CHAPTER VI

EXHAUST SYSTEMS

The function of the exhaust system is to collect and dispose of the exhaust gases discharged by the engine with a maximum reduction in exhaust noise and with a minimum effect upon the power output, life, and maintenance of the engine. In addition, this system is usually called upon to supply heat for the airplane cabin and/or cockpit, and for the engine induction system as may be necessary. Early type airplanes had no provision for collecting the exhaust gases in a common manifold or collector, but instead, were fitted with short stacks that discharged the exhaust gases of each individual cylinder directly into the atmosphere. This arrangement has been discarded on practically all installations in favor of a collector. The features of the collector installation are: (a) decreases noise level of the exhaust, (b) decreases exhaust glare, and (c) provides a means whereby the heat of the exhaust can be utilized.

The exhaust manifold is an influencing factor in the life and maintenance of an engine, since its design determines the back pressure imposed on the exhaust ports of the individual cylinders. The effect of back pressure in the exhaust on the power of an engine is given in Table IV. The effect on engine life and maintenance is somewhat unestablished, but there is little doubt that excessive back pressures at the exhaust port of a cylinder are conducive to piston ring and valve troubles. Therefore, in view of these conditions, and since the power curve in the specification is based on zero back pressure, it becomes necessary to establish a limitation on the back pressure. This limitation has been established as 12 inches of water on an individual cylinder, and the pressure difference between any two individual cylinders must not exceed twenty-four inches of water. Experience has shown that these requirements can easily be met with a manifold designed in accordance with present day practices. By exercising care in the design and manufacture of the manifold the exhaust back pressures can be held well within these allowable limits.

The quantity of exhaust gas the collector is required to handle is equal to the combined amount of the fuel and air consumed by the engine. Figures 69 and 70 show some data gathered on exhaust gas weight and temperature versus power on an aircraft engine in the 1000 horse-power class. While these data are applicable to specific cases of manifold design where a flow analysis is required, it is general practice to design an exhaust manifold in accordance with a few simple design principles that have been established on the basis of service experience. In every design these general design principles should be considered in addition to the detail requirements of the procuring agency for which the airplane is being built.

TABLE IV

Percent power loss per inch of mercury back pressure on exhaust ports.

Engine	Percent Power Loss per Inches Hg. Back Pressure
R760-ET and E1	.30
R975-E1, E2 and R760-E3	.38
R & GR1820-F50	.63
R & GR1820-G1 and G2	.71
R & GR1820-G3, G103A and G106A	.96
R & GR1820-G102A and G5	1.12

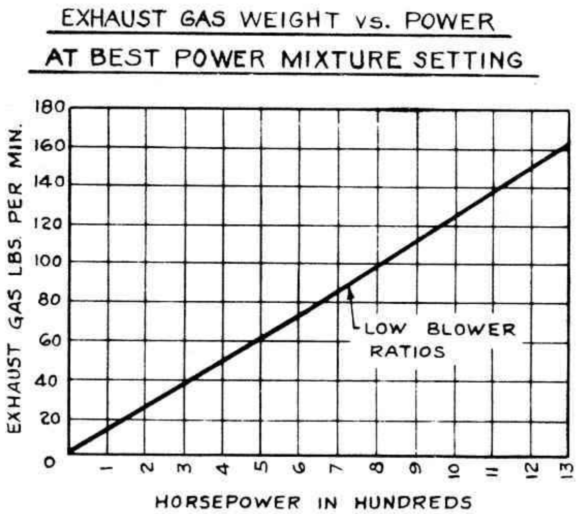


Figure 69

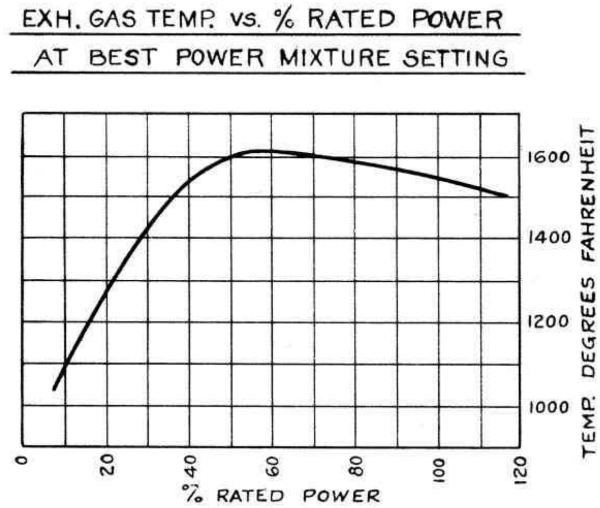


Figure 70

General Design Details

(a) Back Pressure

The exhaust back pressure, measured as outlined in Section II of this Manual, should be less than the specified maximum.

