CHAPTER V

INDUCTION SYSTEM

The induction system of an aircraft engine consists of the passages between the carburetor and the cylinder combustion chamber. By careful study in design of these passages the engine manufacturer has from time to time increased the power output of his engine. In fact, improvements in the design of the engine induction system have been next in importance to supercharging as a means for increasing the power in modern aircraft engines. By this same token, then, the aircraft manufacturer can carry out this same principle of induction system refinement for increasing the performance of his airplane by careful design of the portion of this system that is in his control, that is, the portion ahead of the carburetor.

The requirements of the induction system ahead of the carburetor are as follows:

1. It must supply air to the carburetor in sufficient quantity to meet the demands of the engine.

2. The temperature of the air supplied to the carburetor must be such to avoid loss of engine power.

3. A means for regulating the temperature of the air supplied to the carburetor must be provided.

4. Air flowing through the ducts ahead of the carburetor should encounter a minimum of aerodynamic losses and when entering the carburetor should be free from turbulence.

5. The heater system, ducts, valves, and so on, must be capable of withstanding normal wear due to vibration, wide temperature variation, and explosive pressures such as obtained during an engine back fire.

Carburetor Ram

The quantity of air required by the engine is given in Figure 63. While this quantity is not exact, it will be found to be sufficiently accurate for use in making air scoop calculations. The Wright Aeronautical Corporation's engine specifications give the power rating of the engine based on zero ram, or atmospheric pressure, at the top deck of the carburetor. Obviously, while operating the engine with no forward velocity of the airplane, there will be a depression or negative pressure at the top deck of the carburetor equal to the velocity head necessary to produce the

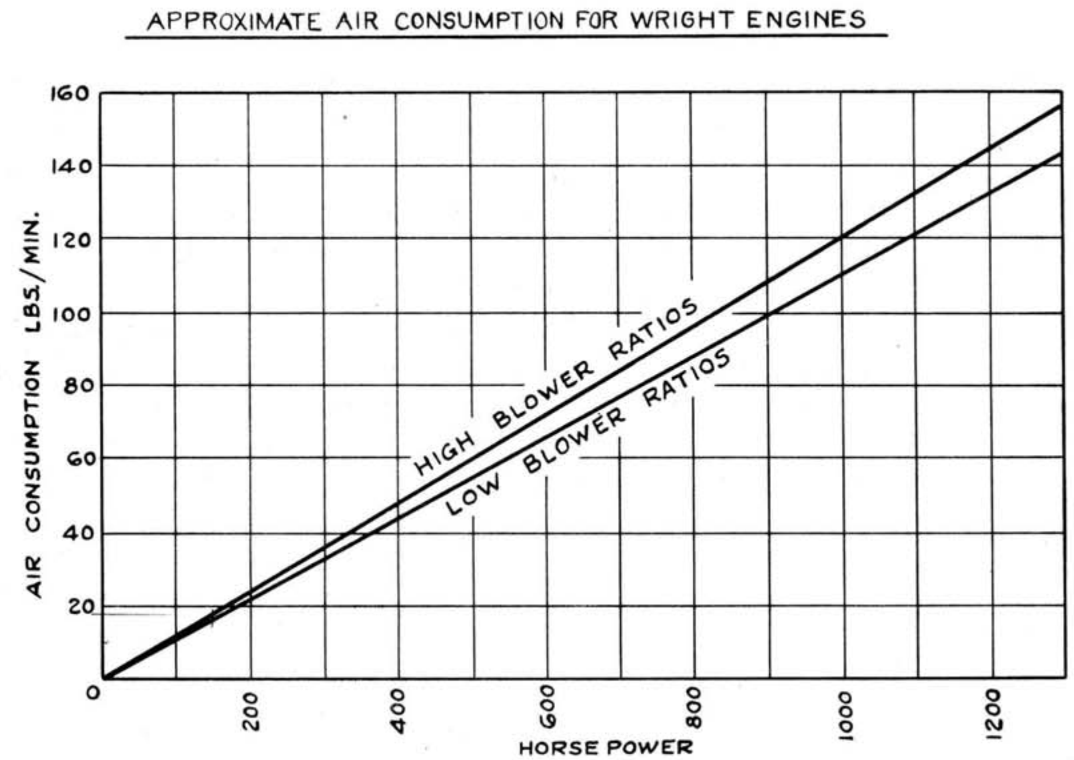


Figure 63

required air flow plus the air scoop losses. With a ramming type air scoop, this negative pressure will become positive as the airplane speed increases, reaching its maximum at the maximum indicated speed of the airplane. The fact that a negative pressure exists at the top deck of the carburetor is not serious except that it slightly reduces full throttle power. For each inch of water negative ram, the Cyclone engine loses 4.3 horse-power. Positive pressure serves only to increase the critical altitude for any full throttle manifold pressure by the amount shown on the engine specification.

