

May 25, 1937.

J. SQUIRES

2,081,645

METHOD OF PRODUCING PROPELLER BLADES

Filed July 5, 1933

7 Sheets-Sheet 1

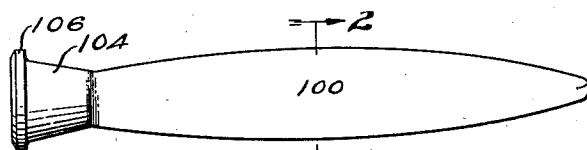


FIG. 1.

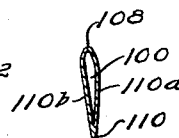


FIG. 2.

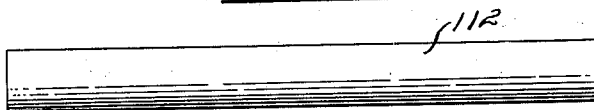


FIG. 3.



FIG. 4.

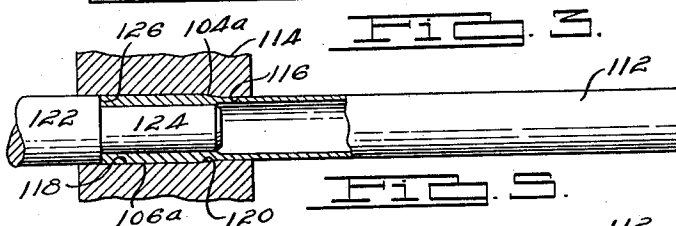


FIG. 5.

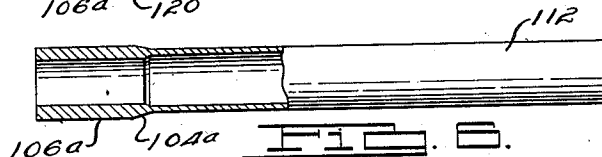


FIG. 6.

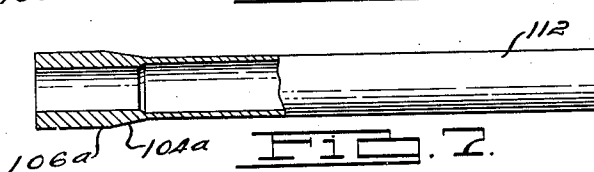


FIG. 7.

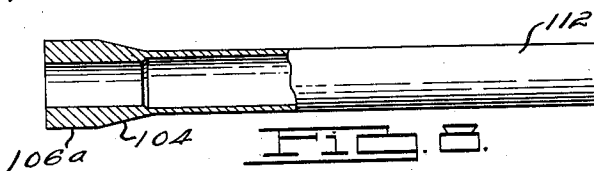


FIG. 8.

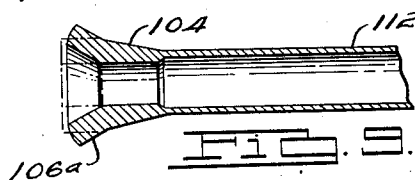


FIG. 9.

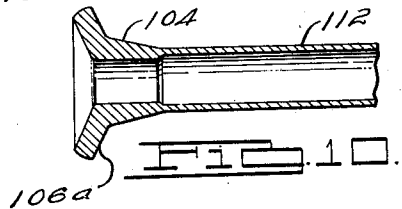


FIG. 10.

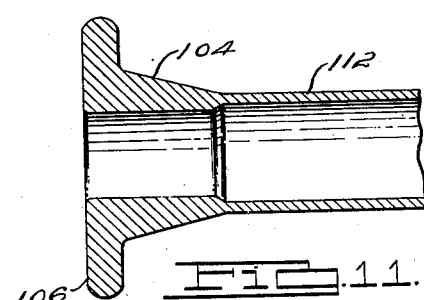


FIG. 11.

INVENTOR  
John Squires.

BY

Harness, Wickey, Pierce & Hann.  
ATTORNEYS.

May 25, 1937.

J. SQUIRES

2,081,645

METHOD OF PRODUCING PROPELLER BLADES

Filed July 5, 1933

7 Sheets-Sheet 2

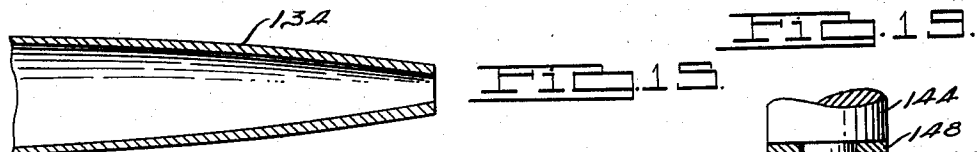
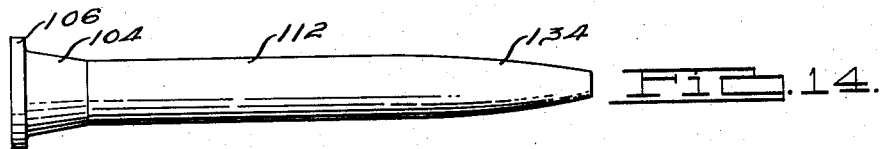
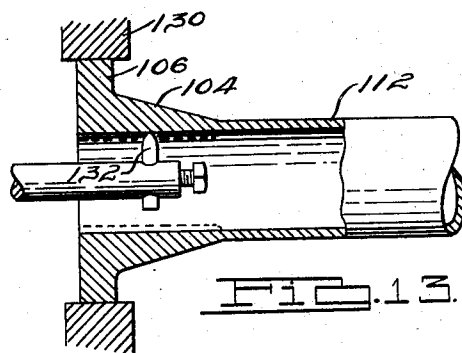
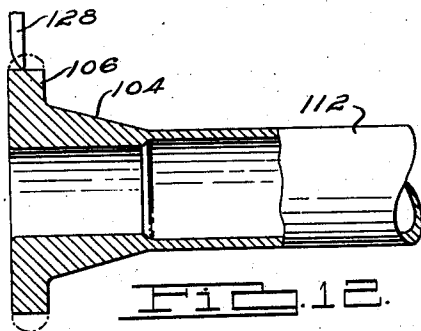


FIG. 16.

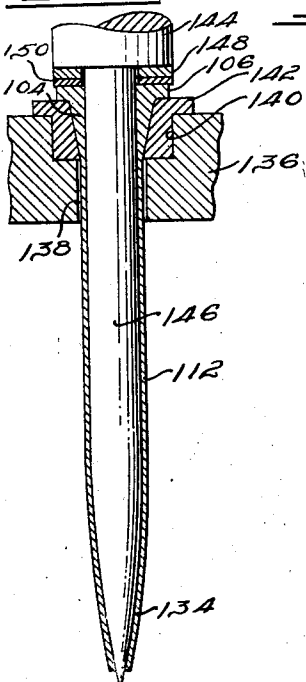


FIG. 17.

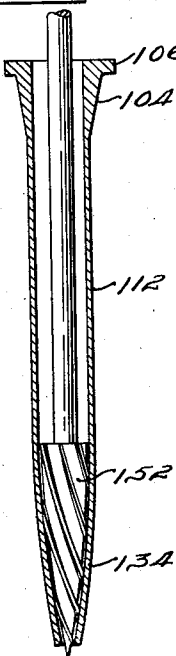
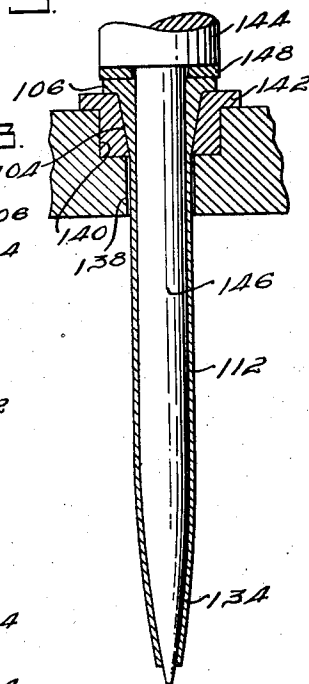
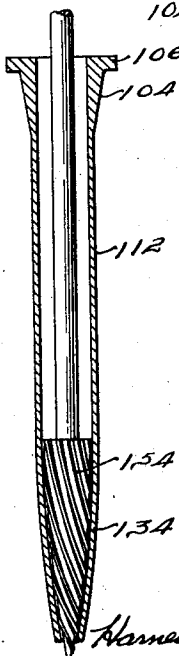


FIG. 18.



INVENTOR  
John Squires  
BY  
Harnett, Kieley, Pierce & Hann.  
ATTORNEYS.

May 25, 1937.

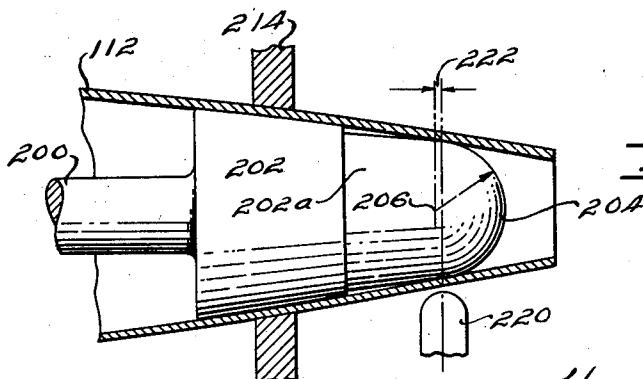
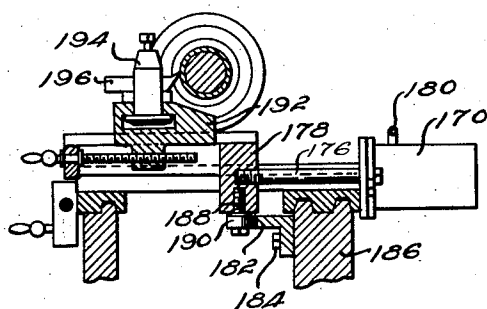
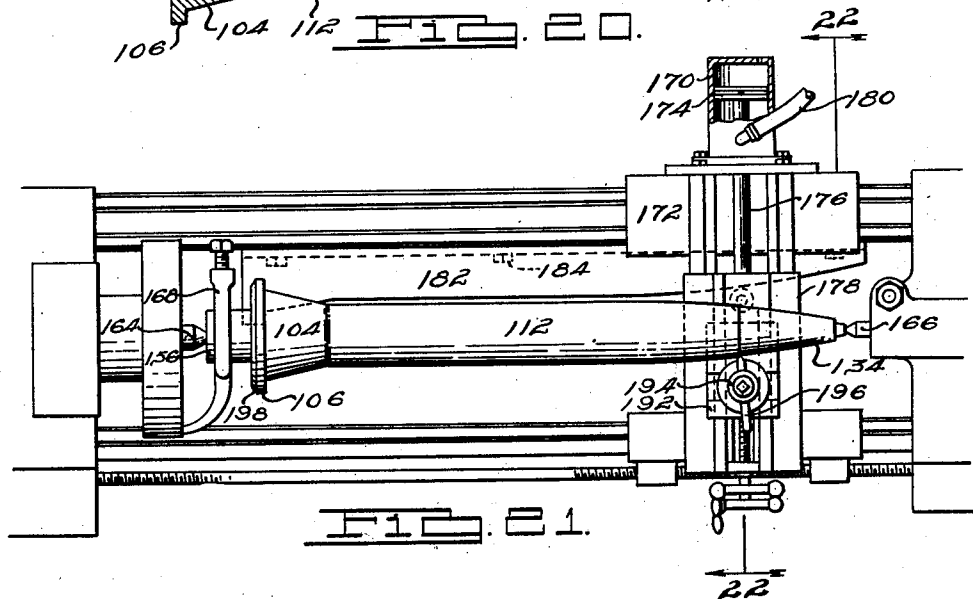
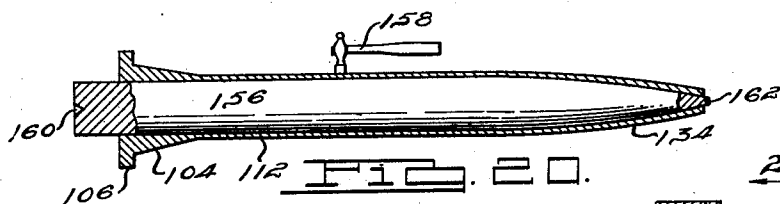
J. SQUIRES

2,081,645

METHOD OF PRODUCING PROPELLER BLADES

Filed July 5, 1933

7 Sheets-Sheet 3



INVENTOR  
John Squires.  
BY  
Harness, Wickey, Pierce & Hann.  
ATTORNEYS.

May 25, 1937.

J. SQUIRES

2,081,645

METHOD OF PRODUCING PROPELLER BLADES

Filed July 5, 1933

7 Sheets-Sheet 4

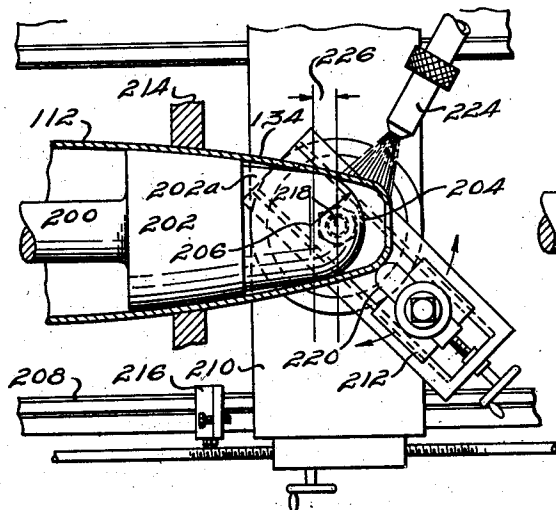


FIG. 24.

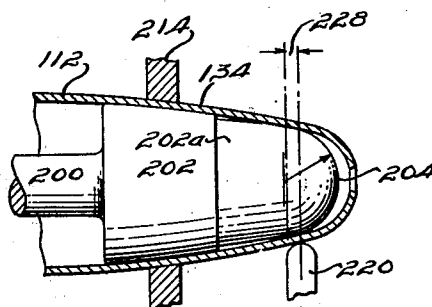


FIG. 25.

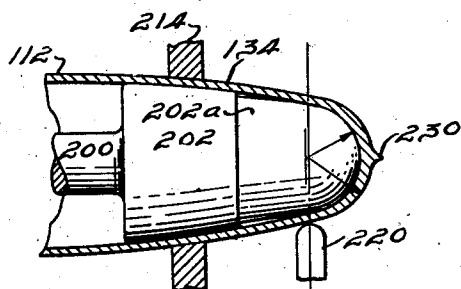


FIG. 26.

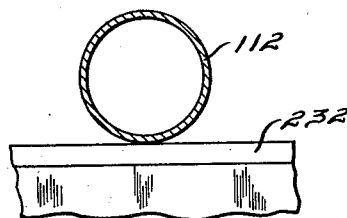


FIG. 27.

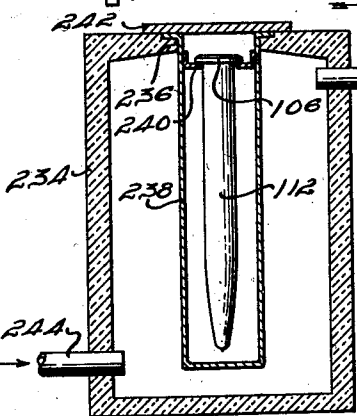
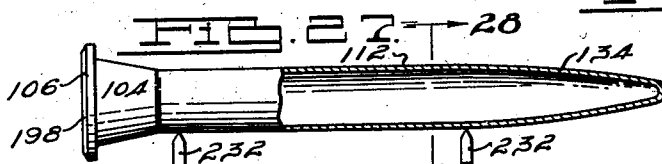


FIG. 29.

INVENTOR

John Squires.

BY

Harnett, Wicks, Pierce & Mann.  
ATTORNEYS.

May 25, 1937.

J. SQUIRES

2,081,645

METHOD OF PRODUCING PROPELLER BLADES

Filed July 5, 1933

7 Sheets-Sheet 5

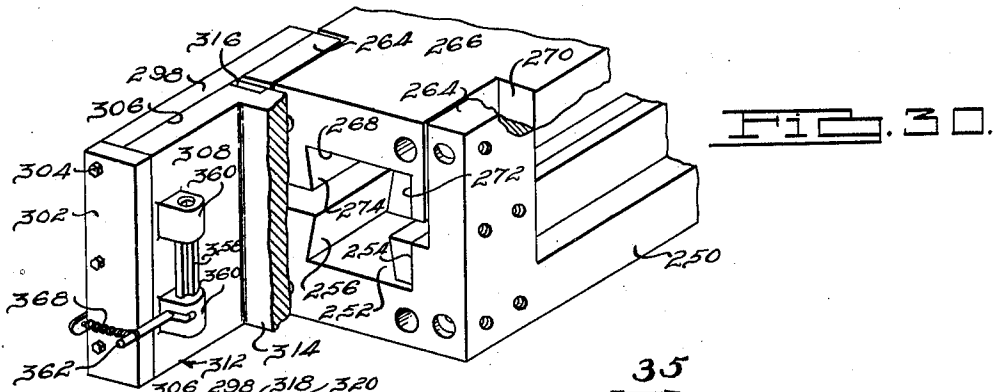


FIG. 30.

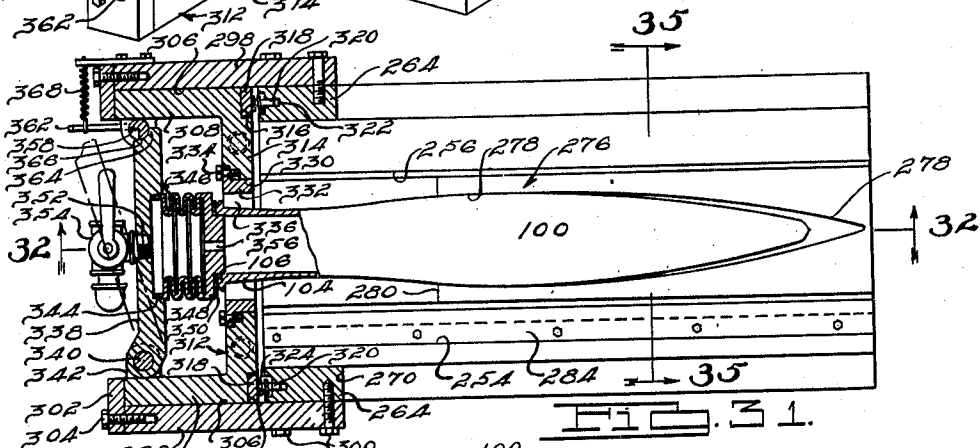


FIG. 31.

