REPORT No. 74

# CONSTRUCTION OF MODELS FOR TESTS IN WIND TUNNELS



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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS



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BY

F. H. NORTON

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## THE CONSTRUCTION OF MODELS FOR TESTS IN WIND TUNNELS.

By F. H. Norton.

### INTRODUCTION.

It is the general tendency of model makers, especially those who are used to working in wood, to underestimate the accuracy required in the construction of models for wind tunnel tests. In most pattern making an error of a hundredth of an inch is of no importance, but if this error occurs on an aerofoil, the model is valueless for testing purposes. The model maker, however, is not always to blame for the errors in the model, for these are often due to inaccuracies in laying out the drawing of the model to a small scale. Also models that are not of the proper size or weight are difficult or impossible to test. For these reasons a large amount of time and material has been wasted in constructing models, perhaps well finished, but unsuitable for wind tunnel experiments. It is the purpose, therefore, of this report to describe the methods, materials, and sizes that have been successfully used in this work.

### TYPES OF MODELS.

The type of model most tested in wind tunnels is the single aerofoil of standard size, for the purpose of determining the aerodynamic properties of a certain section. Single wings are also tested with varying aspect ratio and plan form, and biplane and triplane combinations are often tested without body or struts. The wings, whether tested alone or on a complete machine, require the most careful reproduction of any part of an airplane. If the aerofoil is thin it should be constructed of a light aluminum alloy, as thin wooden wings will not hold their shape, no matter how carefully made, and it is difficult to fasten a spindle into the end. Thick models like struts and propeller sections, however, are best constructed of wood. Metal aerofoils should be constructed to within 0.002 inch of the given ordinates, and wooden ones to 0.004 inch. The angle of incidence should not vary along the wing more than 0.1 of a degree, but a slight curvature along the span of the wing, giving an effect of dihedral or kathedral angle, does no harm. Unless a wing is intended for a special test, such as aspect ratio, it should always be of standard size to insure strict comparison between different sections. In 4-foot tunnels a section 3 by 18 inches is used, and in larger tunnels corresponding sizes. Whenever possible the wing should be held by an end spindle, threaded directly into the end of the wing if of metal, one-third of the distance from the leading edge. (Fig. 1.) All standard aerofoils should have square ends and an aspect ratio of 6.

Bodies, floats, and hulls are made of wood and need not be as accurately constructed as aerofoils. The maximum error, however, should be kept within 0.02 inch on large models and 0.01 inch on small ones. The spindle is usually attached to the body by screwing it into the wood, the spindle being made with a wood screw point. If the model is bulky it should be made of a light wood, hollowed out to reduce the weight, as every pound added to the model means an addition of about 3 pounds to the weight on the pivot point, for 2 pounds must be added to the lower part of the balance in order to keep the center of gravity stationary.

A complete model should have a span of about 18 inches (not more than 21 inches) for a 4-foot tunnel, and weigh not more than 3 pounds. It must not, however, be lightened in such a way as to cause deformations at high velocities. The wings should be correctly aligned in incidence, stagger, sweepback, and dihedral within 0.1 of a degree. The stabilizer should be easily adjustable, and a line should be marked along the propeller axis on the side of the body, in order to facilitate lining the model in the tunnel. It has been usual to attach the spindle directly to the body of the airplane as shown in figure 2. This type of spindle, however, creates a large disturbance of the air flow that is hard to correct for, so that it seems better, whenever possible, to attach the spindle to the tip of the wing. (Fig. 3.) Models should have stream lined struts, but the wires are usually omitted, and unless the model is to be used for stability tests the control surfaces need not be movable.

Model propellers are so similar to the full-sized ones that little need be said in regard to their construction. They should have the same degree of accuracy as wooden aerofoils.

## MATERIALS.

The materials used in constructing these models should be light and capable of holding their shape. Thin parts like struts and wings are best constructed of metal, but the other parts are usually made of wood. Wings can be made of pure aluminum, but this material is rather soft, and better results are obtained by using a harder alloy having better machining properties. Magnesium cuts easily and smoothly and is considerably lighter than aluminum, but at present is hard to cast without blowholes. Perhaps the best alloy for this purpose is the very common one with 8 per cent copper and 92 per cent aluminum. If it is desired to construct a wing of great permanence for a standard, or for tests at high speeds, it should be cut from steel, but this is at present a

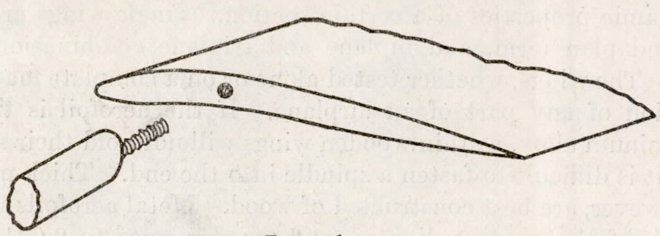


FIGURE 1.

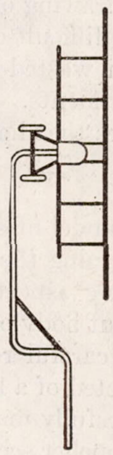


FIGURE 2.

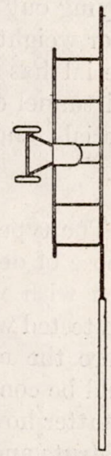


FIGURE 3.

rather expensive process. An aerofoil for pressure distribution tests is best made of brass, because of the necessity of using solder. Wings of a more or less temporary character can be made of plaster or wax as described later.

Wood to be used for thick wings and bodies should be well seasoned and clear. As the expense for material is very small compared with labor expense, only the highest quality stock should be considered. The wood for aerofoils need not be light, but rather hard and close grained, such as maple, beech, boxwood, or holly. The maple is the easiest to procure and it is quite satisfactory when the stock is selected.

## WOODEN AEROFOILS OF CONSTANT SECTION.

The process of making a 3 by 18 inch aerofoil will be described, the method, however, applying to any size of wing. This process has been successfully used for several years by Mr. Edward Tighe, model maker for the Massachusetts Institute of Technology. It should be remembered that, although wood can be worked to a very thin section, it will not hold its shape unless of considerable thickness, and the use of thin wooden aerofoils is not to be recommended where any permanency is desired.

A $\frac{7}{8}$-inch board of well-seasoned maple is cut along the grain into narrow strips that are planed $\frac{1}{4}$-inch wide. Every other strip is reversed and ten $\frac{1}{4}$-inch strips placed together with two face strips $\frac{1}{2}$-inch wide. This reversal of strips eliminates any tendency for the blank to curl, as each strip pulls in the opposite direction from its neighbors. The strips are placed in a drying oven and heated to about 100° C., spread with hot glue, and clamped together,

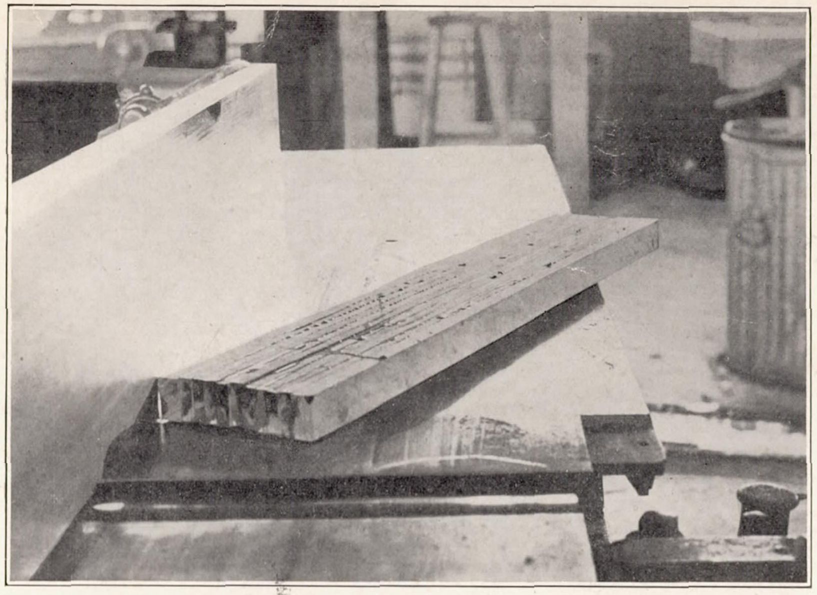


FIG. 4.

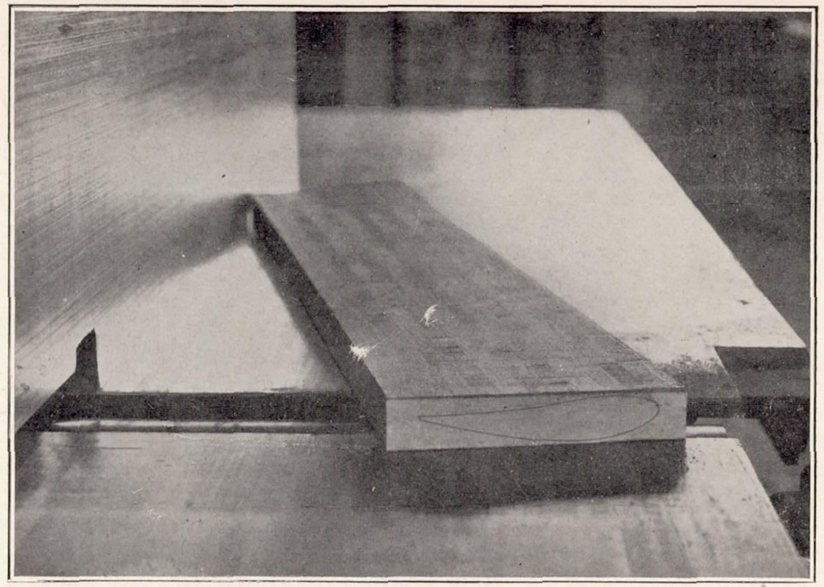


FIG. 5.