Taking everything into consideration, ram, or a positive static pressure on the top deck of the carburetor, is desirable as it (a) gives the airplane a higher altitude rating, with resultant higher speed, (b) lowers the speed at which full throttle take-off power will be obtained, and (c) serves to prevent leakage of warm air into the carburetor intake system through poorly fitted hot air valves in the scoop.

Assuming frictionless flow through the carburetor air duct, zero ram will be obtained when the dynamic head due to flight velocity is equal to the velocity head in the duct required to produce the flow of air to meet engine requirements. When the losses which are present in the induction system ahead of the carburetor are considered, it will be found that in a normal air scoop design almost twice the velocity pressure necessary to meet engine requirements at a given power is required before zero ram is obtained. Summing it up, the carburetor ram is dependent upon the air consumption requirements of the engine, the losses in the induction system ahead of the carburetor, and the dynamic head due to flight velocity.

Carburetor Air Scoop Design

Since the power output of the engine is a function of the velocity head of the air supply at the top deck of the carburetor, it is important that the air scoop be designed to utilize the dynamic head available due to the flight velocity and transfer it to the top deck of the carburetor with a minimum of losses. The major losses in the scoop are obtained at its entrance and at the turns. The loss at the entrance is due to the initial acceleration of the air and is known as vena contracta loss. The loss at the turns is principally due to shock loss and turbulence. These losses are stated in terms of velocity pressure at the indicated section and represent the pressure loss due to flow or the additional pressure required to cause a predetermined flow.

Figure 64 illustrates several types of entrances applicable to carburetor air ducts. It is worthy of note that a radius 15% of the depth or diameter of the scoop entrance is quite efficient, but a sharp leading edge is very inefficient. The design of the scoop entrance should not only provide efficient flow of the air passing into it, but its external contour should be such to avoid turbulence of the air flowing over it. In other words, the scoop body should be well faired into the cowl so air flow disturbance around it is reduced to a minimum. To obtain optimum airplane performance the design of the carburetor air scoop entrance cannot be overlooked.

Next in importance is the design of the scoop elbow, which is necessary in an arrangement where the air scoop entrance is perpendicular to the engine crankshaft. Figure 65 shows data on the losses in elbows of square section in terms of R/D, or radius of turn/depth. A correction factor is included for changes in aspect ratio and degree of turn. As will be seen from the figure, the simplest way to keep the losses in elbows at a minimum is to use large radius ratios and large aspect ratios. This, however, is not always possible as the space available above the carburetor top deck dictates the radius ratio and the shape of the carburetor top deck dictates the aspect ratio. In this case, the addition of a splitter in the turn, or of turning vanes, offers the only way of reducing the losses. These devices change the properties of the elbow by changing the radius and aspect ratio of the section in question.

The frictional resistance of any duct to the flow of air, varies as the square of the velocity. The frictional resistance also varies with the density of the air

