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AIR-FUEL RATIO DETERMINATION

A THESIS
Submitted to the faculty
of the College of Engineering
in partial fulfillment of the
requirements for the degree of
Bachelor
of
Mechanical Engineering

by

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FORWARD

"In the beginning there was none and now there is some."

Thus spoke an unknown sage centuries ago with regard to our existence in the realm of reality. While he specifically was speaking in reference to material things coming from nothing, he might also, have been looking at the development of the dynamometer laboratory at the University of Detroit. In its own small way, the evolution of this laboratory from a once fond dream of the department heads and members of the administration, to the marvelous example of inspired student ingenuity and workmenship that it is now, probably parallels any other endeavor which men have made in their ever ceaseless making of something out of nothing. In referring to "nothing" I mean "nothing" with respect to equipment, money and skilled workmen, and not to the absence of existence of anything tangible. To make a statement like that after having spent five years in a Jesuit institution invites either a longer stay so the venerable fathers could change the way of our thinking, or else, direct excommunication.

Ever since the day when the Mechanical Engineering department was given the "OK" to "go ahead and build your dynamometer room," there has been an endless array of students who, not knowing anything in particular about dynamometers, have gone ahead under very able leadership to build one of the finest dynamometer laboratories in this part of the country. As has been stated many times by the man who has had the most to do with the lab since its present construction was started, Professor John J. Uicker: "Maybe we haven't as many chromed bolts and nuts and as much copper tubing, but we can do practically what any of the others can do now, and in a few years we will be able to do anything that they can do." I think that these words have been the watchword of the men who have worked under Professor Uicker's leadership and will be for those who follow in our footsteps.

It has been the practice of those who have been actively employed by the Mechanical Department, when deciding upon the topic of their senior thesis, to try and solve some of the problems relative to the construction of the laboratory, or in the building of the many pieces of equipment so vital to the functioning of a "working" lab. It is through this kind of thinking by the students who have gone before, those of us of the present and they who will be of the future, that this lab has prospered and this thesis of which we now write was made possible.

When in 1949, Gordon Millar, Albert LaRou and

William Walton submitted their thesis titled, "Utilization Of Air-Flow Measurement As An Aid To Internal Combustion Engine Development" and in 1950, when Henry Fedorchuk built his famous fuel-weighing system, the pattern or mold for our thesis was formed. Through combining both Millar's and Fedorchuk's thesises into one compact unit and presenting a method, whereby, the results of the individual elements could be correlated, a new thesis was born, as was a fine piece of usable equipment. It is this accomplishment that is the thesis of which we write.

When our thesis, which we call "Air-Fuel Ratio Measurement," had its inception, it was originally planned to have two units, one to measure the air and another to measure the fuel. During its construction, however, it was decided that the two pieces of equipment would take too much room in the already crowded lab, and so the two units were joined in matrimony, as it were, to exist as one. In this respect, the authors owe a great deal of gratitude to two of the young engineers employed by the Department in the dynamometer lab, Mr. Arthur Hammond and Mr. Peter Pentescu, for their very helpful suggestions.

It is sincerely hoped that the development of what we hope to be a very valuable piece of equipment during this project, will materially aid future internal combustion engine work at the University of Detroit.

ACKNOWLEDGEMENTS

The writers wish to achnowledge the following people for their very helpful advice and material aid:

Professor John J. Uicker, for many patient hours spent in consultation, practical hints on laboratory procedure and for his many inspiring lectures when they were needed to keep body and spirit functioning as a team.

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Mr. Arthur Hammon, without whose wide practical experience our never ending flood of questions concerning construction would have inundated.

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Mr. Victor Wiktorowski, without whose many patient hours with a paint brush, the unit would be drab and not befitting the part it is to play in the laboratory.

Mr. Y.W. Yamauchi, for his many practical hints and suggestions relative to the solving of some of the most difficult problems encountered.

Professor L.S. Johnston, for his generosity in lending us the manuscript of his latest book on Nomography, without which the calculation and construction of the correction charts used in this thesis would not have been possible.

Pat and Fran, without whose inspiration and constant spuring of our ambitions, this thesis would never have been completed on time.

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ABSTRACT OF THESIS

One of the problems encountered in internal combustion engine analysis is the accurate measurement of the air-fuel ratio. In order to produce the highest specific power output, it is of great importance to have the correct air-fuel ratio corresponding to the load on the engine.

This thesis attempts to utilize the results of two former thesises in the development of a unit capable of determining the air-fuel ratio of an engine under varying load conditions. The authors of this thesis have tried to improve on both the design and the method used in interpreting the results of each unit.

If we can determine from the Millar thesis the amount of air that an engine uses for a specific period of time under a known load condition, and from Mr. Fedorchuk's thesis, the amount of fuel consumed by the engine for the same period of time and put these results together, we have the air-fuel ratio for the engine corresponding to the load and time period under consideration. This, then, is the crux of our endeavor.

A procedure to be used by those attempting to determine the air-fuel ratio of engines with this device has been prepared and appears in the thesis proper. In an

attempt to prove the worth of this apparatus, a number of tests on a Dodge truck engine were performed. During these tests an attempt was made to determine the air-fuel ratios under varying load conditions. The results of these tests can be found in the appendix.

It has been concluded that the apparatus developed during the course of this project, if used with reasonable care, can be used very successfully for air-fuel ratio determination.

CHAPTER I

DESIGN AND CONSTRUCTION OF RACK

The rack is the framework which houses the air-fuel ratio measuring apparatus. The dimensions are such as to raise the outlet ports of the plenum chamber to a height of six feet above the floor and yet to maintain stability with regard to location of center of gravity when the fuel system is installed. Angle iron, $2\frac{1}{2}$ x 2 x $\frac{1}{4}$, was used throughout and all joints are electrically welded.

Shelves to hold the plenum chamber, the relay board for the fuel-measuring system, the fuel-measuring system itself, and to store the orifices and carburetor adopters, have been placed within the unit. These shelves with the exception of the one holding plenum chamber, are of 5/8 inch plywood bolted to angle-iron braces. The locations of these shelves in the unit are such as to permit adequate space for the separate parts of the apparatus.

Enclosing the framework is 1/2 inch plywood fabricated in such a manner that no fastening devices can be seen. The panels are held to the framework by wood screws inserted from the inside. Provision has been made for removing the panels which would permit access to the vitals of the unit either for inspection or for work. These panels are fastened from the outside by 5/16 inch wing-nuts which are turned onto 5/16 inch studs set into the framework. On the front panel is mounted a chart table which holds both the individual orifice charts and the nomographic charts in a position to facilitate use. On the under side of this chart table is a small sheet-metal pan which holds the charts not being used. This sheet-metal pan is constructed in such a manner so as to have a small lip at the front which prohibits the charts from falling out of the pan when the apparatus is being moved. Indentations have been cut into the holding pan so as to make removal of the charts an easy task.

The entire unit rolls on swival type casters of sufficiently rugged construction as to enable them to hold 300 pounds per caster. The wheels are five inches in diameter, one inch in tread width and made of rubber. The large wheel and heavy-duty type construction enables the unit to be moved about over rough terrain without the possibility of the casters failing or getting caught in large cracks or troughs. These casters have been welded to the frame and thus no future loosening of the caster plates need be feared. In an attempt to make the unit as stable as possible during the tests and in order to store the unit without fear of its moving from its placed position, two of the four casters provided, are of the locking type.

The plenum chamber has been provided with a sheet metal housing, with provision on the orifice end for the orifices. The entire unit has been painted with two coats of machine tool grey to match the color scheme of the apparatus in the dynamometer laboratory.

CHAPTER II

THE AIR-MEASURING SYSTEM

The air-measuring system makes use of orifices which have been calibrated with a plenum chamber and the results presented in the form of curves plotted on Cartesian Coordinates. On these coordinates, the obscissas represent the pressure drop across an orfice and on the ordinate is plotted the quantity of dry air used in pounds per minute as metered by the orifice.

Air-flow measurement tanks for use in internal combustion engine analysis are not new. For many years they have been used in one form or another and the design limits of the tanks are pretty well established. There are three prime considerations which must be born in mind when selecting a tank that will serve with the degree of accuracy required. They are as follows:

1. The volume of the tank must be large enough to dampen out all pulsations that could possible be transmitted from the intake manifold of the engine to the manometer used to determine the pressure drop across the orifice.

2. The total pressure-drop across the tank should not exceed the pressure drop of a good quality air-filter when used at the same air-flow rates.

3. The measuring orifices should be easily inter-

changeable in order that the various sizes can be installed during a run in a minimum of time.

The plenum chamber used by Millar in 1949, to calibrate orifices satisfies the above requirements with respect to design. Therefore, we are using in this project the air-measuring system as designed by Millar in 1949.

The orifices to be used in this air-measuring system will measure air in the range as tabulated below:

Orifice Number	Range (# dry air/hour not corrected)
1	40-180
2	85-300
3	150-580
4	250-900
5	450-1290

The following table gives an indication of the range of engine sizes which can be tested with the available orifices:

Engine Displacement	RPM	#/hr. (80% Vol. Eff.)
65	4,000	254
135	3,600	508
235	3,600	884
377	3,600	1415

It can be readily seen that all but the largest displacement engine can easily be tested by the orifice range possessed at this time. At any rate, construction of a larger orifice could be carried out at a later date.

After deciding upon the feasibility of utilizing the air-measuring system developed in 1949, it was necessary to locate the tank and the orifices. After many arduous days of searching the tunnels under the engineering building, the authors were rewarded by finding a rusted old fifty-five gallon oil drum and five orifices which, by noting the markings on them, were found to be those used in Millar's tests in 1949. We were also able to verify the fact that the drum we found was the air-measuring tank used by Millar in conjunction with these same orifices. This was accomplished by noting in Millar's thesis write-up that he had painted a large "A" in yellow on the drum and had welded two three inch outlets to the side of the tank. These same conditions were present on the drum we found. Also, we were able to find the hole which had been drilled for the manometer tap. The description of the orifice backing plate in the thesis matched the plate with the hole in it which was found welded to one end of the barrel. Taking all these facts into consideration and also the verbal testimony of certain members of the department, namely, Professor J.J. Uicker, Mr. Henry

Fedorchuk and Mr. Y.W. Yamauchi, all of whose words are above reproach, there can be absolutely no doubt as to the veracity of this being the air-measuring system calibrated by Millar in 1949. Therefore, in lieu of this fact, the authors have every right to use the charts presented in the written thesis with the orifices and plenum chamber found in the basement of the engineering building and expect that the results of the measurements taken with this system will be as indicated in Millar's thesis of 1949.

In order that the fifty-five gallon drum be used as the plenum chamber in our thesis it was necessary to be sure that it was in good repair. Accordingly, after a thorough inspection, it was found that the manometer tap would have to be repaired and the threaded studs used to hold the orifices onto the plenum chamber, having been broken off at some time or another, would have to be drilled out of the orifice backing plate. After these repairs were made the drum was cleaned of rust inside and out, all the dents that could be removed were hammered out and the outside painted machine tool grey.

It was necessary to enlarge the diameters of the holes drilled through the periphery of the orifices in order that the threaded studs holding the orifices to the backing plate could pass without interference. The orifices are held in place on the backing plate by wing nuts turned onto the threaded studs. Be using these wing nuts instead of the conventional type it is possible to change the orifices in a minimum of time.

The plenum chamber was then mounted on the framework at the very top, where it set into a cradle fashioned of angle iron. The tank is made fast to the framework by anchoring it to the cradle with aluminum cable drawn tight around the periphery of the drum at each end.

There are two four inch flexaust hoses which attach to the outlets on the side of the tank to carry the air from the plenum chamber to the carburetor air-intake. As the outlets are three inches in diameter and the hose four inches, an adapter for each outlet was made by machining a three inch coupling to an outside diameter of four inches. These adapters are turned onto the threaded outlets by means of a Spinner wrench. When engines with only one air intake are being tested, the second tank outlet is closed off with a three inch plug which screws into the adapter and the hose can be stored on the bottom shelf of the framework.

As the size of the carburetor air-intakes vary with the particular engine under test, it was necessary to construct transition pieces for each of the engines being used in the dynamometer laboratory. These adapters make it possible to use the same four inch hose for all the engines. The adapters are constructed of galvanized sheet-metal. The method of construction is that used by practicing sheet-metal contractors and is described as follows:

1. The sizes of the two ends of the transition piece is first determined.

2. The process of surface developing the piece to be made and cutting a pattern out of paper is performed.

3. The pattern is transferred to the metal and the piece cut out.

4. The sheet metal layout is then rolled and formed to the desired shape and the joints soldered.

Transition pieces constructed in the manner just described have been made for the following engines used in the dynamometer laboratory. The 1953 Hudson pacemaker, 1952 Lincoln, 1938 Dodge truck engine and the 1950 Continental Industrial engine. When it is desired to determine the air consumption of engines other than these just mentioned, it will also, be necessary to construct transition pieces for them. The transition pieces, as otherwise the orifices, and unused hose, are stored on the bottom shelf of the unit. They can thus be carried with the unit whatever its orientation.

