f \left[\frac{\pi/2\left[D_f^2 - D_{co}^2\right] + \pi D_f t}{\pi/2\left[D_f^2 - D_{co}^2\right] + \pi D_f t + \pi D_{co} s}\right]$$

$$+ \quad T_c \left[\frac{\pi D_{co} s}{\pi/2\left[D_f^2 - D_{co}^2\right] + \pi D_f t + \pi D_{co} s}\right] \quad ..(11)$$

$$T_{fc} = 151 \left[\frac{\pi/2\left[(1.96)^2 - (1.00)^2\right] + \pi \times 1.96 \times 0.04}{\pi/2\left[(1.96)^2 - (1.00)\right] + \pi \times 1.96 \times 0.04 + \pi \times 1.00 \times 0.11}\right]$$

$$+ \quad 181 \left[\frac{\pi \times 1.00 \times 0.11}{\pi/2\left[(1.96)^2 - (1.00)^2\right] + 1.96 \times 0.04 + \pi \times 1.00 \times 0.11}\right]$$

$$T_{fc} = 162 \text{ F}$$

3. Principle Investigation

The sample calculations shown below were for 0.11 inch fin spacing, position A, 65 mph velocity range.

Upstream Air Speed (actual)

$$V_t = \left[2\ g\ R\ T'_a \left(\frac{P_t - P}{P_t}\right)\right]^{1/2} \quad \dots\dots\dots\dots\dots\dots(12)$$

$$P_t = (28.2 \times 13.6) + 4.13 = 387.13'' \ H_2O$$

$$P_s = (28.2 \times 13.6) + 2.08 = 385.08'' \ H_2O$$

$$V_t = \left[2 \times 32.2 \times 53.3 \times 544 \left(\frac{387.13 - 385.08}{387.13}\right)\right]^{1/2}$$

$$V_t = 99.2 \text{ feet per second}$$

Upstream Air Velocity (Standard Conditions)

Standard air: 80 F, 28.92"H_g, 0.0734 lb/cu ft

$$V_s = \left(\frac{P_s \times 5.2}{R\ T_a' \times 0.0734} \right) V_t \ \ldots\ 5.2 \text{ psf/" } H_2O \ \ldots (13)$$

$$V_s = \left(\frac{385.08 \times 5.2}{53.3 \times 544 \times 0.0734} \right) \quad 99.2$$

V_s = 93.5 feet per second

or 93.5 x 0.682 mph/fps = 63.7 miles per hour

Average Cylinder Temperature

$$T_c = (T_2 + T_3 + T_4)/3 \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

$$T_c = (148 + 149 + 141)/3$$

T_c = 146 degrees F.

Surface Heat-Transfer Coefficient

$$q = \frac{Q}{A \triangle T_c} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

$$A = \left[(\pi/2)\ (D_f^2 - D_{co}^2) + \pi\ D_f\ t \right] N$$

$$+ (L - N\ t)\ (\pi \times D_{co})$$

$$= \left[(\pi/2)\ (1.94^2 - 1.00^2) + \pi \times 1.94 \times 0.04 \right] 27$$

$$+ (4.00 - 27 \times 0.04)\ \pi \times 1.00$$

= 132.68 square inches

$\triangle T = T_c - T_a$ = 146 - 84 = 62 degrees F

Q = Volts x Amps x 3.42 Btu/hr /watt

= 55 x 8.8 x 3.42 = 1655 Btu per hour

$$q = \frac{1655}{132.68 \times 62}$$

q = 0.201 Btu/sq in-hr-F

Over-all Heat-Transfer Coefficient

$$U = \frac{Q}{A_c \Delta T_c} \qquad \text{.............................} (16)$$

$$A_c = \pi D_{co} L = \pi \times 1.00 \times 4.00 = 12.58 \text{ sq in.}$$

$$U = \frac{1655}{12.58 \times 62}$$

$$U = 2.12 \text{ Btu/sq in.-hr-F.}$$

G. Data and Results

PRELIMINARY INVESTIGATION, VELOCITY AND TEMPERATURE TRAVERSE DATA AND RESULTS

Approx. Air Speed, mph	65																										
Cylinder Positions	A			B			C			D			E			F			G			H			I		
	T_a F	SP "H_2O	TP "H_2O	T_a F	SP "H_2O	TP "H_2O	T_a F	SP "H_2O	TP "H_2O	T_a F	SP "H_2O	TP "H_2O	T_a F	SP "H_2O	TP "H_2O	T_a F	SP "H_2O	TP "H_2O	T_a F	SP "H_2O	TP "H_2O	T_a F	SP "H_2O	TP "H_2O	T_a F	SP "H_2O	TP "H_2O
1	79	1.89	3.77	79	1.87	3.75	79	1.76	3.72	77	1.74	3.70	77	1.65	3.57	77	1.66	3.58	77	1.40	3.44	77	1.53	3.45	77	1.00	3.07
2	79	1.87	3.75	79	1.87	3.75	79	1.76	3.65	77	1.74	3.63	77	1.64	3.48	77	1.66	3.55	77	1.40	3.37	77	1.52	3.40	77	1.00	3.00
3	79	1.83	3.70	79	1.83	3.71	79	1.72	3.62	77	1.67	3.62	77	1.60	3.48	77	1.62	3.50	77	1.35	3.37	77	1.44	3.39	77	0.98	2.98
4	79	1.73	3.90	79	1.74	3.92	79	1.55	3.83	77	1.54	3.78	77	1.47	3.67	77	1.50	3.69	77	1.27	3.30	77	1.31	3.55	77	0.83	3.17
5	79	1.71	3.94	79	1.72	3.95	79	1.55	3.84	77	1.53	3.80	77	1.44	3.72	77	1.45	3.74	77	1.23	3.56	77	1.27	3.57	77	0.81	3.20
6	79	1.76	3.94	79	1.75	3.95	79	1.59	3.83	77	1.54	3.80	77	1.47	3.72	77	1.46	3.73	77	1.25	3.54	77	1.26	3.58	77	0.81	3.20
7	79	1.77	3.85	79	1.77	3.86	79	1.59	3.74	77	1.55	3.72	77	1.47	3.65	77	1.47	3.67	77	1.26	3.55	77	1.27	3.51	77	0.81	3.15
8	79	1.85	3.96	79	1.82	3.92	79	1.70	3.80	77	1.67	3.81	77	1.59	3.74	77	1.64	3.75	77	1.43	3.58	77	1.43	3.60	77	0.99	3.33
9	79	1.80	3.94	79	1.81	3.90	79	1.70	3.80	77	1.65	3.78	77	1.57	3.72	77	1.61	3.72	77	1.42	3.58	77	1.43	3.59	77	0.98	3.28
10	79	1.75	3.91	79	1.74	3.89	79	1.60	3.81	77	1.60	3.78	77	1.50	3.73	77	1.50	3.72	77	1.30	3.59	77	1.31	3.58	77	0.88	3.26
11	79	1.70	3.94	79	1.72	3.91	79	1.52	3.83	77	1.51	3.79	77	1.44	3.74	77	1.45	3.74	77	1.26	3.58	77	1.27	3.58	77	0.80	3.28
12	79	1.69	3.95	79	1.68	3.93	79	1.51	3.84	77	1.49	3.80	77	1.42	3.74	77	1.43	3.76	77	1.24	3.59	77	1.24	3.60	77	0.78	3.33
13	79	1.71	3.92	79	1.72	3.91	79	1.54	3.78	77	1.50	3.75	77	1.44	3.73	77	1.44	3.72	77	1.22	3.54	77	1.25	3.58	77	0.78	3.20
14	79	1.73	3.87	79	1.72	3.85	79	1.55	3.74	77	1.51	3.73	77	1.45	3.66	77	1.44	3.67	77	1.23	3.50	77	1.25	3.52	77	0.78	3.15
15	79	1.87	3.93	79	1.82	3.89	79	1.70	3.84	77	1.65	3.78	77	1.56	3.69	77	1.61	3.72	77	1.40	3.55	77	1.42	3.60	77	0.97	3.26
16	79	1.86	4.05	79	1.82	4.01	79	1.71	3.93	77	1.66	3.90	77	1.57	3.87	77	1.61	3.84	77	1.40	3.67	77	1.43	3.80	77	0.98	3.40
17	79	1.82	4.05	79	1.74	4.01	79	1.64	3.93	77	1.62	3.90	77	1.53	3.86	77	1.51	3.86	77	1.32	3.68	77	1.33	3.75	77	0.97	3.40
18	79	1.72	4.02	79	1.69	3.98	79	1.55	3.90	77	1.52	3.88	77	1.45	3.83	77	1.45	3.85	77	1.27	3.67	77	1.28	3.75	77	0.85	3.39
19	79	1.75	3.80	79	1.71	3.80	79	1.55	3.70	77	1.52	3.70	77	1.46	3.58	77	1.46	3.57	77	1.25	3.50	77	1.28	3.57	77	0.83	3.13
20	79	1.75	3.57	79	1.72	3.57	79	1.56	3.50	77	1.53	3.43	77	1.47	3.40	77	1.46	3.40	77	1.24	3.32	77	1.28	3.37	77	0.83	2.94
21	79	1.75	3.58	79	1.72	3.57	79	1.57	3.49	77	1.54	3.45	77	1.47	3.40	77	1.46	3.39	77	1.24	3.30	77	1.28	3.33	77	0.83	2.91
Ave Temp, F	79			79			79			77			77			77			77			77			77		
Ave VH "H_2O	2.10			2.10			2.16			2.16			2.16			2.16			2.22			2.22			2.31		
Ave Air Speed, mph	68.3			68.3			69.3			69.5			69.5			69.5			70.5			70.5			71.8		
Max Var Air Speed, mph	71.6			71.3			72.3			72.7			73.0			73.2			73.2			73.7			75.3		
Amt (mph)	3.3			3.0			2.8			3.2			3.5			3.7			2.7			3.2			3.5		
Var (%)	4.8			4.4			4.0			4.6			5.0			5.3			3.8			4.5			4.9		
Positions	18			17,18			12,18			18			18			18			18			18			12		

ROOM AIR CONDITIONS
Temperature, 78F
Barometer. 228.20" Hg

FIGURE 18-a

PRELIMINARY INVESTIGATION, VELOCITY AND TEMPERATURE TRAVERSE DATA AND RESULTS (CONTINUED)

Approx. Air Speed, mph	55						45						35					
Cylinder Positions	A		F		G		C		D		I		B		E		H	
	SP "H_2O	TP "H_2O	SP "H_2O	TP "H_2O	SP "H_2O	TP "H_2O	SP "H_2O	TP "H_2O	SP "H_2O	TP "H_2O	SP "H_2O	TP "H_2O	SP "H_2O	TP "H_2O	SP "H_2O	TP "H_2O	SP "H_2O	TP "H_2O
1	1.31	2.60	1.11	2.43	0.91	2.30	0.72	1.56	0.72	1.57	0.35	1.16	0.48	1.01	0.38	0.92	0.33	0.85
2	1.32	2.61	1.11	2.43	0.91	2.30	0.72	1.56	0.72	1.57	0.35	1.20	0.48	1.01	0.39	0.93	0.33	0.85
3	1.31	2.54	1.10	2.40	0.91	2.25	0.72	1.54	0.72	1.57	0.35	1.20	0.48	1.00	0.39	0.92	0.33	0.85
4	1.25	2.60	1.13	2.43	0.89	2.30	0.73	1.53	0.72	1.54	0.35	1.20	0.48	1.00	0.39	0.92	0.33	0.85
5	1.21	2.63	0.98	2.46	0.83	2.32	0.72	1.52	0.72	1.58	0.35	1.20	0.48	1.00	0.39	0.91	0.33	0.84
6	1.20	2.64	0.99	2.47	0.82	2.33	0.72	1.52	0.72	1.59	0.35	1.20	0.48	1.00	0.39	0.91	0.33	0.84
7	1.21	2.64	0.99	2.47	0.82	2.32	0.72	1.52	0.72	1.57	0.35	1.20	0.48	1.00	0.39	0.91	0.33	0.84
8	1.27	2.70	1.10	2.50	0.87	2.37	0.71	1.53	0.72	1.57	0.35	1.21	0.48	1.00	0.39	0.91	0.33	0.84
9	1.27	2.70	1.10	2.51	0.88	2.38	0.71	1.53	0.72	1.57	0.35	1.22	0.48	1.00	0.39	0.91	0.33	0.84
10	1.25	2.66	1.08	2.50	0.88	2.37	0.71	1.53	0.72	1.58	0.35	1.21	0.48	1.00	0.39	0.91	0.33	0.84
11	1.20	2.67	1.04	2.50	0.85	2.37	0.71	1.53	0.72	1.58	0.35	1.22	0.48	1.00	0.39	0.91	0.33	0.84
12	1.16	2.68	0.99	2.50	0.81	2.36	0.71	1.53	0.72	1.57	0.35	1.22	0.48	1.00	0.39	0.91	0.33	0.84
13	1.17	2.67	0.98	2.50	0.80	2.36	0.70	1.53	0.72	1.57	0.35	1.21	0.48	1.00	0.39	0.91	0.33	0.84
14	1.18	2.64	0.99	2.48	0.80	2.32	0.70	1.53	0.72	1.57	0.35	1.21	0.48	1.00	0.39	0.91	0.33	0.84
15	1.29	2.68	1.08	2.51	0.90	2.41	0.70	1.53	0.72	1.57	0.35	1.19	0.48	1.01	0.39	0.93	0.33	0.86
16	1.29	2.72	1.09	2.55	0.89	2.42	0.70	1.53	0.72	1.56	0.35	1.19	0.48	1.01	0.39	0.93	0.33	0.86
17	1.28	2.72	1.08	2.55	0.85	2.37	0.70	1.54	0.72	1.57	0.35	1.21	0.48	1.01	0.39	0.93	0.33	0.86
18	1.23	2.71	1.05	2.55	0.82	2.30	0.70	1.54	0.72	1.56	0.35	1.22	0.48	1.01	0.39	0.93	0.33	0.86
19	1.22	2.61	1.02	2.49	0.82	2.23	0.70	1.54	0.72	1.57	0.35	1.22	0.48	1.01	0.39	0.93	0.33	0.86
20	1.21	2.40	1.01	2.49	0.82	2.08	0.70	1.53	0.72	1.56	0.35	1.21	0.48	1.00	0.39	0.91	0.33	0.85
21	1.21	2.40	1.01	2.25	0.82	2.07	0.70	1.42	0.72	1.41	0.35	1.08	0.48	0.95	0.39	0.85	0.33	0.80
Ave VH "H_2O	1.39		1.43		1.47		0.82		0.84		0.85		0.52		0.53		0.52	
Ave Air Speed, mph	55.7		56.8		57.2		42.8		43.3		43.5		34.1		34.4		34.1	
Max Var Air Speed, mph	58.3		58.3		59.0		43.4		43.8		44.0		34.4		34.7		34.4	
Var (mph)	2.6		1.5		1.8		0.6		0.5		0.5		0.3		0.3		0.3	
Var (%)	4.7		2.6		3.1		1.4		1.2		1.2		0.9		0.9		0.9	
Positions	12		13		13		-		-		-		-		-		-	

ROOM AIR CONDITIONS

Temperature, 84 F

Barometer, 28.11 "Hg

FIGURE 18-b

PRELIMINARY INVESTIGATION
FINNED CYLINDER TEMPERATURE DISTRIBUTION
DATA AND RESULTS

Cylinder Position	A				C				E				G				I				A*				A**	B**
Approx. Air Speed, mph	65	55	45	35	65	55	45	35	65	55	45	35	65	55	45	35	65	55	45	35	65	55	45	35	65	65
Upstream Air Temp. F	93	93	93	93	93	94	94	94	94	94	94	94	93	93	93	91	91	91	91	91	91	91	91	91	91	91
SP. "H_2O	2.10	1.50	0.91	0.62	1.85	1.32	0.84	0.57	1.75	1.23	0.79	0.49	1.59	1.09	0.75	0.41	1.24	0.84	0.53	0.36	2.01	1.40	0.91	0.60	2.07	2.17
TP. "H_2O	4.10	2.85	1.83	1.10	3.80	2.73	1.83	1.11	3.77	2.65	0.71	1.05	3.61	2.51	1.67	0.98	3.41	2.35	1.51	0.94	3.95	2.86	1.83	1.16	4.17	4.15
F 1	172	183	190	219	162	169	182	198	156	156	177	193	164	171	182	204	236	266	249	299						
i 2	177	189	205	225	167	175	189	206	162	171	184	199	172	179	192	214	238	265	240	287	176	185	204	222	174	175
n T 3	196	209	227	248	165	190	206	222	176	169	199	216	187	196	209	234	238	265	248	299						
n e 4	163	175	193	211	152	160	176	191	147	157	170	186	157	166	172	204	218	239	226	272	165	177	197	216	155	156
e m 5	162	169	191	207	148	156	169	184	143	150	164	179	149	157	168	196	218	245	235	282	158	167	186	204	158	155
d p 6	177	188	205	226	167	175	189	206	162	171	183	199	172	179	193	214	232	254	240	287	176	185	204	222	174	175
e 7	145	160	169	186	130	137	148	160	130	136	145	159	131	137	146	162	213	233	280	272						
C r 8	152	162	178	198	141	150	162	178	140	146	159	173	147	156	165	186	235	259	247	296						
y a 9	157	165	180	201	141	150	162	176	144	151	162	177	152	160	172	191	242	265	251	300						
l t 10	151	160	177	195	141	150	162	178	141	149	160	174	148	156	168	189	219	240	232	276	151	160	177	196	150	152
i u 11	158	167	183	204	147	157	169	186	146	155	168	182	157	162	174	196	227	249	237	284	156	165	182	203	160	162
n r 12	173	181	199	221	162	172	186	204	159	168	181	196	171	181	193	215	249	273	258	306						
d e 13	172	181	199	222	161	167	182	200	158	166	181	198	171	181	193	215	208	227	223	265						
e 14	179	189	206	229	165	176	191	209	164	173	187	205	177	188	199	222	219	239	233	282						
r (F) 15	187	197	216	239	174	186	199	218	172	182	196	213	186	194	208	230	234	254	244	293						
16	177	188	204	226	166	175	189	206	162	170	183	199	172	179	193	213	232	254	241	287	176	185	204	222	174	175
Temp (T_c)	181	190	207	229	165	177	192	208	164	169	185	202	174	181	194	217	234	261	244	293						
Temp (T_2)	177	189	205	225	167	175	189	206	162	171	183	199	172	179	192	214	232	255	240	287	176	185	204	222	174	175
Var T_2 from T_c, %	2.2	0.5	1.0	1.8	1.2	1.1	1.6	1.0	1.2	1.2	1.1	1.5	1.2	1.1	1.0	1.4	0.9	2.3	1.6	2.0						
Temp (T_f)	161	171	187	203	150	159	172	189	149	156	169	184	159	166	178	200	227	248	243	286						
Temp (T_{11})	158	167	183	204	147	157	169	186	146	155	168	182	157	162	174	196	227	249	237	284	156	165	182	203	160	162
Var T_{11} from T_f, %	1.9	2.3	2.1	0.5	2.0	1.3	1.7	1.6	2.0	0.6	0.6	1.1	1.3	2.4	2.3	2.0	0.0	0.4	2.5	0.7						
Temp (T_{10})	151	160	177	195	141	150	162	178	141	149	160	174	148	156	168	189	219	240	232	276	151	160	177	196	150	152
Var T_{10} from T_f, F	10	11	10	8	9	9	10	11	8	7	9	10	11	10	10	11	8	8	11	10						

ROOM AIR CONDITIONS

Temperature,	86F
Barometer,	28.14" Hg

Notes:

All runs were made with approximately constant power input to test section except runs I-45 and 35 which were run at reduced constant power.

