

LOW-SPEED WIND-TUNNEL OPERATION AND MAINTENANCE MANUAL



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I. INTRODUCTION

The purpose of this report is to present a brief history of the origin of the tunnel and the philosophies which influenced its design, to outline operating procedure, to describe in some detail items which require checking or maintenance, and to list the pertinent drawing numbers which apply to the tunnel.

Tunnel Operation Procedure

The tunnel should not be operated by personnel until they are familiar with this report and have been checked out on the system. To serve as an aid, a check list is given below.

I. STARTING PROCEDURE OF MOTOR GENERATOR SET

- A. Check oil level in all motor bearings.
- B. Make certain that the doors beneath the motor sets are open to the outside.
- C. Start motor by using lock switch key. This is located in the motor house.
- D. Make certain that the motor "throws over" to the synchronous windings; you will hear a circuit breaker drop into the circuit.
- E. Turn on the overhead fan. Usually only the fan over the M-G set is required.
- F. Lift each oil cap and make certain that the oil dipper rings are rolling about the shaft.
- G. Be sure that the doors are locked when you leave the motor house.

II. WIND-TUNNEL STARTING PROCEDURE

- A. Check test section for loose tools, dirt, and dust.
- B. Make certain model is installed securely.

- C. Close tunnel.
- D. Turn on fan-bearing temperature indicators.
- E. Adjust the zero level of manometer so the meniscus falls on the etched line when set at the zero position.
- F. Turn both speed-control resistors clockwise to their zero-speed stop limit.
- G. Press the "close" button of the d-c Motor Switch; a red light will turn on, indicating that the circuit has been closed.
- H. Advance the main motor speed control by turning in a counterclockwise direction. This is the black iron wheel in the center of the control panel. Be sure to advance the potentiometer slowly; otherwise there is a danger of shearing the pins coupling the fan hub to the shaft.
- I. The main speed control is a step speed adjustment; for fine speed adjustment between steps, use the small rheostat to the right of the main speed control.
- J. After the tunnel has come up to speed, read the height of the water column in the manometer on the control board. The speed of the tunnel is given by:

$$q = 1.028 \Delta p \quad ,$$

$$U_{fps} = 2.90 \sqrt{T} \sqrt{\Delta h} \quad ,$$

where:

q = Dynamic pressure in the test section in lb per sq ft,

Δp = Difference in static pressure between settling chamber and test section in lb per sq ft,

U_{fps} = Test section speed in fps,

\sqrt{T} = Test section temperature in °R, and

$\sqrt{\Delta h}$ = Difference in static pressure between settling chamber and test section in in. of water as measured on the control panel manometer.

- K. During operation of the tunnel, the bearing temperatures should remain very low; if they are high, shut down immediately.
- L. The d-c motor armature current should not be carried past 1600 amp, as indicated by the ammeter on the control panel. There is danger that

the commutator may start to spark to such an extent that the air between two poles will become ionized and a short circuit or a "flash over" will occur. This will burn out the motor.

III. SHUTTING-DOWN PROCEDURE

- A. To reduce the speed of the wind tunnel, rotate the main speed-control handle in a clockwise direction. While reducing the speed, you should observe the "d-c motor armature current" meter on the control panel; do not allow it to read negative. This can happen if you reduce the speed control too fast; then the fan motor becomes a generator and the a-c motor will have to act as a brake.
- B. To shut the wind tunnel off, press the "open" button of the "d-c motor switch." The red light on the panel will go out. Before shutting down, it is advisable to reduce the current in the motor armature circuit to a low level by reducing the speed control. This action will increase the life of the circuit breaker contacts materially. If the wind tunnel is being used intermittently throughout the day, it is advisable to keep the M-G set running continuously.
- C. To turn off the M-G set, press the a-c motor stop button either on the control panel or in the motor house.
- D. Turn off the overhead fan in the motor house.
- E. Make a visual check of the machinery.
- F. Make certain the motor-house doors are closed when you leave.

II. HISTORY

After World War II the Air Force became interested in the effects of gusts upon airplanes and wanted to determine the feasibility of a large-scale gust-simulation device.

In 1952 The University of Michigan contracted with the Air Force to undertake a study of the method of simulating a gust in a wind tunnel at subsonic speeds. From preliminary work two techniques were developed which were tried experimentally in a small open-return tunnel. One technique, that of a moving bump, offered promising results and a larger-scale system was built and tested. This report is concerned with this wind-tunnel system. As a matter of history, the gust device proved satisfactory; however, by the time it was developed, emphasis was being placed upon supersonic development problems. With the advent of Sputnik I, plans for a larger test system concerned with subsonic gust re-

sponse were given a very low priority.

It was not the policy of the Air Force to construct complete facilities. An agreement was made whereby the University furnished the return circuit of the tunnel from station 14 to station 41 (see Fig. 2). Design work started in 1953. Preliminary plans provided for a tunnel structure capable of withstanding a pressurization of 2 atmospheres and reduced pressure operation of 1/2 atmosphere. Bids from several steel-fabricating companies which specialized in wind tunnels were received and all were rejected because of the cost. In view of the excessive cost required to have a tunnel shell capable of these loads, plus the cost necessary to maintain the pressurization level, it was decided to design the tunnel for atmospheric pressure operation only. New bids were sent out and the Nooter Corporation of St. Louis, Missouri, received the bid. Construction of the tunnel was started in 1954 and completed in 1956. The University acted as the general contractor to keep the costs at a reasonable level.

The guiding design philosophy was:

1. to get as much tunnel as we could for our money;
2. to keep the operation and control of the system as simple as possible, since there is a large changeover of personnel using the tunnel;
3. to be conservative in design; and
4. to design the test section and tunnel to fit the needs of research and teaching.

This tunnel was built at a total cost of about \$230,000. In 1958 the Air Force deeded its share to the University and the University is now fully responsible for its operation.

III. AERODYNAMIC SPECIFICATIONS

The tunnel is designed to have a speed range of from 0 to 230 fps. Speeds in excess of this can be obtained by increasing the fan rpm.

Turbulence level in the tunnel has been measured and found to be:

$$\frac{\bar{u}}{U} \leq 0.01\% \text{ at } 100 \text{ fps}$$

(The hot-wire anemometer was not sufficiently sensitive to make an accurate measurement.)

$$\frac{\bar{u}}{U} = .02 \text{ at } 200 \text{ fps}$$

\bar{v} and \bar{w} are approximately greater than the \bar{u} by a factor of 4. Details of the test section are given on page 11.

IV. GENERAL DESCRIPTION OF THE CIRCUIT

The tunnel is a closed-return type having unequal circuit legs and is similar to the RAE 3-x-4-ft tunnel (see Figs. 1 and 2). This circuit did not decrease the overall efficiency of the tunnel; in fact, it probably slightly increased it. However, the main reason for its selection was that it represented an economical fabrication circuit for the tunnel. The centerline dimension and angles are shown in Fig. 4.

