THESIS

"A STUDY OF CARBURETION OF
GASOLINE,-
INCLUDING THE DESIGN AND
TESTING OF A VENTURI-TYPE
CARBURETOR."

B Y

JOS. A. BEATTIE

CLASS OF NINETEEN HUNDRED
AND SEVENTEEN,

DEPARTMENT OF MECHANICAL ENGINEERING

THROOP COLLEGE OF TECHNOLOGY

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C O N T E N T S

PART ONE

PART TWO

I N T R O D U C T I O N

It has been the writer's belief for some time that the automobile gasoline engine has been highly developed in all of its parts except the carburetor. This apparatus, so essential to the proper and efficient operation of the engine, has not received the attention which its importance demands. To reach its present state it has passed through various stages of experimental evolution, in fact it has been developed through experimentation, and not from a study of the fundamental principles underlying its operation. As a result of this there are dozens of carburetors on the market at the present time, each claiming superiority over the others. The construction, arrangement of details, and operation, are as varied as the different types of carburetors are numerous. Some have no adjustments whatever, while others have as many as five. A carburetor which seems to work well on one make of engine, works very badly on another.

Mr. Browne, in the introduction to his "Handbook of Carburetion" expresses the above idea very clearly where he says in part:

"Concensus of public opinion, both technical and lay, would undoubtedly be singularly unanimous in welcoming the complete abolition of the carburetor. No part of a motor vehicle is less understood or more abused, in thought and deed. No other part of the entire mechanism of the car is subjected to the indignities that are heaped upon the carburetor.

This condition will continue to exist until the genius which has already made such colossal strides in automobile engineering turns its serious attention to an understanding of the fundamental laws governing carburetion.

------ the lack of uniformity exhibited by the great and ever-increasing variety of carburetors on the market proves that, as yet, no comprehensive principle of automatic regulation of the gas to air ratio has been generally recognized."

It is the purpose of this thesis to make a study of carburetion, with the object in view of designing a carburetor which is simple and positive, and which will maintain a constant ratio of fuel and air over a wide range of operation.

The study will be both theoretical and practical; the theoretical in order to know the fundamental laws on which to base the design; and the practical, to know the actual service requirements of an automobile carburetor. The latter will be studied by testing several types of standard carburetors on an engine, noting especially the operating characteristics, requirements, and fuel consumption.

REQUIREMENTS OF A CARBURETOR

It is generally supposed that mixtures of various ratios of fuel and air are required over the different conditions of operation imposed on gasoline engines. This supposition is without a doubt erroneous, and has arisen from the fact that on starting an engine, and possibly at low engine speeds, an excessive amount of fuel must be delivered by the carburetor in order that the low velocity air column may carry into the cylinders sufficient vaporized fuel to form a combustible mixture.

It has been shown by many experiments that a mixture with a certain definite ratio of gasoline vapor and air reaches a maximum pressure in the shortest space of time when ignited; whereas any deviation from this ratio, either towards richness or leanness, produces a lower maximum pressure in a longer time with a consequent decrease in power. Diagram No.1 clearly shows this fact. These are the results of many experiments conducted at the Massachusetts Institute of Technology.

The correct mixture need not necessarily be the theoretically perfect one, in fact most investigations have shown that a slight excess of fuel gives the best results. This is directly opposite to Steam and Gas Engineering practice; as in gas engine design it is customary to allow 15% excess air; while in boiler work as high as 50% excess air is allowed for the proper combustion of coal, and a somewhat smaller excess for oil. This difference can be attributed to the fact that in the gasoline engine a certain proportion of the fuel is not properly vaporized, consequently an excess is necessary in order that the vaporized portion may form a correct mixture with the air present.

Some very interesting tests have been carried on at Purdue University in connection with carburetor performance. Diagram No.2 is here reproduced from these experiments. The curve shows that the engine will run with a mixture of less than .055 lb of gasoline per pound of air, but will not pull well with so lean a mixture. As more fuel is added, the power increases rapidly until nearly full power is reached, when the curve becomes almost horizontal, increasing slowly to a maximum, then decreasing slowly for a time, but finally reaching a point where it falls off rapidly. The richest mixture with which the engine could be run was .155 lb. of gasoline per pound of air; nearly three times as rich as the leanest mixture. In other words, a carburetor may be adjusted to as lean a mixture as can be used to carry full load, after which the amount of gasoline can be nearly doubled without seriously affecting the power capacity of the engine. This explains in part why cars of the same make show such different mileages per gallon of gasoline.

The function of a carburetor does not end with the correct proportioning of fuel and air. Its further duty is to atomize the fuel and to thoroughly mix the minute particles with the air, in order that they may be quickly vaporized and form a homogeneous explosive gas with it. Though vaporization begins in the carburetor, the process continues through the manifold and valve chambers, and even in the cylinder. The sooner the vaporization is completed the better, as most of the fuel entering the cylinder in liquid form is cracked by the heat of combustion, and forms carbon, which is deposited in the cylinder and on the spark plug. Also a part of the liquid fuel finds its way into the crankcase where it mixes with the oil, lessening the latter's usefulness as a lubricant.

The majority of automobile engines now provide some means of heating the air supply, and on certain machines the fuel also is heated. Vaporization is greatly aided by using heated air and fuel, but the advantages are to some extent offset by the loss in volumetric efficiency, resulting from too much heat. This loss is nearly 2% for every 10 ° F. increase in the temperature of the charge.

The latest development in the application of heat is in the "Hot-spot manifold". In this the hot exhaust gases are utilized to heat a plate on the intake manifold. The hot plate is located at a bend in the intake manifold, so that the heavier fuel particles in the mixture strike against it on making the turn, and are quickly vaporized. In this way heat is applied where most needed, and does away with the necessity of overheating the whole charge.

The air velocity through carburetor and intake manifold deserves careful consideration. High velocity produces thorough atomization and prevents deposition of fuel particles in the manifold passages. But the advantages of high velocity must be balanced against the volumetric loss by velocity, which increases rapidly with increase in air velocity. The carburetor and manifold passages should therefore be as large as possible consistent with proper performance at the slowest engine speeds.

In summary, the requirements of a carburetor are as follows:

1 - Constant ratio of fuel and air

2 - Thoroughly atomized, homogeneous mixture

3 - Least possible volumetric loss,- viz: low velocity, small friction loss, and small loss due to heating the charge.

DESCRIPTION OF APPARATUS

E N G I N E .

A stock Ford engine was used in all of the tests. Specifications as follows:

Four cylinders, four cycle. Cylinders cast en bloc , with water jackets and upper half of crank case integral. Cylinder bore three and three-quarters inches; piston stroke four inches. Full twenty horsepower.

B R A K E

The power developed was measured by means of a Froude type water brake, having a Rotor about six inches in diameter by two inches wide.

C A R B U R E T O R S

1 - Holly Standard 1917 Model for Ford Engines

2 - Stromberg Type B-#3, Carburetor

3 - Ensign Type G Carburetor size 1 inch for Ford engines.

4 - Modified Venturi-type carburetor designated as B-1.

OTHER APPARATUS.

Fairbanks-Morse Scales for weighing gasoline and cooling water, and for measuring the power developed.

Schuchardt and Schutte Tachometer for obtaining engine speed.

Thermometers for obtaining temperature.

F O R M U L A S U S E D.

POWER MEASUREMENTS

The power developed by the engine was measured in all cases by a Froude Water Brake. The Power equation for this type of brake is the same as that for a Prony type brake, i.e.:

$$H.P. = \frac{2\pi R N W}{33.000}$$

Where R = distance in feet from centre of shaft to knife edge on end of lever arm.

N = Revolutions per minute

W = Pounds force exerted by end of lever arm.

The lever arm R. in this brake is 6.30 inches. Therefore the horsepower developed when W is one pound and N is one revolution per minute, is

$$H.P. = \frac{2\pi \times 6.30 \times 1 \times 1}{12 \times 33.000} = .0001$$

$$\text{or } H.P. = .0001 \times N \times W$$

CALORIFIC VALUE OF FUEL.

Several samples of the gasoline used in the different runs were tested for heating value in a Parr Calorimeter. As these determinations require considerable time, the following approximate formula taken from Hirshfeld and Barnard's Heat-Power Engineering, was used in most cases:

"The higher calorific value of U. S. petroleum and its distillates, ranging from crude oil to gasoline, varies quite regularly with the specific gravity of the material, and is expressed approximately by the following formula, which may be assumed correct within 2 per cent:

B.T.U. per pound = 18,650 plus 40 (B - 10)

in which B = degrees on the Baume hydrometer -- ".