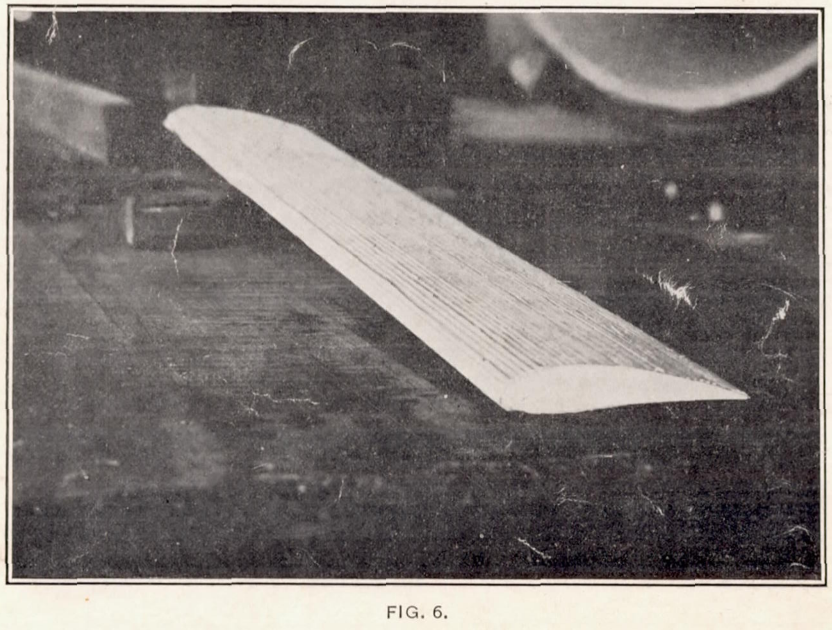


FIG. 6.

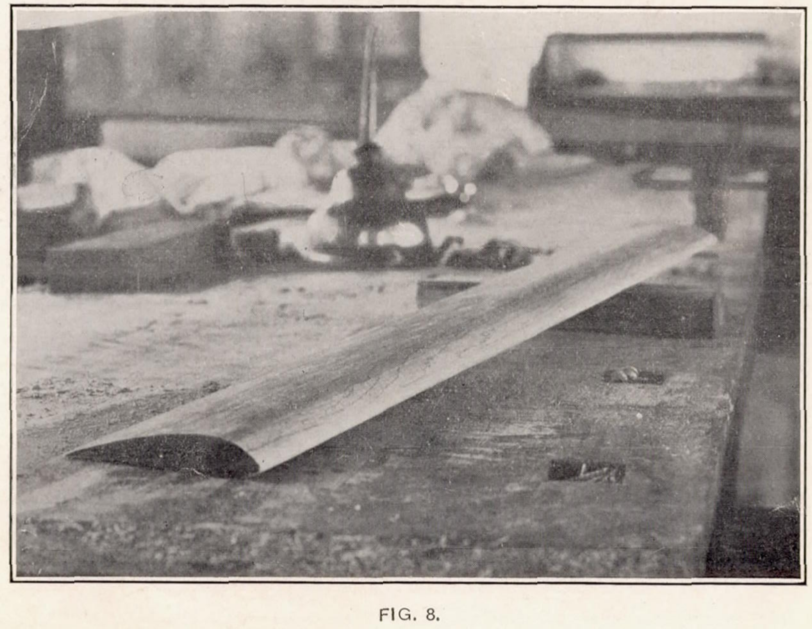


FIG. 8.

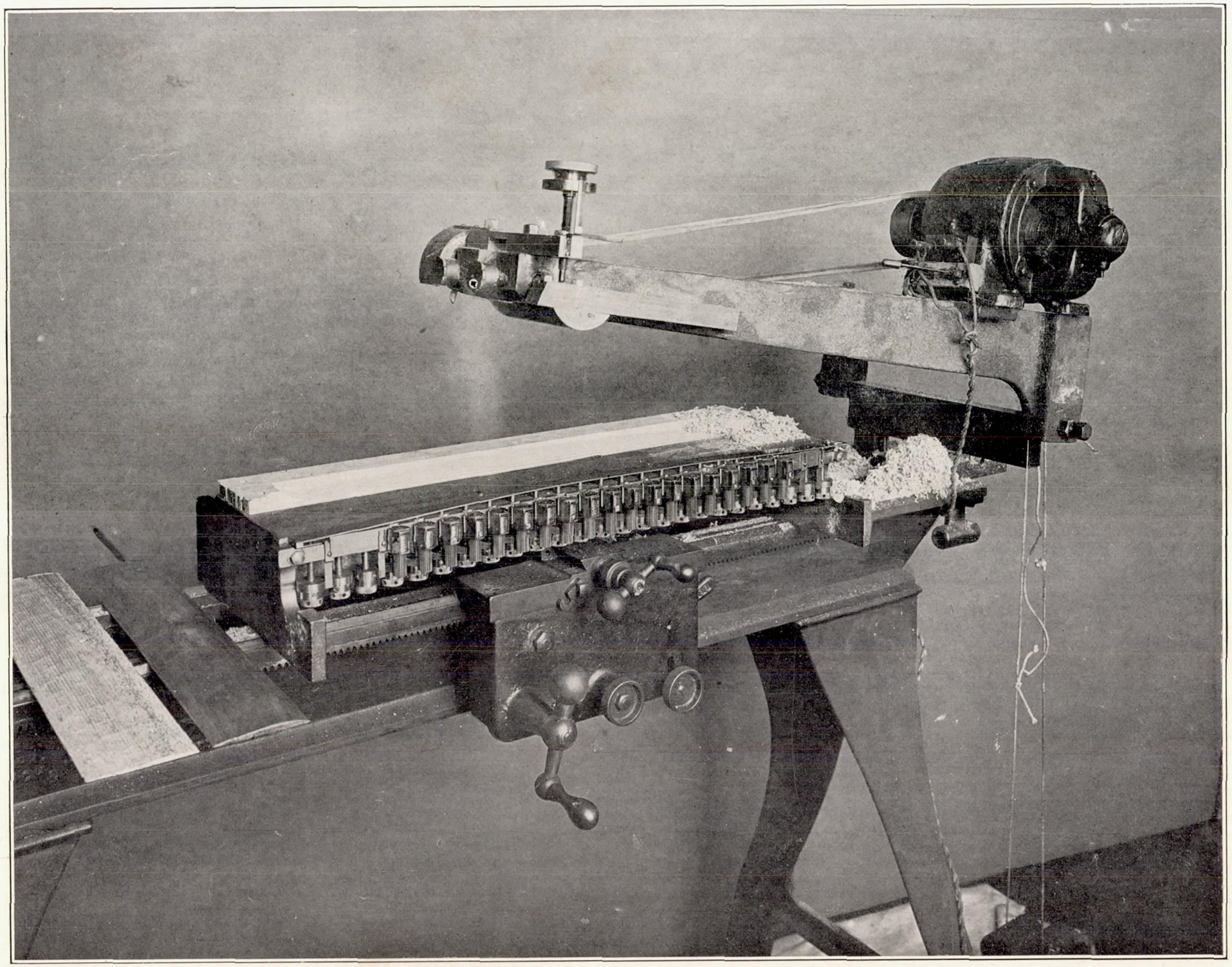


FIG. 9.

with heavy blocks on each side so that the total length will be under even pressure. The blank is left in the clamps for from 12 to 24 hours. It is then allowed to age for a few weeks to take up any initial warp (fig. 4). As the hardened glue, adhering to the faces of the blank quickly dulls edge tools, it should be removed as far as possible with a glue scraper.

Both faces of the blank are now made flat and parallel on a planer. It is of the utmost importance in this work to keep all tools sharp, and the importance of always removing the same amount of material from the opposite faces of a piece of stock should also be emphasized, for if this is neglected the material will always curl toward the face from which the larger amount of stock is removed. When both faces are true one edge is squared up on the planer and the ends are trimmed off on the circular saw, making the blank ready for cutting to the desired section.

An accurate outline of the desired section is drawn with India ink on white paper on a 15-inch or a 30-inch chord, using a medium fine line. This drawing is carefully stretched on a board and photographed on a process plate to a 3-inch chord. If this negative is printed on contrast paper a fine black line should result on a white background. The error in length of the reduced section should not be more than half a hundredth of an inch, which may require several trials in focusing. The print is trimmed and fastened to the end of the blank, preferably with vegetable glue. (Fig. 5.)

A saw table is set up with a sharp, rather wide, rip saw, hollow ground but having no set. The trued edge of the blank is placed against the saw guide and a light cut is taken along one face of the wing, and the depth is gradually increased until the saw just touches the black line on the photographed section. The guide is moved along about the width of the saw and the cut repeated, with a proper depth to touch the section at the new point. A magnifying glass is useful to accurately gauge the depth of the cut. After a few cuts have been made in this manner the blank is turned over and the same operation is repeated on the back, in order to prevent warping. This process is continued until all the wood has been removed except a few ridges to support the blank on the saw table. These ridges are now removed and the blank is ready for trimming. (Fig 6.)

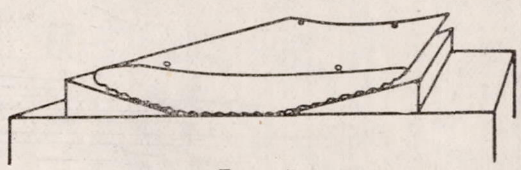


FIGURE 7.

