THE CONSTRUCTION OF A MODEL OF A
HIGH SPEED WIND TUNNEL

by

CARLETON GEORGE FANGER

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APPROVED:

[redacted]

Professor of Aeronautical Engineering In Charge of Major

[redacted]

Head of Department of Mechanical Engineering

[redacted]

Chairman of School Graduate Committee

[redacted]

Dean, Graduate Division

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I. INTRODUCTION

As a result of the growing popularity of the aeronautical engineering division at Oregon State College, and the deficiency in this division's laboratory facilities, the idea of a specially-designed wind tunnel was conceived and accomplished by Mr. Edward B. Shields in his thesis, "Design of a Wind Tunnel for the Oregon State College Aeronautical Laboratory." It is in the interest of the continuation and development of Mr. Shields' work that the author has selected as a thesis project the construction of a scale model of this tunnel.

There were several important considerations leading to the selection of this construction as the next phase in the development of the Oregon State College wind tunnel. Financially, the cost of building the tunnel, as designed by Mr. Shields, is prohibitive, due to the present high material and labor costs. Furthermore, the feasibility of building the full-size tunnel, with the corresponding outlay of a considerable sum of money, without further investigation into the design characteristics, was considered highly questionable. The most practical means of determining the general characteristics of a wind tunnel have been found to be the construction and testing of a small-scale model. The practicality of this decision was further strengthened by the author's plan to make the model construction flexible in nature, in order that entire sections could be removed and replaced by other sections of particular interest. Because of the incorporation of this feature in the construction of the scale model, it will actually serve a dual purpose; providing the information desired for the Shields' design, and serving as a permanent laboratory test installation.

Mention should be made of the fact that there is a definite limitation in the type of tests than can be run with the small-model wind tunnel. The usefulness of model tunnels is largely restricted to the indication of general trends in tunnel design characteristics. However, from the standpoint of student instruction, quantitative results are not particularly necessary.

Considerable care has been taken to make the scale model as exact a replica of the proposed wind tunnel as was physically possible. The model was built to a scale of one-eighth of the full-size tunnel. This reduces the two by four foot test section of the tunnel to a model test section of three by six inches. From this it is easily seen that there are certain physical limitations as to the extent to which the duplication can be carried in the model of the original design. The indicated changes thereby necessitated are, however, relatively minor, and are insignificant from the standpoint of the resultant tunnel characteristics.

II. GENERAL REQUIREMENTS

In general, it is necessary that the model tunnel, as a finished product, be as near a scaled duplication of the original tunnel design as possible. This has been managed quite effectively by a painstaking study of construction techniques by the author before initiation of construction activity.

From the standpoint of student instruction, and airflow study, it is required that as much of the tunnel interior be accessible to the eye as is feasible from the constructional viewpoint. This means the use of some transparent material for the top panels in all rectilinear sections. It would also indicate the desirability of making all test section panels from a transparent material.

It is considered essential to keep the cost of construction of the model at a minimum, due to the limited funds available for this purpose. To avoid excessive costs, careful study of each phase of the construction is essential. This indicates the necessity of making certain compromises with respect to materials and equipment. The optimum combination of quality of material, equipment, and cost will then be the criteria upon which a scale selection is based.

In the interest of versatility, it is necessary to construct and assemble the model tunnel in such a manner as to facilitate removal and replacement of entire sections. Consequently, the section joints must be made in such a way as to seal completely when clamped together, and yet be easily and quickly removable.

All major sections of the model must be accessible through detachable panels for purposes of general maintenance and periodic adjustments.

III. GENERAL DESCRIPTION

The model wind tunnel is of the closed-jet, closed-circuit type, and is constructed to a scale of one-eighth full size. Plywood, sheet metal, and Plexiglas are used in the fabrication of the tunnel sections.

The overall dimensions of the model are: 68 inches in length, 29 inches in width, and 12 inches in height.

The test section is three inches high, six inches wide, and nine inches long. All panels of the test section are made of Plexiglas, with the top panel being removable for purposes of model replacement and adjustment.

Immediately after the test section is a sheet metal transition section which is, in effect, a diffuser section. This section expands from a rectangular three by six inch cross section to a circular six and one-quarter inch section in a length of fifteen inches. The tunnel static vents are located on the rectangular end of this section. The circular end attaches to the fan safety ring which is provided as a safety precaution for operating personnel. The ring is made from six inch metal piping cut and machined to the desired dimensions. It provides protection by a constant wall thickness of three-eighths of an inch.

To return from the circular section adjoining the safety ring to a rectangular section, another sheet metal transition section is used, this time passing from the six and one-fourth inch circular section to a square, six inch section.

The square end of the transition section mentioned attaches to a 180 degree, six by six inch plywood-Plexiglas elbow duct. The side and bottom panels of this elbow duct are made of one-half inch Plexiglas. The airflow is directed through the 180 degree turn by two sets of sheet metal vanes. These vanes are made of 0.025 of an inch, 24 ST aluminum sheet, and are one and one-eighth inches in radius, with 0.706 of an inch gap distance.

A large plywood-Plexiglas return diffuser section connects the above-mentioned 180 degree elbow to a second 180 degree elbow, running the length of the rear side of the tunnel. This diffuser increases uniformly from the six by six inch section to a nine by twelve inch section in a length of 44 inches. Sides and bottoms are of half-inch plywood construction, while the top is of three-eighths inch Plexiglas for both the diffuser and the large end duct. The vanes in this end duct are of the same material as that used for the vanes of the other elbow duct. They have a two and one-eighths inch radius, and a gap distance of 1.41 inches.