To correct the specific gravity for temperature variation, the following formula was used:

$$S = \frac{s}{1 - .0007\ (t-60)}$$

Where S = specific gravity at 60° F.

s = " " " t° F.

t = temperature in F.°

This formula was taken from Browne's Handbook of Carburetion.

To reduce specific gravity to the Baume scale, the following formula, taken from the same book, was used.

Specific gravity = 140 ÷ (130 plus Degrees B)

Curve I shows the results of these calculations. The curve is practically a straight line, except near the lower limits where the head H_g influences the Velocity V_f very much. At a certain velocity of air the fuel velocity becomes zero. This velocity may be found as follows:

$$.00165\,V_a^2 - 1.34 = 0$$

$$V_a^2 = \frac{1.34}{.00165} = 812 \qquad V_a = 28.5 \text{ ft.per sec.}$$

If H_g were equal to zero, then V_f would vary directly as V_a:

$$V_a = \sqrt{2\,gh_a} \qquad H_a = \frac{V_a^2}{2\,g} = H_f\,\frac{W_f}{W_a}$$

W_f and W_a = Wt. of equal volumes of air and fuel.

$$H_f = \frac{V_f^2}{2\,g}$$

$$\frac{V_a^2}{2\,g} = H_f\,\frac{W_f}{W_a} = \frac{V_f^2}{2\,g}\left(\frac{W_f}{W_a}\right) = \frac{V_a^2}{2\,g}$$

$$\therefore\; V_f^2 = V_a^2\,\frac{W_a}{W_f} \quad\text{and}\quad V_f = V_a\sqrt{\frac{W_a}{W_f}}$$

and for a constant ratio of $\frac{W_a}{W_f}$ the velocity of fuel will equal a constant times the velocity of air. A carburetor of this type $(H_g = 0)$ should keep a constant ratio of air to gas. provided the sp. gr. of the fuel remained constant. This type has the practical difficulties of preventing a loss of fuel when the engine is not running, also to prevent erratic operation of the carburetor due to vibration of the machine.

From Curve I the impossibility of setting the needle valve for constant mixture at all speeds can be seen, especially when attempting to do this at the low speeds where it is usually done. This lower range of velocities is used in order to reduce volumetric loss which becomes excessive at the upper range.

For example, if it is assumed that the proper mixture is obtained with $V_f = 2$ and $V_a = 60$ keeping this ratio, for $V_a = 600$ V_f should be 20; but from the curve $V_f = 24.3$, or an increase of 21.5%.

So far three solutions seem possible:

1 - To adjust the simple type of carburetor ($H_s = K \equiv 0$) for the high range;

2 - To devise a means of keeping the mixture constant when adjusted at the low range;

3 - To make use of the type where $H_s = 0$.

The first method would mean using the upper range of velocities with a considerable volumetric loss (about $8\frac{3}{4}$% at 400 feet per second - Chart I in Browne, Handbook of Carburetion). Due to the high volumetric loss this method will not be considered.

The second method necessitates a close adjustment at a slow speed of engine, and a means of keeping this ratio constant. By using the low velocity range, volumetric loss will be cut down to the lowest possible value.

The third method will not be considered, due to its practical difficulties already mentioned, but the advantages offered by the second warrant its further development.

$$V = \sqrt{2\,gh}$$

$$\frac{V_a}{V_f} = \frac{\sqrt{2\,gh_a}}{\sqrt{2\,gh_f}} \qquad V_f = \frac{V_a\sqrt{2gh_f}}{\sqrt{2gh_a}} = \frac{V_a\sqrt{h_f}}{\sqrt{H_a}} =$$

$$V_f = V_a\left(\frac{H_f}{H_a}\right)^{\frac{1}{2}}$$

Water weighs - 62.355 lb. per cu.ft. at 62° F.

Air " .0761 " " " " 62° F.

Assume sp.gr. of gasoline = .74 at 60° F.

$$\frac{H_f}{H_a} = \frac{\frac{P}{W_f}}{\frac{P}{W_a}} = \frac{P}{W_f} \times \frac{W_a}{P} = \frac{W_a}{W_f} = \frac{.0761}{.74 \times 62.355}$$

$$V_f = V_a\left(\frac{.0761}{.74 \times 62.355}\right)^{\frac{1}{2}} = .0406\ V_a$$

If the carburetor is now set so that with an air velocity of 60 ft per second, a fuel velocity of 2 feet per second, results: in order to keep this mixture constant an air velocity of 840 feet per second would require a fuel velocity of 28 feet per second. From the curve it is seen that the actual fuel velocity is 34.1 feet per second or 6.1 feet per second too great.

A V_f of 6.1 = a V_a of $\frac{6.1}{.0406} = 150.2$

The fuel velocity may be reduced the required amount by directing the fuel nozzle into the air current with the proper angle, so that the component of the air velocity along the fuel nozzle axis shall equal the excess fuel head of 6.1 feet per second.

Assume that $\frac{1}{4}$ of the fuel velocity is along line of air velocity.

$V_a = 840 \text{ plus } \frac{1}{4} \times 28 = 847$

$V_f(\text{excess}) = 6.1 - \frac{6.1}{.0406} =$

150.2(ft/sec.of air)

$V_a \times \text{COS } \theta = 150.2$

$\text{Cos } \theta = \frac{150.2}{847} = .1773 \quad \theta = 79° \, 47'$

To find what effect this will have at other points along the curve, for example when

$V_a = 480$

$480 \text{ plus } .17 \times 19.5 = 483.5$

$483.5 \times .1773 = 85.8$

$V_f = .0406 \times 85.8 = 3.48$

and $19.5 - 3.48 = 16.02$ instead of 16 even

$V_a = 60$

60 plus $.17 \times 2 = 60.4$

$60.4 \times .1773 = 10.7$

$V_f = .0406 \times 10.7 = .4350$

$2.14 - .43 = 1.71$ instead of 2

$V_a = 120$ $\quad$ $120 \text{ t } .177 \times 4 = 120.71$

$120.71 \times .1773 = 21.4$

$V_f = .0406 \times 21.4 = .87$

$4.73 - .87 = 3.86$ instead of 4

At the lower range the mixture will be a little weakened but the decrease is within 3 or 4%.

θ will be made $= 80°$

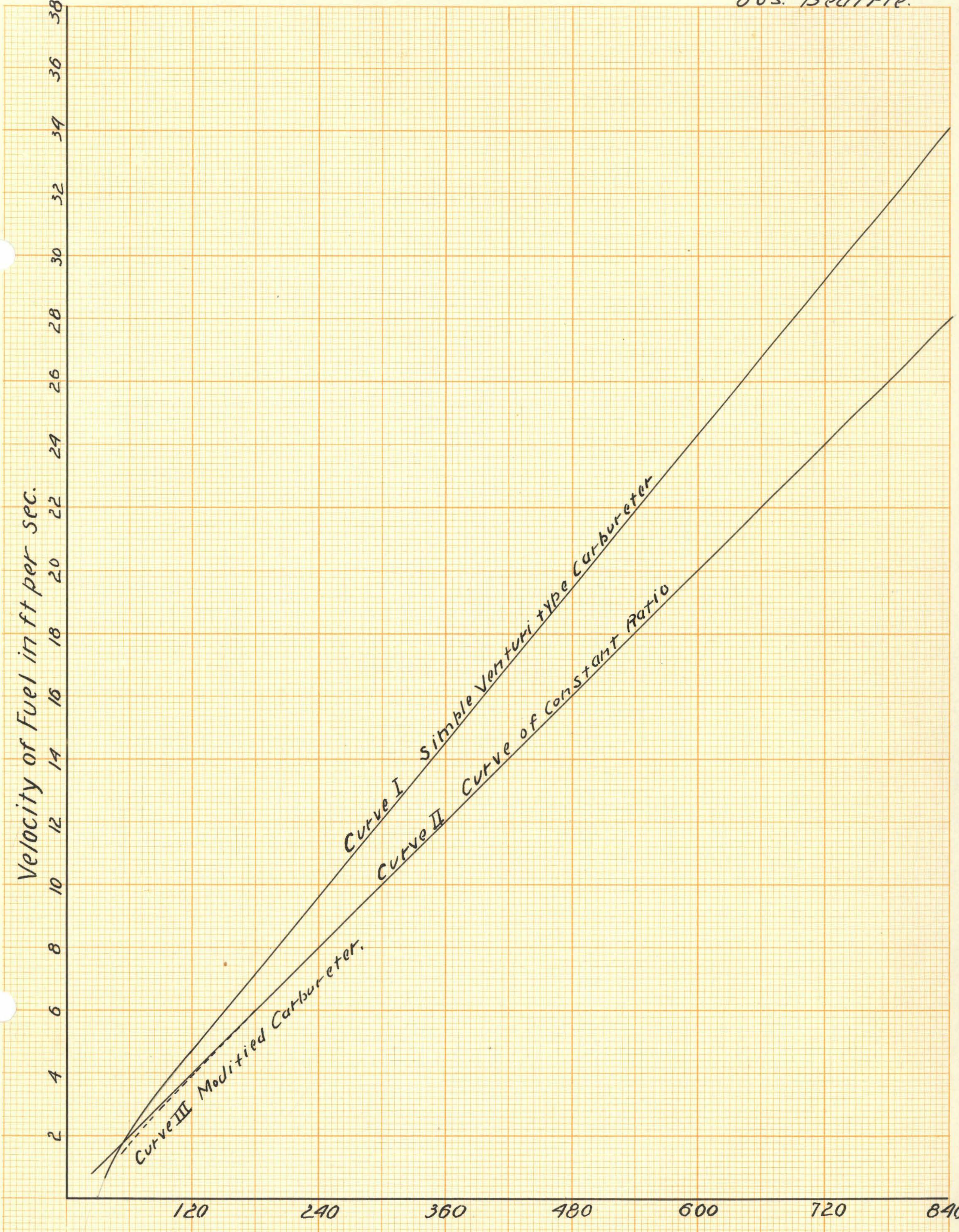
To aid in the evaporation of the fuel after it leaves the nozzle, a piece of brass, shown in the sectional drawing, is placed in the tube beyond the nozzle. This piece is given an approximate stream line form to reduce friction and also to insure contact of the air over the entire surface.