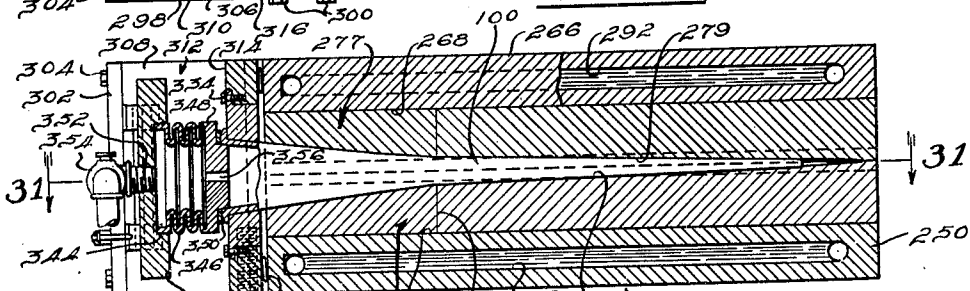


FIG. 32.

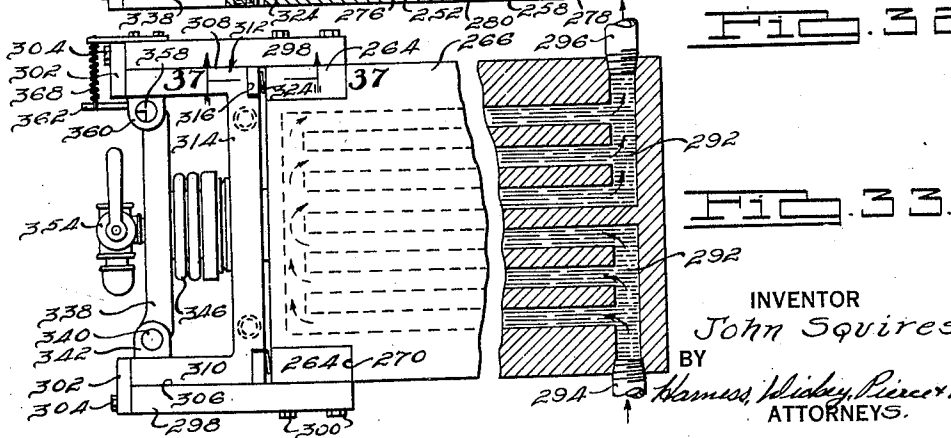


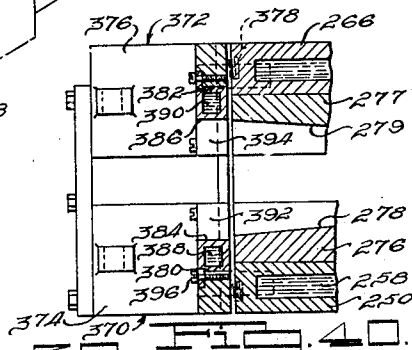
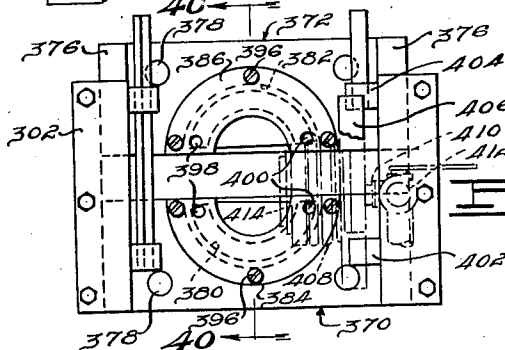
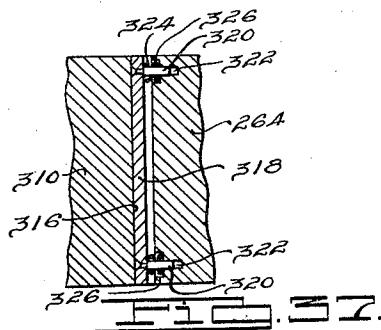
FIG. 33.

INVENTOR  
John Squires.  
BY  
Hamm, Wiley, Pierce & Hann  
ATTORNEYS.

J. SQUIRES

# METHOD OF PRODUCING PROPELLER BLADES

7 Sheets-Sheet 6



John Squires.

BY

Harness, Wickey, Pierce & Hann.  
ATTORNEYS.

May 25, 1937.

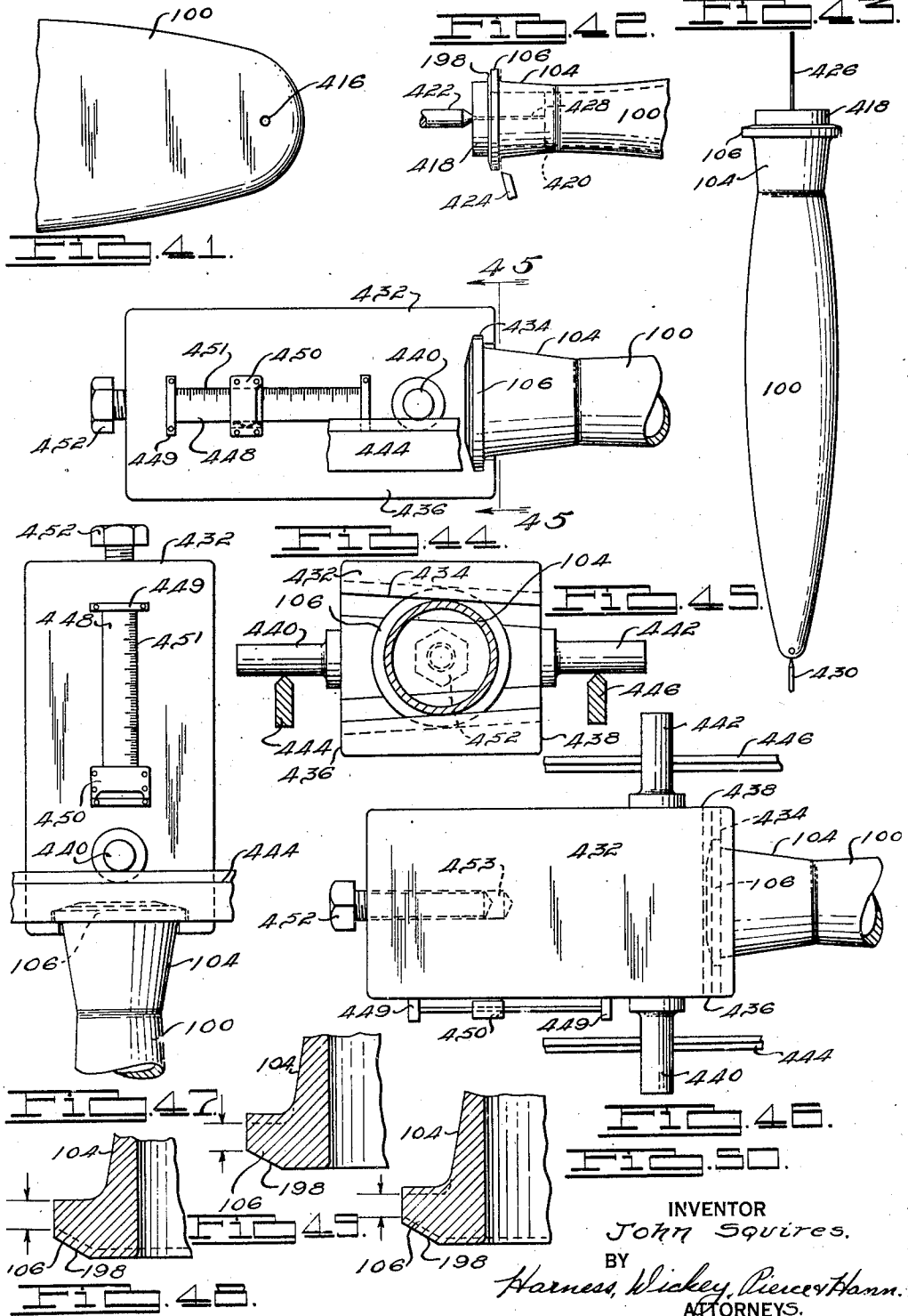
J. SQUIRES

2,081,645

METHOD OF PRODUCING PROPELLER BLADES

Filed July 5, 1933

7 Sheets-Sheet 7



INVENTOR  
John Squires.

BY  
Harness, Wickey, Pierce & Hann.  
ATTORNEYS.

## UNITED STATES PATENT OFFICE

2,081,645

METHOD OF PRODUCING PROPELLER  
BLADESJohn Squires, Hagerstown, Md., assignor to  
United Aircraft Corporation, East Hartford,  
Conn., a corporation of Delaware

Application July 5, 1933, Serial No. 679,133

78 Claims. (Cl. 29—156.8)

This invention relates to airplane propellers and particularly to the blades thereof, the principal object being the provision of a blade for such propellers together with improved methods for producing and testing such blades.

In accordance with the present invention a propeller blade is made from a seamless metallic tube of substantially uniform diameter both internally and externally. One end of the tube is upset and made thicker. A portion of the thickened end of the tube is then turned outwardly to make a circumferential flange. The other end of the tube is then swaged or otherwise tapered to a somewhat smaller diameter both internally and externally. The blank is then held by the flange while there is inserted into it a mandrel under sufficient pressure to bring the internal dimensions of the tube to approximately the size of the mandrel. After the mandrel is withdrawn the inner face of the smaller end of the tube is dressed to substantially the size desired in the finished tube. The tube is again held by the flange and the mandrel inserted into it the tip end seating upon the dressed portion at the smaller end of the tube. The mandrel is then forced home under pressure causing the main body portion of the tube to expand, contract or deform beyond its elastic limit. This will cause the tube to permanently assume an interior size substantially exactly corresponding to the external dimensions of the mandrel which is of the size desired for the further operations on the tube. The sized tube upon a correspondingly sized mandrel is then placed in a lathe where the surface of the tube is acted upon in such a way as to cause the wall of the tube to very closely approach the thickness desired in the finished product. Preferably the wall will be somewhat tapered in thickness being thinner at the smaller end of the tube. A mandrel or support is then placed in the tube engaging it near the smaller open end. While so carried, in a turning lathe, the metal at the smaller end of the tube is heated and as it becomes plastic it is worked upon by a spinning tool or the like to entirely close the tube at the smaller end at the same time slightly thickening the metal and forming a small nipple thereon. The blank is then freely revolved on horizontal supports to ascertain its heaviest portion if any. The closed tube is then preferably suspended by the flange in a heating furnace and brought to a proper temperature for the final forming operation. The forming operation is performed by placing the heated blank, properly positioned with respect to its heavy line, between

a pair of dies where it is held by its flange. Air under pressure is admitted to the interior of the tube and the dies are caused to come together and press the tube in proper form for an airplane propeller. The shaped tube may then be again suspended by its flange in a furnace and heated to relieve strains in the metal after which it may again be inserted in the dies which may be suitably cooled to chill the metal and cause the propeller to set in its final form. For convenience the dies may be made in separate sections so that they may be partially or wholly changed to produce blades of different characteristics. The die cavity toward the tip or smaller end of the blade may be of somewhat larger capacity than the finished blade. The means for supporting the blade by its flange for the pressing and finishing operation may be resiliently mounted so as to conveniently provide for contraction of the metal when cooling. The propeller blade when taken from the dies may have the nipple formed at its tip removed and a small hole drilled in its camber face near the tip. The flange may now be dressed or cleaned up and the blade suspended from a centering spider mounted in the flange end of the tube over a marker for marking on the tip the other end of the longitudinal axis of the blade. The blade may then be mounted by its flange in a balancing stand and appropriately corrected to bring its static moment into correspondence with a predetermined standard. This may be done by cutting or dressing the flange in accordance with the need indicated by the balancing mechanism. Suitable polishing, finishing, heating, straightening and correcting operations may take place at suitable points during the operation. It will be understood the description here given is a general outline of what has been found workable, further details of which will appear hereinafter. All of the matter here stated is not essential to all phases of the invention and may not all be necessary with respect to any individual propeller.

Objects of the invention include the provision of a propeller blade formed from standard tubular stock through subjecting the same to suitable forming operations; to provide for gradually reducing the thickness of the walls of a hollow propeller blade or blade blank from its inner to its outer end, so as to vary the strength of the blade at different points of its length, according to stresses encountered at such points in use, and thus greatly reduce the magnitude of centrifugal stresses arising in such use.

Other objects include certain steps of operation in the method of forming a propeller blade among which are included the formation of a hollow blank having one end thereof of smaller dimensions than the opposite end thereof, and accurately predetermining the interior size, shape and contour of such blank prior to bringing such blank to blade formation; to accurately predetermine the interior dimensions of such blank and thereafter machine the exterior of such blank in predetermined accordance with the internal dimensions thereof; to predetermine such internal dimensions of the blank by a radial stretching of the blank beyond the elastic limit of its material; to predetermine such internal dimensions of the blank by axial stretching of the blank beyond the elastic limit of its material; to predetermine such internal dimensions of the blank by radially and axially stretching of the blank beyond the elastic limit of its material; to accurately predetermine the internal dimensions of such blank at least in part by forcing into the blank a mandrel of predetermined shape, size and contour with sufficient force to stretch the material of the blank, or at least a portion thereof, beyond the elastic limits of the material of which it is formed; to accurately predetermine the interior size, shape and contour of at least a portion of said blank by forcing into it a mandrel which will cause such portion to be stretched both axially and radially to thereby cause the interior walls of said portion to set and to conform permanently to the complementary surface of the mandrel.

Other objects of the invention reside in the method of forming a propeller blade which includes the machining of the interior surface of the smaller end portion of the blade blank prior to accurately predetermining the interior size, shape and contour of the remaining interior dimensions of the blank; machining the interior surfaces of the smaller end of the blank and thereafter forcing into the blank a mandrel of predetermined size, shape and contour whereby to stretch the metal beyond its elastic limit to cause the interior surfaces of the blank to conform to the external surfaces of the mandrel; to accurately predetermine the interior size, shape and contour of at least a portion of the smaller end of the blank by a machining operation and thereafter causing the remaining interior walls of the blank to conform to a predetermined size, shape and contour by stretching the blank beyond the elastic limit of its metal over a mandrel of predetermined size, shape and contour.

Other objects of the invention reside in the method of forming a propeller blade blank including closing the small end of the blank; closing the small end of the blank in such a manner as to provide an extra thickness of metal at such end; closing such small end of the blank by a succession of passes of a spinning tool; closing such small end of the blank by working the metal of such end over the end surface of a mandrel mounted within the blank; closing such small end of the blank by working the metal of such end over a mandrel received therein so as to cause the interior size, shape and contour of such end to conform to the external size, shape and contour of such mandrel; and to close such end by working the metal thereof over the corresponding end of a mandrel in such a manner as to cause a nib or nipple to be formed at the tip of such end by flowing excess metal in the end toward the tip thereof.

Other objects include predetermining the interior size, shape and contour of a propeller blade blank and then machining the exterior of the blade in predetermined relationship with respect to the interior surface thereof; accurately predetermining the interior size, shape and contour of a blank, placing said blank upon a mandrel whose exterior surface accurately conforms to the interior surface of the blank, and then machining the exterior surface of the blank in predetermined relationship to the exterior surface of the mandrel.

Other objects include the provision of a method of making a propeller blade blank including operating upon a length of tubular stock to form a flange at one end thereof and to bring the other end to smaller dimensions; operating upon such length of stock to bring its internal dimensions into conformance to a predetermined size, shape and contour, operating upon the exterior of said stock to bring the wall thickness thereof to that desired in the finished product and then operating upon said blank so formed to bring it to the desired blade shape; operating upon a tubular piece of metal to bring it into generally tapered conformation with the ends thereof open, machining the tube thus tapered to bring its wall thickness to desired finished condition, closing the small end of the tube and thereafter pressing the tube to the desired blade shape; and to provide a method of forming a blade as outlined above in which the surface of the tube is polished before the tube is pressed to blade formation.

Other objects include improvements in the method of making propeller blades including certain steps of operation designed to result in a product of material uniformity in quality; to provide a method including certain steps of operation in the formation of a blank for propeller blades, in certain steps of operation in modifying the blank into blade formation, and in certain steps in and methods of heat treatment of the blank after it has been formed to shape.

Other objects of the invention are to obviate both statically and dynamically unbalanced conditions in propellers of the type used on airplanes; to provide an improved balancing method for this purpose by which corrections may be individually made in each blade of the propeller; and to provide a method of this kind permitting rendering identical the moment characteristics of propeller blades with respect to a corresponding reference plane of each so that one or both blades of a propeller may be removed and replaced without requiring the assembled propeller to be rebalanced or even necessitating an investigation of its balance.

Other objects include subjecting a propeller blade blank or a propeller blade or portions thereof to certain heat treatments prior to, during, or after various operations thereof in the process of manufacture whereby to maintain the structure and/or physical properties of the material thereof in the desired state during the manufacture and to result in a finished article having the desired qualities and structure of material therein.

Other objects include the provision of a propeller blade having a thickened shank portion provided with a securing flange; to provide a novel method of forming a flange on the shank end of a propeller blade blank; and to provide a method of forming a flange on the shank end of a propeller blade blank including first thickening the metal of such end and then gradually working the extremity of such end outwardly whereby to

form a flange without distorting the flow lines of the metal from which the flange is formed.

Other objects include the provision of a method and means for accurately locating the center of mass of a propeller blade on the longitudinal axis of the blade; and the provision of a method of accurately forming the portion of a propeller blade to be received in the hub of a propeller blade in accurate conformance with the axial line of the blade.