The contraction section connects the second elbow duct with the test section. This section is made from sheet metal, as were the two transition sections mentioned previously. As in the original, the contraction ratio is six to one, the entrance area being 108 square inches and the discharge area 18 square inches.

All interior tunnel dimensions stated in the foregoing discussion are scaled down from the dimensions of the original design.

To facilitate minor periodic adjustments and general maintenance, the Plexiglas top panels of the two elbow ducts and the rear diffuser section are removable, being sealed by felt stripping and wood screws along the butt joints. The Plexiglas top panels were provided for visual study of airflow patterns, and for general inspection purposes.

Since the model tunnel sections are required to be removable for purposes of interchangeability, the connection joints are flanged and bolted together either by a series of carriage bolts or machine screws, depending upon the construction material of the sections being joined. Each of these joints is sealed by felt gasketing.

The turning vanes in the elbow ducts are installed in very much the same manner as prescribed in the specifications for the full-size tunnel. There are a few minor variations, however. The five-sixteenths of an inch studs are slotted and soldered to the vane ends. The vanes are then held in place by nuts. It can readily be seen that the tightening of the nuts on the opposite ends of the vane will introduce a tendency for twist in the vanes, due to their necessarily thin cross section. This tendency has been virtually eliminated by the slotting of the exposed ends of the studs, in order that the stud can be held by a screw driver while the nut is being tightened, thus preventing rotation of the stud and subsequent twist of the vane. Due to the stiffness of the vane material, and the relatively short length of the vane as compared to its chord length, little vibrational difficulty is anticipated. The vane extremities are effectively held rigid by end pressures exerted on the vane by the tunnel walls as the vanes are tightened, thus minimizing any vibrational tendency that may exist. Each vane is easily adjustable.

This is accomplished merely by loosening the nuts at the ends of vanes and adjusting the vane by rotation of the end studs with a screw driver.

The wind tunnel impeller is powered by an Army P-1 type 24-30 volt, 200 ampere aircraft generator, run as a direct current motor. This motor is capable of delivering from three to five horsepower to the impeller. The direct current supply is provided by a second P-1 type aircraft generator, driven by a ten horsepower, alternating current, squirrel-cage induction motor. The ten horsepower motor is powered by a 220 volt line supply. The direct current motor is mounted outside the tunnel, driving the impeller directly by means of a half-inch shaft. Impeller speed is controlled by means of a manually-operated field rheostat. A nacelle hub shroud is provided to direct airflow in the impeller region, and serves also as a covering for the shaft bearing housing and impeller retaining ring. The forward portion of the shroud is attached to the impeller ring. It is essentially nothing more than a small propeller spinner. The rear portion is retained in position by attachment to the interior bearing housing supports. The impeller has eight detachable blades. The blades have NACA 4412 sections, and chords are 1.8 inches at the root and 1.3 inches at the tip. The blade length is 1.53 inches, with an additional seven-eighths of an inch shank length.

At this point it may be of interest to note that something of a comparison of relative performance may be drawn between the scale model and the original. Mr. Shields indicated that an expression, termed the energy ratio, serves as measure of tunnel performance.

The energy ratio is, in effect, the ratio of kinetic energy per second in the air stream at the working section, to the energy per second at the powerplant shaft, which, Mr. Shields showed, was reduceable to the expression:

$$E_T = \frac{\eta}{\lambda}.$$

Where,

η = estimated overall efficiency = 0.713

$\lambda = \Delta H_T/q_o$ = 0.274 (for model).

Where,

ΔH_T = total tunnel pressure drop

q_o = test section dynamic pressure.

The calculation of the model tunnel energy ratio yields a value of 2.6 as compared to a value of 2.28 for the original tunnel design. This would seem to indicate that the model tunnel may be expected to give better performance characteristics than the original, which may not necessarily be a valid assumption, principally because the same overall efficiency has been assumed. Such an assumption is not entirely justifiable since the model fan efficiency, due to its small size (six inches in diameter), may be considerably less than that for the original tunnel design.

Drawings in the appendix of this thesis give all details of the model tunnel that are basically different from those incorporated in Mr. Shields' thesis. They are as follows:

Eighth-Size Model Wind Tunnel

Subject	Drawing No.
Overall arrangement	100106
Plan detail	100107
Detail fan safety ring and fan	100108

IV. SPECIAL DESIGN CONSIDERATIONS

A. Powerplant and drive.

The basic consideration upon which the success and development of this model tunnel rested was the availability and the expense involved in procuring a suitable powerplant. Because of this the scale of the model was actually decided upon only after a satisfactory powerplant was obtained.

Obviously, the powerplant size was one element in the model construction that could not be scaled down. It was, therefore, necessary to make a series of approximations as to power requirements for different scale sizes, and determine then the power needed for each scale size to give relatively the same tunnel characteristics as those given by the full-size tunnel. It was finally decided that the needed tunnel characteristics could be obtained with a one-eighth size tunnel, and a drive capable of furnishing 3.5 horsepower to the impeller. A search was made resulting in the finding of a ten horsepower, alternating current, 60 cycle, three-phase, 220 volt, squirrel-cage induction motor. Further checks into the possible scale sizes for use with this power supply resulted in the ultimate selection of the one-eighth size model.