(b) Cross Section Area

Experience has shown that the cross sectional area of the manifold at any point should not be less than that obtained by application of the formula given below:

$$\text{Net area (square inches)} = .04 \times \text{Takeoff Horsepower} \times \frac{\text{Number of cylinders connected}}{\text{Total number of cylinders}} \qquad (13)$$

Where internal restrictions exist in the exhaust system, the coefficient (.040) should be increased to (.045) or more depending upon the nature of the restriction.

Equation (13) is equivalent to a design factor of 25 horsepower power-loading per square inch of cross-sectional area. This value has been established through a study of the frictional losses accompanying the flow of gases and is well established by practice. The frictional losses in a manifold vary directly with the absolute temperature of the gas and inversely as the fifth power of the tube diameter. The power-loading in the manifold tailpipe may be more or less than the 25 horsepower mentioned above depending on the location of the tailpipe outlet. Certain locations will assist the flow of gases out of the manifold, and others will obstruct the flow.

Figure 71 illustrates a typical preliminary layout of an exhaust collector for a "G100" Cyclone engine. This manifold has a single outlet for application of a tailpipe. A developed view, such as this, is convenient for computing weights, cross-sectional areas, and methods of connection between the various sections. The size of the individual cylinder outlets should be as indicated on the engine installation drawing.

(c) Shape

Experience on many arrangements of exhaust systems has indicated that the shape of the individual sections of the manifold may be equally important as the area for obtaining reduction in exhaust back pressure. Circular sections are recommended. Streamline or elliptical sections have often been tried in an attempt to reduce drag or to avoid interference where space is limited; however, due to increased tooling costs and troubles due to cracks in service such practice is generally avoided.

The exhaust system should be shaped so as to induce tangential flow of the gases at all intersections and to avoid abrupt changes of curvature or cross-sectional area which would change the flow characteristics. It is important to provide tangential entry of the gases from the individual cylinder outlets upon entering the manifold proper. This can be obtained by making the angle between the individual stack and the manifold proper a maximum of 30^0. Refer to Figure 75. Particular care should be paid to the actual junction of the individual stack and the manifold proper to insure that there are no overhanging edges and that generous radii are used at the joint. It is also good practice to widen out the individual stack before it enters the body of the manifold.

It is desirable to taper the manifold in changing from one cross-sectional area to another, as shown in Figures 72, 73, and 74. This practice results in simple and light construction. The welded joints between the individual stacks and the manifold body are generally made of the scarf type.

(d) Material

A great many materials are available for the construction of manifolds. Early manifolds were made of Armco Iron but at present the use of some grade of stainless steel or nickel alloy is generally preferred. It is desirable to use a corrosive resistant material since the exhaust gases contain a high lead and sulphuric content. Manufacturers of these materials will gladly cooperate with the airplane manufacturer in selecting the proper material for the purpose intended.