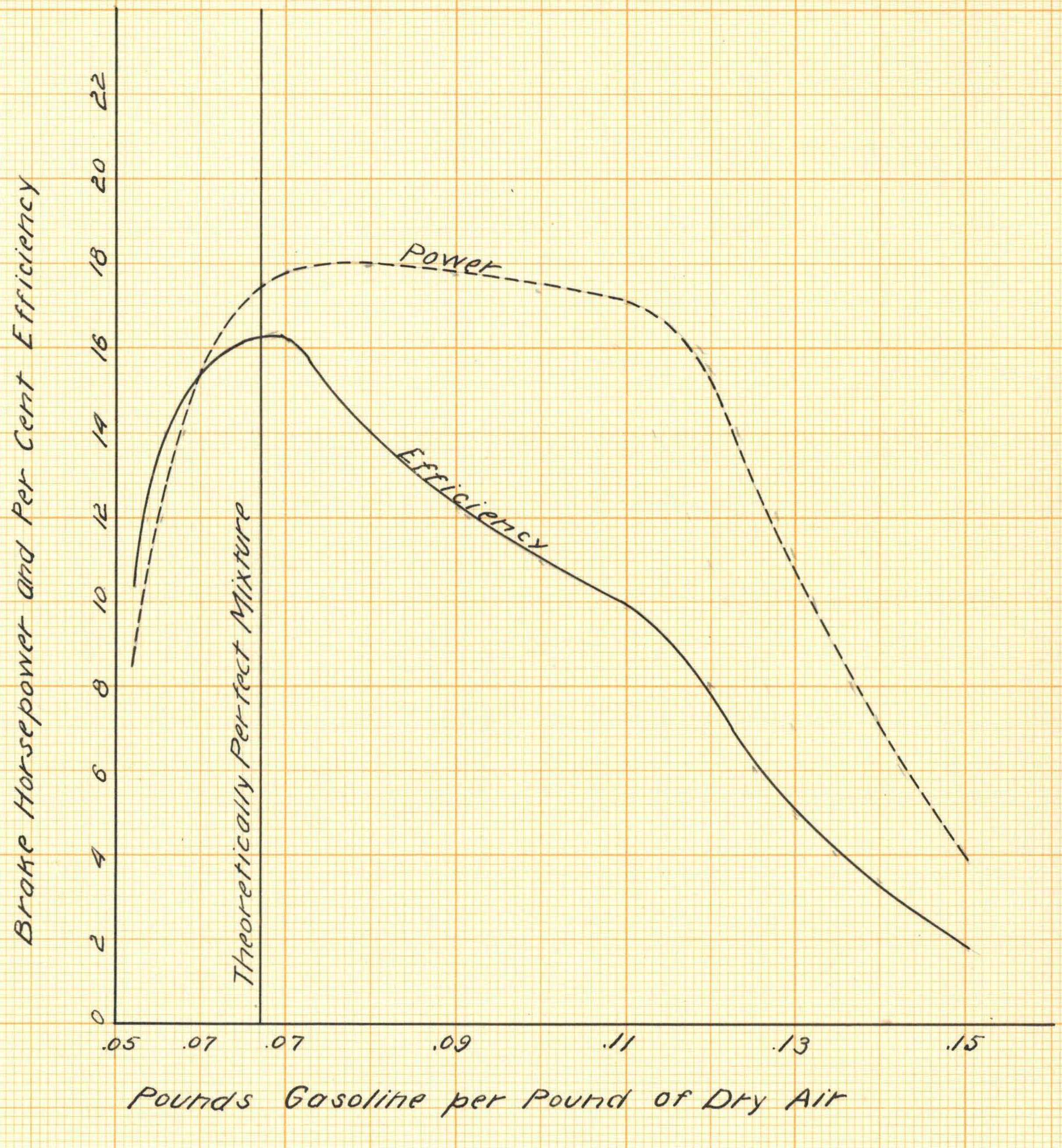
The area of the tube should expand gradually from the throat to the maximum diameter therefore it is necessary to shape that part of the tube which contains the evaporating piece so that the annular area will increase evenly. The proper shape is determined as shown in Drawing #1.

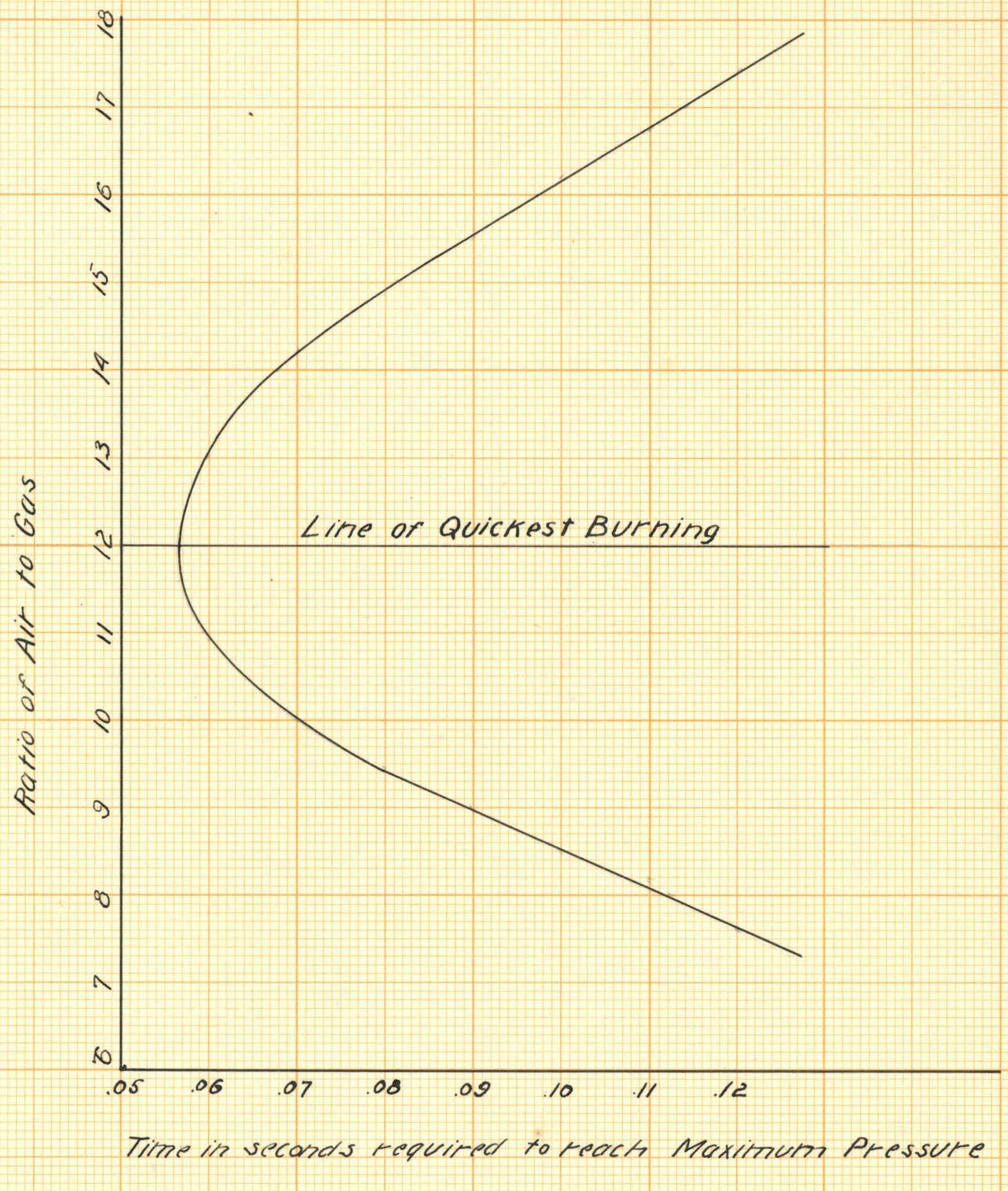
To insure ease of starting a valve is placed at the entrance to the tube. By closing this the suction on the fuel jet is increased, causing a rapid flow of fuel.