A more satisfactory motor for the purposes of the powerplant design for this model tunnel could not have been found, since a squirrel-cage induction motor is substantially a constant speed motor, having about five to ten percent drop in speed from no load to full load (1, p.190-196).

In order to provide for the relatively sensitive impeller speed control required in this type of installation, a modified Ward-Leonard power supply system was designed (see wiring diagram in appendix). Essentially, the original system makes use of two generators driven by an alternating current motor. These generators furnish the field and armature supply for the direct current, impeller drive motor. The modified system used for this tunnel is fundamentally the same, with the exception that the field supply generator was obviated. This was considered permissible in this design as the aircraft type generators used furnish their own field. The alternating current induction motor drives an Army P-1 type, 30 volt, 200 ampere aircraft generator, which in turn furnishes the armature and field supply for a second P-1 type generator being driven as a direct current motor. This direct current motor then drives the wind tunnel impeller. The output of this motor is figured to vary from three to five horsepower, depending upon the speed at which it is operated.

The full-size tunnel design calls for an indirect V-belt drive for the impeller. This is, in the case of the model tunnel, impractical, of course. Therefore, it was necessary to design a special drive for use in this installation. From a practical standpoint, the only logical means of driving the impeller was by means of a direct shaft drive. This meant running the shaft through the end of the small 180 degree elbow duct along the central axis to the impeller, with one bearing support on the interior near the impeller and another just outside the tunnel. It also necessitated the cutting of portions from the vanes to make way for the shaft. Shaft design equations (2, p.292-294) were used in the calculation of the shaft size and the minimum length between bearing supports. The shaft size from power transmission considerations, was not critical--calculations yielding a value of 0.19 of an inch for the shaft diameter. The required shaft size could be determined from knowing the length of shafting needed between supports. This calculation showed that three-eighths of an inch commercial steel shafting would be satisfactory. As a practical matter, however, the shaft size of one-half inch diameter used in this drive was chosen. This shaft design was checked for critical speed, that is, the speed at which the number of revolutions per second of the shaft is equal to the frequency of its natural vibration (3, p.518-520). The critical speed was found to be approximately 3900 revolutions per minute (assuming an impeller weight of four pounds). A double-roll, self-aligning, five-sixteenths of an inch SKF ball bearing was used in each bearing support for the shaft. These bearings are mounted in housings made from two inch steel bar stock, with holes drilled and reamed through the center to accomodate the bearings. The bearing housing on the interior of the tunnel is secured to the inner wall of the safety ring by means of four, one-eighth of an inch strap iron spokes, each mounted at 45 degrees from the horizontal center line of the tunnel. It should be noted that this makes it virtually impossible for the impeller to shift with respect to the safety ring. The external bearing housing is tied to the tunnel platform and to the motor mount by means of one-eighth of an inch strap iron strip, giving it lateral as well as vertical rigidity.

B. Impeller safety ring.

The original tunnel design calls for a safety ring made of reinforced concrete. This would be impractical for the scale model, since the interior dimension of the safety ring is only six and one-quarter inches in diameter. It was therefore decided that the ring should be made from half-inch, hot-rolled, steel plate, which could be heated, forged, welded, and machined to the proper dimensions. However, this plan was abandoned when it was found that six-inch steel pipe was available which could be machined to size in a relatively few number of operations. This ring was made to fill the entire gap between the two sheet metal transition sections fore and aft of the fan plane. In the Shields' design part of this gap was taken by a circular sheet metal section. This was impossible and impractical in the model since the distance is only in the order of two to three inches. The wider safety ring was considered highly desirable from the design standpoint, as well as for added safety considerations. This greater width made possible the mounting of the interior bearing housing directly to the inner wall of the safety ring, the advantage of which has been mentioned in the preceding section of this chapter.

C. Impeller design.

The entire impeller design procedure outlined in Mr. Shields' thesis had to be carried through for the model tunnel due to the unpredictable nature of scale effect on the blade forces. The author had originally planned to send the impeller specifications to some manufacturing concern and have it made to order, provided it could be done without entailing too great an expense. However, no manufacturer could be found that could produce a fan of the required specifications without making special dies, or forms, which would in itself entail a great deal of expense. As a consequence, this plan had to be discarded recently, leaving the author faced with the necessity of constructing the impeller himself. To give the reader something of an idea of the work involved, it might be well to state the general impeller specifications that had to be satisfied. The impeller is to be 6.0625 inches in diameter, with a minimum blade length of 1.5 inches; it must be designed to run at speeds of up to 10,000 revolutions per minute; it must be capable of absorbing up to five horsepower; and it must have a minimum hub (retaining ring) diameter of 2.5 inches. As may well be seen this was one of the most difficult problems encountered in the project.

As in the Shields' design, the impeller blades for the model tunnel were made using NACA 4412 airfoil sections. To obtain the desired blade area, eight blades with a root chord of 1.8 inches, and a tip chord of 1.3 inches were required. The blade span was, of necessity, set at the maximum of 1.53 inches. It was considered impractical to give the blade any twist with so short a span. Strength requirements dictated a shank diameter of approximately one-fourth of an inch. This was increased to three-eighths of an inch to take care of possible stress raisers in the shank-to-blade section. Due to the necessarily small size required for the retaining ring, and the relatively small (half-inch) shaft, it was decided that the ring should be threaded onto the shaft and held in position by a nut, rather than keying it to the shaft. Left hand threads are necessary here since the impeller rotates in a clockwise direction, looking toward the shaft end of the drive. The blades are anchored to the retaining ring by screwing the shanks into tapped radial holes in the ring. After the blade is set at the desired angle, a thin-head nut on the blade shank is tightened against the ring to hold the blade in position during fan balancing operations. The fan can be balanced by drilling away some of the metal retaining ring material on its periphery. When the balancing of the impeller has been completed, small pins are inserted from the edge of the safety ring through the ends of the blade shanks, thereby holding the blade at the exact prescribed angle. It is believed that this impeller design will be satisfactory for the purposes for which the tunnel has been built.