FIGURE 19

PRINCIPLE INVESTIGATION DATA AND RESULTS
FOR
0.11" FIN SPACING

Cylinder Position	Approx Air Speed, mph	Room Air Temp, °F DB	Room Air WB	Room Air Bar "Hg	Upstream Air Temp °F	Upstream Air SP "H_2O	Upstream Air TP "H_2O	Power to Test Sect. Amps	Power to Test Sect. Volts	Finned Cylinder Temperature, °F (Thermocouple Number) 1	2	3	4	5	6	7	8	Air Speed Vs (mph)	Coef of Heat-Transfer, q Btu/sq in.-hr-°F
A	65	75	58	28.20	84	2.08	4.13	8.8	55	148	148	149	141	141	129	128	127	63.7	0.201
	55	75	58	28.20	84	1.45	2.85	7.7	48	138	138	140	134	134	124	124	123	52.8	0.180
	45	75	58	28.20	83	0.94	1.88	6.9	44	137	137	137	132	132	125	125	122	43.2	0.151
	35	75	58	28.20	84	0.62	1.17	6.5	41	136	136	138	134	134	127	125	125	33.1	0.132
B	65	75	58	28.20	84	2.11	4.11	9.0	57	145	145	148	143	143	130	123	127	63.2	0.217
	55	75	58	28.20	84	1.48	2.92	8.0	51	141	141	143	138	138	129	122	126	53.7	0.185
	45	75	58	28.20	84	0.95	1.89	7.1	45	138	138	140	139	139	127	121	125	43.4	0.150
	35	75	58	28.20	84	0.63	1.16	6.3	40	136	136	137	131	131	126	121	125	32.6	0.128
C	65	75	58	28.20	84	2.00	4.01	9.1	57	142	142	143	137	137	125	126	124	63.7	0.235
	55	75	58	28.20	85	1.40	2.78	8.0	51	139	139	140	134	134	125	126	122	52.8	0.199
	45	75	58	28.20	85	0.90	1.85	7.1	44	136	136	136	130	130	123	123	120	43.6	0.165
	35	75	58	28.20	85	0.54	1.15	6.6	41	135	135	135	130	130	123	125	121	34.9	0.146
D	65	75	58	28.20	85	2.04	3.99	9.0	59	143	143	149	142	142	128	123	123	62.3	0.229
	55	75	58	28.20	84	1.46	2.83	8.6	54	140	140	145	144	141	126	123	123	52.3	0.194
	45	75	58	28.20	85	0.92	1.85	7.5	47	136	136	141	135	135	125	122	122	43.2	0.179
	35	75	58	28.20	85	0.57	1.13	7.0	44	137	137	141	135	135	127	123	123	33.5	0.150
E	65	75	58	28.20	81	1.87	3.95	10.2	64	148	148	151	143	143	128	125	122	64.2	0.254
	55	75	58	28.20	81	1.29	2.74	9.2	58	145	145	148	140	140	128	126	123	53.7	0.219
	45	75	58	28.20	81	0.81	1.75	8.5	53	145	145	146	139	139	129	127	125	43.4	0.187
	35	75	58	28.20	81	0.50	1.08	7.4	47	141	141	142	134	134	127	125	122	34.1	0.155
F	65	75	58	28.20	81	1.94	4.00	10.0	63	141	141	148	141	141	127	125	124	63.8	0.262
	55	75	58	28.20	81	1.35	2.87	9.2	58	140	140	148	140	140	129	126	125	55.0	0.226
	45	75	58	28.20	81	0.87	1.82	8.2	51	139	139	145	137	137	127	125	125	43.5	0.184
	35	75	58	28.20	82	0.56	1.15	7.3	46	136	136	140	133	133	126	125	124	34.3	0.161
G	65	75	60	28.08	85	1.66	3.81	9.6	60	151	151	151	141	141	126	128	125	65.0	0.236
	55	75	60	28.08	85	1.11	2.57	8.6	54	149	149	149	140	140	126	126	125	53.6	0.197
	45	75	60	28.08	85	0.69	1.68	7.4	47	143	143	143	135	135	126	123	121	44.2	0.164
	35	75	60	28.08	85	0.42	0.97	6.8	43	141	141	141	134	134	126	125	124	32.8	0.134
H	65	75	60	28.08	84	1.66	3.77	10.2	64	153	153	162	149	149	128	124	125	64.3	0.238
	55	75	60	28.08	84	1.17	2.62	9.2	58	150	150	158	145	145	127	123	127	53.4	0.200
	45	75	60	28.08	84	0.72	1.70	8.3	53	150	150	152	144	144	127	122	126	44.1	0.175
	35	75	60	28.08	84	0.44	1.04	7.4	47	150	150	150	140	140	127	118	127	34.5	0.143
I	65	75	60	28.08	85	1.18	3.41	6.2	39	140	140	143	132	132	127	122	127	65.1	0.119
	55	75	60	28.08	85	0.81	2.34	5.8	36	140	140	145	135	135	128	122	128	55.0	0.098
	45	75	60	28.08	85	0.54	1.51	4.7	30	134	134	139	131	131	128	121	128	43.7	0.073
	35	75	60	28.08	85	0.32	0.86	4.0	25	130	130	133	126	126	125	117	125	32.8	0.057

Upstream Air Traverse Position: 19

Approximate Finned Cylinder Outer Surface
Average Temperature: 132°F

TEST CYLINDER SPEC:

Fin width	0.48"	Finned cylinder OD	1.96"
Fin thickness	0.04"	Cylinder OD	1.00"
Fin spacing	0.11"	Cylinder length	4.00"
No. fins	27		

FIGURE 20

PRINCIPLE INVESTIGATION DATA AND RESULTS
FOR
0.16" FIN SPACING

Cylinder Position	Approx Air Speed, mph	Room Air Temp, $^{\circ}$F		Bar	Upstream Air			Power to Test Sect.		Finned Cylinder Temperature, $^{\circ}$F (Thermocouple Number)									Air Speed Vs (mph)	Coef of Heat-Transfer, q Btu/sq in.-hr-$^{\circ}$F
		DB	WB	"Hg	Temp $^{\circ}$F	SP "H_2O	TP "H_2O	Amps	Volts	1	2	3	4	5	6	7	8	9		
A	65	76	62	28.20	88	2.03	4.04	7.6	48	143	143	147	147	147	129	130	128	130	63.0	0.212
	55	76	62	28.20	88	1.43	2.83	7.1	44	139	139	145	142	142	130	130	128	130	52.7	0.196
	45	76	62	28.20	88	0.90	1.87	6.5	41	140	140	145	142	142	130	131	129	130	43.8	0.163
	35	76	62	28.20	88	0.62	1.14	5.9	37	137	137	142	139	139	130	131	128	130	32.1	0.144
B	65	76	62	28.20	87	1.94	4.02	7.9	50	143	143	148	145	145	130	131	125	130	64.2	0.230
	55	76	62	28.20	87	1.35	2.83	7.2	45	139	139	145	142	142	130	130	125	130	54.2	0.198
	45	76	62	28.20	87	1.17	2.46	7.0	43	139	139	144	141	141	129	130	125	129	49.8	0.188
	35	76	62	28.20	86	0.58	1.15	5.9	37	138	138	142	141	141	130	130	126	130	33.6	0.137
C	65	78	66	28.11	87	1.92	3.94	8.3	51	144	144	151	146	146	129	129	125	130	63.2	0.238
	55	78	66	28.11	87	1.33	2.74	7.8	48	144	144	149	145	145	130	130	125	130	52.6	0.244
	45	78	66	28.11	87	0.85	1.76	6.9	42	139	139	145	140	140	130	130	125	130	42.5	0.181
	35	78	66	28.11	89	0.53	1.10	6.5	40	144	144	149	145	145	130	133	129	134	33.6	0.154
D	65	78	66	28.11	88	1.92	3.92	8.5	53	147	147	152	148	148	131	132	126	132	62.6	0.249
	55	78	66	28.11	88	1.33	2.74	7.8	48	144	144	150	146	146	131	132	126	132	52.5	0.244
	45	78	66	28.11	87	0.86	1.77	6.8	43	139	139	143	138	138	129	129	124	129	42.4	0.186
	35	78	66	28.11	87	0.54	1.14	6.4	40	140	140	142	141	141	132	131	128	133	34.4	0.160
E	65	78	66	28.11	91	1.85	3.92	9.0	55	152	152	160	155	155	130	135	130	134	63.4	0.257
	55	78	66	28.11	91	1.25	2.76	8.1	51	150	150	156	152	152	130	132	130	133	54.5	0.224
	45	78	66	28.11	91	0.81	1.77	7.4	46	148	148	153	149	149	131	133	130	135	43.4	0.194
	35	78	66	28.11	91	0.50	1.11	6.7	42	146	146	151	136	136	132	132	130	135	34.7	0.179
F	65	78	66	28.11	91	1.85	3.95	9.0	55	150	150	158	154	154	126	133	130	134	64.1	0.265
	55	78	66	28.11	91	1.25	2.72	8.2	52	150	150	157	152	152	130	134	130	136	54.4	0.232
	45	78	66	28.11	91	0.80	1.77	7.4	46	149	149	154	149	149	130	133	131	135	43.7	0.191
	35	78	66	28.11	91	0.50	1.11	6.6	41	148	148	150	146	146	130	132	130	135	34.6	0.160
G	65	78	66	28.11	90	1.72	3.81	9.1	56	155	155	162	155	155	128	135	130	138	64.1	0.256
	55	78	66	28.11	90	1.13	2.62	8.3	51	154	154	160	154	154	130	134	131	134	54.0	0.217
	45	78	66	28.11	90	0.72	1.70	7.2	44	148	148	153	146	146	128	131	129	134	43.8	0.181
	35	78	66	28.11	90	0.43	1.04	6.5	40	148	148	151	145	145	130	131	130	135	34.1	0.150
H	65	78	66	28.11	91	1.63	3.76	8.5	53	149	149	156	148	148	128	130	127	135	64.5	0.253
	55	78	66	28.11	90	1.06	2.51	7.9	49	148	148	155	148	148	128	131	129	135	53.2	0.218
	45	78	66	28.11	90	0.71	1.67	7.3	45	148	148	153	146	146	130	131	130	136	43.3	0.188
	35	78	66	28.11	90	0.42	0.99	6.6	41	148	148	152	144	144	130	132	131	138	33.7	0.155
I	65	78	66	28.11	90	1.16	3.42	6.1	38	149	149	151	144	144	130	133	130	142	66.5	0.135
	55	78	66	28.11	90	0.78	2.34	5.6	34	147	147	151	143	143	132	133	132	142	55.1	0.113
	45	78	66	28.11	90	0.55	1.52	4.9	30	144	144	147	141	141	130	132	130	138	43.7	0.087
	35	78	66	28.11	90	0.38	0.95	4.2	26	140	140	143	138	138	130	131	130	136	33.7	0.074

Upstream Air Traverse Position: 19

Approximate Finned Cylinder Outer Surface
Average Temperature: 132°F

TEST CYLINDER SPEC:

Fin width	0.48"	Finned cylinder OD	1.96"
Fin thickness	0.04"	Cylinder OD	1.00"
Fin spacing	0.16"	Cylinder length	4.00"
No. fins	20		

FIGURE 21

PRINCIPLE INVESTIGATION DATA AND RESULTS
FOR
0.26" FIN SPACING

Cylinder Position	Approx Air Speed, mph	Room Air			Upstream Air			Power to Test Sect.		Finned Cylinder Temperature, °F (Thermocouple Number)									Air Speed Vs (mph)	Coef of Heat-Transfer, q Btu/sq in.-hr-°F
		Temp, °F DB	WB	Bar "Hg	Temp °F	SP "H_2O	TP "H_2O	Amps	Volts	1	2	3	4	5	6	7	8	9		
A	65	78	65	27.92	88	1.44	3.96	6.5	40	139	139	139	141	141	128	128	128	132	62.2	0.244
	55	78	65	27.92	88	1.32	2.78	6.0	37	138	138	138	141	141	128	128	128	132	53.5	0.212
	45	78	65	27.92	88	0.85	1.77	5.3	32	135	135	136	138	138	128	128	127	130	42.6	0.173
	35	78	65	27.92	88	0.55	1.11	4.6	29	131	131	131	132	132	125	124	124	125	33.1	0.151
B	65	78	65	27.92	88	1.89	3.85	6.4	40	138	138	138	141	141	128	128	120	132	61.3	0.245
	55	78	65	27.92	88	1.28	2.69	5.8	37	135	135	135	138	138	125	125	120	130	52.7	0.218
	45	78	65	27.92	88	0.91	1.80	5.4	33	133	133	136	139	139	128	128	123	131	41.8	0.181
	35	78	65	27.92	88	0.50	1.10	4.9	30	132	132	135	136	136	127	127	121	131	34.3	0.156
C	65	78	65	27.92	88	1.86	3.87	6.8	43	139	139	140	141	141	127	125	129	130	62.7	0.273
	55	78	65	27.92	88	1.28	2.69	6.3	39	136	136	138	139	139	127	124	125	128	52.7	0.240
	45	78	65	27.92	88	0.80	1.76	5.8	36	136	136	138	139	139	128	125	126	130	43.4	0.204
	35	78	65	27.92	88	0.52	1.07	5.2	33	135	135	137	138	138	129	125	126	130	32.9	0.171
D	65	78	65	27.92	88	1.92	3.89	6.9	43	138	138	140	144	144	127	127	124	132	62.2	0.272
	55	78	65	27.92	88	1.31	2.72	6.3	40	138	138	140	143	143	127	127	125	132	52.4	0.232
	45	78	65	27.92	88	0.85	1.77	5.8	36	138	138	138	141	141	127	127	125	132	42.6	0.199
	35	78	65	27.92	88	0.51	1.08	5.2	33	134	134	134	137	137	127	125	124	130	33.4	0.177
E	65	78	65	27.92	88	1.85	3.85	7.4	46	145	145	145	148	148	130	130	127	135	63.3	0.286
	55	78	65	27.92	88	1.24	2.69	6.3	40	138	138	138	139	139	124	124	123	129	53.0	0.246
	45	78	65	27.92	88	0.81	1.73	5.8	37	135	135	135	139	139	125	125	123	129	43.2	0.218
	35	78	65	27.92	88	0.50	1.03	5.5	34	138	138	138	140	140	128	128	126	133	31.6	0.179
F	65	78	65	27.92	88	1.83	3.87	7.4	46	145	145	143	147	147	127	127	125	134	63.3	0.291
	55	78	65	27.92	88	1.24	2.67	6.9	43	145	145	144	148	148	129	128	127	137	54.3	0.249
	45	78	65	27.92	88	0.79	1.74	5.9	37	138	138	138	140	140	127	127	125	133	43.3	0.208
	35	78	65	27.92	88	0.52	1.03	5.5	34	138	138	138	139	139	128	128	126	134	31.6	0.182
G	65	72	68	27.72	81	1.67	3.73	7.9	50	147	147	147	148	148	127	127	122	133	63.3	0.291
	55	72	68	27.72	81	1.12	2.62	7.2	45	144	144	144	144	144	126	126	123	133	54.3	0.251
	45	72	68	27.72	81	0.72	1.66	6.4	41	139	139	139	139	139	126	126	122	134	43.2	0.216
	35	72	68	27.72	81	0.46	0.98	6.0	38	140	140	140	140	140	128	127	125	135	32.6	0.188
H	65	72	68	27.72	81	1.56	3.64	8.1	51	148	148	148	152	152	130	130	125	138	64.0	0.296
	55	72	68	27.72	81	1.18	2.83	7.3	45	142	142	142	142	142	125	125	122	138	56.8	0.262
	45	72	68	27.72	81	0.69	1.65	6.7	42	145	145	145	145	145	129	128	126	136	43.4	0.214
	35	72	68	27.72	82	0.44	0.96	5.9	37	138	138	138	138	138	126	126	124	133	32.0	0.189
I	65	72	68	27.72	82	1.08	3.27	5.1	32	133	133	133	133	133	125	122	121	129	65.4	0.156
	55	72	68	27.72	82	0.72	2.23	4.8	30	132	132	133	132	132	125	123	123	131	54.5	0.137
	45	72	68	27.72	83	0.44	1.45	4.2	26	132	132	136	134	134	129	126	128	133	44.4	0.104
	35	72	68	27.72	83	0.29	0.90	3.6	22	127	127	128	127	127	123	120	123	125	34.7	0.704

Upstream Air Traverse Position: 19

Approximate Finned Cylinder Outer Surface Average Temperature: 132°F

TEST CYLINDER SPEC:

Fin width	0.48"	Finned cylinder OD	1.96"
Fin thickness	0.04"	Cylinder OD	1.00"
Fin spacing	0.26"	Cylinder length	4.00"
No. fins	13		