The wing is held down to the bench by brads in the end and the irregular faces are wedged up in order to prevent strain as shown in figure 7. The terraces left by the saw are carefully planed down with a fine set plane until the grooves just disappear. A convex plane is required for concave surfaces, but should be sharp and set fine, as the maple may be somewhat cross-grained. The surface is next scraped with steel or glass to take out any lumps, is rubbed down with fine sandpaper, and the leading and trailing edges rounded off. After the ends of the wing are squared off to the proper length, the surface is filled, given two coats of shellac, and rubbed down with pumice. (Fig. 8.)

If this work is done carefully, the aerofoll wiil nowhere have an error of over 0.005 inch and the average error will be much smaller. It should be noted that any number of wings of the same section may be cut from one photographic section by running several blanks through the saw at each setting, care being taken to have the blanks of the same thickness.

## WOODEN AEROFOILS OF VARYING SECTION.

Wings that do not have a constant section are much more difficult to construct than the usual type. They, may, of course, be worked down by template in the same way as a propeller blade, but as this is, at best, a rather long and inaccurate process, a special machine has been developed for this purpose. The principle of this machine consists in guiding a revolving cutter along a predetermined curve by means of an adjustable template. A general view of the machine is shown in figures 9 and 10. An iron bed plate (*a*) is mounted on the cross feed of an engine lathe, the overhanging ends steadied by guides (*K*) which rest on the ways, but allow the wing bed to be moved laterally and longitudinally in the same way as the tool post. The wing blank (1) is screwed to the surface of this bed. A brass bar (*b*) is fastened to the front of the bed plate, and carries 25 micrometer screws spaced 1 inch on centers. These screws are $\frac{1}{4}$-inch, 40 threads, with a spherical top and a 50-tooth gear pinned to the lower end.

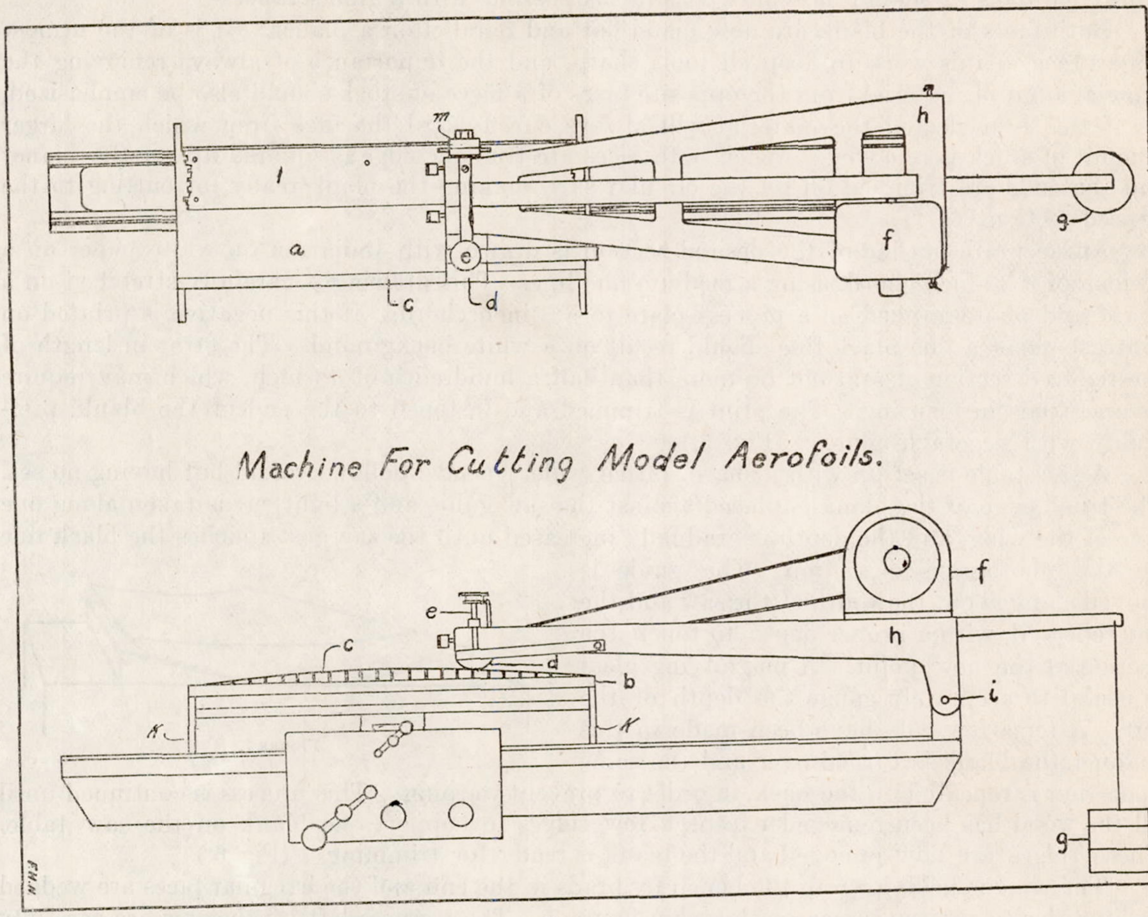



FIGURE 10.

In order to make the setting of so many screws quick and accurate, a direct reading counter was geared directly to each one as shown in figure 11. This device saved much time and many

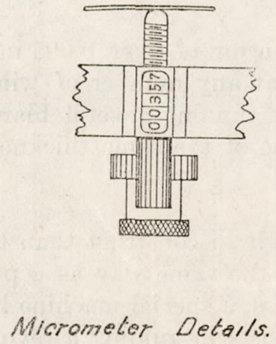



FIGURE 11.

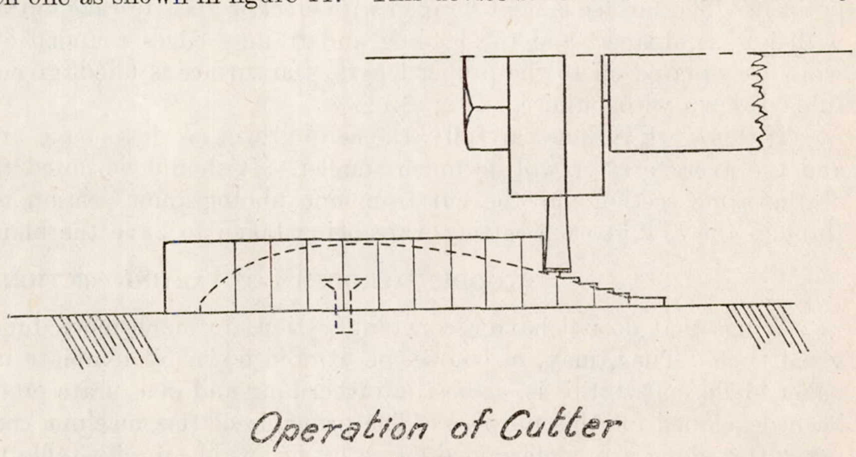



FIGURE 12.

mistakes, for 410 settings are required for each surface of a wing. A steel spring (*c*) rests on the rounded tops of the screws, forming a smooth adjustable guide for the shoe (*d*), which has the same radius of curvature as the cutter radius (3-inch). A spring $\frac{3}{4}$-inch wide and

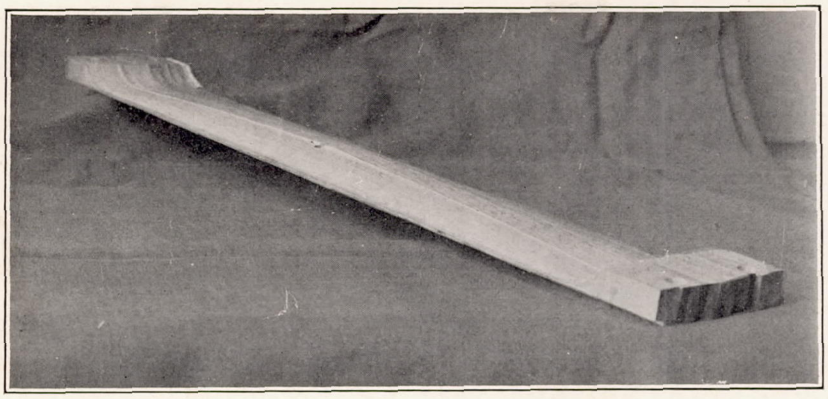


FIG. 13.

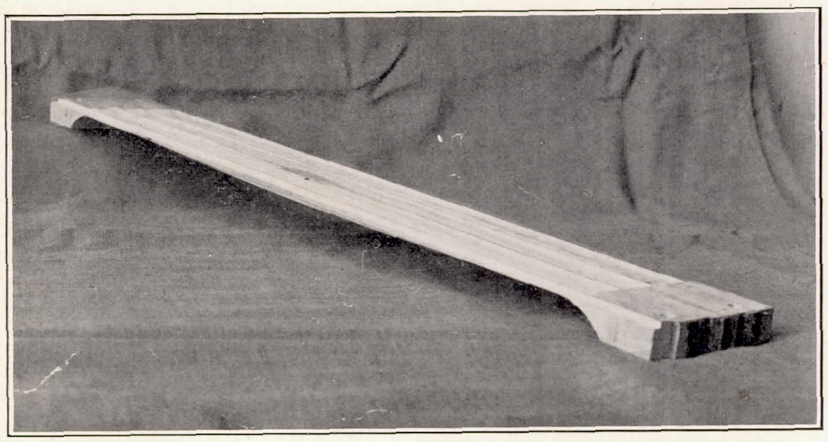


FIG. 14.