V. CONSTRUCTIONAL REQUIREMENTS AND TECHNIQUES

A. Choice of materials.

The major consideration in the construction of the model wind tunnel sections was not structural strength requirements, as it was in the case of the full-size tunnel. The controlling factor in the choice of structural material size is, in this instance, a matter of obtaining material of a thickness large enough to make the fabrication physically possible. From the strength consideration alone panels of one-half of an inch in thickness or less would be satisfactory. However, the procurement of fasteners sufficiently small to be used with this weight of material is impossible. For this reason it was necessary to go to materials with a minimum thickness of three-eighths to one-half of an inch.

Material choice was further restricted by the necessity of using material which could be finished to give the smoothest surface possible.

The visual requirements for the tunnel, as well as the element of cost also entered into the material selection.

The optimum combination of the above factors resulted in the selection of one-half inch, water-resistant plywood for the side and bottom panels, and the selection of three-eighths of an inch Plexiglas for the top panels of all rectilinear sections, with the exception of the test section. Visual requirements necessitated the use of Plexiglas for all four sides of this section. Sheet metal was selected for the contraction and transition sections, due to the complex nature of these shapes.

B. <u>Type of joints</u>.

For the size and type of material selected, the only practicable method of jointing the plywood pahels of the plywood-Plexiglas sections was to butt them together, securing them with glue and wood screws. The glue serves a dual purpose of acting as a seal as well as a binding agent.

The purpose for which the tunnel was built renders the installation of removable sectional joints mandatory. This has been accomplished by flanging the ends of each of the plywood-Plexiglas sections with one by one inch oak strips. The sheet metal sections have angle flanges, while lugs are provided on the fan safety ring for attachment purposes. The joints are clamped together by a series of carriage bolts for the plywood-Plexiglas joints, and by machine screws for the metal-to-metal joints. A seal is obtained at each of these sections by the use of one-eighth of an inch felt gasketing.

To facilitate general maintenance of the tunnel sections, it was essential that the Plexiglas panels in the rectilinear sections be removable. This has been managed by attachment of the Plexiglas with wood screws, using felt gasketing to seal the butt joints.

C. <u>Test section</u>.

An effort has been made in the test section layout to retain simplicity of construction and still meet all of the required specifications. It was not considered feasible to incorporate special removable panels on the test section sides due to the size of the section. Instead, construction has been so arranged as to make possible the removal of the entire top of the test section by the removal of six wing nuts on the top, and the releasing of three screws on each end. This has been arranged by drilling three, one-eighth of an inch pilot holes into the top edge of each side panel, screwing three-sixteenths of an inch machine screws into these holes as far as the screws will go (making certain they are tight), and sawing the heads from them. The top Plexiglas panel (with holes drilled along its edges to match those in the sides) can then be placed in position and wing nuts, replacing the sawed-off screw heads, tightened to seal the gasketed joint. Also, the top flanges of the adjoining sheet metal sections have slotted holes for the three-sixteenths of an inch screws which screw into the end of the top panel. These may be unscrewed slightly, and the top panel lifted off when the wing nuts are removed.

D. Tunnel mount.

Because the model tunnel is but a foot in height, some type of mount had to be provided to raise it to a height where it could be observed comfortably while in operation. However, the comparatively large power input to the fan indicated the possibility of encountering vibrational difficulties in the event that the tunnel was not securely anchored. With these two considerations in mind, the tunnel base was designed and built. The table top, or platform dimensions were made 96 by 48 inches since the tunnel itself is 68 inches in length and 29 inches in width. The table frame height was made 24 inches, leaving the table platform at a height of 27 inches. From the observational standpoint it may have been better to have made the height greater, but the greater height would decrease the rigidity of the table and would, therefore, be poor from vibrational considerations.

One by six inch pine boards were used for bracing and tying together four, two by twelve inch planks which provide the base for a three-quarter of an inch, four by eight foot plywood sheet. This plywood top is secured to the planking by means of two-inch, flat head screws. The table rails were made from two by six inch fir, and the legs from four by four inch fir. The tunnel mount when assembled was anchored to the concrete floor by means of cast iron angles bolted to the table legs and to the floor. The tunnel was mounted on the table top with one-eighth by one inch strap iron strips cut to support it at various points. The tunnel was fastened to these strap iron supports by means of machine screws--a thick soft rubber washer being placed between the tunnel and the strap iron to act as a shock absorber.

It is believed that this arrangement will cut vibrational characteristics to a minimum, and will be entirely satisfactory for operational and visual purposes.

E. Power supply.

The power requirements for the model tunnel made it necessary to install it at the airport aeronautical laboratory. Except for this it would have been more desirable and convenient to have had it installed here at the campus aeronautical laboratory.

VI. CONSTRUCTION PROCEDURE

The general tunnel construction operations leading to the final assembly of the tunnel may best be explained by means of the following topical outline.