Further objects include a method of obtaining a predetermined condition of balance of a hollow metallic propeller blade by applying material to the interior surface thereof; the method of obtaining such balance by applying a paint-like or similar material to an interior surface thereof; and the method of obtaining such balance by applying such material to the interior of the blade through an opening in a wall of the blade.

The above being among the objects of the present invention, the same consists in certain novel features of construction of a propeller blade and/or a blank therefor, and apparatus for producing and/or testing such blade and/or blank, and methods and/or processes and/or steps of methods and/or processes capable of use during one or more of the phases of operation involved in the production of such blade and blank, as above pointed out, or as will be more specifically brought out in connection with the following description, reference being had to the accompanying drawings forming a part thereof.

In the accompanying drawings which illustrate suitable embodiments of the invention herein involved, and in which like numerals refer to like parts throughout the several different views,

Figure 1 is a side elevational view of a completed propeller blade of a type with which the present invention deals.

Fig. 2 is a transverse sectional view taken through the body of the propeller blade shown in Fig. 1 as on the line 2—2 of Fig. 1.

Fig. 3 is a side elevation, and Fig. 4 is an end elevation, of a tube of the type which preferably forms the initial piece of stock from which the airplane propeller of the present invention is finally formed.

Figs. 5 to 13 inclusive are partially broken, partially sectioned, side elevational views, Figs. 11 to 13 being enlarged, which illustrate successive steps of operation upon one end of the piece of stock shown in Figs. 3 and 4 during the formation of a flange thereon which, after subsequent operations, will serve as means for supporting the propeller blade in a hub structure.

Fig. 14 is a side elevational view of the piece of stock shown in Figs. 3 and 4 after it has been subjected to the operation illustrated in Figs. 5 to 13 inclusive whereby a flange is formed upon one end thereof, and after it has been tapered and reduced in diameter especially at the opposite end to form a small end.

Fig. 15 is an enlarged fragmentary vertical sectional view taken axially through the small end of the piece of stock or blank shown in Fig. 14 and illustrating how the wall thickness of such end is increased during the operation of forming the small end.

Fig. 16 is a more-or-less diagrammatic sectional view taken along the axis of the blank shown in Figs. 14 and 15 and illustrating the method and apparatus preferably employed for initially sizing the interior of the blank.

Figs. 17 and 18 show the blank resulting from the operation indicated in Fig. 16, in axial sec-

tion, and illustrate successive steps of machining the interior surfaces of the small end portion thereof.

Fig. 19 is a view similar to Fig. 16 and illustrates the final step of operation in and apparatus for bringing the interior size, shape and contour of the blank into conformance with a predetermined standard.

Fig. 20 shows the blank resulting from the operation indicated in Fig. 19, in axial section, and mounted upon a mandrel for the purpose of testing the accuracy of its internal dimensions.

Fig. 21 is a more-or-less diagrammatic fragmentary plan view, illustrating the blank indicated in Fig. 20 mounted upon a mandrel in a lathe and in the process of having its exterior surface machined.

Fig. 22 is a transverse sectional view taken on the line 22—22 of Fig. 21.

Fig. 23 is an enlarged fragmentary sectional view of the small end of the blank after it comes from the lathe indicated in Figs. 21 and 22, and illustrating the apparatus employed for closing the small end of the blank and before such apparatus has acted upon the blank.

Fig. 24 is a view similar to Fig. 23 but illustrating additional apparatus employed in the closing of the small end of the blank and illustrating the small end of the blank after one of the initial closing operations thereon.

Fig. 25 is a view similar to Fig. 23 and illustrating the small end of the blank after a further closing operation thereon.

Fig. 26 is a view similar to Fig. 25 and showing the small end of the blank after it has been completely closed.

Fig. 27 is a partially broken, partially sectioned side elevational view of the blank, after it has had its small or nose end closed as indicated in Fig. 26, mounted upon a pair of knife edges for the purpose of determining the position of the possible heavy side thereof.

Fig. 28 is an enlarged transverse sectional view taken on the line 28—28 of Fig. 27.

Fig. 29 is a more-or-less diagrammatic reduced vertical sectional view taken centrally through a furnace in which the blank in the form illustrated in Figs. 27 and 28 is shown positioned, and which furnace may be employed for heating the blank to condition it for subsequent pressing operation and/or for heat treating the blank.

Fig. 30 is a fragmentary perspective view of an improved forming apparatus preferably employed for pressing the blank indicated in Fig. 29 to blade shape, showing parts thereof removed to disclose the underlying structure.

Fig. 31 is a horizontal sectional view taken centrally through the forming apparatus as on the line 31—31 of Fig. 32, showing the dies thereof in closed position and illustrating the manner in which the blank is mounted and internally supported.

Fig. 32 is a vertical sectional view taken on the line 32—32 of Fig. 31.

Fig. 33 is a fragmentary partially broken top plan view of the apparatus illustrated in Fig. 31, a portion of the upper wall having been removed to disclose the cooling medium passages therein.

Fig. 34 is a front end view of the forming apparatus showing the die holders and dies in their adjacent closed position.

Fig. 35 is a transverse vertical sectional view taken on the line 35—35 of Fig. 31.

Fig. 36 is a front end view, similar to Fig. 34,

but showing the die holders and dies spread apart and the blank supported between the dies in spaced relation to both thereof.

Fig. 37 is a fragmentary vertical sectional view taken on the line 37—37 of Fig. 33.

Fig. 38 is a fragmentary perspective view of a quenching apparatus into which the forming apparatus above disclosed may be conveniently converted by the addition of accessory equipment and showing a further development of this phase of my invention.

Fig. 39 is a front end elevation of the structure in Fig. 38.

Fig. 40 is a fragmentary longitudinal sectional view taken vertically through the center of the structure shown in Figs. 38 and 39, as on the line 40—40 of Fig. 39.

Fig. 41 is a fragmentary enlarged side elevational view of the tip of the propeller blade showing the drainage or vent opening provided therein.

Fig. 42 is a fragmentary side elevational view of the shank end of the blade illustrating an initial machining operation upon the flange thereof.

Fig. 43 is a side elevational view of the propeller blade illustrating the procedure preferably employed in determining the center line or axis of the blade which is to pass through the center of mass of the blade.

Fig. 44 is a side elevational view of the apparatus preferably employed for determining the final location of the flange at the root of the blade with respect to the center of mass of the blade, a fragment of a propeller blade being shown mounted therein.

Fig. 45 is a sectional view taken on the line 45—45 of Fig. 44.

Fig. 46 is a plan view of the apparatus shown in Fig. 44.

Fig. 47 is a side elevational view of the apparatus of Fig. 44 in a vertical position.

Figs. 48, 49 and 50 illustrate the positions at which metal may be removed from the flange of the blade, shown enlarged, in order to bring the final position of the flange into predetermined accordance with respect to the center of mass of the blade as determined by the apparatus illustrated in Figs. 44 to 47, inclusive.

It will be understood that in the following specification and its reference to the accompanying drawings, a plurality of steps or series of steps of operation have been shown and disclosed which have been found, when combined with each other, to result in certain economies in production and desired accuracy and quality in the resultant blade produced. However, it is not to be understood that the invention, in its broader aspects, is to be limited to the employment of all or even substantially all of such steps or series of steps of operation throughout the manufacture of a propeller blade, for many of such steps or series of steps of operation are, in and of themselves, novel and constitute a separate and distinct part of the present invention regardless of any other step or series of steps of operation that may lead up to or may follow such particular step or series of steps of operation. Accordingly, it will be understood that wherever, in the following specification, a particular step or series of steps of operation is capable of being employed independently of any other steps or series of steps of operation, such step or series of steps of operation is, in and of itself, to be considered a complete invention, separate and

distinct from any other feature or features of operation disclosed herein, and is to be so interpreted in the claims except where otherwise apparent. Likewise a propeller blade is shown and described consisting as a whole of various parts or elements. While the features shown combine to make a desirable propeller, the invention is not confined to all details shown as combined, but the various features or phases of the propeller blade may comprise inventions and may be used alone or in other connections or without all the other features or phases illustrated.

Referring now to Figs. 1 and 2 of the drawings, a propeller blade of the type particularly adaptable to the practices of the present invention, is shown. This propeller blade is of hollow construction, and preferably formed of steel, and includes a main body portion 100 having a tip 102 at one end thereof and a shank portion 104 at the opposite end thereof. Although, in accordance with the broader aspects of the present invention, the particular means provided in connection with the shank portion 104 for aiding in securing the propeller blade in a hub structure (not shown) is more or less immaterial, a preferred form of such means is shown in Fig. 1 in the form of a single outwardly extending annular flange 106 at the root end of the shank portion 104. It will also be understood that the main body portion 100 of the propeller blade is generally of airfoil section, and provided with a leading edge 108 and a trailing edge 110, and has a front or camber face 110a and a rear or flat face 110b, and that preferably the main body portion 100 is more or less twisted or warped over its length in order that each increment of the length thereof has substantially the same pitch as any othersuchincrement. The hollow type of propeller blade is preferred generally for the reason that when properly constructed, it provides maximum strength for a given weight. While all phases of the invention are not confined thereto, the following description will deal solely with the preferred form and manner of making the propeller blade shown in Figs. 1 and 2. It may also be noted that although the propeller blade shown in Figs. 1 and 2 may be constructed of material other than steel, the following description will deal solely with the construction of such blade made from steel, and should it be desired to form such a blade from material other than steel, those skilled in the art will readily recognize such variations or changes in the methods hereinafter described as will be necessary in such cases.

In Figs. 3 and 4 is shown the piece of stock or blank 112 which forms the starting point for the manufacture of the blade shown in Figs. 1 and 2. This piece of stock or blank 112 is a cylindrical steel tube of suitable length and of an external and internal diameter slightly larger and smaller than the respective external and internal diameters of the finished blade respectively at a point adjacent the outer end of the shank portion 104. Of course, in the broader aspects of the invention, the particular composition of the steel employed may vary in accordance with the desire of the particular designer or manufacturer, but for the purpose of illustration in the present case, will be considered to be of that type known as 4130-X, the composition of which is well known to those in the industry and is disclosed, as for instance, in the S. A. E. Handbook published by Society of Automotive Engineers, Inc., 29 West 39th Street, New York, New York. Another composition of steel disclosed in said S. A. E. Hand-

book and known as 6135 is also suitable for the blank 112, as are many others there disclosed.

Preferably, the first operations upon the blank 112 are in connection with the formation of the shank 104 and flange 106, as disclosed in Figs. 5 to 13, inclusive. The first of these operations, as indicated in Fig. 5, include placing one end of the blank 112 in a die structure, indicated generally at 114. This die structure is provided with an opening 116 therein, which relatively closely embraces the circumference of the blank 112 at one end of the die structure and beyond such end of the die structure the opening is enlarged in diameter in concentric relation with respect to the opening 116, as at 118, this portion being joined to the opening 116 through a tapered shoulder portion 120. In positioning the blank 112 in the die structure 114, as illustrated in Fig. 5, the left hand end of the blank 112 is preferably located slightly inwardly or to the right from the left hand face of the die structure, and the blank 112 is suitably anchored against movement to the right, as indicated in Fig. 5. As indicated in Fig. 5, there is employed a ram 122 of a diameter to be freely received within the enlarged portion 118 of the opening in the die structure 114, and thereby to be guided therein. The ram 122 is provided with a pilot extension 124 of slightly smaller outside diameter than the internal diameter of the blank and which accordingly provides a shoulder 126 at the junction of the ram and pilot 124. The pilot 124 is entered into the bore of the blank 112 and the body of the ram 122 is entered into the opening 118 a sufficient distance to bring the shoulder 126 into contact with the corresponding end of the stock 112 and sufficient pressure is exerted upon the ram 122 to cause the corresponding end of the blank 112 to be upset and thereby cause it to conform externally to the walls of the opening 118 and of the shoulder 120, and internally to conform to the diameter of the pilot 124. This operation forms an enlarged cylindrical portion 106a which eventually will provide the flange 106, and an outwardly tapered portion 104a which when brought to completed form will provide part of the shank portion 104. This end of the blank is, of course, preferably previously brought to a forging temperature, approximately 2200° F. in the case of the particular steel disclosed, for the purpose of subjecting it to this step of operation.

Upon completion of this operation, the blank 112 is removed from the die structure, and the upset end thereof is again brought to forging temperature and again placed in a die structure similar to the die structure 114, to be again acted upon by a ram similar to the ram 122. The only difference is that in this case the opening in the die structure which corresponds to the opening 118 in Fig. 5 is of greater diameter than the opening 118, while the opening in the die structure corresponding to the opening 116 in Fig. 5 is the same as in Fig. 5, and accordingly the length of the shoulder in the die structure corresponding to the shoulder 120 in Fig. 5, is correspondingly increased. The diameter of the ram in this case, corresponding to the ram 122, is of course increased in accordance with the increase in diameter of the opening in which it is to be received, and the diameter of the pilot corresponding to the pilot 124 in Fig. 5 is slightly reduced over the diameter of the pilot 124. With the modified die structure and ram the upset end of the blank 112 is again acted upon in substan-

tially the same manner as described in connection with Fig. 5, the result being substantially as indicated in Fig. 6; that is, the external diameter of the portion 106a is increased, and the internal diameter is decreased over that indicated in Fig. 5, and the length of the tapered shoulder 104a is increased, while the length of the end operated on is somewhat decreased.

The upset end of the blank 112 may be then again heated to forging temperature and may be again subjected to the action of apparatus similar to that disclosed in Fig. 5 to further increase the diameter of the portion 106a and the length of the shoulder 104a and decrease the internal diameter of the blank over the length of these portions so as to bring this end of the blank into substantially the form indicated in Fig. 7. This end of the blank 112 is subjected to as many repetitions of this type of operation as is deemed necessary to bring this end of the blank into approximately the condition indicated in Fig. 8, having proper regard to the grain structure and flow lines of the grain of the metal in such end. For this latter reason it will be apparent that, although the end of the blank as indicated in Fig. 3 could be brought to the condition illustrated in Fig. 8 in a single operation instead of a plurality of operations as disclosed, the grain structure of the metal in such case might be adversely affected and the flow lines of the grain of the metal might be unduly distorted from the viewpoint of obtaining maximum strength in this portion of the final product. By following out a suitable number of operations as described, it is possible to maintain substantially the same grain structure and grain flow lines as occur in the original piece of stock or blank 112.

When the blank 112 reaches the form indicated in Fig. 8, the tapered shoulder portion 104a has assumed substantially the form and size of the shank portion 104 in the finished blade, its size of course being slightly larger for the purpose of leaving sufficient stock thereon to clean it up in subsequent machining operations. The thickness of the portion 106a at this stage of operation is substantially greater than the thickness of the flange 106 in the final product. The internal diameter of the blank over the length of the portions 106a and 104, as indicated in Fig. 8, has been reduced sufficiently so that upon removing the excess metal from the interior of the blank at this point to bring it into conformance with the diameter of the main body portion of the blank, any roughness or other imperfections which may have appeared on the interior of the blank at this point during the upsetting operation will be fully removed.

It will be understood that the exact sizes or proportions indicated in the drawings are not essential and that the deformation of the end of the blank 112 and at other points in the operation may be carried out to whatever extent is desired or expedient to produce the desired propeller blade or blank.

The next steps of operation deal with the outward bending of the portion 106a so as to form a blank, as indicated in Fig. 11 from which the flange 106 may be formed. These steps of operation include preferably three or more steps as indicated in Figs. 9, 10 and 11 in which the portion 106 of the blank, as indicated in Fig. 8, is gradually bent outwardly with respect to the axis of the blank until the metal of such portion is brought into a plane perpendicular to the axis of the blank as indicated in Fig. 11. These

operations are preferably not of an upsetting character but consist rather of an outwardly bending or belling of the portion 106a so as not to disturb the grain structure or grain flow lines of this portion and, of course, are preferably conducted while this portion of the blank is at about forging temperature. The operation may be performed in any suitable number of steps. The final step of operation in bringing this end of the blank to the form indicated in Fig. 11 may, if necessary, include a certain amount of forming, as distinguished from pure bending or belling, in order to obtain the desired contour of this end. The entire procedure may be effected by any desired suitable known means which are not shown.

The next operation, which is illustrated in Fig. 12, consists in mounting the blank 112 in a lathe or other suitable structure in which the blank may be accurately centered and by means of a tool such as 128, turning the periphery of the flange portion 106 into a cylindrical form concentric with the axis of the blank 112.

This end of the blank 112 is then accurately centered, as by means of a stead rest 130, in a lathe or other structure and the excess metal in the bore formed during the upsetting process disclosed in Figs. 5 to 8, inclusive, is then removed, as by means of a tool such as 132 where the amount of metal to be removed is relatively large, or by other suitable means, so as to bring this portion of the bore into accurate conformance with the initial bore of the blank, and then this portion is ground, buffed or otherwise acted upon to bring the internal surface thereof into smooth, polished and unbroken relation with respect to the bore of the main body portion thereof. The manner of forming the flange described in connection with Figs. 5 to 13, inclusive, has been found to be a practical way of providing a flange on the tube, but the decreasing of the internal dimensions of the blank during the flange forming operation and subsequent removal of the excess metal of the bore at this end of the blank is not my invention and may be eliminated if desired or other suitable flange forming operations may be adopted in the place of that described. The above described method of flanging the blank forms the subject matter of my application for Letters Patent of the United States for Improvements in method of flanging metal tubes, filed January 27, 1937, Serial No. 122,631, the same constituting a division of the present application.

The next step of operation is in connection with inwardly tapering especially the end of the blank 112 opposite the flange 106 to form a small, nose or tip portion 134 as indicated in Fig. 14. This operation upon the blank may be conducted by one or more suitable swaging or other operations well known to those skilled in the art, and while the operation may be a cold swaging operation in whole or in part, particularly in the final stages, the blank or such end of the blank is preferably repeatedly brought to a forging temperature so as to maintain the plasticity of the metal during the operation and maintain the proper grain structure and grain flow lines of the metal. One commercial way to produce this taper is by the use of clapper dies, using several dies and gradually getting the tapered shape in several passes in the dies. While the taper is especially noticeable toward the small or nose end of the blank it may be tapered slightly throughout substantially its entire length. In addition, it is

preferable to normalize and pickle the blank before beginning these operations, and, if necessary, one or more times during the tapering process. Also, before the final tapering operations on the nose portion 134, it is preferable to normalize, pickle and straighten the blank. The normalizing treatment in the case of the particular steel specified as by way of example may be to raise the temperature of the blank to 1625-1675 degrees F. in a suitable furnace, holding the temperature at this value for approximately twenty minutes, and then shutting off the heat and letting the blank cool in the furnace until its temperature falls below 1200 degrees F. when it may be removed to cool in the air or for further operations about to be described.

