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TITLE

THE EFFECT OF SEVERAL VARIABLES ON REQUIRED INTERCOOLER VOLUME

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REVISIONS

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2/25/41	JORDAN	All	NOTE: Figs. 1,2, and 10 have been revised to agree with Harrison "Aircraft Cooling Handbook" dated Aug. 1940. All other curves and Calculations are based on Harrison date of 10-3-39	

INTRODUCTION

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The problem of choosing the correct intercooler for a given supercharged engine installation is complicated by the number of variables involved.

It is the purpose of this report to consider a given engine airplane combination, calculate the intercooler required for the various flight conditions and determine the critical design condition. Also, an estimate will be made of the importance of each of the following variables on the size of intercooler required:

1. Intercooler Shape
2. Critical Altitude
3. Carburetor Air Temperature
4. Atmospheric Temperature

An estimate will also be made of the effect of intercooler volume on maximum speed.

METHOD OF CALCULATING RESULTS

In order to reduce the number of variables involved in the problem to a value which could be handled in a paper of this scope it was necessary to set certain basic conditions constant. These conditions, as described in this paragraph, will be used to obtain the data presented in the rest of the report. The conditions were chosen with a view towards making the results of general significance, however, it is well to remember that all answers are subject to the limitations given below.

The Airplane :

The theoretical airplane is one which climbs at an air speed having a dynamic head (q) of 8 inches of water independent of altitude. The total cooling air pressure drop across the intercooler is equal to 1q or 8 inches of water.

The airplane has a level flight maximum speed of 400 m.p.h. true airspeed at 20,000 feet. This airspeed varies with altitude in such a manner that the dynamic head (q) remains constant.

The pressure drop across the cooling air face of the intercooler in high speed level flight is 25% of the dynamic head (.25q). It is assumed that a controllable exit contracts the cooling air stream the correct amount to give .25q across the intercooler. The value .25q for the pressure drop was chosen as a compromise between cooling considerations and drag considerations.

The Engine:

The engine is rated as developing 1500 H.P. at 20,000 feet. It is equipped with a two speed, two stage gear driven supercharger. It is assumed that the supercharger maintains sea level pressure at the entrance to the carburetor up to the critical altitude. On engines of this type the maximum available amount of supercharging, that furnished by the auxiliary stage in the high speed gear ratio, must be cut in at some altitude below the critical. At this altitude the compression ratio of the supercharger is approximately the same as at critical altitude (since the impeller tip speed is the same), and in order to maintain sea level pressure at the carburetor it is necessary to throttle the air at the engine air intake.

The performance of the supercharger is in agreement with that discussed in Ref. 1 and is representative of current design.

The supercharger maintains sea level pressure up to 20,000 feet and at that altitude has an adiabatic efficiency of 65% under standard conditions, where adiabatic efficiency is the ratio of the power required for adiabatic compression ($n = 1.4$) to the actual power required.

$$\text{Eta } \eta = \frac{T_a - T_1}{T_b - T_1}$$

η = adiabatic efficiency
T_1 = initial temperature
T_a = final temperature if compression were adiabatic
T_b = actual final temperature

However: $T_a = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$ and $T_b = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$

Where: P_1 and P_2 are the initial and final pressures, γ is the adiabatic compression exponent (1.4) n is the actual compression exponent.

Substituting in formula (1)

$$\eta = \frac{\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1}{\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1}$$

For an adiabatic efficiency of 65%, an initial pressure of 20,000 feet and a final pressure of sea level, the exponent n solves as 1.72. This value was assumed to remain constant for all other conditions.

For a constant tip speed, the compression ratio of a supercharger varies with the absolute temperature of the entering air according to the formula: (Ref. 2)

$$R_1 = \left[\frac{T_0}{T_1}\left(R_0^{\frac{n-1}{n}} - 1\right) + 1\right]^{\frac{n}{n-1}}$$

Where R_1 and R_0 are the compression ratios corresponding to intake temperatures of T_1 and T_0

Substituting T_a/T_0 and T_b/T_1 for $(R_0)^{\frac{n-1}{n}}$ and $(R_1)^{\frac{n-1}{n}}$,

and rearranging the terms equation 3 becomes.

$$T_a - T_0 = T_b - T_1$$

Where T_a and T_b are the final temperatures corresponding to initial temperatures of T_0 and T_1

It is therefore seen that for a given impeller tip speed, the temperature rise thru the supercharger remains constant. The temperature rise at 20,000 ft. under standard conditions calculates to be 172°F, for the assumed adiabatic efficiency of 65%. This value of temperature rise is used to obtain all results with the high speed auxiliary stage blower engaged for the supercharger with a critical altitude of 20,000 ft.

The temperature of the air at the intake to the supercharger is corrected for adiabatic temperature rise due to ram.

The Intercooler:

The intercoolers used in these calculations are the cross flow Harrison Type, having identically shaped passages in the engine air and cooling air directions. The performances of the various shapes of intercoolers are given on Figs. 1,2, 3 and 4 and 10. These curves are plotted from tables furnished by the Harrison Radiator Division, General Motors Co., dated Aug. 3, 1940. The values of pressure drop furnished by Harrison were corrected to standard density before plotting on the $\Delta P\ \rho/\rho o$ scale.

All of the volumes mentioned in this report are for each of two intercoolers connected in parallel. For an engine air flow of 7 lbs. per BHP. hr. the flow thru each intercooler is 88 lbs. per minute. (1)

In describing the various coolers, the following nomenclature will be used:

EA10 - Length of core in engine air direction is 10 inches.
CA10 - Length of core in cooling air direction is 10 inches.
H 10 - Third dimension is 10 inches.

A diagram of a typical intercooler is shown in Fig. 9.

The temperature of the cooling air at the face of the intercooler is assumed to be atmospheric plus the adiabatic temperature rise due to ram. The cooling air density is taken as the standard atmospheric density for a given altitude corrected for the temperature and pressure rise at the face of the intercooler.

The weight of the intercooler is assumed to vary directly with the volume. Approximately 30 cubic inches of core volume equals 1 pound.

Figs. 1 to 4 give the performances of six different shapes

(1) The specific air consumption of two stage engines varies. It may go as high as 7.6 lbs. per BHP hr.

of intercoolers. The intercooler volume required to maintain 100°F carburetor air temperature in a climb at 20,000 ft. for an atmospheric temperature of standard plus 30°F, was calculated for each shape. The results are presented in Table 1.

TABLE 1

No.	Engine Air Length EA	Cooling Air Length CA	Third Dimension H	Volume Cu. In.
1	10	10	21.4	2140
2	14	10	14.4	2020
3	18	10	11.4	2060
4	10	8	22.4	1795
5	14	8	14.7	1645
6	18	8	11.0	1585

Note: Method of calculation shown in Appendix - Problem 1.

If the length of the core in the cooling air direction remains constant, an increase in the engine air core length has the following effects:

(a) Decreases the volume required. This effect, however, diminishes with further increase in engine air core length and soon the volume reaches a minimum value.

(b) Reduces the area of the cooling air face. Since the pressure drop remains constant this is accompanied by a corresponding decrease in cooling air flow.

(c) Increases the engine air pressure drop due to the combined effects of smaller face area and longer core length.

If the length of the core in the engine air direction remains constant, a decrease in the cooling air core length has the following effects:

(a) Decreases the volume required by a relatively large amount.

(b) Increases the cooling air flow.

(c) Increases the engine air pressure drop.

It is seen then that the intercooler volume can be decreased indefinitely at the expense of the engine air pressure drop and the cooling air flow.

The engine air pressure drop should be kept as low as possible, since to maintain the same pressure at the carburetor, the supercharger compression ratio must increase with an increase in engine air pressure drop, thus raising the temperature of the air at the exit of the supercharger. A value of .6 inches Hg. is a reasonable maximum to set for engine air pressure drop.

The quantity of cooling air flow should also be kept low, since as it increases, not only does the internal cooling air horse-power go up but also the external drag due to intake scoops, exits, etc. is increased.

The final intercooler selected must have a low engine air pressure drop and must embody a compromise between intercooler volume and quantity of cooling air flow. It must also be of a reasonable shape to permit installation and support.

An inspection of Table 1 shows that intercooler No. 5 is a reasonable compromise. The engine air pressure drop is about .55 inches of Hg.

Intercooler No. 6, although somewhat smaller in volume, gives an engine air pressure drop of 1.17 inches of Hg. which is higher than the limit set.

Inter cooler No. 4 has a 9% higher volume and cooling air flow.

Therefore, an intercooler having the same cooling air length and engine air length as No. 5 was used in all further calculations. The third dimension (H) was varied to meet the requirements of each separate problem.