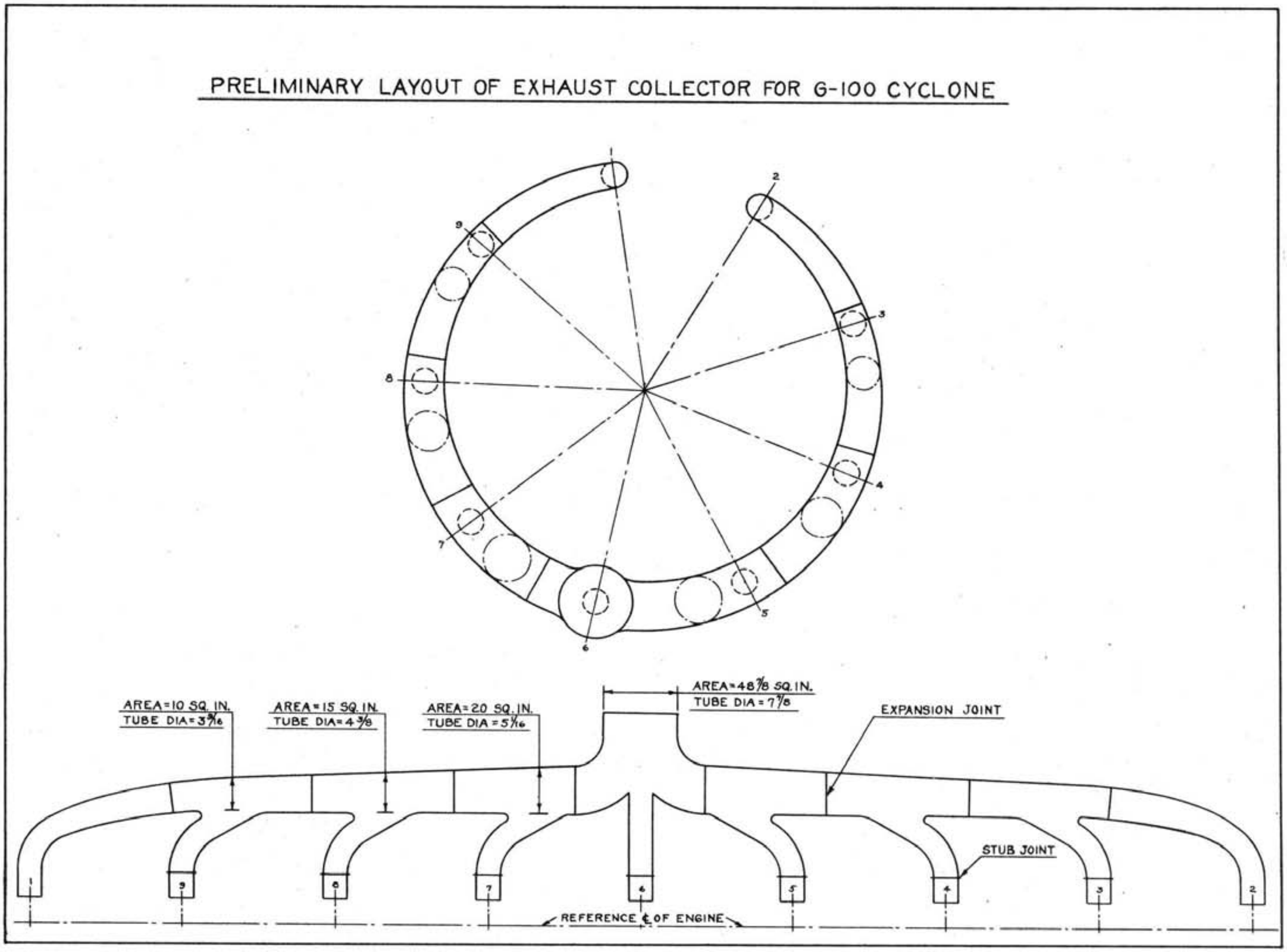
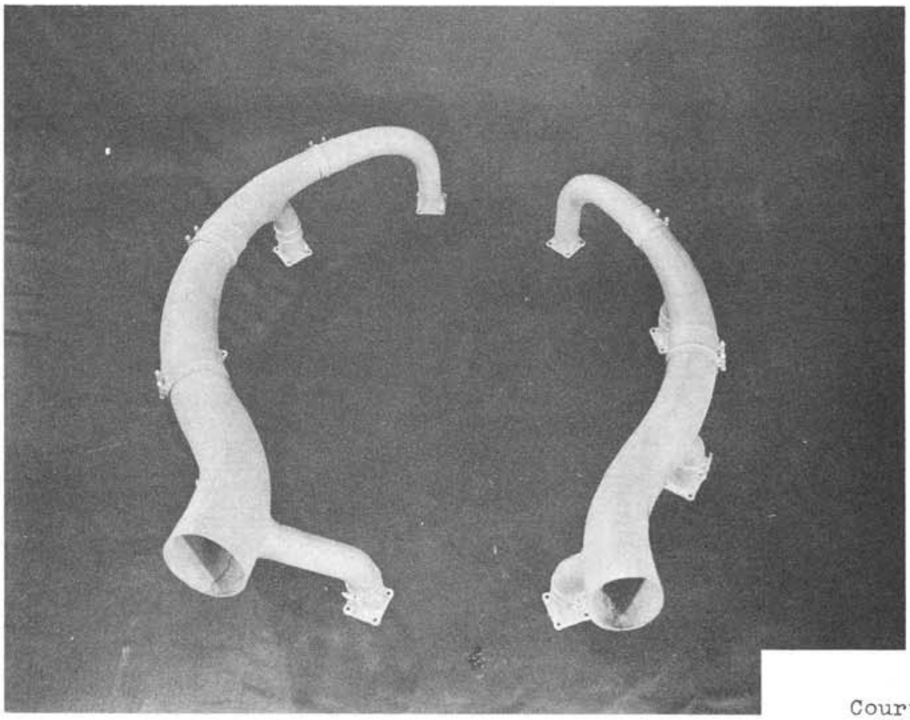
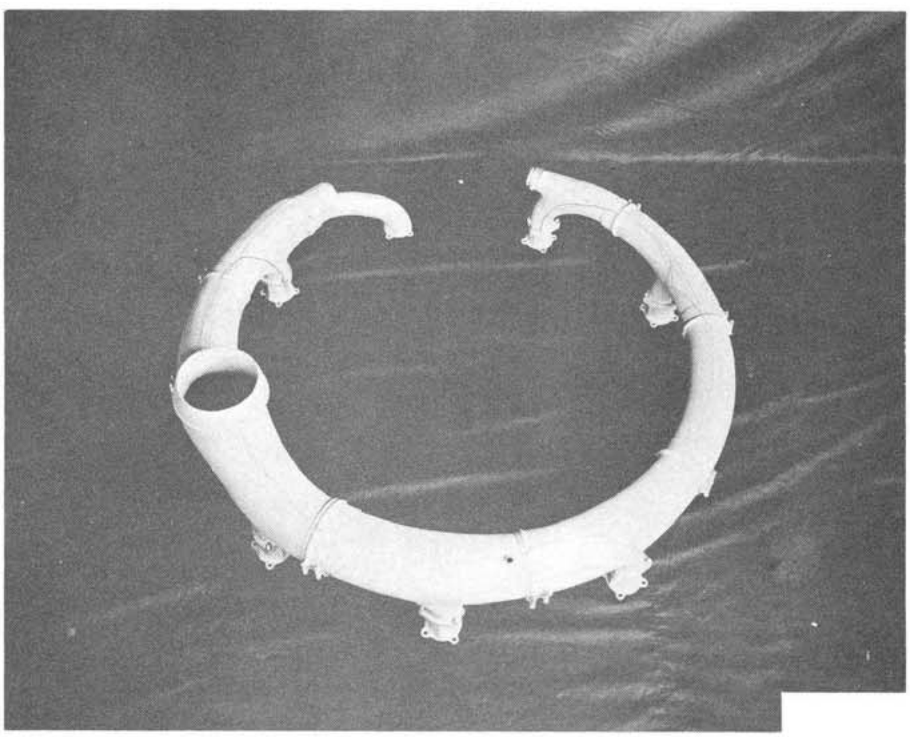