Referring to Fig. 2, the wind enters the test section at station 1. The dimensions of the test section are: height, 5 ft; width, 7 ft; and length, 25 ft. Exit from the test section is at station 2. Conversion from a rectangular to a circular cross section is immediately made in the first portion of this diffuser. In this section the equivalent cone angle of the diffuser is 3° . The remainder of the first diffuser has an expansion angle of 5° .

The first and second corners, stations 4-5 and 6-7, have the same dimensions; there is no channel expansion between them. The turning vanes are made of rolled flat plate stock with a rounded leading edge and a tapered trailing edge (see Drawing 20038). A gap-chord ratio of 0.50 is used for all turning vanes. On leaving the second corner, the flow is accelerated about the forward inner body of the fan (see Fig. 3). The diameter of this inner body is 65% of the outer shell diameter. The fan is located at station 8-9 (see page 9 for details of this section). Following the fan is a straightener vane. Details of this section are given in Appendix B. A long after body follows the straightener vanes and allows the flow to expand gradually to the full channel. From station 10 to station 11 the channel expands with an equivalent cone angle of 5° .

At station 11-12 the third corner is located. The turning vanes are made in the same manner as the other corners. Its chord is 3 ft. Following the turning vanes, the channel is converted from a circular cross section to a rectangular one, station 12-13; an equivalent cone angle expansion of $3-1/2^\circ$ accompanies this conversion.

The last corner is rectangular in cross section; this eliminates the flow separation troubles that can occur at the junctions of the vanes and the side walls for circular sections. The turning vanes have a chord of 3 ft. After the turning vanes and just before the rapid expansion section, an atmospheric vent for the tunnel is located (see page 11).

From station 14-15 the channel area is rapidly increased. To keep the flow attached to the walls, a screen is stretched across the channel 6 ft from its entrance. Following this is the settling chamber. Here five screens are stretched across the section at 2-1/2-ft intervals. After the last screen, there is a 10-ft length in the settling chamber before the nozzle starts. Details of the settling chamber are given on page 10.

From station 16 to 1, the flow is accelerated to the test-section velocity.

See below for the details on the construction of this section.

V. STRUCTURAL DESIGN

The tunnel shell is largely made of steel and is circular in cross section from station 3 to 12. The use of a circular cross section was primarily dictated by structural and economic reasons. Furthermore, noise problems are reduced on curved plates as compared to flat plates.

The pressure distribution throughout the tunnel for a speed of 250 fps is shown in Fig. 5. One of the curves represents an atmospheric vent just downstream from the test section. The other curve is for the vent located upstream of the settling chamber. Design conditions considered both loading situations.

From station 2 to station 8, the structure is made of 1/4-in. rolled plate with reinforced rings on the outside. Section 8-9, the fan section, is made of 1-in. rolled steel plate and is machined on the inside to a 10-ft diameter. From section 10 to 14 the prime structure is made of 3/8-in. steel plate. In sections 12-14 the flat panels are reinforced by 4-in. angles or beams which carry the loads from the panels into a ring structure.

From section 14 to 2, the structure is one of a series of steel frames about the channel, with plywood panels bolted on the inside to form the channel walls. Specially formed "hat" section beams are used from stations 14 to 16. Within these beams are mounted the attachment and tensioning mechanism of the screens. In this section 3/4-in.-thick marine bonded plywood panels are used (see Fig. 6).

To develop the curved walls of the nozzle, station 16-1, wood beams carved to the nozzle contour are attached to the inside of the steel ring structure. Plywood sheets 1/2 in. thick are then fastened to these beams by means of glue and screw nails (see Fig. 7).

The test section is built in a similar manner. Six-in. junior "I" beams form the fundamental load-carrying frame. To this frame are bolted 1-1/4-in.-thick plywood panels which form the walls (see Fig. 8).

ATTACHMENT OF TUNNEL TO GROUND

The tunnel is anchored to the ground at two points: stations 8-9 and 14-16 (see Fig. 9). The concrete base on which the fan section (8-9) is mounted also forms the foundation on which the drive motors are mounted. Thus alignment is assured between the fan and the motor even if the foundation settles. The other permanent tie point is the settling chamber. At station 10 an expansion joint

is provided to allow for dimensional changes in the tunnel. The test section of the tunnel is mounted separately on rubber pads and is not attached rigidly to the rest of the circuit. This was done to keep the vibration and noise level in the test section to a minimum value.

ACCESS TO THE TUNNEL CIRCUIT

There are access doors in each leg of the tunnel (see Fig. 3). Not shown in Fig. 3 are the rapid expansion and settling chamber section doors. On the south side of the tunnel, or on the bottom side as viewing Fig. 3, there are removable panels between each of the screens in the settling chamber. There is also one ahead of the screen in the rapid expansion section. These panels are behind the metal siding that protects the wooden structure from the weather.

If you wish to inspect the dust screen supported by the fourth corner turning vanes, or inspect the first metal screen, the easiest way to enter is by the door between the third and fourth turning vanes. You can slide through the turning vanes to enter the rapid expansion section.

DETAILED DESCRIPTION AND MAINTENANCE INSTRUCTIONS OF THE POWER PLANT

The speed range of the tunnel is obtained by varying the fan rpm. A d-c motor using a Ward-Leonard circuit is used to drive the fan by means of a direct shaft. The control circuit is shown in Fig. 10. The d-c motor has full field voltage across its windings at all times. Speed control is obtained by changing the field current in the generator. This will change the armature currents of the generator and motor. Two rheostats are used to control the field current: a large step rheostat, and a small continually variable one. Gross speed settings are made with the step rheostat, and the latter provides continuity of resistance values between the steps. A heavy-duty circuit breaker is used to open and close the armature circuit. This breaker is actuated by a solenoid system. The start and stop buttons control the solenoid which operates the circuit breaker. The circuit is designed to start only under a zero-load condition to prevent sudden starting loads from occurring. On starting, the step rheostat must be on the off position. At that setting, a microswitch is engaged which completes the start button circuit. The armature breaker can then be closed upon action of the start circuit. The tunnel is started by moving the step potentiometer off from the zero potential step.

To stop the tunnel, it is necessary only to press the stop button. However, to protect the circuit breaker, it is desirable to reduce the armature current before opening the breaker. This can be done by reducing the generator field current. Do not reduce the generator field current too fast. Because of the inertia of the motor-fan system, it is very easy for the role of the generator and motor to be interchanged, and in this case the a-c motor would have to act as a brake.

About the only danger to this control system is that the motor field circuit may open up. In this case the motor would start to run away. To prevent this, a spring-loaded centrifugal switch is placed on the end of the motor shaft. This switch has been set to open at approximately 650 rpm. Upon opening, the solenoid is energized in such a manner that the armature breaker is opened. The breaker will remain open until the centrifugal switch is manually re-set.

The a-c motor which drives the generator is a synchronous motor. It is started as an induction motor at reduced voltages. After the motor has reached speed and is synchronized, it is thrown over to the synchronous windings. To start this system, a key-lock start switch is used. This switch is located on the starting panel in the motor house. The switch is located here to make the operator certain that the equipment is in shape and that personnel are not around the machinery. Stop buttons for the a-c motor are located on the starting box panel and also on the wind-tunnel speed-control panel.