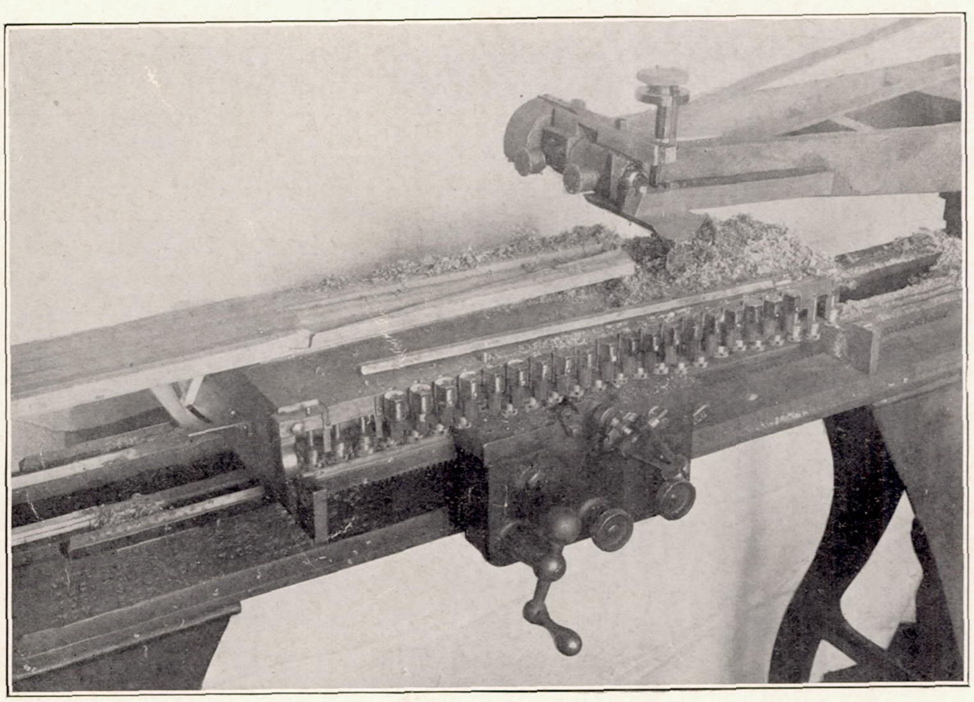
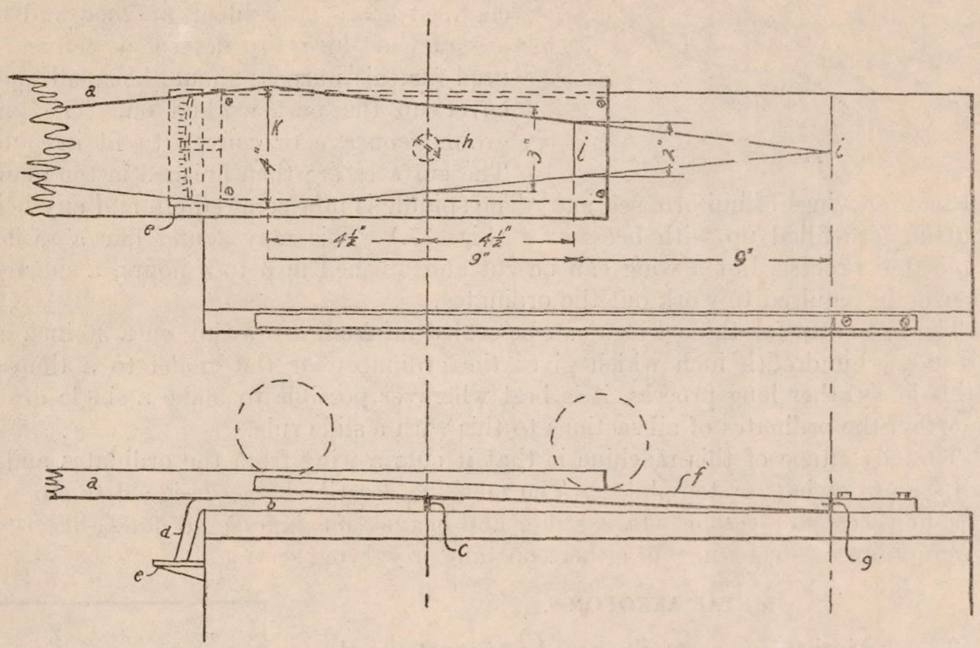


FIG. 15.

0.038-inch thick was found best suited for ordinary work. A frame (*h*), pivoted at (*i*), and holding the $\frac{1}{6}$-horsepower motor (*f*) allows the cutter (*m*) to move only in a vertical direction. The cutter is made to follow the curve of the spring by the guide (*d*), which rests lightly on it. This is adjusted vertically by the screw (*e*) for cutting wings of uniform section (when the spring is horizontal) and for setting the cutter to the proper height after sharpening. For cutting wood a two-bladed cutter $\frac{1}{4}$-inch wide is driven at 5,000 revolutions per minute by a belt directly from the motor.

The material best suited for making models that are tested soon after completion, just as in the case of thick wings of uniform section, is laminated maple, and the blanks are made up in the way described for such wings in the preceding section of this report.




METHOD OF CUTTING WINGS WITH VARYING CHORD
AND WITH
STRAIGHT LINES FROM CENTER TO TIP.

FIGURE 16.

The blank is screwed down to the base plate with 5 machine screws and the back is cut by starting $\frac{1}{4}$ inch from the leading edge of the blank and taking a cut across with the micrometer screws set for the first row of ordinates. The wing is moved laterally to the next position, and another cut taken. (Fig. 12.) This is repeated until the whole surface is cut. Three or four ridges should be left on the back of the wing in order to support it evenly when cutting the other face; also a groove should be cut for the spindle. The blank is then turned over and cut in the same manner on the other side. The surface is then an even set of terraces (photographs of the blank in this condition are shown in figs. 13 and 14).

A wing of constant section is made in the same way except that the steel spring is kept horizontally on the bedplate and the cutter is adjusted in height by the screw (*e*). This required only one-twentieth of the settings used by the varying section wings.

Figures 15 and 16 show an attachment for cutting wings with a varying chord and straight lines from an ordinate at the center section to a corresponding ordinate at the tip. The guide rests on the straight bar (*c*), as only one-half of the wing can be cut at a time. The blank is screwed to the pivoted base plate (*b*) swinging about its axis (*h*). It will be noticed that the intersection of the leading and trailing edges prolonged (*i*) is opposite the hinge (*g*). With this arrangement it is only necessary to set the ordinates for the mean chord, as the others are automatically obtained from these by swinging the tip of the wing in the opposite direction from the movement of the cross slide when setting the cutter for the mean chord. The scale (*e*) is used to determine this distance. Wings having curved contours and tapering plan form can also be cut, but require a large amount of computation.

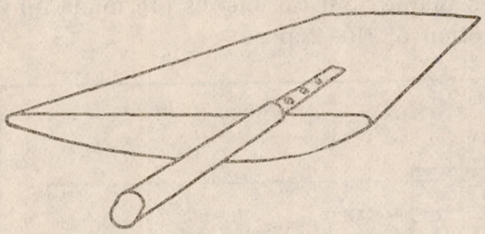


FIGURE 17.

When the section is completed on the machine, the ends are trimmed off, allowing a little extra length to prevent rounding off the corners. The wing is clamped down on a block of wood and the terraces are planed down as described before. The plane used for this purpose should be small enough not to cover up the part worked on. The plane can be ground concave or convex to fit irregular surfaces. The surfaces are then finished in the manner already described for wings of uniform section. The spindle is now screwed on, and any holes or errors in cutting are filled up with beeswax. (Fig. 17.) This may sound like a rather long and complicated process, but a wing can be cut and finished in 6 to 8 hours, a shorter time than that usually required to work out the ordinates.

The ordinates for these wings can be scaled off from a drawing on a 30-inch chord to the nearest one-hundredth inch which gives the ordinates for the model to a thousandth inch. As this is a rather long process, it is best wherever possible to make a single drawing and to proportion the ordinates of all sections to this with a slide rule.

The advantage of this machine is that it cuts a wing from the ordinates and requires no small scale drawings or templates. The machine described was designed to cut wooden aerofoils, but there is no reason why a stiffer and heavier machine could not be used to accurately cut aluminum or steel wings of either constant or varying section.

## METAL AEROFOILS.

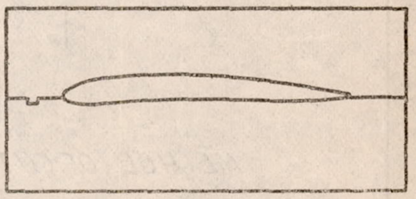


FIGURE 18.

The majority of aerofoils are best constructed of aluminum and very satisfactory ones have been made of this material by the following method. Steel templates are made to fit the upper and lower surfaces, from one-sixteenth inch tool steel worked by hand to within 0.001 inch of the given contour. The two halves are fitted together as shown in figure 18. It is well to check the dimensions of the templates on a dividing engine before proceeding further. A block of aluminum, preferably rolled stock, is trued up on one side to a plane surface. This surface is then clamped down to the bed of a small planer, and the upper surface is planed down to within about a hundredth of an inch of the finished size of the wing. The upper surface is now worked down by hand with file and scraper, using the plane surface as a reference, until it everywhere fits the template. This must be done very carefully by a skilled workman, and requires considerable time (from 30 to 100 hours). The lower surface is now worked down to fit the second template, using the upper template as a reference. In this way the wing is made straight and of uniform thickness. The ends of the wing are milled off square, and one end is drilled and tapped for spindle. This method should give a wing that is everywhere within 0.002 inch of the given dimensions.

