Design of an Apparatus for Testing Aeroplane Fabric at Low Temperature

by

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Mr. A. L. Merrill,
Secretary of the Faculty,
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Cambridge, Mass.

Dear Sir:

I herewith submit for your approval my thesis entitled "Design of an Apparatus for Testing Aeroplane Fabric at Low Temperature."

Sincerely yours,

ACKNOWLEDGMENT

I wish to express my appreciation to Professor Schwarz for supervising this thesis and for his suggestions as to the best way to test the fabric. Thanks are also due to Professor Berry and Professor Wilkes for their suggestions on the construction of the apparatus.

Table of Contents

INTRODUCTION

Countries that have such severe winters that railway and waterway transportation is stopped find the aeroplane an ideal means for connecting sections that would be otherwise isolated. In these sections temperatures as low as - 60°F. are commonly encountered and under these conditions metals are very brittle and break easily under a shock load. The effect has been studied quite thoroughly on metals, but little or no thought has been given to the possibility that the fabric covering of the wings also becomes brittle. In the case of metals, those whose impact values are low at low temperature have been avoided in design and if the fabric too should prove to be brittle at low temperatures it is certainly advisable to use a covering of greater strength.

In testing materials the most desirable test is that in which the conditions are exactly similar to actual conditions, but this is very often impossible. However, it is better to have some results showing approximately the behaviour of the material in question than none at all. Before deciding upon the most suitable method of testing aeroplane fabric., the method of attaching it to the wing and its action on the wing while in flight should be known.

The ordinary fabric covered aeroplane wing is composed of three main parts, a front and a rear spar, ribs, and fabric. The spars are usually long wooden members at right angles to the direction of flight. On these are spaced the ribs at distances increasing from the fuselage to the tip of the wing. The ribs are about 1/2" wide and are the forms for the shape of the wing. The fabric is placed over this skeleton frame work in the untreated condition and is then given a coat of dope and allowed to dry. The fabric is then sewed to the wing and the ribs and several coats of dope are applied till the fabric is as tight as a drum. As a result of this tightening process, the ribs are well defined and the fabric is pulled over their comparatively sharp edges.

In flight, an aeroplane is supported by lift on the top of the wing and by an upward deflecting force on the bottom of the wings. Approximately two-thirds of the supporting force is derived from the lift on the top surface of the wings so the fabric has considerable tension in it. There is not only this tension, but also the fabric is undergoing a continuous flexing action due to the vibration of the motor. The frequency is the same as the revolutions per minute of the motor and the amplitude is approximately one-eighth of an inch. It is this last action that is believed will cause any weakening in the fabric that may occur at low temperature, and it is very likely that the weakening will take place where the fabric passes over the sharp edges of the ribs. From the foregoing it is evident that the fabric should be subjected to a flexing test and the apparatus should be so designed that conditions at the ribs may be studied.

The next question is the proper size of specimen to use. The average rib spacing near the fuselage is approximately 12" and this distance increases gradually to about 20" at the tip. Naturally for the same amplitude the largest angle of flexure will occur in the shortest span so a 12" span should give results for the worst case. In sewing the fabric to the ribs, the stitches are about three inches apart and since it may be desirable to give a tension test to the specimen after its flexing test, holes should be avoided. From a sample 10" wide it should be possible to obtain three specimens three inches wide and free from holes.

To test the fabric for use at - 60°F, tests should be made at lower temperature,- down to-80°F for example. The simplest means for producing those low temperatures is in an insulated box with solid carbon dioxide as the coolant. The design of such a box cannot be done by the use of exact mathematics, but must be based upon previous experience and an approximate calculation may be made to obtain a rough idea of the heat flow into the box and the rate at which the coolant may be expected to sublime. The size of specimen chosen was 12" x 10" and since other apparatus was to be placed in the box, the container for the specimen was made 16" x 16" x 12". A three-inch wall of solid carbon dioxide was to surround the apparatus on four sides and three inches of insulating material was to surround the whole. This original plan was shown to

Professor Walker. He was of the opinion that the apparatus was suitable for the temperature desired and calculations as suggested by Professor Berry upheld his statement. Professor Walker suggested that the carbon dioxide be immersed in a bath of alcohol in order to give better conduction. The carbon dioxide sublimes and the resulting gas would hinder the heat transfer. Professor Berry also made a valuable suggestion. After the carbon dioxide sublimes it is still at a low temperature and if permitted to escape directly into the air, it would represent a loss. He suggested that the apparatus be so designed that this cold gas surrounds the whole apparatus and thereby cuts down the heat losses. Despite Professor Walker's opinion that three inches of insulation was sufficient, it was felt advisable to make it four inches in case the workmanship was such that cracks existed in the outer box and raised the heat losses.