Before starting, the oil reservoirs in each of the three bearings of each set should be inspected. Sight glasses are provided on the side of the bearing. A good high-grade nondetergent motor oil of SAE 30 should be used. Babbited bearings are used in the machine, and dip rings which roll around the shaft are used to carry oil to the upper part of the bearings. After the motor has been started, the bearing cap covers should be opened and the motion of the oil dip rings observed. If the dip rings are not rolling about the shaft, shut down immediately. Operation of the machinery in the motor house will cause its temperature to rise. Particularly in the summer the temperatures could get dangerously high and cause bearing trouble. To provide adequate circulation, there is an air duct below each of the machines which is open to the atmosphere. On the roof are two fans which carry the air out of the building. The fan over the motor-generator set has been reduced in speed, and, normally, this one fan is sufficient to keep the machinery cool under most conditions. There are damper-type doors in the air ducts below the machines which can close the duct to the outside. Before starting, inspect these doors to be sure that they are open.

The synchronous motor is run directly off the 4800-volt incoming line. When working on the motor or in the fan section, the main fuses should be pulled, in addition to carrying the key to the start switch. To pull the main fuses, the front of the starting cubicle must be opened to allow access to the fuses. A 5-ft maple pole with a metal hook is used to pull the fuses. Be sure that the pole is clean and dry. Furthermore, the operator should wear rubber gloves which are provided, and stand on a dry rubber pad. With 4800 volts, you will not have a chance to make a second mistake. Personnel should be cautioned to treat the d-c circuit with just as much respect. There are sufficient current capacities to easily electrocute oneself. The wiring diagram of the complete speed-control system is shown in Fig. 15, and the schematic of the starting cubicle is shown in Fig. 16. Professor J. Carey of the Electrical Engineering Department is familiar with this equipment and can be called in for consultation. An electrical inspection arrangement has also been set up with:

Miller-Sheldon Electric Company

Telephone TYler 4-3800

1930 McGraw Avenue

Detroit, Michigan

Attention: Mr. Medsker, Manager, Electrical Repair Service

This company is familiar with heavy-duty machinery, and with this equipment in particular. It has been arranged that this company will make an inspection three to four times a year, with the understanding that the University has full responsibility for the machinery and that the company will act in an advisory capacity only.

VI. FAN SYSTEM

There are 10 blades attached to the fan hub. The tunnel speed is controlled by varying the rpm of the fan. For simplicity, the blades can be changed in pitch by manual adjustment only. The blades are made of laminated spruce wood, using techniques similar to those used with wooden airplane propellers. After the blades were finished, a plastic sheath was applied to the surface. This greatly improves the impact resistance of the blade and reduces corrosion effects of small particles. Drawing number 20103 shows the plan view of the blade; this drawing is reproduced in Fig. 11. Some of the dimensions of the blade are:

Number of blades:	10
Blade span:	24.50 in.
Root chord:	26.65 in.
Tip chord:	17.35 in.
Blade twist:	17°
Airfoil:	RAF 6

Ordinates of the airfoil are given in Appendix B.

An airplane propeller ferrule is attached to the shank of each of the blades. The ferrule is one used by Beech Aircraft Corp.; their drawing number is R201-216, dated 1945.

The fan blades were made by the Flottorp Corp. of Grand Rapids, Michigan. At the time of writing this report, the company had moved to Florida and was no longer making wooden blades. However, one additional blade was made and is stored at the tunnel.

The fan hub is a welded steel structure made up of thick plates to provide a rigid mount for the blade attachment. Drawing 20101 shows the hub structure. Fan blades are held to the hub by means of a split hub block that clamps the fan blade ferrule and is attached to the hub plate. See Drawings 20122, 20121, and

20104 for detail. A general idea of the attachment scheme is given in Fig. 12. The fan-hub assembly is shown in Fig. 13. References to the design drawings are given in Appendix A.

Inspection of the fan-hub assembly and fan shaft bearings should be made about every 6 months. Entrance covers of the forward and aft inner bodies should be removed. On removing the cover plates from inspection holes of the front fan disc, you can inspect the attachment of the fan to the hub. Adjustment of the fan blade to a new pitch angle is made by loosening the four castillated nuts nearest the blade shank and removing the screws that hold the blade-root skin fairing to the fan-hub skin. After adjustment, the castillated nuts should be tightened and secured, and the holes in the blade-root skin fairing should be re-drilled or elongated to match the nut location. You should make sure of three other items on the fan hub:

- (1) that the aluminum skin about the blade shank has not become loose,
- (2) that the shear pins are tight; and
- (3) that both end-hub discs are tight.

Figure 14 shows the general assembly of the fan hub, bearings, and power shaft. The forward bearing is an SKF-SDAF-22234 and the rear bearing is an SKF-SAF-22230. Fan thrust is taken out at the forward bearing location. The bearings are lubricated with grease; use "Lubriko M-2 special." This grease can be obtained from the Detroit Ball Bearing Company. Inspection of the grease level and filling the bearing can be made most easily by removing the bearing caps. You should be careful not to pack the bearing with too much grease. However, under normal operation conditions, the bearings seem to be able to run for much longer periods without requiring grease.

The power shaft is a 12-in. tube with a Thomas-Flexible coupling on both ends (see Drawing 20047). One end of the coupling attaches to the d-c motor and the other end to the fan shaft. The design consideration of the entire fan hub, fan shaft, and power-shaft system was to keep the system torsionally as stiff as possible to reduce modes of vibration which could influence the aerodynamics of the fan.

VII. SETTLING CHAMBER AND SCREENS

As discussed earlier, the settling chamber has a steel-frame structure with plywood walls. The steel frame is used to carry out the pressure loads and the wooden walls were used because of economy and to reduce the noise level in this section. Six screens are stretched across the channel (see Fig. 3). The steel frames that form the tunnel load structure are also used to enclose the mechanism required to stretch and support the screens. The supporting mechanism is shown in Fig. 14. The tube and clamping bars extend the full length on the four sides of each screen. Five screen hangers support each side. Two adjacent sides are

tied directly to the steel frame, while the other two sides are spring loaded. The screens have been pulled up until they are "drum-tight." No technique has been devised to check accurately the screen tension.

The pressure in a major portion of the tunnel is below atmospheric, and dust-laden air tends to leak into the system. Occasionally the last corner and screens need cleaning. The floor of the tunnel can be easily cleaned by using a vacuum cleaner. The screens are cleaned by using a long pole with a brush at the end. With this unit the screens can be thoroughly brushed. Extreme caution should be exercised in working around the screens. The cost of one screen is about \$2,000 and it would easily cost another \$2,000 to \$5,000 to install it.

VIII. TEST SECTION

Detailed drawings of the test section and its assembly are listed in Appendix B. Maintenance and operation of the test section are straightforward and require no explanation.

IX. AIR VENT

The tunnel is vented to the atmosphere at station 14. A slot in the floor 4 in. wide and 8 ft long is connected to a duct that runs beneath the settling chamber and into the laboratory. The exit of this duct in the laboratory is covered with a furnace filter. The vent is within the laboratory to keep the make-up air cleaner and to reduce pressure fluctuations caused by winds.