The manometer selected to determine the pressure differential across the orifices is an Ellison Inclined Draft Gage. This instrument has a range of four inches of water and can be read accurately to 0.01 inches. The indicating medium used in the manometer is Ellison petroleum oil of specific gravity 0.834.

Within the draft gage unit is a bubble level. This level is used to indicate whether or not the unit can be used with accuracy in determining pressure differential. The monometer casing itself is mounted to a leveling device which enables the unit to be used under conditions where the floor is not level. By turning the adjusting screw which is connected to the leveling device, the manometer can be leveled as indicated by the bubble gage.

The correction curve which has been determined for the manometer was obtained in the following manner: the manometer unit was leveled by sight, utilizing the bubble leveling gage contained within the unit; by means of a Hook-Gage calibrating device, the manometer error was determined over the entire range of from zero to four inches; plotting the correction which must be added algebraically to the indicated manometer reading, against the indicated monometer readings established our correction curve. This correction curve can be used with reasonable accuracy in determining the corrected manometer reading of any run if the bubble gage is kept level, as per calibration conditions.

It can readily be seen from the air-measuring system set-up that the manometer, which is an inclined draft gage, measures the drop in pressure experienced by the air as it is accelerated in velocity passing through the orifice. The orifice itself, being mounted on the outside face of one end of the plenum chamber, is under no pressure other than atmospheric. Therefore, it can be seen that the manometer measures the amount of vacuum produced by the air flowing through the orifice with respect to atmospheric pressure. It is also obvious, that in order to accurately determine the quantitative rate of flow of air, under conditions differing from those of calibration, factors other than merely barometric pressure must be considered. These factors are relative humidity and temperature, and are taken into account as correction factors in chapter four.

CHAPTER III

FUEL-MEASURING SYSTEM

The fuel-measuring system as it now exists in the "Air-Fuel Ratio Measuring Unit" could hardly be recognized as being the fuel-measuring system devised and constructed by Mr. Fedorchuk in 1950. The basic elements, as likewise, the system of measurement itself remain. With respect to other than these two considerations, however, the unit is entirely new. The authors would like to let it be known at this time that in order to produce results with this unit, which would be sufficiently accurate for laboratory work, it will be necessary to calibrate this unit with respect to quantitative flow rate. The authors regret that due to lack of sufficient time, it was not possible for us to calibrate the unit as we would have liked to have done. The new unit as it stands, however, except for the fuel system calibration already mentioned, is ready for use. It is suggested by the authors that the calibration of the fuel system take place as soon as is convenient, either as a thesis project or as a private work project of the laboratory crew.

FUEL-MEASURING SYSTEM DESIGN

The fuel-measuring system as redesigned by the authors has in it a head tank which has connected to it the main feed line from the dynamometer fuel pump system. In the dynamometer room there is maintained by means of an automatic regulating valve at the main pump line, a pressure of three psi, on all panel fuel feed lines. By means of an air-escape valve on the top of the head tank a desired head in the tank can be arrived at and maintained. On the opposite side of the head tank connected by 3/4 inch sweat fitted copper tubing, is a 3/4 inch, two way 110 volt, sixty cycle, A.C. operated solonoid valve of explosion-proof construction. Connected to the solonoid valve by sweat fitted copper tubing is a weighing tank situated on a balance scale. Between the head tank and the fuel-weighing tank located at the top of the tanks is a 5/8 inch plastic hose which permits the maintenance of a pressure equilibrium between the two tanks. On the fuel-weighing tank side of the solonoid valve there is situated in the 3/4 inch line, a 3/4"-3/4"-3/8" sweat fitted tee. The 3/8 inch line from the tee is the engine feed line and has in it a Carter ceramic filter. The reason for having the filter in the line is to eliminate the possibility of foreign matter such as rust or dirt from entering the fuel pump mechanism of the engine under test. Connected in series with the filter and situated between the filter and the tee, is a manually operated drain-valve which has copper tubing extending through the flooring into a drain tank. The reason for having this valve in the line is in order to be able to drain the entire system of fuel when finished testing. The drain valve was installed in this line because the engine feed line is the lowest line in the system and thus, hydrostatically, is the best drain line.

In order to provide faster filling of the fuel-weighing tank under large fuel consumption conditions, a second line to the fuel-weighing tank was installed. This line is ½ inch in diameter and has connected in it a ½ inch, 110 volt, sixty cycle, A.C. operated solonoid valve which is operated by a switch situated on the back panal in the lower right hand corner. By opening this valve, fuel flows directly from the main head tank supply line, which is under room pressure of three psi., to the fuel-weighing tank. Connecting the solonoid valve to the fuel-weighing tank is plastic hose which permits different orientations of the tank due to the scale balance. Wrapped around this plastic hose and the plastic hose connected between the 3/4 inch tee and the fuel-weighing tank, is fine wire which prevents the hose from kinking and thus prevents possible constriction of the fuel flow.

A micro-switch is situated on a piece of wood in such a position so as to be able to make and break contact depending upon the position of the scale platforms. This micro-switch is connected to the relay board located above and controls the opening and closing of the solonoid valve situated in the line connecting the head tank to the fuel-weighing tank. It also starts and stops the timer which measures the time necessary for the consumption of a given weight of fuel. The micro-switch is set to operate whenever the scale pointer passes the "O" position on the dial.

THEORY

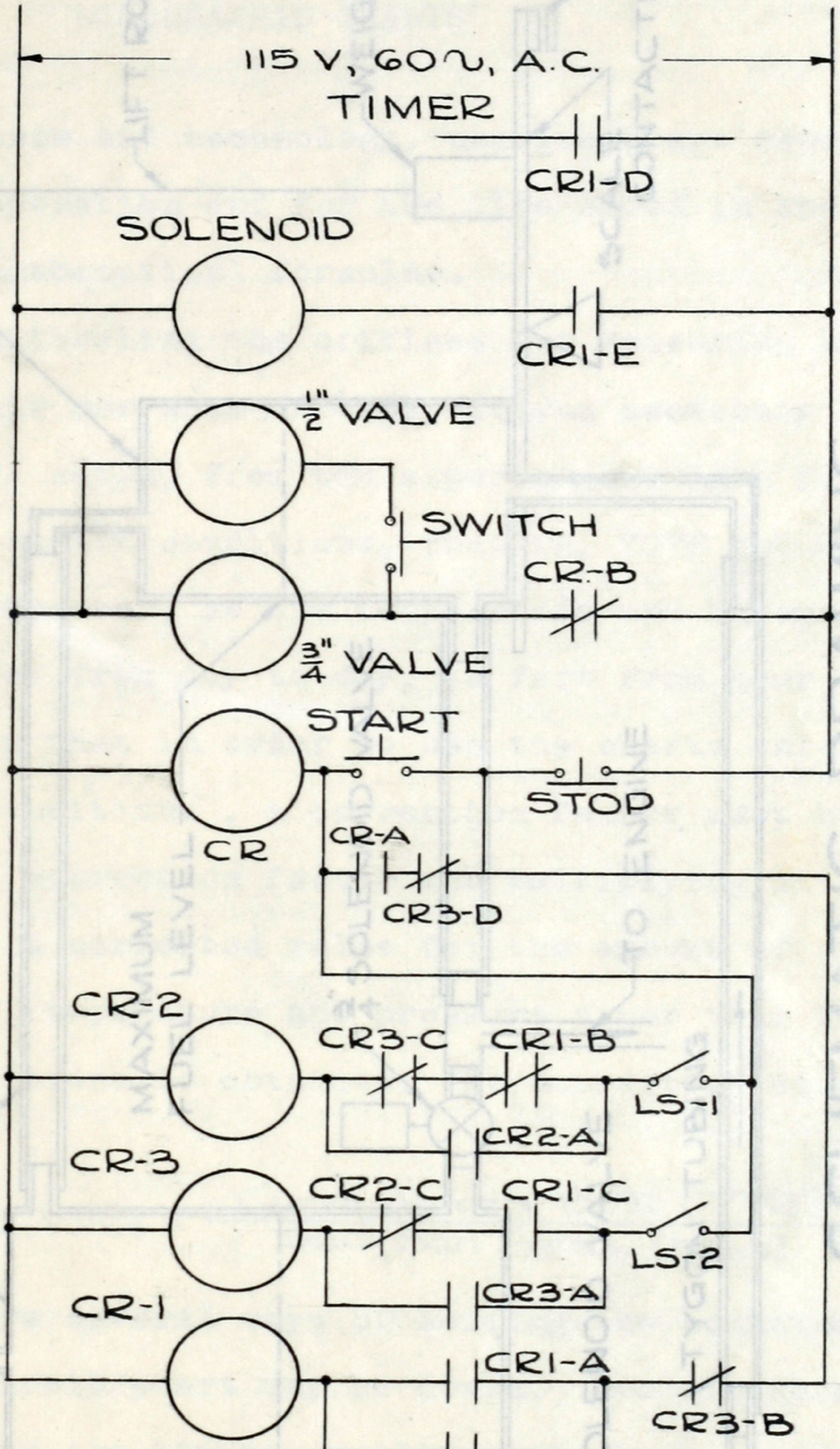
The theory behind the operation of this fuel-measuring system is briefly as follows:

Fuel can flow from the head tank through an A.C. operated solonoid valve to a fuel-weighing tank mounted on a platform scale. Connected into the line feeding the fuel-weighing tank and located between the solonoid and the tank is a tee, one end of which feeds the engine. When the solonoid valve is opened and the engine is being fed from the engine feed line, fuel flows from the head tank through the solonoid to both the engine and the fuel-weighing tank. It is in this manner that fuel is gotten into the fuel-weighing tank. If the solonoid valve is then closed, the engine will draw its fuel from the weigh tank mounted on the platform balance. As the engine consumes fuel from the weigh tank, the scale will come to balance with the weights which have been placed on the opposite platform. When this occurs, the micro-switch which is located in a position so as to be tripped by the movement of the platform, is actuated. This action starts a timer and energizes a motor which raises a one pound weight from the platform. The scale then becomes unbalanced with the fuel-weighing tank on the heavy side. Since the scale was balanced before the one pound weight was removed by the motor, it now stands to reason that the amount which the scale is unbalanced is equivalent to the weight which was removed, or, one pound.

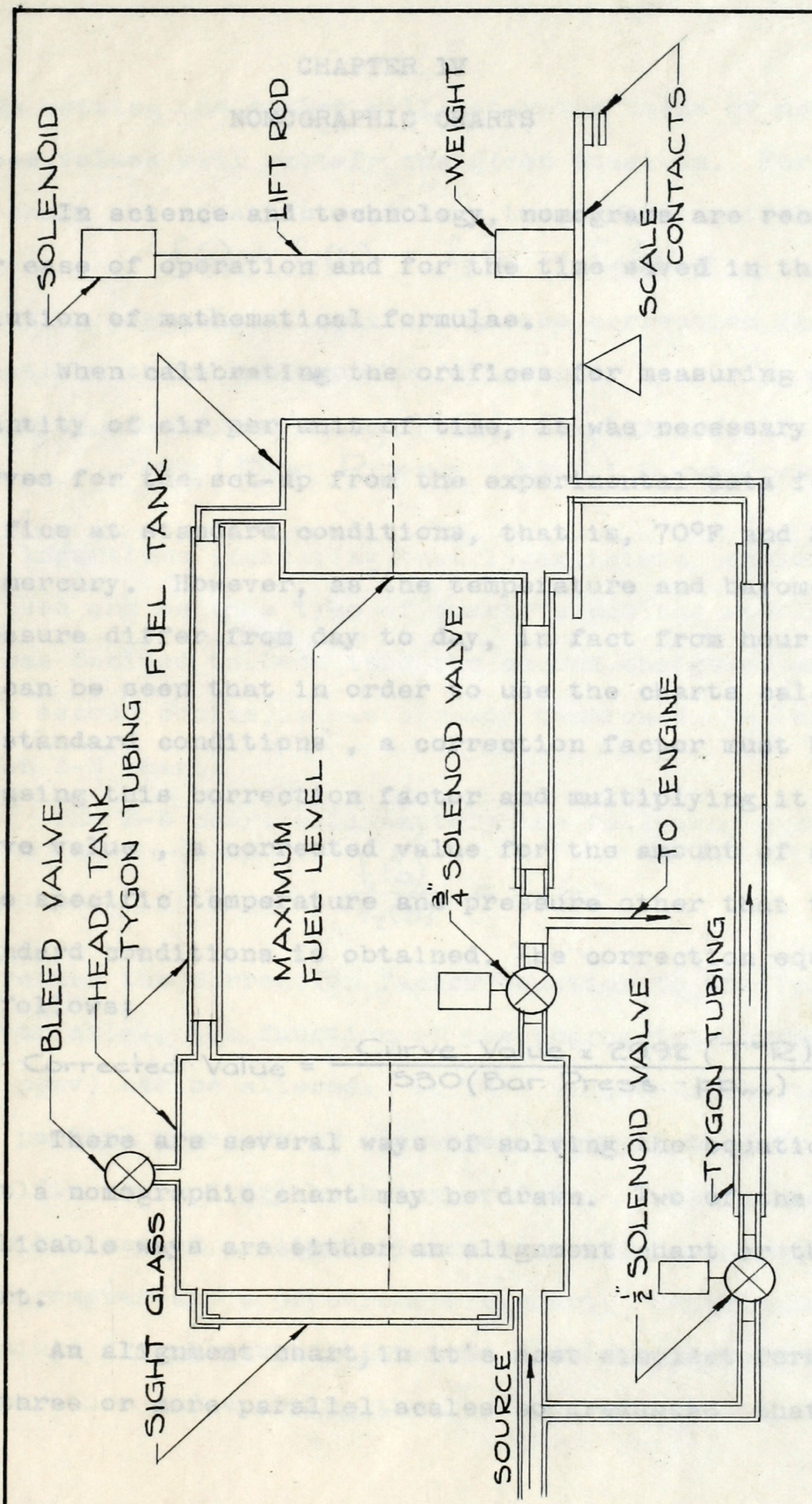
As the engine draws fuel from the fuel-weighing tank, the scale tends to balance out once again. When an amount of fuel, equal to the weight which was removed from the other side, is consumed from the fuel-weighing tank by the engine, the scale will once again balance. At this time the micro-switch is once again tripped and a result, the timer is stopped and the motor which had been holding the measuring weight off the opposite platform is de-energized permitting the weight to rest once again on the platform. Also occuring as a result of the micro-switch being tripped is the energizing of the solonoid valve in the line connecting the head tank to the fuel-weighing tank. This permits the engine to once again draw fuel from the head tank, and also, starts the recharging of the fuel-weighing tank.