PRELIMINARY LAYOUT OF EXHAUST COLLECTOR FOR G-100 CYCLONE
AREA=10 SQ. IN.
TUBE DIA=3 9/16
AREA=15 SQ. IN.
TUBE DIA=4 3/8
AREA=20 SQ. IN.
TUBE DIA=5 5/16
AREA=48 7/8 SQ. IN.
TUBE DIA=7 7/8
EXPANSION JOINT
STUB JOINT
REFERENCE ℄ OF ENGINE

Figure 71



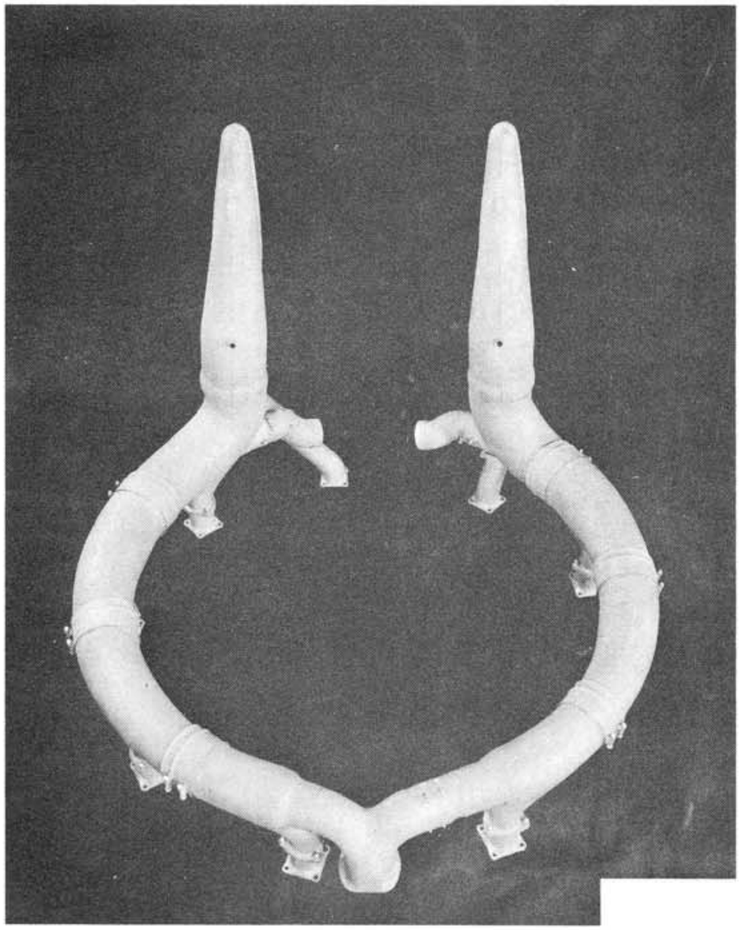
Courtesy of Solar
Aircraft Co.