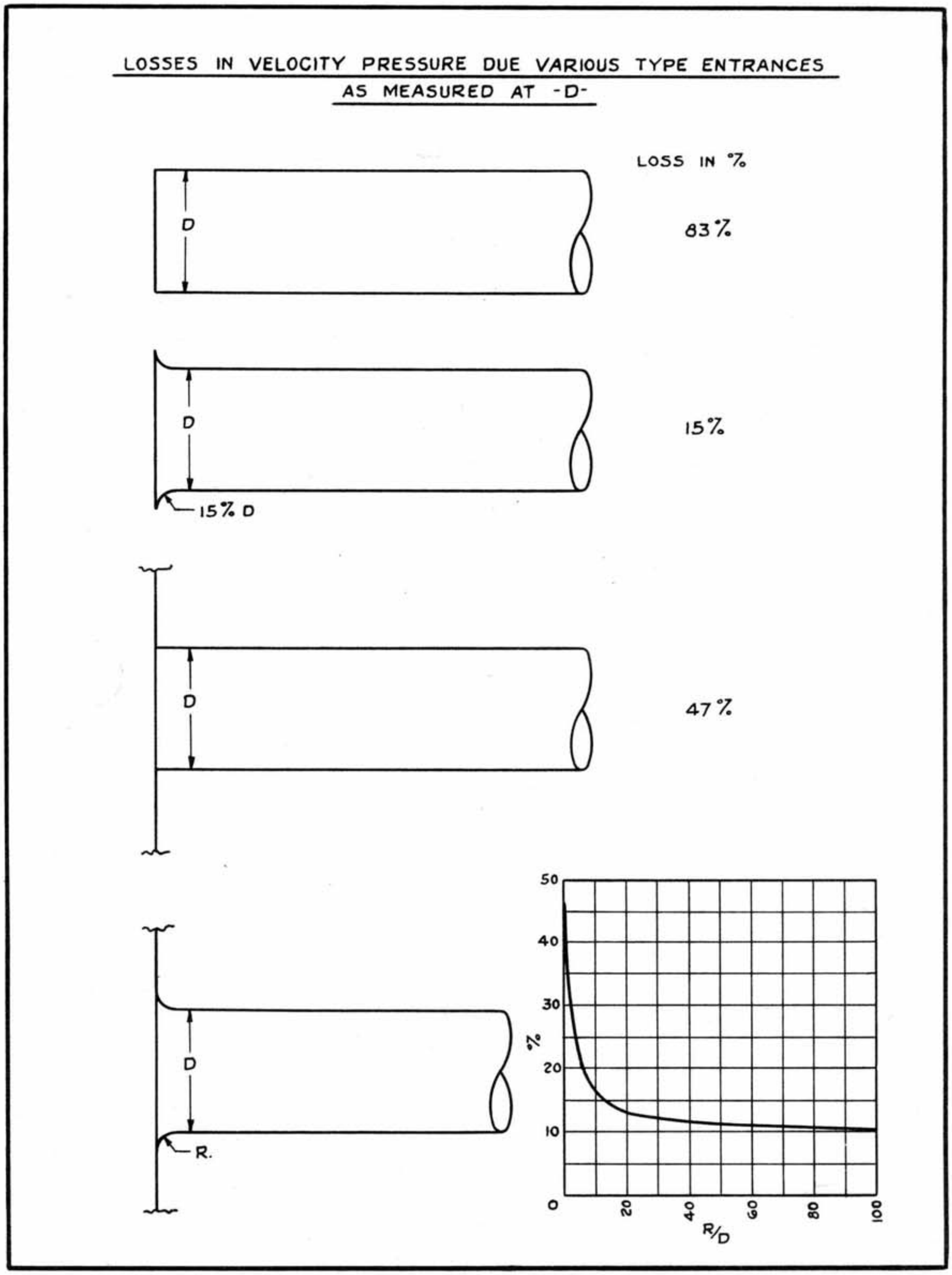

LOSSES IN VELOCITY PRESSURE DUE VARIOUS TYPE ENTRANCES
AS MEASURED AT -D-
LOSS IN %
D
83%
D
15%
15% D
D
47%
D
R.
50
40
30
%
20
10
0
20
40
60
80
100
R/D