As a result of the head tank and the fuel-weighing tank being connected at the top by a plastic hose, there exists between the two tanks an equilibrium of pressure. By means of this equilibrium there can be maintained any desired level in the two tanks by operating the air-escape valve on the head tank.

Difficulty was encountered with respect to the filling of the fuel-weighing tank when an engine was operating at a high fuel consumption rate. The head tank was unable to supply, hydrostatically, sufficient fuel for both the engine and the weigh tank. It was then decided that an auxilliary method of filling the fuel-weighing tank was necessary to permit operation under heavy fuel consumption conditions. This was accomplished by installing a separate line from the main feed directly to the fuel-weighing tank. Into this line was placed an A.C. operated solonoid valve similiar to the main control valve in the main supply system of the unit. This valve was connected to aswitch which could be manually operated when the occasion demanded it. By means of this set-up the operators could, when the condtions ofthe test warrented it, throw the auxilliary feed system into operation. Caution must be exercised in using this auxilliary feed system however, as if it is allowed to remain in operation for too long a period, flooding of the system is possible.



CONTROL CIRCUIT



SCHEMATIC DRAWING OF DEVELOPED WEIGHT MEASURING SYSTEM

CHAPTER IV

NOMOGRAPHIC CHARTS

In science and technology, nomograms are recognized for ease of operation and for the time saved in the repeated solution of mathematical formulae.

When calibrating the orifices for measuring a certain quantity of air per unit of time, it was necessary to draw curves for the set-up from the experimental data for each orifice at standard conditions, that is, 70°F and 29.92 in. of mercury. However, as the temperature and barometric pressure differ from day to day, in fact from hour to hour, it can be seen that in order to use the charts calculated at standard conditions , a correction factor must be derived. By using this correction factor and multiplying it by the curve value , a corrected value for the amount of air at some specific temperature and pressure other that that of standard conditions is obtained. The correction equation is as follows:

$$\text{Corrected Value} = \frac{\text{Curve Value} \times 29.92\,(T^{\circ}R)}{530\,(\text{Bar. Press.} - pp_{wv})}$$

There are several ways of solving the equation so that a nomographic chart may be drawn. Two of the more applicable ways are either an alignment chart or the Z-N chart.

An alignment chart, in it's most simplest form, consists of three or more parallel scales so graduated that a straight line cutting the scales will determine three or more points whose values will satisfy the given equation. For this type of chart the equation must have the following form:

$$f_1(a) + f_2(b) + f_3(c) = f_4(d)$$

Applying the general equation to the correction factor equation, there evolves the following:

$$\log(\text{Curve Value}) + \log(T^\circ R) + \log(.0564) - \log(\text{Bar. Press.} - pp_{wv}) = \log(\text{Corr. Value})$$

The logarithms indicating that logarithimic scales must be used and as this type of chart is not too easily drawn, it was decided to look into the second choice of solution. This second choice, as was already mentioned, is the combination Z-N chart.

The Z-N chart will satisfy the following equation:

$$\frac{f_1(a)}{f_2(b)} = f_3(c)$$

To reduce the correction factor equation to the least number of variables, the function of the (barometric pressure - the ppwv) can be altered. It is a simple matter to obtain the partial pressure of the water vapor in the air at some specific wet and dry bulb temperature. This can be done with the use of a sling psychrometer or an aspiration psychrometer and a psychrometric chart. Using values obtained from the chart for some specific wet and dry bulb temperature and applying them to the following equation:

$$RH = \frac{pp_{wv}}{p_{sat}}$$

wherein R.H. is the relative humidity, ppwv is the partial pressure of the water vapor in the air, p_{sat} is the pressure at which saturation occurs corresponding to a specific temperature. This value is obtained from the steam tables.

Applying the results of the above equation to the correction factor equation produces an equation with three variables and determines one of the unknowns. As the Z-N chart will only satisfy two variable and one unknown, it is necessary to break down the equation further. In order to show this, a general equation will be set up and the solution to the actual equation will come later.

The general equation for a Z-N chart as stated before in this chapter is as follows:

$$\frac{f_1(a)}{f_2(b)} = f_3(c)$$

The correction factor equation has the following form:

$$\frac{f_1(a) \cdot f_2(b)}{f_3(c)} = f_4(d)$$

wherein all functions are the variable quantities and function sub 4 is called the unknown quantity. Rearranging the equation so that it appears thus:,

$$\frac{f_1(a)}{f_4(d)} = \frac{f_3(c)}{f_2(b)}$$

and by letting each equation be equal to some other quantity for example say function sub 5, the following form appears:

$$\frac{f_1(a)}{f_4(d)} = \frac{f_3(c)}{f_2(b)} = f_5(x)$$

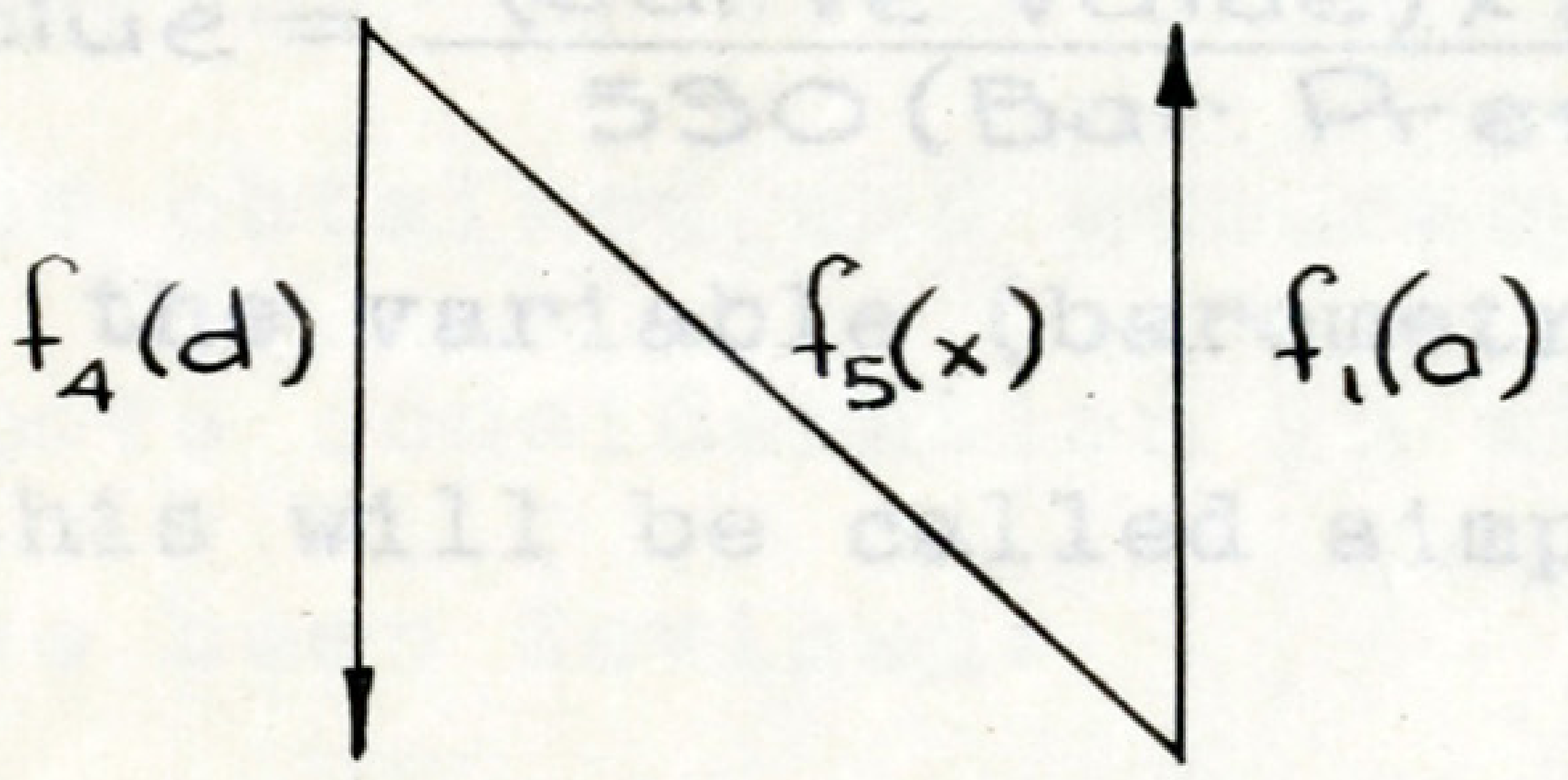
or simply,

$$\frac{f_1(a)}{f_4(d)} = f_5(x) \qquad (1)$$

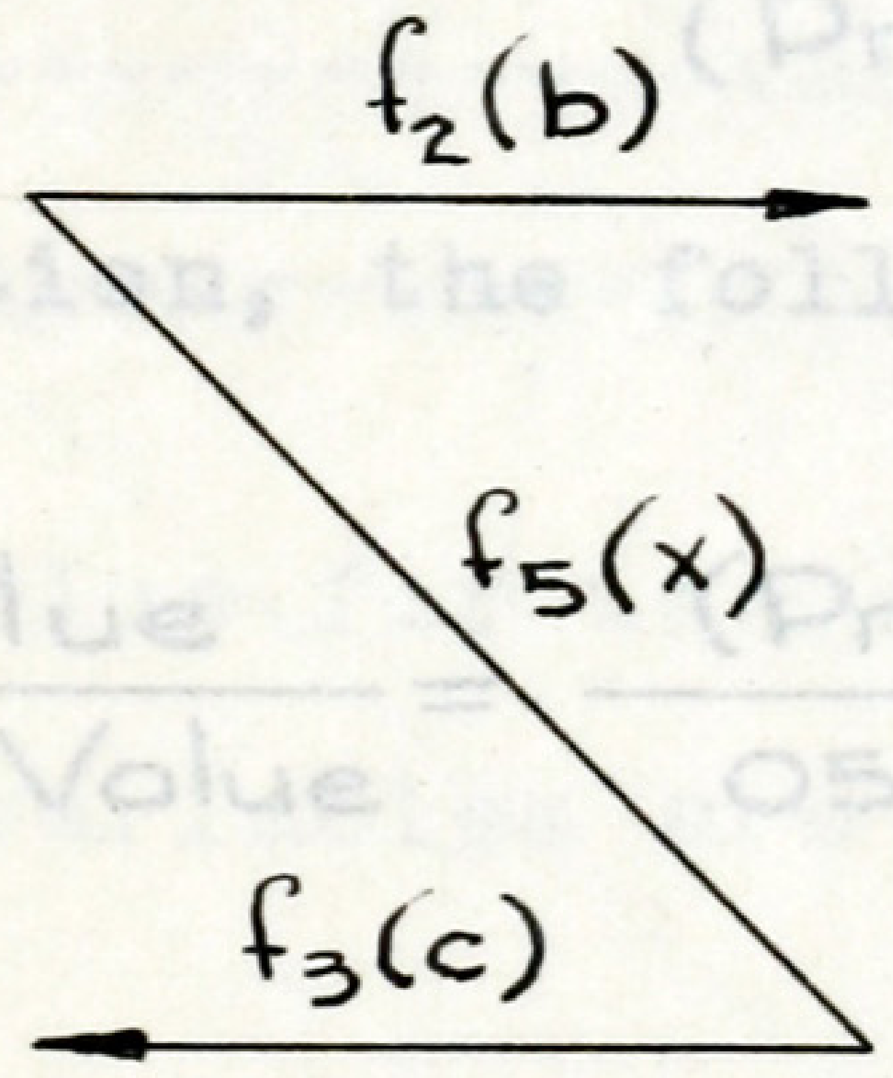
and

$$\frac{f_3(c)}{f_2(b} = f_5(x) \qquad (2)$$

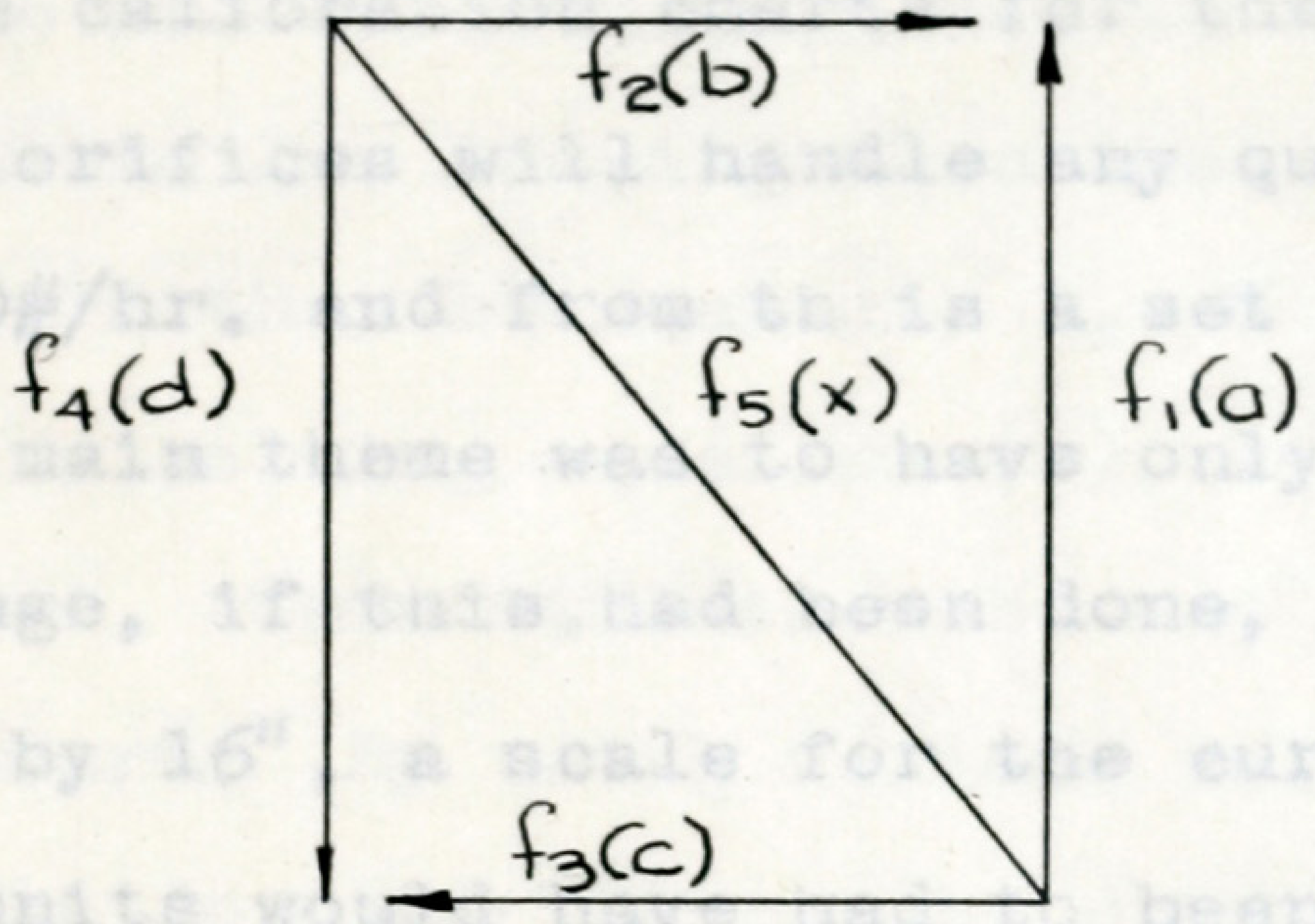
The N- chart for equation (1) will then appear as follows:



and the Z chart for equation (2) will then be,



It can easily be seen that if equation 1) and (2) are equal to the same quantity, that is function sub 5, then any value for f_5 (x) appearing on diagram (1') will correspond to the same value on N diagram (2'). It then follows that the two charts can be combined and appear in the form;



Now apply the solution to the actual correction factor equation as follows:

$$\text{Corrected Value} = \frac{(\text{Curve Value}) \times 29.92\,(T°R)}{530\,(\text{Bar. Press.} - pp_{wv})}$$

As stated before, the variable (barometric pressure - ppwv) is combined and this will be called simply pressure. Therefore:

$$\text{Corrected Value} = \frac{(\text{Curve Value}) \times .0564\,(T°R)}{(\text{Pressure})}$$

From the general solution, the following solution is apparent.

$$\frac{\text{Curve Value}}{\text{Corrected Value}} = \frac{(\text{Pressure})}{.0564\,(T°R)}$$

and

$$\frac{\text{Curve Value}}{\text{Corrected Value}} = \frac{(\text{Pressure})}{.0564\,(T°R)} = X$$

or

$$\frac{\text{Curve Value}}{\text{Corrected Value}} = X \qquad (3)$$

and similarily,

$$\frac{\text{Pressure}}{.0564\,(T°R)} = X \qquad (4)$$

From the calibration charts for the orifices, it is seen that the orifices will handle any quantity of air from 0#/hr. to 1300#/hr. and from this a set of limits is obtained. At first, the main theme was to have only one chart covering the entire range, if this had been done, however, for charts of a size 10" by 16", a scale for the curve value of 1" equal to 100 units would have had to been used. It can be seen that this would have been less accurate than if two charts were drawn, one handling 0-650#/hr. and the other handling 650-1300#/hr. By doing this, a scale of 1" equal to 50 units can be obtained, and accuracy as close as 1#.

With the above consideration in mind, the following set of limits have been devised:

Curve value------------------varies from 0-650#/hr.
$T^{o}R$ ------------------ varies from $510^{o}R$ to $560^{o}R$
Pressure ------------ varies from 27" to 32" Hg.

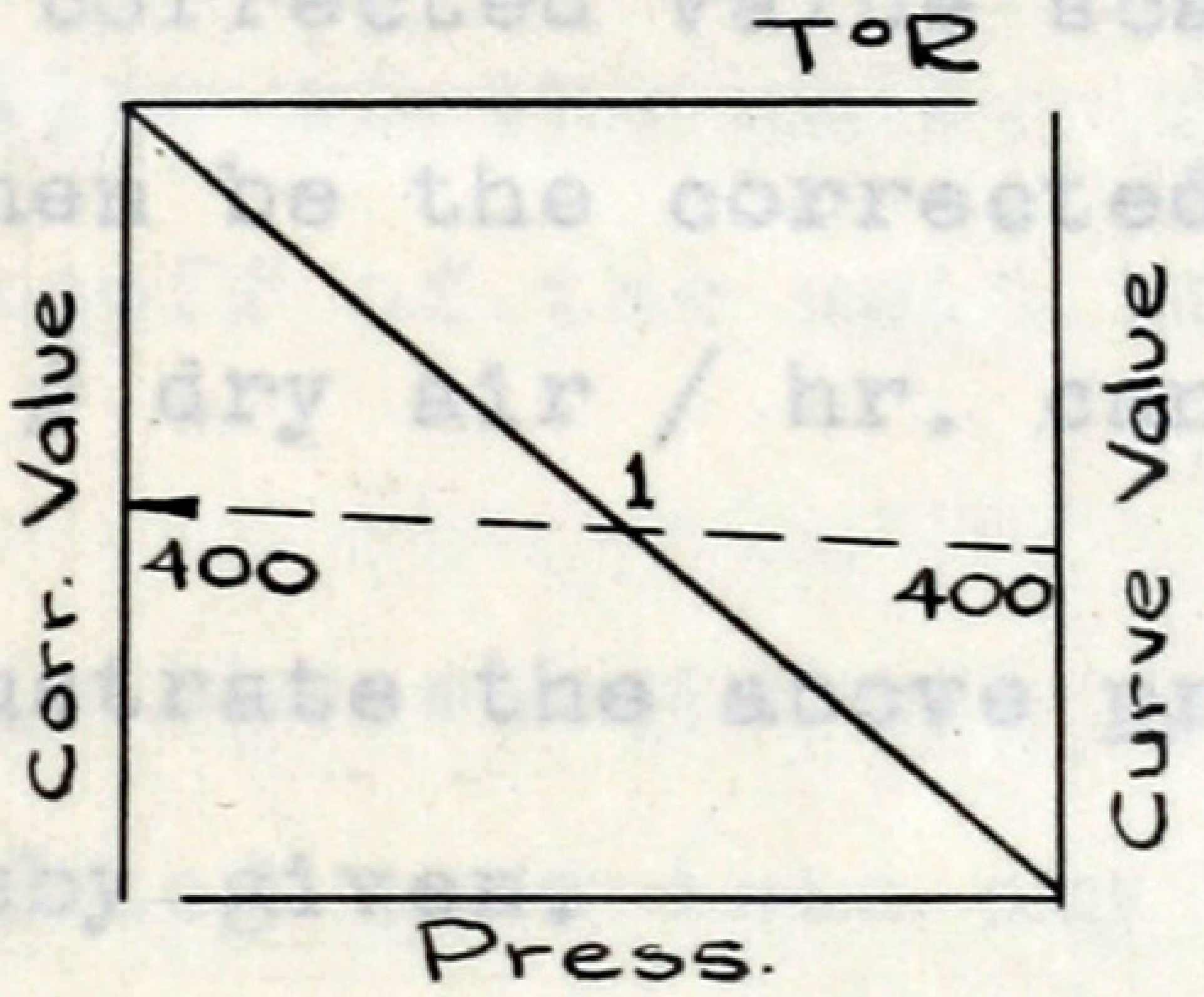
To obtain a maximum value for the corrected value, the maximum value of the variables are substituted into the equation yielding;

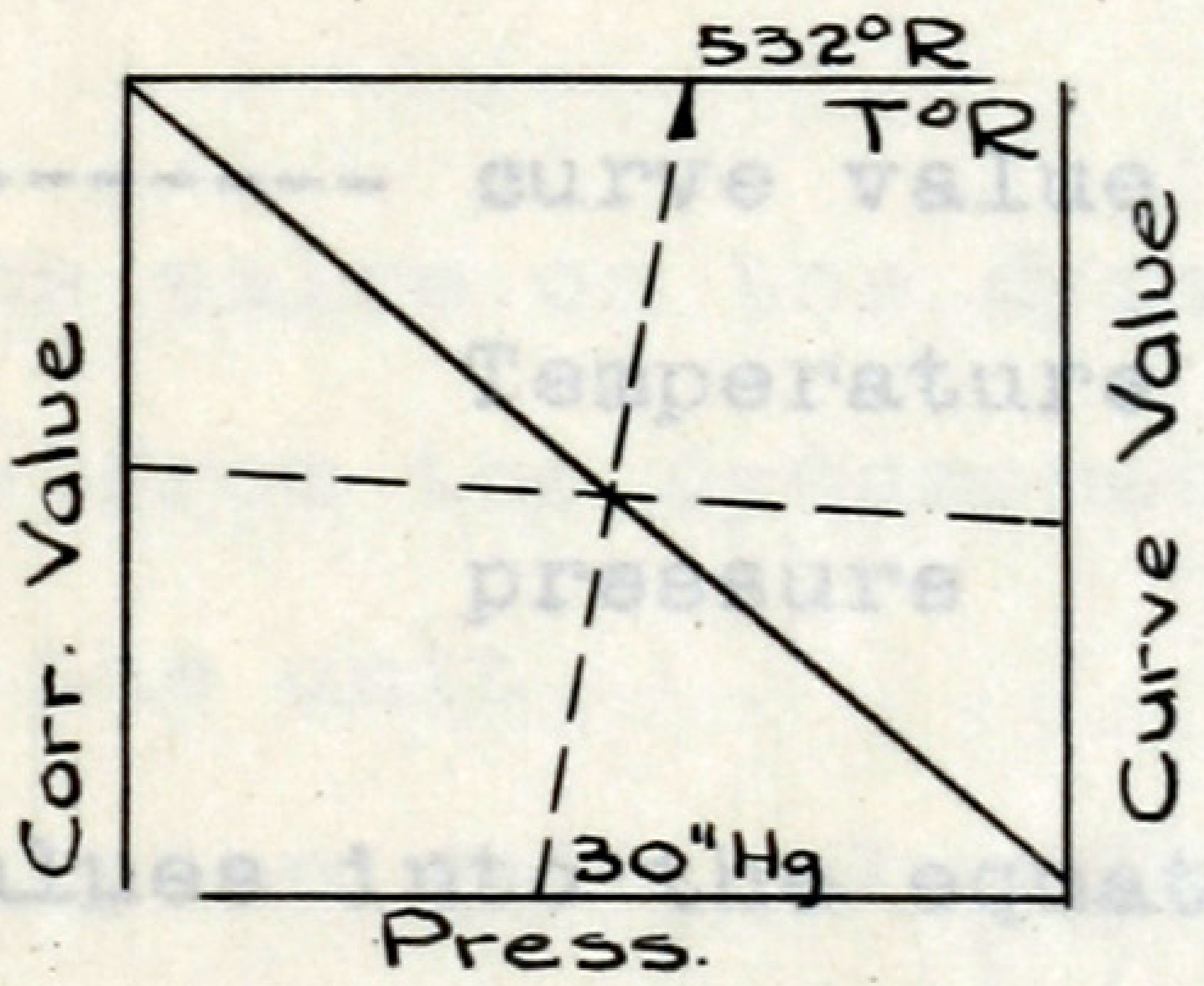
$$650 \times \frac{29.92\,(560)}{530\,(28.00)} = 735\ \#/hr.$$

Therefore the limits for the corrected value are now known, ie, 0-750#/hr. and will fall withinthe limits of the size of the chart which is 15" if the scale of 1" = 50 units is used.