Design of Refrigerating Apparatus.

To fulfill the above suggestions the apparatus was designed as follows. The illustrations in the appendix will make the explanation clearer. The box containing the specimen (Fig. 1) was necessarily made of metal to hasten the heat transfer and to hold the liquid alcohol. Copper would have been desirable but it was too expensive so galvanized iron was used. A box 22" x 22" x 12" was made of this metal and then a wall of the same material was put in the box to form a space 3" wide around the inside. To hold the four inches of insulating material around the metal box, a wooden box (Fig. 5) 30" x 30" x 16" are made. In the final set-up the tops of these boxes (Fig.8) was in the same plane and a low box (Fig. 2.) 30" x 30" x $5\frac{1}{2}$" covers them. This latter box contains four inches of mineral wool which was used as an insulator throughout. It is comparatively cheap and it has the same coefficient of conductivity as that of cork. Holes $1\frac{1}{2}$" in diameter were drilled in the covering box (Fig. 2.) directly above the carbon dioxide. The purpose of these will be apparent shortly. As stated before Professor Berry suggested that the still cold carbon dioxide gases be utilized to reduce the heat losses. To do this another wooden box (Fig.4) was made of such dimensions that when the foregoing apparatus was set up in it an air space one-quarter of an inch separated them.

The action is as follows. (See Fig. 8.) Heat enters the apparatus and causes the coolant to sublime. The resultant gas would fall into the specimen container or into the insulating material because of its density if it were not for the fact that the edges of all the boxes are covered with felt which enables the covers to fit tightly. Pressure builds up in the carbon dioxide container and forces the gas out into the air space through the holes previously mentioned. The combination of pressure amd density causes the gas to cover the top of the box and then fall down the sides and then cover the bottom where it exits through six holes drilled near the center of the outer box. Holes are also drilled in the final cover (Fig.3) to coincide with the holes in the inner cover so that if it is necessary to replenish the carbon dioxide, it may be done by removing the corks and dropping the required amount directly into the container.

The desired temperature is maintained by adding more coolant than is necessary and then raising the temperature by means of electric bulbs in the specimen box. The bulbs are low in the box as a reasonably good temperature gradient may be expected. The rapid flexing of the sample will also cause the air to be in continuous motion so there is more reason to expect a rather uniform temperature from top to bottom of the box. If the amount of refrigerant in the apparatus should be too great it may be possible to maintain a constant temperature by putting a rheostat in series with the lights and adjusting it until a reasonable equilibrium is obtained. A potentiometer and themocouple provide a flexible means of measuring the temperature.

Calculations of Refrigerating Apparatus

As stated before, an exact calculation is impossible for an apparatus of this type. The calculations are further complicated by the space containing gaseous carbon dioxide in movement. There is no data on hand that would give the proper coefficient of conductivity through the film on each wall of the space. The safest thing to do is to assume that the space is filled with air that is not moving. In that way a higher heat loss will be computed and the results will be on the safe side. The box will be treated as a sphere. The dimensions are taken from the figures in the Appendix and the following list gives the coefficients of conductivity in B. T. U s per square foot per inch per degree Fahrenheit per hour.

MATERIAL	COEFFICIENT
Wood	.26
Mineral Wool	.29
Air film (inside)	1500
Air film (outside)	2

$$Q = \frac{4\pi\ (T_1 - T_2)}{\left[\frac{\left(\frac{1}{V_1} - \frac{1}{V_2}\right)}{k_1} + \frac{\left(\frac{1}{V_2} - \frac{1}{V_3}\right)}{k_2} + \frac{1}{A_1 V_3^2} + \frac{1}{A_1 V_4^2} + \frac{\left(\frac{1}{V_4} - \frac{1}{V_5}\right)}{k_2} + \frac{1}{A_o V_5^2}\right.}$$

$$= \frac{4\pi\ \ 70 - (-80)}{\left[\frac{\left(\frac{1}{11} - \frac{1}{15}\right)}{.29}12 + \frac{\left(\frac{1}{15} - \frac{1}{15.75}\right)}{.26}12 + \frac{1}{1500}\left(\frac{1}{15.75^2} + \frac{1}{16.00^2}\right) + \frac{\left(\frac{1}{16.00} - \frac{1}{16.75}\right)}{.26}1 - \frac{1}{2 \times 16.75}\right]}$$

$$= \frac{1884}{1.005 + .1475 + .00000528 + .0129 + .0298}$$

$$\frac{1884}{1.1952}$$

$$= 1575 \text{ B.T.U. / hour.}$$

It requires 242 B.T.U. per hour to sublime a pound of dry ice, so according to the heat loss, six and one-half pounds of the ice will be used each hour. This figure is much too high and should not be used as an indication of the actual consumption.