Another method, applying mainly to brass and steel wings, makes use of a milling machine in the following manner: A slab of rolled brass or steel is trued up on one face and soldered to a trued heavy block that is fastened on the bed of a milling machine. The cutter is set

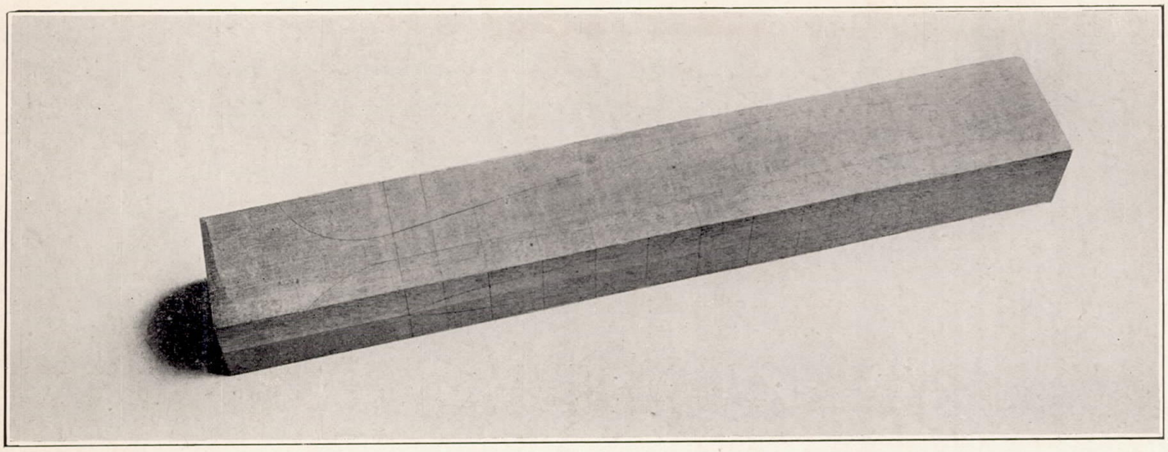


FIG. 24.

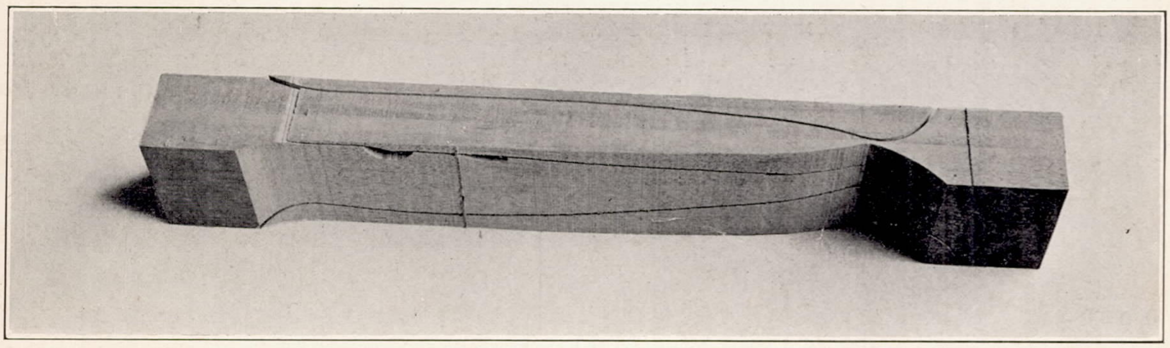


FIG. 25

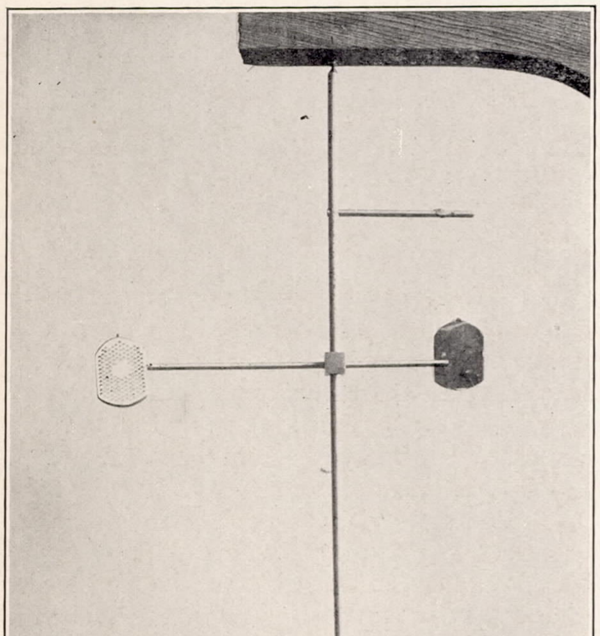


FIG. 34.

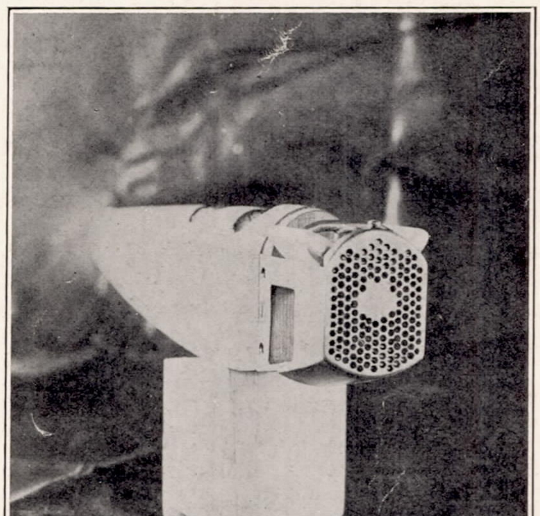


FIG. 35.

down until it just touches the lower block, and the edge of the wing blank is squared off. The cutter is now moved inward 0.05 inch and raised an amount determined by a table of ordinates for the section. These ordinates are scaled off of a drawing to 10 times scale in the same way as for the wooden sections. A series of cuts are taken across the wing until the upper surface is completely formed, leaving two narrow ridges to determine the original surface. The blank is unsoldered from the lower block, and the cut surface is filled with solder or lead and fastened down to the block, with the other face up, taking care that the ridges on the cut surface are in firm contact with the block. The squared edge of the blank is now lined up carefully with the milling machine ways, and the second surface is cut in the same manner as the first. After unsoldering the wing from the block all possible solder is wiped off, and the blank is ready for finishing. This is done by filing down the terraces until the grooves have just disappeared, which should leave a smooth and accurate surface. This method requires no templates nor as much skill as the preceding one, but is considered unsuitable for aluminum wings, as this metal does not hold solder, nor can it be machined to the finished size without the danger of tearing.

Brass wings can be cut with a one-toothed formed cutter, but it does not pay to make a cutter unless several wings of the same section are to be made. It is also rather difficult to get a smooth surface with this type of cutter.

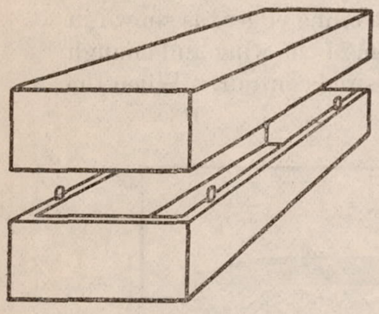


FIGURE 19.

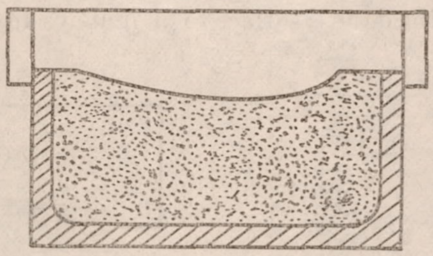


FIGURE 20.

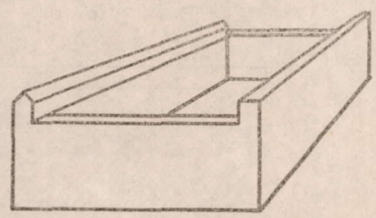


FIGURE 21.

As the wind speed in which aerofoils are tested is increased beyond 100 miles an hour it is necessary to use steel for models in order to prevent excessive deflection of the wing. Although it has apparently never been tried, it is probable that some method could be devised for machine grinding steel wings on a surface grinder to a high degree of accuracy.

## OTHER METHODS OF MAKING AEROFOILS.

It is sometimes convenient to make aeroifols up in a quicker and less permanent manner, when they are to be used only for one test soon after construction. It is also desirable to be able easily to make a small change in some particular region of the wing without making a new model. The following methods have been used successfully here and abroad, but can probably be improved on by more extensive use.

The following method is used for making complete aerofoils. Two channel-shaped metal flasks, with upper edges machined are fitted together with dowel pins, as shown in figure 19. Two accurate templates (positive) are made to the sectional form of the wing, with lugs at the end to fit on the flask and guides to keep it square. (See fig. 20.) The flasks are now filled with well-calcined plaster of Paris that has been mixed into a rather thick paste. The templates are used as scrapers to roughly form the wet plaster to shape. After the plaster has set, the templates can be used to finish the molds down to the correct size. A very good finish can be obtained in this way, but the final finish should not be given until the plaster is dry or the shrinkage may distort the molds. The surfaces are now painted with linseed oil and the flask is clamped together. One end is plugged and a spindle held in the correct position. The spindle may well run completely through the wing as reenforcement. The mold may now be filled at the top with a thin mixture of plaster or by some melted wax which possesses considerable hardness and strength when cool. After the mixture is set the wing is removed and the upper end trimmed off to the proper length. If carefully made the model should have a good finish and be, initially atl east, quite accurate. The wing will not be very permanent and should be tested soon after completion. Also it will not possess sufficient strength to make it available for tests at high speeds.

Another method of making plaster wings has been devised by the Curtiss Co. An iron bed having two trued ways (fig. 21) is nearly filled with a mixture of paraffin and Montan wax. When cold the wax is scraped down with a positive steel template to fit one surface of the wing. The template is carried on a carriage and can be gradually lowered as shown in figure 22. When this surface is completed a thin layer of wet plaster is spread on the wax and a sheet-steel core is pushed down to correspond with about the center of the wing, more plaster is added to the top, and is allowed to set. Before it becomes completely hard the template for the other surface is fastened in the carriage and the plaster is scraped down to size, the template being set to give the correct thickness. These wings can be made quite thin, but are not strong and must be handled with great care, and it is neccessary to support them with a center spindle.