FIGURE 22

PRINCIPLE INVESTIGATION DATA AND RESULTS
FOR
0.36" FIN SPACING

Cylinder Position	Approx Air Speed, mph	Room Air			Upstream Air			Power to Test Sect.		Finned Cylinder Temperature, $^{\circ}$F (Thermocouple Number)									Air Speed Vs (mph)	Coef of Heat-Transfer, q Btu/sq in.-hr-$^{\circ}$F
		Temp, $^{\circ}$F DB	WB	Bar "Hg	Temp $^{\circ}$F	SP "H_2O	TP "H_2O	Amps	Volts	1	2	3	4	5	6	7	8	9		
A	65	74	60	27.68	82	1.81	3.81	6.5	41	145	145	148	146	146	130	134	131	127	62.4	0.249
	55	74	60	27.68	82	1.21	2.65	5.7	36	137	137	140	140	140	125	128	126	122	52.9	0.216
	45	74	60	27.68	82	0.75	1.69	5.3	34	138	138	142	140	140	128	132	128	126	43.0	0.186
	35	74	60	27.68	82	0.45	1.03	4.7	30	135	135	138	136	136	126	129	126	123	33.7	0.157
B	65	74	60	27.68	82	1.85	3.87	6.4	41	139	139	146	139	139	124	130	129	125	62.7	0.267
	55	74	60	27.68	82	1.22	2.72	5.8	37	138	138	144	133	133	126	126	130	123	54.1	0.230
	45	74	60	27.68	82	0.77	1.78	5.4	34	136	136	144	133	133	128	127	130	125	44.5	0.196
	35	74	60	27.68	82	0.47	1.11	4.7	30	132	132	139	130	130	125	125	128	123	35.1	0.163
C	65	74	60	27.68	82	1.84	3.83	6.9	44	143	143	152	148	148	130	134	132	127	62.2	0.276
	55	74	60	27.68	82	1.25	2.75	6.4	40	142	142	150	147	147	130	133	132	126	54.0	0.240
	45	74	60	27.68	82	0.82	1.77	5.8	36	139	139	146	143	143	129	132	130	126	43.2	0.206
	35	74	60	27.68	82	0.50	1.10	5.4	34	137	138	146	142	142	130	132	130	125	34.3	0.184
D	65	74	60	27.68	81	1.89	3.93	6.9	41	143	143	150	146	146	125	130	130	120	63.2	0.274
	55	74	60	27.68	81	1.28	2.75	6.3	40	141	141	146	143	143	123	130	130	120	53.7	0.244
	45	74	60	27.68	81	0.83	1.80	5.8	37	139	139	145	140	140	124	130	128	119	43.0	0.215
	35	74	60	27.68	81	0.53	1.10	5.5	34	141	141	147	143	143	128	133	131	123	32.8	0.181
E	65	69	54	27.70	74	1.91	3.97	8.0	51	153	153	165	158	158	128	135	130	130	63.8	0.289
	55	69	54	27.70	74	1.29	2.75	7.3	46	150	150	159	154	154	127	134	130	130	54.0	0.253
	45	69	54	27.70	74	0.82	1.75	6.5	41	146	146	154	149	149	127	133	128	130	43.1	0.211
	35	69	54	27.70	74	0.48	1.13	6.1	38	146	146	154	148	148	129	135	130	132	36.0	0.186
F	65	69	54	27.70	73	1.88	3.96	7.9	50	148	148	157	149	149	126	130	126	128	64.3	0.303
	55	69	54	27.70	73	1.26	2.75	7.6	48	151	151	162	153	153	128	136	132	135	54.7	0.267
	45	69	54	27.70	74	0.82	1.77	6.8	42	149	149	158	147	147	129	135	132	133	43.5	0.222
	35	69	54	27.70	74	0.52	1.10	5.8	37	141	141	148	139	139	126	131	128	129	34.1	0.187
G	65	70	64	28.13	71	1.67	3.82	8.4	54	155	155	164	160	160	125	134	129	130	66.1	0.305
	55	70	64	28.13	73	1.13	2.67	7.7	48	151	151	160	156	156	125	133	129	131	55.8	0.261
	45	70	64	28.13	74	0.71	1.70	6.8	43	147	147	155	151	151	125	133	129	132	44.8	0.228
	35	70	64	28.13	76	0.45	1.05	6.1	39	148	148	152	150	150	128	135	130	133	34.5	0.193
H	65	70	64	28.13	79	1.56	3.73	8.2	52	159	159	168	157	157	132	138	125	139	65.8	0.314
	55	70	64	28.13	79	1.06	2.61	7.3	46	151	151	159	146	146	130	133	123	136	55.8	0.277
	45	70	64	28.13	79	0.67	1.68	6.5	42	146	146	153	139	139	128	132	123	133	45.1	0.245
	35	70	64	28.13	79	0.41	1.06	6.0	38	146	146	152	137	137	130	133	123	136	36.1	0.208
I	65	70	64	28.13	81	1.10	3.39	5.7	36	144	144	146	151	151	131	132	129	136	67.4	0.186
	55	70	64	28.13	83	0.72	2.35	5.0	32	141	141	143	141	141	130	130	130	133	57.1	0.163
	45	70	64	28.13	83	0.49	1.50	4.3	28	138	138	146	141	141	130	130	132	134	45.0	0.122
	35	70	64	28.13	84	0.28	0.95	3.8	24	133	133	140	135	135	127	127	130	130	36.6	0.106

Upstream Air Traverse Position: 19

Approximate Finned Cylinder Outer Surface
Average Temperature: 132°F

TEST CYLINDER SPEC:

Fin width	0.48"	Finned cylinder OD	1.96"
Fin thickness	0.04"	Cylinder OD	1.00"
Fin spacing	0.36"	Cylinder length	4.00"
No. fins	10		

FIGURE 23

PRINCIPLE INVESTIGATION DATA AND RESULTS
FOR
0.56" FIN SPACING

Cylinder Position	Approx Air Speed, mph	Room Air			Upstream Air			Power to Test Sect.		Finned Cylinder Temperature, °F (Thermocouple Number)									Air Speed Vs (mph)	Coef of Heat-Transfer, q Btu/sq in.-hr-°F
		Temp, °F DB	WB	Bar "Hg	Temp °F	SP "H_2O	TP "H_2O	Amps	Volts	1	2	3	4	5	6	7	8	9		
A	65	75	63	28.04	84	1.78	3.88	5.7	36	148	148	145	145	145	130	130	131	131	64.2	0.260
	55	75	63	28.04	84	1.21	2.73	5.2	33	146	146	142	142	142	130	130	130	130	54.7	0.228
	45	75	63	28.04	84	0.74	1.74	4.7	29	142	142	140	141	141	130	130	130	130	44.4	0.187
	35	75	63	28.04	84	0.45	1.10	4.3	27	141	141	139	141	141	132	130	131	131	35.8	0.163
B	65	75	63	28.04	84	1.77	3.85	5.8	36	150	150	146	146	146	132	131	127	130	63.8	0.260
	55	75	63	28.04	84	1.20	2.73	5.2	33	147	147	145	142	142	130	130	127	128	54.9	0.220
	45	75	63	28.04	84	0.74	1.74	4.6	29	144	144	143	143	143	130	130	127	130	44.4	0.175
	35	75	63	28.04	84	0.48	1.09	4.3	27	145	145	144	142	142	132	132	128	130	34.8	0.152
C	65	75	63	28.04	84	1.92	3.98	5.7	36	148	148	148	144	144	130	130	130	130	63.6	0.255
	55	75	63	28.04	84	1.29	2.79	5.2	33	145	145	145	141	141	127	127	128	128	54.5	0.224
	45	75	63	28.04	84	0.84	1.82	4.9	31	144	144	144	141	141	130	130	130	130	43.8	0.202
	35	75	63	28.04	84	0.54	1.08	4.4	28	143	143	142	140	140	130	130	130	130	32.7	0.167
D	65	75	63	28.04	84	1.98	4.03	5.9	37	145	145	146	145	145	130	130	130	124	63.6	0.280
	55	75	63	28.04	85	1.35	2.83	5.4	34	143	143	143	144	144	129	129	130	125	54.2	0.248
	45	75	63	28.04	85	0.86	1.84	4.9	31	142	142	143	141	141	130	130	130	125	44.0	0.210
	35	75	63	28.04	85	0.54	1.13	4.3	27	137	137	137	135	135	126	126	126	122	34.1	0.178
E	65	75	63	28.04	85	1.94	4.01	6.2	39	156	156	154	150	150	132	132	132	132	63.8	0.280
	55	75	63	28.04	85	1.33	2.82	5.6	35	151	151	150	148	148	132	132	132	132	54.3	0.237
	45	75	63	28.04	85	0.84	1.81	5.0	31	148	148	145	143	143	130	130	130	130	43.8	0.202
	35	75	63	28.04	85	0.54	1.13	4.6	28	144	144	142	141	141	130	130	130	130	36.6	0.177
F	65	75	63	28.04	85	2.03	4.08	6.5	41	156	156	156	153	153	134	134	134	134	63.6	0.298
	55	75	63	28.04	85	1.39	2.90	5.7	36	149	149	149	147	147	131	131	132	130	54.7	0.256
	45	75	63	28.04	85	0.90	1.88	4.9	30	144	144	142	139	139	128	128	128	128	44.0	0.202
	35	75	63	28.04	85	0.56	1.18	4.5	28	139	139	139	138	138	128	128	128	128	35.1	0.183
G	65	72	62	27.95	80	1.74	3.81	7.0	44	159	159	159	155	155	131	131	133	131	63.8	0.310
	55	72	62	27.95	80	1.17	2.67	6.3	39	154	154	154	149	149	130	130	130	130	54.6	0.268
	45	72	62	27.95	79	0.73	1.71	5.6	34	148	148	148	144	144	128	128	128	128	44.2	0.219
	35	72	62	27.95	79	0.47	1.08	5.1	32	145	145	145	142	142	128	128	128	128	34.8	0.197
H	65	72	62	27.95	80	1.69	3.79	6.9	43	153	153	155	151	151	130	130	128	133	64.6	0.319
	55	72	62	27.95	80	1.13	2.63	6.3	39	154	154	153	150	150	131	131	128	133	54.6	0.266
	45	72	62	27.95	80	0.72	1.69	5.6	35	149	149	146	144	144	130	130	128	130	44.0	0.234
	35	72	62	27.95	77	0.46	1.08	5.1	32	145	145	144	142	142	128	128	127	129	35.1	0.191
I	65	72	62	27.95	80	1.12	3.35	5.3	33	145	145	145	140	140	131	126	128	132	66.4	0.218
	55	72	62	27.95	80	0.75	2.32	5.1	32	148	148	150	144	144	135	130	133	138	55.8	0.191
	45	72	62	27.95	79	0.47	1.49	4.2	26	138	138	140	137	137	130	125	130	131	45.1	0.145
	35	72	62	27.95	80	0.29	0.88	3.9	24	136	136	139	135	135	129	125	129	129	34.2	0.129

Upstream Air Traverse Position: 19

Approximate Finned Cylinder Outer Surface Average Temperature: 132°F

TEST CYLINDER SPEC:

Fin width	0.48"	Finned cylinder OD	1.96"
Fin thickness	0.04"	Cylinder OD	1.00"
Fin spacing	0.56"	Cylinder length	4.00"
No. fins	7		

FIGURE 24

SUPPLEMENTAL RESULTS OF PRINCIPLE INVESTIGATION

(1). Over-all Heat-Transfer Coefficient for 65 mph Air Speed.

Fin Spacing in.	Cylinder Angle Deg	U Btu/sq in.-hr-F
0.11	0	2.19
	30	2.47
	45	2.80
	60	2.44
	90	1.22
0.16	0	1.84
	30	2.05
	45	2.13
	60	2.06
	90	1.06
0.26	0	1.43
	30	1.61
	45	1.66
	60	1.68
	90	0.92
0.36	0	1.20
	30	1.27
	45	1.35
	60	1.38
	90	0.82
0.56	0	0.92
	30	0.97
	45	1.03
	60	1.12
	90	0.76

(2). Surface Heat-Transfer Coefficient as Defined by the NACA for 0.11" Fin Spacing and Zero Fin-Plane/Air-Stream Angle.

Cylinder Position	Upstream Air Speed, mph.	$V\rho_1 g$	NACA q
A	63.7	6.86	0.246
	52.8	5.68	0.203
	43.2	4.65	0.169
	33.1	3.57	0.140
B	63.2	6.78	0.260
	53.7	5.74	0.215
	43.4	4.67	0.171
	32.6	3.51	0.138

FIGURE 25

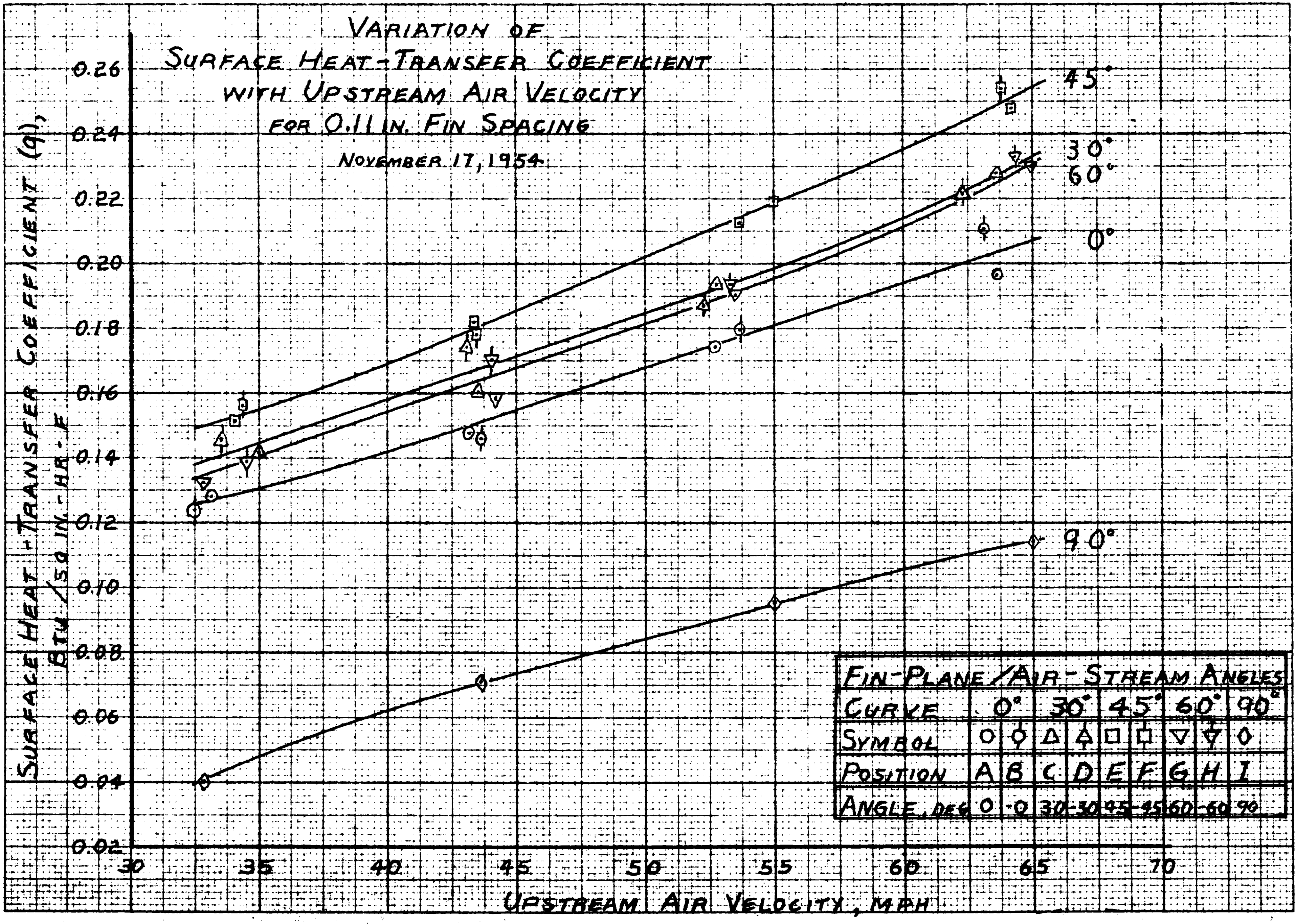

VARIATION OF
SURFACE HEAT-TRANSFER COEFFICIENT
WITH UPSTREAM AIR VELOCITY
FOR 0.11 IN. FIN SPACING
NOVEMBER 17, 1954
SURFACE HEAT-TRANSFER COEFFICIENT (q),
BTU / SQ IN - HR - F
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
30
35
40
45
50
55
60
65
70
UPSTREAM AIR VELOCITY, MPH
45°
30°
60°
0°
90°
FIN-PLANE / AIR-STREAM ANGLES
CURVE 0° 30° 45° 60° 90°
SYMBOL ○ ⦶ △ ⧊ □ ⊡ ▽ ⧩ ◇
POSITION A B C D E F G H I
ANGLE, DEG 0 -0 30 -30 45 -45 60 -60 90