A butterfly type of throttle valve is placed at the other end of the tube to control the speed of the engine.

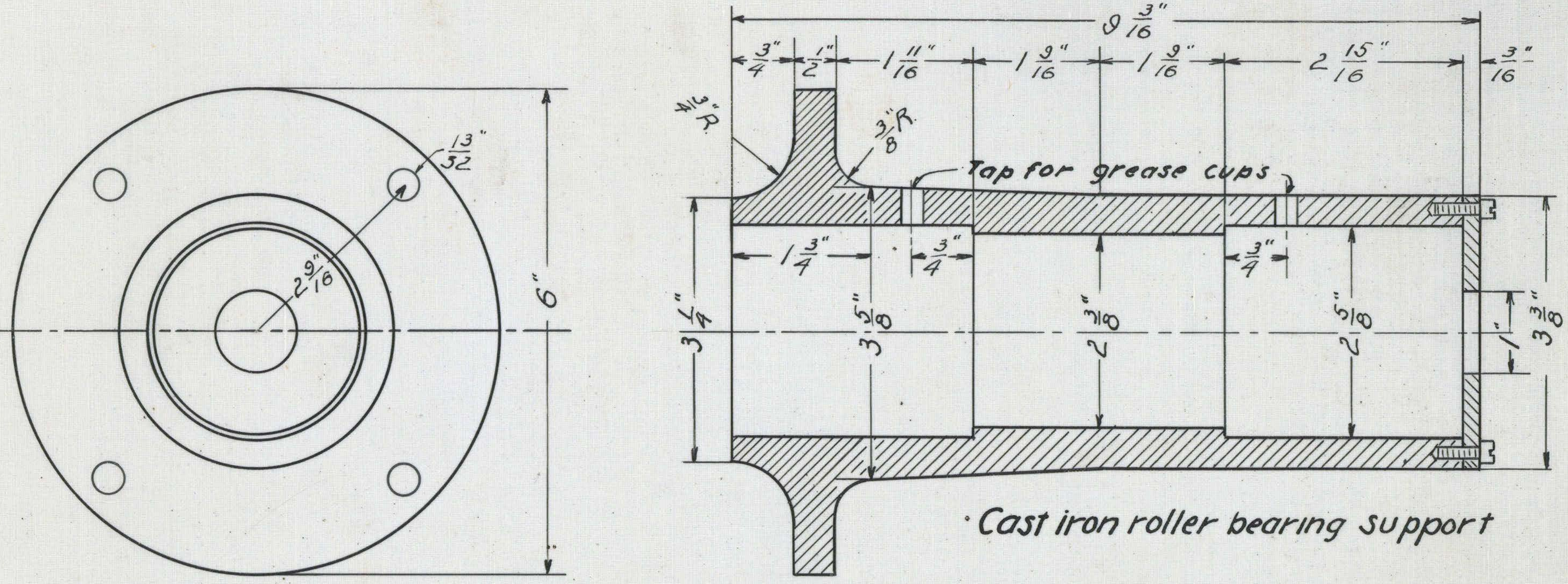
Jos. Beattie.


Velocity of Fuel in ft per sec.
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
120
240
360
480
600
720
840
Velocity of Air in ft. per sec.
Curve I Simple Venturi type Carbureter
Curve II Curve of Constant Ratio
Curve III Modified Carbureter.

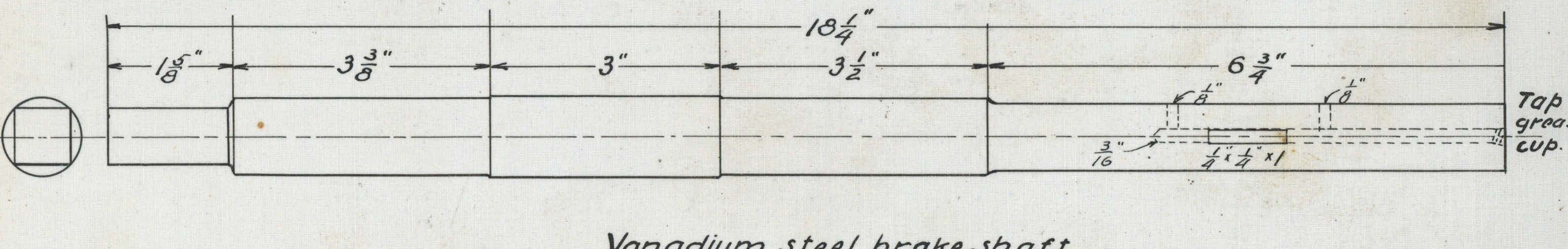

Brake Horsepower and Per Cent Efficiency
0
2
4
6
8
10
12
14
16
18
20
22
Theoretically Perfect Mixture
Power
Efficiency
.05
.07
.07
.09
.11
.13
.15
Pounds Gasoline per Pound of Dry Air


Ratio of Air to Gas
18
17
16
15
14
13
12
11
10
9
8
7
6
Line of Quickest Burning
.05
.06
.07
.08
.09
.10
.11
.12
Time in seconds required to reach Maximum Pressure