When it is desired to make a series of changes in only one face of the aerofoil, it can be most conveniently done by taking a metal wing having the desired permanent surface, and with the other surface cut below any desired change on this part. Negative templates are made of thin sheet metal for all the desired forms, cut to slide over the leading and trailing edges, as shown in figure 23. The wing is placed in a shallow trough that fits the plan form of the wing and enough melted beeswax is poured over the desired surface to fill it above any desired contour. When the

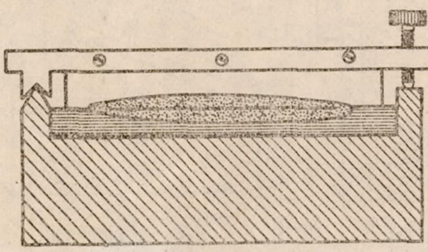


FIGURE 22.

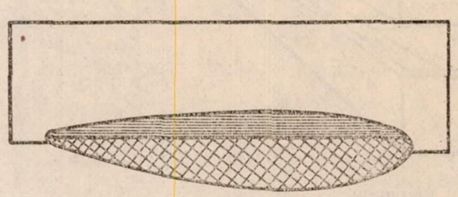


FIGURE 23.

wax has fully cooled it can be scraped down to the required size by template. The template may be held by hand, but a more satisfactory job can be done by holding it in a milling machine and running the model under it. In this way a very excellent surface can be formed equal in accuracy and finish to a wooden one. The wing must be tested within a few hours of the time it is scraped in order to be sure that the wax does not deform. The same method can be used with plasticine, but this material does not give as good results as the wax.

## BODIES AND HULLS.

The construction of bodies and hulls requires less accuracy than wings, so that it will be necessary merely to outline the general methods used in their making. Large models should be cut to 0.02 inch and small ones to 0.01 inch of the given dimensions. For a 4-foot tunnel, no body should be more than 36 inches long nor 5 inches in diameter nor weigh more than 2 pounds, so that it is necessary to hollow all large models. The best woods to use for these models is white pine or bay mahogany, woods that are light, easy to work, and not liable to warp.

Small bodies may be made of one piece sawed out to the correct profile in two planes, as shown in figures 24 and 25. The edges cut off in the first sawing are lightly bradded on to the body in order to steady it when sawing the second side. The four sides are then planed down accurately to size, and by the aid of templates the corners are worked off with plane or spokeshave. The surface is then scraped and finished with shellac rubbed down with pumice and oil. If a fuselage has a spinner on the nose, it is best to turn this part down separately on a lathe and dowel it on to the fuselage, working the squared block down to the spinner. Cockpits should be cut to at least half the depth of the body, but no details inside, such as the seat, need be included.

Wind shields, however, should be put in place and knobs representing the men's heads fastened to the rear of the cockpit.

Large bodies (over 18 inches long and $2\frac{1}{2}$ inches in diameter) should be made hollow. This is best accomplished by cutting out a series of lifts from thin stock ($\frac{1}{4}$ inch). These are sawed out and planed accurately to outline and the whole set glued together with hot glue, being held in alignment by dowel pins on the base plate as shown in figure 26. When the glue is hard the pins can be cut off flush and the outside surface of the model planed down smoothly to the contour lines of the lifts. This method gives a light and accurate model requiring few templates for finishing. A line should always be marked on the side of the body parallel with the propeller axis, in order to aid in lining up the model.

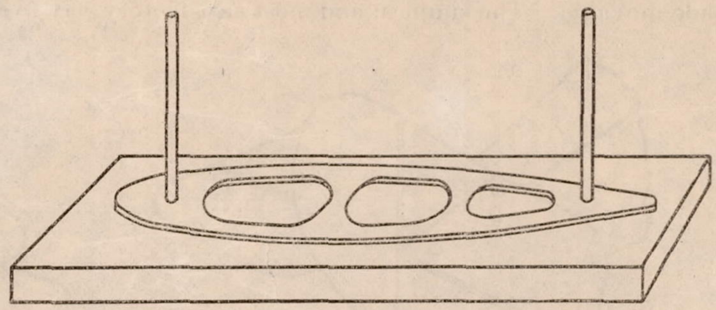


FIGURE 26.

Flying boat hulls and seaplane floats are constructed in the same way and require no special comment.

### STABILIZERS.

Stabilizers can be worked out of aluminum in the same way as aerofoils and require the same degree of accuracy. If the stabilizer is thin it will not be too heavy if made of brass, which is preferable to aluminum in everything except weight.

It is important that the stablizer may be easily and accurately adjusted for angle of incidence. A maximum adjustment of 5 degrees is sufficient, but all mechanism for the adjustment must be in the body that it may not disturb the air flow. It is also desirable to have both halves of the stabilizer turn together.

A satisfactory and simple method is shown in figure 27. The two halves of the stabilizer are mortised out and fitted into the sides of the brass cylinder (*a*) with brass pins (*b*) all filed flush with the stabilizer surface. The brass cylinder is a friction fit in the split ring (*c*) screwed into the wood of the body.

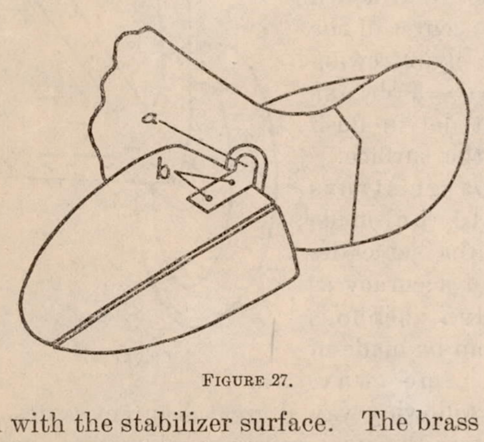



FIGURE 27.

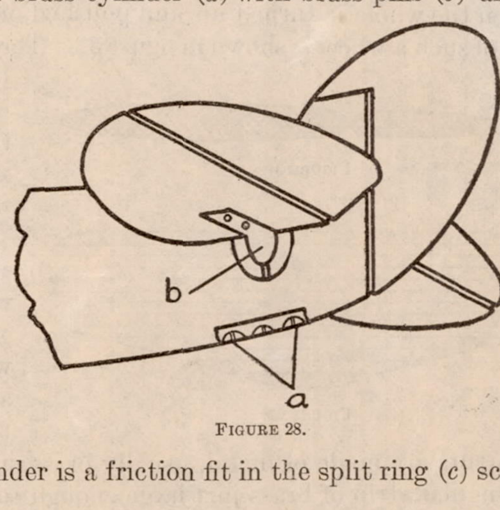



FIGURE 28.

In figure 28 a similar arrangement is used except that a finer and more positive adjustment is assured by the two adjusting screws (*a*) passing from the bottom of the body to the sides of the brass cylinder (*b*). Figure 29 shows a way of adjusting a stabilizer that rests on the top longerons. A grooved brasss plate (*a*) is set in the top of the body, and a rocker on the lower side of the stabilizer rests on it. The angle is changed by adjusting screws at (*c*) and (*d*). Another method, figure 30, has the stabilizer hinged at (*a*) and the upper edge is held up against the screws (*b*) by springs. By adjusting these screws the angle is changed.

A template should be provided with every model to fit the stabilizer in order to line it up. The back of the template should be parallel to the stabilizer cord.

## CONTROL SURFACES.

If it is desired to use the model for stability work, the ailerons, elevator, and rudder are made movable. The simplest and most satisfactory way to accomplish this is to cut the surfaces

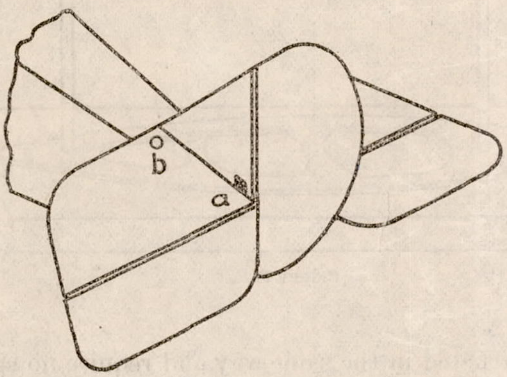



FIGURE 29.

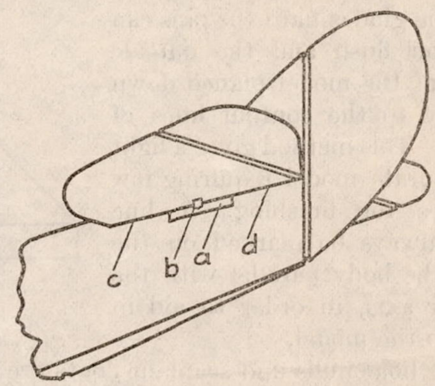



FIGURE 30.

with a very fine jeweler's saw, beveling the inside edges and inserting several pieces of soft brass wire as dowel pins. This allows the surface to be held in any position without danger of its turning. The size of the wires and their spacing depend, of course, on the size of the model and the velocity at which it is tested. (Fig. 31.)

## CHASSIS.

The wheels when small may be turned out of solid maple, but if the wheel is to be tested alone, and is therefore large, it should be glued up of pine laminations and left hollow. The laminations are sawed out roughly on the band saw, glued together, and then the whole is turned up and polished on a lathe. A cross section of such a wheel is shown in figure 32. The spindle is attached to the center of the wheel by screwing it into a brass socket, let in flush with the surface.

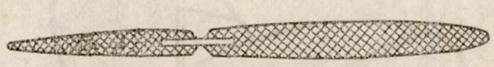


FIGURE 31.

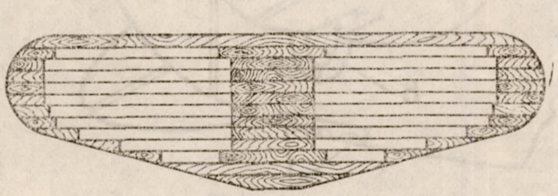


FIGURE 32.