The next step is to find the scales for the $T^{o}R$ and pressures. Going back to equation (3), choose values for the curve value and corrected values so that (x) will come out to be equal to 1. Knowing then that (x) is equal to 1. equation (4) will then be equal to 1, Using some value for pressure and solving equation (4), some value of T°R will be obtained. This will then be one point on the T°R scale of the chart. By using various values of the pressure, a complete scale for the T°R can be obtained and the chart may then be completed.

Graphically , the aforementioned solution for the T°R scale will be as follows:





A scale of 1" equal 4 units was used for the pressure and therefore, the scale for the T°R would be 1" equals 70.7 units. The chart to cover the second range of values for the variables is solvable in the same manner as the above.

PROCEDURE FOR USING THE NOMOGRAPHIC CHARTS

It is very simple to use the charts. Values are obtained for the variables. Pressure is known, likewise temperature and the curve value. Therefore to use the charts, join the proper value on the pressure scale with the proper value on the temperature scale. As will be noticed, the line joining these two points (called an isopleth) intersects the diagonal. Then by joining this point of intersection with the proper point for the curve value, a second value , or isopleth, is developed and this will intersect the corrected value scale at a some point. This point will then be the corrected value, and thus the corrected value of # dry air / hr. can be obtained.

Example: To illustrate the above procedure, an example is hereby given.

Let -------- curve value - 350#
Temperature = $532^{o}R$
pressure = 28.55" Hg.

Substitute these values into the equation and the following form is obtained:

$$350 \times \frac{29.92\,(532)}{530\,(28.55)} = \underline{368}\ \#/hr$$

this value is then read as the corrected value on the charts.

CHAPTER V

PROCEDURE

The procedure to be used in determining the air-fuel ratio is as follows:

PRELIMINARY PROCEDURE

1. Wheel the unit into position by the engine to be tested and lock the brake casters to prevent any disturbing of the original orientation.

2. Connect the dynamometer fuel supply system to the main supply line of the unit. Also connect the engine feed line takeoff of the unit to the fuel pump of the engine.

3. Energize the electrical system of the unit by plugging the attached cord into any convenient 110 volt, sixty cycle supply.

4. Open the valve on the dynamometer panel permitting fuel to flow from the dynamometer supply system to the head tank of the unit.

5. Energize the main solonoid valve by throwing the toggle switch mounted on the front panel.

6. Control the amount of fuel which will determine the head on the weigh tank by manipulating the air escape valve mounted atop the head tank. The operating level in the head tank as determined from the sight gage should

be about one and one-half inches from the top of the glass. By means of the pressure equilibrium existing between the head and weigh tanks, the same level as set on the head tank will exist in the weigh tank.

7. Start the engine and let warm up to operating conditions.

8. Choose an orifice, depending upon the air consumption anticipated, and mount to the orifice backing plate on the plenum chamber.

9. With the manometer control valve in the "off" position, connect the flexible hose leading from the plenum chamber side outlet to the carburetor air intake. The utilization of the carburetor adapters to make the connection is necessary.

At this point, the apparatus is ready to begin the actual testing. The procedure to be used during the actual test is as follows:

TEST PROCEDURE

1. Record the barometric pressure, temperature, relative humidity, and the partial pressure of water vapor existing in the laboratory.

2. Turn the manometer control valve to the "on" position and after the indicating medium within the manometer steadies itself, note and record the reading.

It is important during the remainder of the test that the load on the engine and the speed remain constant at the conditions which existed during reading of the monometer.

3. Put sufficient weights on the right side platform of the scale balance to produce a scale reading of 0.02 to the left of the "O" position as indicated by the pointer on the scale dial.

4. Push the start button located in the middle of the front panel. This sets the relays located on the relay board above, and closes the main solonoid valve. The engine is now drawing its fuel from the fuel weigh tank on the scale.

5. As the fuel is consumed by the engine, the pointer indicating the balance between the weights on the right side platform and the five weigh tank, moves to the right rowards the "O" position. When the "O" position is reached, the micro-switch tripps starting the timer and energizing the motor which lifts the measuring weight from the right side platform. When this occurs, the scale is unbalanced again, and the pointer moves to the left of the "O" position.

6. As the engine consumes fuel from the fuel weigh tank, the pointer moves to the right towards the "O" position. When the pointer reaches the "O" position, the micro-switch tripps again, stopping the timer, lowering

the measuring weight and opening the main solonoid valve.

7. The engine is now using fuel which is coming from the head tank. The fuel which is not being by-passed for use by the engine, recharges the fuel weigh tank. In order to facilitate the filling of the weigh tank, the auxilliary supply system can be put into operation by throwing the toggle switch located on the rear panel.

8. Knowing the time necessary for the consumption of the measured amount of fuel, and having kept the engine speed and load constant, it is now possible to utilize the orifice and nomographic charts in determining the ratio of air to fuel used by the engine.

CONCLUSIONS AND RECOMMENDATIONS

Without having the correction charts for the fuel system which would have to be determined from calibration tests, it is impossible to say how accurate are the results of the tests which were performed. The results, however, which were obtained, closely parallel those which are known to exist. That is, air-fuel ratios from 14:1 to 18:1 are common in the type of engine which was utilized for the tests. The engine used was an experimental Dodge truck engine of 1938 vintage. Complete specifications regarding this engine can be found on the data sheets used in the tests.

The air system has been calibrated and in lieu of this fact it would seem that the air measured should have been correct. It is suggested, however, that the air calibration curves be checked at a future date in order to absolutely verify their accuracy. It is also suggested that as soon as is possible, the fuel system be calibrated.

The auxilliary solonoid valve should be replaced with a new 110 volt, sixty cycle solonoid valve. The reason for this is that this valve was constructed by the authors from two old solonoid valves and while the seating of the valve is satisfactory, the noise which it makes when operating is very disturbing.

After these recommendations have been carried out, the department should have a very usable and valuable piece of equipment.

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APPENDIX

DATA FOR A TYPICAL RUN ON A 1938 DODGE TRUCK ENGINE.

Engine Specifications:- T135, 6 cylinders, L-head
Bore- 3.75", Stroke- 5.00"
Piston Displacement- 331 cu. in.
Compression Ratio- 6.5 to 1
Maximum Torque- 270 ft-lbs at 1200 rpm
Maximum Brake Horsepower- 128 at 3000 rpm

Temperature and Barometric Conditions:- Wet Bulb Temperature- 58°F
Dry Buld Temperature- 74°F
Relative Humidity- 36.5%
Barometric Pressure- 29.24 in. of mercury
Saturation Pressure at 74°F- 0.8462 in of mercury
$pp_{wv} = (RH)(p_{sat})$ - 0.309 in of mercury
Bar. Press. - pp_{wv} = 28.93 in of mercury

RPM	Load	Time min/#	Fuel #/hr	Press. Drop in of water	Air #/hr	A-F Ratio
2717	Full	1.0167	59.0	2.74	803	13.6 to 1
2303	Full	1.5950	37.7	1.60	639	16.9 to 1
2004	Full	1.9340	30.9	1.16	544	17.7 to 1
1720	Full	2.6800	22.4	0.74	424	18.9 to 1

DATA FOR CALIBRATION OF ELLISON INCLINED DRAFT GAGE.