THE EFFECT OF CRITICAL ALTITUDE ON VOLUME OF REQUIRED INTERCOOLER

As the critical altitude is raised the compression ratio of the supercharger is increased, thus causing higher engine air temperatures. Also the cooling air flow for a given pressure drop decreases due to the lower density. These two effects are but partially compensated by the lower cooling air temperature and the net result is an increase in intercooler volume with critical altitude.

Fig. 7 shows the intercooler volume required plotted against critical altitude. A sample calculation is given in the appendix, problem 2.

The curve is very nearly a straight line from 15,000 ft. to 25,000 ft. A 5,000 foot increase in critical altitude necessitates a 14% increase in intercooler volume.

The curve will, of course, no longer be a straight line once the isothermal atmosphere is reached, nor will it be straight at the lower altitudes where the cooling air temperature of standard plus 30°F approaches the 100°F temperature set for the carburetor air.

The curve indicates that the critical altitudes of engines may be increased considerably over the values in common use today without increasing the intercooler burden to a limiting extent, provided the supercharger exponent does not increase.

In the isothermal atmosphere (above 35,000 ft.) the intercooler volume will increase more rapidly with increase in critical altitude.

CRITICAL DESIGN CONDITIONS

It is of primary importance to the designer to know what set of conditions imposes the greatest load on the intercooler. These conditions will design the size of intercooler required for a given installation.

The conventional pressure control for an exhaust driven supercharger involves regulation of the exhaust gas supply to the turbine in such a manner as to maintain a constant pressure at the carburetor. The compression ratio consequently varies with altitude and reaches a maximum at critical altitude. The curve of intercooler required against altitude (below the critical) would therefore be similar to Fig. 7, and the critical design condition would occur at the critical altitude.

For a two stage engine having a gear driven supercharger, it is necessary to cut in the auxiliary stage high speed blower at some altitude below the critical. This automatically sets the compression ratio at the value it would have at critical altitude (except for the secondary effect of intake air temperature on compression ratio). Since the pressure at the carburetor must remain the same as at critical altitude, the intake air must be throttled to some lower pressure before it enters the supercharger.

Figure 5 shows the variation of carburetor air temperature with altitude for a series of intercoolers. These temperatures are for the climb condition with the auxiliary stage high speed engaged.

The curves indicate that for a given intercooler with a constant cooling air pressure drop, the carburetor air temperature is approximately 13°F higher at the altitude at which the high speed auxiliary stage must be cut in (15,000 ft.) than it is at critical altitude (20,000 ft.).

A similar series of curves for the maximum speed level flight condition is presented in Fig. 4. It is important to keep in mind the assumption made under "Method of Calculating Results", when considering these curves. A sample calculation is given in the appendix, problem 3.

The slope of the curves for the high speed condition is about the same as for the climb condition. The important thing to note, however, is that for a given intercooler the carburetor air temperature is higher in the level flight condition than in climb, despite the fact that the cooling air pressure drop is also higher.

A comparison of Fig. 5A and Fig. 6A shows that at 15,000 ft. the carburetor air temperature is 100°F in climb and 116°F in level flight.

The increase in carburetor air temperature in the level flight condition is due solely to the adiabatic heating of the cooling air and the engine air as it is decelerated in front of the engine and in the diffuser. The increase in temperature at 400 m.p.h., true air speed is 29°F.

Unfortunately this increase in intake air temperature cannot be compensated for by a reasonable increase in the cooling air pressure.drop. In fact, in the above instance, a pressure drop of 1q (45 inches of H20) would not reduce the carburetor air temperature from 116oF to 100°F.

In calculating the carburetor air temperature for the high speed condition the pressure drop was assumed to be 1/4q. This represents a compromise between intercooler volume and cooling air drag.

As previously mentioned, Fig. 5B and 6B show carburetor air temperatures of 100°F and 116°F at 15,000 feet for climb and level flight respectively. However, if it is assumed that the auxiliary stage high speed must be cut in at 15,000 ft. to maintain rated horse-power in climb, then in the high speed condition the added ram will enable the engine to maintain rated horsepower to some higher altitude before necessitating the use of the auxiliary stage high speed. This altitude is approximately 19,000 feet.

The conclusions to be drawn from Fig. 5 and 6 are that the highest carburetor air temperature with a given intercooler, occurs not at the critical altitude but at the altitude at which the high speed blower must be cut in. For airplanes with a high maximum speed such as the one discussed in this paper, the carburetor air temperature will be slightly higher in high speed level flight than in climb if the cooling air pressure drop is held down to a reasonable value.

In designing an intercooler for these critical conditions, it is assumed that the pilot will change speeds at the correct altitude. Should he shift to high speed at too low an altitude the carburetor air temperature will rise above the design value. However, it is well to remember that the intercooler must be able to maintain a safe carburetor air temperature under extreme summer conditions (Std. +30oF). At all other times the atmospheric temperature is considerably lower and the carburetor air temperature is decreased accordingly.

The critical design conditions discussed above applied to gear driven superchargers. The highest carburetor air temperature, with an exhaust driven supercharger will occur at critical altitude. Therefore the exhaust driven type will require a small intercooler than the gear driven type. For the airplane discussed in this paper an exhaust driven type would require 25% less intercooler volume than the gear driven type to maintain the same maximum carburetor air temperature.

EFFECT OF ALLOWABLE CARBURETOR AIR TEMPERATURE AND ATMOSPHERIC TEMPERATURE ON INTERCOOLER VOLUME

The function of an intercooler is to maintain a carburetor air temperature below a certain value. This maximum temperature is specified by the engine manufacturer and is determined by the detonation characteristics of the engine. Berger and Chenoweth (Ref. 1) suggest that the carbuertor air temperature not exceed 100°F.(1) While this value seems low it must be realized that after passing through the carburetor the air is again compressed and therefore reheated before it reaches the cylinders. The temperature of the charge in the cylinder (and consequently the tendency toward detonation) is determined by the carburetor air temperature and the compression ratio of the final stage of the supercharger.

Fig. 8 shows the effect of allowable carburetor air temperature on intercooler volume. In considering these curves it should be remembered that an increase in intercooler volume is accompanied by a corresponding increase in cooling air flow.

The curves become very steep at low values of carburetor air temperature, and will approach infinity as the allowable carburetor air temperature approaches the cooling air temperature. With an atmospheric temperature of standard +30°F a 31% increase in intercooler volume is required to reduce the carburetor air temperature from 110°F to 100°F.

The larger part of the engine air temperature drop is accomplished in a small portion of the intercooler core, all the rest is needed to coax the last few BTU's across the small temperature difference that exists in this region between the engine air and the cooling air.

It is therefore seen that present day intercoolers work in an inefficient range. The same number of BTU could be taken from the engine air with a much smaller intercooler if the allowable carburetor air temperature were higher. This problem could be solved to the satisfaction of the engine installation engineer if the superchargers were designed to give a greater portion of the pressure rise in the auxiliary stage before the intercooler, and less in the final stage. However, such a change would have other effects on engine performance which it is not the province of this paper to discuss.

The effect of atmospheric temperature on the intercooler volume required to maintain a given carburetor air temperature can be obtained from the two curves in Fig. 8. For carburetor air temperatures of from 80 to 110°F, a one degree rise in atmospheric temperature causes approximately one degree rise in carburetor air temperature. Therefore, atmospheric temperature has about the same effect as allowable carburetor air temperature on required intercooler volume for the range generally encountered in practice.

(1) The figure recommended by the engine manufacturer should be used when available.

EFFECT OF INTERCOOLER VOLUME ON MAXIMUM SPEED

In considering the optimum intercooler for a given installation the following question arises. It is conceded that a certain minimum intercooler volume is required to cool the carburetor air and thus prevent detonation. However, since a large intercooler means greater charge weight and therefore greater power, why bother with the minimum size, why not use the largest cooler that can be installed in the airplane.

The effect of a 140% increase in intercooler volume on the maximum speed of the assumed airplane will be considered in detail.

From Fig. 6 A and C the carburetor air temperatures for the high speed condition at 20,000 ft. are 126 and 85°F.

Assuming that the brake horse power varies inversely as the square root of the absolute temperature of the intake air, this reduction in temperature gives a 3.7% increase in brake horse power or 55.5 H.P.

For a propeller efficiency of 85% this is equal to 47 thrust horse power.

The larger cooler uses 34.5 cubic feet per second more cooling air than the smaller cooler. The increase in internal cooling air horse power for two intercoolers (Q) (OP) is 5.22.

Assuming a pumping efficiency of 50% $\left(\frac{(Q)(\Delta P)}{(\Delta D)(\nu)}\right)$, the total increase in cooling air horse power is 10.44 H.P.

The larger intercoolers are 96 pounds heavier than the small ones. To maintain the same stalling speed with this added weight the airplane structure must be increased by approximately an equal amount.