Figure 64

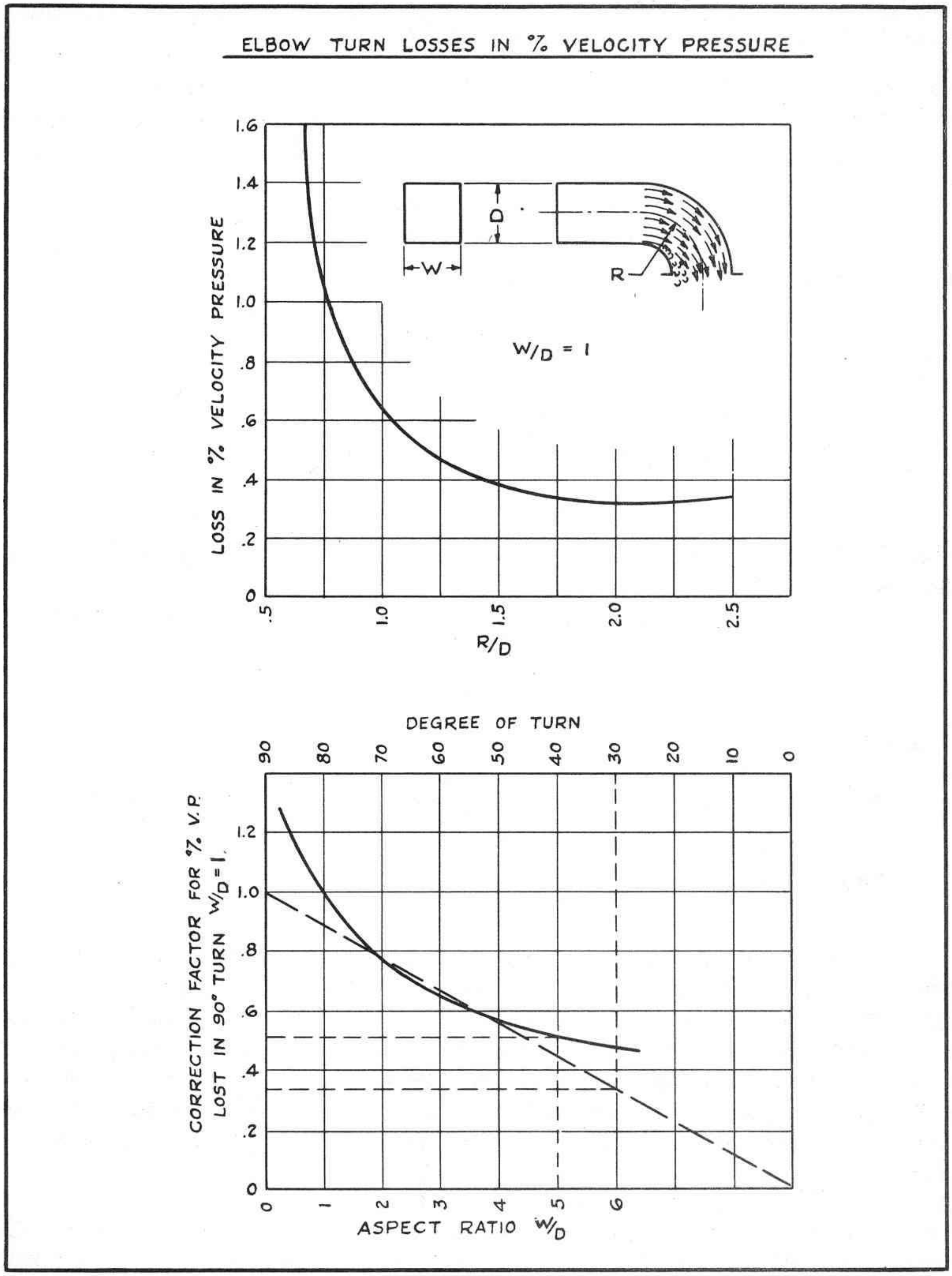

ELBOW TURN LOSSES IN % VELOCITY PRESSURE
LOSS IN % VELOCITY PRESSURE
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
.5
1.0
1.5
2.0
2.5
R/D
D
W
R
W/D = 1
DEGREE OF TURN
90
80
70
60
50
40
30
20
10
0
CORRECTION FACTOR FOR % V.P. LOST IN 90° TURN W/D = 1
1.2
1.0
.8
.6
.4
.2
0
0
1
2
3
4
5
6
ASPECT RATIO W/D

Figure 65

and the kinematic viscosity. Since, in the majority of designs the air scoop is rectangular in shape, this type will be considered.