A. Basic tunnel structure.

1. Plywood-Plexiglas sections
   - (a) Order materials
   - (b) Cut plywood to size
   - (c) Shape turning posts for 180 degree elbow ducts
   - (d) Mark and drill holes for butt joints
     - (1) Pilot holes for wood screws
     - (2) Large holes for screw shanks
   - (e) Countersink drilled holes
   - (f) Tentatively assemble individual sections
   - (g) Cut one by one inch flanges to length and miter
   - (h) Clamp flanges in position
     - (1) Disassemble sections
     - (2) Drill holes for screw shanks
     - (3) Drill pilot holes through into flanges
     - (4) Countersink holes
     - (5) Attach flanges by means of screws

(i) Tentatively reassemble individual sections

(j) Match adjoining sections and mark mating flanges

(k) Disassemble sections

(l) Remove flanges

(m) Drill bolt holes with mating flanges clamped

(n) Replace and glue flanges

(o) Drill holes for corner vanes

(p) Fill countersinks, irregularities with wood putty

(q) Sand and shellac all interior plywood surfaces

(r) Assemble plywood panels of sections

(s) Glue all wood-to-wood joints (wiping all excess glue from interior surfaces with damp cloth)

(t) Wax all interior surfaces

(u) Cut felt stripping for Plexiglas-to-wood joints

(v) Mount corner vanes in place

(w) Complete sectional assemblies

(x) Cut and glue felt stripping onto flanges

(y) Cap off all open ends with butcher paper to prevent damaging of interior surfaces

2. Sheet metal sections

(a) Draw specifications for each section for sheet metal shop

(b) Drill holes in flanges of wood-to-metal and metal-to-metal sections

(c) Make slots in flanges for Plexiglas-to-metal junctions

(d) Finish interior surfaces with fine steel wool

(e) Wax interior surfaces

(f) Cut and glue felt stripping onto flanges

(g) Seal open ends with butcher paper

3. Plexiglas test section

(a) Drill pilot holes in edges and ends of sides

(b) Drill matching one-fourth inch holes in top and bottom panels

(c) Screw one and one-half by three-sixteenth inch stove bolts into the top and bottom edges of the sides

(d) Cut off stove bolt heads

(e) Cut and glue felt stripping to top and bottom panel junctions

(f) Slip top and bottom panels into place

(g) Secure with wing nuts

(h) Wax interior surfaces

(i) Seal open ends

4. Impeller safety ring

(a) Cut from piece of six inch pipe

(b) Machine one face

(c) Machine inside to 6.25 inch diameter

(d) Machine other face to required length

(e) Finish inner surface with steel wool

(f) Braze small attachment lugs around ring periphery

(g) Weld large brackets along horizontal center line

(h) Weld interior bearing support to wall

(i) File roughness from weld joints

B. <u>Corner vane production</u>

1. Large vanes

(a) Cut to size

(b) Fabricate dies

(c) Heat treat to 670 degrees F.

(d) Form in die

(e) Make studs

(f) Solder studs

2. Small vanes

(a) Cut to size

(b) Fabricate die

(c) Form with die

(d) Make studs

(e) Solder studs

C. Impeller fabrication.

1. Blade pattern

(a) Make root and tip airfoil templates (NACA 4412 airfoil sections) from aluminum plate

(b) Saw templates from plate

(c) File templates to exact size

(d) Cut piece of oak down to approximate blade dimensions

(e) Mount templates on oak piece

(f) File and sand oak down to templates

(g) Remove templates and finish tip of blade

(h) Shape blade shank and attach

(i) Fillet blade shank to blade with plastic wood

(j) Shellac and polish pattern

2. Blade casting

(a) Make molds

(b) Cut and melt down strips of 24 ST aluminum sheet

(c) Pour aluminum into molds

(d) File and steel wool blades to proper shape, weight, and smoothness

(e) Thread shanks of blades

3. Retaining ring

(a) Cut from piece of two and one-half inch bar stock

(b) Machine to size

(c) Drill and tap to thread on drive shaft

(d) Drill and tap radial holes for blade shanks

(e) Thread blade shanks into retaining ring and secure with shank nuts

(f) Balance impeller by removing material from ring periphery

4. Shroud

(a) Turn from piece of hardwood

(b) Attach spinner to leading edge of retaining ring

(c) Attach stationary portion of shroud to bearing housing supports

D. <u>Impeller drive</u>.

1. Interior bearing housing

(a) Cut from two inch bar stock

(b) Drill and ream hole for bearing seat, leaving flange on one face for taking thrust

(c) Seat bearing in housing

2. Exterior bearing housing the same, but with no provision for thrust

3. Bearing mounts

(a) Cut and bend one-eighth by one inch strap iron

(b) Weld strap iron to housings

4. Shaft

(a) Turndown shaft to bearing size on either end

(b) Thread back two inches on the impeller end, and one inch on the motor end

5. Installation

(a) Screw shaft into motor drive shaft

(b) Screw fan onto shaft, until the retaining ring is against the bearing housing

(c) Tighten nut to hold impeller in place

(d) Attach spinner

(e) Mount rear portion of shroud

(f) Pack opening where shaft enters tunnel

E. <u>Tunnel mounting</u>.

1. Table frame

(a) Cut lumber to length

(b) Cut mortises and tenons

(c) Drill holes for lag screws

(d) Glue joints and tighten lag screws

2. Table top

   (a) Cut lumber to length

   (b) Tie two by twelves together with one by six cross-braces

   (c) Place top on table frame

   (d) Anchor in place by running lag screws through the platform into the rails

   (e) Attach four by eight foot, three-fourth inch plywood table top with wood screws