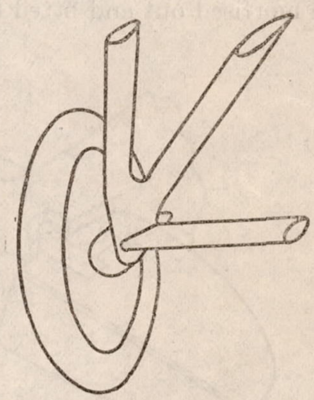


FIGURE 33.

Large struts should be made with the same degree of accuracy as wooden aerofoils and can be made in the same way. Small struts are made of metal, usually brass, in the following way, if great accuracy is desired. A rectangular strip of brass just large enough to contain the strut section is soldered to a heavy block of metal, and is lined up truly on the miller bed. A series of cuts are now taken along the strut with the corner of the cutter just touching the contour of the section, inscribed on the end, leaving a short uncut section at the other end in order to hold the strut square when this side is soldered to the block. The cut surface while still on the block is carefully filed down until the cutter marks have just disappeared, leaving the surface smooth and true. The strut is turned over and the operation repeated on the other side. If this is carefully done, an accurate strut will result, but if greater precision is desired the cutter may be set by the micrometer head to a given set of ordinates, in the same way used in cutting aerofoils.

The axle is usually made like a strut and the wheels are pinned to the ends. Shock absorbers are fastened to the axle just inside the wheels with pins or glue, and are of stream-line form in most models. (Fig. 33.) Where the shock absorber on the full-sized machine is unstreamlined it may be reproduced on the model by winding a hard cord or wire of suitable size about the axle.

### RADIATORS.

Although radiators are usually constructed of a solid block of wood, or are omitted altogether, there is no reason why this important portion of the structure should not be represented with fair exactness. This is accomplished by using a fine gauze screen, or, better, a perforated brass plate having the same resistance in proportion to a flat plate of the same size as has the full-sized radiator. In order to get the proper resistance the radiator and flat plate of the same size are mounted on opposite sides of a freely turning spindle, but at such a distance as gives a balance when the proper resistance of the radiator is reached. A short dummy spindle must be provided to counter balance the greater length of the spindle attached to the radiator. The holes in the radiator are gradually enlarged until it balances the plate. A model J N 4H radiator is shown in figure 34, mounted for balancing. The ratio of resistances between the radiator, and a flat plate of the same size ranges roughly from one-half to two-thirds, depending on the type of the radiator. A nose radiator should have a motor behind it and an outlet for the air in accordance with the large machine. A Hispano Suiza motor and radiator model is shown in figure 35.

### THE COMPLETE MACHINE.

The completeness with which the minor parts of the airplane are reproduced on the model depends largely on the purpose for which it is tested. For instance, should the model be used only for determining the balance of the machine and the stabilizer setting, all small parts may be omitted, as they will not affect the balance appreciably. If, however, the model is used to determine the performance of the full-sized machine, or to obtain scale corrections, such parts as exhaust stacks, control arms, shock absorbers, etc., should be attached. To have strict agreement with the full-sized machine, wires and fittings, which furnish a large portion of the total drag, should be placed on the model, but, because of the difficulty of reproducing the wires and fittings on small models; and because the small wires do not have a resistence proportional to their size, wires have been omitted on practically all models. With a tractor-type radiator, the passage for the air to escape around the engine should be of the same proportions as in the full-sized machine. It would be very desirable to employ much larger models than are used now in order that all details might be included. With a 6-foot model it should be possible to very closely determine the performance of any new machine.

The wings of the model should be made of aluminum or steel by the methods described above, but usually with such a chord as to make the model some definite scale of the full-sized machine. The size of the model should be proportioned to the size of the tunnel, and the weight should be kept as low as possible consistent with stiffness at the maximum speed at which the model is to be run. Care should be taken on every part of the model to insure accuracy, finish, and sufficient strength to allow of handling.

When the wings are cut to the proper section, the plan form of the wing is laid out on the lower surface of each, with a fine scratched line. The outline is sawed roughly to size and then filed squarely to the line. By the aid of templates the ends are rounded off in the correct manner and carried smoothly into the finished surface of the wing. Wings having dihedral can be cut three-fourths through at the center section with a fine saw and the wing bent to the proper angle by means of templates. Sweep back, if present, is best accommodated by cutting the wing in the center to the proper angle on the milling machine and halving the pieces together, as shown in figure 36. The point of attachment of the struts is marked on the upper surface of each wing, and by means of tapered blocks the strut holes are bored and tapped.

(Fig. 37.) It is important that the direction of the holes be tapped exactly in the direction of the strut or it will be impossible to line the machine up closely. Also the threads in one wing should be right-handed and in the other left-handed. Another method of fastening interplane struts is to thread the ends of the struts and drill the wing, holding the struts to the wing with countersunk nuts, as shown in figure 38. This allows the use of stream-line struts, but they must be cut correctly to length as little adjustment can be made after assembly.

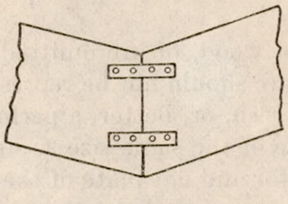


FIGURE 36.

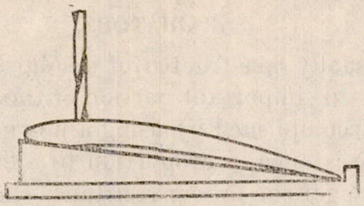


FIGURE 37.

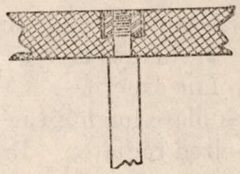


FIGURE 38.

Interplane struts having no incidence wires on the full-sized machine, as in the portal, I or K trusses, are made of a single piece of brass on the model and formed accurately to fit the surfaces of the wing. They are fastened with flat-headed screws passing through the wing, as shown in figure 39. This completes the work on the single wings.

The chassis is fastened to the body, either by pinning the struts into the body with pins that are continuations of the struts, or by bending the struts sharply as they meet the body so that the face of the strut is parallel with the side of the body and is mortised in flush with the surface and held by a small wood screw. If the lower wing passes through the body, as is generally the case, an accurate section of the wing is marked on the body, and with a fine band

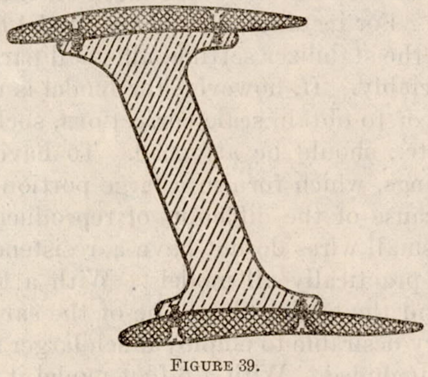


FIGURE 39.

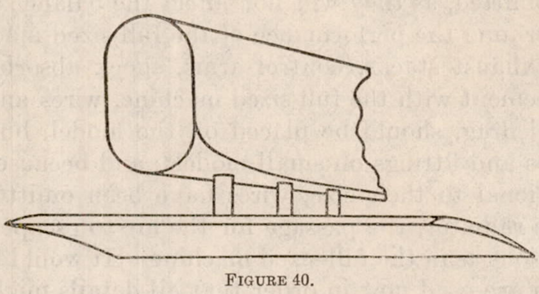


FIGURE 40.

saw the wood inside this section is cut away, with an entrance cut at the trailing edge. The lower wing can be slipped into this opening and screwed firmly in place by two wood screws inserted from below. Should the wing pass below the body, it can be held by long, slender wood screws passing through the wing into the body. The wing is held away from the body the correct distance by stream-lined spacers, as shown in figure 40.

The empennage is attached to the body, the leading edge of the stabilizer square with the axis of the body, and the fin and rudder parallel with the line of flight. The tail skid is usually made from the same piece of metal as the fin.

The body struts to the upper wing are attached in the same way as the chassis struts and are held at the other end by machine screws passing through the wing into the upper end of the strut. The interplane struts are made of a piece of steel wire cut to the right length and threaded on the ends with left and right threads. It is stream-lined when in place by a brass fairing.

The model is now ready for lining up, a process that must be done with the greatest care, in order that it may be relatively as well lined as the full-sized machine. In order to do this the fuselage is clamped securely to a plane surface, right side up and with the propeller axis horizontal. A pair of similar templates are now made that will go under the chord of the upper and lower wings on either side of the body in such a way as to fix the angle of incidence of each, their stagger and dihedral. The position of these templates is shown in figure 41. The interplane struts are now put in place and approximately adjusted, and the lower plane is set to its correct angle of incidence by shimming where it passes through the body. With the aid of the templates the upper wing is adjusted by turning the struts, the opposite threads on which enable them to act as turnbuckles, until the wings are correct in all ways. The

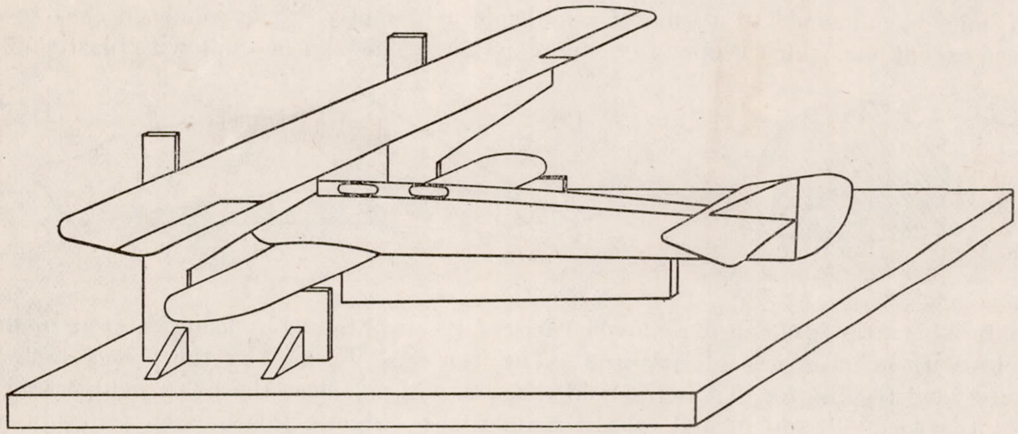


FIGURE 41.

brass fairings can now be attached with a soldering iron. They should all be lined up along the axis of the body. It is well to check up the alignment of the machine after mounting it on the balance in order to be sure that there is no error of more than one-tenth degree at any point.