BRAKE SHAFT and BEARING



Cast iron roller bearing support



Vanadium steel brake shaft

Ford Motor

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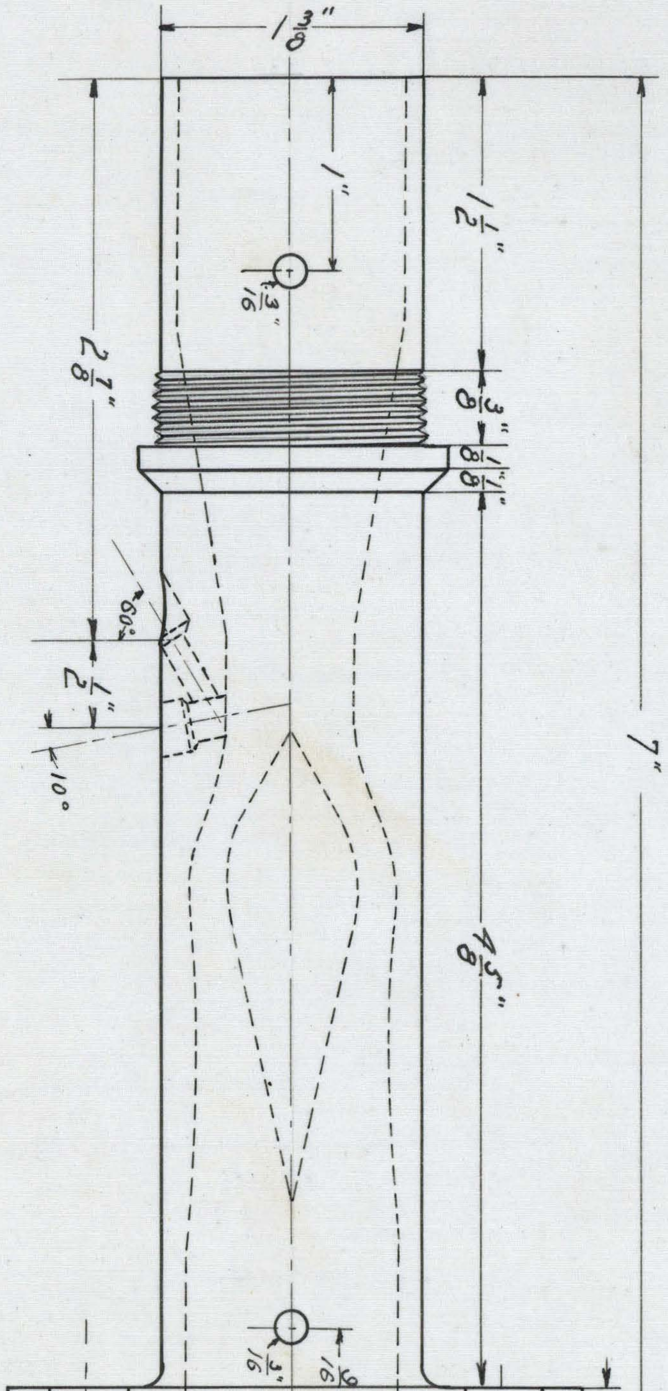
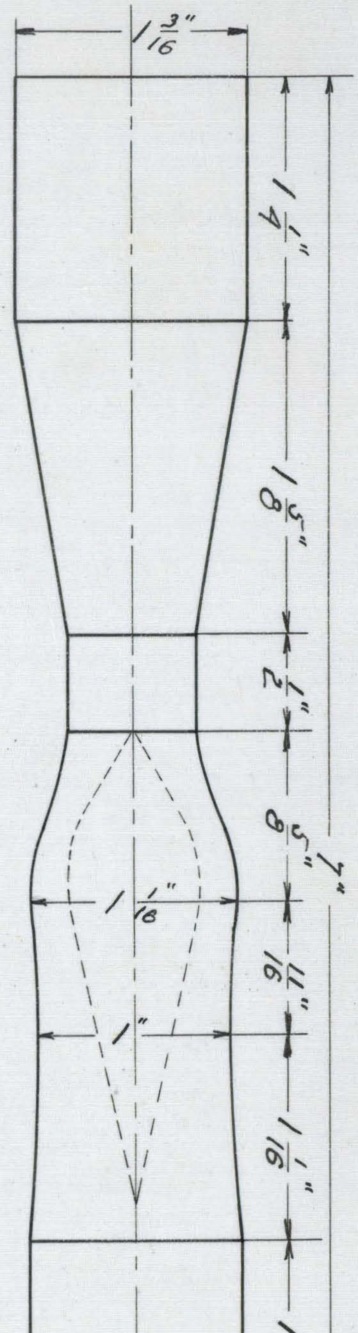
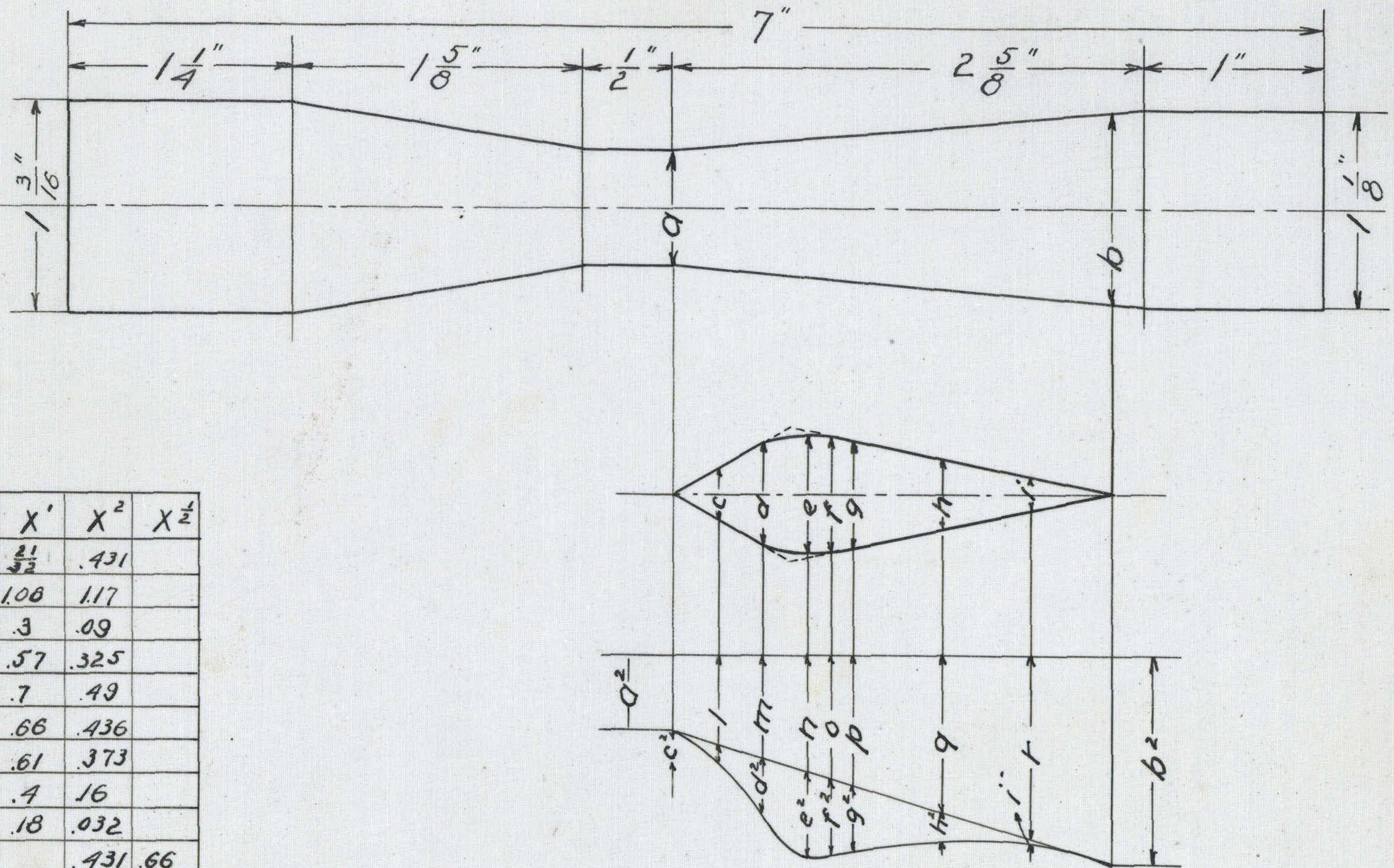
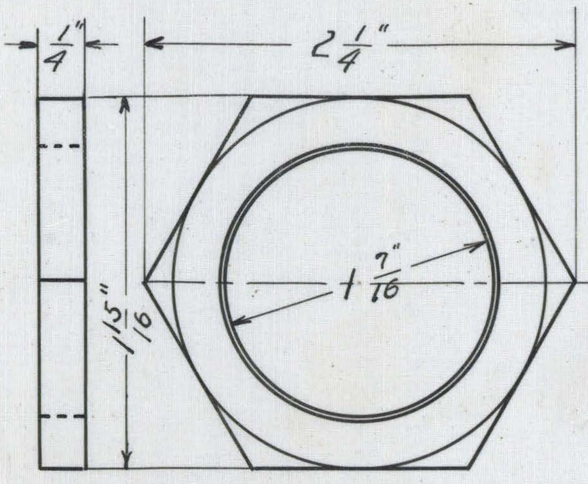
2/8/17.