The total weight increase then amounts to 192 pounds.

If an overall lift drag ratio of 7 is assumed, then a 192 pound weight increase will be accompanied by a 27.4 pound drag increase, or 29.2 horse power at 400 miles per hour.

The total added drag horse power is 10.44 - 29.2 39.6H.P.

The net increase in thrust horse power is 47.2 - 39.6 or 7.6 H.P., which is equivalent to about 0.8 miles per hour increase in top speed.

It should also be noted that if the engine is already at rated power with the high carburetor air temperature, no more power may safely be taken even if made available thru lower intake temperatures. In this case the larger intercooler could only be used to add a few hundred feet on the critical altitude.

The preceding analysis shows that the performance gains due to the large intercooler are so small as to be negligible. Since space is at a premium on modern aircraft the use of large intercoolers frequently causes crowding of other items, complication of the structure and other ills. In general it may be stated that the best overall installation can be obtained by using the smallest intercooler that will prevent detonation under the previously discussed critical design conditions.

CONCLUSION

Although this discussion has dealt with a particular airplane engine supercharger combination, the following general conclusion seems to be indicated:

1. The correct shape of intercooler for a given installation cannot be determined by any hard and fast rule. If the engine air pressure drop is arbitrarily set at some maximum value (.6 inches "Hg.) changes in shape which reduce the volume cause the cooling air flow to increase. The final intercooler must be the result of a compromise between volume, cooling air flow, and installation considerations.

2. The size of the intercooler required increases as the critical altitude is raised, but not at a prohibitive rate.

3. For an airplane having a gear driven supercharger, the highest carburetor air temperature occurs at the altitude at which the high speed auxiliary stage cuts in, rather than at the critical altitude.

   Because of this fact, the gear driven supercharger requires a larger intercooler than a turbo-supercharger.

4. For airplanes having high top speeds, the adiabatic temperature rise at the intake causes the carburetor air temperature to be higher in the high speed level flight condition than in climb, if the cooling air pressure drop across the intercooler is kept down to a reasonable value.

5. An increase in atmospheric temperature increases the carburetor air temperature by about the same amount.

6. A decrease in allowable carburetor air temperature means a large increase in required intercooler volume. A reduction in carburetor air temperature from 115°F to 100°F. increases the total intercooler weight by about 30 lbs. for the engine discussed in this report.

7. The increase in charge weight and therefore horsepower due to a larger intercooler is more than offset by the attendant increase in size, weight and drag. The best overall installation is obtained by using the minimum size intercooler that will prevent detonation under extreme summer conditions.

REFERENCES

1. Berger, A.L., and Chenoweth, Opie, Supercharger Installation Problems, S.A.E. Journal, Vol. 43, No. 5, Page 472, November 1938.

2. Ellor, J.E., Some Problems of Supercharging in Aero-Engines, Shell Aviation News, Page 15, January, 1939.

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APPENDIX

The following problems are typical. Results are subject to the limitations indicated by these calculations.

Problem 1.

For an engine air length of 14" and a cooling air length of 8", find the intercooler volume required to maintain a carburetor air temperature of 100°F in climb at 15,000 ft. for an atmospheric temperature of standard + 30°F.

At 15,000 ft. in climb the high speed auxiliary stage must be cut in. Therefore the temperature rise of the engine air thru the supercharger is the same as at the critical altitude of 20,000 ft. (equation 4).

At 20,000 ft. the compression ratio is the atmospheric pressure at sea level divided by the pressure at 20,000 ft. or 2.18.

For a compression exponent (n) of 1.72 this gives a temperature rise of 172°F thru the supercharger.

Atmospheric Temperature at 15,000 ft. = Std. + 30°F = 35.5 F.

Pressure drop across cooling air face of intercooler = 8 inches H20 (from assumed data).

Adiabatic temperature rise at intake due to 8 inches ram = 4.8°F (calculated by formula $T_1/T_2 = (P_1/P_2)^{\frac{\gamma-1}{\gamma}}$

Temperature of air at intake = 35.5 + 4.8 = 40.3°F.

Temperature of air at exit of supercharger = 40.3 + 172 = 212.3°F.

Engine air temperature drop = 212.3 - 100 = 112.3°F

Inlet temperature difference = 212.3 - 40.3 = 172°F

$$\frac{\text{Engine air temperature drop}}{100^\circ\text{F inlet difference}} = \frac{(112.3)(100)}{172} = 65.3^\circ\text{F}$$

Standard Mass Density ρ_1 = .001495 slugs/cu.ft.

Actual mass density at face of cooler = standard density corrected for difference of atmospheric temperature from standard, and for pressure and temperature rise at face of cooler due to ram.

ρ = .00143 slugs/cu.ft.

$\Delta P\ \rho/\rho_o = (8)\ \frac{(.00143)}{(.00238)} = 4.80$ "H_2O"

Engine air flow = 7 lb./B.H.P.Hr.

Total Flow = $\frac{(7)(1500)}{(60)}$ = 175 lbs./min.

Flow / intercooler = 175/2 = 88 lbs./min.

From Fig. 2B at $\Delta P\ \rho/\rho_o$ = 4.80 and engine air temperature drop/ 100°F inlet difference of 65.3, read a required flow of 75 lbs./min./100 sq. inches engine face area.

Actual face area required = 88/75 x 100 = 117.3 sq. inches.

Intercooler volume = (117.3)(14) = 1645 cubic inches.

Problem 2

For an engine air length of 14 inches and a cooling air length of 8 inches, find the intercooler volume required to maintain 100°F carburetor air temperature in climb at 15000 ft, if the critical altitude is 15,000 ft, and atmospheric temperature is standard + 30°F.

Temperature at intake is same as for Problem 1. = 40.3°F.

$\Delta P\ \rho/\rho_o$ is same as for Problem 1. = 4.80 inches of H20

Compression Ratio equals the pressure at sea level divided by the pressure at 15,000 ft. = 1.775

For a compression exponent (n) of 1.72, this compression ratio gives a temperature at the exit of the supercharger of 175°F.

Engine air temperature drop = 175 - 100 = 75°F.

Inlet temperature difference = 175 - 40.3 = 134.7°F.

Engine air temperature drop / 100°F inlet difference = (75/134.7)(100) = 55.7°F.

From curve 2B at $\Delta P\ \rho/\rho_o$ = 4.8 and engine air temperature drop / 100°F inlet difference of 55.7, read required flow of 106 lbs./ min./100 sq. inches.

Engine face area = 88/106 x 100 = 83 sq. inches.

Intercooler Volume = (83)(14) = 1162 cubic inches.

Problem 3

Find the carburetor air temperature under the following conditions.

Engine air length = 14 inches
Cooling air length = 8 inches
Intercooler volume = 1645 cubic inches
Atmospheric Temperature = standard Altitude = 20,000 ft.
High speed level flight condition
Velocity = 400 m.p.h. true air speed.
High speed auxiliary stage engaged.
Standard mass density, ρ_1 = .001267 slugs/ cubic ft.

Dynamic head (q) = $1/2\ \rho v^2$ = 218 lbs./sq.ft.

From standard air speed indicator correction tables, the dynamic head in compressible flow is (218)(1.082) = 236 lbs./ sq. ft.

The adiabatic temperature rise at the intake is 28.8°F.

Atmospheric temperature = -12.4°F.

Intake temperature = -12.4 + 28.8 = 16.4°F.

Mass density corrected for temperature and pressure rise at face of cooler = .00148 slugs/ cubic ft.

From assumed data, the pressure drop across the cooling air face of the intercooler is 1/4 q.

q = 236 lbs./sq.ft. = 45.4 inches H20
ΔP = 45.4/4 = 11.35 inches H20

$\Delta P\ \rho/\rho_o$ = (11.35) .00148/.00238 = 7.06 inches H20

Engine air temperature rise is 172°F. (see Problem 1)

Temperature at exit of supercharger = 16.4 + 172 = 188.4

Engine air flow = 88 lbs. per minute.

Engine face area = Volume/Length = 1645/14 = 117.3 sq. in.

Engine air flow/100 sq. inches = 88/117.3 = 75 lbs/min.

From Fig. 2B at $\Delta P\ \rho/\rho_o$ = 7.06 inches H20 and engine air flow = 75 lbs. per minute per 100 sq. inches read 68.5°F engine air temperature drop per 100°F inlet temperature difference.

Inlet temperature difference = 188.4 - 16.4 = 172°F.

Engine air temperature drop = (68.5)(172)/100 = 118°F.

Carburetor air temperature = 188.4 - 118 = 70.4°F.