As will be apparent to those skilled in the art, such operation upon the end of the blank 112 to form the nose portion 134 may result in a thickening of the wall of the blank of this portion in somewhat the manner indicated in Fig. 15. Such operation upon the end of the blank to form the nose portion 134, due to the crowding in of the metal thereof, may cause folds, wrinkles or other imperfections to develop upon the inner surface of the nose portion 134 of the blank 112.

After the above described operation the internal shape, size and contour of the blank 112 is approximately but of slightly smaller dimensions than that desired in the completed blank immediately prior to pressing it to blade formation, and the following steps of operation upon the blank are preferably those dealing with the bringing of the internal size, shape and contour of the blank into exact conformance with that desired in the completed blank, and the preferred method of accomplishing this result will now be explained in detail.

The bed 136 of a suitable power press or bull dozer is provided with an opening 138 therein. One end of the opening 138 is enlarged as at 140 in order to receive the die insert 142 therein. The die insert 142 is provided with a central opening concentric with the opening 138 and formed complementary to the tapered shoulder 104 of the blank 112 and the blank 112 is inserted therein in the manner illustrated in Fig. 16 with the face of the flange 106 resting against the face of the insert 142 so as to take the force of the stretching operation. The ram 144 of the power press has secured thereto a mandrel 146, the size, shape and contour of which conforms exactly to the predetermined internal size, shape and contour of the desired finished blank and which, accordingly, is slightly larger than the interior size, shape and contour of the blank 112 in the condition in which it is represented in Fig. 14. The mandrel 146 is preferably tapered over the main body portion thereof a slight amount to give greater ease in inserting and removing it from the blank. A ring or spacing washer 148 is preferably placed about the mandrel 146 and against the shoulder formed at the junction between the mandrel 146 and ram 144 for the purpose of relieving this shoulder of any wear that might otherwise occur in subsequent operations and for accurately controlling the amount of penetration of the mandrel into the blank. In addition, for use in connection with the first operation of the mandrel 146 upon the blank 112, a supplementary ring or spacing washer 150 is employed in conjunction with the ring 148. The length of the mandrel 146 is preferably such that when the ring 148 contacts with the surface of the flange 106, the mandrel 146 will have been forced fully home in the blank 112.

Consequently, in the initial operation of the mandrel 146 upon the blank 112, the ring 150, which for blank forming blades of usual sizes is preferably in the neighborhood of one-half of an inch thick, will permit the mandrel to be forced into the blank only to within this distance of its final position.

Before any attempt is made to force the mandrel 146 into the blank 112 by the power press, the exterior of the mandrel 146 is preferably coated with white lead and graphite or other suitable lubricant, and then the mandrel 146 is forced into the blank 112 to the position indicated in Fig. 16. In forcing the mandrel 146 into the blank 112 as illustrated in Fig. 16 which operation is conducted while the blank 112 is cold, that is, not artificially heated, the mandrel causes the blank to be stretched until its internal size, shape and contour is forced to conform to the external size, shape and contour of the mandrel, and ordinarily this causes the blank to be stretched both radially and axially. It may be noted that, because of the reduced dimensions of the nose portion 134 of the blank and because of the increased wall thickness of this portion produced during the nose forming operation, ordinarily very little stretching of the nose portion 134 will be caused by the mandrel 146 and consequently when once the nose portion of the mandrel 146 contacts with the nose portion 134 of the blank, further inward movement of the mandrel 146 will tend to stretch the blank longitudinally or axially. Under such circumstances should, for any reason, any portion of the interior wall surface of the body portion of the blank 112 be not in firm contact with the outer surface of the mandrel 146, the subsequent axially stretching of the blank 112 as the mandrel 146 is forced in will tend to cause a radial contraction of the blank which, in most cases, will bring substantially all portions of the interior wall into contact with the surface of the mandrel, and consequently remedy this undesired condition. It may also be noted that inasmuch as this operation is designed to initially and permanently size the interior of the blank, the material of the blank must ordinarily be stretched beyond its elastic limit by the movement of the mandrel so that the effect of such stretching will be permanent.

The next operations are concerned with bringing the interior size, shape and contour of the nose portion 134 of the blank 112 into accurate conformance with a predetermined standard. It has been explained above that ordinarily this is impractical by the use of the mandrel 146 alone for the reason that the nose portion 134 is of reduced diameter and of increased wall thickness, but it will be apparent that in any case the mandrel 146 would not in all cases remove any folds or wrinkles on the interior surface of the nose portion 134 that may have appeared during the nose forming operation referred to in connection with Fig. 14. Consequently, in order to be absolutely sure that no folds, wrinkles or other defects remain and that the interior size, shape and contour of the nose portion 134 will accurately conform to a predetermined standard, it is subjected to one or more reaming operations in which metal is actually removed from the interior surface of the nose portion 134.

Such removal of metal from the interior surface of the nose portion 134 is conveniently accomplished by the employment of formed reamers such as the reamer 152 illustrated in Fig. 17 and

the reamer 154 illustrated in Fig. 18, the reamer 152 being illustrated as a roughing reamer and the reamer 154 being illustrated as a finishing reamer, but it will be apparent that as many reamers of this type may be employed for completing the operation as is found to be necessary or desirable, at least the final reamer being shaped and operated to produce the exact shape and size finally desired in the nose portion of the blank.

By these operations the interior size, shape and contour of the nose portion 134 is brought into accurate conformance with the predetermined standard desired in the finished and completed blank and corresponding to the size of the tip of the mandrel 146. The blank 112 is then replaced in the press apparatus illustrated in Fig. 16, omitting the collar 150 as illustrated in Fig. 19, in unheated condition, and then the mandrel 146 is again forced home in the blank 112. With the ring 150 omitted the mandrel 146 may be forced completely home in the blank. The tip of the mandrel seats on the correspondingly formed interior of the nose portion of the blank and as it is thrust in, operates on the main body of the blank between the nose portion and the flange 106 which is held immovable by the block 142. This operation causes sufficient stretching of the blank in either a radial or axial direction, or both, to bring the entire interior surface of the blank into contact with the surface of the mandrel and so into the size, shape and form desired in the finished blank and as governed by the exterior size, shape and contour of the mandrel 146. Since the stretching is beyond the elastic limit of the metal the final form will be substantially retained. It will, of course, be understood that this operation, like the operations illustrated in Fig. 16, is preferably accomplished while the surface of the mandrel 146 is well lubricated as, for instance, with a mixture of white lead and graphite. Because of the irregular form of the original tube it may be that parts of it will not need stretching to assume the size of the corresponding portion of the mandrel but the mandrel is forced into the blank with sufficient pressure to stretch beyond the elastic limit the metal of those portions which are deformed with the result that after the mandrel is removed the interior of the blank remains substantially the size of the mandrel throughout its entire area. After this operation, the tube 112 is preferably again subjected to a normalizing treatment and again pickled.

The blank thus produced is then inspected for the purpose of determining whether it will be capable, upon further operations, of producing a perfect completed blank. This inspection may involve the checking of all the external dimensions of the blank and rejecting all of such blanks as do not have enough metal on their exterior surfaces to properly clean up when the blank is externally machined to size. Enough metal being assured on the exterior surfaces of the blank for such purposes, the interior surface of the blank is then thoroughly cleaned and visually inspected and all blanks having obvious defects internally thereof, such as holes, seams, folds or reamer marks making them unfit for use, are then rejected. In the absence of such defects the blank is then inspected to insure that its interior size, shape and contour sufficiently closely conform to the predetermined standard desired to be acceptable for further operations. This is preferably accomplished by the use of another mandrel, such as 156 in Fig. 20, which is identi-

cal to the mandrel 146 in exterior size, shape and contour. The mandrel 156 is preferably first well lubricated as with white lead and/or graphite and is forced into the blank 112 under a pressure which, although not sufficient to permanently distort the blank, is sufficient to insure complete and accurate positioning of the mandrel therein. A suitable pressure will be adopted by one versed in the art. It may be desirable to employ in the neighborhood of two hundred tons for a blank of ordinary size. This having been done, it is then possible, by tapping the surface of the blank by suitable means such as a hammer 158, to determine if there are any areas of the blank which are not in full contact with the surface of the mandrel 156 and, if not in contact, the relative expanse of such area. If such area is present and the extent thereof too great to be acceptable, the area may be marked and then subjected to a swaging or other operation to reduce this particular portion of the blank and the blank again subject to the operation illustrated in Fig. 19 which will generally remedy the condition and, if remedied as determined by a repetition of the inspection steps above referred to, may then be carried on for further operations with other acceptable blanks. Each acceptable blank is then subjected to the following operation.

It will be observed from an inspection of Fig. 20 that the mandrel 156 is provided at opposite ends with center openings 160 and 162 respectively. The mandrel 156, with a blank 112 mounted upon it, as indicated in Fig. 20, is then mounted in a lathe between centers such as 164 and 166 cooperating with the center openings 160 and 162 respectively. Conventional means such as the dog 168 may be employed for rotating the mandrel 156 and blank 112 in the lathe. Suitable means are employed for removing from the surface of the blank sufficient material to bring the wall to the desired thickness as measured from the surface of the internal mandrel. The lathe itself, as indicated in Figs. 21 and 22, may be modified for the purpose of this operation and some of these modifications are as follows. The usual cross feed on the lathe is disconnected and an air cylinder 170 is mounted on the back of the usual carriage 172. A piston 174 within the cylinder 170 is connected as by means of a piston rod 176 with the main transverse carriage slide 178. An air line 180 under suitable control is connected into the cylinder 170 between the piston 174 and the forward end thereof. A forwardly extending form member or template 182 is secured, as by means of screws 184 (see Fig. 22), to the forward face of the rear member of the bed of the lathe. A stud 188 fixed to and projecting downwardly from the under surface of the main cross slide 178 is provided at its lower end with a roller 190 in the plane of the form member or template 182. When air is introduced into the cylinder 170 through the hose connection 180, the pressure of the air acting upon the piston 174 urges the main cross slide 178 toward the rear and the roller 190 into contact with the forward surface of the template 182, and upon longitudinal movement of the carriage 172 of the lathe, the cross slide 178 and parts carried thereby are caused to move inwardly or outwardly in conformance with the configuration of the forward face of the template 182. In accordance with conventional construction, a compound slide 192 is carried by the main cross slide 178 and in turn is provided with a tool post 194 in which a suit-

able cutting tool, as for instance, a tool such as 196 may be secured.

The outer face of the template 182 is so formed that the roller 190 in moving across the face thereof will cause the point of the tool 196 to follow a path in exact accordance with the external shape desired in the finished blank, and the mandrel 156 is so located between the centers 164 and 166 as to bring the blank 112 axially into such position that it will transversely correspond with corresponding faces of the template 182. In this respect, it may be noted that the guiding edge of the template 182 is so formed and located with respect to the exterior surface of the mandrel 156, and consequently the inner surface of the blank 112, that the tool 196 in being guided by the template 182 in removing stock from the exterior surface of the blank 112 will cause the walls of the blank 112 to taper from maximum thickness adjacent the shank 104 to minimum thickness at the outer end of the nose 134, the amount of taper thus provided varying according to that degree found desirable or necessary in the final product.

Accordingly, with the parts arranged as indicated and explained, the carriage 178 is run to one end of the lathe and the tool 196 is moved inwardly a sufficient distance to take a roughing cut from the exterior of the blank 112. It is locked in this position and then the longitudinal feed of the lathe is set so as to cause the tool 196 to travel over the length of the blank 112 in the path regulated by the template 182. In this manner stock is removed from the exterior surface of the blank for instance from the extreme nose end thereof up to the flange 106, but no stock is removed from the flange 106 at this stage of the operation. If necessary, additional cuts are then taken from the exterior of the blank in the manner above described until the wall thickness of the blank approaches to within a few thousandths of an inch of that desired in the final product. At this point use of the tool 196 is discontinued. A suitable hand grinder (not shown) is then employed to remove material from the exterior of the blank so as to bring the blank to its exact final wall thickness and to impart a highly smooth finish to its exterior surface. If desired, the ground surface of the blank may then be additionally polished as by buffing or the like. The dimensions thus produced may approach exactness within as little as .002 of an inch.

When the above operation has been completed, the flange 106 is roughed out, preferably not closer than one-sixteenth of an inch of finished size so as to leave ample material for finish and for use in connection with the balancing operations to be later described. This roughing out operation includes the step of breaking or beveling off the root end face of the flange 106, as at 198.

The next operation upon the blank deals with closing the nose of small end of the blank and this is preferably accomplished by the use of a spinning operation such as is indicated in Figs. 23 to 26, inclusive. In connection with the closing of the small end of the blank, it has been found desirable, although not necessary in all cases and particularly where the tip is relatively small, to increase the wall thickness of the blank at the extreme closed end portion thereof and also, although not necessary in all cases, to provide a projecting nipple about the point of closure for the reason that during pressing of the blank to blade shape a considerable amount of bending and stretching of the metal in the extreme

end portion occurs, and unless a suitable amount of metal is provided at this point, particularly where the small end of the blank is not relatively small, a crack is liable to develop in the finished article.

In carrying out this spinning operation the blank 112 being removed from the mandrel 156 is placed upon another mandrel, indicated at 200 in Figs. 23 to 26, inclusive. This mandrel forms the subject of my application for Letters Patent of the United States, Serial No. 718,573, filed April 2, 1934, the same constituting a division of the present application. This mandrel 200 does not necessarily need to contact with the blank 112 over the full length of the blank but in any case must have an end portion 202 which accurately fits and is properly centered in the inner end portion of the nose 134 of the blank. The extreme end of the portion 202 is rounded as at 204 into exact conformance with that desired for the interior surface of the end of the blank. Preferably, the end surface 204 is partially spherical in shape with a center located as at 206. After the mandrel 200 has been thus formed it is preferable to cut it down or relieve it in diameter toward the tip. This relief, which is indicated at 202a, may begin a little over an inch back from the tip and need not be very deep, as little as five thousandths of an inch having been found satisfactory. The purpose of this cut is to keep the end of the blank from actual contact with the mandrel. It has been found that when the blank is in actual contact with the mandrel it is difficult to keep the end of the blank hot enough to be conveniently and properly worked. By cutting out the mandrel as shown the blank is kept from contact therewith and the heat is not so readily conducted away from the portion of the blank which is to be spun.

The mandrel 200 with the blank 112 thereon is then mounted in a suitable lathe or other turning machine which may include, as indicated in Fig. 24, a bed 208 upon which is longitudinally movable a main slide 210 upon which is supported a compound slide 212. The nose end of the blank may be suitably supported as by a steady rest 214, care being taken in adjusting it to allow for any subsequent expansion of the blank which may occur due to heating the tip thereof for the spinning operation. A stop 216, as indicated in Fig. 24, is preferably provided for engagement with the slide 210 so as to limit movement of the carriage 210 and consequently the pivotal axis 218 of the compound slide 212 to the left as viewed in the figure. The stop 216 is preferably adjusted and fixed so that the pivotal center 218 of the compound carriage 212, and consequently the spinning tool 220 carried thereby, may be limited in its approach toward the center 206 of the end surface 204 of the mandrel by a distance indicated in Fig. 23 at 222 equal to the added wall thickness desired for the extreme tip portion of the blank 112.

In operation, and referring now to Fig. 24, the mandrel 200 and blank 112 are rotated in the lathe and flame from a torch such as 224 is played upon the end portion of the blank 112 to bring it to a suitable condition of plasticity as for instance that indicated by a bright red coloring of the metal at the nose or tip. The carriage 210 is moved to the right until the pivotal axis 218 of the cross slide 212 is spaced a distance such as 226 outwardly from its predetermined final position as determined by the stop 216, and

the spinning tool 220 is thus brought to a position such that when it is swung about the axis 218 it will engage only the extreme end portion of the nose 134 of the blank 112. As soon as the heat from the flame of the torch 224 has brought the extreme end portion of the blank to a sufficient condition of plasticity, as above described, the compound carriage 212 and the tool 220 carried thereby is swung about the axis 218, preferably in a counter-clockwise direction as viewed in Fig. 24, and the tool 220 thus coming in contact with the extreme end portion of the nose or tip causes it to be spun in as indicated in Fig. 24. The main slide 210 is then moved a short distance to the left, as viewed in the figures, until the distance 226 in Fig. 24 has been reduced, for instance, to a distance indicated at 228 in Fig. 25 at which time the tool 220 is again swung around the pivotal axis 218 to spin the extreme tip of the blade further inwardly as indicated in Fig. 25. This movement of the main slide 210 carrying with it the spinning tool 220 is repeated as many times as is desirable or necessary, taking care that each pass of the tool 220 is an "easy" pass so as to insure a smooth flow of the metal of the tip, and until the carriage 210 has finally been brought up against the stop 216 and the tool 220 has caused the outer surface of the extreme tip of the blank to be spun into a semi-spherical surface merging smoothly with the outer wall of the nose 134 of the blank 112 as indicated in Fig. 26. Toward the end of the operation one of the passes of the tool 220 will go past the center of the blank thus ensuring a complete a closure of the end as possible. An excess of metal is provided in the end of the blank so that the tip wall may be somewhat thicker than the immediately adjoining part. After the tip has been closed the last pass of the tool 220 is restrained from passing center and so manipulated as to raise at the extreme end of the blank a small nipple 230 as clearly indicated in Fig. 26. It is understood, of course, that the flame from the torch 224 continues to play against the tip end of the blank during these operations and may keep such end at such temperature that when the end is finally closed, as indicated in Fig. 26, the metal of the tip may weld itself together at the line or point of closure.