Specifications:- Factory calibrated in inches of water

Utilizing petroleum of specific gravity = 0.834

Range - 0 to 4 inches of water

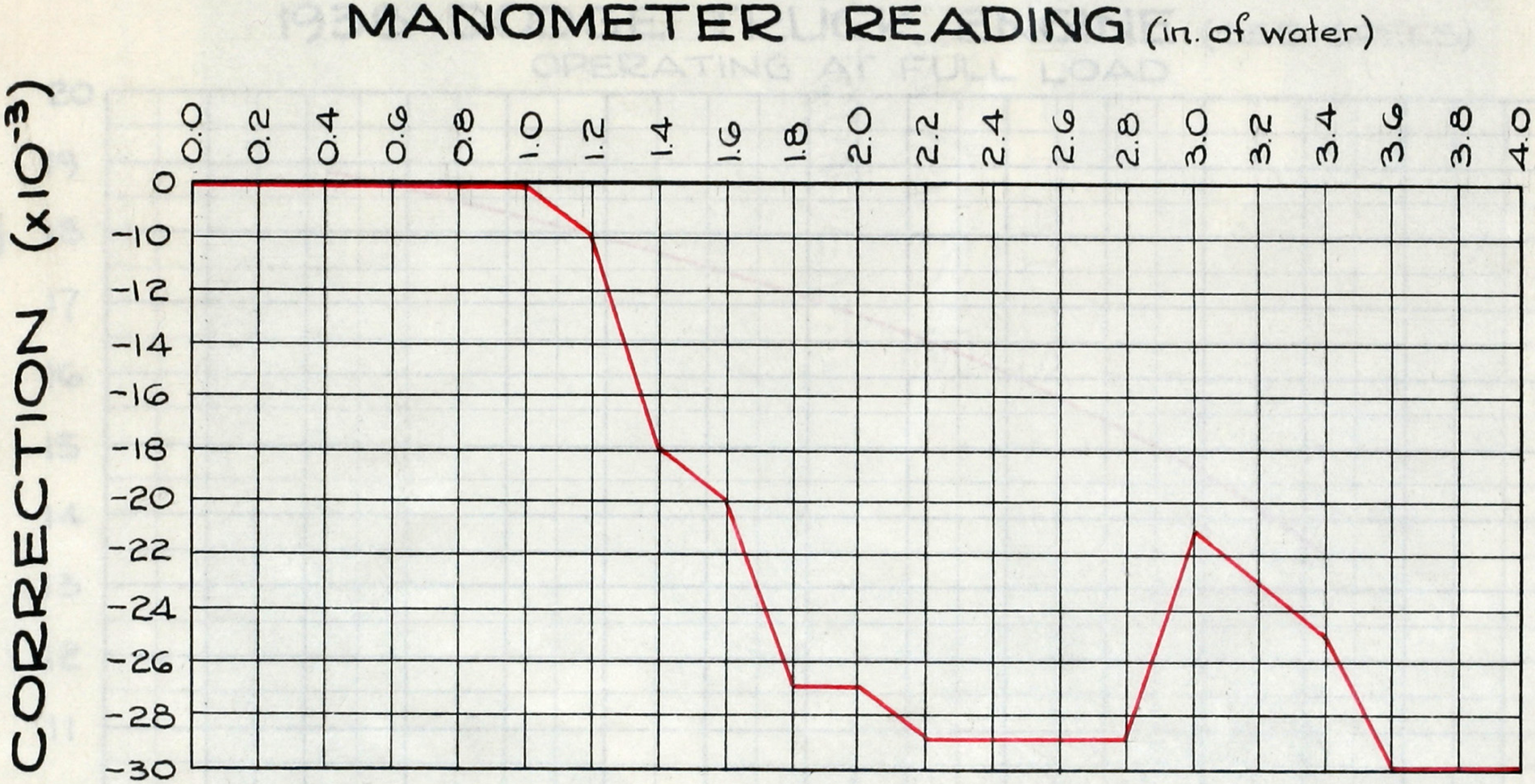
Instruments of Calibration

(1) Hook Gage

(2) Oscilloscope

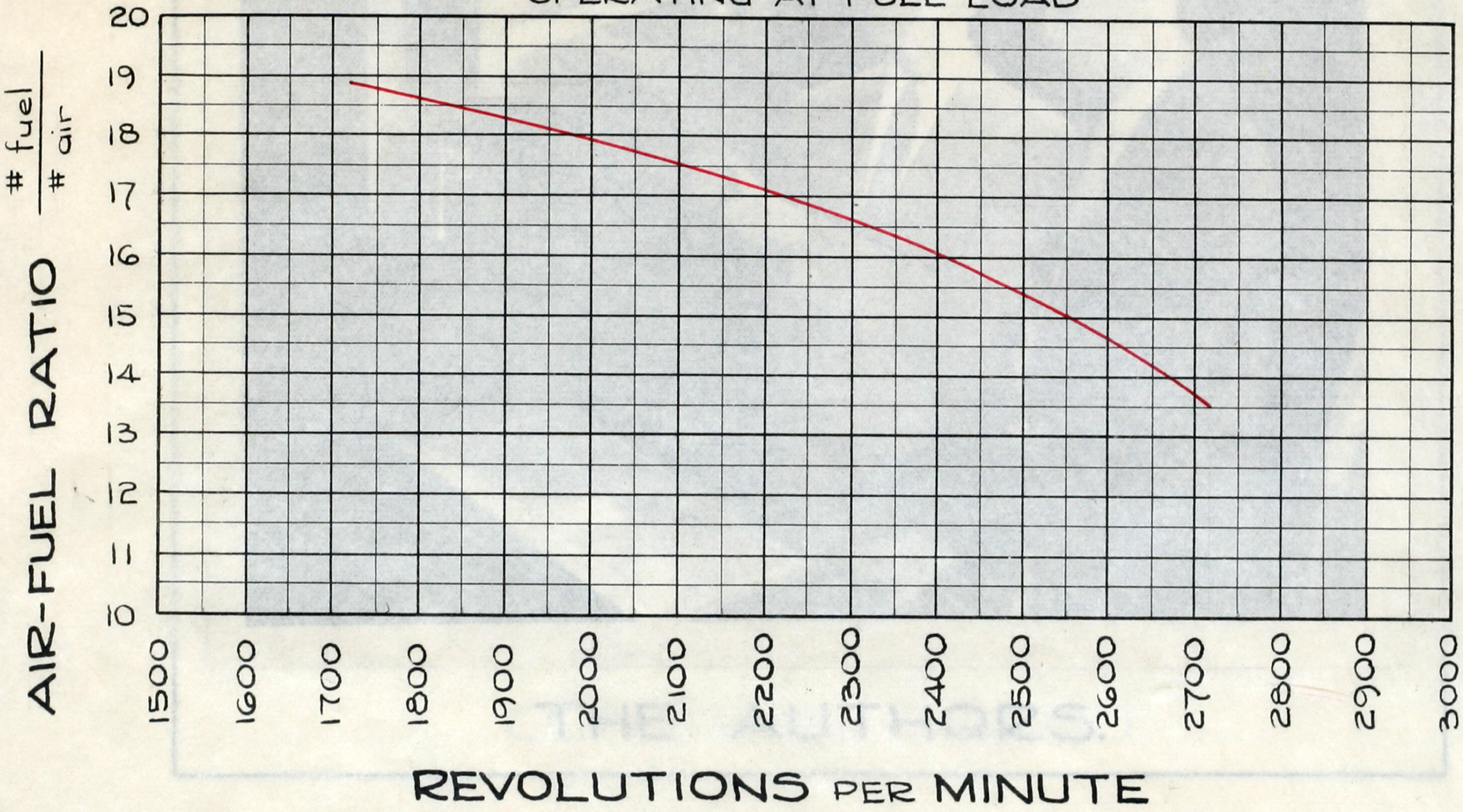
Note:- This calibration took place under the condition of leveling the manometer by sight.

HOOK GAGE	MANOMETER	CORRECTION
0.200	0.200	0.000
0.400	0.400	0.000
0.600	0.600	0.000
0.800	0.800	0.000
1.000	1.000	0.000
1.200	1.210	-0.010
1.400	1.418	-0.018
1.600	1.620	-0.020
1.800	1.827	-0.027
2.000	2.027	-0.027
2.200	2.229	-0.029
2.400	2.429	-0.029
2.600	2.629	-0.029
2.800	2.829	-0.029
3.000	3.021	-0.021
3.200	3.223	-0.023
3.400	3.125	-0.025
3.600	3.630	-0.030
3.800	3.830	-0.030
4.000	4.030	-0.030

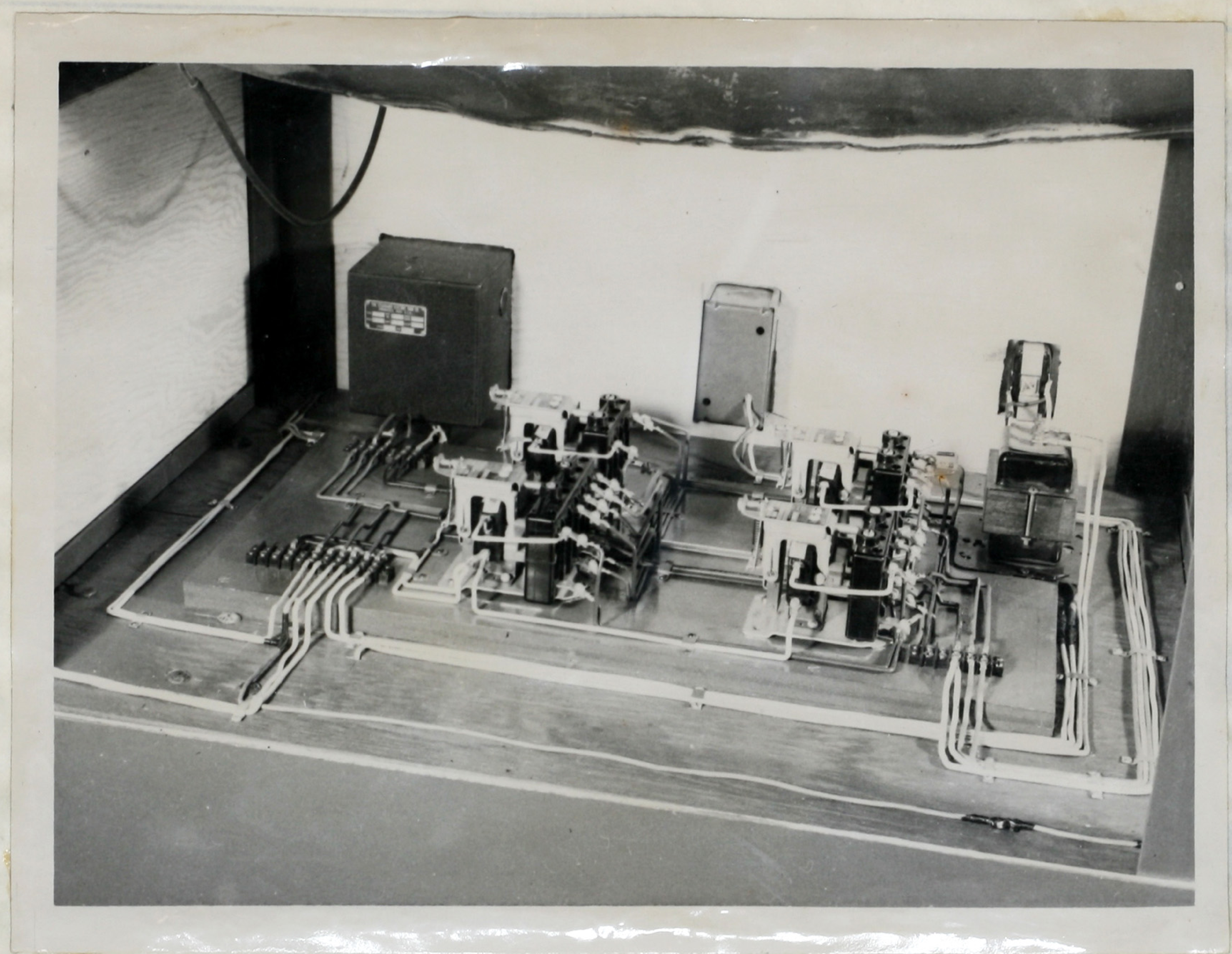


CORRECTION CURVE
FOR
ELLISON INCLINED DRAFT GAGE

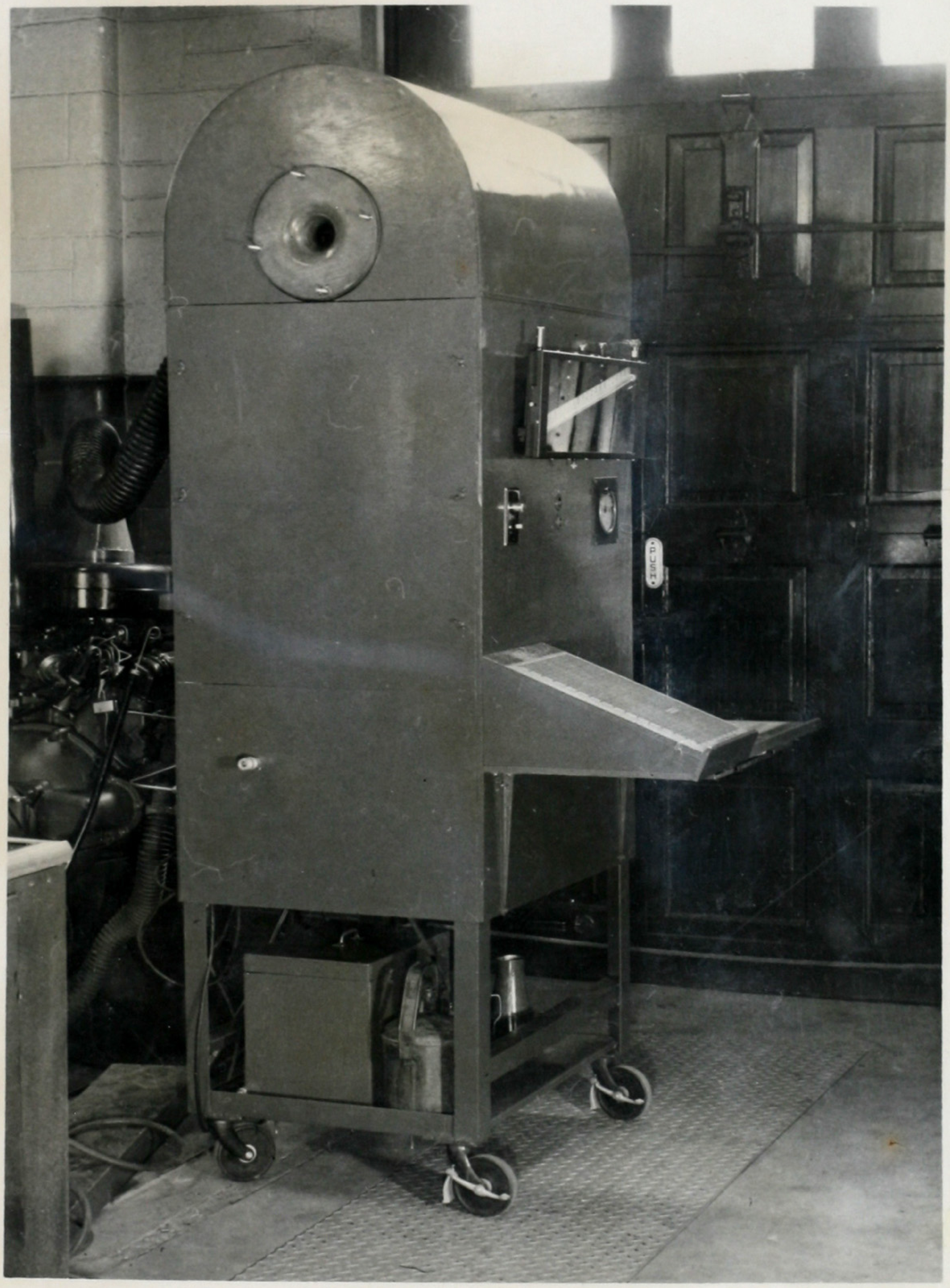
CURVE SHOWING AIR-FUEL RATIO FOR A 1938 DODGE TRUCK ENGINE (SEE SPECS) OPERATING AT FULL LOAD



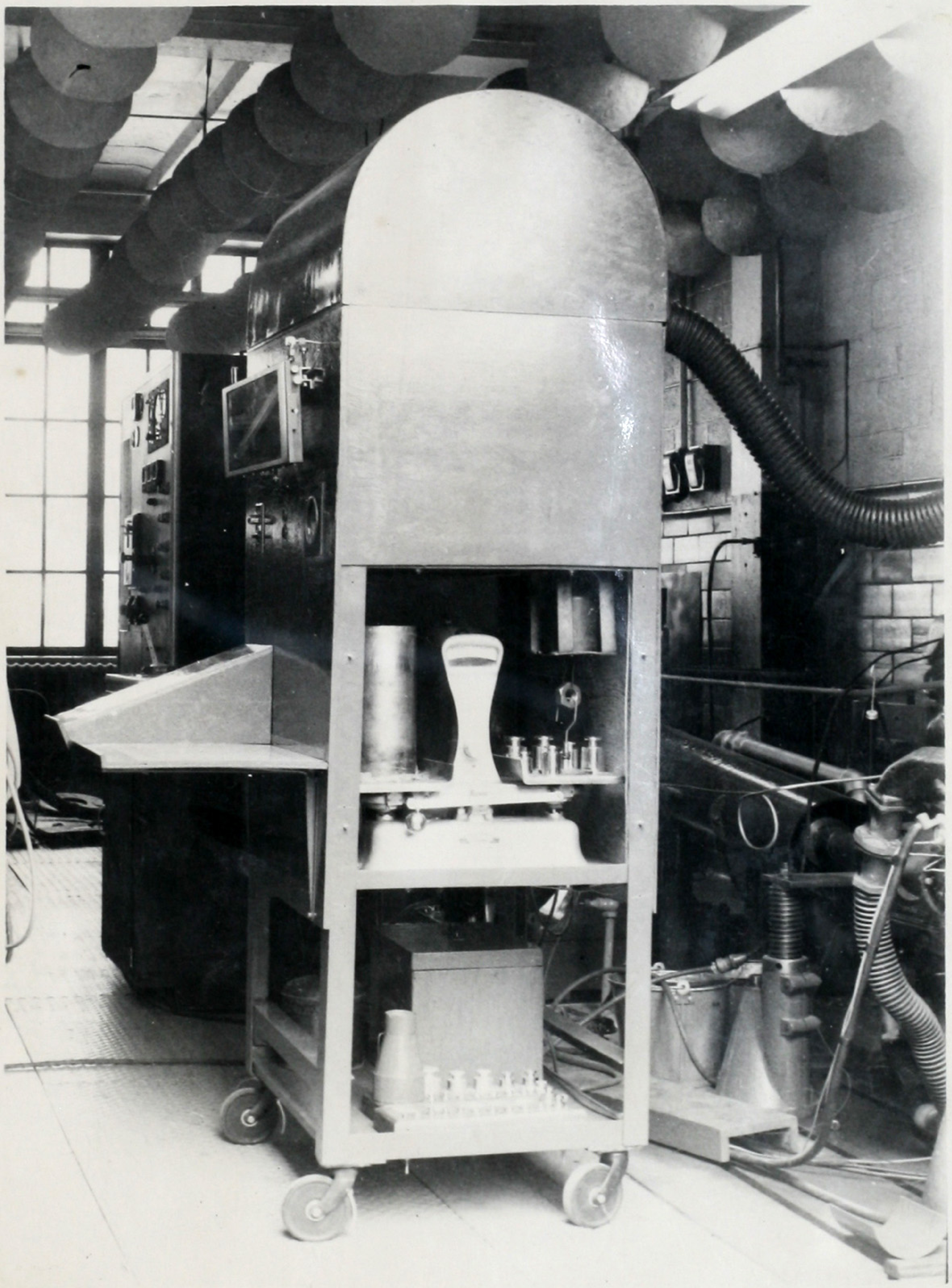
THE AUTHORS.