The pressure, in inches of water, required to maintain a given velocity, or the loss of head caused by friction, which is numerically equal to it, can be expressed as:

$$P_2 = \frac{(L)\ (a+b)\ (\rho V)^2}{(c)\ (2ab)\ (624)} \qquad (11)$$

where

P_2 = pressure loss in inches of water

L = length of duct in feet

c = coefficient of friction

ρ = standard density of air

V = velocity in feet per minute

The expression a+b/2ab is the reciprocal of the hydraulic mean radius for a rectangular duct where:

a = width in feet

b = depth in feet

The value of c varies as follows:

For smooth sheet, such as aluminum or steel 60

For wire brushed or galvanized sheet. 55

For smooth sand cast surfaces 50

It will be found that the frictional loss for the length ducts normally used in aircraft induction systems is negligible when they are smooth and free from sharp corners. However, internal protrusions, such as bolts, rivets, bosses, valves, etc., seriously increase this duct loss and should therefore be avoided. Such conditions also cause turbulence in the airflow at the top deck of the carburetor which may have an adverse effect on the metering of the carburetor. For highest efficiency, the internal surface of the duct must be free from obstructions in the path of the air flow.

Having given the location and area (refer to Table III) of the carburetor top deck and linear velocity of the air at this point, the first step in designing the air scoop is to establish the location and size of the scoop entrance that will utilize the dynamic