X. TROUBLE SHOOTING

In the course of about two years of tunnel operation, certain troubles have occurred. It is the purpose of this section to outline them and the corrective measures taken.

A. ICING IN THE FAN SECTION

Probably one of the most common troubles has been the collection of ice in the fan section in the winter months. Moisture tends to collect on the tunnel shell due to a drop in temperature, particularly in the night. Over a period of time water will collect on the floor of the fan section to a depth that will come in contact with the fan blades. With a cold spell, this water will form ice and on starting the fan, it will rub the tips of the fan. Under such circumstances, it is best to open up the fan section and chip the ice out.

A similar situation exists between the fan shaft and the fairing about it. Ice tends to form between the two pieces. Holes have been drilled through the bottom of the fan shaft fairing to help drain the water out.

In both cases, a very distinct rubbing noise is heard upon starting the fan. Usually it is advisable to shut down and clean out the ice in this case.

B. SHUTDOWN OF M-G SET

At times the a-c motor-generator set has suddenly shut down with the result that the tunnel stops also. This trouble has usually been caused by someone putting such a heavy demand upon the power line that the line voltage drops causing the a-c motor to pull out of synchronization. Then the machine is automatically shut off.

C. D-C MOTOR DOES NOT START

If the a-c motor system is operating properly and the d-c motor does not start, the first place to check is the over-speed control of the d-c motor. If this switch is functioning correctly, then the generator field and the armature circuit breaker system should also be investigated. Have an electrician familiar with this type of machinery make this check; you can easily be electrocuted.

XI. RECOMMENDED CHANGES

Certain changes are recommended in the tunnel system on the basis of experience.

A. SEPARATE MOTOR-GENERATOR SET FOR FIELD SYSTEM

One exciter is being used to supply the synchronous motor-generator field and motor field. The generator and motor have eight poles each. These have been wired in a series-parallel circuit of 4 poles in series. The current demanded of such a system is so great that the exciter is being operated at or near its peak level, and it is not possible to get to full motor speed with the exciter current limitations.

It is strongly recommended that a separate motor-generator set be used to supply the fields of both the generator and d-c motor. The present exciter would supply only the synchronous motor.

B. ICING OF FAN SECTION

It would be difficult to prevent ice formation in the tunnel; however, the water could be drawn out of the circuit. A series of about 3/4-in. holes spaced every 5 in. could be drilled along the bottom of the fan section. A collector cup could be placed to the outside of the fan section. This cup should be air-tight so that, during tunnel operation, air does not leak into the circuit.

C. SUN SHIELD

In the summer months the temperature in the tunnel can become quite high. This is due in part to the radiant heating effect from the sun. A sun shield about the steel shell would be of great help. This shield should be designed to aid in the convective cooling of the tunnel and perhaps have provision for spray cooling.

XII. SHUTDOWN FOR EXTENDED PERIODS

If the wind tunnel is shut down for extended periods of time, two months or more, the a-c motor should be started occasionally to prevent the insulation of the coils from becoming damp. Running the a-c motor twice a week for 4-hr periods would probably be sufficient. However, if the a-c motor is not operated for an extended period of time, the resistance of the coils should be measured by a competent electrician. It may be very likely that the coils will have to be dried out by passing a current of reduced voltage through them for a period of time to dry them out. In any event, if the motor has not been operated for an extended period of time, have an electrician determine if the motor is in starting condition.

APPENDIX A

INDEX OF DRAWINGS ON WIND TUNNEL

Listed below are the drawings which apply to the tunnel. At the time of writing this report, the drawings are being stored at the North Campus Laboratory.

WIND-TUNNEL SHELL (NOOTER DRAWINGS)

Nooter drawing numbers

JN-D 10769	Detail of Station 2 and 3 and Station 3 and 4
JN-D 10770	Detail of Station 4 and 5
JN-D 10770A	Full-Scale Layout of Turning Vanes in Section 4
JN-D 10771	Detail of Station 5 and 6, Section 6
JN-D 10772	Detail of Station 6 and 7
JN-D 10773	Detail of Station 7 and 8 and Station 8 and 9
JN-D 10774	Detail of Station 9 and 10
JN-D 10775	Detail of Station 10 and 1
JN-D 10776	Assembly of Gust Generator
JN-D 10950	Foundation Drawing for Gust Generator Model
JN-D 11678	Structural Supports for Roofing and Siding on Gust Generator
JN-D 11680	Structural Supports for Siding and Roofing on Gust Generator

ROOFING AND SIDING ABOUT SETTLING CHAMBER AND NOZZLE (H. H. ROBERTSON COMPANY DRAWINGS)

ER 1 Univ. of Mich. Gust Generator
ER 2 Univ. of Mich. Gust Generator

GENERAL CIRCUIT ARRANGEMENT

20015 - Sketch of 5-x-7 tunnel
20019 - Plan view of 5-x-7 tunnel

TEST SECTION

20054 - Test-section assembly
20055 - Door to test section
20056 - Partition between doors - test section
20057 - Test-section leg supports
20093 - Caster assembly

- 20094 - Wheel holder
- 20095 - Base plate
- 20096 - Parts - support and caster
- 20123 - Test-section support beams

DIFFUSER SECTION AND TURNING VANES

- 20038 - Turning vanes for corners

SETTLING CHAMBER AND NOZZLE

- 20018 - Sketch of steel framing between station 14 to station 1
- 20024 - Details of steel frames
- 20030 - Sketch of settling chamber foundation
- 20074 - Roofing and siding for sections 8, 9, and 10
- 20075 - Roofing and siding for sections 8, 9, and 10
- 20076 - Roofing and siding for sections 8, 9, and 10
- 20077 - Roofing and siding for sections 8, 9, and 10
- 20090 - Screen assembly - gust tunnel
- 20108 - Beam bearing plate
- 20109 - Position of beams and beam supports
- 20110 - Settling chamber and contraction section
- 20111 - Contraction section beams
- 20112 - T brackets for nozzle beams support
- 20113 - Beam supports types K, L, M, and N
- 20114 - Beam supports types CD, F, and G
- 20118 - Screen hanger
- 20119 - Screen hanger assembly

FAN AND HUB SECTION

- 20043 - Fan blade
- 20046 - Revision of Nooter drawing JN-D 10771
- 20101 - Fan hub
- 20102 - Sectional views of fan hub
- 20103 - Fan blade
- 20104 - Rough shape of fan block
- 20105 - Hub end plates
- 20122 - Fan hub and drill pattern
- 20124 - Fan and power shaft assembly
- 20125 - Fan hub and shaft assembly
- 20127 - Location of forward and aft hub plates relative to fan hub
- 20129 - Fan-hub block dimensions
- 20131 - Forward inner body supports

FAN SHAFT AND POWER SHAFT

- 20023 - Sketch of power shaft system
- 20047 - Shaft
- 20048 - Shaft-gust tunnel
- 20086 - Collar-gust tunnel
- 20086A- Collar fan shaft
- 20126 - Collar attachment detail