3. Tunnel supports

   (a) Obtain necessary base blocks

   (b) Shape to required size

   (c) Determine placement of blocks and mount with lag screws (through from underneath side of table)

   (d) Assemble wind tunnel sections on base

      (1) Butt flanges together and bolt

      (2) Attach necessary tunnel fasteners

      (3) Anchor tunnel to base blocks

   (e) Align external bearing, D-C motor (adjust stand)

F. <u>Powerplant</u>.

1. A-C motor installation

   (a) Find 220 volt, 60 cycle, three phase power source

(b) Mark and drill holes in concrete floor for motor mount

(c) Install expanders and anchor motor

(d) Make electrical connections to motor from 220 volt source (with power switch on table, preferably)

2. Generator and D-C motor installation

(a) Arrange drive and mount for generator

(b) Make necessary electrical connections from generator to D-C motor

(c) Mount D-C motor on table with electrical connections to field rheostats

VII. SUGGESTED IMPROVEMENT

A. Impeller.

It is the author's belief that the impeller will prove to be the most troublesome element of the tunnel installation. Considerable time has been devoted to the development of this design, and to the development of fabrication for its assembly.

From purely theoretical considerations, the impeller as designed will meet all specifications. It is pointed out, however, that standard equations for impeller design may not necessarily give accurate results for an impeller of such small proportions. Apparently some scale effect factor is present and must, therefore, enter into the design calculations. Scale effect, in itself, is not a newly discovered phenomenon. An appreciable amount of research work has been done on the subject. However, references wherein scale effect influences on impeller design are discussed are difficult to find. Because of the difficulty encountered at this point, and the research necessary to obtain more concrete information, the author decided to use the standard design equations, making what seemed to be a reasonable allowance for this factor. For this reason, it is quite possible that the impeller design could be improved considerably by a more accurate blade stress analysis.

As may well be imagined, the fabrication of an impeller of the stated specifications, with the available facilities and labor, was an almost impossible task. However, since it was a matter of either improvising an impeller or going without, various fabrication techniques were studied by the author with an eye toward the practicable nature of each. Available equipment and labor dictated that the various impeller elements be made individually. For example, the idea of integrally casting the entire impeller was quickly discarded due to the limited foundry facilities and the skilled labor needed for making an accurate pattern. The problem thus became one of developing some technique whereby the blades could be made simply and yet accurately. The size of the blade and its delicate nature indicated that precision casting or, more commonly, the "lost wax" method of casting should be used. A study of this process disclosed that its use is restrictive, being practicable only where skilled labor and appropriate foundry facilities are available. Due to the very thin trailing edge of the blade airfoil, some type of dynamic or centrifugal casting was thought to be desirable. A check of foundry facilities showed that a centrifugal casting installation was being set up, but would not be available for some time. This left only one remaining possibility, that being to cast the blades statically, and then to work them down to size--a process which at best leaves much to be desired. To assure a relatively smooth casting, and to make it possible for the molten aluminum to run into the thin trailing edge portion of the mold, the pattern was dipped in melted paraffin, the trailing edge being held downward as the pattern was drawn out to give an extra thick coating at this point. The resultant castings were accordingly somewhat thick, and had to be finished down so that the blade contours and weights were identical, or as nearly so as was physically possible.

Other elements of the impeller design and fabrication are discussed elsewhere in this thesis under their respective headings.

From the foregoing discussion it can readily be seen that the fabrication process used was far from the best method known, but had to be used under the circumstances. Any of the other methods mentioned would undoubtedly result in a much improved product. However, it is suggested that centrifugal castings of the blades, using a metal pattern and a plaster-of-paris mold, be made when this foundry installation is complete. It is further suggested that a commercial impeller of these specifications be procured as soon as one becomes available, to assure maximum tunnel efficiency.

The blade angle for this particular design is to be approximately 58 degrees from the fan rotation plane to the root chord. However, the greater the speed for which a propeller is designed, the greater the angle at which the blades should be set (4, p.299). This indicates the possibility of obtaining improved impeller characteristics by changing the blade settings. It is suggested, therefore, that test runs be made at various blade angles to determine the best possible blade setting.

B. Power supply.

There is a possibility that the modified Ward Leonard system used will, under favorable conditions, have a tendency for hunting. Since this was considered to be a rather remote possibility, and since it was desired that the power system be kept as simple as possible, the modified system was used. If this tendency is serious, the author would suggest the use of the regular Ward Leonard system described in section IV of this thesis. Essentially, the only difference is that in the latter system the generator and direct current motor fields are separately excited. The arrangement eliminates the possibility of hunting since the motor and generator no longer operate as a synchronous unit. This change can easily be brought about by driving a 30 ampere, 24-30 volt, aircraft excitation generator with the ten horsepower alternating current motor, and by making minor wiring adjustments.

VIII. RECOMMENDATIONS FOR FUTURE DEVELOPMENT

A. Smoke injection.

Airflow patterns are always of interest from an instructional viewpoint. It is suggested that provisions be made for the injection of smoke for this purpose. Separation effects can in this way be more readily discerned than by any other means.