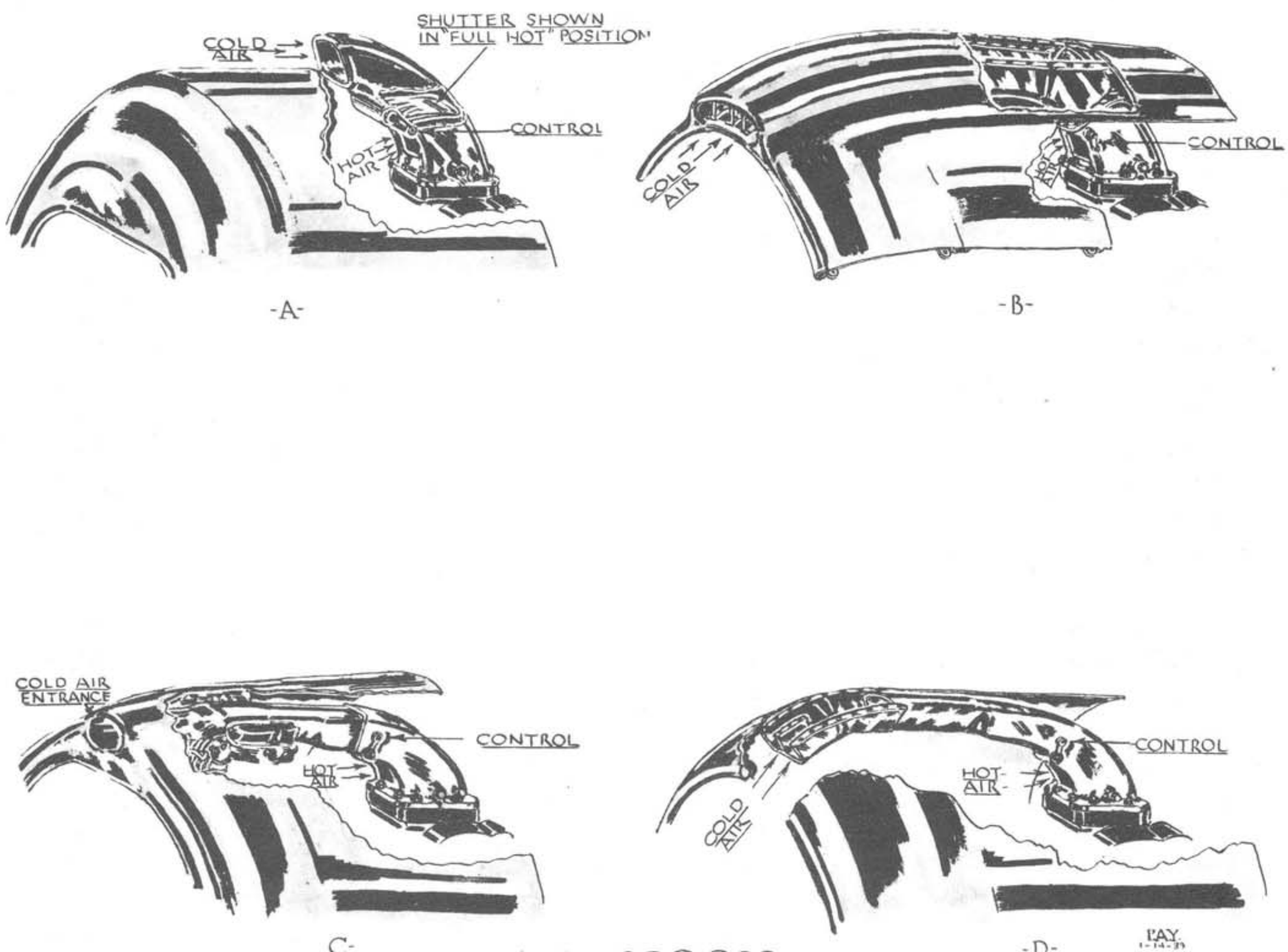
Table III

	Carburetor	Area of Top Deck in Square Inches
Stromberg	NA-F7F	31.73
	NA-R9A	19.80
	NA-R7A	15.4
Chandler-Evans or Holley	1375C	32.80
	1685C	40.30

head available due to flight velocity, and then transfer this velocity head by means of ducts and elbows to the carburetor top deck with a minimum of losses. Illustrations of various styles of carburetor air scoops generally used today are shown in Figure 66. Illustration (a) shows a type scoop that projects above the cowl line, well to the rear of the propeller, and is exposed to the air flow on the outside of the cowl. This style of scoop is simple and rugged and is generally used where scoop drag is of little importance. Illustration (b) shows a type built into the cowl but its ducts and entrance are located outside of the cowl limits. The entrance is located closer to the propeller to take benefit of the propeller slipstream. Illustration (c) shows a completely internal scoop, which is possible when the cowl diameter is made sufficiently large to provide enough room for a duct of suitable size. This entrance location is well placed for obtaining benefit from the propeller slipstream.

As previously stated, the carburetor air scoop entrance should be located to utilize the dynamic head available due to flight velocity. In attempting to accomplish this, the designer should consider that certain points on the airplane are exposed to dynamic head plus propeller slipstream velocity and a carburetor air scoop located at such a point will naturally benefit in ram. Fortunately, such a condition exists at a very convenient location for a carburetor air scoop entrance, that is, in the cowl leading edge contour directly in back of the propeller. The entrance should be perpendicular to the cowl leading edge. Illustrations (b) and (c) in Figure 66, show scoop entrances that benefit by slipstream velocity. Illustration (d) is also an effective air scoop but does not utilize the effect of slipstream velocity. Its advantage is in the fact that its entrance loss is relatively low since the velocity change at the entrance is not severe. Its disadvantage is that the air feeding the scoop is usually pre-heated slightly by the engine.

The size of the inlet is dependent upon the type of service for which the airplane is intended. There is little point in making an entrance larger than the carburetor top deck, and the lower limit would be a size just large enough to pass the required quantity of air to meet engine requirements, taking into account scoop losses at



AIR SCOOPS

Figure 66

maximum flight velocity. It will be found that an air scoop which is the proper size for high speed level flight will be too small for full-throttle climb, and a scoop designed for climb or take-off will offer too much airplane drag during high-speed level flight. Therefore, a compromise must be effected between designing a scoop for maximum ram and one for minimum drag. In other words, the type of performance which is most critical to the airplane in question will establish the size of the air scoop entrance.

The carburetor temperature rise over outside air should not be greater than 10° F. with the scoop set for full cold air. This requirement not only eliminates the possibility of excessive carburetor air temperature under critical conditions, but minimizes the power loss resulting from high carburetor air temperature. This power loss is a function of the square root of the ratio of absolute carburetor air temperature (T) to standard absolute altitude temperature (T_a) or,

$$\text{Corrected Horse-power} = \text{Brake Horse-power}\ (T/T_a)^{\frac{1}{2}} \qquad (12)$$

It is often found that when the ram is not positive under all conditions of flight, poorly fitted hot air valves will permit leakage of hot air from the heater system into the carburetor. Another source of hot air into the carburetor inlet is