MOTOR SYSTEM

- 20028 - Plan view of motor foundation
- 20029 - Front and sectional views of motor foundation
- 20081 - Motor base layout
- 20130 - Speed control wiring diagram - low-speed wind tunnel and power plant
Hyde and Bobbio Mechanical and Electrical Contractors
Drawing E-5
- 20132 - Panel wiring diagram and schematic
The Electric Products Company, Cleveland 12, Ohio
Drawing 404-405, D43057

FORWARD INNER BODY

- 20063 - Forward inner body
- 20083 - Inner body frame
- 20097 - Forward inner body
- 20098 - Forward inner body detail

AFT INNER BODY

- 20091 - Detail of aft inner body section
- 20092 - Inner body

STRAIGHTENER VANES

- 20070 - Straightener vane assembly
- 20071 - Straightener vane jig
- 20072 - Straightener vane mold
- 20073 - Straightener vane pattern
- 20027 - Preliminary sketch of straightener blade

FOUNDATION

- 20033 - Foundation layout

- 20028 - Plan view of motor foundation
- 20029 - Front and sectional views of motor foundation
- 20030 - Sketch of settling chamber foundation
- 20040 - Suggested minimum ground levels

APPENDIX B

DIMENSIONS AND ORDINATES FOR VARIOUS COMPONENTS OF THE TUNNEL CIRCUIT

1. NOZZLE SECTION

Dimensions are given relative to the centerline of the tunnel. The origin is at a station 25 ft upstream from the entrance to the test section and in the plane of the last hat section frame (see Drawings 20110 and 20111). Dimensions are given to the inside wall of the test section and are to the nearest 1/8 in.

Station	Length	Height from C.L.	Width from C.L.
1	0' 0"	9' 11-2/8"	12' 11-2/8"
2	1' 3"	9' 11-2/8"	12' 11-2/8"
3	2' 6"	9' 10-6/8"	12' 11-2/8"
4	3' 9"	9' 9-5/8"	12' 10-5/8"
5	5' 0"	9' 6-7/8"	12' 7-6/8"
6	6' 3"	9' 2-5/8"	12' 2-6/8"
7	7' 6"	8' 8-3/8"	11' 7-3/8"
8	8' 9"	8' 0"	10' 9-4/8"
9	10' 0"	7' 1-7/8"	9' 8-4/8"
10	11' 3"	6' 2-7/8"	8' 5-3/8"
11	12' 6"	5' 3-5/8"	7' 2"
12	13' 9"	4' 4-6/8"	5' 11-5/8"
13	15' 0"	3' 8"	5' 0"
14	16' 3"	3' 1-4/8"	4' 3-4/8"
15	17' 6"	2' 9-5/8"	3' 10-4/8"
16	18' 9"	2' 7-6/8"	3' 8"
17	20' 0"	2' 7-6/8"	3' 6-4/8"
18	21' 3"	2' 6-6/8"	3' 6"
19	22' 6"	2' 6-2/8"	3' 6"
20	23' 9"	2' 6"	3' 6"
21	25' 0"	2' 6"	3' 6"

2. FAN BLADE PROFILES

See Drawings 20103 and 20045. Airfoil is an RAF section F. Ordinates are given for the stations as defined in drawing 20103.

- X = distance from the leading edge
- Y = height above chord line
- R_L = leading edge radius
- R_T = trailing edge radius
- Z' = position of the blade tip relative to the axial centerline of the blade.

All dimensions are parallel and normal to the "station 0" chord plane. β = angle of twist relative to "station 0."

Station 0		Station 1		Station 2		Station 3	
X	Y	X	Y	X	Y	X	Y
0	0.29	0	0.28	0	0.27	0	0.25
0.33	0.72	0.32	0.68	0.30	0.65	0.29	0.62
0.67	0.97	0.63	0.92	0.60	0.88	0.58	0.84
1.33	1.36	1.27	1.29	1.21	1.23	1.15	1.18
2.00	1.65	1.90	1.57	1.81	1.50	1.73	1.43
2.67	1.84	2.53	1.75	2.42	1.67	2.30	1.59
4.00	2.06	3.80	1.96	3.63	1.87	3.46	1.78
5.33	2.19	5.06	2.08	4.84	1.98	4.61	1.89
8.00	2.29	7.60	2.17	7.25	2.08	6.91	1.98
10.67	2.27	10.13	2.15	9.67	2.06	9.22	1.96
13.33	2.16	12.66	2.05	12.09	1.96	11.52	1.87
16.00	2.00	15.19	1.89	14.51	1.81	13.82	1.72
16.67	1.74	17.72	1.65	16.93	1.57	16.13	1.50
21.33	1.39	20.26	1.32	19.34	1.26	18.43	1.20
24.00	0.96	22.79	0.91	21.76	0.87	20.74	0.83
25.33	0.75	24.05	0.71	22.97	0.68	21.89	0.65
26.65	0.29	25.32	0.28	24.18	0.27	23.04	0.25
R_L	0.29	R_L	0.28	R_L	0.27	R_L	0.25
R_T	0.29	R_T	0.28	R_T	0.27	R_T	0.25
Z'	12.00	11.40	1.48	10.84	1.98	10.27	2.28
β	0°	3.09°		5.74°		8.12°	

Station 4		Station 5		Station 6		Station 7		Station 8	
X	Y	X	Y	X	Y	X	Y	X	Y
0	0.24	0	0.23	0	0.22	0	0.20	0	0.19
0.27	0.59	0.26	0.56	0.25	0.53	0.23	0.50	0.22	0.47
0.55	0.80	0.52	0.76	0.49	0.71	0.46	0.67	0.43	0.63
1.10	1.12	1.04	1.06	0.98	1.00	0.93	0.94	0.87	0.88
1.64	1.36	1.56	1.29	1.47	1.22	1.39	1.15	1.30	1.07
2.19	1.51	2.08	1.43	1.96	1.36	1.85	1.28	1.74	1.20
3.29	1.70	3.12	1.61	2.95	1.52	2.78	1.43	2.60	1.34
4.38	1.80	4.15	1.70	3.93	1.61	3.70	1.52	3.47	1.42
6.57	1.88	6.23	1.78	5.89	1.69	5.55	1.59	5.21	1.49
8.76	1.86	8.31	1.77	7.86	1.67	7.40	1.57	6.94	1.48
10.96	1.77	10.39	1.68	9.82	1.59	9.25	1.50	8.68	1.41
13.15	1.64	12.46	1.55	11.78	1.47	11.10	1.38	10.41	1.30
15.34	1.43	11.54	1.35	13.75	1.28	12.95	1.20	12.15	1.13
17.53	1.14	16.62	1.08	15.71	1.02	14.80	0.96	13.88	0.90
19.72	0.79	18.69	0.75	17.68	0.71	16.65	0.67	15.62	0.62
20.81	0.61	19.73	0.58	18.66	0.55	17.58	0.52	16.48	0.49
21.91	0.24	20.77	0.23	19.64	0.22	18.50	0.20	17.35	0.19
R_L	0.24	R_L	0.23	R_L	0.22	R_L	0.20	R_L	0.19
R_T	0.24	R_T	0.23	R_T	0.22	R_T	0.20	R_T	0.19
Z'	9.70	9.12	2.65	8.60	2.76	8.00	2.86	7.45	2.83
β	10.26°	12.19°		13.95°		15.55°		17.00°	

3. STRAIGHTENER VANE PROFIT

See Drawings 20027 and 20070 blade profit - NACA Symmetrical section with constant thickness along the vane.