CONTROL CIRCUIT

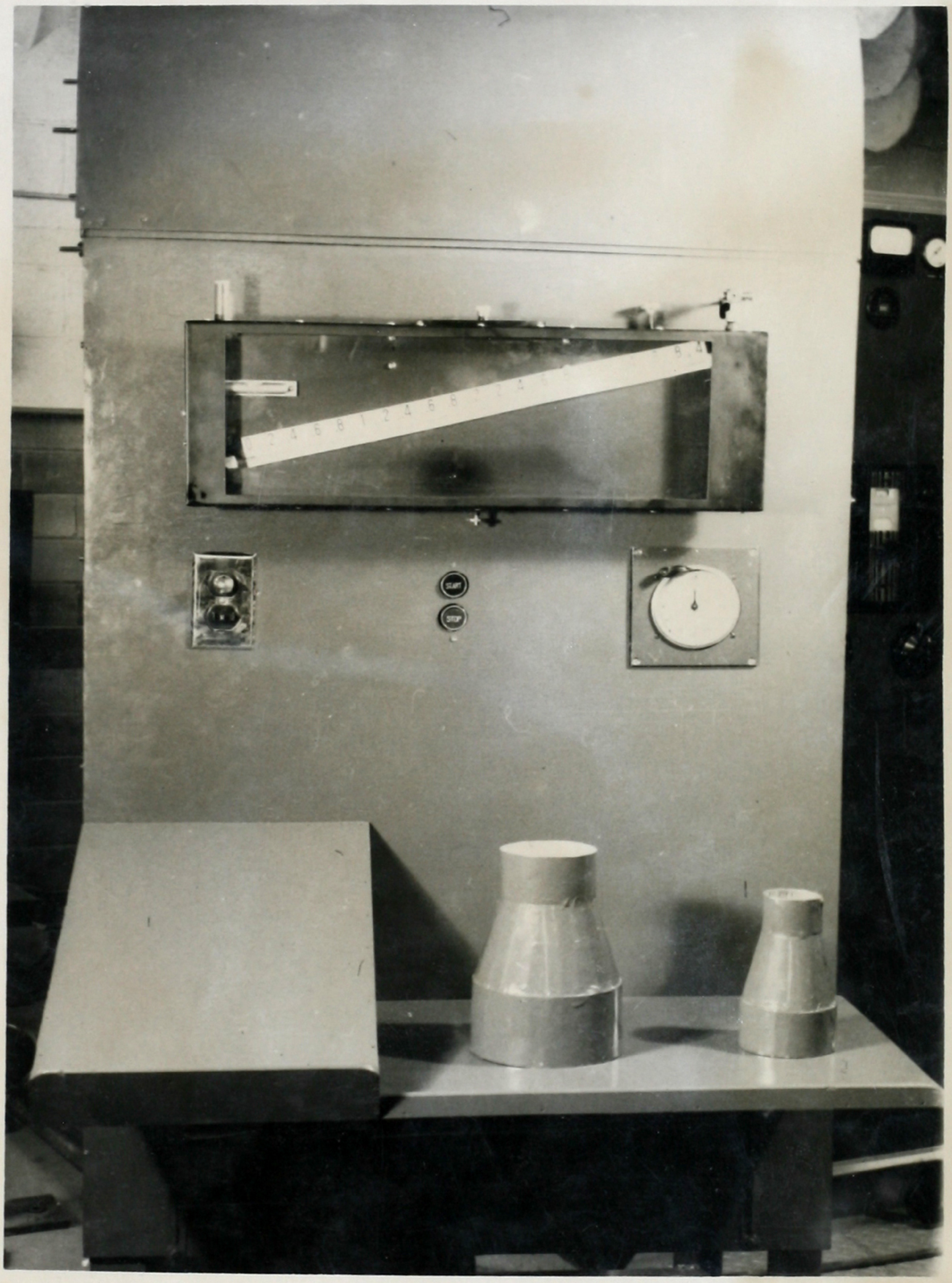


THE AIR-FUEL RATIO
MEASURING UNIT



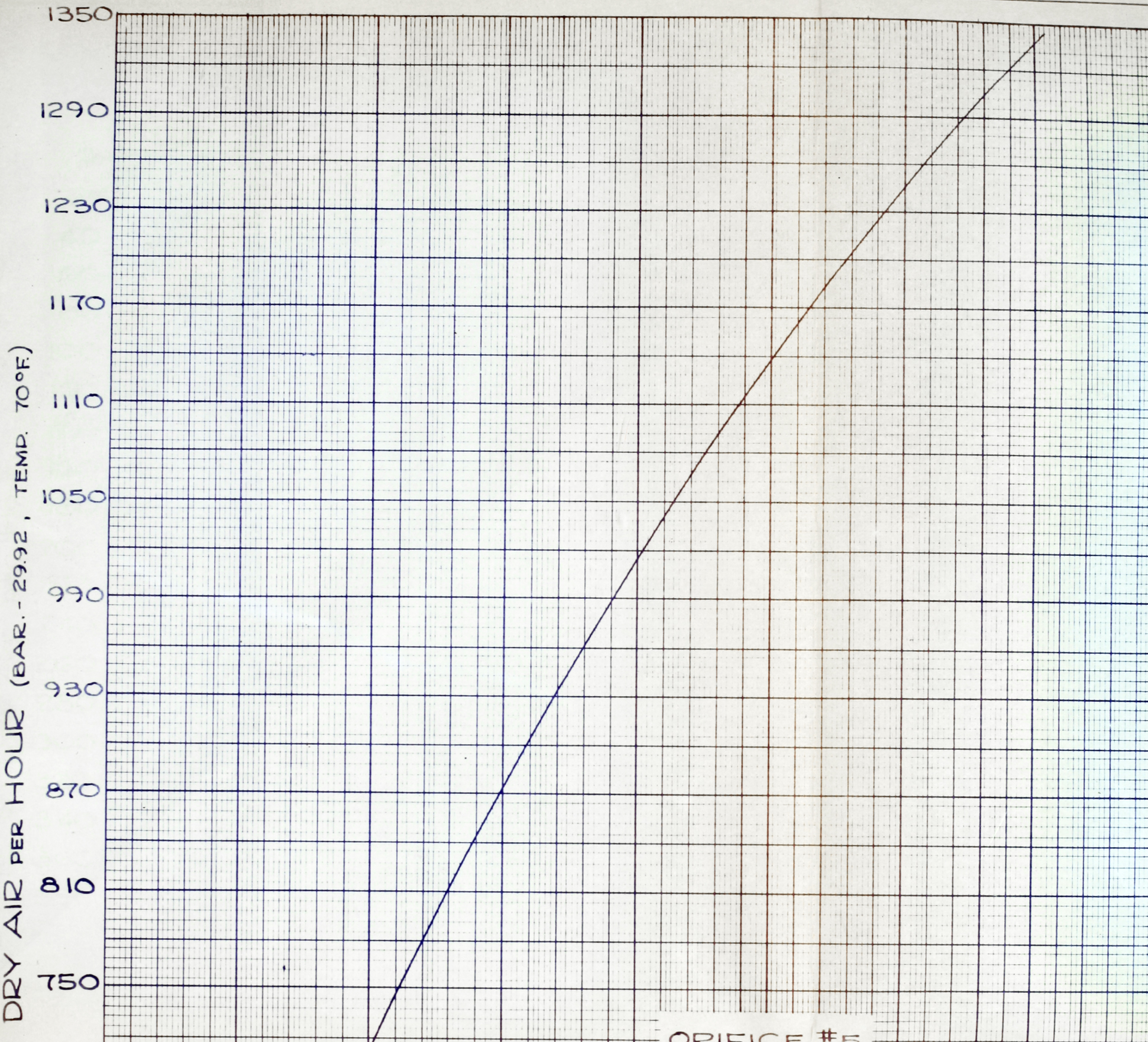
VIEW SHOWING PART OF FUEL WEIGHING APPARATUS

EQUIPMENT USED IN OPERATION



FRONT PANEL


POUNDS OF DRY AIR PER HOUR (BAR. - 29.92, TEMP. 70°F)
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
PRESSURE DROP (IN. OF WATER)
ORIFICE #4



POUNDS OF DRY AIR PER HOUR (BAR. - 29.92, TEMP. 70°F)
1350
1290
1230
1170
1110
1050
990
930
870
810
750
690
630
570
510
450
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
PRESSURE DROP (IN. OF WATER)
ORIFICE #5

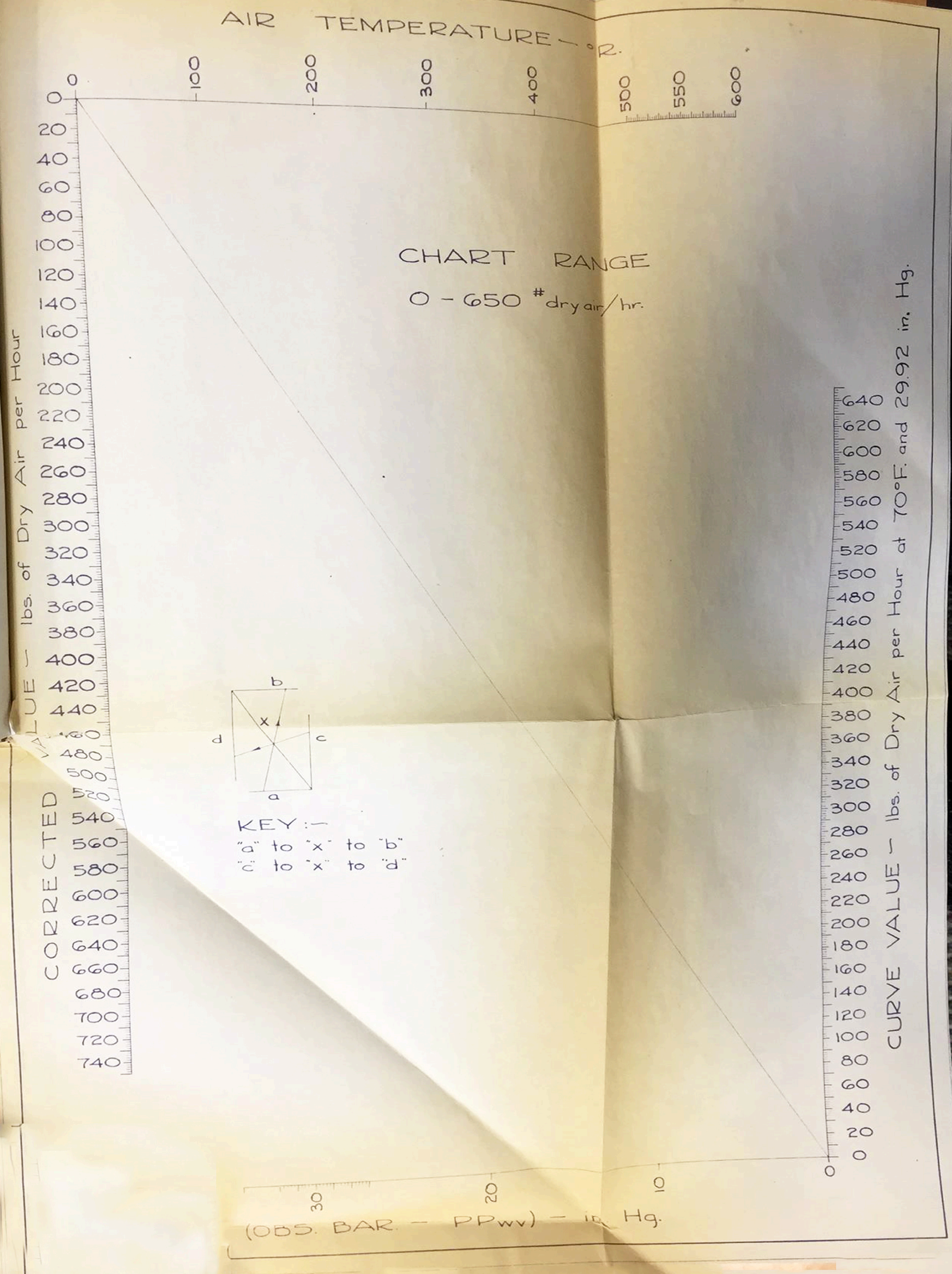


CHART RANGE

0 - 650 #dry air/hr.