Figure 72



Courtesy of Solar
Aircraft Co.

Figure 73



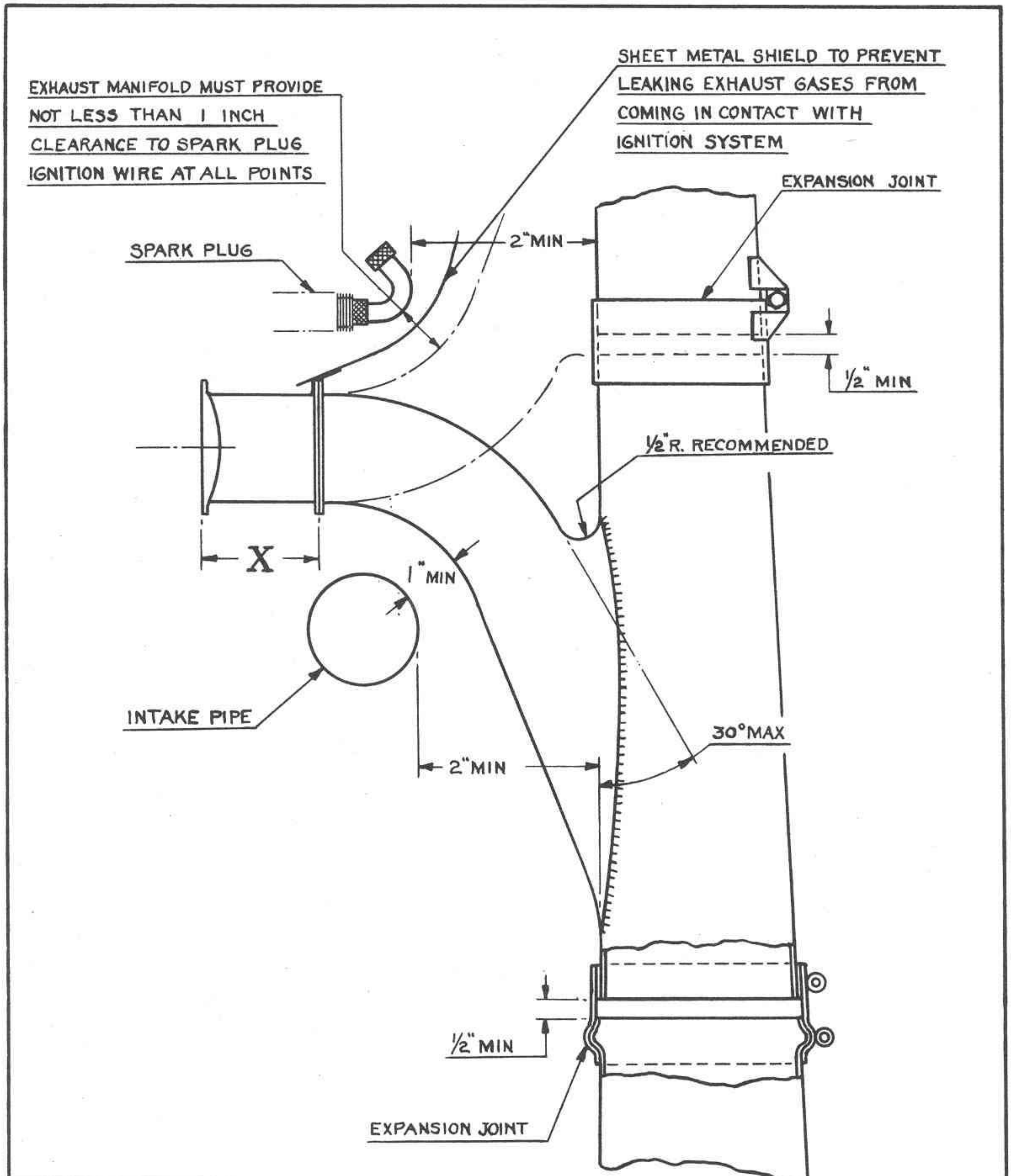
Courtesy of Solar Aircraft Co.