FIGURE 26

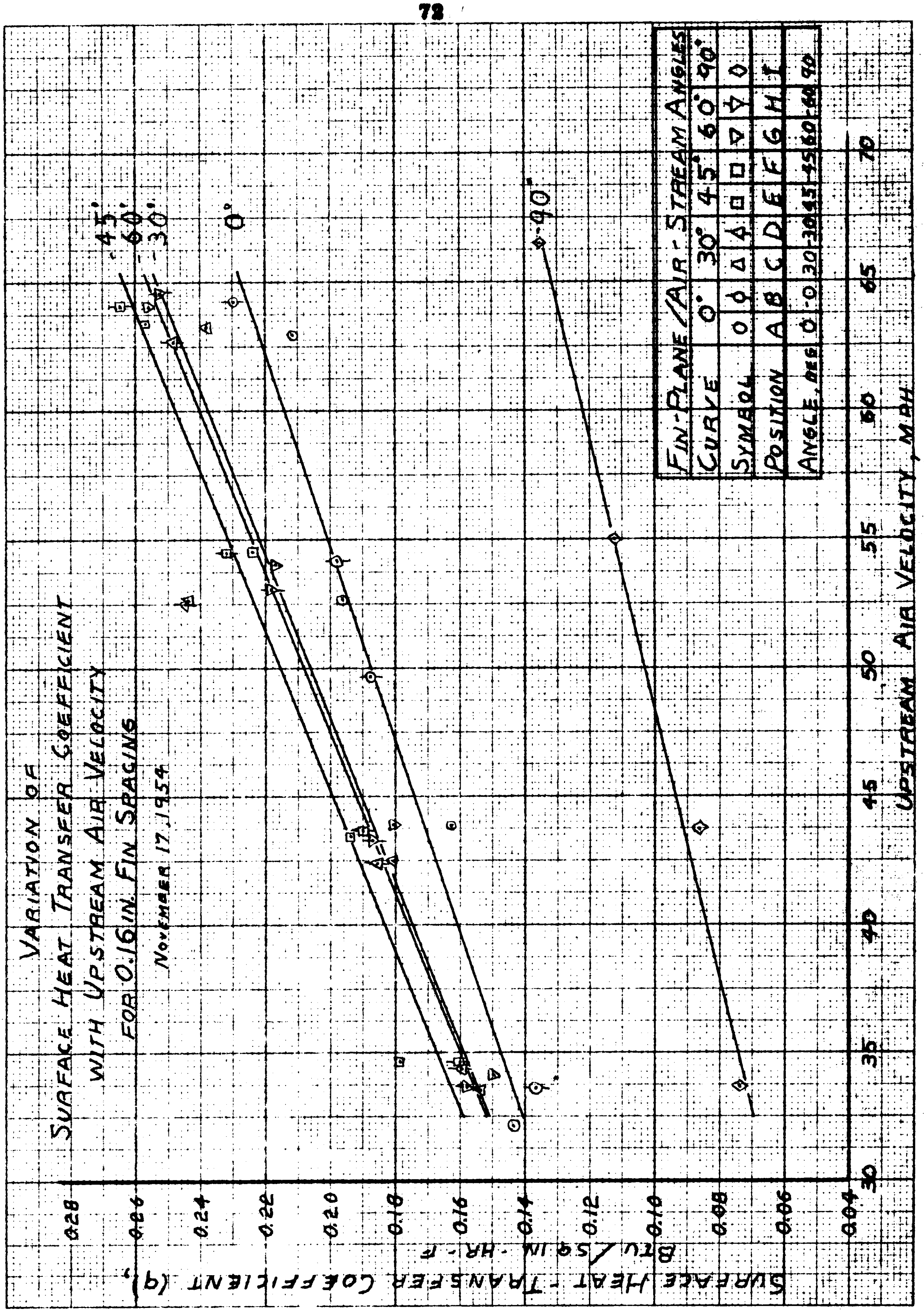

VARIATION OF
SURFACE HEAT TRANSFER COEFFICIENT
WITH UPSTREAM AIR VELOCITY
FOR 0.16 IN. FIN SPACING
NOVEMBER 17, 1954
-45°
-60°
-30°
0°
90°
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
SURFACE HEAT TRANSFER COEFFICIENT (q),
BTU/SQ IN - HR - F
30
35
40
45
50
55
60
65
70
UPSTREAM AIR VELOCITY, MPH
FIN-PLANE/AIR-STREAM ANGLES
CURVE 0° 30° 45° 60° 90°
SYMBOL ○ ○̣ △ △̣ ▫ □ ▽ ▽̣ ◇
POSITION A B C D E F G H I
ANGLE, DEG 0 -0 30 -30 45 -45 60 -60 90

FIGURE 27

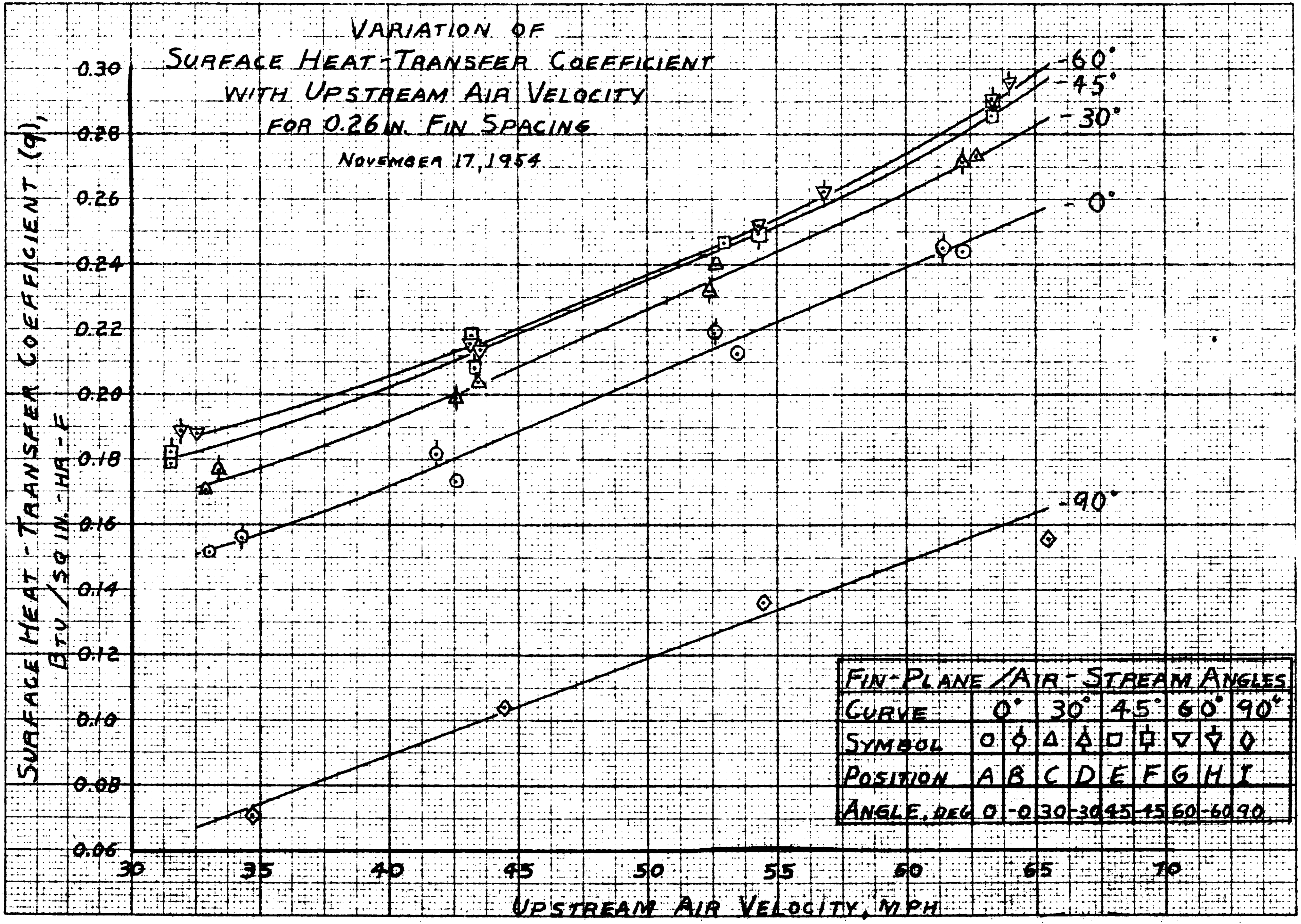
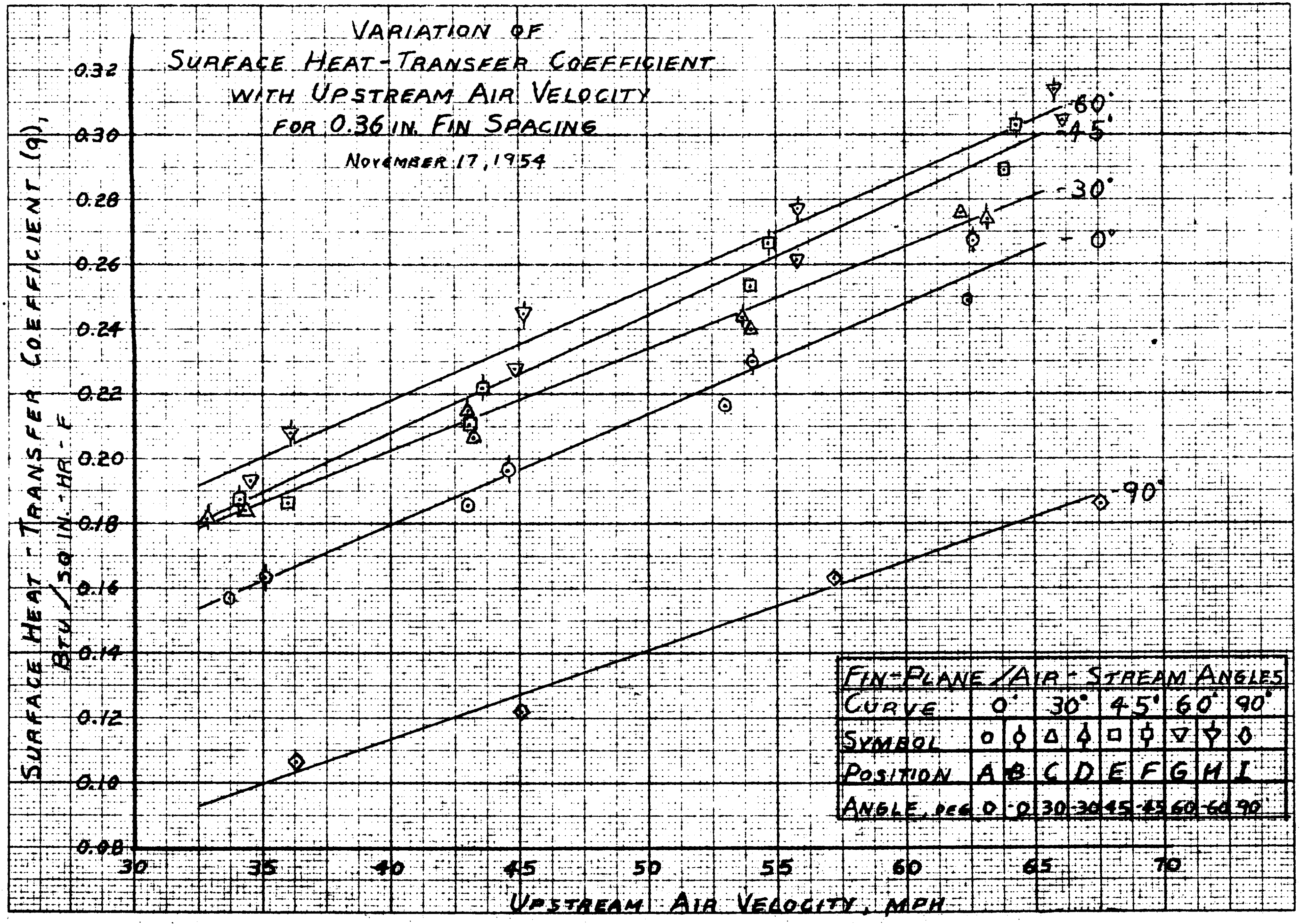

VARIATION OF
SURFACE HEAT-TRANSFER COEFFICIENT
WITH UPSTREAM AIR VELOCITY
FOR 0.26 IN. FIN SPACING
NOVEMBER 17, 1954
SURFACE HEAT-TRANSFER COEFFICIENT (q),
BTU/SQ IN.-HR-F
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
30
35
40
45
50
55
60
65
70
UPSTREAM AIR VELOCITY, MPH
-60°
-45°
-30°
-0°
-90°
FIN-PLANE / AIR-STREAM ANGLES
CURVE 0° 30° 45° 60° 90°
SYMBOL ○ ⌽ △ △ □ □ ▽ ▽ ◇
POSITION A B C D E F G H I
ANGLE, DEG 0 -0 30 -30 45 -45 60 -60 90

FIGURE 28



VARIATION OF
SURFACE HEAT-TRANSFER COEFFICIENT
WITH UPSTREAM AIR VELOCITY
FOR 0.36 IN. FIN SPACING
NOVEMBER 17, 1954

FIGURE 2.9

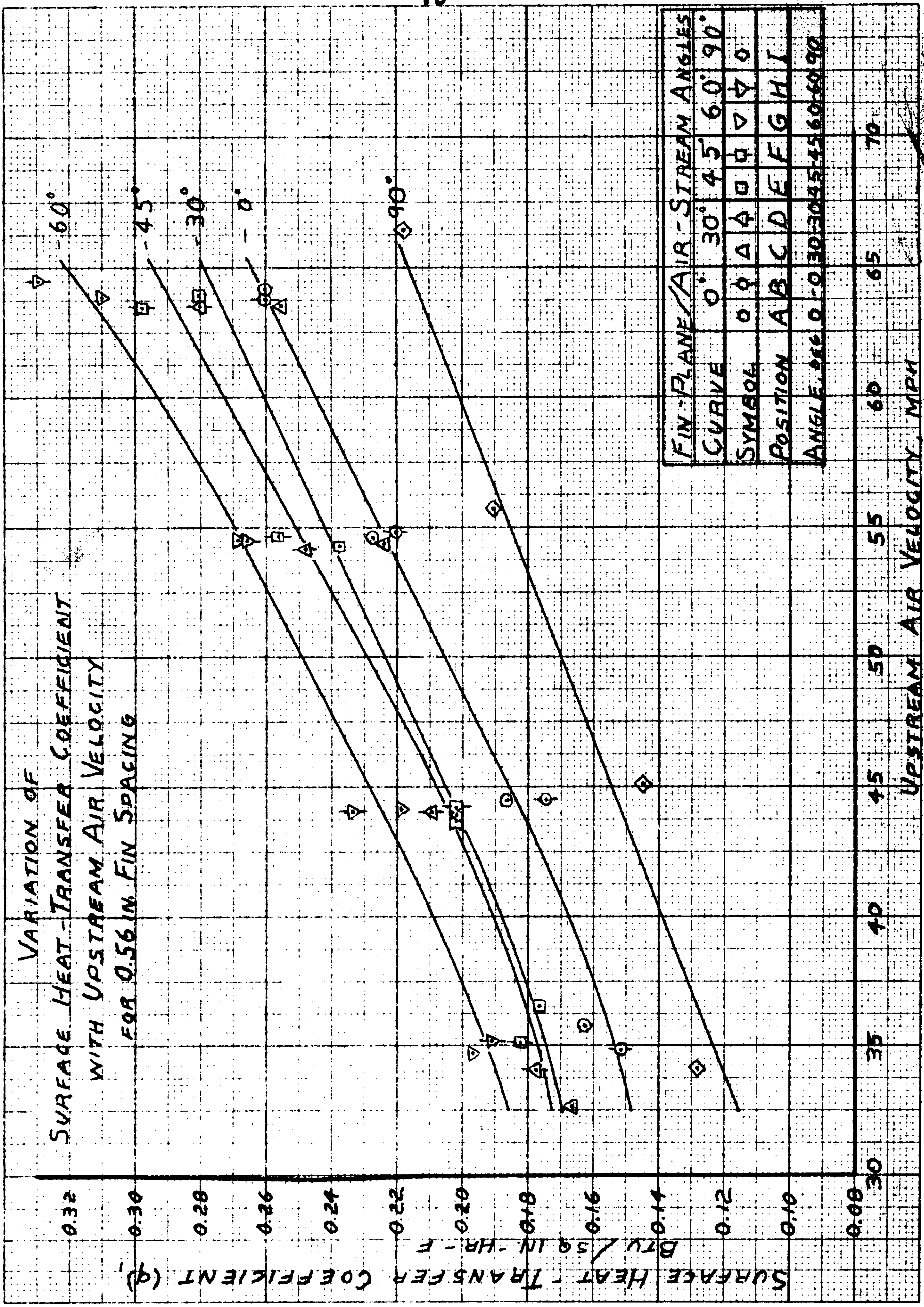

Variation of
Surface Heat-Transfer Coefficient
with Upstream Air Velocity
for 0.56 in. Fin Spacing
Surface Heat-Transfer Coefficient (q_1)
Btu / sq in - hr - F
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
30
35
40
45
50
55
60
65
70
Upstream Air Velocity, MPH
-60°
-45°
-30°
-0°
90°
Fin-Plane / Air-Stream Angles
Curve 0° 30° 45° 60° 90°
Symbol ○ ⌽ △ △ □ □ ▽ ▽ ◇
Position A B C D E F G H I
Angle, deg 0 -0 30 -30 45 -45 60 -60 90

Figure 30

VARIATION OF
SURFACE HEAT-TRANSFER COEFFICIENT
WITH FIN-PLANE / AIR-STREAM ANGLE
FOR 0.11 IN. FIN SPACING
NOVEMBER 17, 1954