The thickened end portion surmounted by the nipple 230 reinforces the end of the blank so that it may not break open under the stresses produced when the blank is deformed into the blade form in the pressing dies to be described. Upon completion of the closing operations on the end of the blank the newly closed end portion of the blank is preferably polished and buffed so as to bring it to the same condition of finish as the main body portion of the blank.

The next operation is to normalize the newly formed tip portion of the blade to restore its proper grain structure and this step may be conveniently accomplished by heating the tip end of the blank to about 1625° F. to 1675° F., in case of the particular metal specified, and allowing it to slowly cool in a sand box to below 1200° F. In order to avoid surface disturbance during this operation the blank may be coated with some such protective material as Kemick. After the tip has been normalized in this manner the length of the blank is then checked and any blank whose length is obviously too great or too small to be acceptable in the final product is rejected.

The acceptable blanks are then placed singly in the device shown in Figs. 44, 45 and 46 to determine whether or not it will be possible to form the finished flange 106 out of the material provided therefor in the blank as thus far formed, and still maintain the proper moment in the finished blade as measured from the tip face of the finished flange 106. The method of determining this fact with the apparatus indicated in Figs. 44, 45 and 46 will be fully apparent in the description which will follow later in regard to locating the tip face of the flange 106 with respect to the center of mass of the blade, and consequently a detailed description of this apparatus and the manner of employing it to determine the question of sufficiency of stock in the rough flange 106 will not be given at this point. It may be mentioned, however, that should such apparatus indicate that there is not sufficient stock in the rough flange 106 for this purpose, and it is not possible to buff down the outer surface of the blank so as to sufficiently shift the center of gravity of the blank to remedy this defect, as is possible in some cases, then the blank is rejected.

The next operation is to determine whether or not the blank is heavier on one side or the other and, if so, to mark the heavy side. If necessary, the blank may be straightened before proceeding. Whether or not the blank has a heavy side is determined by mounting it upon a pair of horizontal spaced parallel knife edges 232, as indicated in Figs. 27 and 28, the heavier side, if any, of course coming to rest at the bottom of the blank on the knife blades, and the flange 106 is then marked to indicate the heavy side for reasons which will hereinafter be apparent. In cases where such blanks are in quantity production, it is also preferable at this point to stamp the serial number and the blank number on the outside diameter of the flange 106 so as to enable later identification.

After the above operation the blank is then weighed again to again check its accuracy and to insure that it comes within the permissible limits of weights necessary to produce satisfactory final blades, and if found to be satisfactory, it is then subjected to a suitable treatment to remove all rust, grease or other foreign matter from both inner and outer surfaces. This cleaning operation may be accomplished, as a matter of illustration, by the use of a product commercially known as "Deoxidine" and placed on the market by the American Chemical Paint Company, of Ambler, Pennsylvania. After the blank has thus been thoroughly cleaned, it is coated inside and outside with a material designed to keep its surface clean and to prevent oxidation and decarburization of its surface under the influence of heat, and then placed in a furnace. Such coating material may, for instance, be coal oil but I prefer to employ a material particularly prepared for such purpose and commercially produced and marketed under the name of "Kemick" by the American Chemical Paint Company, of Ambler, Pennsylvania, and which is more-or-less in the nature of a paint and is similarly applied. The blank, especially when so protected, may be heated in any suitable type of furnace, heated in any suitable or conventional manner and capable of simultaneously receiving one or more blades therein, for further manipulation.

One suitable type of such furnace is indicated in Fig. 29 by way of illustration only. As indi-

cated in this figure, the furnace is shown as having refractory walls 234 and a central opening 236 in the top thereof in which is received and supported a suitably sized tube 238 closed at its bottom and open at its top. Brackets 240 are secured to the inner surface of the tube 238 a suitable distance downwardly from the top thereof, and by means of these brackets the blank 112 may be suspended vertically by inter-engagement of its flange 106 therewith, in generally spaced relation with respect to the sides of the tube 238 and in such a position that there is no possibility of setting up stresses in the walls of the blank which might cause distortion of the blank so that it would not properly align with the die depressions in the operations hereinafter described. A cover member 242 is preferably placed over the upper end of the tube 238 during the heating process so as to prevent possible circulation of air in the tube 238 and blank 112. A suitable flame may be introduced into the furnace 234 as by means of a tube 244 which projects through the walls of the furnace adjacent the bottom thereof and the products of combustion may be exhausted from the furnace as through a tube such as 246 positioned adjacent the top of the furnace, so as to insure an even heating of the tube 238 and the blank 112 contained therein. The blank 112 is allowed to remain in the furnace for a sufficient length of time to bring its temperature up to that suitable for forming, approximately 1625° to 1675° F. in the case of the material as previously referred to as being preferable for the formation of the blank, and after being maintained at this temperature for a suitable length of time for all of the metal to reach a substantially uniform temperature which may be, for instance, fifteen to twenty minutes, it is then removed and immediately placed in the dies which are provided for pressing the blank to blade shape, and which, as will later be described, may be further employed for the purpose of quenching the blade.

An understanding of the method followed in pressing the blank to blade shape in the dies will, however, be of aid in the proper understanding of the die structure and, accordingly, a short statement of this method is given at this point. The dies themselves form no part of the present invention but constitute the subject matter of my co-pending application for Letters Patent of the United States for improvements in Apparatus for forming propeller blades, filed July 5, 1933, Serial No. 679,134. It will be understood that the die structure includes two main parts relatively movable toward and away from each other, the adjacent faces of the parts having opposed depressions therein which cooperate, when the dies are in closed position, to form a recess of the exact shape and contour and, except preferably for the outer stages of the blade, as will be explained in greater detail, the exact size of the desired finished blade. In this connection it may be noted that in the broader aspects of the present invention the die depressions may cooperate to form a depression conforming exactly throughout to the exact size, shape and contour of the desired finished blade, but a more limited phase of my invention deals with making the outer or tip stages of the depressions wider and longer than the corresponding portions of the desired blade, this having been found desirable under certain conditions, and accordingly this last feature is shown in the drawings, the former being apparent therefrom.

In operation, the blank is taken from a furnace such as that described in connection with Fig. 29 for instance, in a highly heated condition, the die parts are spread apart, the heated blank is placed between the die parts and its interior is placed under a suitable air pressure, and the dies are then brought together, causing the exterior of the blank to assume the shape of the walls of the die depressions. The purpose of placing the interior of the blank under air pressure is to cause it to be expansively pressed outwardly into contact with the walls of the die depressions during the pressing operation, thereby insuring substantially complete contact between the blank and the walls of the depressions over the entire outer surface of the blank. The air pressure employed for this purpose, while high enough to insure the effectiveness of its purpose is, of course, not sufficiently high to endanger bursting of the walls of the blank. It has been found that an air pressure of three hundred pounds per square inch is usually ample for the purpose described, but this pressure may vary in accordance with the size and wall thickness of the particular blank being worked upon. In applying such air pressure to the interior of the blank it is, of course, necessary for optimum results that such pressure be exerted at the desired maximum value substantially immediately upon admitting the air to the blank and be maintained at such value during the operation. For this reason it is preferable to employ an air reservoir tank (not shown) in connection with the air supply and maintain the pressure in it at a sufficiently high figure to insure an ample supply of air for the operation at the desired value. An air pressure of 300 pounds per square inch is preferably employed in the blank during the pressing operation.

In any case it will be apparent in connection with this phase of operation that the temperature of the blank and the pressure of the air to which the interior of the blank is subjected have, of course, a certain relation between them, the temperature necessarily being such as to permit the necessary bending of the walls of the blank into blade formation without causing any undesirable stress or fracture of the metal of the walls and, of course, sufficiently high to insure the internal pressure of the air forcing the blank into substantial contact with all surfaces of the die depressions when the dies are brought together, but preferably a temperature not so high as to permit the expansive force of the air to stretch the metal of the blank.

In placing the heated blank between the dies, it is further desirable to maintain the main body portion of the blank out of contact with the dies until the dies are actually brought together, for otherwise any area of the blank which contacted with the dies might be cooled to such an extent that when the dies were brought together that area would have become so rigid as not to properly conform to the shape of the corresponding depression wall area of the dies. Unequal cooling might also set up undesirable unequal stresses in the metal at various points in the blank. In view of the fact that the shank portion 104 of the blank is not deformed during the pressing operation, this portion of the blank is preferably employed for supporting the blank in the dies before the dies are brought together as it thus makes little difference whether it is pre-cooled or not.

Where the dies are employed for successively

forming a large number of highly heated blanks to blade shape, by repeated contact with successive heated blanks the die parts in some cases are liable to be heated to such a degree as to become detrimental, and for this reason it may be preferable to provide suitable means for regulating the temperature of the die parts. This may conveniently be accomplished by circulating a controlled supply of water through the die parts. Furthermore, in view of the fact that a preferred later step in the manufacture of the blades is a quenching operation to harden the blade material, and a preferred method of quenching the blades is to place them between relatively cold die parts contacting substantially the entire outer surface of the blades, the same die parts as are employed for forming the blanks to blade shape may be employed in quantity production for the quenching operation if suitable means are provided for cooling the die parts. The water passages referred to above offer a suitable means for accomplishing the desired cooling of the die parts.

In the form shown in Figs. 30 to 37, inclusive, my improved propeller blade forming apparatus includes a lower block or die holder 250 which normally rests upon the lower platen of a press, and is provided with a longitudinal recess 252 which is bounded by a vertical side wall 254 and an inclined side wall 256. As indicated in Fig. 32, the die holder 250 is cored internally or otherwise suitably provided with passages 258 for circulating a cooling medium substantially throughout its entire length and breadth. As best indicated in Fig. 35, the passages 258 are provided with a communicating inlet 260 and a communicating outlet 262 which, in practice, are connected to a convenient source of water supply and drain pipe respectively.

Formed on the front corner portions of the lower die holder 250 are upright posts 264 of substantially rectangular cross-section. An upper die holder 266 having a recess 268 which is complementary to the recess 252 of the lower die holder is mounted in superimposed relation thereon. The opposite front corner portions of the upper die holder are provided with recesses 270 for slidably receiving the posts 264 of the lower die holder. The side wall 272 of the recess 268 is vertical and is located substantially in alignment with the side wall 254 of the lower recess 252, and the other side wall 274 of the recess 268 is inclined oppositely with respect to the side wall 256 of the other recess.

Seated in the recesses 252 and 268 of the die holders 250 and 266 are dies 276 and 277 respectively having longitudinally extending blade forming recesses 278 and 279 respectively formed in their opposed faces which recesses cooperate to form a single recess which conforms in size, shape, contour and pitch with the size, shape and contour, except for the nose end as will hereinafter be more fully explained, and pitch of the finished blade shown in Fig. 1 which it is desired to form. The die parts 276 and 277 are preferably split transversely of their length and intermediate their ends as at 280 and are detachably secured to their respective die holders by longitudinally extending gibs or wedge members 284 and 286 (see Fig. 35) which are held in place by bolts 288 and 290 respectively screwed into the die holders 250 and 266 respectively. The dies are held against outward or lateral displacement from the recesses by the inclined walls

thereof and by the inclined sides of the gibs 284 and 286.

By replacing those portions of the dies 276 and 277 inwardly of the line of split by portions of either greater or lesser length than those shown, the same outer die portions may be employed to produce blades of different lengths. By this means a considerable saving in die costs may be realized in the production of blades of different lengths. It may be desired to employ various butt end die sections with varying tip end die sections and the construction described makes them easily interchangeable to produce any desired combination, without the necessity of making complete dies of all the various types needed.

It will also be noted from an inspection of Figs. 31, 32 and 35 that the depressions 278 and 279 in the dies 276 and 277 are wider and longer than the corresponding portion of the blade in the outer stages thereof. This may exist for as much as sixty percent of the length of the blade toward the tip end. This is arranged by extending those surfaces of the die depressions 278 and 279 which give such portion of the blade its desired surface conformation in length, out to near the parting line of the dies, and extending the corresponding surfaces of the dies laterally to near the parting line in a tangential direction with respect to the natural radius of the respective edge portions of the blades formed therein. This permits the making of blades of various lengths with the pitch twist continuing uniformly together with the proper longitudinal and lateral conformation.

It is to be understood that except for the outer portions of the depressions 278 and 279 which may be made wider and longer than the corresponding portions of the blades to be produced thereby, as above pointed out, the perimetrical dimensions of the die depressions at any given transverse cross section through them is substantially equal to the perimetrical dimensions of the corresponding section of the blank 112 to be shaped between them, so that when the blank is pressed to blade shape, no outward stretching or inward crowding of the metal of the blank occurs, such metal being merely bent to shape.

The upper die holder 266 is internally cored or otherwise suitably provided with cooling medium passages 292 which communicate with a supply pipe 294 and a drain pipe 296 at the opposite sides of the holder.

A pair of parallel plates 298 are located adjacent the outer sides of the upright posts 264 of the lower die holder and are rigidly secured thereto by bolts 300. The plates 298 protrude beyond the forward ends of the die holders and they are provided at their outer extremities with inwardly extending cleats 302 which are secured in place by bolts 304. The cleats 302 form channel ways 306 between their inner sides and the front edges of the posts 264 in which side flanges 308 and 310 of a channel shaped support or cross head 312, having a web 314, are slidably received. As best shown in Figs. 31 and 37, the inner edge portions of the flanges 308 and 310 are provided with recesses 316 in which shoes 318, preferably comprising rectangular metal bars, are seated. The shoes 318 carry pins 320 which are received in apertures 322 formed in the posts 264 of the lower die holder 250 and the shoes are yieldably held in spaced relation to the posts 264 by springs 324 which surround the

pins 320 and are seated in recesses 326 in the forward edges of the posts and surrounding the apertures 322. These shoes 318 normally bear upon the cross head 312 urging the same outwardly against the inner sides of the cleats 302.

As best shown in Fig. 36, the entire cross head 312 is yieldably supported on coil springs 328 which are seated upon the lower press platen 330. The springs 328 normally hold the cross head 312, and the blank 112 when supported thereby, more or less centered between the dies and out of contact with both dies, as indicated in Fig. 36.

The web 314 of the cross head 312 is provided with an enlarged central opening 330 of circular contour in which a collar 332 for receiving the shank portion 104 of the tubular blank 112 is detachably mounted by screws 334. The collar 332 is provided with preferably horizontally and laterally extending slots 336 which may register with the flattened portions toward the leading and trailing edges which are formed on the resulting blade and permit the blade to be withdrawn from and through the collar during removal of the blade from the forging apparatus. The forming apparatus may be readily conditioned for manufacturing blades of various dimensions by removing the collar 332 and replacing it with a collar of suitable inner diameter and by substituting proper dies or die sections for the dies 276 and 277 shown. The cross head 312 serves as the sole support for the propeller blade blank before the dies are brought together and by reason of the elevated position in which it is held by the springs 328, it locates the tubular blank 112 in spaced relation between the dies 276 and 277 when they are spread apart and in registration with their recesses 278 and 279 and holds the blank out of contact with the dies and their supporting structures so as to prevent cooling of localized areas of the blank before compression thereof to blade shape.

In supporting the blank internally by pneumatic or other fluid pressure after it is positioned in the collar 332, it is necessary to form a communicative connection between the open end of the blank and a source of pressure in a brief time interval in order to prevent excessive cooling of the blank before the forming operation. This is successfully accomplished by providing the connecting means on a breech block 338 which is swingably mounted on a vertical breech block pin 340 that is mounted in brackets 342 on the flange 310 of the cross head 312. A relatively positive seating of the air inlet 356 on the flange 106 should be provided. This may be accomplished by a suitable washer or other contacting member, or the contacting member may be somewhat resilient. Such a resilient seating device is illustrated as provided by the syphon or bellows 346, but this may not be essential. The inner side of the breech block 338 has a recess 344 in which the outer end of a metallic bellows or syphon 346 is suitably secured in sealed relation therewith. Mounted on the inner end of the bellows or syphon 346 is a head 348 having a central protruding boss which is received in the open end of the tubular blank 112. A washer or gasket 350, preferably comprising copper or other suitable material, is provided between the flange 106 of the root end of the tubular blank and the face of the head 348 for forming an air tight seal between the head of the bellows and the flange of the blank.

Leading to the interior of the bellows 346 and formed in the breech block 338 is an aperture 352 in which a nipple of an outwardly extending valve 354 is mounted. The valve 354 communicates through a flexible connection with a source of pressure (not shown) and when open supplies air or other gas under pressure to the interior of the bellows 346 and from the latter to the interior of the tubular blank through a restricted orifice 356 in the head 348 of the bellows. The side of the head 348 within the bellows 346 is larger in area than the end of the boss which extends into the open extremity of the blank and therefore a force differential is created by the pressure on the opposite sides of the head 348 which presses the gasket 350 upon the flange 106 of the blank with a pressure of large magnitude, thus forming an effective seal at the open end of the blank. Any leakage which may occur from the interior of the blank tends to increase this force differential and accordingly increases the pressure upon the extremity of the blank preventing continued leakage. In practice, with the pressure of 300 pounds per square inch in the blank, a load of 6000 pounds may be exerted on the flange by suitably proportioning the parts referred to, thus tending to insure sufficient pressure within the blank to cause it to hug the dies when they are closed.

As best shown in Figs. 30 and 31, the breech block is releasably held in a closed position by a latch device which includes a vertical cylindrical bar 358 journaled in bearings 360 mounted on the flange 308 of the cross head 312. This bar is provided with an axially extending V-shaped groove in its surface and it is provided with an outwardly extending radial pin 362 by which it may be rotated to bring the V-shaped groove into registration with a protruding edge portion 364 on the free side of the breech block. Adjacent the projecting lip 364 of the breech block is a recess 366 in which the cylindrical portion of the bar 358 is received when the latter is held in locking position by the spring 368 engaging the pin 362. The breech block may be unlocked and swung to open position, shown in dotted lines in Fig. 31, by moving the pin 362 against the tension of the spring 368 and so rotating the bar 358 in a counter clockwise direction to allow the projecting lip 364 on the breech block to pass by the groove in the bar 358.