A test was run on the apparatus to determine the temperature that could be obtained in it. The box will hold approximately one hundred pounds of the refrigerant but only twenty pounds and a gallon of radiator alcohol were put in. The temperature was registered by a thermocouple placed at the top of the box. The lowest recorded temperature was $-84^{\circ}F$ and at the end of the test the thermocouple was pulled to the bottom of the box and $-87^{\circ}F$ was attained there. The distribution evidently is very good and with the apparatus running the flexing of the fabric should make the temperature even more uniform.

Design of Mechanical Apparatus

In an airplane wing, it is the fabric between the ribs that rises and descends, but to produce those same conditions is a bit difficult. Since the motion is relative, the same results should be obtained by fixing the moving fabric and causing the rib to move up and down. The purpose is to cause flexing of the fabric passing over the ribs and it is evident that that is achieved equally well by making the ribs vibrate. A rectangular frame was made as shown in Fig. 6 to accommodate the specimen and the ribs (Fig.7) is represented by a strip of wood 1/2" x 1/8" x 12" glued and nailed to a 3/4" x 3/4" x 12" block for a stiffener.

The stresses involved in the mechanical equipment of the apparatus are so small that it is useless to figure the correct sizes for the various parts. The results would be too small for practical purposes. The vibratory motion is obtained from a cast iron eccentric (Fig. 7) fastened to the shaft of a synchronous motor turning over at 1800 R.P.M. A steel strap (Fig.7) was made to fit over the eccentric. The motor and its accessories were placed outside the box so it was necessary to transmit the motion from the eccentric to the rib by means of a small steel rod (Fig.7). A right and a left hand thread were cut on the ends so that the rod could be screwed simultaneously into the eccentric strap and the rib. A steel block (Fig.7) was attached to the rib by screws and a thread cut in it to take one end of the rod.

All the moving parts require lubrication. The eccentric was lubricated by a grease cup screwed into the strap. The steel rod has to be lubricated and it also has to be held vertical otherwise there will be a tendency to tear the fabric. Both of these requirements were satisfied by screwing a bronze plate (Fig.8) on the bottom of the outer box, and bolting a similar plate to the specimen container. Under each one of the plates was placed a piece of felt impregnated with oil. Holes were drilled and reamed in the plates so that they are just large enough to prevent the rod from sticking in them. The boxes were so adjusted that the holes in the bronze plates were directly in line.

As stated before, electric bulbs supply the heat necessary to raise the temperature. There are four of them connected in parallel so that the failure of one will not ruin a test. A switch on the outside of the box controls the lights.

The photographs in the Appendix show the apparatus in three different positions. P-1 shows the apparatus set up ready for a test. The eccentric and electric motor were disassembled previously so they are not shown. The main purpose of the photograph is to show the method of supporting the apparatus. P-2 is an interior view showing the arrangement of the boxes, the electrical circuit, and the angles to which the fabric frame is bolted to prevent it from moving. P-3 is similar to P-2 and differs from it only in that the bulbs were inserted and the frame with the fabric prepared for a test was put in.

Assembling for a Test

To run a test the following procedure is suggested. One end of a piece of fabric 24" x 10" is tacked to the underside of the frame and is pulled over the rounded ends of the frame with a tension just sufficient to remove all the wrinkles and the free end is tacked as before. A coat of dope is applied and when this is dry the rib is sewed to the fabric - precautions being taken to have it centred and perpendicular to the frame. A number of coats are then applied till the desired tautness is obtained. It is assumed that the refrigerating apparatus is assembled as shown in Fig. 8 with the exception that the covers are removed. Screw the rod about one-eighth of an inch into the rib and set the frame into the apparatus and bolt it down. Put the eccentric and strap loosely on the shaft and screw the rod into the strap until the fabric is horizontal on the frame. Adjust the eccentric so that the line joining its centre and the centre of the shaft are horizontal and then tighten the set screw in the eccentric hub. If that is not done the movement of the fabric will not be uniform in each test. In one case the oscillations may be entirely above a horizontal and in another they may be entirely below the horizontal, so that the fabric will not be run under the same conditions each time. Consequently any conclusion that might be made would be erroneous. Insert the bulbs and put the coolant into the container and place the covers on. The apparatus is now ready for a test.

No work has been done on the low temperature testing of fabrics before so no definite procedure can be outlined. It may be advisable to make several runs at room temperature, and for various lengths of time to determine how long the fabric remains unchanged and then run the cold tests for the same time. Part of each specimen should be subjected to microscopic (~~tensile~~) test. Such tests may be of no avail, but the investigator may have a knowledge of textiles and be in a position to suggest better test methods.