B. Sheet metal diffuser.

A total angle of divergence of 11 degrees and 40 minutes, or a divergence angle of five degrees and 50 minutes with the horizontal was used in the Shields' design. The recommended maximum angle is three and one-half degrees. The design was justified by the argument that there was no divergence in the horizontal plane, therefore the effective divergence angle could be considered to be within the recommended range. The author is not convinced that this explanation is satisfactory, and contends that since separation along any particular surface will occur at a certain angle, even a negative divergent angle on the adjoining perpendicular surfaces will not keep that separation from occurring. It is believed that much better tunnel characteristics will be obtained by replacing this diffuser with one corresponding more nearly to the recommended. The author, therefore, recommends the building of such a section (and a buffer section to be inserted in the rear leg of the circuit to care for the elongation), if tunnel performance characteristics are poor. Note should be made of the fact that witnessing of separation is impossible in this section since it is made of sheet metal.

C. Air exchanger.

It is noted that Mr. Shields made no provision for an air exchanger in his tunnel design. Whether or not an exchanger is necessary is a matter of conjecture. However, it is believed that there will be a tendency for the air to heat in the model tunnel if it is run for relatively long periods of time. If such is the case, some provision for tapping off a small percentage of the air and replacing it by cooler air should be made. The most likely placement for such an exchanger would be at the large end of the rear diffuser.

D. General.

As was mentioned earlier, this project was to serve a dual purpose; to serve as a permanent laboratory installation, as well as to check the Shields' tunnel design. Versatility is obtained from the design feature whereby sections can be removed and replaced by other sections. Replacing one section would, in any event, require the replacement of another--as a buffer if the change results in a change in length, and as a matching section if the change brings about a resultant change in cross section.

It is suggested that the development and testing of this wind tunnel be selected as a graduate thesis project to assure a proper and worthwhile laboratory installation.

IX. BIBLIOGRAPHY

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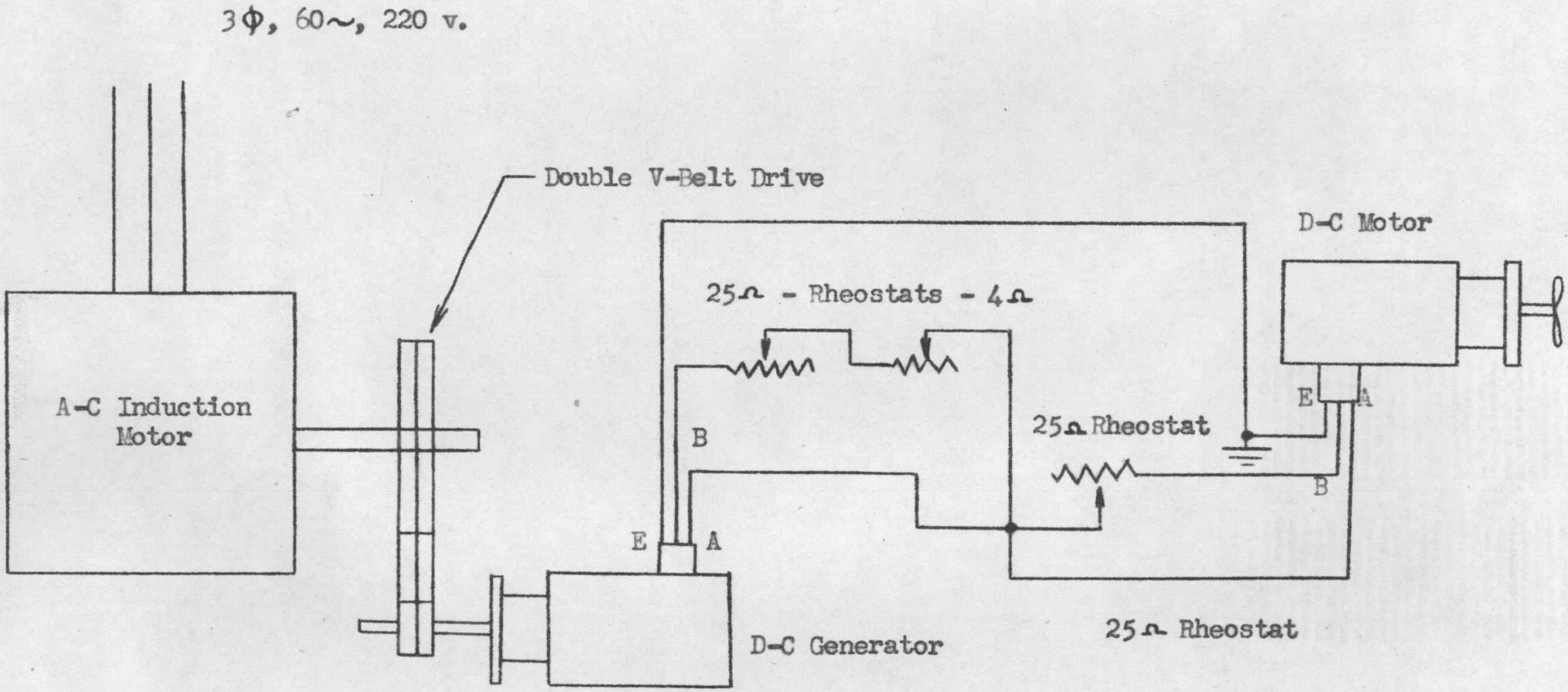
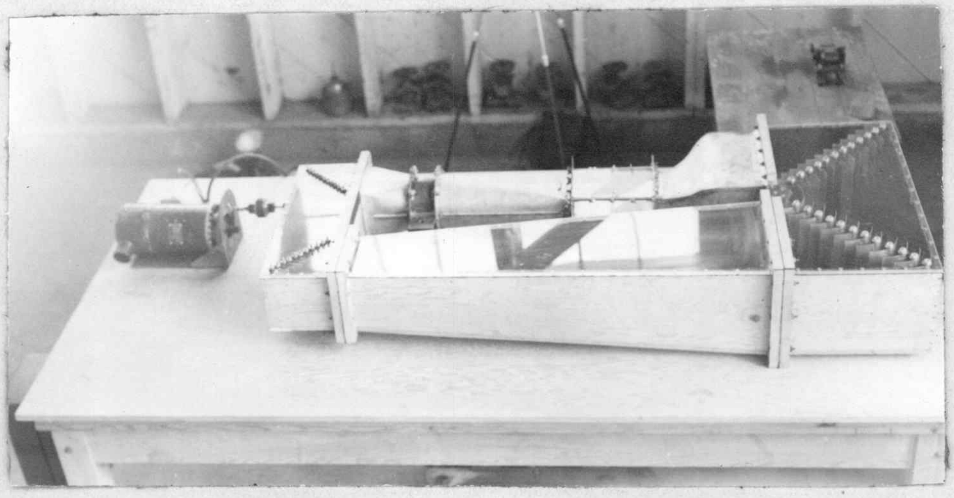
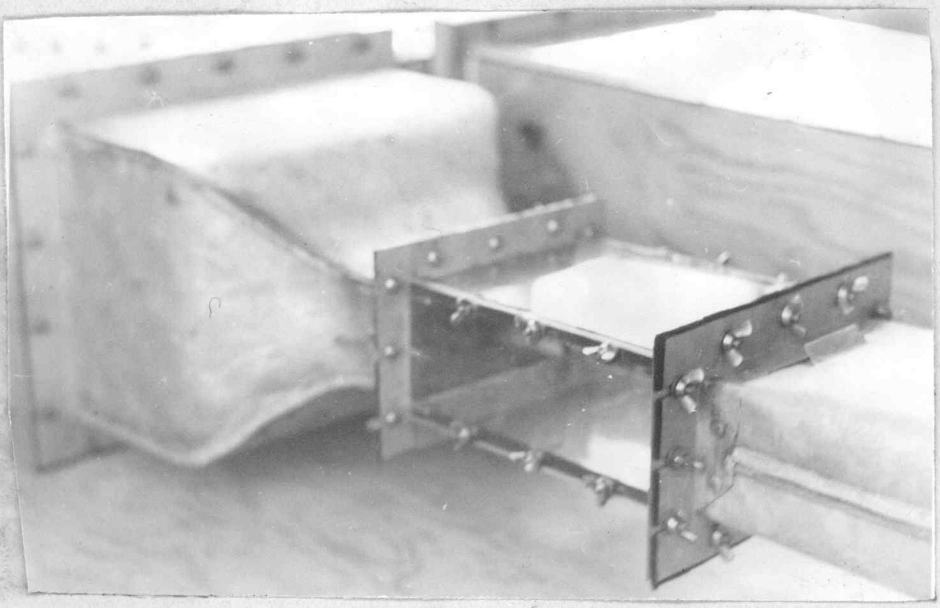