KEY:—

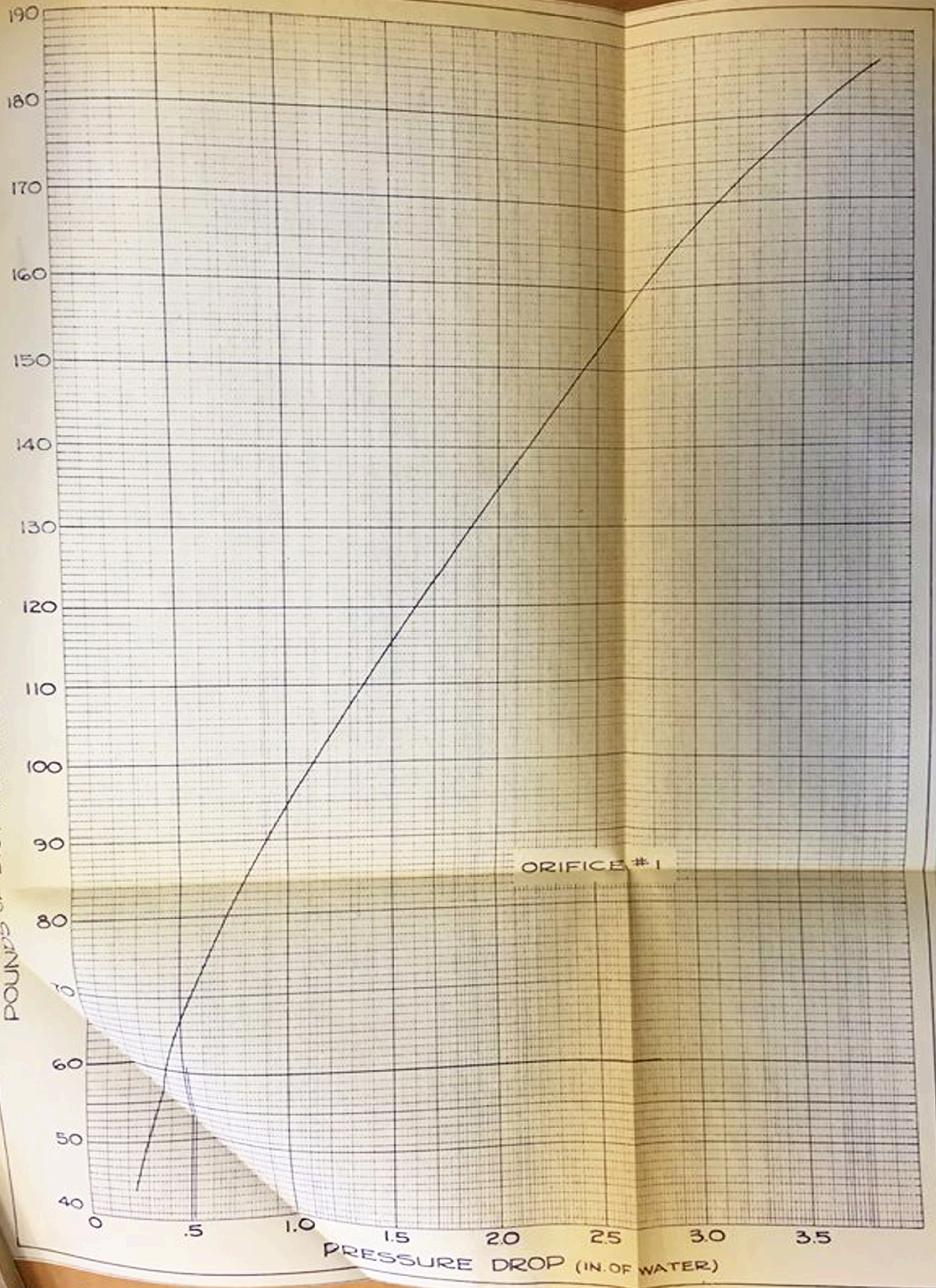
"a" to "x" to "b"

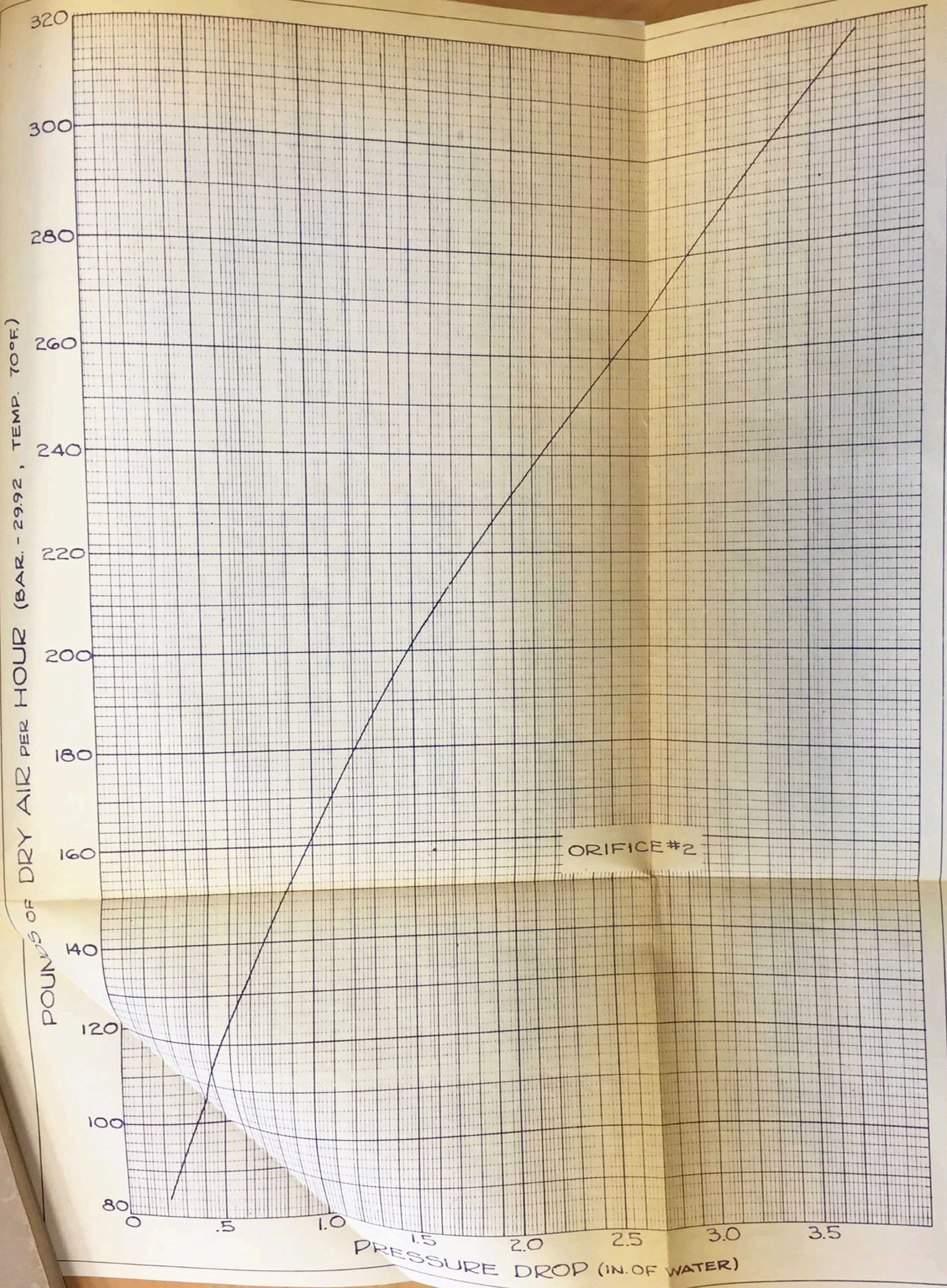
"c" to "x" to "d"

CHART RANGE

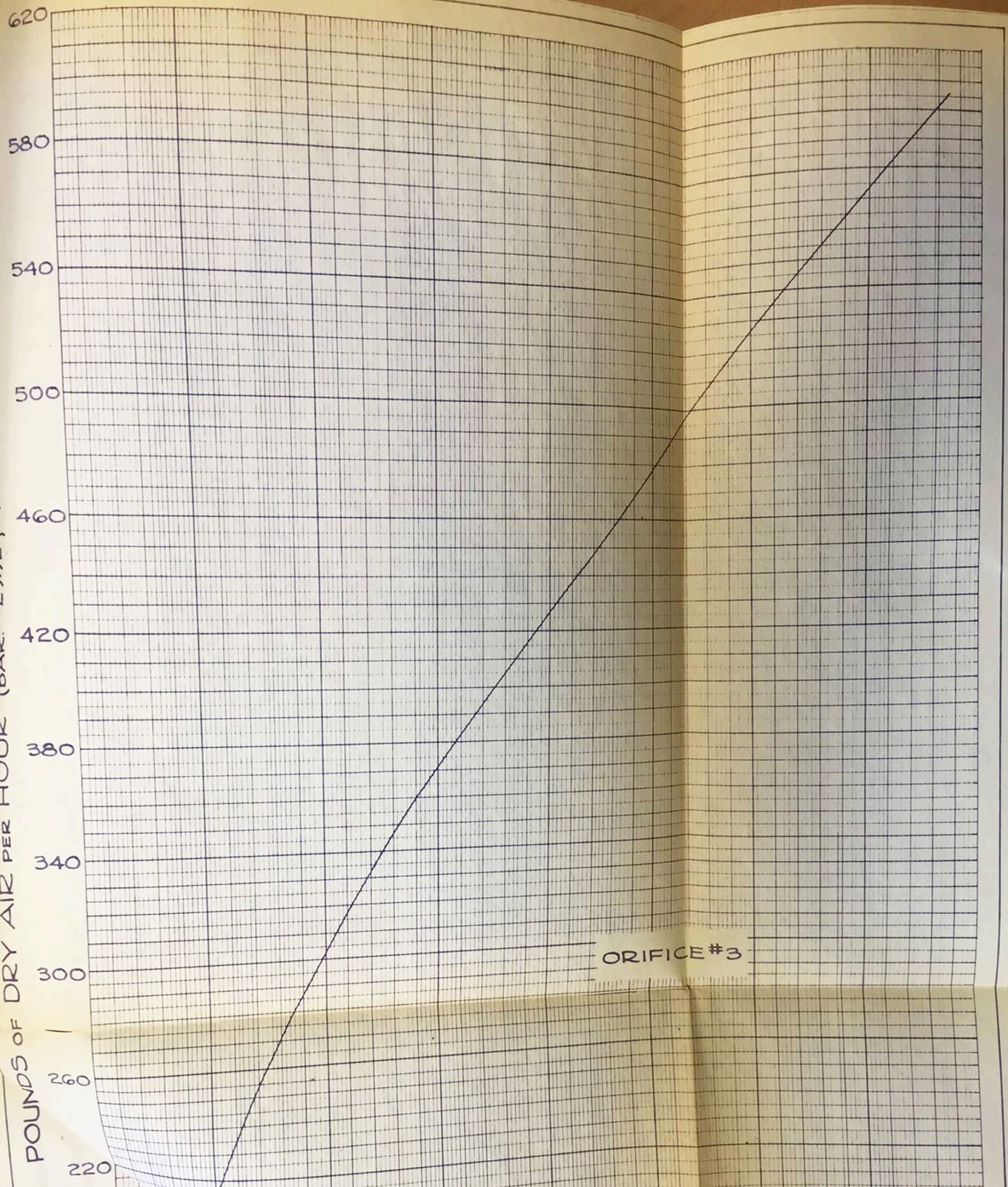
650 – 1350 #dry air/hr.

KEY:—
"a" to "x" to "b"
"c" to "x" to "d"


ORIFICE #1
POUNDS of DRY AIR PER HOUR (BAR.- 29.92, TEMP. 70°F)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
PRESSURE DROP (IN. OF WATER)



320
300
280
260
240
220
200
180
160
140
120
100
80
POUNDS OF DRY AIR PER HOUR (BAR. - 29.92 , TEMP. 70°F.)
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
PRESSURE DROP (IN. OF WATER)
ORIFICE #2


620
580
540
500
460
420
380
340
300
260
220
180
140
POUNDS OF DRY AIR PER HOUR (BAR. - 2992, TEMP. 70°F.)
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
PRESSURE DROP (IN. OF WATER)
ORIFICE #3