APPENDIX.

Apparatus and CO_2 container. 26 Gauge Galvanized Sheet Iron.

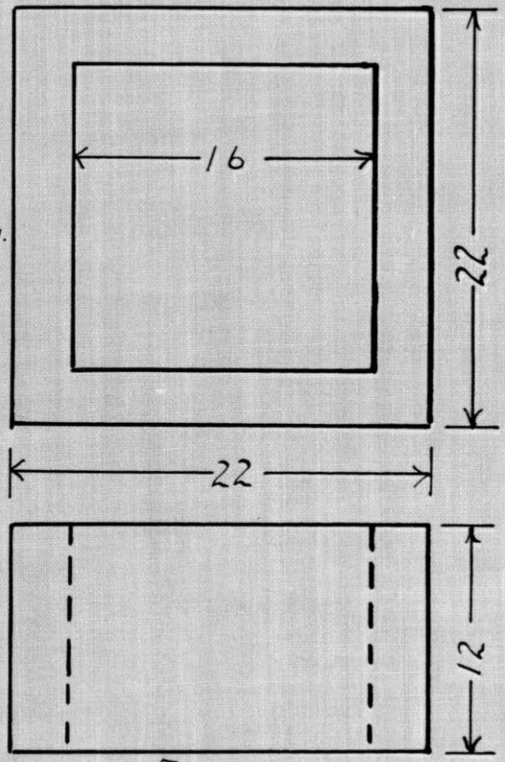
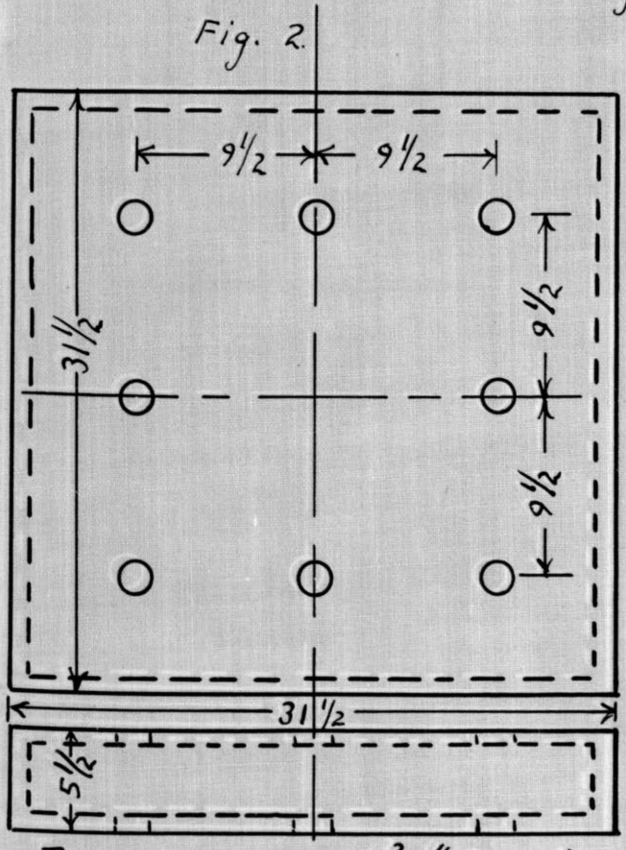


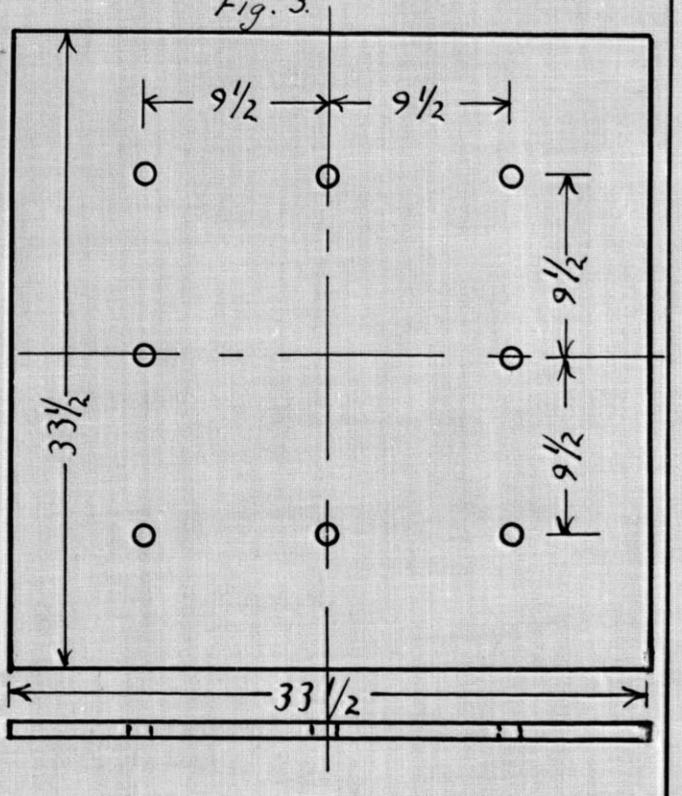
Fig 1.