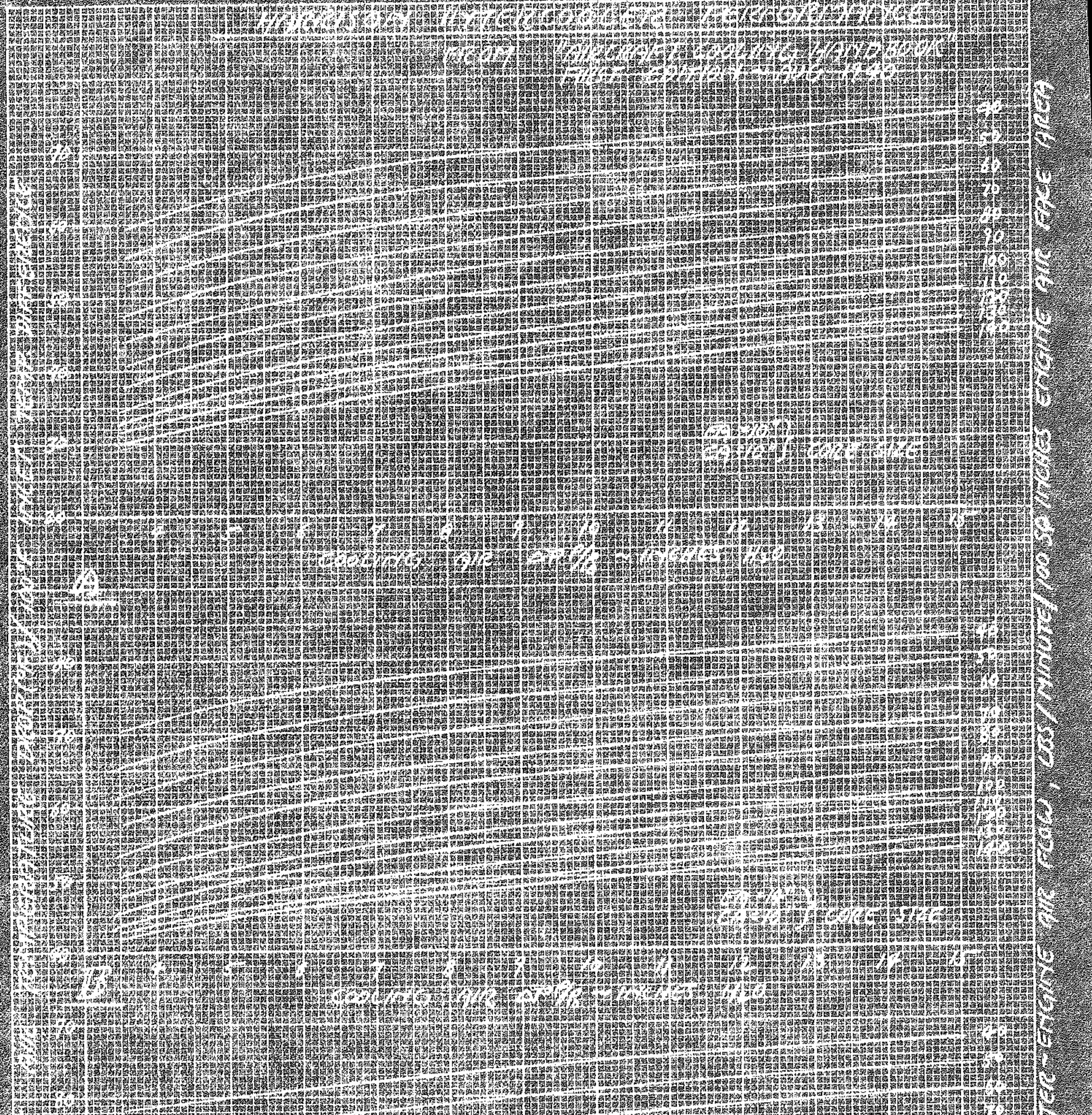

HARRISON INTERCOOLER PERFORMANCE
FROM "AIRCRAFT COOLING HANDBOOK"
FIRST EDITION – AUG 1940
CORE SIZE
COOLING AIR ΔP/σ – INCHES H2O
A
B
C
PARAMETER – ENGINE AIR FLOW, LBS/MINUTE/100 SQ INCHES ENGINE AIR FACE AREA

FIG. 1

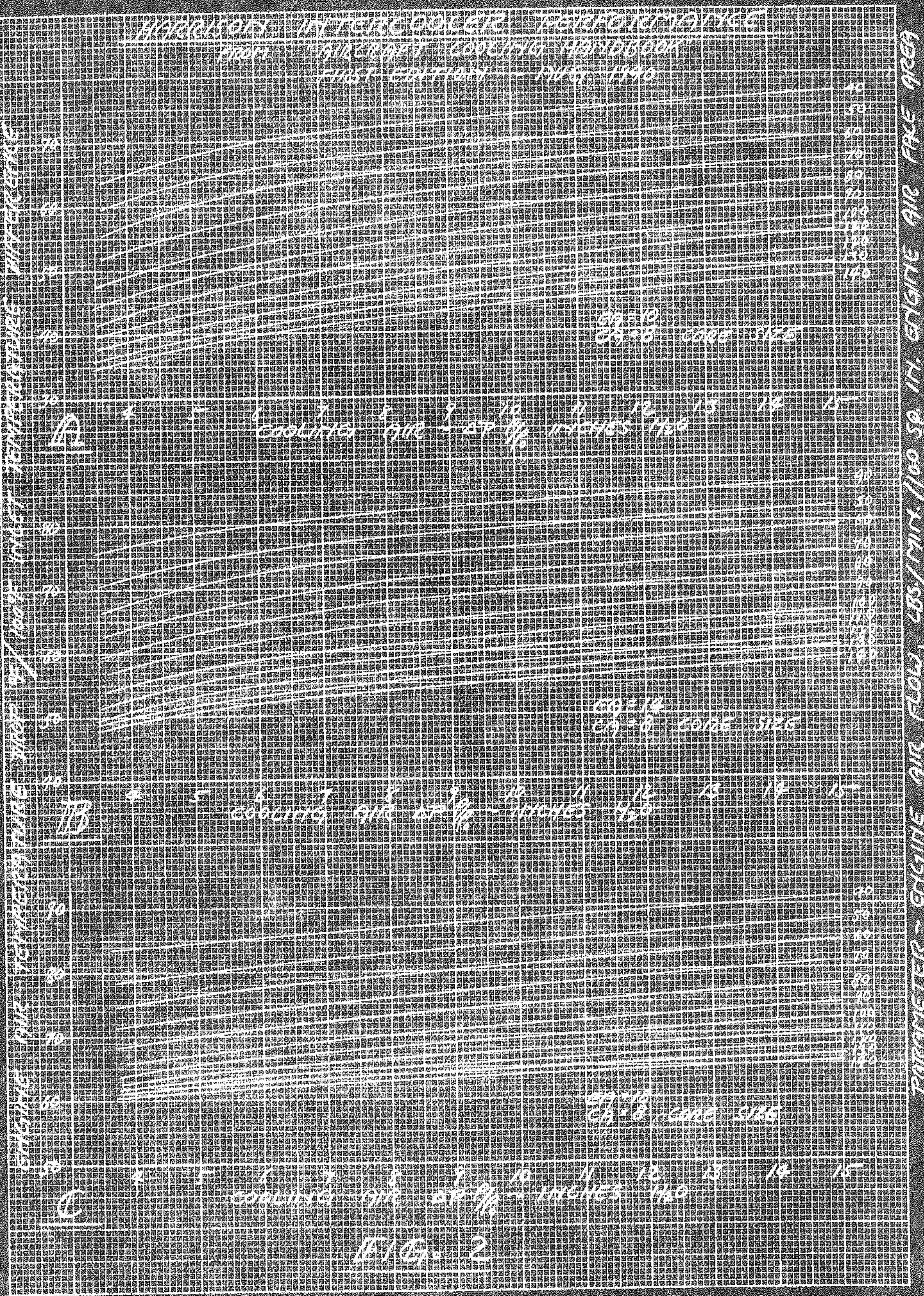

HARRISON INTERCOOLER PERFORMANCE
FROM "AIRCRAFT COOLING HANDBOOK"
FIRST EDITION
ENGINE AIR TEMPERATURE DROP °F/100°F INLET TEMPERATURE DIFFERENCE
PARAMETER – ENGINE AIR FLOW, LBS/MIN./100 SQ. IN. ENGINE AIR FACE AREA
CORE SIZE
COOLING AIR ΔP – INCHES H_2O
A
B
C