In operation, either the upper or lower die holders may be moved so as to bring the dies together, but the lower die holder 250 is preferably lifted vertically upward with substantial force by mechanism (not shown) of the character customarily used in die forming operations. A tubular blank 112 of the type shown in Fig. 27, having a flange 106 on its open end is heated to a workable temperature as in the manner described in connection with Fig. 29 and is lifted preferably by tongs inserted in the open end of the blank and inserted through the central opening in the replaceable collar 332 while the cross head 312, lower die holder 250 and upper die holder 266 are in the relative positions shown in Fig. 36, and while the breech block 338 is open. In order to obtain uniformity of final product and insure optimum conditions of balance in the finished product, the heavy side of the blank, if any, as determined and marked in the manner described in connection with Figs. 27 and 28, is positioned on the centerline of the dies which form the flat face 110b of the blade, these being the lower dies 276 and 278, as shown. The blank

112 is inserted through the central opening of the collar 332 until the flange 106 thereof engages the outer side of the collar and then the breech block 338 is swung to a closed position with the boss of the head 348 of the bellows 346 extending into the open end of the blank, the gasket 350 being located between the flange 106 and the head 348. The cross head, which is yieldably held in an elevated position by the springs 328, positions the blank in registration with the recesses 278 and 279 of the dies 276 and 277, and holds the blank out of contact with the dies and their supporting structure so as to prevent pre-cooling of localized areas of the blade, as previously mentioned, although it may be that, at least before the breech block is shut, the blade being more or less loosely held in collar 332, may sag so as to touch the die at its tip, but this may not be harmful as the nipple 230 or the thicker wall may prevent dangerous pre-cooling during the short period of contact if any.

Before the lower die holder 250 and die 276 are urged upwardly to compress the blank to blade shape, the valve 354 is opened so as to admit air into the bellows 346 and to supply air to the interior of the tubular blank. The pressure in the interior of the bellows is applied directly on the inner side of the head 348, holding the head in air sealing relation against the flange 106 of the blank. A pressure of 300 pounds per square inch is preferably employed where a blank of usual size is made of the ordinary range of low carbon steels and this pressure is preferably substantially immediately built up in the blank so as to internally support the latter and to hold all portions of its wall in contact with the surfaces of the recesses in the dies when the lower die is urged upwardly from the position shown in Fig. 36. The lower die, in moving upwardly, first engages the blank and rapidly moves it, together with the cross head 312, upwardly against the weight of the blank and the force of the springs 328 until the dies 276 and 277 contact with each other and the blank which then assumes its desired blade shape in the depressions 278 and 279 between them. The flanged end of the blank, of course, constantly maintains its engagement with the head 348 during movement of the cross head in the die closing operation. The closing movement of the dies is so rapid that the dies contact the entire blank at as near the same time as possible. This is desirable in order to avoid unequal chilling which might occur if there was die contact at one point before another. This rapid and complete contact makes it possible to act upon the blank while all the metal is at a temperature to be readily shaped.

As the blank cools and shrinks its tapered end is free to contract longitudinally in the tapered portions of the die recesses. The other end portion of the blank, however, is allowed to move inwardly with respect to the dies against the action of the springs 324 which yieldably hold the cross head 312, upon which the flange 106 of the blank 112 bears, in spaced relation to the adjacent ends of the die holders. In this manner, setting up of internal strains in the propeller blade during cooling thereof is minimized.

The dies and die holders may be protected from overheating by repeated contact with successive blanks, when used continuously in such pressing operations, by circulating a cooling medium through the passages 258 in the lower die holder and 292 in the upper die holder. As previously mentioned, the provision of such cooling medium

circulating passages further adapts the dies and die holders for use in a preferred subsequent quenching operation as previously mentioned.

When the pressed blank in the dies has cooled sufficiently to insure its retaining its now blade-like form, which will ordinarily be after a period of about one minute, the valve 354 is closed, the air is released from the interior of the blade, and the breech block 338 is swung back, and the blank, which is now transformed to a blade, is removed, the notches 336 in the collar 332 functioning to take care of the increase in lateral dimensions of the blade as compared to corresponding dimensions in the blank.

Blades thus received from the dies are checked for length, and are then subjected to a suitable cleaning treatment to remove all paint and scale from the outside of the blade. This cleaning operation may be conveniently accomplished in any suitable and convenient manner.

While the blades thus formed are, for the most part, in commercially acceptable form, I find it desirable, in accordance with the present invention, in order to make a more perfect product, to subject them to a heat treatment substantially as follows. The cleaned blade is now again coated with "Kemick" or the like and returned to a furnace, such as that disclosed in Fig. 29 for instance, and suspended by the flange in the same manner as previously described, and is there subjected to a heat soaking process for a sufficient length of time to evenly diffuse the carbides in the metal when carbides are present therein, or for a sufficient length of time to effect other desirable changes in the structure of the metal. The length of this soaking treating, as well as the temperature at which it is carried on will, of course, vary according to the particular metal of which the blade is formed, but for low carbon steels I have found that soaking the blade for approximately thirty minutes at a temperature in the neighborhood of 1625 to 1675 degrees Fahrenheit will suffice. This same soaking treatment not only evenly diffuses the carbides in the metals, with other usual effects to the structure thereof, but, furthermore, relieves any strains that may have been set up in the metal in the die-pressing operation.

The blade is now removed from the furnace and may again be placed while at high heat within the same dies just described, or equivalent dies, which are closed, and the blade is then subjected internally to air pressure as previously described. Air pressure in the neighborhood of 300 pounds per square inch is found to be satisfactory, although pressure of either above or below this figure, preferably above, may be employed as well. As before, a complete and rapid closure of the dies is desirable to produce the best result. This treatment not only forces out any small depressions or irregularities in the surface of the blade that may have failed to disappear in the original pressing operation, and not only will straighten the blade if the same has become warped at all in the soaking treatment due to the relieving of the strains in the metal but, more important, the air under pressure may force all portions of the blade surface into contact with the surfaces of the depressions of the dies, and in doing so causes a chilling of the metal of the blade and prevents separation and segregation of the carbides in the metal thereof, or other undesirable changes in the structure of the metal. At the same time that the main body portion of the blade is being chilled in the dies, a spray of

water may be directed on the flange 106 thereof to cause a like effect. A period of two minutes in the closed dies will usually be found ample to effect the desired chilling of the blade. While this operation of putting the exterior walls of the blade into contact with the relatively cold walls of the dies is a chilling operation on the blade, I prefer to call it a "die-quenching" operation, since the results are in all ways analogous to immersing hot steel in a cooling liquid.

This die-quenching effect on the blade serves the same purpose as conventional quenching treatments, and may be intensified, modified and/or controlled in several ways, one of which is by the provision of water passages such as 258 and 292 in the die supports 250 and 266 each provided with suitable inlets 260 and 294 respectively, and suitable outlets 262 and 296 respectively. This, or an equivalent method of cooling the dies may be found to be essential where the time element between the removal of one blade and the insertion of the next is limited, but it will be recognized that in any case the main requirement is an adequate temperature difference between the dies and the work to effect the proper quench, regardless of the method of obtaining such temperature difference. It will be obvious that it is possible to obtain any degree or rate of cooling to correspond to any degree or type of quench in various ways such as by varying the rate of passage of a multiplicity of blades through the dies, by varying the temperature of the dies themselves by either varying the rate of the cooling fluid passing through them or the temperature of such cooling fluid, and further by varying the temperature of the blank itself. Thus, a quick, simple and economical method of quenching the blank is provided.

Instead of relying solely upon a spray of water to cool the flange end of the blade during the quenching operation, as above described, it may be desirable to so modify the die apparatus as to permit a more accurately controlled cooling of the flange end of the blade. This may be conveniently accomplished by using the lower and upper die holders 250 and 266, their respective dies 276 and 277 and the pair of forwardly extending parallel plates 298, shown in Figures 30 to 37, inclusive, in conjunction with the lower and upper cross head sections 370 and 372, respectively, shown in Figs. 38, 39 and 40. The cross head sections 370 and 372 are provided with side flanges 374 and 376, respectively, which are located between the ends of the die holders 250 and 266 and the cleats 302 mounted on the front edges of the plates 298, as previously described. The cross head sections 370 and 372 are secured against vertical displacement from the lower and upper die holders with which they respectively register by dowel pins 378 mounted on the cross head sections and fitting loosely in co-operating apertures in the ends of the die holders. The loose fitting relation of the dowel pins in their apertures permits the sections to move axially of the die holders and the sections are yieldably retained in spaced relation to the ends of the die holders by the same spring shoes 318 and springs 324, as described in connection with Figs. 30 to 37, inclusive, and which normally hold the forward edges of the flanges 374 and 376 of the cross head sections against the cleats 302 on the plates 298. The weight of the lower cross head section 370 may be sufficient to keep it from rising from the lower die holder and it may not be necessary to provide the dowel pin 378 therefor.

Formed in the cross head sections 370 and 372 are complementary, semi-cylindrical recesses 380 and 382 in which are seated semi-cylindrical tubular ring segments 384 and 386 having cooling medium passages 388 and 390, respectively. The ring segments 384 and 386 are provided with complementary seats 392 and 394 for receiving the root end portion or shank of the propeller blade and they are detachably held in place on the cross head sections 370 and 372 by screws 396. The ring sections 384 and 386 are provided with inlet apertures 398 and outlet apertures 400 for permitting a cooling medium, such as water, to be circulated through the passages 388 and 390.

Formed on the side flanges 374 and 376 of the right hand side of the cross head sections 370 and 372 are hinge elements 402 and 404 on which a breech block 406 (see Fig. 39) is swingably mounted, substantially in the manner illustrated in Fig. 31. The breech block 406 and the bellows or siphon 408 which it carries, are substantially identical in construction to the breech block 338 and the bellows 346 which has been described in detail in connection with Figs. 31, 32 and 33. The bellows 408 communicate with an inlet pipe or nipple 410 of a valve 412 which is provided for controlling the admission of air to the interior of the bellows and to the interior of a propeller blade with which the head 414 of the bellows 408 registers in operation.

As will be apparent with the modified die structure just described, the rings 384 and 386 contact the face of the flange 106 and shank portion 104 of the blade and, being water cooled, may effect substantially the same degree of quenching on these portions of the blades as the main dies on the body portion of the blades.

In this arrangement the hot blade will not be initially supported by its shank so as to be held out of contact with the dies as shown in Fig. 36 since the rings 384 and 386 are not supported by the springs 328. The hot blade may then be layed directly on the lower die and the dies closed so suddenly and rapidly that uniform contact over the entire surface of the blade may be procured as promptly as possible.

The blades thus quenched are, after removal from the dies, again checked for length.

The next operation consists in a treatment for drawing the hardness of the blade material, and this is conveniently accomplished by returning the blades to a furnace, such as that described in connection with Fig. 29, and subjecting them to a heat soaking operation at proper temperature and duration. For the type of steel previously specifically referred to as an example, a temperature of approximately 825 to 1000 degrees F. for a period of thirty minutes has been found sufficient.

The nipple 230 may now be filed off and the tip of the blade inspected and polished.

As indicated in Fig. 41, the next operation on the blade is to drill a small opening 416, preferably about three thirty-seconds of an inch in diameter, through the camber wall of the blade at a point closely adjacent the tip thereof. This is for the purpose of allowing the interior of the blade to breathe in operation in response to temperature or other changes and so that any condensation of moisture that occurs within the blade and is thrown out to the tip end thereof under the centrifugal action of the propeller in operation may escape from the blade and thereby not only prevent an unbalanced condition

to be set up in the propeller due to the accumulation of unequal amounts of condensation within the opposite blades, but also to prevent any corrosion that might otherwise occur on the interior of the blade due to the presence of such condensation. The opening 416 is put in the front or camber face of the blade so that the low pressure area at such face during operation of the propeller will aid in discharging the condensation through the opening. The action of centrifugal force will prevent ingress of rain or other foreign matter during operation.

Following this operation the entire exterior surface of the blade is lightly sand blasted in order to thoroughly remove all particles of foreign material and so as to present a thoroughly clean surface. The next operation, as indicated in Fig. 42, is to insert and secure a centering spider 418 in the open end of the blade. The spider 418 has a pilot portion 420 which closely fits the interior surfaces of the blade at the open end thereof so as to accurately locate it with respect thereto. The spider 418 is then mounted on a center such as 422 in a lathe or other suitable machine and a grinding wheel or other suitable tool such as 424 is employed to just clean up the outer or tip end face of the flange 106.

The blade 100 with the spider 418 is then removed from the machine, and the blade and spider are then suspended as indicated in Fig. 43 by a flexible wire or cord 426 which is centrally located with respect to the plug 418, as for instance by passing through a central opening 428 therein (see Fig. 42). The blade is suspended in the manner indicated in Fig. 43 until it assumes a position of rest, after which a prick punch such as 430 located in substantially absolute axial alignment with the cord 426 is employed to prick mark the extreme tip of the blade 100. This procedure is not my invention but is described as a suitable step to be adopted in the manufacture of a proper propeller. By this method it is assured that a line passing through the blade 100 and including the axis determined by the prick punch 430 and the cord 426 will pass through the center of mass of the blade. Consequently, it will be apparent that if the end faces of the flange 106 are machined accurately in a plane at right angles with the line determined by the point of the prick punch 430 and the axis of the cord 426, and the blade is assembled into a completed propeller with the flange 106 located accurately in a plane parallel to a line radial to the axis of rotation of the propeller, the center of mass of the blade 100 will be on a radial line passing through the center of the flange 106 and, consequently, no bending stresses will be set up in the blade itself which might occur if the center of mass of the blade were offset from such radial line. This method of balancing will tend to eliminate the possibility of dynamic unbalance in the completed blade. The manner of accurately locating the end faces of the flange 106 with respect to the above mentioned line will be described later.

In order to maintain dynamic balance in a propeller which is made up of interchangeable blades, it is essential that the moment which the mass of each blade of the propeller creates with respect to the axis of rotation of the propeller be equal to the moment of each other blade. The moment created by a blade is a function of its mass and the distance of its center of mass

from the axis of rotation of the propeller, and therefore changes in the moment of a blade, may be produced by shifting the blade bodily outwardly or inwardly with respect to the axis of rotation of the propeller. In the present instance a standard moment is established by suitably trimming off the axial faces of the flange 106. Any suitable flange or propeller holding means may be formed on the blade or blank. The flange 106, which is shown in the present case as illustrative of one means for securing the blade in the hub of the propeller, is constructed for reception in a hub in the manner disclosed and claimed in my United States Patent #1,897,536, issued February 14, 1933, on Propeller. As illustrated in said patent the single flanges of the blades are received in complementary grooves in the hub, and as the grooves are equidistant from the axis of rotation of the propeller, the position of the flange with respect to the center of mass of the blade determines the distance of the center of mass of each blade from the axis of rotation of the propeller and consequently its moment.

The complementary grooves of the propeller hub in which the flanges of the blades are received, are accurately machined and they are accurately located at equal distances from the axis of rotation of the propeller hub. Only the axial side faces of the flanges 106 are engaged by the walls of the groove and thus either the outer or inner side faces of the flanges may be relied upon to determine the locations of the centers of mass of the blades from the axis of location of the propellers. In practice, the flange 106 is intentionally made thicker initially than the groove of the hub in which it is to be received so as to permit corrections to be made in the location of the center of mass of the blade, and the outer axial or tip end face of the flange 106 initially occurs in slightly too close proximity to the center of mass of the blade to allow the blade, as originally formed, to balance the standard moment differential of the testing apparatus. As the blanks from which the blades are formed are sized accurately both internally and externally the distribution of weight in all blades is substantially alike and therefore only slight corrections in the locations of their centers of mass are required.

In Figs. 44 to 50, inclusive, is illustrated a method and apparatus for equalizing the moments of the blades of a propeller with respect to the axis of rotation thereof. The apparatus and the method of balancing blades thereby form the subject matter of my United States Letters Patent No. 2,028,254, issued January 21, 1936 on Apparatus for balancing propeller blades, and No. 1,968,540, issued July 21, 1934 on Method of balancing propeller blades. This apparatus includes a block 432 of substantial weight having a tapering dovetailed groove 434 centrally disposed at one end which extends between and is open at the respectively opposite sides 436 and 438 of the block 432 for receiving the flange 106 of the propeller blade. The groove 434 is undercut in parallelism with the side edges thereof, as best shown in Fig. 44, the undercut portion being shaped in section complementary to the section of the flange 106 so as to removably receive the flange therein and thereby enable the blade to be secured relative to the block 432 without contact of the block with the shank of the blade.

Formed on the respectively opposite sides 436 and 438 of the block 432 are trunnions 440 and

442 which rest upon the knife edge supports 444 and 446 respectively and pivotally support the block. The trunnions 440 and 442 are in alignment with each other but they are in misalignment with the center of mass of the block 432. They are located in closer proximity to the end of the block in which the flange receiving groove 434 is formed than to the opposite end of the block. This arrangement sets up a moment differential between the portions of the block on respectively opposite sides of the axis of the trunnions 440 and 442 which is of a predetermined amplitude. The trunnions are equidistant from the top and bottom of the block and their axis lies in the central plane passing through the center of the groove 434.

A graduated bar 448 is provided on one side of the block 432 substantially in the plane passing through the axis of the trunnions 440 and 442 and the horizontal center line of the groove 434. The graduated bar 448 is offset slightly from the side of the block 432 by means of supports 449 arranged preferably at the ends of the graduated bar 448 so as to provide room for a weighted slide 450 which straddles the graduated bar 448 and may be moved longitudinally thereon. When moved toward its extreme left hand position in Fig. 44 the weighted slide 450 augments the moment differential of the block 432. When a propeller blade is mounted in the groove of the block the weighted slide 450 may be moved to the right or to the left so as to balance the propeller blade supported by the block. The scale 451 on the bar 448 may be suitably arranged to conveniently indicate changes necessary in the flange of the propeller blade to bring its moment to the desired standard. A convenient arrangement is to graduate the scale 451 in tenths of an inch and to provide a slide 450 having a weight equal to 1/100th of the weight of the blade. With this arrangement each graduation on the scale will correspond to 1/1000th of an inch variation in the location of the face of the flange 106. Thus when with the blade mounted in the balancing apparatus it is found that the weighted slide 450 has to be moved one graduation on the scale in order to produce accurate balancing it indicates that the face of the flange 106 must be trimmed 1/1000th of an inch in order to produce the desired static moment in the blade.