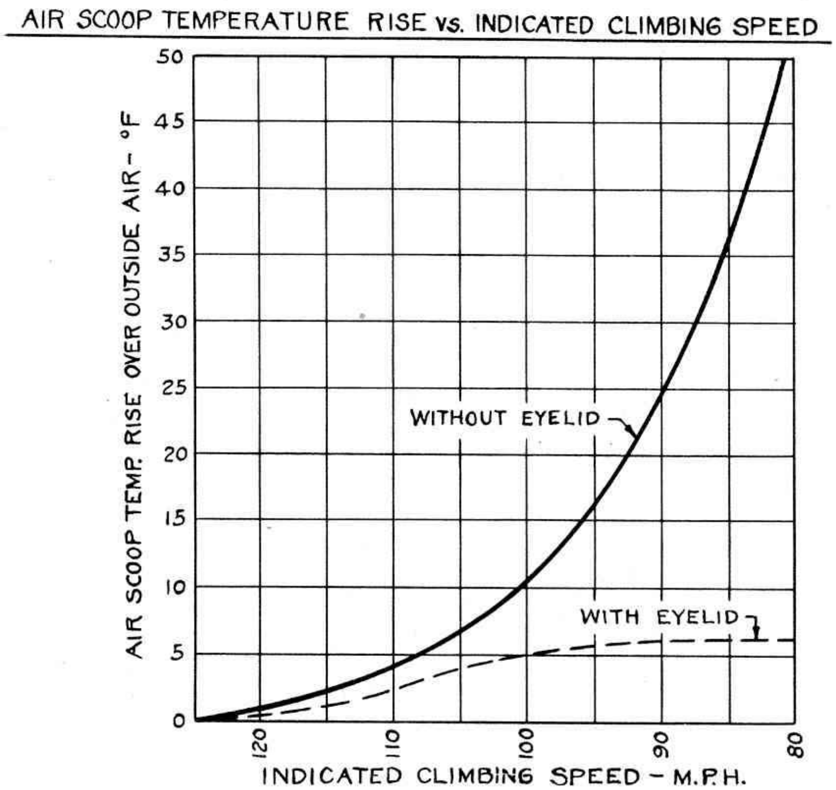


Figure 67

spillage out of the cowl frontal opening. This usually occurs at low climbing speeds and can be corrected by the addition of a spill plate at the top of the cowl frontal opening. Illustration of such a spill plate is shown in Figure 31. A scoop design having an entrance at the cowl leading edge is especially sensitive to spillage conditions; hence, with such a design the carburetor temperature rise should be carefully checked during all conditions of flight. Figure 67 illustrates results of tests for temperature rise over outside air versus air speed in a climb for a standard over-cowl scoop fitted to an engine cowl with and without a spill plate.

Experience has shown that scoops taking air from under the cowl and just ahead of the cylinders usually are subject to excessive carburetor air temperature rises. This condition, of course, is dependent upon air flow conditions within the cowl and is not true on all designs. With this design of scoop care must be taken not to obstruct the air flowing over the cylinders.

Carburetor Air Heaters

Carburetor air heater systems used for elimination of ice in the carburetor have passed through a long period of evolution. Early engines were equipped with "hot spots" which consisted of an exhaust heated tube over which the vaporized charge was passed. Although this method helped to heat the charge and thereby aid vaporization it did not remove the ice which formed on the carburetor parts between the fuel nozzles and the hot spot. It therefore became necessary to preheat the air supplied to the carburetor.