FIG. 2

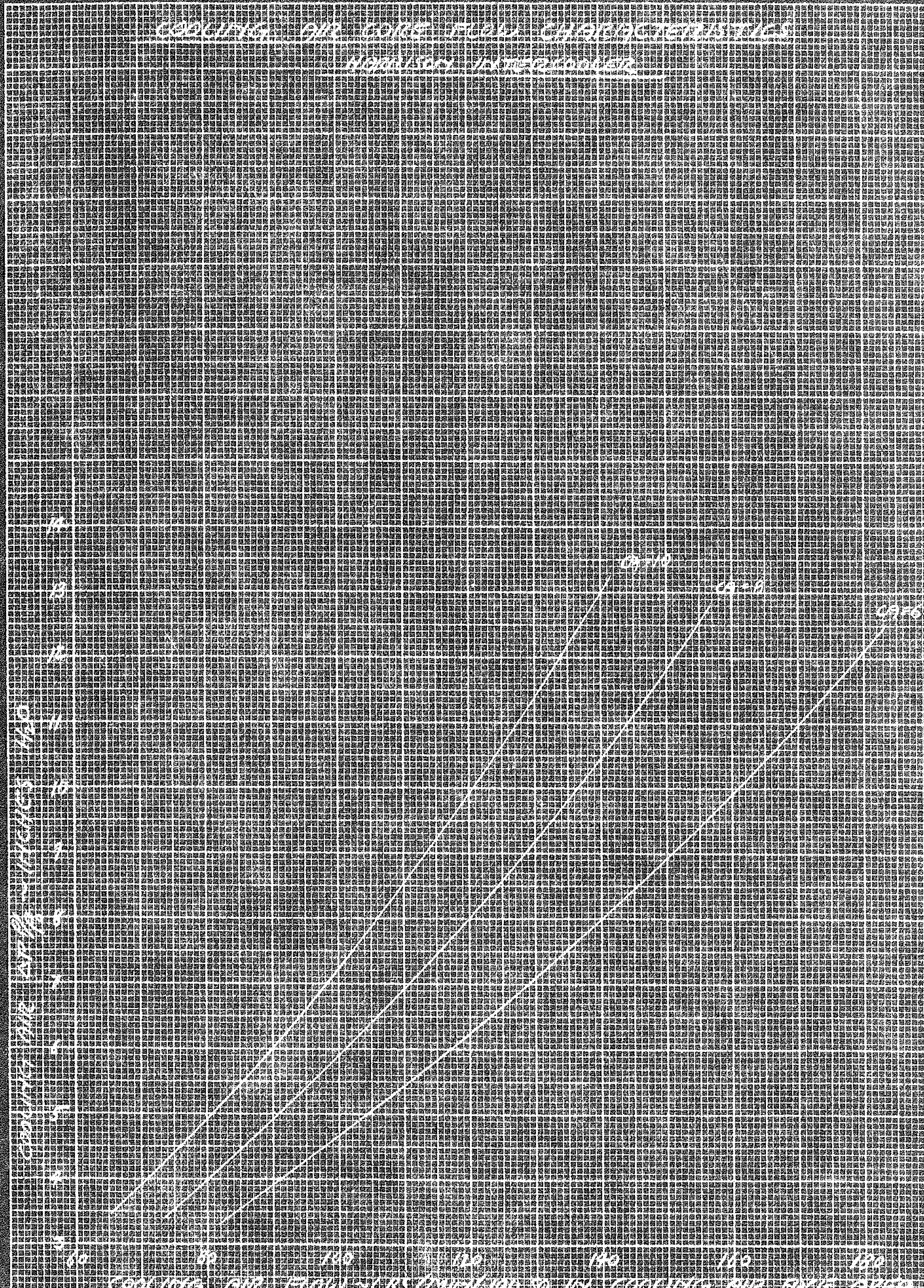

COOLING AIR CORE FLOW CHARACTERISTICS
HARRISON INTERCOOLER
CA=10
CA=8
CA=6
COOLING AIR ΔP ~ INCHES H_2O
3
4
5
6
7
8
9
10
11
12
13
14
60
80
100
120
140
160
180
COOLING AIR FLOW ~LBS/MIN/100 SQ IN COOLING AIR FACE AREA

FIG. 3

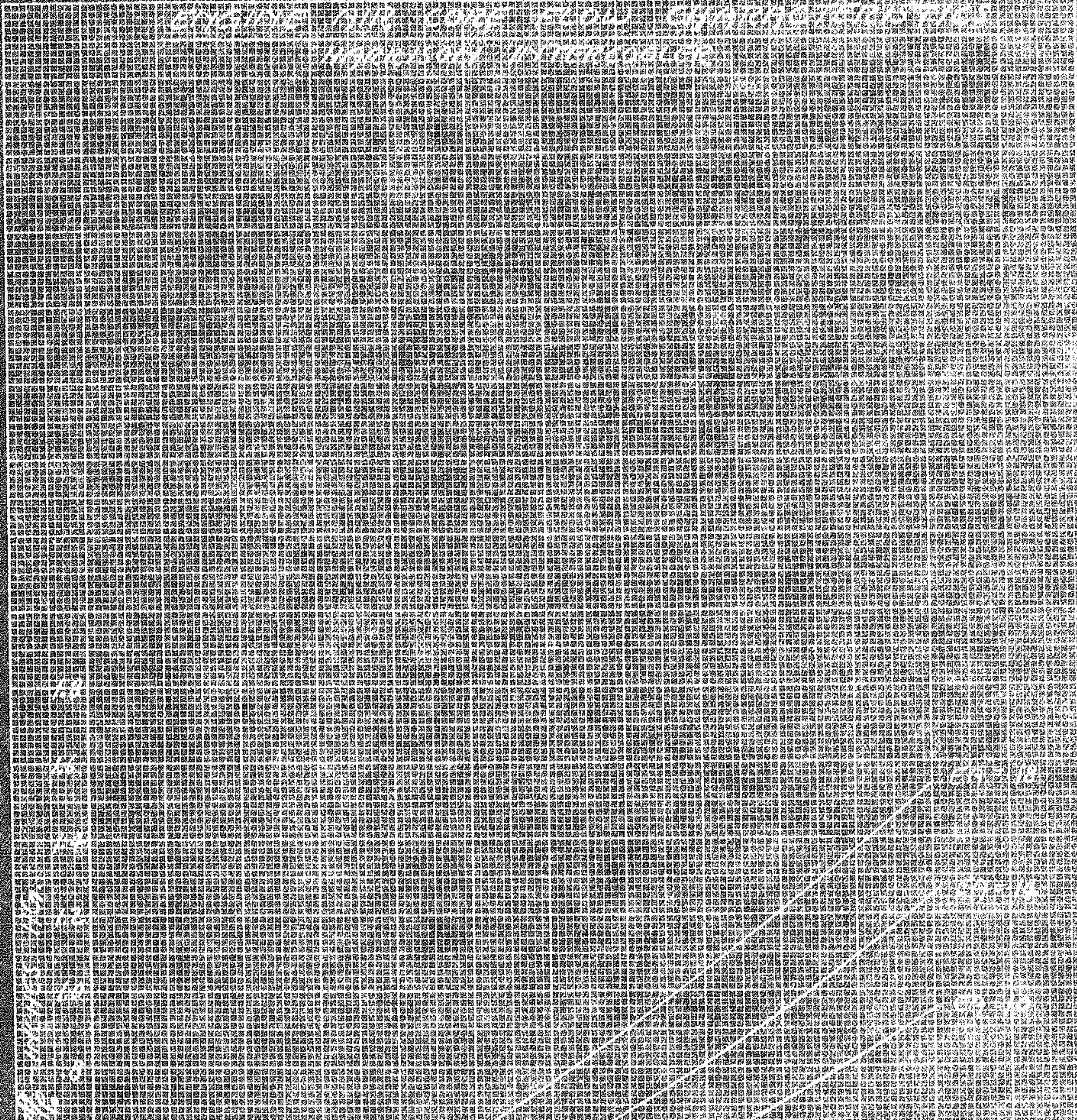

ENGINE AIR CORE FLOW CHARACTERISTICS
HARRISON INTERCOOLER
1.8
1.6
1.4
1.2
1.0
0
40
60
80
100
120
140
ENGINE AIR FLOW LBS/MIN/100 SQ. IN. ENGINE AIR FACE AREA