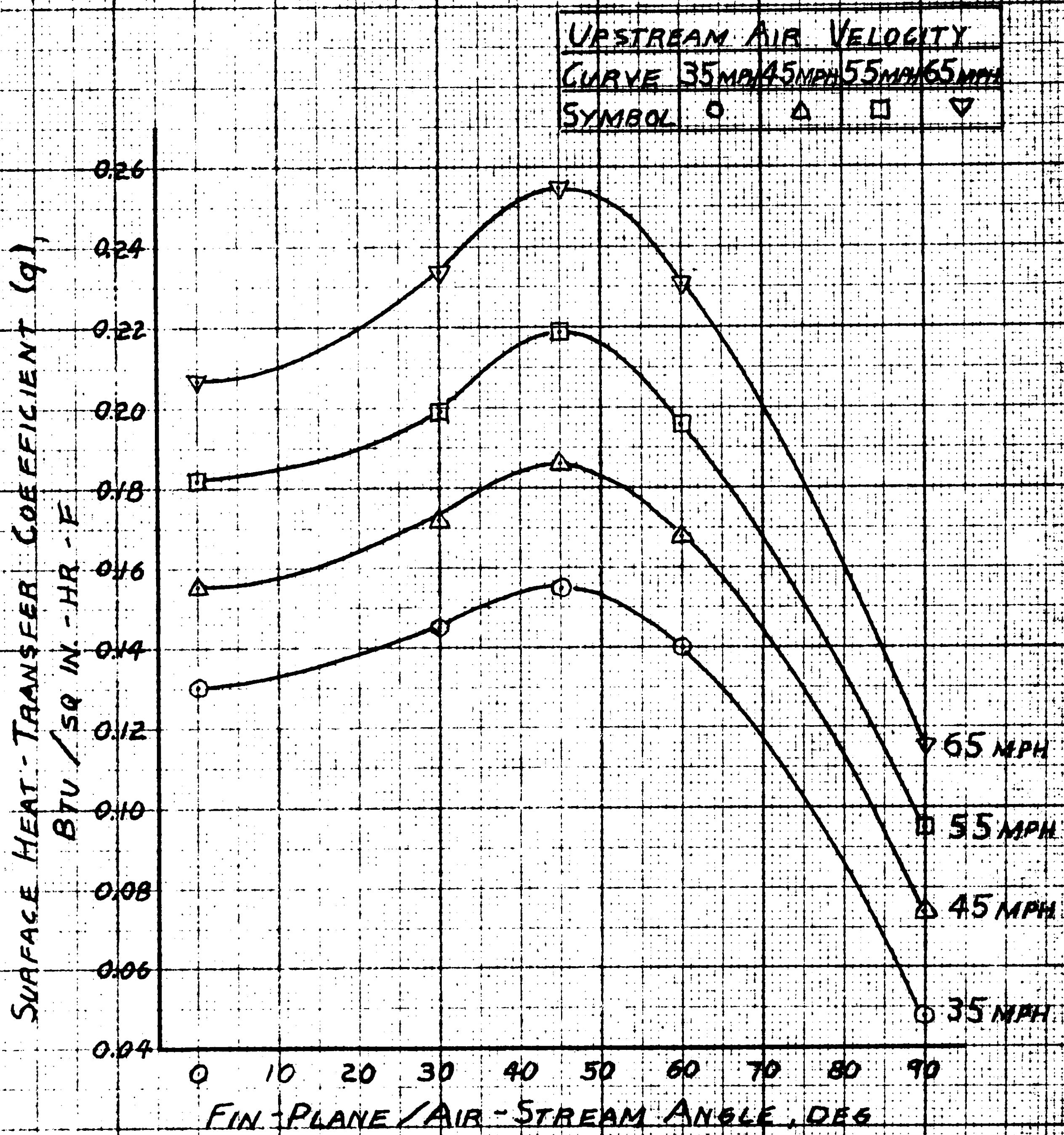
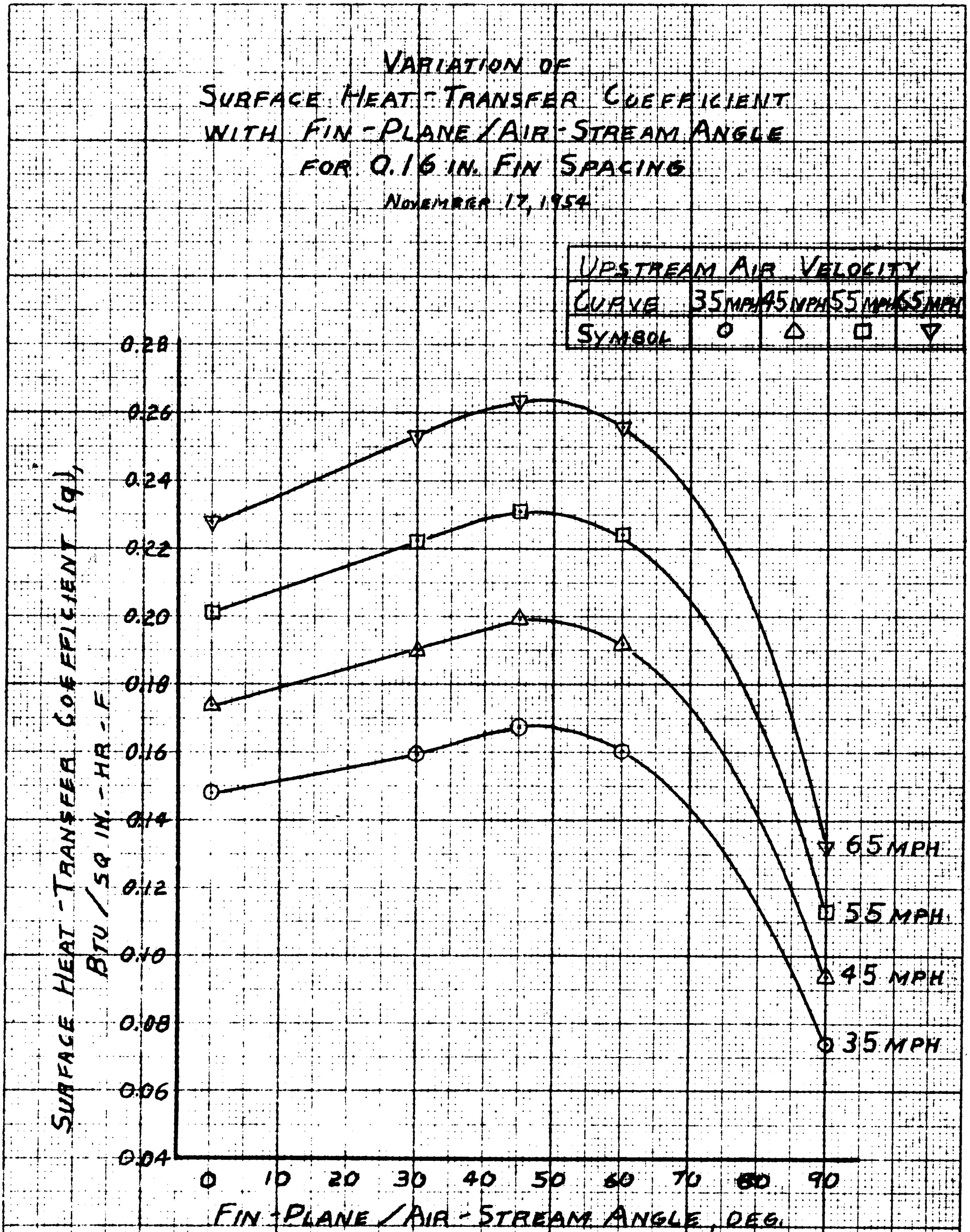


FIGURE 31



VARIATION OF
SURFACE HEAT-TRANSFER COEFFICIENT
WITH FIN-PLANE/AIR-STREAM ANGLE
FOR 0.16 IN. FIN SPACING
NOVEMBER 17, 1954

FIGURE 32

VARIATION OF
SURFACE HEAT-TRANSFER COEFFICIENT
WITH FIN-PLANE/AIR-STREAM ANGLE
FOR 0.26 IN. FIN SPACING

NOVEMBER 17, 1954

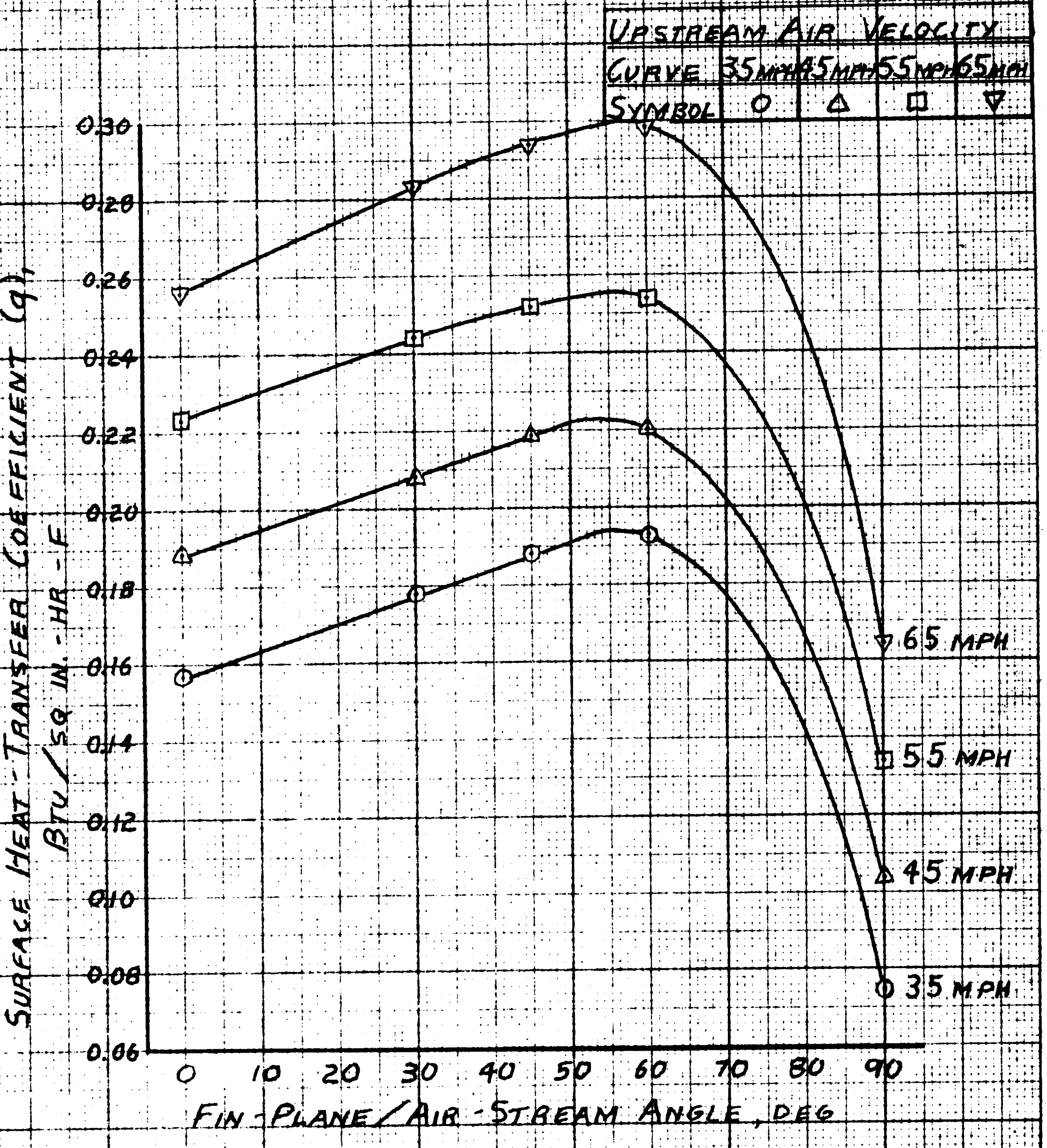
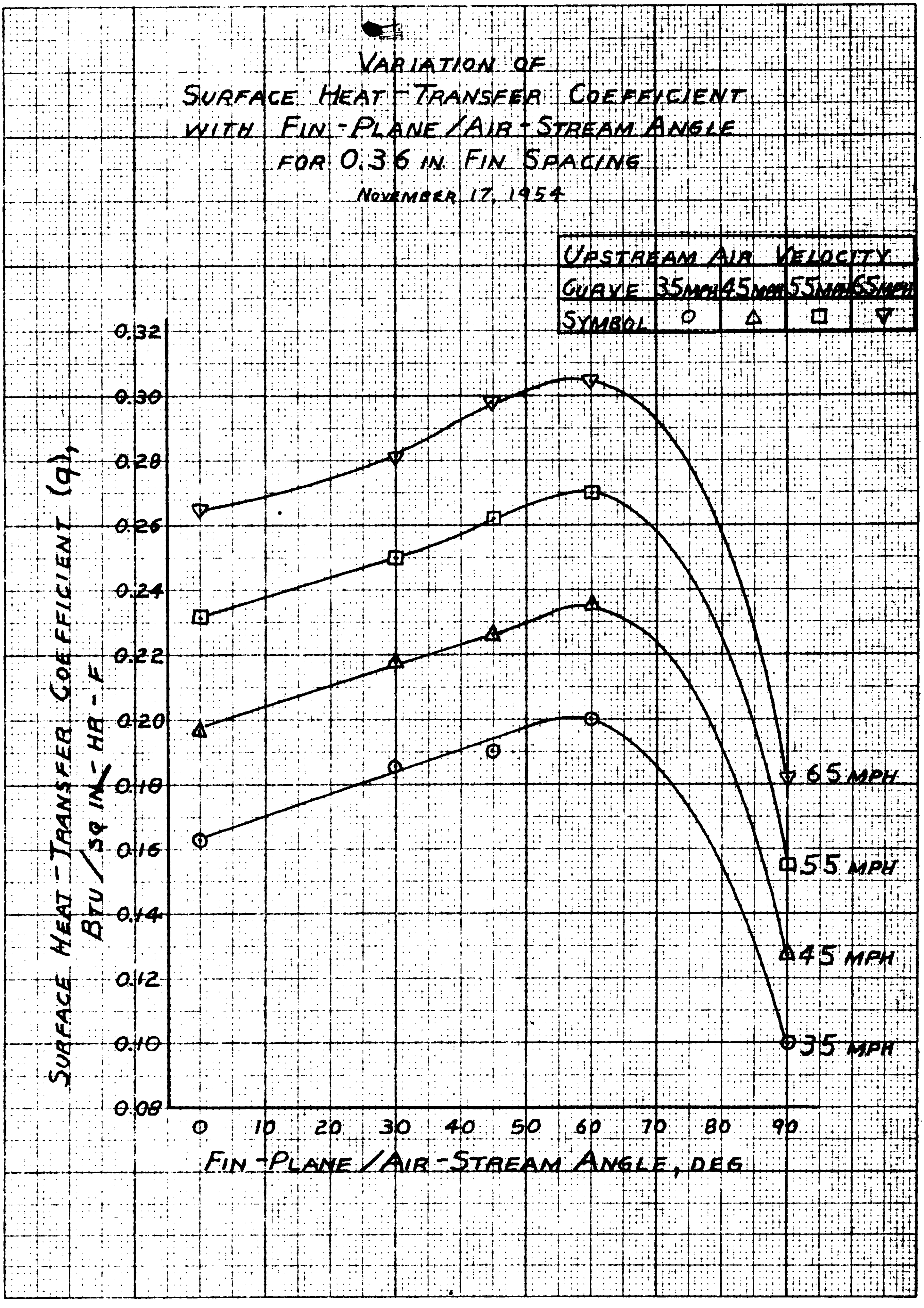
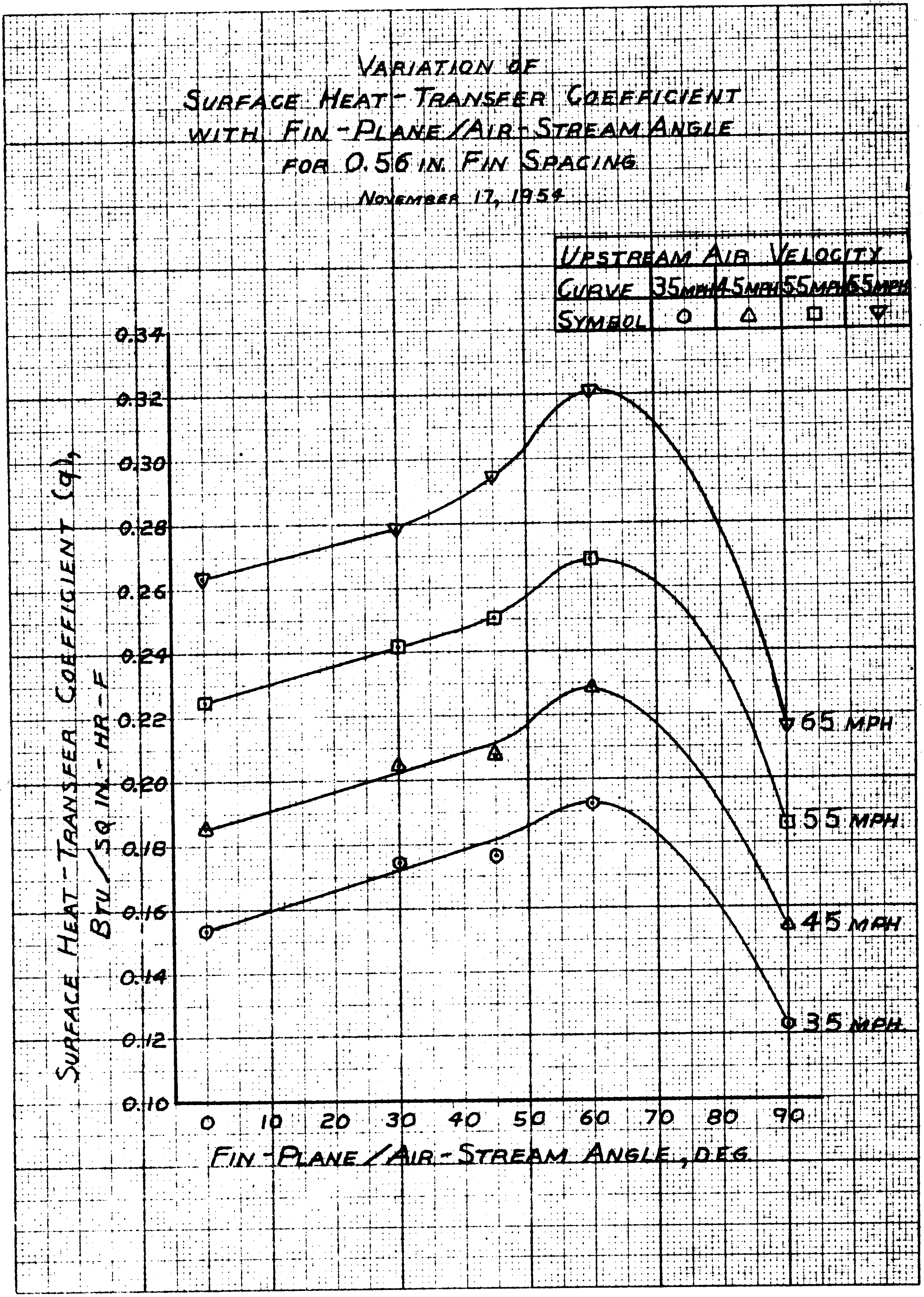


FIGURE 33



VARIATION OF
SURFACE HEAT-TRANSFER COEFFICIENT
WITH FIN-PLANE/AIR-STREAM ANGLE
FOR 0.36 IN. FIN SPACING
NOVEMBER 17, 1954

FIGURE 34



VARIATION OF
SURFACE HEAT-TRANSFER COEFFICIENT
WITH FIN-PLANE/AIR-STREAM ANGLE
FOR 0.56 IN. FIN SPACING
NOVEMBER 17, 1954