Fig. 2.



Inside Cover (¾" Pine)

Fig. 3.



Outside Cover (¾" Pine)

Scale - 1/10 Full Size.

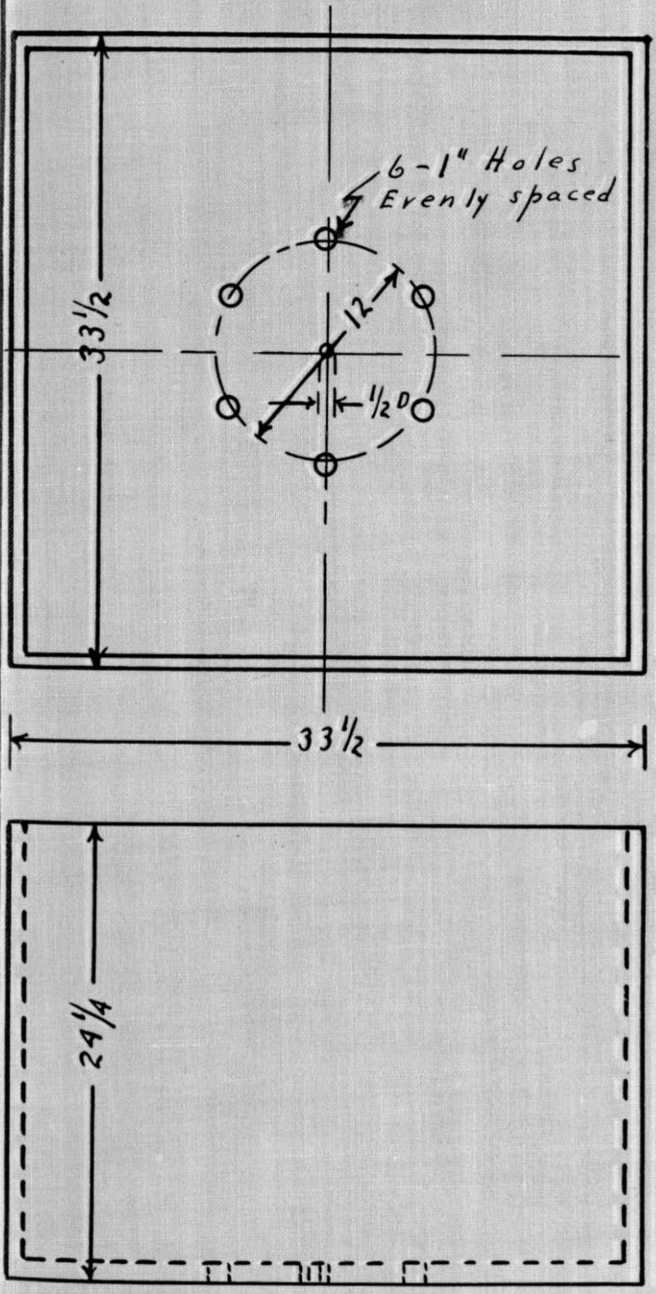


Fig. 4.
Outside Box (3/4" Pine)