Terminal A - Armature
Terminal B - Field
Terminal E - Ground (common)

MODIFIED WARD-LEONARD POWER SUPPLY.



WIND TUNNEL INSTALLATION



TEST SECTION WITH CONTRACTION CONE


SEC. A-A
SEC. B-B
SEC. D-D
SEC. C-C
NOTE: ALL DUCT DIMENSIONS ARE INSIDE DIMENSIONS
TUNNEL PARTING JOINTS
1/2" PLYWOOD AND PLEXIGLAS
1/2" PLYWOOD & PLEXIGLAS
1/2" PLYWOOD AND PLEXIGLAS
TEST SECTION
SHEET METAL
5/8" PLEXIGLAS
SHEET METAL
SHEET METAL
STEEL SAFETY RING AROUND FAN PLANE
MOTORIZED AIRCRAFT GENERATOR - 200 AMP. 30V.
BEARING MOUNT
TUNNEL BASE
CONSTANT 6 1/2" DIAM. SECTION IN FAN REGION
TRANSITION - CIRCLE TO SQUARE
OVERALL ARRANGEMENT FOR
MODEL OF
HIGH SPEED WIND TUNNEL
OREGON STATE COLLEGE
DEPARTMENT OF
MECHANICAL ENGINEERING
AERONAUTICAL DIVISION
SCALE: 4" = 1 Ft. 0"
DRAWN BY: C. Fanger
APP'VD BY:
DWG. NO. 100106

PLAN DETAIL OF
MODEL OF
HIGH SPEED WIND TUNNEL

OREGON STATE COLLEGE
DEPARTMENT OF
MECHANICAL ENGINEERING
AERONAUTICAL DIVSN.

SCALE: HALF SIZE	DRAWN BY: C. Fanger APP'VD. BY: B.R.	DWG. NO. 100107

DRIVE ASSEMBLY FOR

MODEL OF
HIGH SPEED WIND TUNNEL

OREGON STATE COLLEGE
DEPARTMENT OF
MECHANICAL ENGINEERING
AERONAUTICAL DIVISION

SCALE: FULL SIZE	DRAWN BY: C. Ranger APPROVED BY:	DWG. NO. 100108