FIGURE 35

VARIATION OF
SURFACE HEAT-TRANSFER COEFFICIENT
WITH FIN-PLANE/AIR-STREAM ANGLE
FOR 35 MPH UPSTREAM AIR VELOCITY

NOVEMBER 18, 1954

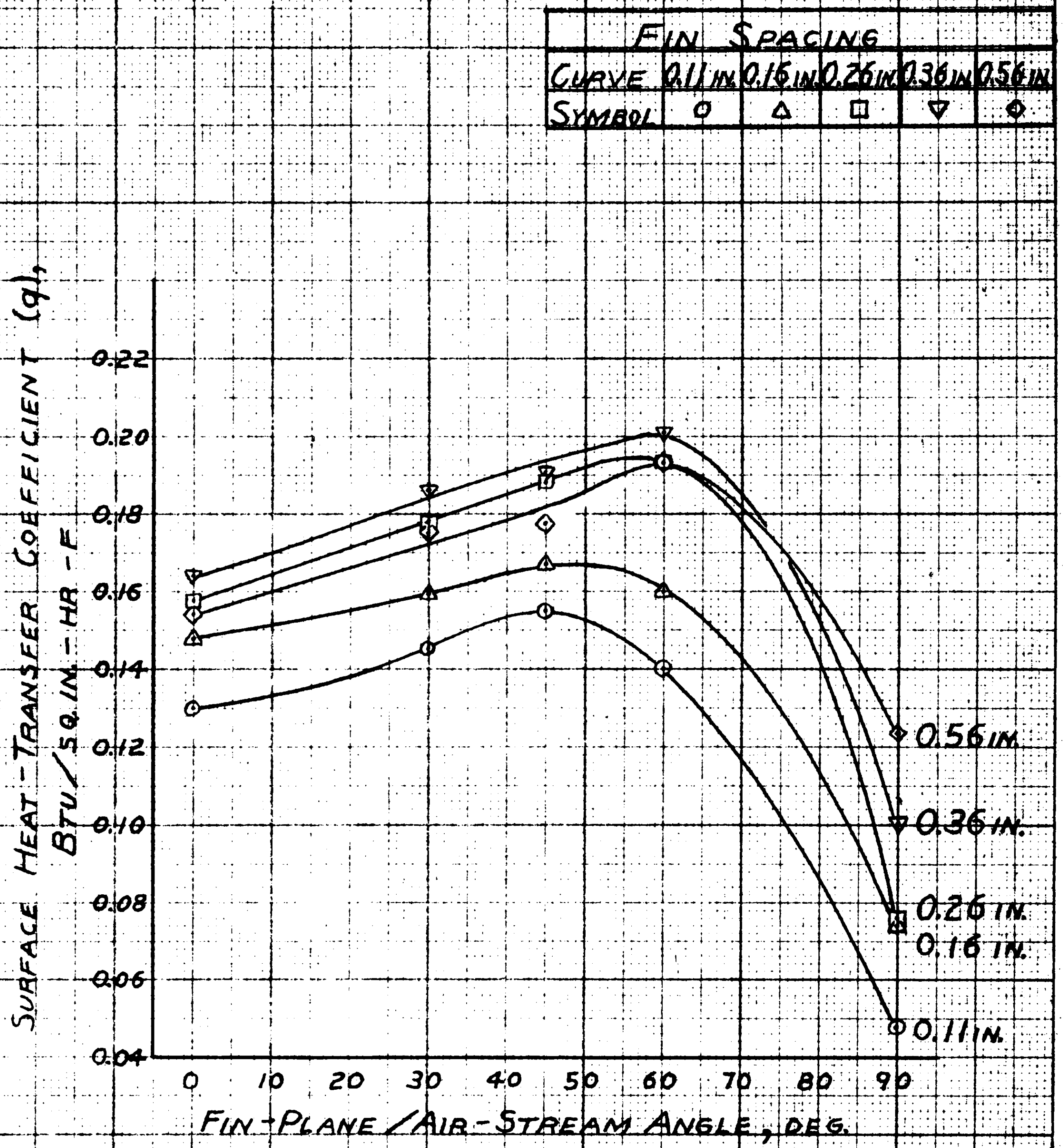


FIGURE 36

VARIATION OF
SURFACE HEAT-TRANSFER COEFFICIENT
WITH FIN-PLANE/AIR-STREAM ANGLE
FOR 45 MPH UPSTREAM AIR VELOCITY

NOVEMBER 18, 1954

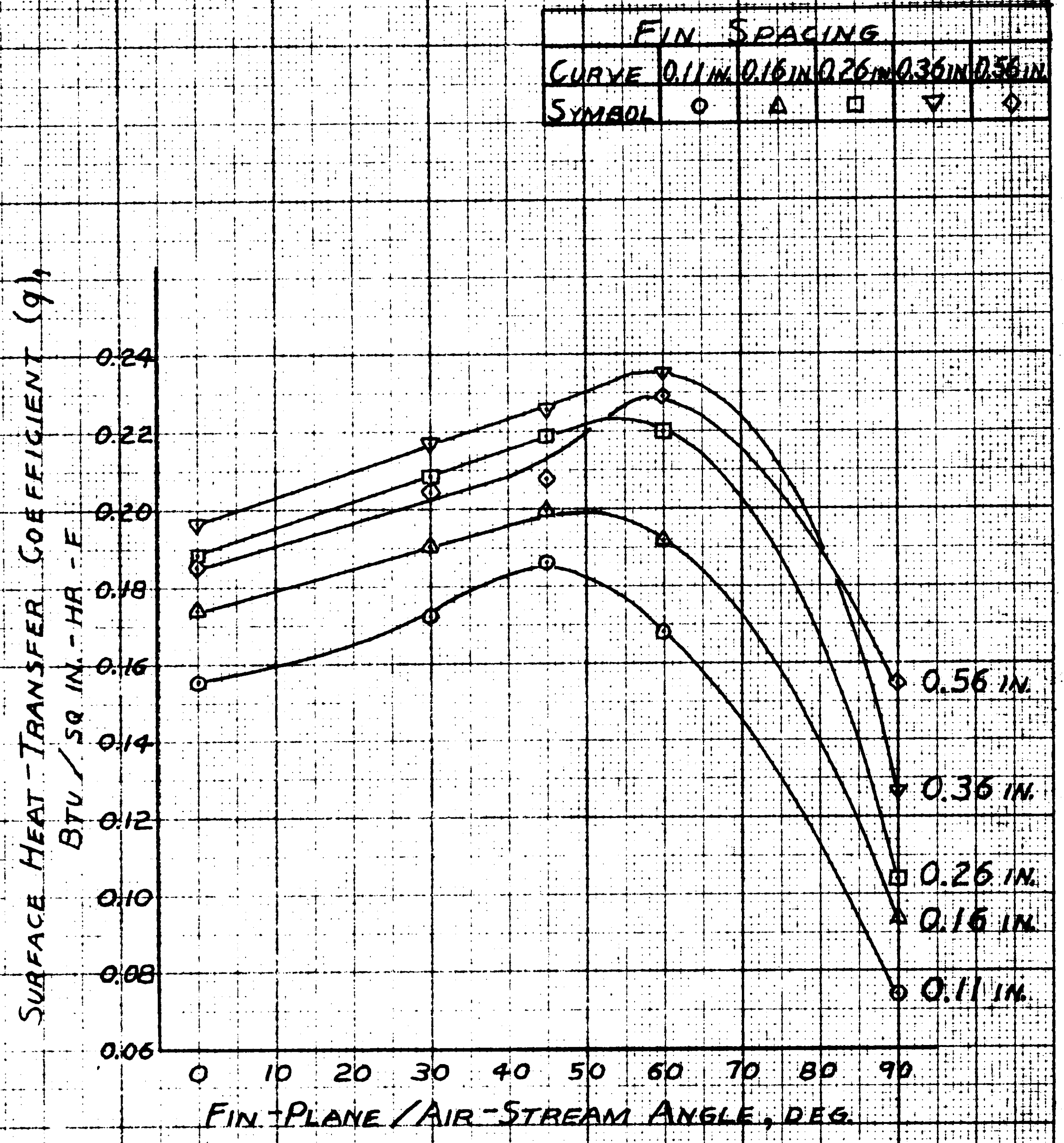


FIGURE 37.

VARIATION OF
SURFACE HEAT-TRANSFER COEFFICIENT
WITH FIN-PLANE/AIR-STREAM ANGLE
FOR 55 MPH UPSTREAM AIR VELOCITY
NOVEMBER 18, 1954

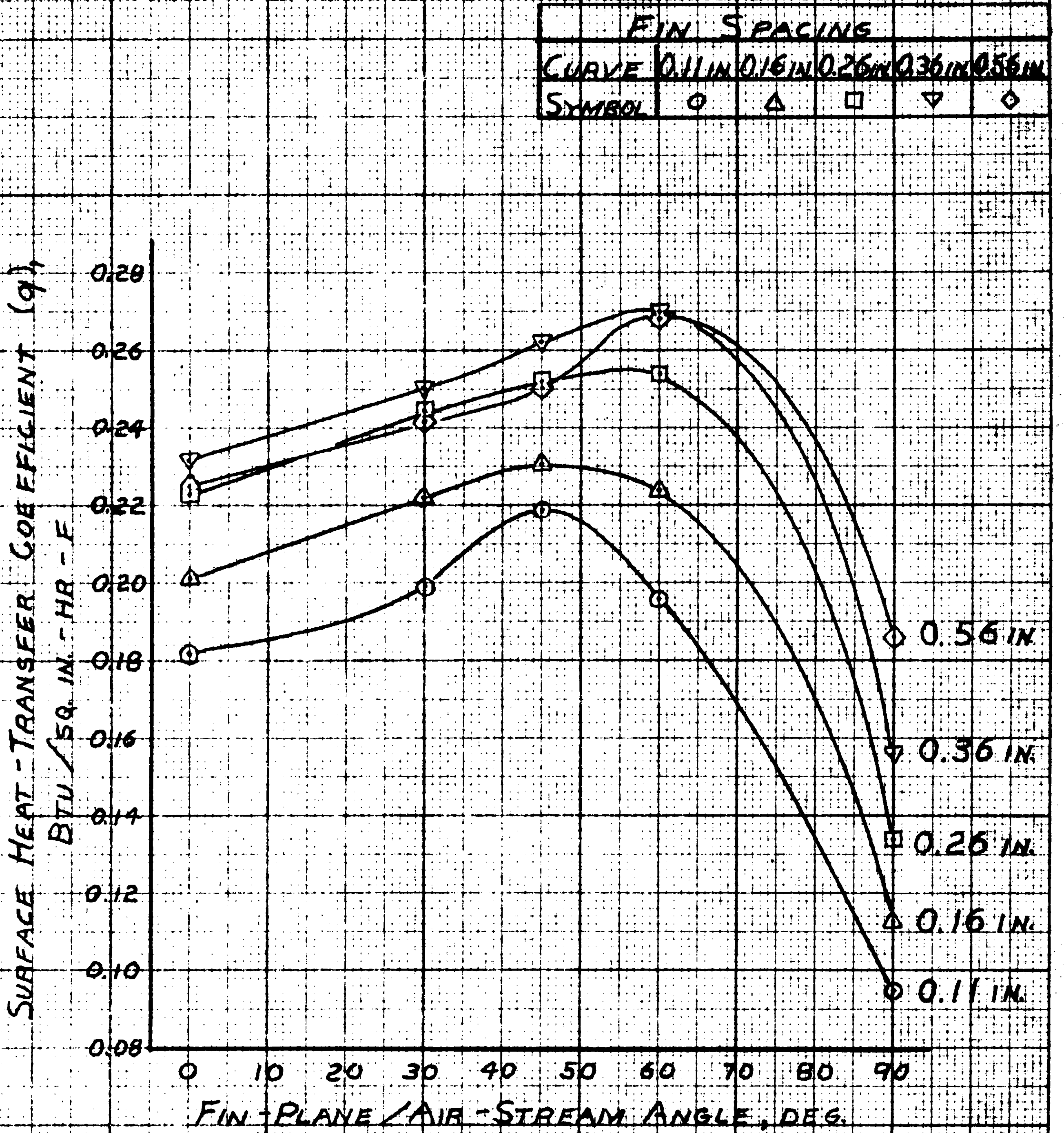


FIGURE 38

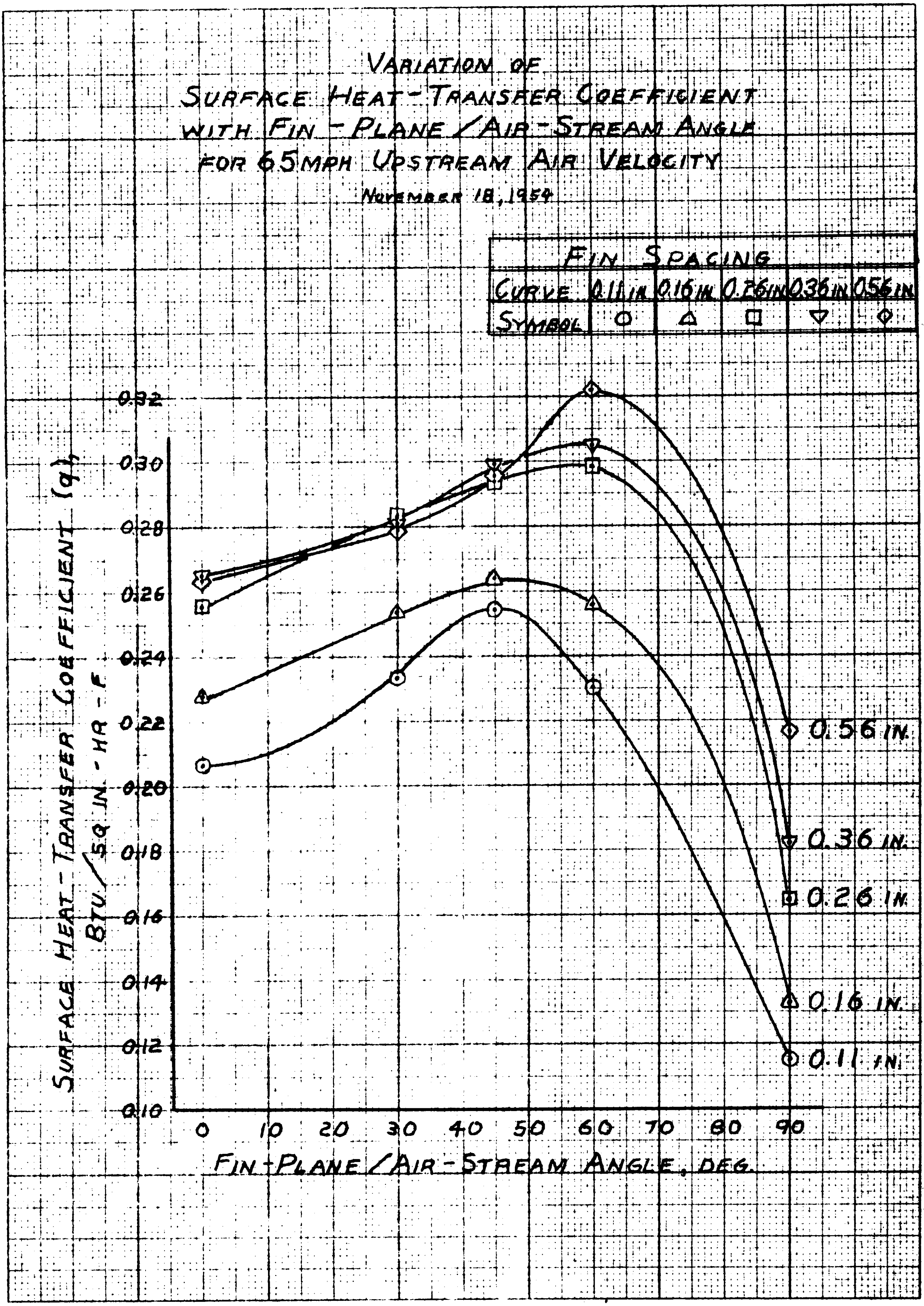
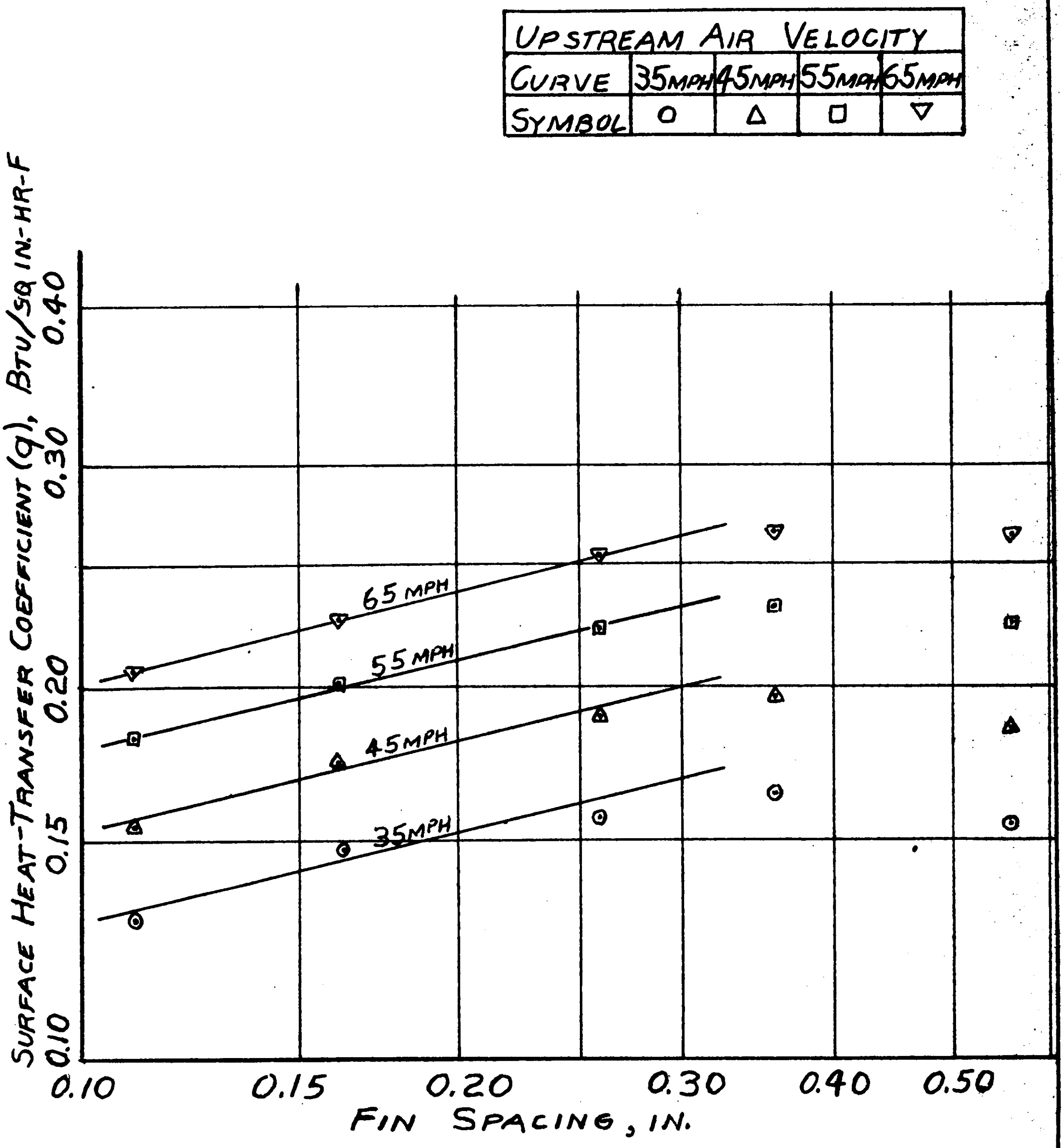

VARIATION OF
SURFACE HEAT-TRANSFER COEFFICIENT
WITH FIN-PLANE / AIR-STREAM ANGLE
FOR 65 MPH UPSTREAM AIR VELOCITY
NOVEMBER 18, 1954
FIN SPACING
CURVE 0.11 IN 0.16 IN 0.26 IN 0.36 IN 0.56 IN
SYMBOL ○ △ □ ▽ ◇
SURFACE HEAT-TRANSFER COEFFICIENT (q), BTU / SQ IN - HR - F
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0
10
20
30
40
50
60
70
80
90
FIN-PLANE / AIR-STREAM ANGLE, DEG.
0.56 IN.
0.36 IN.
0.26 IN.
0.16 IN.
0.11 IN.