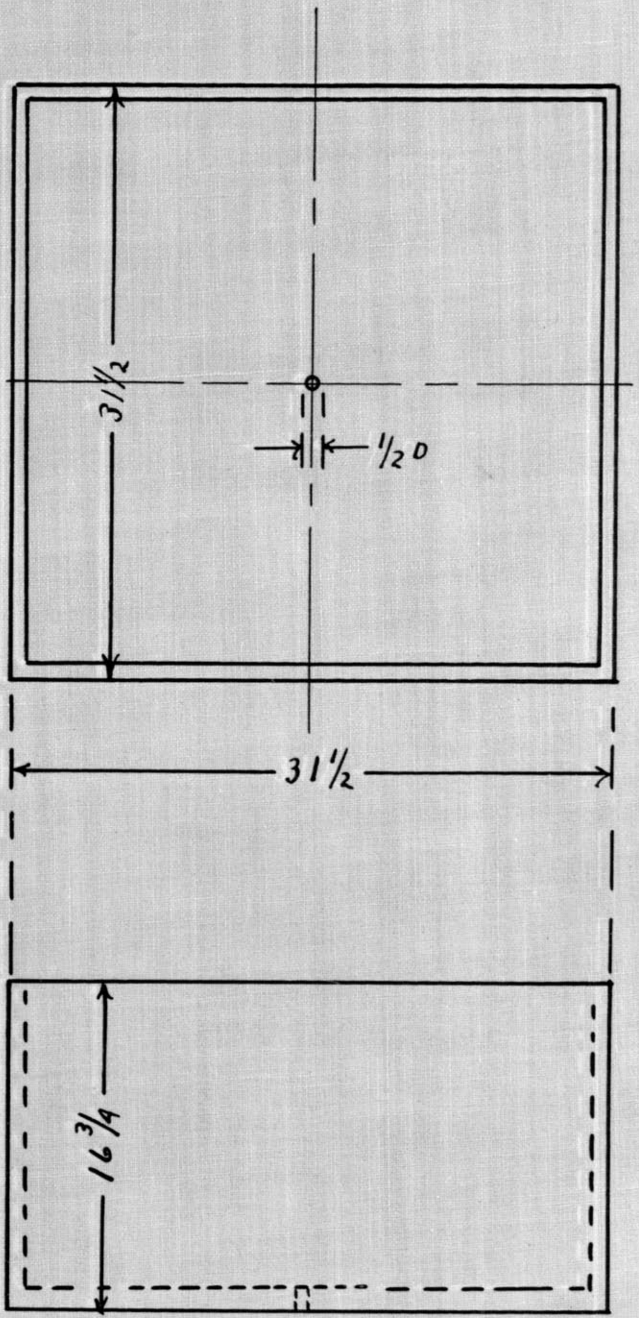
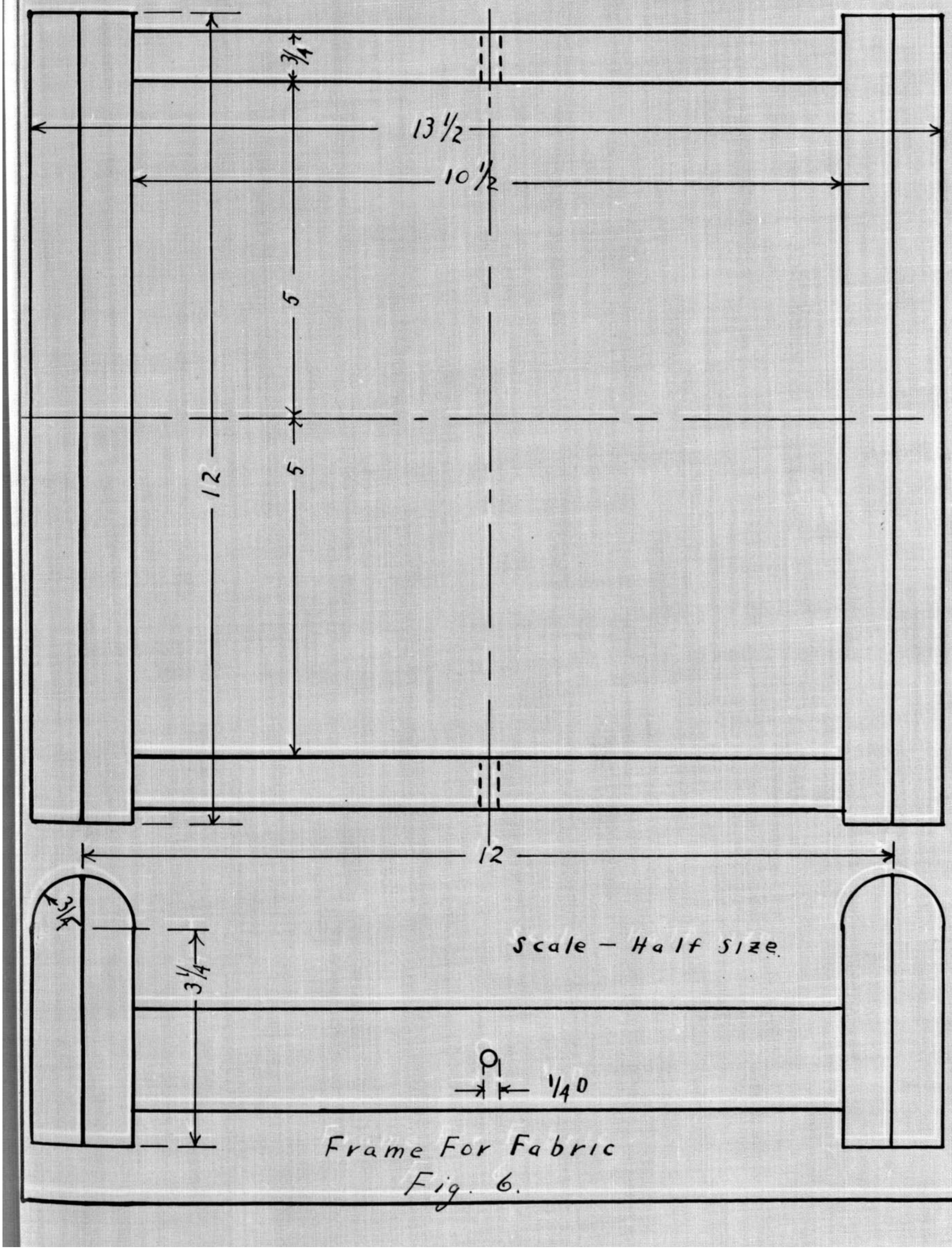