The weight of the block 432 and the location of the trunnions 440 and 442 thereon may be difficult to predetermine exactly and accurately. In order to aid in adjusting the moment differential and produce the condition which is desired for testing the blade, there may be provided means in the block 432 for adjusting its moment. This may conveniently consist of a bolt 452 or the like threaded into a seat 453 in the end of the block 432 opposite the groove 434. The seat 453 should preferably lie in the plane passing through the axis of trunnions 440 and 442 and the center line of the slot 434. It will be perceived that the bolt 452 may be moved in or out of its seat 453 to produce the balancing effect desired.

The description of the balancing apparatus so far relates to the use of the apparatus when the propeller is in a horizontal position and such use is important as has been indicated. Since the propeller, the adjustable bolt 452, the weight 450 and the bar 448 are all symmetrically arranged with respect to the axis of the trunnions 440 and 442, it is possible to turn the apparatus on the

knife edges 444 and 446 so that the propeller extends in a vertical direction as indicated in Fig. 47. Since the face of the flange 106 is at right angles to the axis of the propeller, the apparatus should remain at rest with the pin prick in the tip of the propeller directly under the axis of the trunnions 440 and 442 and a trial of the balancing apparatus in the vertical position thus may be a convenient method of assuring that the center of gravity of the propeller is actually in the axis determined by the pin prick.

If the blade upon testing exactly balances the standard moment differential of the apparatus, then the root end side face of the flange 106, including the beveled face 198, and the inner extremity of the blade is trimmed, as illustrated in Fig. 48, so as to produce a flange 106 of predetermined thickness without changing the location of the tip end side face of the flange. If the cut required at the tip end side face of the flange 106 is sufficient to reduce the thickness thereof to its predetermined thickness, then the root end side face of the flange 106 is left unaltered, as indicated in Fig. 49, except perhaps to more accurately dimension the beveled face 198. These two cases are not usual ones. Generally the tip end side face is trimmed off sufficiently to bring the blade into exact balance with the moment differential of the apparatus and then the root end side face and inner extremity of the blade is machined slightly, as indicated in Fig. 50, to produce a flange 106 of predetermined thickness and shape to suit the hub with which it is to be used.

It is, of course, entirely possible to employ the root end side face of the flange 106 as the reference plane for determining the location of the center of mass of a blade from the axis of rotation of a propeller hub in which the blade is to be mounted. Under these circumstances the root and side face of the flange 106 is machined first during modification of the flange to bring the blade into balanced relationship with a standard moment differential, and then sufficient metal is removed from the tip end side face of the flange 106 to bring the flange to a predetermined thickness.

In either of the above cases, whichever face of the flange 106 is employed as a reference plane in determining the location of the center of mass of the blade, in subsequently reducing the flange to its desired thickness and final location, the following procedure is preferably followed. A spider such as the spider 418 described in connection with Fig. 42 is mounted in the open end of the blade, and the blade is rotated between suitable centers in a lathe or other suitable machine tool, one center being received in the center opening described in connection with the spider 418 and the other center being received in the prick punch mark produced in the tip end of the blade by the prick punch 430 as described in connection with Fig. 43. With the blade thus supported, a suitable tool (not shown) is employed to remove the required metal from the flange 106 to bring it to final shape, size and location. Preferably a grinding tool will be used as thus a more delicate adjustment may be procured. This method of supporting the blade for finishing the flange 106 insures that the plane of the flange 106 will be normal to a line passing centrally through or axially of the flange and also passing through the center of mass of the blade so that, as previously mentioned, there will be substantially no bending stresses set up in the blade itself dur-

ing rotation due to centrifugal action on off center masses in the blade nor will there be produced any dynamic unbalance.

It will be apparent from the above that by the method disclosed herein it is possible to form any number of propeller blades so that their centers of mass will all be located at such points that each blade will have the same static moment about the center of rotation of the propeller of which they are to form a part and accurately located on the axial line of each blade. It is to be particularly noted that these among other features are, as far as I am aware, entirely new in the art.

Heretofore in order to obtain the proper balance in metal propeller blades which are designed for interchangeable use in hubs, the blade to be balanced has been mounted in a hub together with a standard blade. The assembly has then been mounted on horizontal knife edges and the blade being balanced operated on in a suitable way to remove sufficient material to produce a static balance against the standard blade, or it may even happen that in order to produce the balance, instead of taking material from the propeller, in some instances holes may be drilled in the shank of the blade and lead or some heavier metal inserted to produce the proper balance. By this method the centers of gravity of the two blades are brought into proper relations to produce equality of moment. This having been done with the blades in a horizontal position the propeller is turned 90° and the process repeated with the blades in the vertical position. This balancing has generally been looked upon as sufficient in the art and it does tend to bring the centers of gravity of the two blades into such position that a line joining them will pass through the axis of the hub. This balancing process is arduous and difficult to perform requiring much careful labor.

In accordance with the invention of the present application balance is procured by a much simpler method which is more easy to perform and involves less labor. To this end the blade is suspended as indicated in Fig. 43 and the longitudinal axis accurately located through the center of the block 418 and the point marked by the tool 430. With these points located the face of the flange 106 toward the tip of the blade is dressed to a surface practically at right angles to the axis of the blade. The blade is then placed in the balancing mechanism indicated in Figs. 44 to 46 and the horizontal static balance of the blade is then directly procured as already indicated by working with reference to the face of the flange 106 as a basis. It is obvious that since the face of the flange 106 is in a plane at right angles to the longitudinal axis of the blade, which axis passes through the center of the flange, and since the center of gravity of the blade is located on this axis the resultant balance produced in accordance with the indications of the scale in the balancing device of Fig. 44 will actually produce a statically balanced blade with the center of gravity located in its longitudinal axis. If the blade is statically balanced with the center of gravity in the axis dynamic balance will exist when the blade is applied to a hub and actually used on an airplane. Such a result is highly desirable since it makes the blades interchangeable in the propeller without in any way upsetting the balance, thus reducing the chance of unequal strains in the blades and propellers and consequently tending to add to the useful life

of the propeller and insuring smooth operation when the propeller is in use.

After the flange 106 has been formed in the manner above described, the propeller blade is then thoroughly cleaned and it is then preferably placed in a cadmium plating bath and given a light coat of cadmium which is applied to both inside and outside for the purpose of rendering it rustproof. Only a very light coating of cadmium is necessary for this purpose and a coating .0003 of an inch thick has been found sufficient. After the blade has been cadmium plated it is again thoroughly cleaned and the inside is then preferably coated with paint or elastic primer to further render it resistive to the effects of corrosion. The blades thus treated are then again mounted in the balancing apparatus illustrated in Figs. 44 to 47, inclusive, or equivalent apparatus, and are brought to a condition of minute accurate final balance and into conformance with a predetermined standard balance. While this may be accomplished in any desired manner, a convenient method of obtaining the desired result is by the introduction of the required amount of paint, preferably of the type above described, into the interior of the blade, through the opening 416 in the tip of the blade. As will be apparent, by the use of paint interiorly applied an extremely accurate condition of final balance may be obtained and one that accurately conforms to a predetermined standard. The blade itself, as thus balanced, forms the subject matter of my co-pending application for Letters Patent of the United States for improvements in Propeller blade, filed April 2, 1934 and serially numbered 718,574, it being a division of the present application. Adjustments of somewhat greater magnitude, if necessary, may be made by sweating or otherwise applying solder, lead or other suitable materials to the interior of the blade, preferably at or toward the open or flange end. When the blades are applied to a hub the same means may be employed to procure final balance if necessary.

Instead of cadmium plating, the surface of the blade may be nitrided by the usual process, care however being taken not to harden the metal too far in from the surface.

From the above it will be apparent that methods and apparatus have herein been disclosed by means of which a highly efficient propeller blade may be provided, and that by the practices herein disclosed any number of propeller blades may be produced, each of which is so substantially identical with the other as to render it completely interchangeable therewith without the necessity of rebalancing a propeller provided with such blades when a change of such blades is made.

It will also be obvious that various methods and apparatus herein disclosed are each, in and of themselves, entirely novel for the purpose described, and it is to be understood that I do not limit any invention that may be present in any of the before described specific steps of operation or specific apparatus to its use with any other specific step of operation or specific apparatus except as hereinafter specifically claimed. Various changes and modifications will be apparent to those skilled in the art in the heretofore described steps of operation and apparatus after the various steps of operation and apparatus herein explained have been made known to them and, accordingly, it will be apparent that formal changes may be made in the specific embodiment of the invention disclosed without departing from

the spirit or substance of the broad inventions, the scope of which is commensurate with the appended claims.

I claim:

1. In the manufacture of a propeller blade from a hollow cylindrical metal blank, the steps of first tapering said blank both interiorly and exteriorly, and supporting the interior surface of said tapered blank against reduction in size while operating upon the exterior surface to taper the wall thickness of said blank from end to end.

2. In the manufacture of a propeller blade from a hollow cylindrical metal blank, the steps of first tapering said blank both interiorly and exteriorly, supporting the interior surface of said tapered blank against reduction in size while operating upon the exterior surface to taper the wall thickness of said blank from end to end, and closing the small end of said blank.

3. In the manufacture of a propeller blade from a hollow cylindrical metal blank, the steps of first tapering said blank both interiorly and exteriorly, supporting the interior surface of said tapered blank against reduction in size while operating upon the exterior surface to reduce the wall thickness of said blank from end to end, closing the small end of said blank, and modifying the cross-sectional shape of said blank to bring it to the desired final conformation.

4. In the manufacture of a propeller blade from a hollow metal blank, the steps of working the blank to tapered formation and to accurately predetermined internal dimensions, modifying the wall thickness of said blank to substantially that desired in the finished product by removing stock from the exterior surface thereof, closing the small end of said blank, and changing the cross section of said blank to that desired in the finished product.

5. In the manufacture of a propeller blade blank from a hollow metal tube, the steps of tapering said tube and bringing its internal dimensions to predetermined limits, working upon the exterior of said tube while said tube is supported upon a mandrel to bring its wall thickness to substantially finished condition, and closing one end of said tube.

6. In the manufacture of a propeller blade blank, the steps of modifying a hollow metal blank to tapered formation and predetermined internal dimensions, placing said blank upon a mandrel conforming exteriorly to the interior of said blank, reducing the wall thickness of the blank by means of a tool acting upon the exterior surface thereof and maintained in predetermined relation with respect to the surface of said mandrel, and closing the small end of said blank.

7. In the manufacture of a propeller blade, the steps of forming a tubular blank, forcing into said blank a mandrel whereby to cause said blank to internally conform to the external surface of said mandrel, working upon the exterior of said blank in a predetermined relation with respect to the exterior surface of said mandrel whereby to bring the wall thickness of said blank to substantially finished condition, closing the small end of said blank, and modifying the cross-sectional shape of said blank into the desired airfoil section.

8. In the manufacture of a propeller blank, the steps of forming a tube, and forcing a tapered mandrel into said tube while the latter is substantially unrestricted against outward expansion whereby to stretch the metal of said tube beyond the elastic limit thereof thereby to permanently

deform said tube and make it internally conform to the exterior size, tapered shape and contour of said mandrel.

9. In the manufacture of a propeller blank from a hollow metallic tube, the step of forcing a non-cylindrical mandrel into said tube while the latter is substantially unrestricted against outward expansion whereby to stretch at least a portion of the metal of said tube beyond its elastic limit and thereby cause at least said portion to internally conform in size, shape and non-cylindrical contour to the corresponding exterior surface of said mandrel.

10. In the manufacture of a propeller blade blank and blade, the steps of forming a tubular blank one end of which is smaller than the other thereof, inserting a mandrel externally conforming to the interior size, shape and contour of said blank into said blank, machining the exterior of said blank in predetermined relation with respect to the exterior surface of said mandrel, and pressing said blank to blade shape.

11. In the manufacture of a propeller blade blank, the steps of forming a tube of circular section and of generally tapered construction, permanently deforming at least a portion of said tube to bring its internal size, shape and contour into accordance with a predetermined size, shape and contour, and placing said tube on a mandrel and machining the exterior surfaces of said tube in predetermined conformance with the interior surfaces of said mandrel.

12. In the manufacture of a propeller blade blank and blade, the steps of working a cylindrical metallic tube to make one end thereof smaller than the opposite end thereof, forcing a mandrel into said tube whereby to stretch at least a portion of said tube beyond the elastic limit of the material from which it is made and permanently distort it so as to bring the interior size, shape and contour of said portion into accordance with a predetermined standard, machining the exterior surfaces of the tube in predetermined conformance to the interior surfaces thereof, and modifying the cross-sectional shape of said tube to that desired in the finished blade.

13. In the manufacture of a propeller blade blank, the steps of providing a metallic tube of circular cross section having one end thereof smaller than the other end thereof, forcing a mandrel of predetermined size, shape and contour into said tube and expanding at least a portion of said tube beyond the elastic limit of the material from which it is formed, whereby to cause the interior surfaces thereof to conform in size, shape and contour to the exterior surfaces of the mandrel, and machining the exterior surface of said tube in predetermined relation to the interior surface thereof.

14. In the manufacture of a propeller blade blank, the steps of providing a metallic blank of circular cross section having one end thereof smaller than the opposite end thereof, forcing into said blank a mandrel having an external surface conforming in size, shape and contour with a predetermined standard whereby to radially expand the material of said blank beyond the elastic limit thereof and thereby permanently predetermine the size, shape and contour of the interior surface of said blank, and machining the exterior surface of said blank in predetermined relation with respect to the interior surface thereof.

15. In the manufacture of hollow metal pro-

PELLER blades, the steps of forming a tubular blank of circular cross section with one end thereof smaller than the other end thereof, bringing the internal dimensions of said blank into accurate conformance with a predetermined size, shape and contour, mounting said blank on a mandrel and removing stock from the exterior thereof to bring the wall thickness of said blank into accurate conformance with a predetermined standard, and pressing said blank to blade shape between dies.

16. In the manufacture of hollow metal propeller blades, the steps of forming a tubular blank of circular cross section with one end thereof smaller than the other end thereof, bringing the internal dimensions of said blank into accurate conformance with a predetermined size, shape and contour including the step of forcing a mandrel into said blank to expand at least a portion thereof beyond the elastic limit of its material, removing metal from the exterior of said blank to obtain the desired wall thickness, and pressing the blank to the desired blade shape.

17. In the manufacture of a hollow metal propeller blade blank of generally circular section having one end thereof smaller than the other end thereof, the step of accurately predetermining and sizing at least a portion of the interior surface of said blank by permanently deforming such portion by means of a mandrel, of a shape and contour generally conforming to the interior shape and contour of the blank, forced into said blank an amount sufficient to expand the metal of said portion beyond its elastic limit and while said tube is substantially unrestricted against outward expansion.

18. In the manufacture of a hollow metal propeller blade, the steps of forming an elongated hollow metal blank of generally circular cross section, one end of which is smaller than the other end thereof, operating upon the interior of said blank to bring its internal dimensions into accurate conformance with a predetermined size, shape and contour, removing material from the exterior of said blank to bring the wall thickness thereof into accurate conformance with a predetermined wall thickness, and pressing said blank to the desired blade shape, between dies.

19. In the manufacture of a propeller blade from a hollow metal blank, the steps of working said blank to tapered formation, modifying the wall thickness of said blank to substantially that desired in the finished product by removing stock from the exterior surface thereof while substantially completely supporting said blank interiorly thereof, spinning in the small end of said blank, and pressing said blank between dies to bring it to the desired finished cross sectional contour.

20. In the manufacture of a propeller blade from a hollow, cylindrical metal blank, the steps of working said blank to tapered formation and to predetermined internal dimensions, modifying the wall thickness of said blank to substantially that desired in the finished product by removing stock from the exterior surface thereof while substantially completely supporting said blank interiorly thereof, spinning in the small end of said blank, and pressing said blank between dies to bring it to the desired finished cross-sectional contour.

21. In the manufacture of a propeller blade blank, the steps of modifying a hollow metal blank to tapered formation and predetermined internal dimensions, placing said blank upon a mandrel conforming exteriorly to the interior of

said blank, machining the exterior of said blank by means of a tool maintained in predetermined relation with respect to the surface of said mandrel, and spinning closed the small end of said blank.

22. In the manufacture of a propeller blade blank, the steps of modifying a hollow metal blank to tapered formation and predetermined internal dimensions, placing said blank upon a mandrel conforming exteriorly to the interior of said blank, machining the exterior of said blank by means of a tool maintained in predetermined relation with respect to the surface of said mandrel, and artificially heating and spinning closed the small end of said blank.

23. In the manufacture of a propeller blade, the steps of forming a tapered tubular blank of predetermined internal dimensions, inserting into said blank a mandrel externally conforming to the internal surface of said blank, machining the exterior of said tube in a predetermined relation with respect to the exterior surface of said mandrel whereby to bring the wall thickness of said blank to substantially finished condition, closing the small end of said blank, and modifying the cross sectional shape of said blank into the desired airfoil section.

24. In the manufacture of a propeller blade blank from a hollow metallic tube, the steps of working said tube into tapered formation and predetermined internal dimensions, machining the exterior surface of said tube to bring the wall thickness of said tube into substantial conformance with that of the desired finished product, heating the small end of said tube into substantially plastic condition and simultaneously spinning it closed.

25. In the manufacture of a propeller blade from a hollow cylindrical metallic tube, the steps of working said tube into tapered formation and with predetermined internal dimensions, externally machining said tube to bring the wall thickness thereof into substantially finished condition, bringing the small end of said tube to a high temperature and spinning said small end closed.

26. In the manufacture of a propeller blade from a tubular metal blank, the steps of working said blank to tapered formation, machining the exterior of said tapered blank to bring the wall thickness thereof to substantially the desired thickness of the walls of the finished blade, closing the small end of said tapered and machined blank, subjecting said blank to a form pressing operation between a pair of dies, subjecting said blank to a heat treatment, and subjecting said blank to a pressing operation between a pair of cooled dies to bring it to its desired final cross-sectional shape.