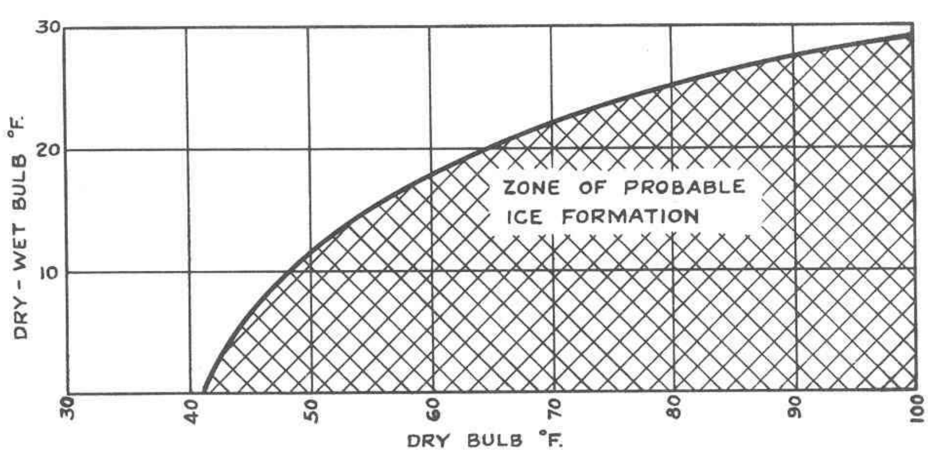


Figure 68

Let us first consider the factors that affect the formation of ice in the carburetor. It is a popular misconception that trouble with carburetor ice is only encountered during cold weather. This is not the case, as many other factors contribute to this problem, for instance: (a) the volatility and heat of vaporization of the fuel, (b) fuel to air mixture ratio, (c) temperature of the carburetor body, (d) quantity of fuel being vaporized (power), and (e) humidity, temperature, and pressure of the intake air. It has been possible to analyze the conditions surrounding a great number of instances where carburetor icing has occurred with modern power plants and to identify the condition with relation to the humidity, or wet and dry bulb temperature. Figure 68 illustrates the results of a great number of test points as obtained during current airline operation. The data show that it is possible for ice to form even at high outside air temperatures if the wet and dry bulb temperature difference is small.

The coldest point in the induction system is just after the carburetor, or in the carburetor adapter. It is therefore, desirable to locate the temperature indicator in this location and when carburetor icing conditions are prevalent, enough preheat should be applied to bring this temperature up to 35 to 40^{o} F. Since there is an average temperature drop through the carburetor of approximately 60^{o} F. during cruising, when 35^{o} F. is put in the adapter the actual carburetor air temperature will be about 95 to 100^{o} F. To provide this it has become necessary to resort to very effective heaters, such as, intensifier tubes within the manifold, or shrouds around the manifold. Both of these style heaters are illustrated in Figures 76 and 77. To satisfy present day requirements, these heaters have been enlarged to the point where it is possible to damage the engine by full application of heat under high power operation during moderate weather. Thus, it is necessary to supply a thermometer in the carburetor adapter to indicate the proper amount of heat to be applied. This indicator should always be placarded to warn the pilot to avoid the use of mixture temperatures above 40^{o} F.

From the standpoint of satisfactory engine operation, it is desirable that the carburetor air heater be designed with the following characteristics in addition to meeting the detail requirements of the operator:

(1) The heat should be uniformly distributed throughout the incoming air before entering the carburetor.

(2) The change in heat and carburetor ram should be as nearly uniform as possible with uniform change in control travel.

(3) When the heater is not in use, the hot air must be by-passed and carried free from the cold air intake, the carburetor body, and the fuel system.

(4) The preheat system should be designed to withstand wide variation of temperature and should be sufficiently rugged to withstand normal engine vibration without excessive wear.

(5) The heater valve and intake system should be designed to withstand the explosive pressure of an engine backfire through the carburetor.

Recently, "non-icing" carburetors have been developed which are so constructed as to have no carburetor parts in the path of the vaporized fuel which is discharged from the nozzles. Extended experience with these carburetors has shown that they are not susceptible to carburetor icing of the familiar kind. However, under atmospheric icing conditions, that is, a wing icing condition, it is possible that ice may form in the carburetor air scoop or on the screen at the top deck of the carburetor in such quantities as to reduce the engine power. It is therefore necessary with these carburetors, to supply a moderate amount of preheat to eliminate this type of ice. This can be accomplished by providing a valve in the air scoop which will close off the scoop cold air supply and take the warm air from behind the cylinders and inside the engine cowling. A scoop of this type is illustrated in Figure 66 a.

With this arrangement of preheat and using a non-icing carburetor, measurement of the carburetor air temperature or mixture temperature is not necessary when an outside air temperature bulb is available on the airplane, and provided it is demonstrated that the preheat obtained is not in excess of 60^{0} F. with full heat on and operating at rated power. Measurement of the carburetor air temperature is recommended when the heat supply is in excess of the above limitation, as in this case, the carburetor air temperature gauge will serve as a definite protection to the engine for preventing the use of excess carburetor heat. With this arrangement of preheat, provision for measuring mixture temperature is not necessary.

When designing the carburetor air scoop, the airplane manufacturer is cautioned that the bottom deck of the scoop must mate perfectly with the top deck of the carburetor. Any irregularities at this parting surface or on the inner walls of the scoop will disturb the air flow at the carburetor top deck and thereby effect the carburetion.

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