Figure 74

(e) Mounting and Location

Exhaust collectors are usually supported directly from the exhaust-port flanges on the cylinder head. With this style of mounting it is desirable to provide gusset plates between the exhaust flange and the individual stack so as to distribute the load along the stack and thereby avoid local cracks. Refer to Figures 72 and 73. Generous welds must be used between the flange and the stack or the gusset plates. In some cases where the collector is very large and heavy it is desirable to support it by means of braces from the airplane structure and then some form of flexible slip joint is required at each individual stack and in some designs at the tailpipe junction.

The collector location is governed by the characteristics of the individual installation. Both the radial dimension, or diameter, and the fore and aft location of the manifold with respect to the engine are governed by the dimensions of the engine mount, cowling, and the required clearances for removal of certain units from



MODEL	X
CYCLONE F-50	2⅝
CYCLONE G	3
CYCLONE G-100	3⅛

NOTE: X INCLUDES ½" CLEARANCE

Figure 75

the engine. This latter point is very important since accessibility to such units as the fuel pump, oil pressure relief valve, Cuno strainer, sump strainer, and so on, is governed by the location of the manifold. When establishing the location, care should be taken to provide suitable clearance space at the intake pipes, carburetor, ignition harness (spark plug elbows), and so on. Refer to Figure 75 for recommended clearances and location dimensions.

Figure 75 also shows the length of spacer required at the exhaust port of the cylinder to allow for removal of a cylinder assembly without necessitating complete removal of the collector. This feature is very desirable from a maintenance viewpoint. The minimum length of spacer which will permit removal of a cylinder without removal of the manifold is indicated as "X".

The outlet or outlets, from the manifold should discharge the gases clear of the airplane structure where there will be no objectionable glare to the pilot or passengers at night. The point of discharge will determine the need for a tailpipe. When a tailpipe is used it is usually desirable to support it from the airplane structure and put a flexible connection at its joint with the manifold.

(f) Expansion and Cooling

The exhaust system must have provision for expansion of the manifold due to temperature change and also to allow for expansion in the engine itself. Figure 75 shows two styles of expansion joints that are used quite extensively with very favorable results. A joint of this type should be provided between all sections of the manifold where such sections are restrained at more than one point. Since the exhaust manifold is somewhat loosely suspended it is necessary to take care in the design of the slip joints so engine vibration will not cause severe wear at each joint. To avoid rapid wear of the manifold it is advisable to weld a steel collar on the manifold at each joint where the sliding motion takes place. The clamps should fit closely to the manifold but be free enough to allow for expansion and slip. Joints that are excessively loose may allow air to leak into the exhaust gas and thereby upset the exhaust analyzer reading, or may allow exhaust flame to escape presenting a serious fire hazard.

It is often desirable to install small shields on the manifold at the joints to deflect the hot exhaust gases away from the ignition harness in case of a clamp or gasket failure. Shields are also used to prevent radiant heat from overheating such points as the spark plug elbows, the fuel pump, and so on. Since the walls of the manifold are usually cherry red, approximately 1000° F., when the engine is running, it is essential to shield any portion of the engine installation that cannot withstand this heat.

Carburetor Air Heaters

When a carburetor preheat system is required, the exhaust manifold is a very convenient source of heat supply. Two methods are in common use for taking heat from the exhaust manifold; a shroud or muff fastened to the outside of the manifold, and an intensifier tube inside of the manifold.

A typical shroud type preheat system is illustrated in Figure 76. In this arrangement the shroud is a portion of the engine inner cowling. The entire compartment for the manifold is made of stainless steel and thus serves as a sub-fire-wall. This manifold compartment, or shroud, is open at the bottom where air from the back of the engine is taken. This air then circulates over the exhaust manifold, picks up heat, and is then fed into the carburetor air scoop. The size of the shroud compartment determines the heating capacity of the system. A close fitting shroud generally provides the most heat. A by-pass arrangement is necessary in the air scoop so there is circulation in the shroud even when the hot air is not being used. This allows for cooling of both the manifold and the shroud.