FIG. 4

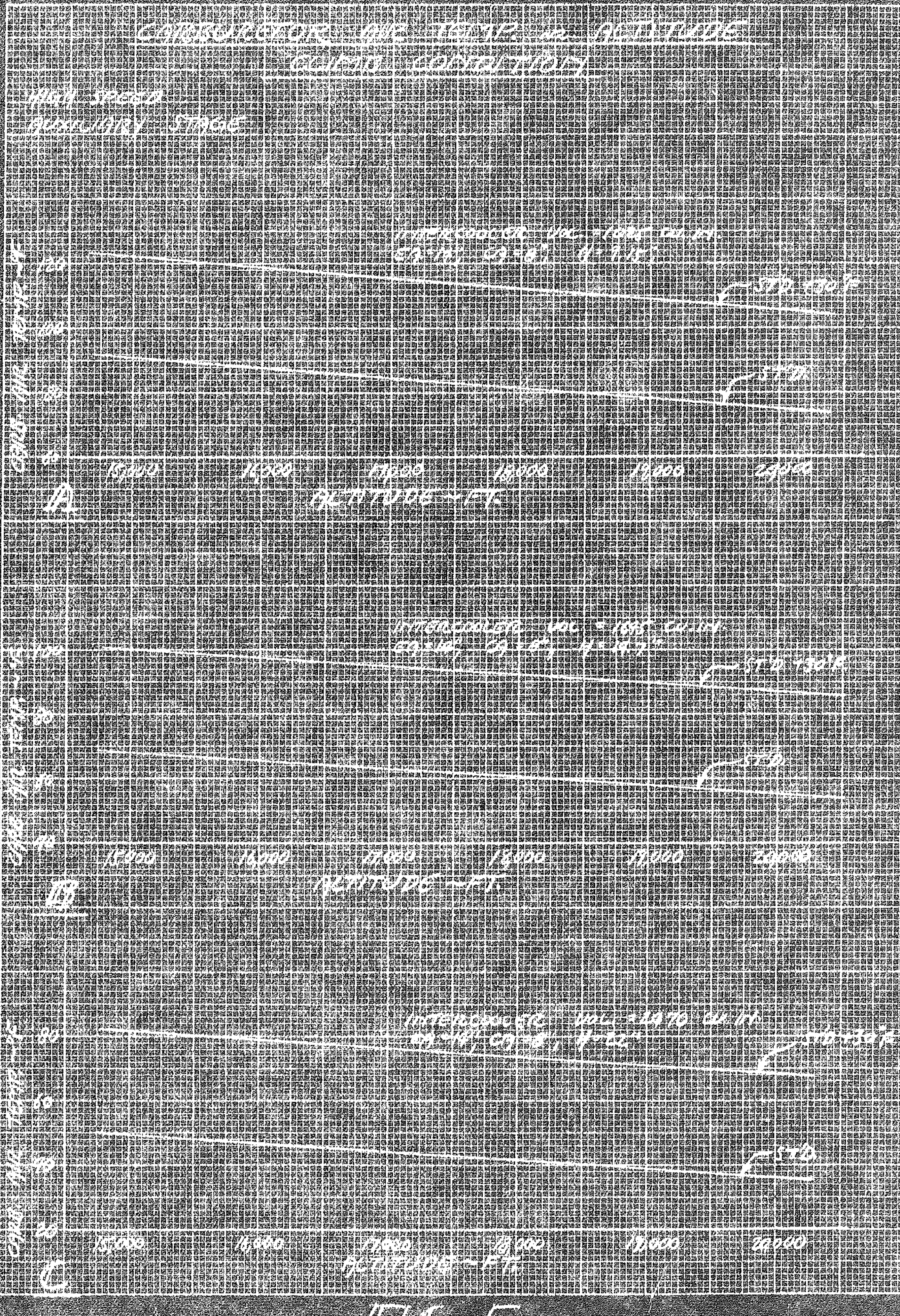

CARBURETOR AIR TEMP vs ALTITUDE
HIGH SPEED
AUXILIARY STAGE
STD +30°F
STD
15,000
16,000
17,000
18,000
19,000
20,000
A
ALTITUDE ~ FT.
STD +30°F
STD
15,000
16,000
17,000
18,000
19,000
20,000
B
ALTITUDE ~ FT.
STD +30°F
STD
15,000
16,000
17,000
18,000
19,000
20,000
C
ALTITUDE ~ FT.

FIG. 5

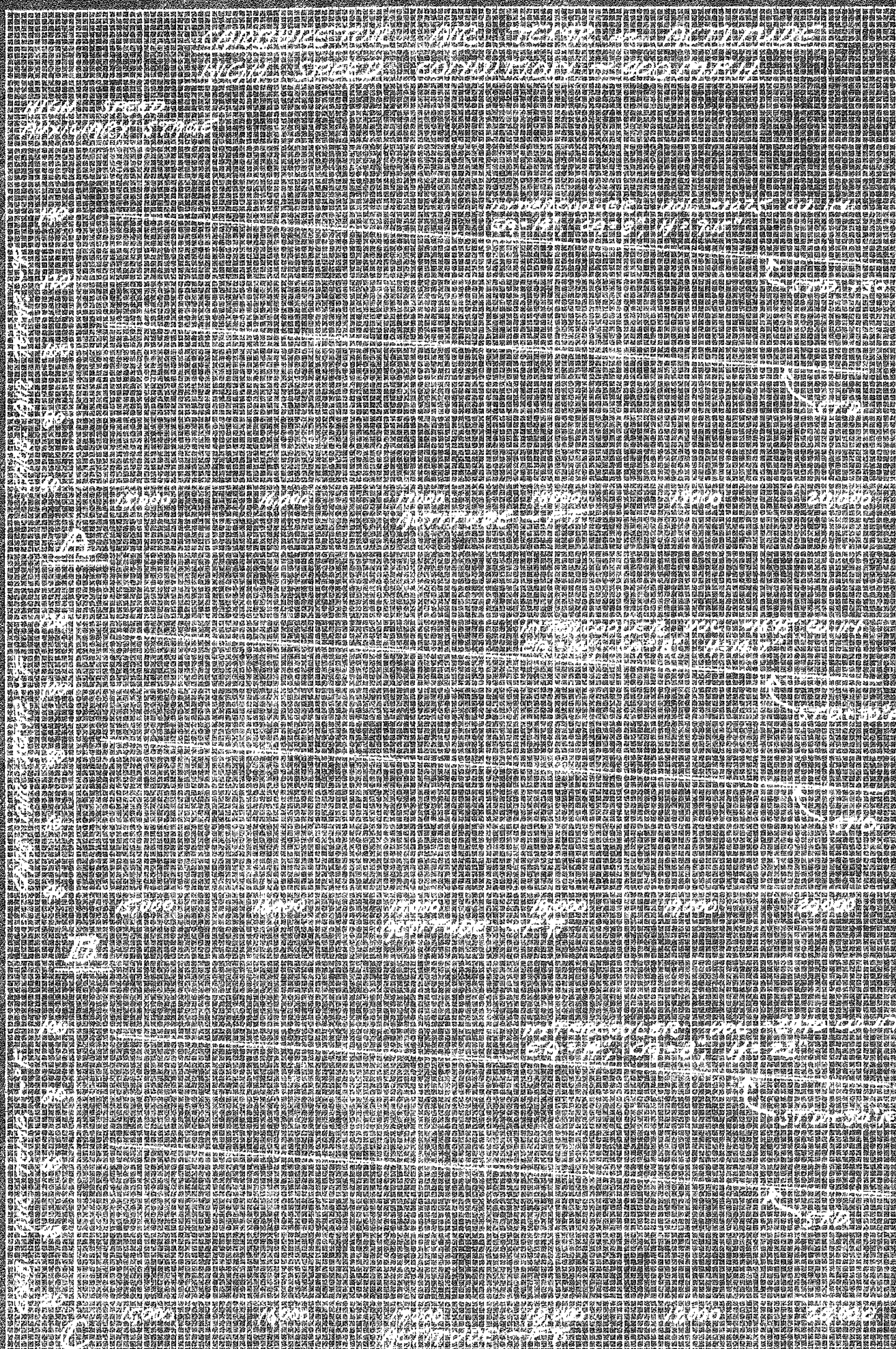


FIG. 6

EFFECT OF CRITICAL ALTITUDE ON INTERCOOLER VOLUME

NOTE: INTERCOOLER VOLUME REQUIRED TO MAINTAIN 100°F CARBURETOR AIR TEMPERATURE IN CLIMB AT CRITICAL ALTITUDE.
VOLUME FOR EACH OF TWO INTERCOOLERS

FIG. 7

EFFECT OF INTERCOOLER VOLUME ON CARBURETOR AIR TEMPERATURE

NOTE: INTERCOOLER VOLUME REQUIRED TO MAINTAIN SPECIFIED CARBURETOR AIR TEMPERATURE IN CLIMB AT 30,000 FT. VOLUMES FOR EACH OF TWO INTERCOOLERS.