The spindle is sometimes attached by screwing it directly into the wood of the body, but if the model is to be used several times a metal socket is best inserted in the wood, as shown in figure 42. This type of spindle, however, is rather unsatisfactory aerodynamically because of its interference with the wings and because it is difficult to determine its effective resistance; that is, the resistance which should be subtracted from the total resistance to give the true resistance of the machine. A better way is to screw the spindle into the tip of the wing. If the forces are large, it is necessary to insert a steel socket into aluminum wings. (Fig. 43.)

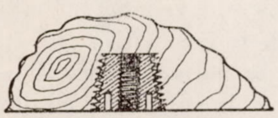


FIGURE 42.

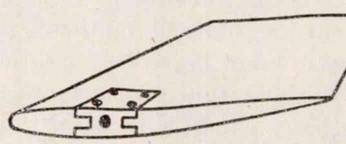


FIGURE 43.

## AEROFOILS FOR PRESSURE DISTRIBUTION.

It is sometimes necessary to know the pressure on each portion of the surface of an aerofoil in order to determine the manner of loading. In order to do this a large number of small holes are bored into the wing at right angles to the surface and each in turn connected to a pressure gauge. As this requires a long time and the connections must not be allowed to interfere with the air flow, the following methods have been adopted:

A method devised by the National Physical Laboratory consists in cutting a series of grooves along each surface of a brass wing at right angles to the chord. They are about $\frac{1}{16}$ inch wide and deep, and are spaced closest together where the pressure gradient is steepest, but 10 or 12 rows is sufficient to each surface. A piece of $\frac{1}{16}$-inch steel hypodermic tube in each groove and smoothed off flush with the surface with solder. (Fig. 44.) A series of holes are now bored along the tubes, on half the span only, as the wing is symmetrical. These holes should be spaced nearer together at the wing tip than at the center. They should be bored with a No. 70 drill and all burrs carefully removed. The tubes should project about ¼ inch beyond the wing tip on the side away from the holes in order to make connections with rubber tubes and yet not interfere with the air flow on the side where the pressure is being taken. (Fig. 45.) The other ends of the tubes are filed flush with the surface, but are left open, so that a cleaning wire may be pushed through the tube. The wing is placed in the tunnel, and each row of holes is connected to a tube of a multiple manometer. Every hole in each row must be closed except one, which is open to the manometer. This can be done with plasticine, but as

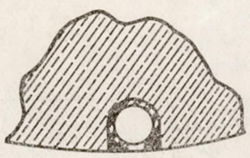


FIGURE 44.

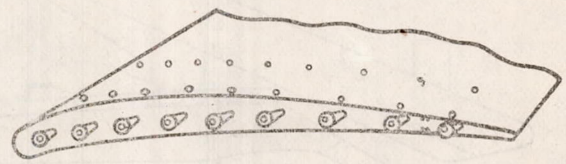


FIGURE 45.

this material is rather difficult to remove better results are obtained by using beeswax melted into the holes with an electric soldering iron. The iron must be kept at the proper temperature to insure good results, for if it is too cold the wax will not close the holes tightly, and if it is too hot the wax will run in and fill the main tubes. Should this happen a fine piano wire can be forced through the tubes to clear them. The holes can also be sealed by small disks of tissue covered with shellac. Care should be taken at each change of holes, to be sure that each hole that should be open is clear and that all the others are closed. This is easily determined by blowing against the wing at each hole with a small rubber tube and watching the manometer. There should be no deflection except at the open holes.

Another method devised in this country, although requiring a little more work on the model, has the advantage that it can be used on thinner sections, as ailerons and tail surfaces, and gives smoother surfaces. Two blocks of brass about ¼ inch thick and of sufficient size to construct the wing, are trued up on one face. These faces are then grooved at corresponding distances along the span under each row of holes. The grooves can be cut with any cutter that will give a square or circular hole when the two halves are placed together. The blocks are carefully tinned and are soldered face to face with $\frac{1}{16}$-inch aluminum wires in the grooves to prevent the solder filling them. The wires can be removed, leaving a series of clear air passages. Holes are now bored through the wing from face to face with a No. 70 drill, as shown in figure 46. The direction of the holes should be closely normal to the finished surface of the wing. The block can now be placed in the milling machine and worked down as described before. Small nipples are soldered to the end of the air passages on the opposite side of the wings from the holes for the attachment of rubber tubes, running clear of the model. Small tube should not be used any further than necessary, as it has a heavy damping effect on the gauge.

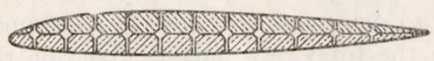


FIGURE 46.

When it is desired to investigate the pressure on a control surface the holes and passages are made in the same way, but it is now impossible to take off the pressure on the side of the machine opposite from that on which the pressure is measured. In order to reduce the interference to a minimum, fine steel hypodermic tubes are carried out several inches from the end of the wing before the rubber tube is attached, as shown in figure 47

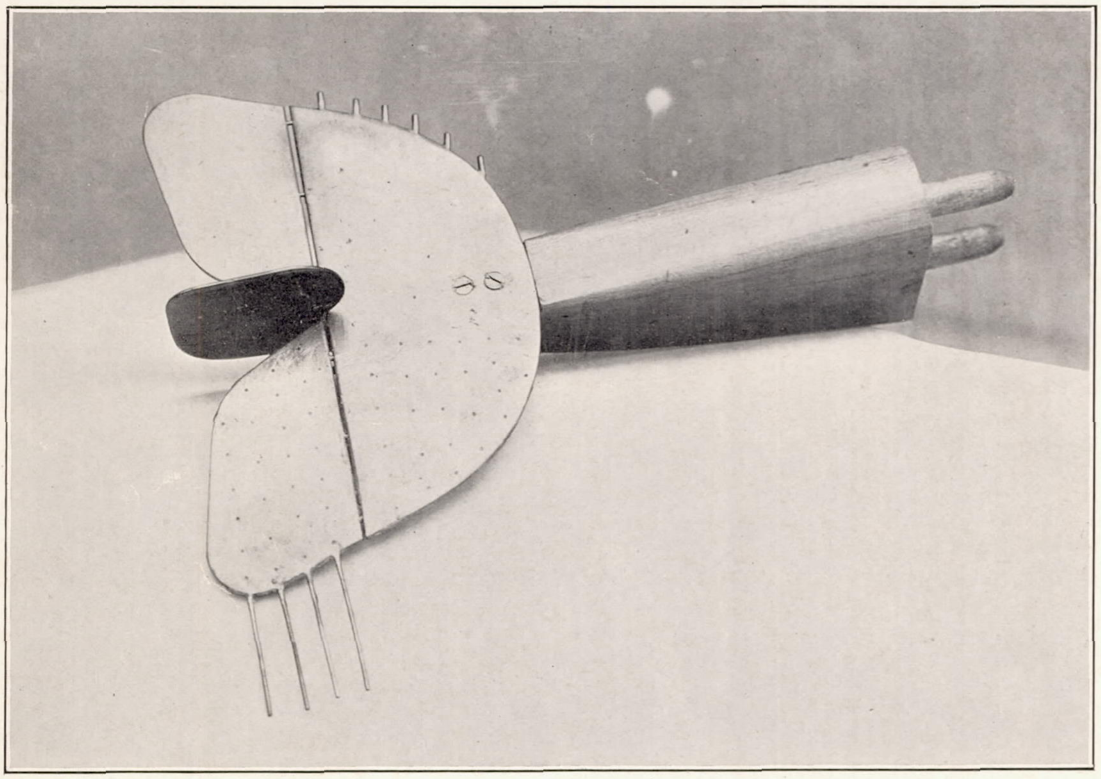


FIG. 47.

## MODEL PROPELLERS.

Model propellers are so similar to full-sized ones that the same methods of construction apply to both. The method most generally employed consists in making a series of templates to fit both upper and lower surfaces of the blade at a series of stations along the radius. The position of these templates should be fixed by screwing them to a plate squarely and with their proper spacing. This allows all the templates to be applied to one face at a time. A series of laminations is glued to the proper thickness and cut out to the given contour. The blades are then worked down by hand to fit the templates, a rather slow and inaccurate method, but the best that has been used.

Another method consists in gluing up laminations that have first been cut to the exact size. The blades are then trimmed down to the contour lines, thus determining the blade. It is difficult to accurately cut the tip of the blade in this way, as the distance between laminations is large in this region.

All model propellers are laminated to prevent warping, the best woods being pine or mahogany, unless the blade has any thin sections, when a closer-grained wood like maple is better. A four-bladed propeller should have each pair of laminations halved together rather than to halve the whole propeller, in order to give a more uniform support to the blade. Each propeller should be carefully balanced and finished with shellac. A steel hub can be bolted to the propeller in the usual way. From the aerodynamic standpoint, it is desirable that the full-sized propeller and the model be made from the same material and by the same method, as the deformations of the blades of the two at like peripheral speeds should then be identical.

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