FIGURE 39



VARIATION OF
SURFACE HEAT-TRANSFER COEFFICIENT
WITH FIN SPACING FOR
ZERO FIN-PLANE/AIR-STREAM ANGLE
FEBRUARY 5, 1955

FIGURE .40

IV. DISCUSSION OF RESULTS

This investigation was the first at the Virginia Polytechnic Institute in the field of heat-transfer from finned cylinders in an air stream. Since there had been no test made on similar cylinder diameters, preliminary investigations were required to determine the velocity profile of the wind tunnel and the temperature distribution of the finned cylinder. The accuracy of the test was limited by the lack of uniformity of the velocity profile. The accuracy of the experimental work was reduced by the small temperature difference between the outer cylinder surface temperature and the inlet air temperature. Since this temperature difference was approximately 50 F, a large error in the value of the surface heat-transfer coefficient (q) resulted when a small error in a temperature measurement was made. It is thought that the accuracy and the effect of the thermocouples of this investigation should compare with those of work by the NACA. Biermann[2], of the NACA, found by test that there was no indication of any appreciable difference in any of the methods of leading the thermocouple wires from the surface, provided that the wire is of less than 0.025 inch diameter. Biermann[2] also found that the precision of the thermocouples was within ± 2 F. The thermocouple wire in this investigation was 24 gage (0.0201 inch diameter), which was approximately 0.025 inch diameter with insulation. For the minimum power input to the cylinder, the maximum error of the voltmeter and ammeter was less than 3%.

There may have been some baffling effect on the finned cylinder by the duct, but this could not be definitely established. A comparison of q as defined by the NACA (NACA q) was made for the 0.11 inch fin spaced cylinder used in this investigation with cylinders of different diameters as tested by NACA (Figure 41). It was found by this comparison that the NACA q for the 0.11 inch fin spacing did not hold to the relation $q \propto 1/D^{0.25}$ by Ellerbrock[5] of the NACA, but appeared to hold to the relation $q \propto 1/D^{0.9}$ as derived by the author of this thesis. The comparison of the 0.11 inch fin spaced cylinder of this investigation with the jacketed cylinders of the NACA (Figure 41) conformed to $q \propto 1/D^{0.25}$ by Ellerbrock[5]. The preceding statements indicate that either the relation found by the NACA was not valid for the range of cylinder diameters as small as one inch, or that the results of

COMPARISON OF SURFACE HEAT-TRANSFER COEFFICIENT FOR FOUR CYLINDER DIAMETERS AND VARIOUS AIR FLOW CONDITIONS

FROM:
BIERMANN[2]. NACA REP. NO. 488, 1935
ELLERBROCK[5]. NACA REP. NO. 676. 1939

AIR FLOW	ORIGIN	CYL DIA	SYMBOL	s	w	t
JACKET	NACA	6.34"	——	0.12"	0.52"	0.03"
JACKET	NACA	3.66"	━━	0.124"	0.50"	0.026"
	VPI	1.00"	- - - -	0.11"	0.48"	0.04"
FREE	NACA	4.66	— —	0.15"	0.67"	0.04"

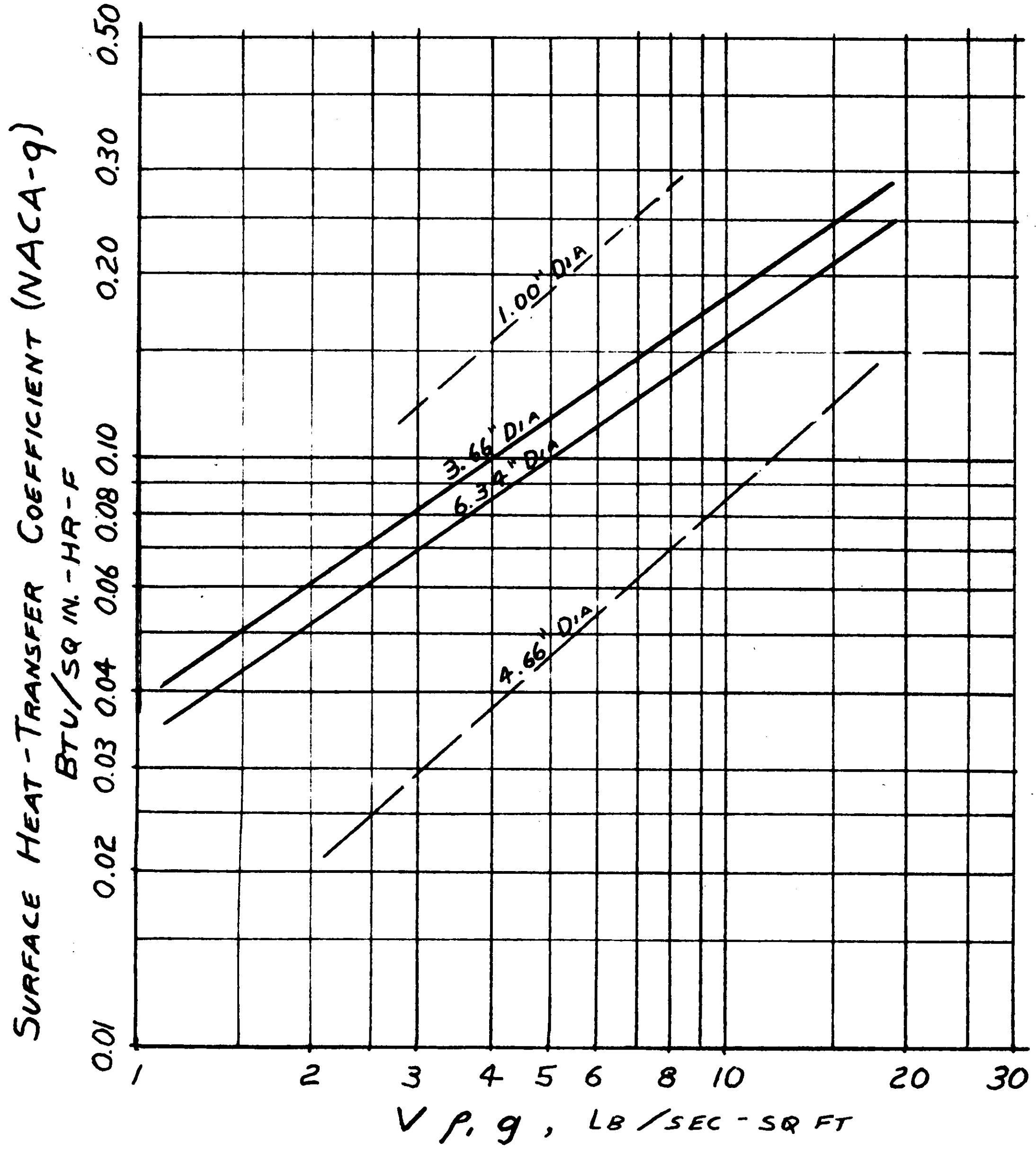


FIGURE 41

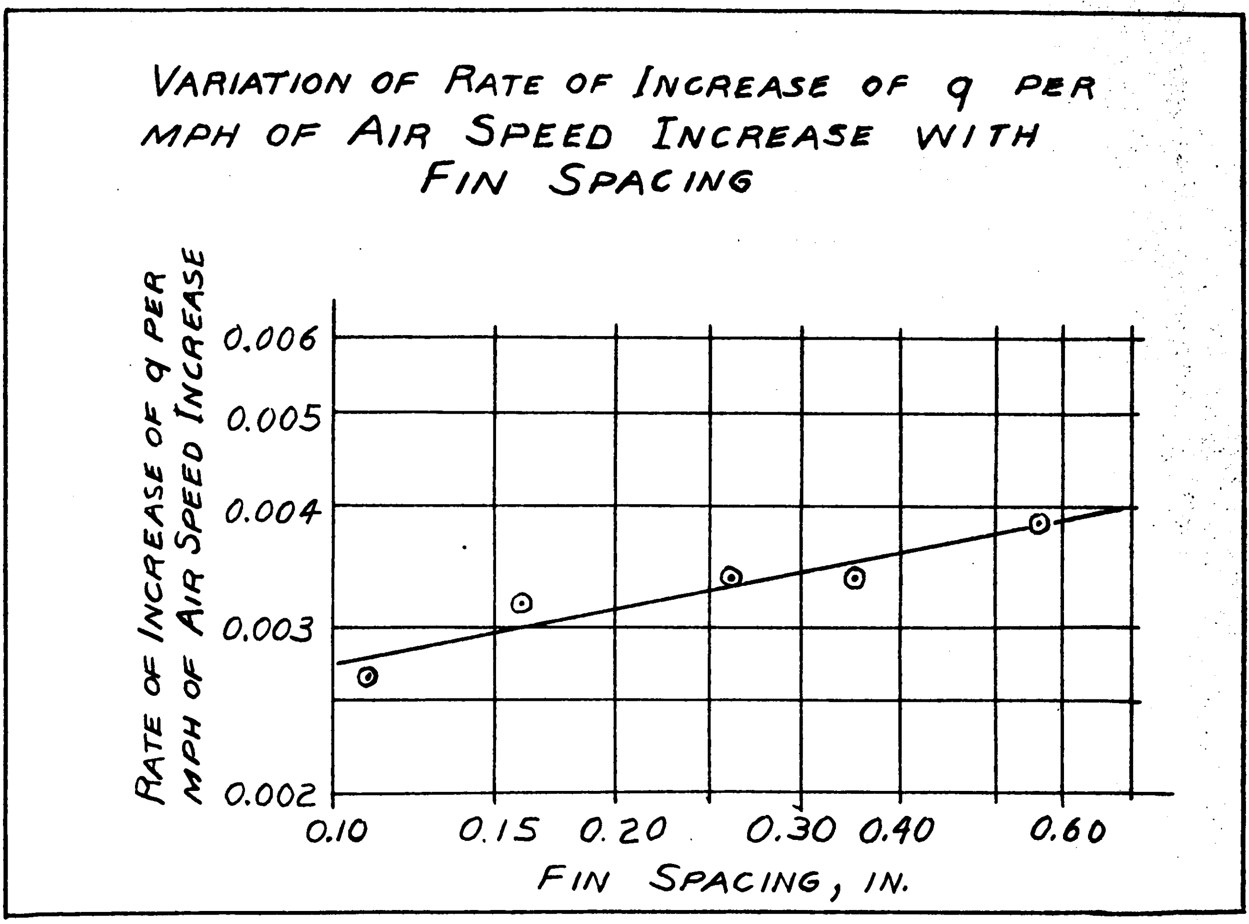
this investigation approached that of jacketed cylinders due to the small clearances between the outer finned cylinder diameter and the tunnel wall.

A summary plot of the basic data obtained from the experimental test is shown in Figures 26 thru 30. As shown in these Figures, the variation of the values of q for the positions A and B (zero fin-plane/air-stream angle) indicate that the results vary to such an extent that the values of q obtained when the air flows upward as it passes over the fins cannot be compared with the values obtained when the air flows downward as it passes over the fins. If the experimental conditions were ideal, it is thought that the values of q for the positions A and B would fall on the curves in Figures 26 thru 30.

For constant upstream air temperature and constant average temperature of the outer surface of the finned cylinder, the relation of q to the upstream air velocity appears to be linear as the curves in Figures 26 thru 30 exemplify no definite trend of non-linearity, except possibly at low air velocities around 35 mph. The rate of increase of q with upstream air velocity may be less at the low velocities. The ratio of q to air velocity in mph for the range of fin spacings from 0.10 inch to 0.60 inch is shown in

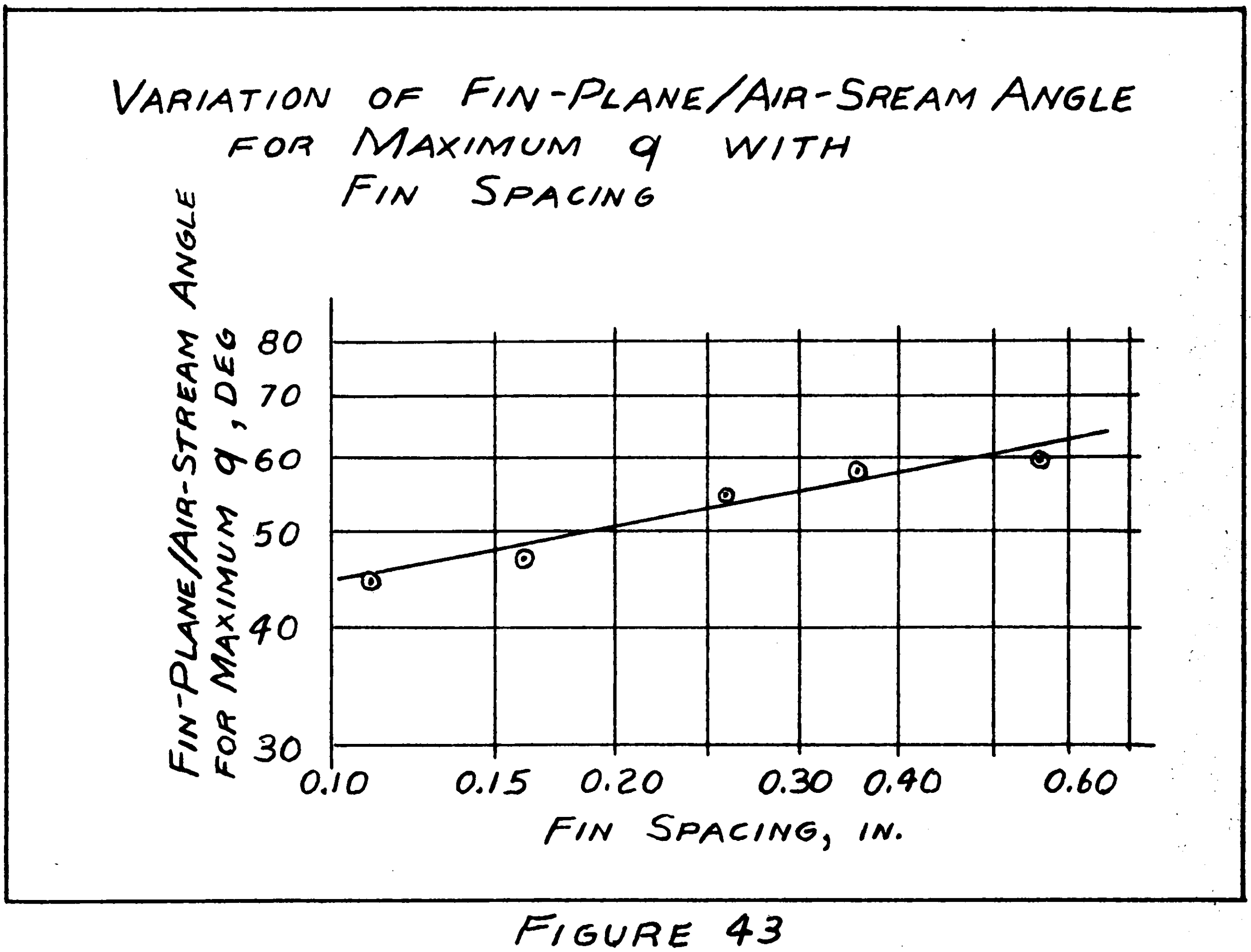
Figure 42. For a comparison of the ratio of q to velocity in this investigation with that of Biermann[2] of the NACA, the variation of q with velocity was plotted on log-log graph paper (Figure 44). Biermann[2] found that q varied as the 0.796 power of air velocity in fps. The results of this investigation indicated that q varied as the 0.75 power of the air velocity in fps, except at large fin spacings (0.56 inch) where the rate was greater. Considering the fact that the q of this investigation differed slightly from the NACA q, the relations compared favorably. For the variations occurring in the test, the range of air velocity was too limited to permit the definite establishment of some relations. For the range of conditions tested with constant inlet air temperature and constant average temperature of the outer surface of the finned cylinder, the rate of increase of q per mph of air velocity increase varies with the 0.2 power of the fin spacing as shown in the following table and in Figure 42.