27. In the manufacture of a propeller blade from a tubular metal blank, the steps of working said blank to tapered formation, machining the exterior of said tapered blank to bring the wall thickness thereof to substantially the desired thickness of the walls of the finished blade, closing the small end of said tapered and machined blank, subjecting said blank to a form pressing operation between a pair of dies, subjecting said blank to a heat treatment, and subjecting said blank to a pressing operation between a pair of cooled dies to bring it to its desired final cross-sectional shape under the influence of expansive pressure in said blank.

28. In the manufacture of a propeller blade from a tubular metal blank, the steps of working

said blank to tapered formation, machining the exterior of said tapered blank to bring the wall thickness thereof to substantially the desired thickness of the walls of the finished blade, closing the small end of said tapered and machined blank, subjecting said blank to a pressing operation between a pair of dies to bring it to its desired final cross-sectional shape, and heating, quenching and drawing said blank.

29. In the manufacture of a propeller blade blank, the steps of forming a cylindrical tube having one end smaller than the other end thereof, expanding at least a portion of said tube beyond the elastic limit of its material by internally applied pressure, internally machining at least a portion of the internal surface of said tube, and internally sizing said tube by means of pressure applied internally thereof.

30. In the manufacture of a propeller blade blank, the steps of forming a cylindrical tube having one end smaller than the other end thereof, expanding at least a portion of said tube beyond the elastic limit of its material by internally applied pressure, internally machining the smaller portion of said tube, and internally sizing said tube by means of pressure applied internally thereof.

31. In the manufacture of a propeller blade blank, the steps of forming a cylindrical tube having one end smaller than the other end thereof, expanding at least a portion of said tube beyond the elastic limit of its material by forcing a mandrel thereinto, internally machining the smaller portion of said tube, and internally sizing said tube by means of pressure applied internally thereof.

32. In the manufacture of a propeller blade blank, the steps of forming a cylindrical tube having one end smaller than the other end thereof, expanding at least a portion of said tube beyond the elastic limit of its material by internally applied pressure, internally machining the smaller portion of said tube, and internally sizing said tube by forcing a mandrel of predetermined size, shape and contour into said tube with sufficient force to deform at least a portion thereof beyond the elastic limit of the material of said tube.

33. In the manufacture of a propeller blade blank, the steps of swaging down an end of a cylindrical tube to form a nose portion of gradually reduced diameter, forcing into said tube a mandrel of predetermined size, shape and contour whereby to initially stretch at least a portion of said tube beyond the elastic limit of its material and into internal conformance with the corresponding surface of said mandrel, removing said mandrel and internally machining said nose portion, and forcing a mandrel of predetermined size, shape and contour into said blank whereby to cause said blank to internally conform permanently to the corresponding outer surfaces of the last mentioned mandrel.

34. In the manufacture of a propeller blade blank, the steps of swaging down an end of a cylindrical tube to form a nose portion of gradually reduced diameter, forcing into said tube a mandrel of predetermined size, shape and contour whereby to initially stretch at least a portion of said tube beyond the elastic limit of its material and into internal conformance with the corresponding surface of said mandrel, removing said mandrel and internally machining said nose portion, forcing a mandrel of predetermined size, shape and contour into said blank whereby to

cause said blank to internally conform to the corresponding outer surfaces of the last mentioned mandrel, and removing metal from the exterior of said tube in accurate conformance with respect to the interior walls thereof.

35. In the manufacture of a propeller blade blank, the steps of forming an open ended hollow tapered propeller blank having a flange at the larger end and a thickened wall at the other end, holding the blank by the flange while forcing a mandrel part way therein, removing the mandrel and machining the interior of the smaller end of the blank to the desired final shape and size, holding the blank by the flange and forcing the mandrel fully into the blank so that its end engages the machined interior thereof and deforms at least a portion of the blank between the flange and machined interior beyond the elastic limit of the metal so that thereafter the interior of the blank retains substantially the size and shape of the exterior of the mandrel.

36. In the manufacture of a propeller blade blank, the steps of forming an open ended hollow tapered propeller blank having a flange at the larger end and a thickened wall at the smaller end, machining the interior of the smaller end to a predetermined desired size and shape, supporting the blank by the flange, thrusting into the blank a tapered mandrel having a smaller end corresponding in size and shape to the machined smaller end so that it seats thereupon and deforms the metal between it and the flange.

37. In the manufacture of a propeller blade blank, the steps of forming an open ended hollow tapered propeller blank having a flange at the larger end and a thickened wall at the smaller end, machining the interior of the smaller end to a predetermined desired size and shape, supporting the blank by the flange, thrusting into the blank a tapered mandrel having a smaller end corresponding in size and shape to the machined smaller end so that it seats thereupon and deforms the metal between it and the flange into substantial conformity to the outer surface of the mandrel so that thereafter the interior of the blank retains substantially the size and shape of the exterior of the mandrel.

38. In the manufacture of a propeller blade, the steps of forming a tapered hollow propeller blank closed at the smaller end by thickened walls and a projecting reinforcing nipple and surrounded by a flange at the larger open end, heating the blank and supporting it by the flange between dies the flange end portions of which correspond to the peripheral diameter of the blank and the tip end portions of which are larger than the peripheral diameter of the blank, and bringing the dies together to form the blank into a blade form by deforming the metal without rupturing it.

39. In the manufacture of a propeller blade, the steps comprising forming a hollow metallic blank, one end of which is smaller than the other, placing said blank between dies having matching depressions in the opposed faces thereof which depressions cooperate to accurately conform to the predetermined size, shape and contour of the root end portion of the desired finished blade and cooperate over a portion of their length to form a depression materially longer and wider than the corresponding tip end portion of the desired finished blade, and bringing said dies together about said blank.

40. In the manufacture of a propeller blade, the steps of forming a hollow metallic blank one end of which is smaller than the other, placing

said blank between dies having matching depressions in the opposed faces thereof which depressions co-operate to accurately conform to the predetermined size, shape and contour of the exterior surfaces of one portion of the desired finished blade, and which cooperate to conform to the thickness of another portion of the desired finished blade but are wider and longer than the last mentioned portion, and then bringing said dies together about said blank.

41. In the manufacture of a propeller blade, the steps of forming a hollow metallic blank one end of which is smaller than the other end thereof, and so pressing said blank to blade shape between dies as to restrict a portion of the length of the blade to the exact size, shape and contour of the corresponding portions of the die depressions, and to restrict another portion of the length of the blade to the spacing and cross-sectional contour of opposed surface portions of the corresponding portions of the die depressions without regard to the width of the blade in said other portion.

42. In the manufacture of a propeller blade, the steps of heating a hollow blank closed at one end, externally pressing said heated blank to blade-like form while subjecting it interiorly to expansive pressure, subjecting said blade to a re-heating operation, and chilling the external surfaces of said reheated blade to harden them by bringing said surfaces into intimate contact with metallic surfaces of a die under the influence of expansive pressure in said blank.

43. In the manufacture of hollow metallic blanks for use in making blades for propellers, the step of internally sizing a blank of a size and shape approximately that desired in a subsequent operation including simultaneously radially deforming and longitudinally stretching the same, and thereby pressing said blank to blade shape and section.

44. In the manufacture of hollow tapered metallic blanks for use in making blades for propellers, the steps of internally sizing said blank including simultaneously radially expanding and longitudinally stretching the same by bringing the tapered end portion of a mandrel of predetermined size, tapered shape and contour into contact with the interior of the tapered end portion of said blank and urging the tapered end portion of said mandrel axially of said blank away from the opposite end thereof.

45. In the manufacture of a hollow metallic blank having a reduced end portion, the steps of internally sizing said blank including first interiorly machining at least a part of said end portion, and forcing into said blank while the exterior of the latter is confined externally only by atmospheric pressure a mandrel of fixed predetermined size, shape and contour.

46. In the manufacture of a hollow metallic blank having a reduced end portion, internally sizing said blank including interiorly machining at least a part of said end portion and expanding the remainder of said blank while the exterior of the latter is confined externally only by atmospheric pressure by forcing into it a mandrel of tapered formation having an end portion conforming in size, shape and contour to said internally machined end portion.

47. In the manufacture of a hollow metallic blank, bringing the internal size, shape and contour thereof into conformance with a predetermined standard, including bringing one end portion of a mandrel, having an exterior surface corresponding in size, shape and contour to said

standard, into engagement with the interior of one end portion of said blank and urging the latter end portion of said blank outwardly axially thereof so as to longitudinally stretch said blank and contract the interior surfaces of the intermediate and other end portions of said blank into conformance with the surfaces of the corresponding portions of said mandrel.

48. In the manufacture of a hollow metal propeller blade, the steps of confining a heated hollow blank between a pair of complementary dies, cooling the internal surfaces of said dies, and chilling the exterior of said blank by forcing the external surfaces thereof against the internal surfaces of said dies by internal pressure.

49. In the manufacture of a hollow metal article, the steps of confining a metal blank between a pair of complementary dies, circulating a cooling medium through the supporting structure of said dies to cool the internal surfaces of the dies, and chilling the exterior of said blank uniformly throughout by introducing a medium under pneumatic pressure into said blank so as to force the external surfaces of said blank into intimate contact with the cooled surfaces of said dies.

50. In the manufacture of a propeller blade from a tubular metal blank having one end of smaller size than the other, the steps of bringing the internal dimensions of said blank into accurate conformance with a predetermined size, shape and contour, bringing the blank to predetermined wall thickness by removing stock from the outside surface thereof and in predetermined relation to the interior surface thereof, and changing the cross-sectional contour of said blank to that desired in the finished product.

51. In the manufacture of a propeller blade from a hollow cylindrical blank, the steps of reducing the dimensions of one end of said blank, working the interior of the blank to accurate predetermined dimensions, bringing the blank to desired wall thickness of the finished product by removing stock from the exterior surface thereof in predetermined relation to the interior surface thereof, and modifying the cross-sectional contour of said blank to that desired in the finished product.

52. In the manufacture of hollow metallic blanks having a reduced end portion, the method of internally sizing said blanks including bringing a reduced end portion of a mandrel of predetermined size, shape and contour into contact with the interior of the reduced end portion of said blank, supporting said blank for unrestricted radial expansion over the greater portion of its length, and urging the reduced end portions of said mandrel and blank axially outwardly whereby to longitudinally stretch the metal of said blank to beyond its elastic limit and to cause it to interiorly conform to the exterior of the intermediate and opposite end portions of said mandrel.

53. In the manufacture of hollow metallic blanks having a reduced end portion, the method of internally sizing said blanks including bringing a reduced end portion of a mandrel of predetermined size, shape and contour into contact with the interior of the reduced end portion of said blank, holding the end of said blank opposite said reduced end and applying force axially to said mandrel whereby to deform said blank and stretch the metal thereof to beyond its elastic limit and cause the blank to interiorly conform to the exterior of said mandrel, and thereafter

varying the cross sectional contour thereof to that desired in the final product.

54. In the manufacture of a propeller blade from a hollow metallic blank having a reduced end portion, the steps of bringing the internal dimensions of said blank into accurate conformity with a predetermined size, shape and contour, internally supporting said blank while operating on its exterior to bring the wall thickness thereof into conformity with that desired in the final product, and varying the cross-sectional contour thereof to that desired in the final product.

55. In the manufacture of a propeller blade from a hollow metallic blank having a reduced end portion, the steps of bringing the internal dimensions of said blank into accurate conformity with a predetermined size, shape and contour, internally supporting said blank while operating on its exterior to bring the wall thickness thereof into conformity with that desired in the final product, and varying the cross-sectional contour thereof to that desired in the final product by pressing said blank between dies while interiorly supporting it against collapsing.

56. In the manufacture of a propeller blade blank, the steps of tapering a tube and bringing its internal dimensions to predetermined limits, and machining the exterior of said tube while said tube is supported internally upon a mandrel to bring its wall thickness to substantially finished condition.

57. In the manufacture of a propeller blade blank, the steps of tapering a tube and bringing its internal dimensions to predetermined limits, placing said tube upon a mandrel conforming exteriorly to the interior of said tube, and machining the exterior of said tube by means of a tool maintained in predetermined relation with respect to the surface of the mandrel.

58. In the manufacture of a propeller blade, the steps of operating on a hollow metal blank having a reduced end portion to make it conform internally to a predetermined size, shape and contour, operating on the exterior of said blank to bring the wall thickness thereof to substantially that desired in the finished product, changing the cross-sectional contour of said blank to approximately that desired in the finished product, heating said blank and chilling the exterior of the latter to harden the material thereof by confining it between dies having surfaces to bring the blank size, shape and contour to that desired in the final product while expansively pressing said blank into contact therewith.

59. In the manufacture of a propeller blade blank from a hollow metal tube, the steps of mounting the tube on a mandrel internally fitting it near one end and slightly smaller than the tube nearer its end, heating the end of the tube and spinning it closed and into internal conformance with the end of the mandrel with increased wall thickness of the tube at the closed end.

60. In the manufacture of a propeller blade blank from a hollow metal tube, mounting the tube on a mandrel internally fitting it near one end and slightly smaller than the tube nearer its end, heating the end of the tube and spinning it closed and into internal conformance with the end of the mandrel by increasing the wall thickness of the tube at the closed end and providing a projecting nipple thereon.

61. Spinning closed the end of a tube for a propeller blade blank by forming an end wall of excessive thickness and wiping the spinning tool across the center so as to completely close the end

of the tube, and reducing the thickness of the end wall by spinning metal thereof into a projecting nipple at the end thereof.

62. Closing the end of a tube to be deformed into propeller blade shape by spinning and forming at the tip a reinforcing nipple, pressing the tube into propeller blade shape and removing the nipple.

63. Closing the end of a tube to be deformed into propeller blade shape by spinning and forming at the tip a reinforcing nipple.

64. In bringing a hollow propeller blade into conformance with a predetermined standard of balance, the steps of determining the error and adding material to the interior walls of the blade to correct it.

65. In bringing a hollow propeller blade into conformance with a predetermined standard of balance, the steps of determining the error, and adding a siccative coating to the interior walls of the blade to correct the error.

66. In bringing a hollow propeller blade into conformance with a predetermined standard of balance, the steps of determining the error, and applying a coating of paint-like material to the interior walls thereof in order to reduce the error.

67. The method of varying the balance of a hollow propeller blade to bring it toward a predetermined condition of balance and simultaneously rendering the interior thereof resistant to corrosion comprising coating the interior of said blade with an adhesive coating of corrosion resisting material.

68. The method of varying the balance of a hollow propeller blade and rendering the interior thereof resistant to corrosion comprising coating the interior of said blade with a coating of non-metallic material.

69. The method of bringing a hollow propeller blade to a condition of minute final balance comprising the addition of suitable amounts an adhesive substance to the interior thereof to obtain the desired balance by inserting it through an opening in a wall thereof.

70. In bringing a hollow propeller blade to a condition of minute final balance, the steps of determining the error in balance and the addition of an adhesive substance to the interior thereof to correct the balance by inserting such substance through an opening in the tip end thereof.

71. The method of balancing a propeller having blades provided at their inner ends with attaching members for securement to a hub which consists in determining the amount each blade varies in its moment characteristic from a standard moment of predetermined amplitude, altering the attaching member so as to change the distance between the same and the center of mass of the blade for equalizing the moment characteristic of each blade with the standard moment, and thereafter applying an adhesive coating to an interior wall of the blade to bring it to a condition of minute final balance.

72. In the manufacture of a hollow metallic propeller blade having a locating flange at one end thereof, the method of bringing said blade to

a desired condition of final balance including, machining said flange in predetermined accordance with the center of mass of the blade, and applying a predetermined weight of an adhesive coating to the interior of the blade.

73. In the manufacture of a hollow metallic propeller blade having a locating flange at one end thereof, the method of bringing said blade to a desired condition of final balance including, machining said flange in predetermined accordance with the center of mass of the blade, applying a predetermined weight of an adhesive coating to the interior of the blade, and bringing said blade to a condition of minute final balance by the application of an adhesive material to the interior of the blade through an opening in the wall thereof.

74. In the manufacture of a propeller blade from a hollow blank of circular cross section and in which the wall thickness of any cross section is substantially uniform throughout, the steps of locating the heaviest side of said blank, and forming said blank to blade shape with the heaviest side thereof at a predetermined location in said blade.

75. In the manufacture of a propeller blade from a hollow blank, the steps of locating the heaviest side of said blank, and forming said blank to blade shape with the heaviest side thereof located in closest proximity to the central longitudinal axis of said blade.

76. In the manufacture of a propeller blade from a hollow blank, the steps of locating the heaviest side of said blank and compressing the blank between complementary die parts having opposed flat surfaces with the previously located heavy side of the blank positioned at the mid-portion of a surface of one of said die parts.

77. In the manufacture of a propeller blade, the method of balancing the mass of the material of the blade with respect to its central longitudinal axis including the steps of supporting a tubular blank of which the blade is to be formed upon transverse, longitudinally spaced horizontal knife edges so as to allow substantially unrestrained rolling thereof, allowing the blank to come to rest, and placing the portions of the blank which rested upon said knife edges at the mid-portion of the die part which forms that plane of the blade which is closest to its central longitudinal axis.

78. In the manufacture of elongated hollow metallic blanks for use in making blades for propellers, the steps of forming a hollow metallic tube having one end smaller than the other thereof, and forcing into the large end of said tube a mandrel approximately conforming to the interior size, shape and contour thereof so as to radially expand those portions of the tube of smaller transverse internal dimensions than the corresponding exterior dimensions of said mandrel and stretching said tube longitudinally so as to cause those portions thereof of greater transverse internal dimensions than the corresponding exterior dimensions of the mandrel to be radially contracted into contact with the mandrel.

JOHN SQUIRES.

## CERTIFICATE OF CORRECTION.

Patent No. 2,081,645.

May 25, 1937.

JOHN SQUIRES.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 21, second column, lines 38, 39 and 40, claim 43, strike out the comma and words ", and thereby pressing said blank to blade shape and section" and insert the same after "thereof" and before the period in line 51, claim 44; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 13th day of July, A. D. 1937.

Henry Van Arsdale

(Seal)

Acting Commissioner of Patents.