NACA 0018.5		NACA 0012	
Distance from Leading Edge	Height Above Chord Line	Distance from Leading Edge	Height Above Chord Line
0	0	0	0
0.44	1.04	0.67	1.02
0.88	1.41	1.35	1.41
1.75	1.92	2.70	1.92
2.62	2.26	4.04	2.26
3.50	2.53	5.39	2.53
5.25	2.88	8.09	2.88
7.00	3.10	10.79	3.10
8.75	3.20	13.48	3.20
10.50	3.24	16.18	3.24
14.00	3.13	21.60	3.13
17.50	2.85	27.00	2.85
21.00	2.46	32.40	2.46
24.50	1.97	37.70	1.97
28.00	1.41	43.10	1.41
31.50	0.78	48.50	0.78
35.00	0.07	53.90	0.07
Leading edge radius	1.27	Leading edge radius	0.85

4. FORWARD INNER BODY DIMENSIONS

Referring to Drawing 20063, dimensions are given along the centerline of the body and normal to the centerline. The origin is at the nose of the body.

<u>Distance Along Centerline in Inches</u>	<u>Radial Distance in Inches</u>
0	15.25
11	26
21	31.5
31	34.75
41	37
51	38
60.75	38.5

5. AFT INNER BODY DIMENSIONS

Drawings 20091 and 20092 show details of the aft inner body. Dimensions of the body are listed below.

X = distance from base of inner body along tunnel centerline

R = radial dimension of inner body

X	R	X	R
0	39.00	132	28.22
12	38.75	144	27.10
24	38.10	156	25.95
36	37.10	168	24.70
48	36.10	180	23.30
60	35.00	192	21.80
72	33.87	204	20.10
84	32.74	216	18.25
96	31.61	228	16.10
108	30.48	240	13.50
120	29.35	248	11.50
		256.3	8.5
		271.3	0

Note that all dimensions are in inches.

APPENDIX C

References pertinent to the 5-x-7-ft low-speed tunnel are given below.

1. H. B. Squire, K. G. Winter, and E. G. Barnes, The R.A.E. 4-ft-x-3-ft Experimental Low Turbulence Wind Tunnel, Part I, Report No. Aero. 2182, Feb., 1947.
2. H. Schur and K. G. Winter, The R.A.E. 4-ft-x-3-ft Experimental Low Turbulence Wind Tunnel, Part II, Measurement of Longitudinal Intensity of Turbulence, Report No. Aero. 2285, Aug., 1948.
3. G. N. Patterson, "Ducted Fans: Design for High Efficiency," ACA, 7 (1944).
4. A. R. Collar, "Cascade Theory and the Design of Fan Straightners," R and M, 1885 (1940).
5. L. C. Garby, K. R. Raman, and R. L. Roensch, Estimation of the Power Factor for the 5-ft-x-7-ft Tunnel, GTM-4, May, 1954.
6. L. C. Garby, Cost Breakdown of the Gust Generator Model, GTM-5, July, 1954.
7. R. L. Roensch, A Method for Determining the Design Specification for a Fan-Straightner Configuration, GTM-6, July, 1954.
8. K. R. Raman, Estimation of Heat Transfer Coefficient and the Evaluation of Temperature of the Air Inside the 5-ft-x-7-ft Gust Generator Model, GTM-7, July, 1954.

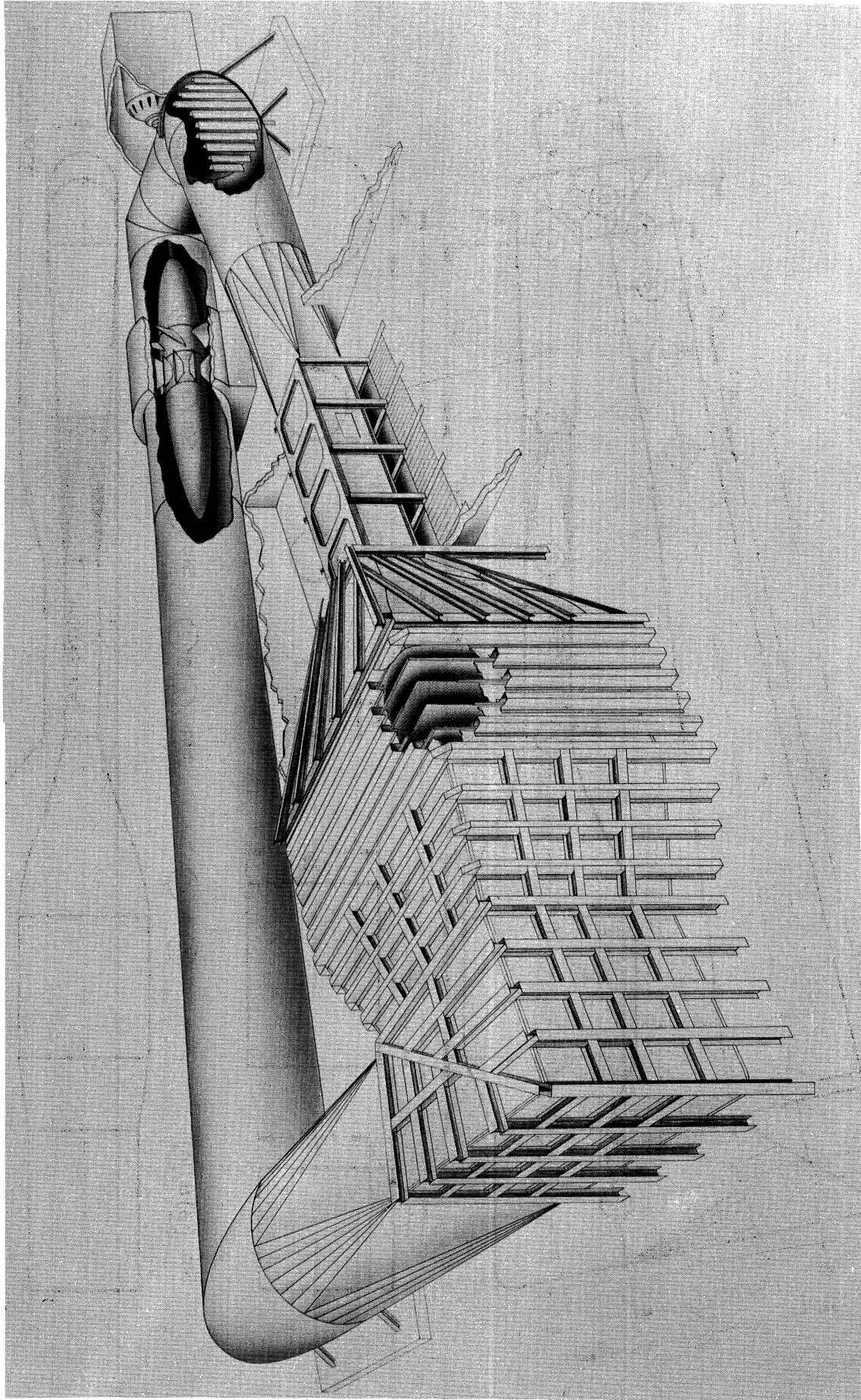


Fig. 1. Sketch of gust generator model.