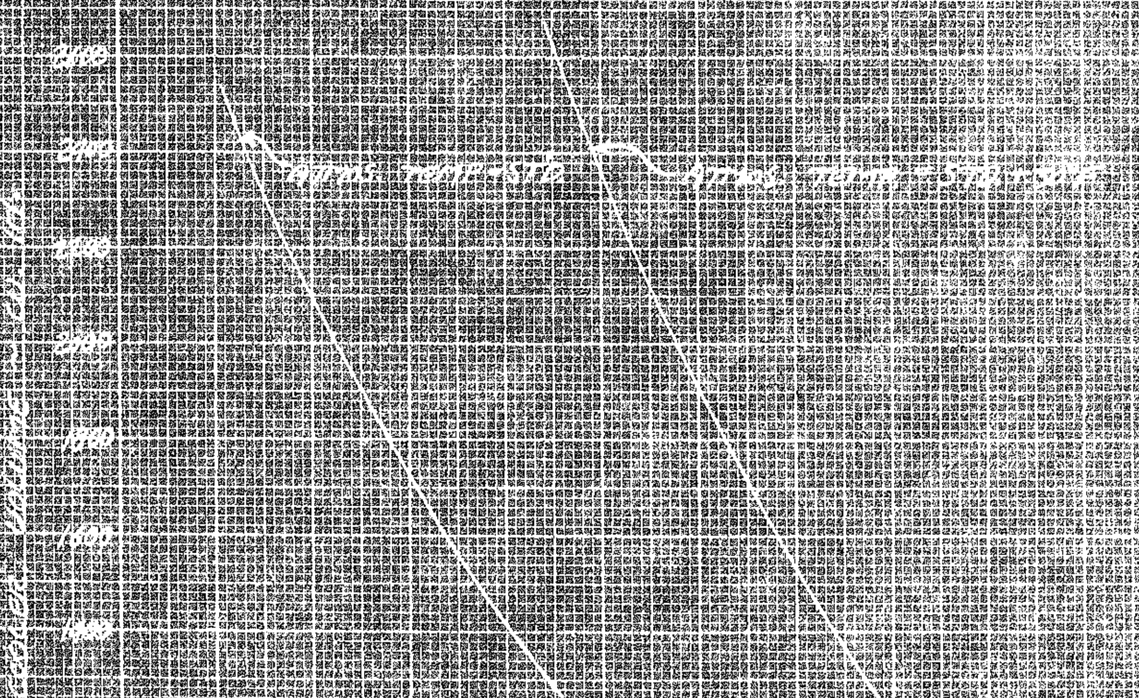


FIG. 8

INTERCOOLER DIAGRAM

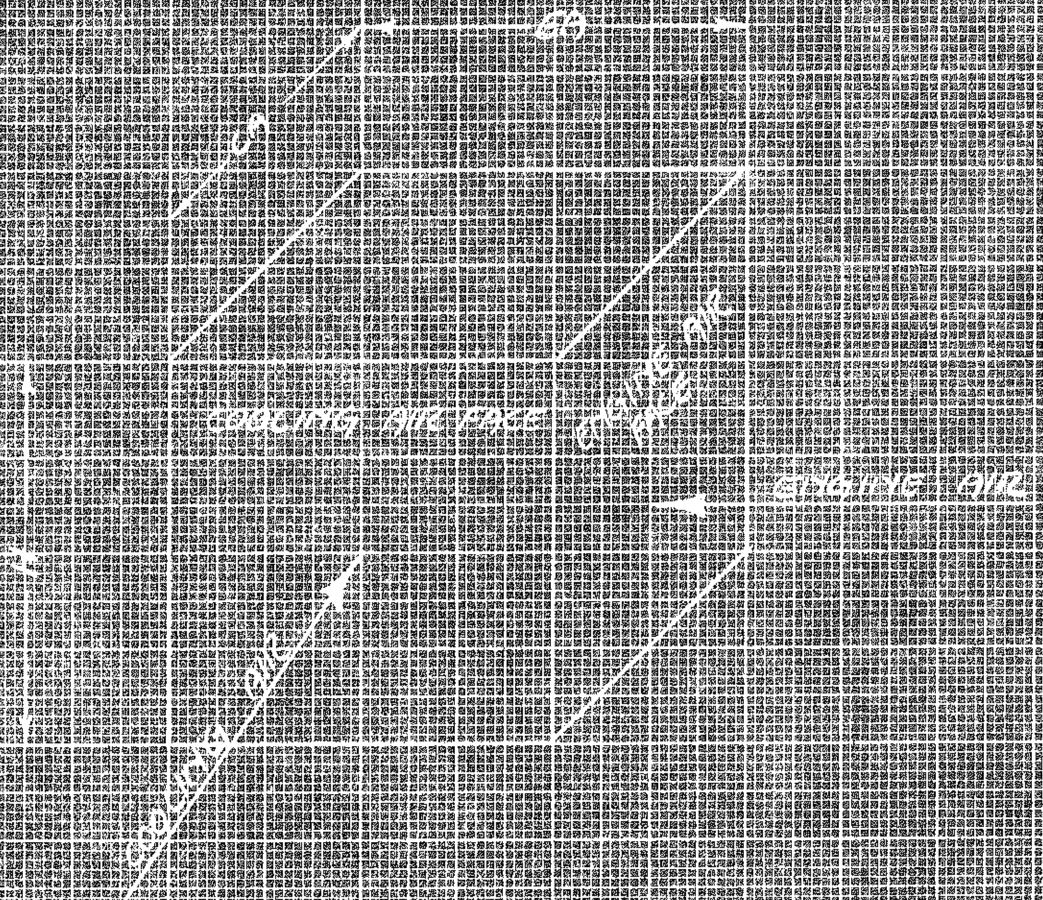


FIG. 9

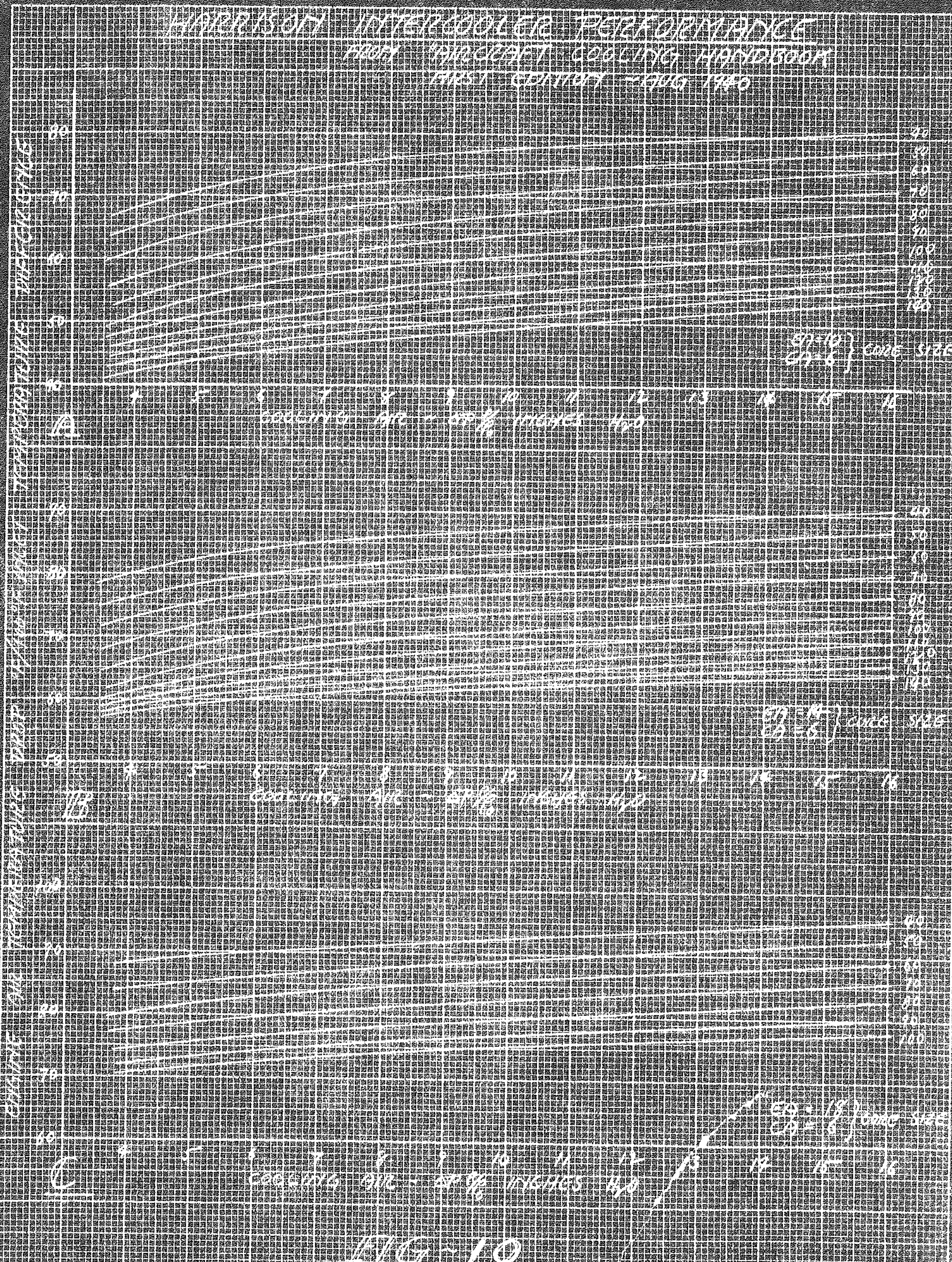

HARRISON INTERCOOLER PERFORMANCE
FROM AIRCRAFT COOLING HANDBOOK
A
B
C
COOLING AIR - INCHES H2O
CORE SIZE
PARAMETER ~ ENGINE AIR FLOW, LBS/MIN/100 SQ IN ENGINE AIR FACE AREA