1 3/8"
1"
1 1/2"
3/16"
2 7/8"
3/8"
1/8"
1/8"
60°
1/2"
10°
4 5/8"
7"
3/16"
9/16"
1/4"
2 1/16"
3"

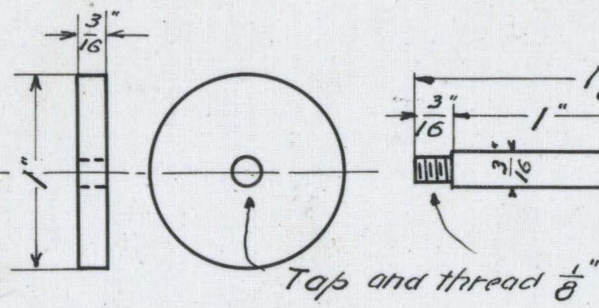

1 3/16"
1 1/4"
1 5/8"
1/2"
5/8"
1 1/16"
11/16"
1"
1 1/16"
1"
7"
1 1/8"

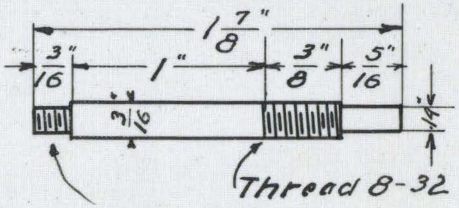


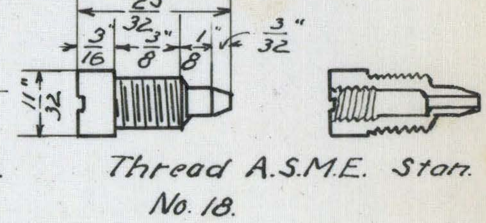
X	X'	X^2	$X^{\frac{1}{2}}$
a	$\frac{21}{32}$	.431	
b	1.08	1.17	
c	.3	.09	
d	.57	.325	
e	.7	.49	
f	.66	.436	
g	.61	.373	
h	.4	.16	
i	.18	.032	
a^2		.431	.66
l	.59		.77
m	.89		.943
n	1.14		1.07
o	1.13		1.06
p	1.1		1.05
q	1.03		1.015
r	1.06		1.03
b^2		1.17	1.08

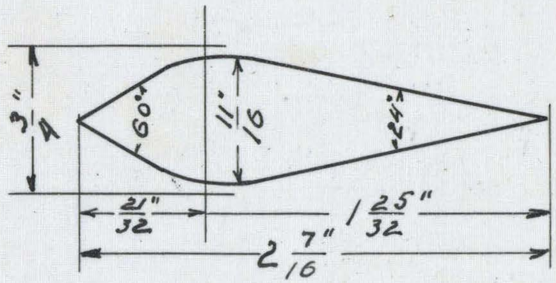


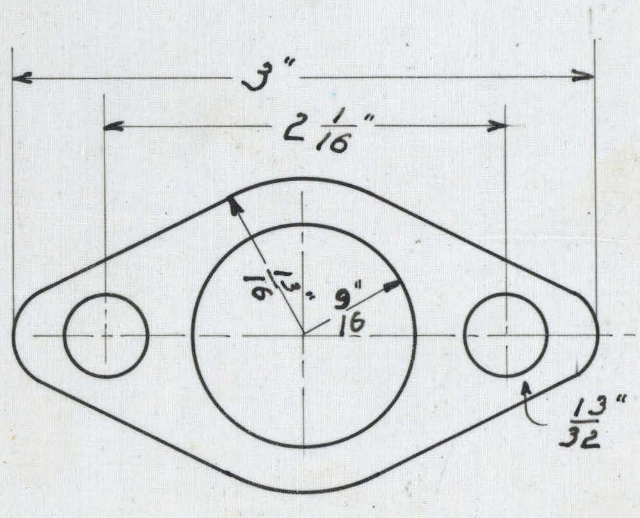
24 Thds. per in.

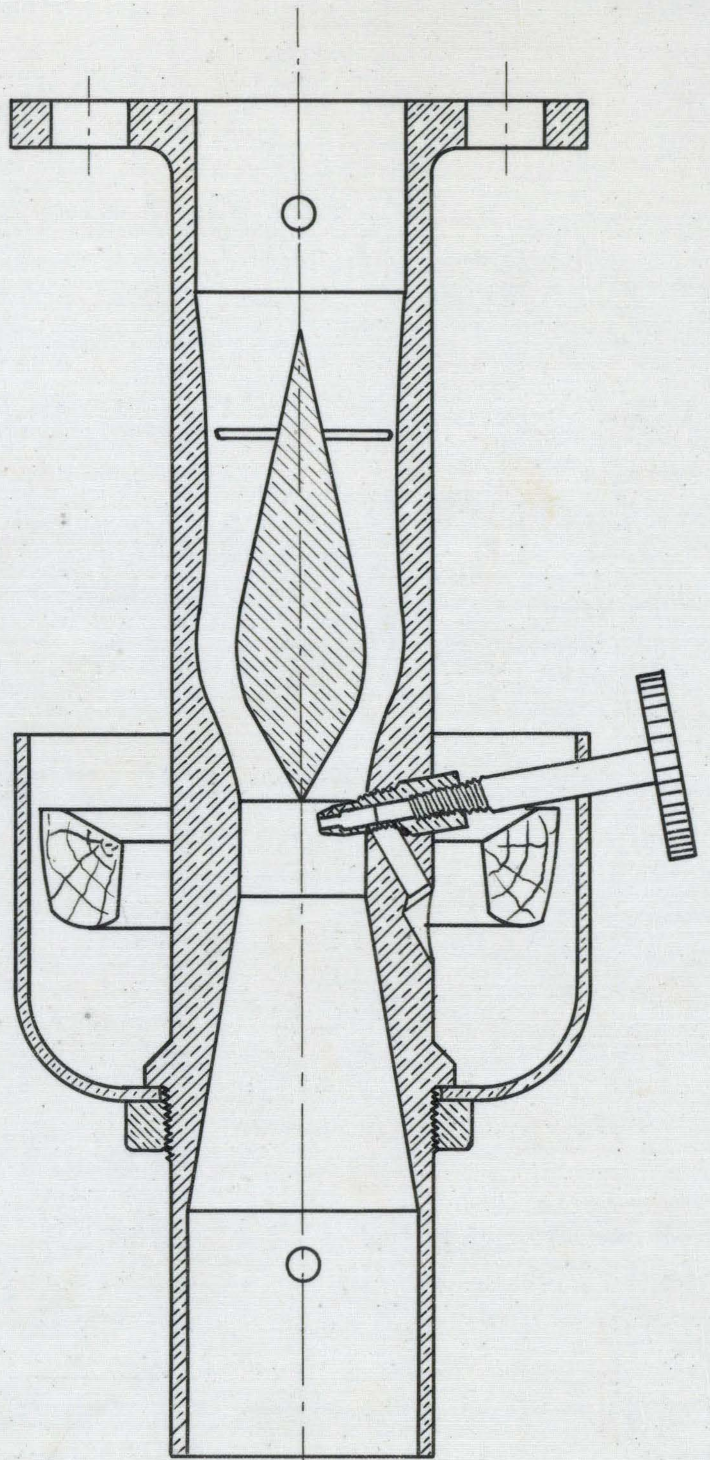












PART TWO

CARBURETOR DESIGN

Fundamental principle of all suction type carburetors:

$V = \sqrt{2\,gh}$

Let V_a = Vel. of air, ft. per sec.

V_f = " " fuel " " "

H_a = Head in ft. of air

H_f = " " " " fuel

H_s = " " " " " nozzle above fuel level in float chamber.

$$V_a = \sqrt{2\,gh_a} \qquad V_a^2 = 2gh_a \qquad H_a = \frac{V_a^2}{2\,g}$$

Head of fuel corresponding to air head =

$$H_a \times \frac{\text{density air}}{\text{density fuel}} = H_a \times \frac{W_a}{W_f}$$

$$= H_a \times \frac{W_a}{\text{spgr} \times W_w}$$

W_a = Wt 1 cu.ft.air

W_f = " " " "fuel

W_w = " " " "water

∴ Neglecting fuel head H_s and fuel friction through nozzle - $V_f = \sqrt{2\,gh_a \frac{W_a}{\text{spgr}\,W_w}}$

But fuel head must be raised a distance H_s against gravity:

∴ $V_f = \sqrt{2\,gh_a \frac{W_a}{W_w\,\text{spgr}} - 2\,gh_s}$ which neglects only the friction losses.

The density of air varies inversely as the absolute temperature. 1 cu.ft. air at 62° F. weighs .0761 lbs.

$\therefore$ at Temp. t° F. weight 1 cu.ft. = $.0761 \times \frac{460 + 62}{460 + t^\circ}$

The density of gasoline has been found to vary as follows:

Spgr = 0.72 (1-.0007 (t°-60))

$$V_f = \sqrt{\frac{\frac{460 + 62}{460 + t^\circ} \times .0761}{62.355 \times S(1-.0007(t^\circ-60))} \times V_a^2 - 2\,gh_s}$$

62.355 = Wt. of 1 cu.ft. water at 62° F.

S = Spgr at 60° F.