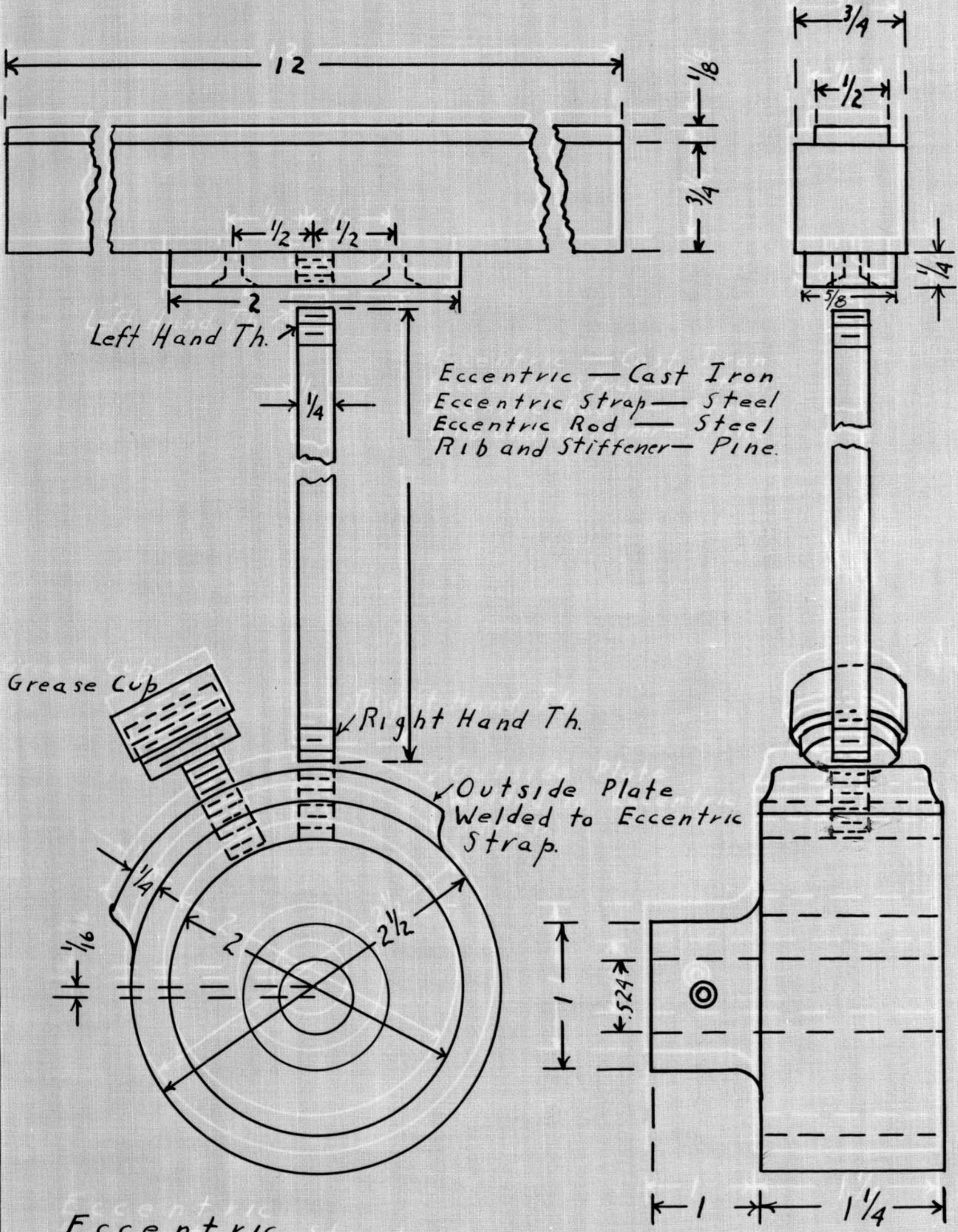