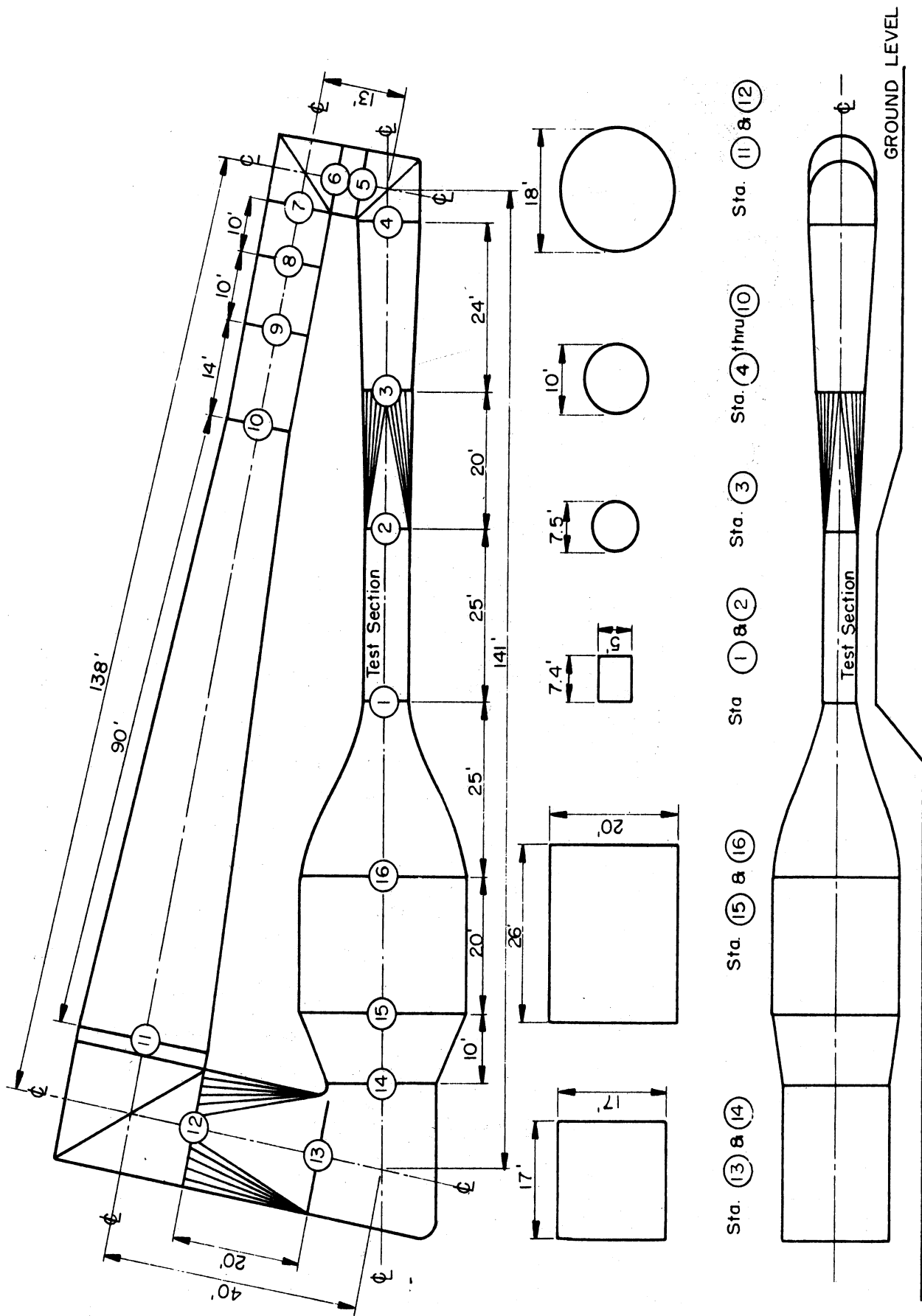
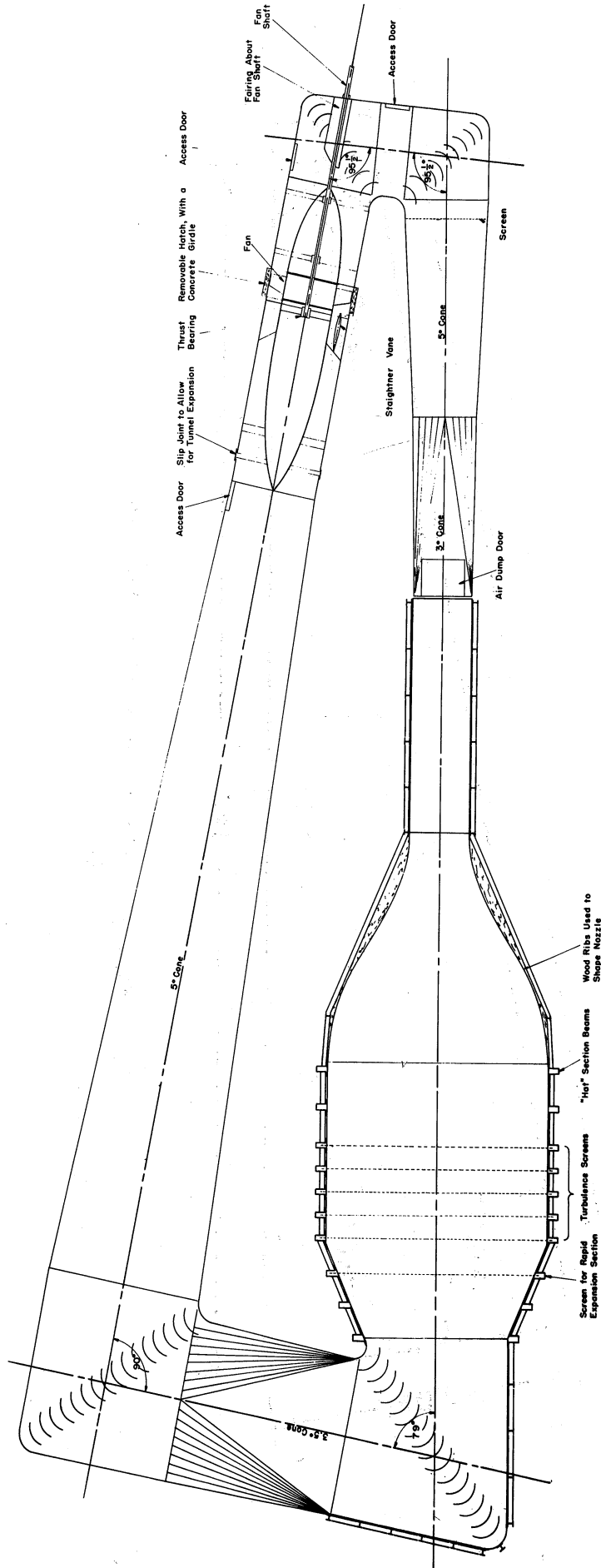


Fig. 2. Sketch of gust generator model.