Assume air temp. to be 100° F. (intake to carburetor)

$\frac{460 + 62}{460 + 100} = \frac{522}{560} \times .0761 = .071$

V_f varies as the square root of the air density or

$\sqrt{.0761} = .276$

$\sqrt{.071} = .266$ % dif. in $V_f = \frac{.01}{.276} \times 100 = 3.6\%$

dif. .010

Assume gasoline temp. 100° F. and Sp.gr. .74 at 60°

$62.355 \times .74 = 46.1 \qquad \sqrt{46.1} = 6.79$

$62.355 \times .74(1-.0007(100-60)) =$

$62.355 \times .74 \times .972 = 44.8 \qquad \sqrt{44.8} = 6.69$

$6.79 - 6.69 = .10 \qquad \frac{.10 \times 100}{6.79} = \frac{10}{6.79} =$ 1.5% plus

The increase in the temperature of the air diminishes its density and consequently the fuel velocity is decreased; while the increase in the fuel temperature diminishes its density and its velocity of flow will be increased. Therefore the differences in velocity due to temperature changes tend to balance each other.

$\therefore$ -3.6 plus 1.5 = about 2% dif. in V_f

The difference is so small that the change in densities due to temperature changes will be neglected. Therefore the formula reduces to the following when gasoline of sp.gr. of .74 at 60° F. is used; and air temp. 62° F.

$$V_f \sqrt{\frac{.0761}{62.355 \times .74} V_a^2 - 2 gh_s}$$

$$= \sqrt{.00165 V_a^2 - 2gh_s}$$

or for fuel of any other density this becomes:

$$V_f = \sqrt{\frac{.0761}{62.355 \cdot Sp\ gr} V_a^2 - 2 gh_s}$$

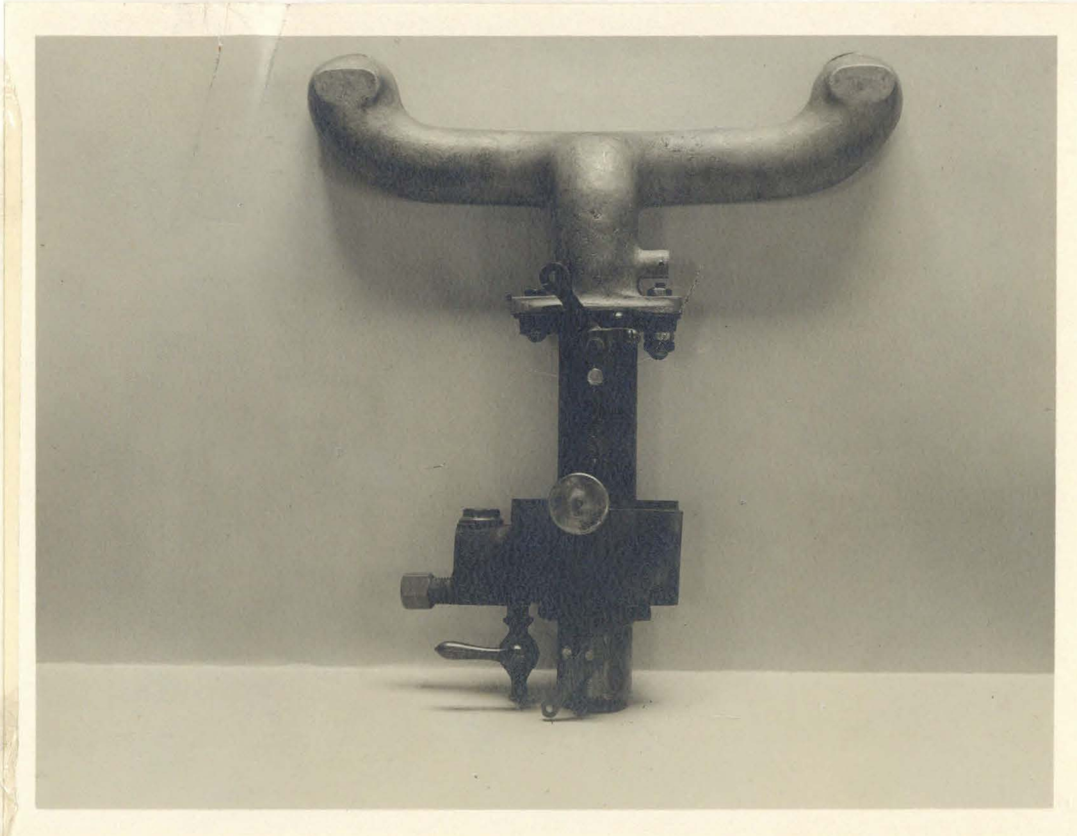
The distance H_s varies from about 1-1/6" to ½" in carburetor practice. In the design of this carburetor ¼ will be used (this factor makes considerable difference in the calculations).

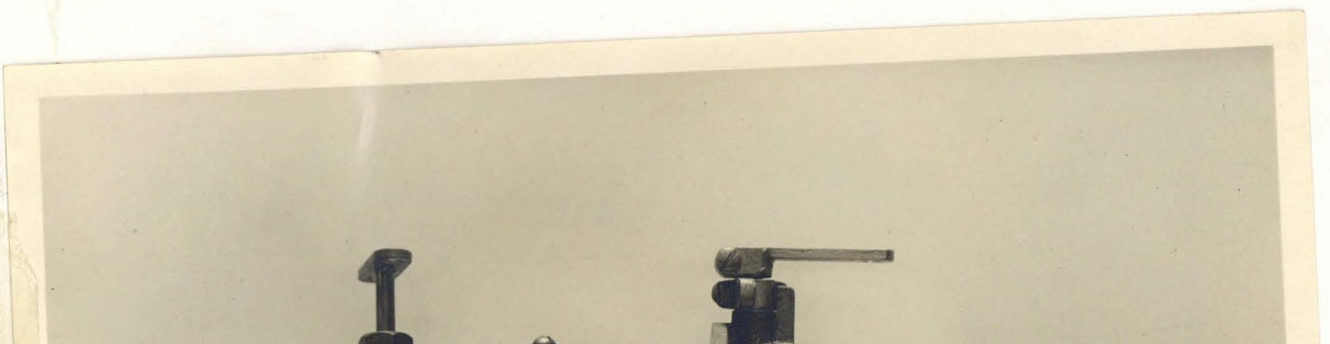
$$\tfrac{1}{4}" = \tfrac{1}{4} \times \tfrac{1}{12} = \tfrac{1}{48} \text{ ft.} = 0.0208 \text{ ft.}$$

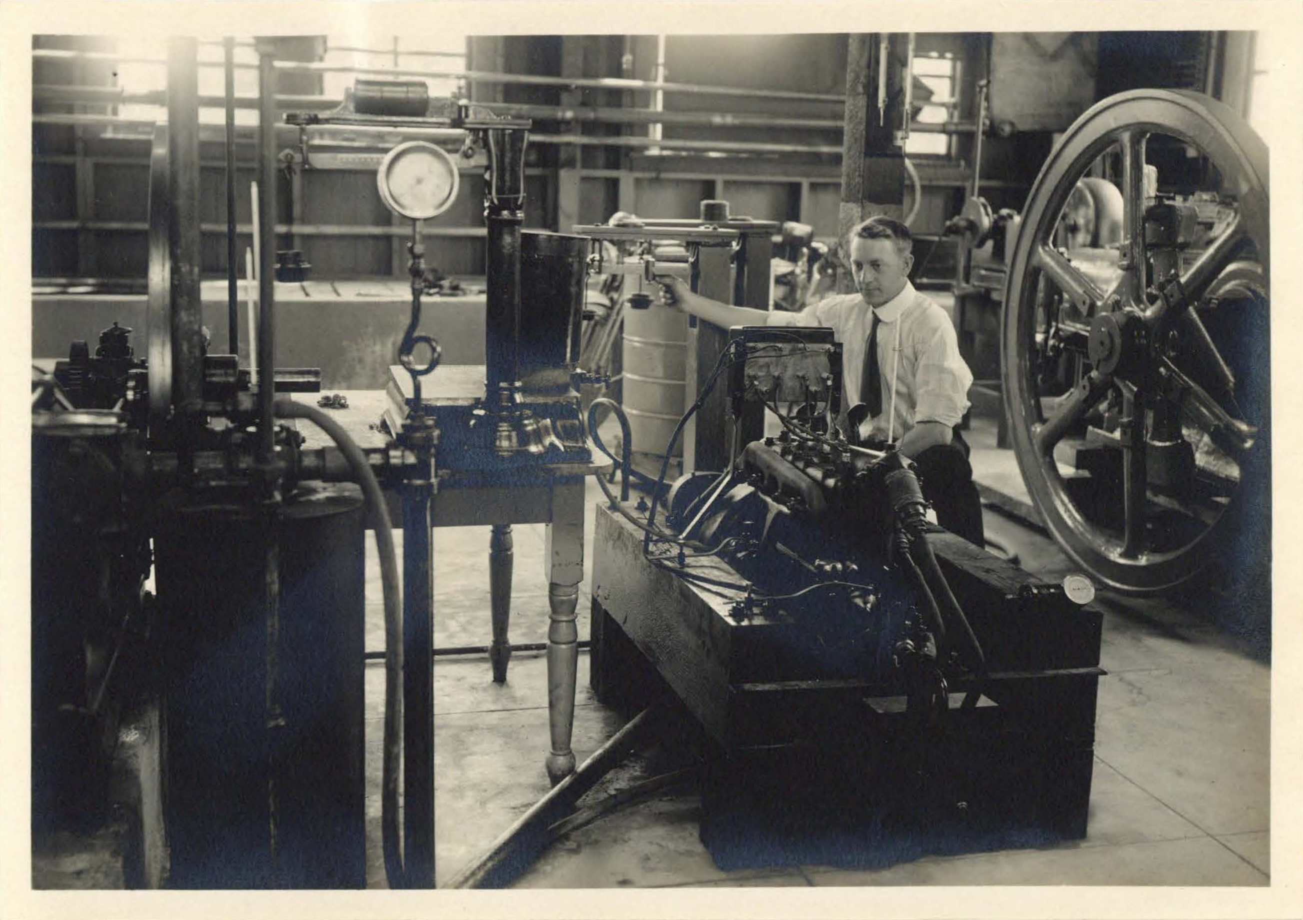
$$V_f = \sqrt{.00165 V_a^2 - 64.4 \times .0208}$$