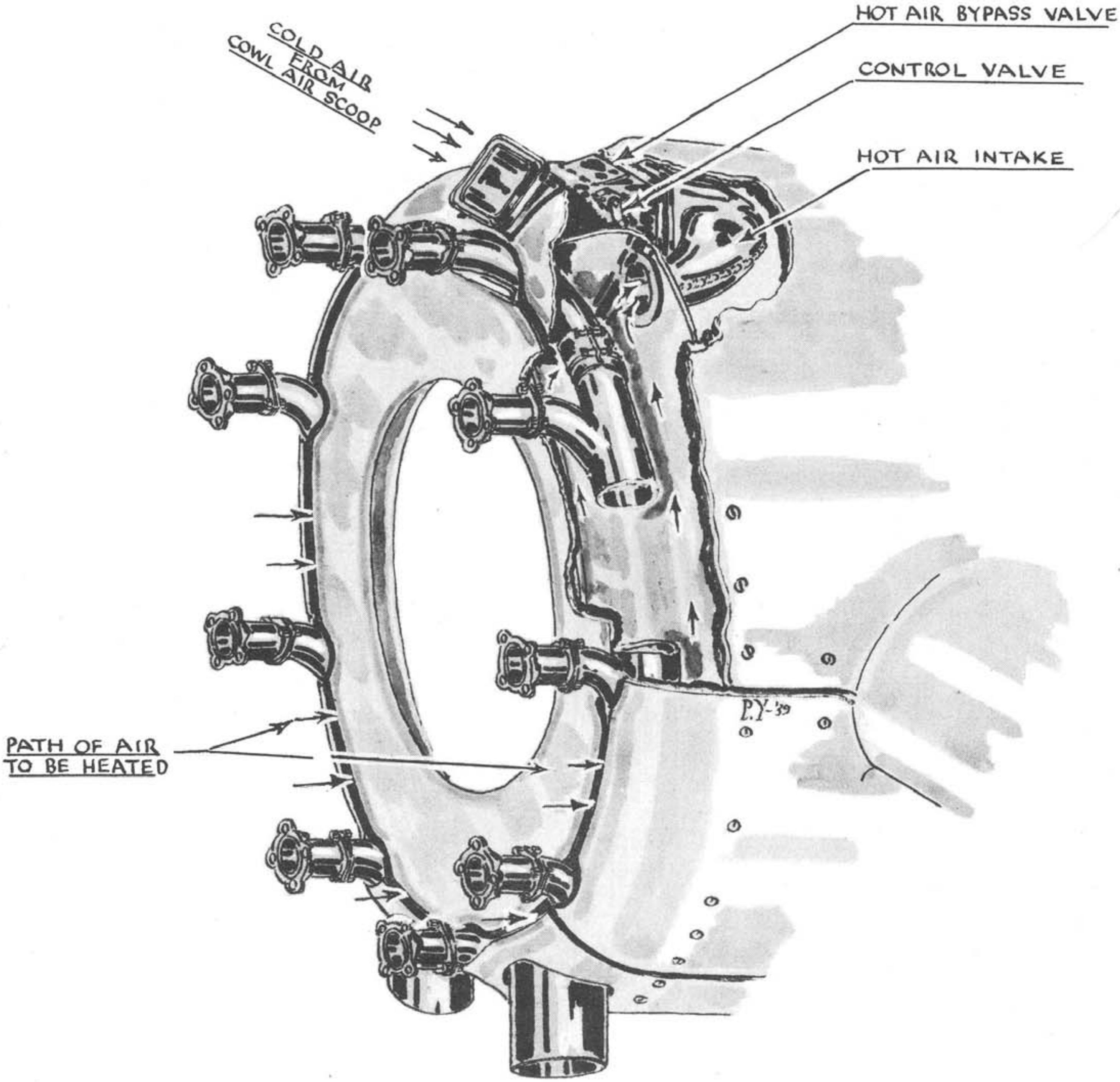
A muff system is similar to the shroud except that it consists of a double walled manifold. Air for preheat is circulated between the two walls. This style of heater is difficult to build, is heavy, and is difficult to maintain in service. It is rapidly becoming obsolescent.

The intensifier tube type heater is very practical and has excellent heating capacity. This type heater is illustrated in Figure 77. The tube should be made of heavy gage stainless steel. It should be divided into two sections, each tube being 3" diameter, and the length should be sufficient to be exposed to the exhaust gases from at least six cylinders. For added heating capacity in this system the tube can be dimpled to produce turbulence in the airflow through the tube.

The heaters discussed above are very effective for preventing ice formation in carburetors that become inoperative when the atmospheric condition is conducive to ice formation. With a "non-icing" carburetor the heater system can be far less complicated. In fact, all that is needed is an alternate air intake. If the cold air intake allows atmospheric ice to form in the scoop or on the carburetor screen then the alternate air intake should use the air at the rear of the cylinders, where enough heat can be obtained to melt any atmospheric ice that may be present. A scoop that serves this purpose is illustrated in Figure 66a.