Fig. 5.
Inside Box (3/4" Pine)

Scale 1/10 Full Size.



Frame For Fabric
Fig. 6.

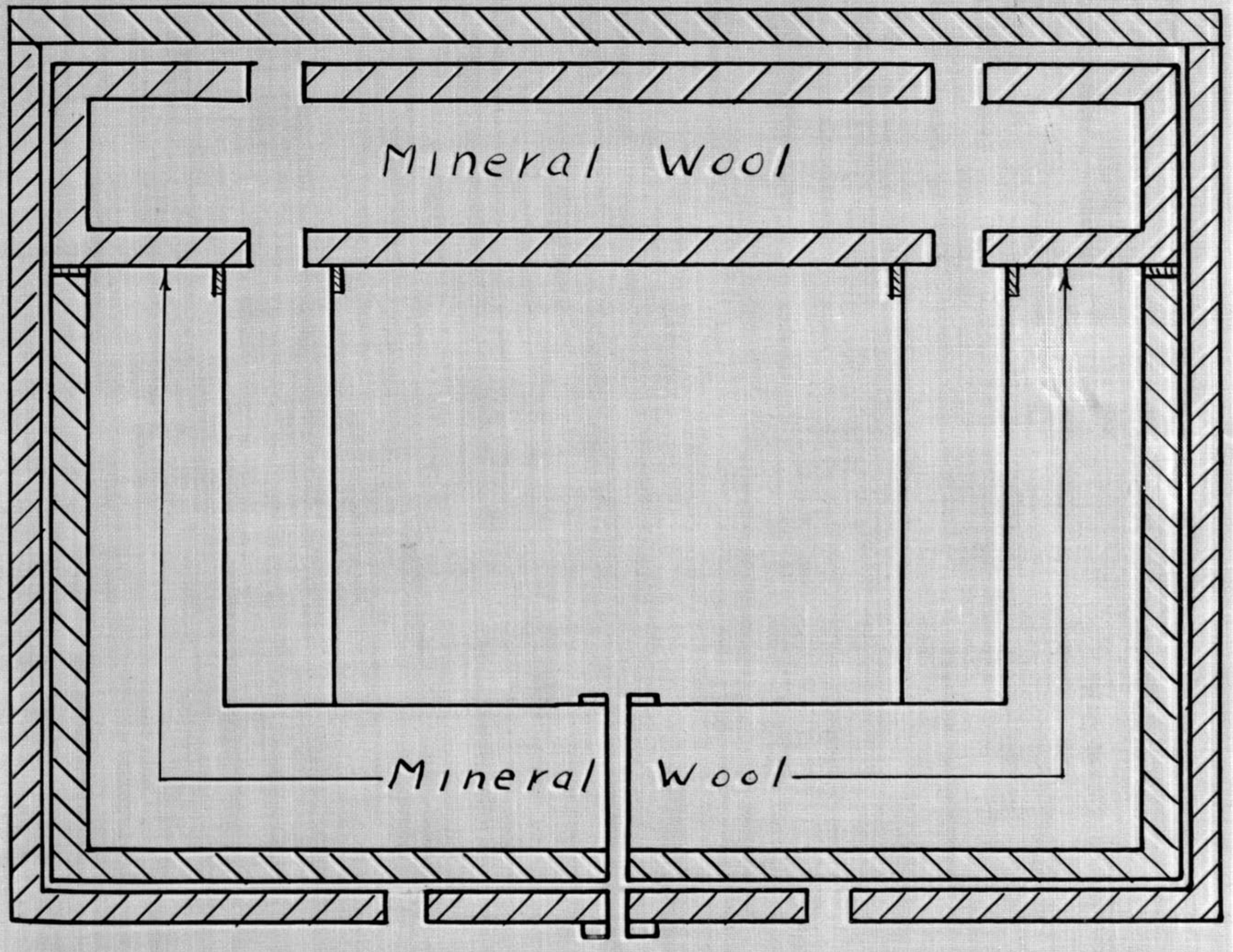


Eccentric — Cast Iron
Eccentric Strap — Steel
Eccentric Rod — Steel
Rib and Stiffener — Pine.

Eccentric
Eccentric Strap
Eccentric Rod
Rib and Stiffener

Fig. 7.

Scale — Full



Cross Section of Assembled Refrigerating Unit

Scale - 1/5 Full Size.

Fig. 8

P - I

P - 2

P - 3