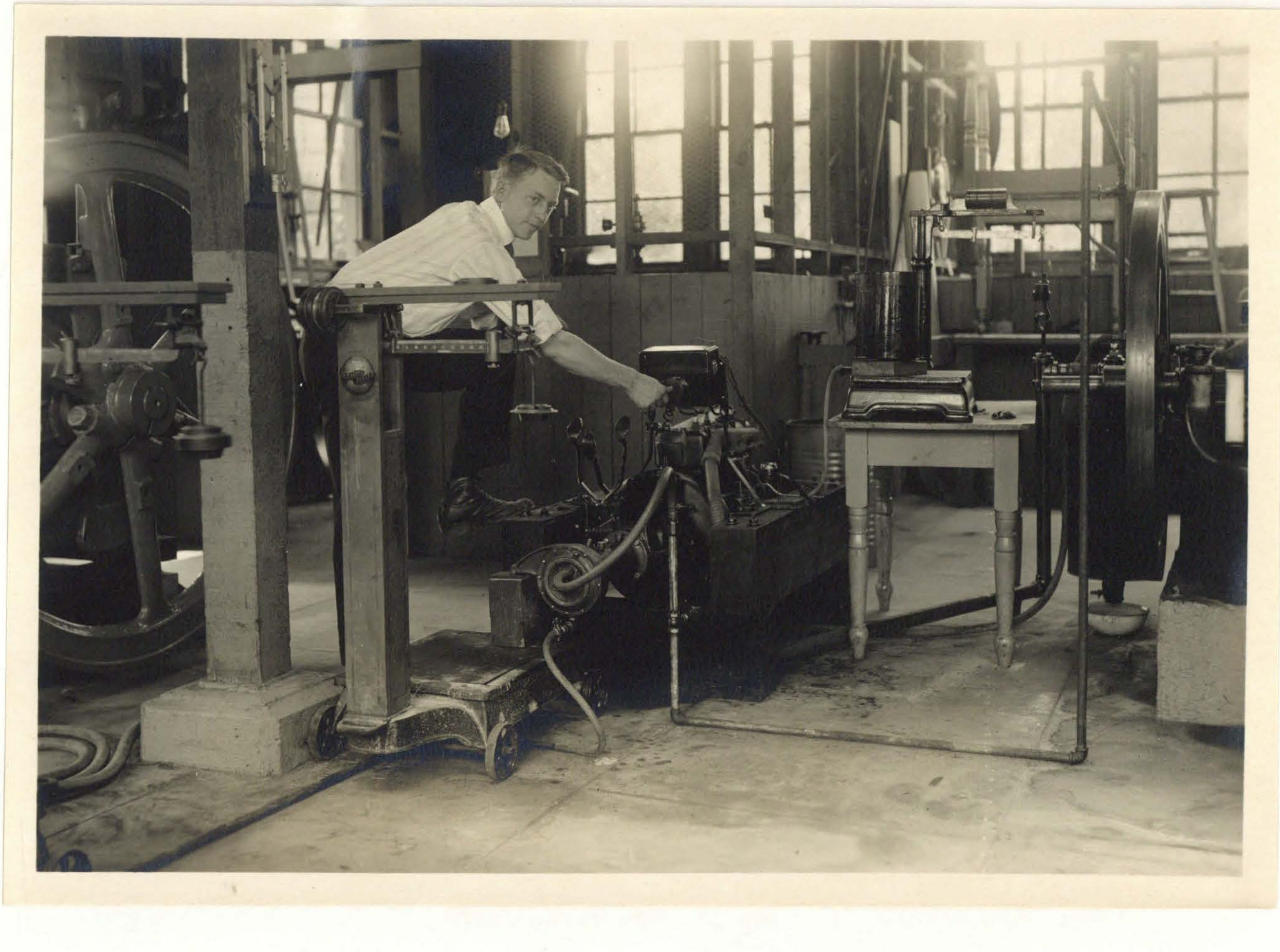
$$= \sqrt{.00165 V_a^2 - 1.34}$$

The velocity of the air is determined principally by starting conditions. When an engine is cranked at starting the velocity of air




1 2 3 4 5





through the carburetor must be sufficient to carry into the cylinders a combustible charge. This velocity is estimated at 7,000 to 9,000 feet per minute, or about 115 to 150 feet per second. (Pagé, The Modern Gasoline Automobile, page 288). Browne Handbook of Carburetion, page 18, states that 60 to 90 feet per second is sufficient with a well designed carburetor.

This carburetor is to be designed for a Ford engine. Assume speed range of engine 150 to 1500 R.P.M.

Cylinders $3\frac{3}{4}$" x 4 (Engine 4 cyl. 4 cycle.)

$\frac{3.75^2 \pi}{4}$ x 4 x 2 x RPM x suction factor = piston disp. per min. in cu.in. = 88.5 x RPM x F - where F = suction factor.

At slow speed F will approach unity and at the high speed it may decrease to .6 or .7 but to allow for speeds above 1500 no correction for F will be made in calculating air displacements and velocities.

150 RPM S=

88.5 x 150 = 13,280 cu.in.per min.

1500 RPM S= 132,800 " " " " "

To cut down volumetric loss (see Browne, Handbook of Carburetion, page 18) an initial velocity through the venturitube of 60 ft per second will be used.

$Q = Va \qquad a = \frac{Q}{V}$

$a = \frac{13,280}{60 \times 60 \times 12} = .307$ Sq. in.

$a = \frac{\pi d^2}{4} = .307 \qquad d^2 = \frac{4 \times .307}{\pi} = .391$

$d = \sqrt{.391} = .625$ or 5/8" diameter of tube at throat.

Using a simple venturitube carburetor, the results would be as follows:

For $V_a = 60$

$V_f = \sqrt{.00165 \times 60^2 - 1.34} = 2.144$

For $V_a = 600 \quad V_f = \sqrt{.00165 \times 600^2 - 1.34} = 24.36$

Thus increasing air supply 10 times has increased fuel supply $\frac{24.36}{2.144} = 11.35$ times

and the mixture will be $\frac{(24.36-21.44)}{21.44} \times 100 = 13.6\%$ richer.

Evidently this form of carburetor would give a varying ratio of mixture of air to gas.

To further study these relations, curves will be plotted of air velocity against fuel velocity.

$V_a = 60 \qquad V_f = \qquad 2.144$

$V_a = 120 \qquad V_f = \sqrt{.00165 \times 120^2 - 1.34} = 4.73$

$V_a = 240 \qquad V_f = \sqrt{.00165 \times 240^2 - 1.34} = 9.67$

$V_a = 360 \qquad V_f = \sqrt{.00165 \times 360^2 - 1.34} = 14.59$

$V_a = 600 \qquad V_f = \sqrt{.00165 \times 600^2 - 1.34} = 24.36$

$V_a = 900 \qquad V_f = \sqrt{.00165 \times 900^2 - 1.34} = 36.50$