FIG-10

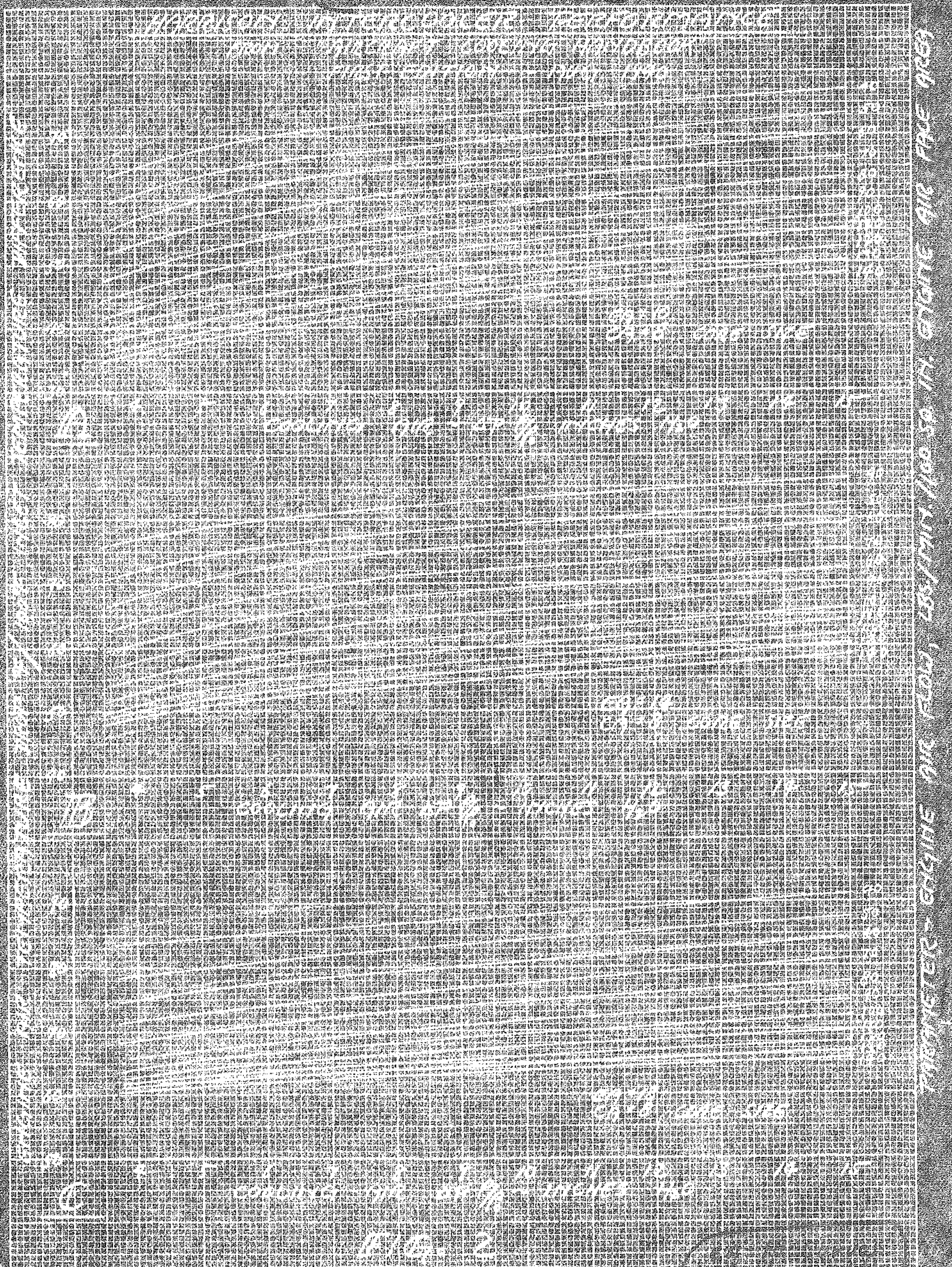
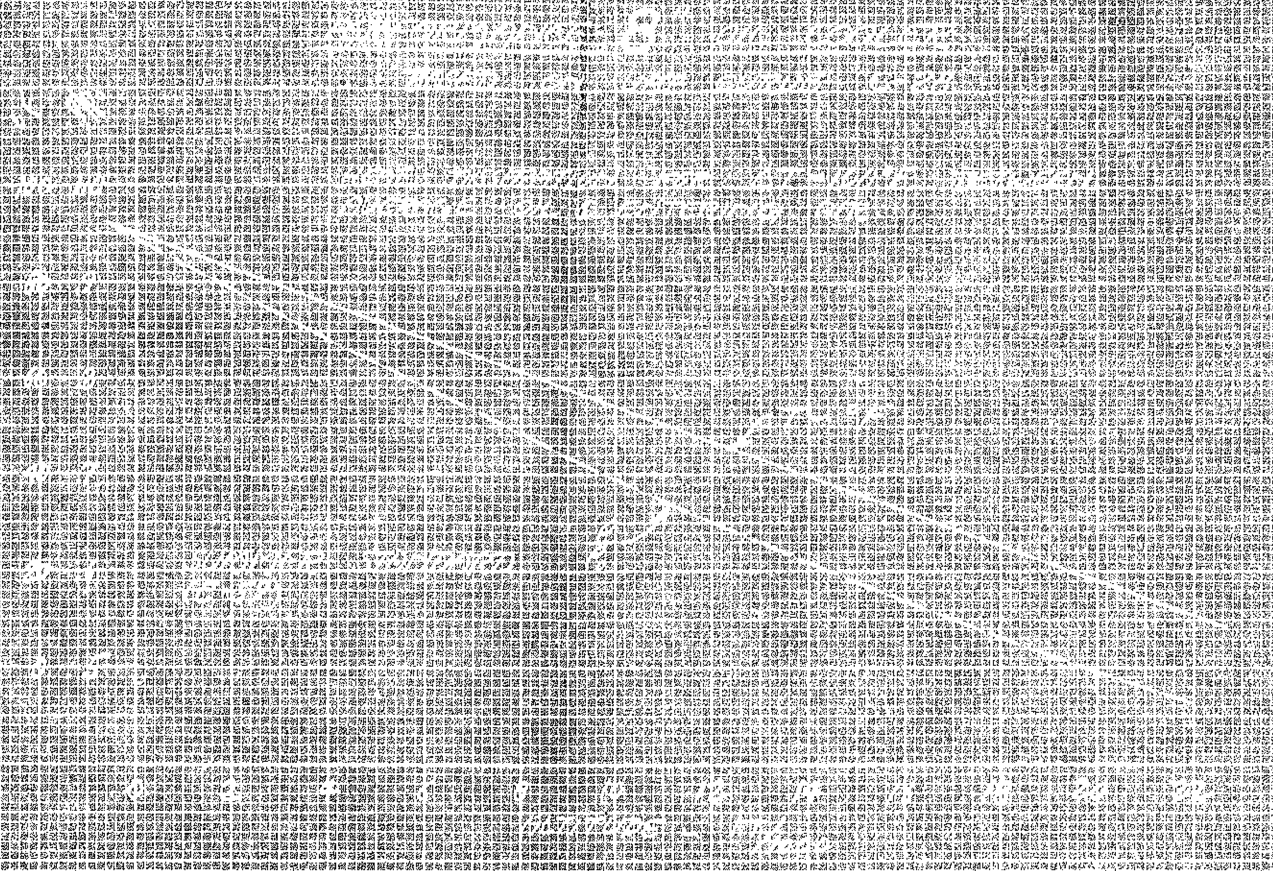

PARAMETER – ENGINE AIR FLOW, LBS/MIN./100 SQ. IN. ENGINE AIR FACE AREA

FIG. 2




20
30
40