Fin Spacing (in.)	Rate of Increase of q per mph of Air Velocity Increase
0.11	0.0027
0.16	0.0032
0.26	0.0033
0.36	0.0034
0.56	0.0039



VARIATION OF RATE OF INCREASE OF q PER MPH OF AIR SPEED INCREASE WITH FIN SPACING

FIGURE 42



VARIATION OF FIN-PLANE/AIR-SREAM ANGLE FOR MAXIMUM q WITH FIN SPACING

FIGURE 43

VARIATION OF SURFACE HEAT-TRANSFER COEFFICIENT WITH UPSTREAM AIR VELOCITY FOR ZERO FIN-PLANE/AIR-STREAM ANGLE

FEBRUARY 14, 1955

FIN SPACING					
CURVE	0.11 IN.	0.16 IN.	0.26 IN.	0.36 IN.	0.56 IN.
SYMBOL	○	△	□	▽	◇

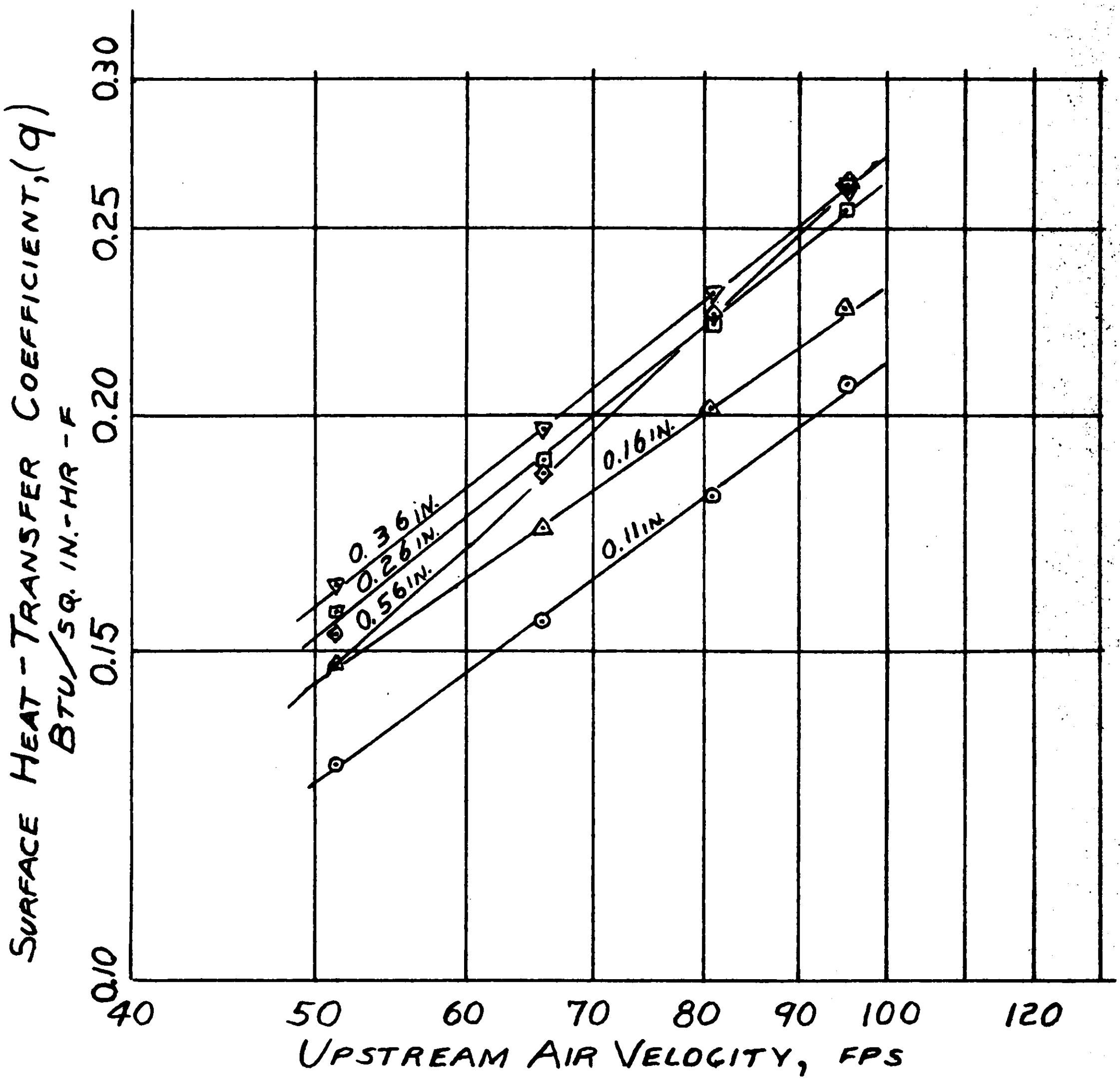


FIGURE 44

For the conditions tested, the fin-plane/air-stream angle appeared to have little or no effect on the rate of increase of q per mph of air speed increase.

A cross plot of Figures 26 thru 30, showing the variation of q with fin-plane/air-stream angle for the fin spacings tested, is shown in Figures 31 thru 35. These Figures yielded curves that were similar in shape to tests conducted by Schey[1]. For the conditions tested, the fin-plane/air-stream angle for maximum value of q varied with the 0.2 power of the fin spacing. This is shown in the following table and in Figure 43.

Fin Spacing (in.)	Fin-Plane/Air-Stream Angle for Max q (Deg)
0.11	45
0.16	47
0.26	55
0.36	58
0.56	60

The maximum value of q is obtained by increasing the turbulence of scouring action of the air against the fin surfaces. Consequently the angle for maximum turbulence increases with fin spacing, as indicated in the test results. The fin-plane/air-stream angle for maximum value of q remained constant over the range of air velocities tested, while in work by Schey[1] the angle that gave the best cooling increased with an increase of velocity. Since the range of the velocities tested was rather small, the angle for maximum value of q may have increased with the air velocity but did not show up in the test results.

The variation of q with fin-plane/air-stream angle for the upstream air velocities tested, is shown in Figures 36 thru 39. For the conditions tested, the variation of q with the fin-plane/air-stream angle for any air velocity did not vary uniformly for the different fin spacings. It is evident from these curves that the maximum value of q varies with fin spacing, as stated in the previous paragraph.

For the conditions of this investigation, q varied as the 0.25 power of the fin spacing up to a fin spacing of about 0.35 inch at which point q began to drop as the fin spacing increased (Figure 40). The relation of q to fin spacing in this investigation somewhat compares with the findings of Biermann[2] which are: For approximately constant heat input, q varies with the 0.322 power of the fin spacing for the range between 0.045 and 0.33 inch fin spacing. Although the q used by Biermann[2] and the q used in this investigation are not exactly the same, the relations should be similar. When large fin spacings occur, the percent effective area of the outer surface area of the finned cylinder decreases, thus decreasing the value of q.

By varying the fin-plane/air-stream angle, the rate of heat-transfer (q) increased in the range of 14 to 25 percent above that of a zero angle. There was no significance attached to the variance of the maximum value of q with fin spacing or upstream air velocity. This increase was much less than that occurring in test by Schey[1]. Schey[1] made the following statement: "With the same temperature for the two conditions and with an air speed of 76 mph, the heat input to the cylinder can be increased fifty percent at 45 degree fin-plane/air-stream angle over that at zero degree." The reason for such a small increase in this investigation may have been due to the small cylinder diameter as compared with a much larger one used by Schey[1]. One of the theories of Schey[1] states that the cooling may be improved because the cylinder forms an elliptical section at angles between 0 and 90 degrees with respect to the air-stream, thereby resulting in more cooling area coming in contact with the air stream. Since the diameter of the cylinder was smaller in this investigation, it may be reasoned that the increase in cooling area coming in contact with the air stream would be less in terms of percent of the total outer area of the finned cylinder.

The data of this investigation could be applied for more practical usage by using the over-all heat-transfer coefficient (U) instead of q. The variation of U with fin-plane/air-stream angle for 65 mph upstream air velocity was plotted (Figure 45). Also the variation of U with fin spacing for 65 mph upstream air velocity was plotted (Figure 46). U can more easily be used in the field than q since the measurements are simpler. The value of U was maximum at the same angle for each fin spacing as q. The value of U appeared to be inversely proportional to the 0.53 power of the fin spacing for constant inlet air temperature and constant average temperature of the outer surface of the finned cylinder, as shown in Figure 46. This relation appears to vary slightly with fin-plane/air-stream angle.

VARIATION OF
OVERALL HEAT-TRANSFER COEFFICIENT
WITH FIN-PLANE/AIR-STREAM ANGLE
FOR 65 MPH UPSTREAM AIR VELOCITY
JANUARY 31, 1955

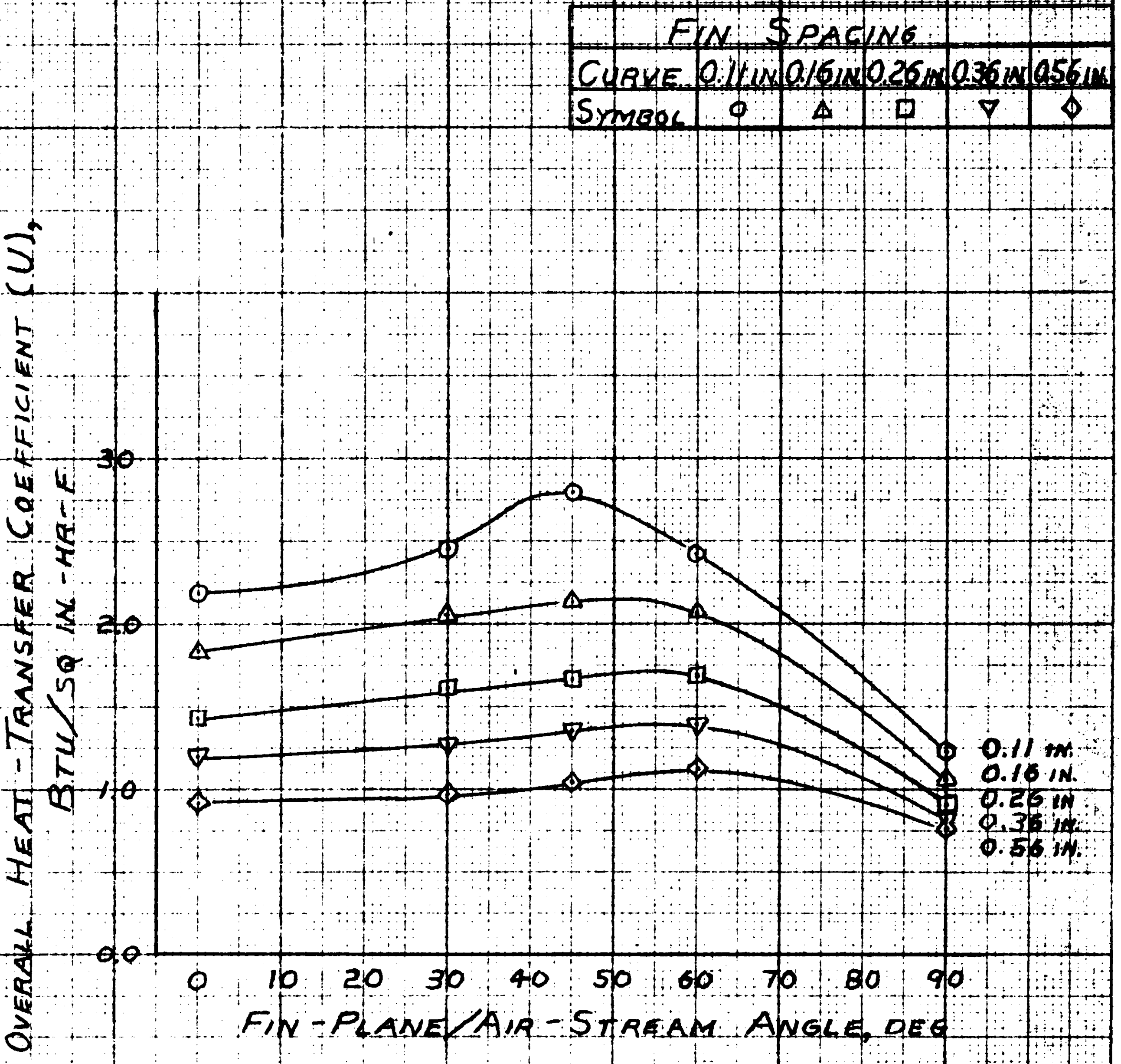


FIGURE 45

VARIATION OF OVERALL HEAT-TRANSFER COEFFICIENT WITH FIN SPACING FOR 65 MPH UPSTREAM AIR VELOCITY

FEBRUARY 2, 1955

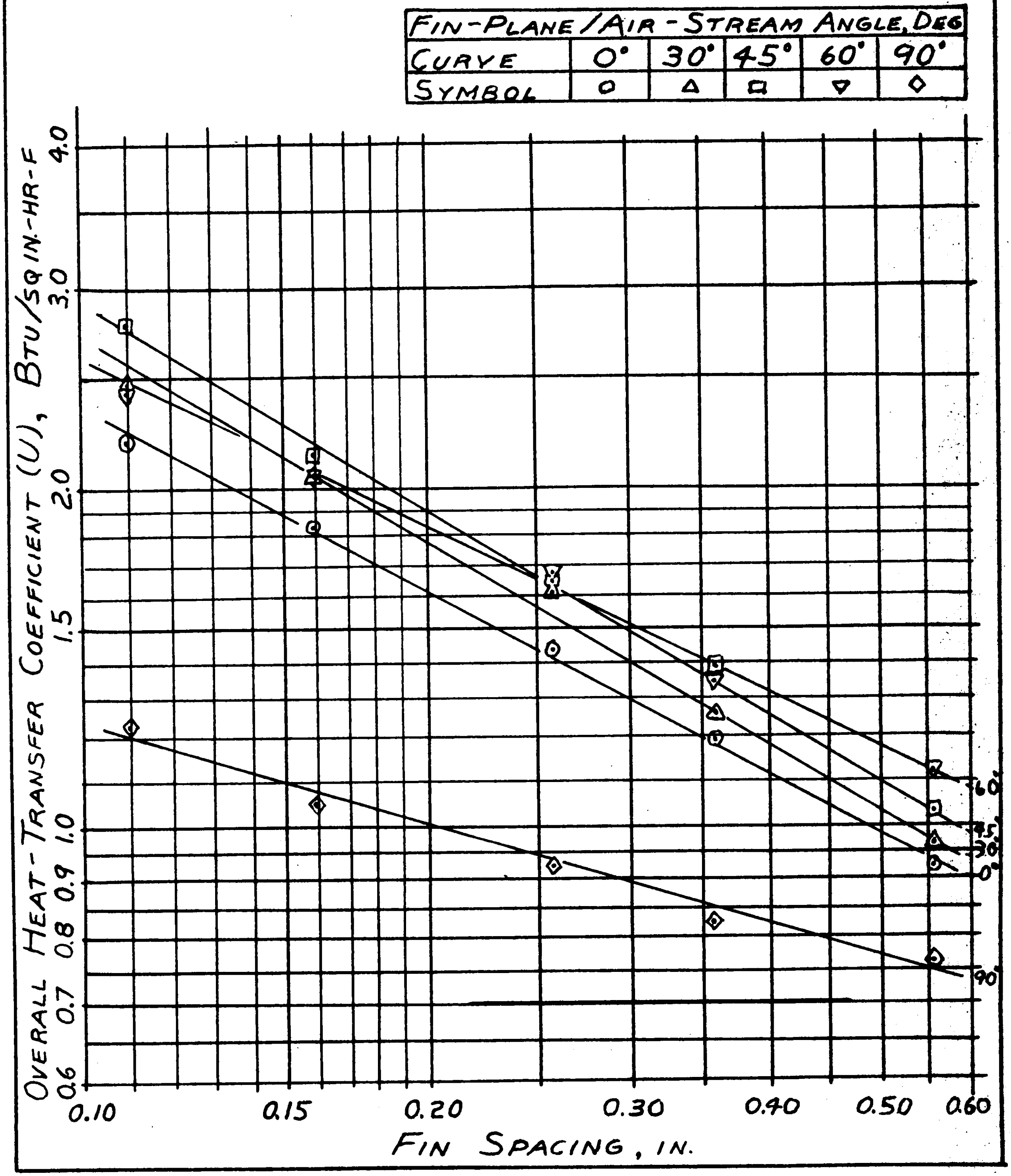


FIGURE 46

V. CONCLUSIONS

The conclusions reached from this investigation are stated in the following paragraphs. The range of air velocities attained in this investigation was too limited and the variations too great to definitely establish all relations.

Varying the fin-plane/air-stream angle increased the surface heat-transfer coefficient (q) to a maximum of 14 to 25 percent above the zero degree angle value. The fin-plane/air-stream angle for maximum value of q varied with the 0.2 power of the fin spacing, the maximum for the 0.10 inch fin spacing being at 45 degrees. For any fin spacing, the angle for maximum value of q remained constant for a change of air velocity. The value of q increased with the fin-plane/air-stream angle from zero to about 50 degrees and then fell to a value much lower than the zero degree position at the 90 degree position.

The value of q varied as the 0.25 power of the fin spacing up to a fin spacing of about 0.35 inch. When the fin spacing went beyond 0.35 inch, q began to drop as the fin spacing increased.

The value of q varied linearly with the upstream air velocity, except possibly at low air velocities around 35 mph. The ratio of the increase of q per mph of air velocity increase varied with the 0.2 power of the fin spacing and remained constant for all fin-plane/air-stream angles for any fin spacing.

No conclusions were drawn as to the variation of q with cylinder diameter since there were indications that the conditions in the wind tunnel approached that of a jacketed cylinder instead of a cylinder in a free air stream.

Due to the variation of the data, no conclusion was drawn as to whether there was any difference in the value of q caused by the air flowing upward or downward as it passes over the fins of the cylinder.

The value of the over-all heat-transfer coefficient (U) varied inversely as the 0.53 power of fin spacing.

VI. RECOMMENDATIONS

This investigation was only a beginning of the investigations that could be conducted on heat-transfer from finned cylinders in an air stream at varying fin-plane/air-stream angles. The investigations conducted by the NACA were for much larger cylinder diameters than the one of this investigation and were intended for application to aircraft air-cooled engines. It is possible that finned cylinders in an air stream at varying fin-plane/air-stream angles can be applied effectively for high rate heat exchangers between liquid and gas.

The author believes that any further investigations on a finned cylinder in a free air stream should be performed in a wind tunnel of sufficient size to rule out the possibility of the air flow approaching that of a jacketed cylinder. It is suggested that a test be made to check the validity of the results of this research on a finned cylinder in a free air stream. In future research it may prove valuable to hold parameters constant rather than unitary values.

To improve the results of future studies the following are recommended:

1. Wide range of air velocities (at least 30 to 150 mph) be used to be able to definitely establish a trend.

2. Run the cylinder much hotter in order to have a greater temperature difference between the cylinder and the air to lessen the effect of errors in temperature measurements.

Some of the future studies that would provide valuable results are:

1. The effect of cylinder diameter on surface heat-transfer coefficient (q).

2. Further study on the topic of this research to broaden the scope of the study and substantiate the results.

3. Apply the empirical equation (A of Literature Review) by Ellerbrock[5] to a wider range of finned cylinder dimensions and to varying fin-plane/air-stream angles.

VII. ACKNOWLEDGEMENTS

The author wishes to express his gratitude to Professor J. B. Jones for his assistance during the research project; to Professors R. K. Will, H. L. Wood, and H. S. Miles, Jr. for their suggestions, constructive criticism, and encouragement; to Messrs. F. H. Grissom and H. M. Smith for their aid in fabrication of the test apparatus; to all others in the department who aided in the completion of this research project; and to Mrs. A. L. Gray for her proofreading.

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