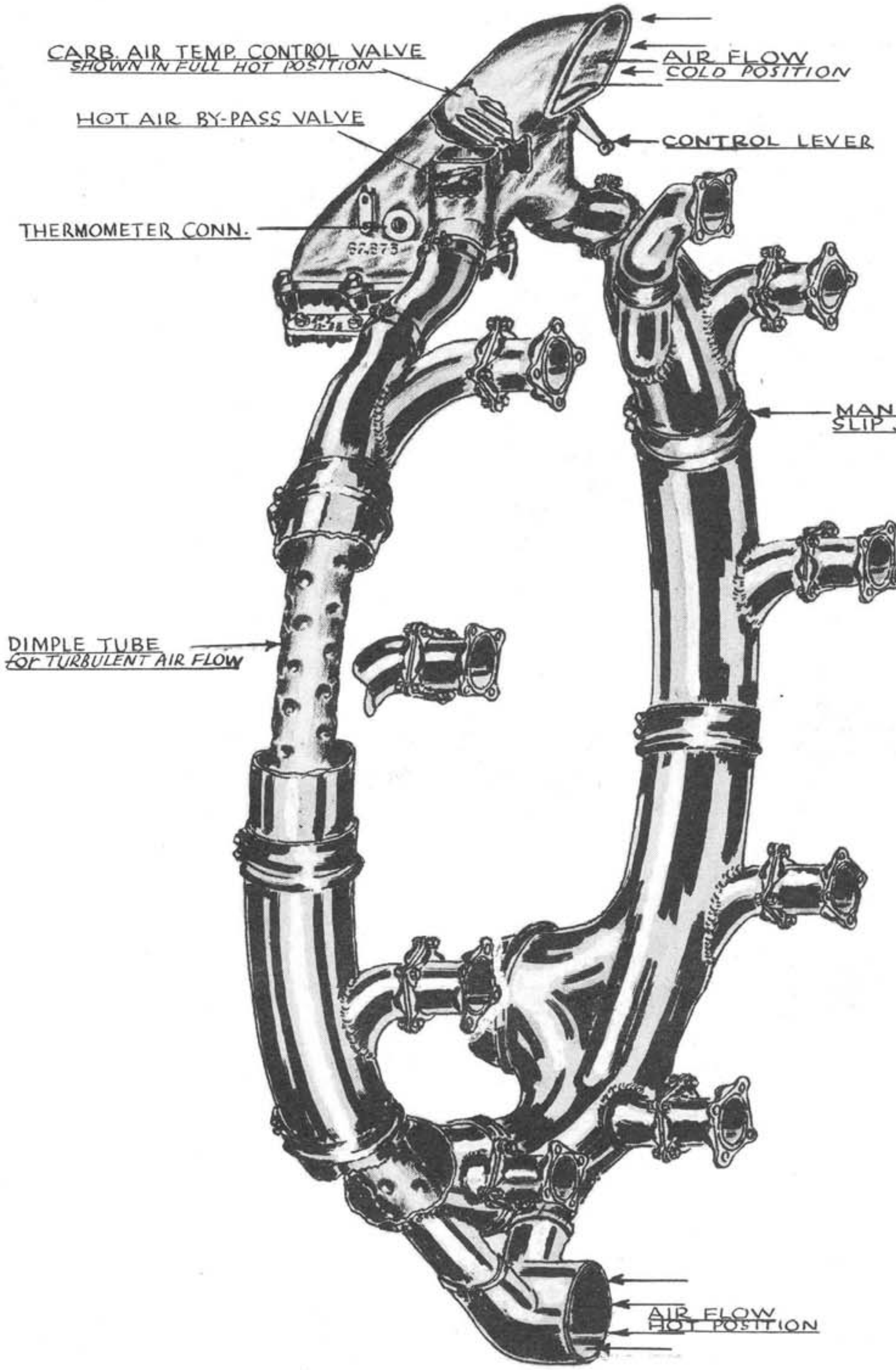
Fuel-Air Ratio Indicator Sampling Tube Installation

Successful operation of this instrument is dependent upon the quantity and temperature of the sample of exhaust gas that is led to the analyzing cell. It is therefore necessary to carefully choose the location of the pick-up tube in the



SHROUD TYPE CARBURETOR AIR HEATER

Figure 76



"INTENSIFIER TUBE" CARB. AIR HEATER and EXHAUST SYSTEM

Figure 77

manifold. The sample should be taken from a point in the manifold where the gases are representative of those leaving the entire engine. A suitable pressure drop must be obtained across the analyzing cell to cause sufficiently rapid action of the indicator and the temperature of the sample must be within definite limits to obtain correct readings on the indicator. The aircraft manufacturer is referred to the analyzer manufacturer's installation data for suggested methods of installation and the pressure and temperature limitations on these instruments.