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Fig. 3. Section view of gust generator model.

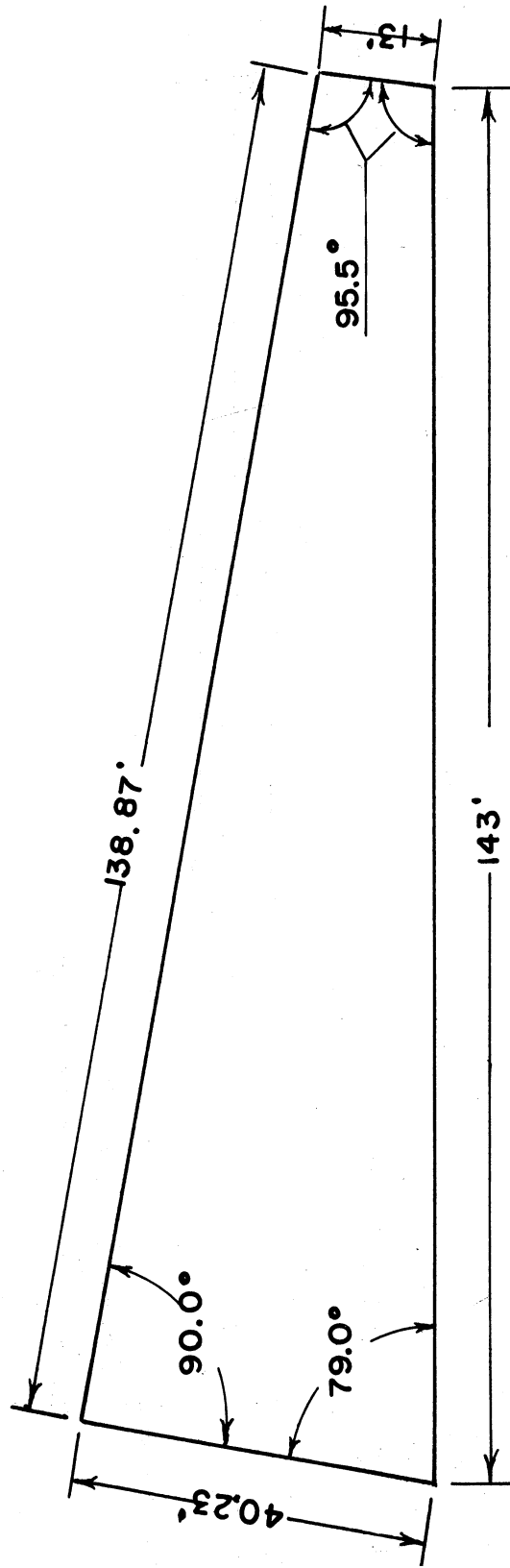


Fig. 4. Tunnel centerline dimensions.
 (Drawing No. 20041)

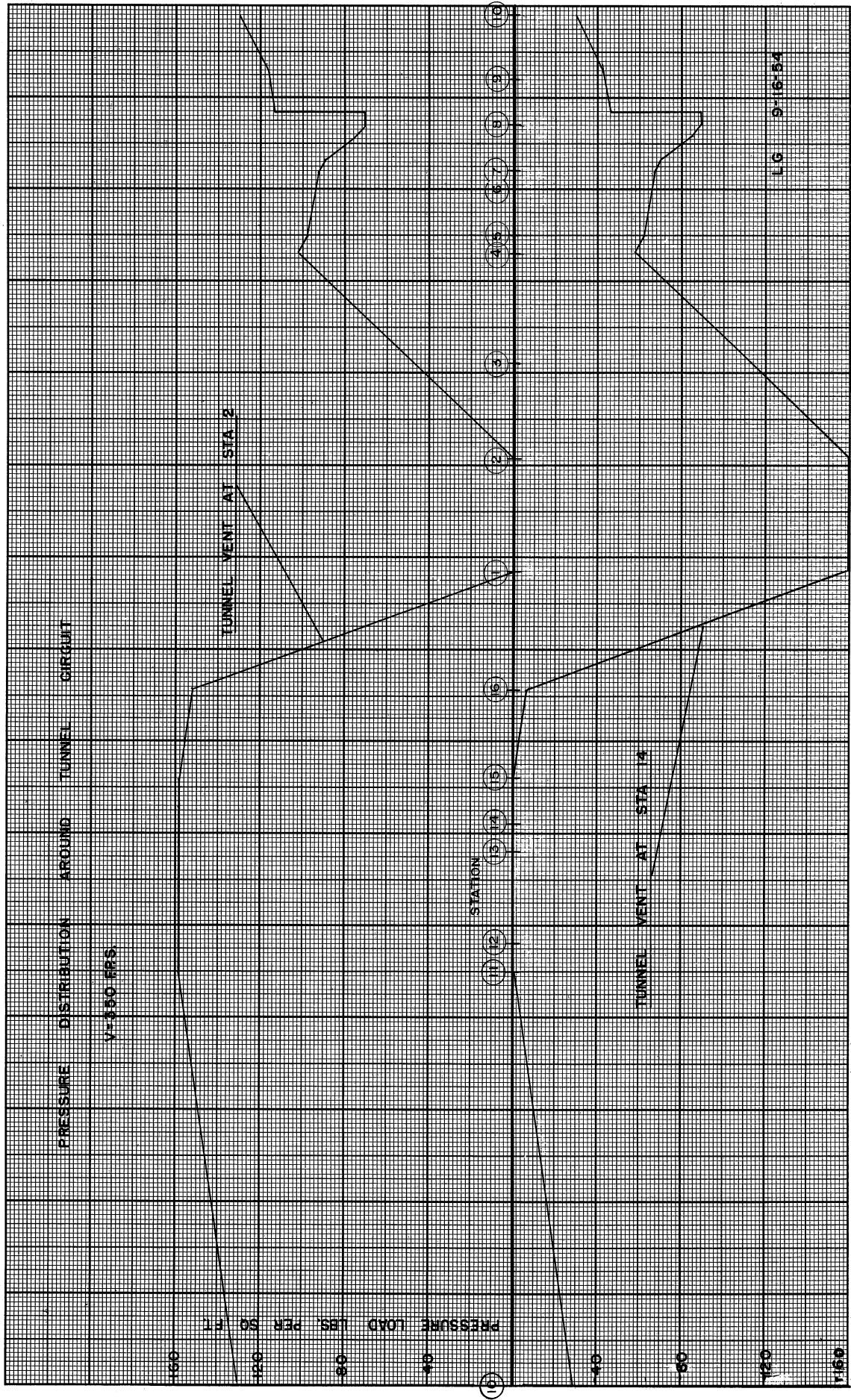


Fig. 5. Pressure distribution around tunnel circuit.

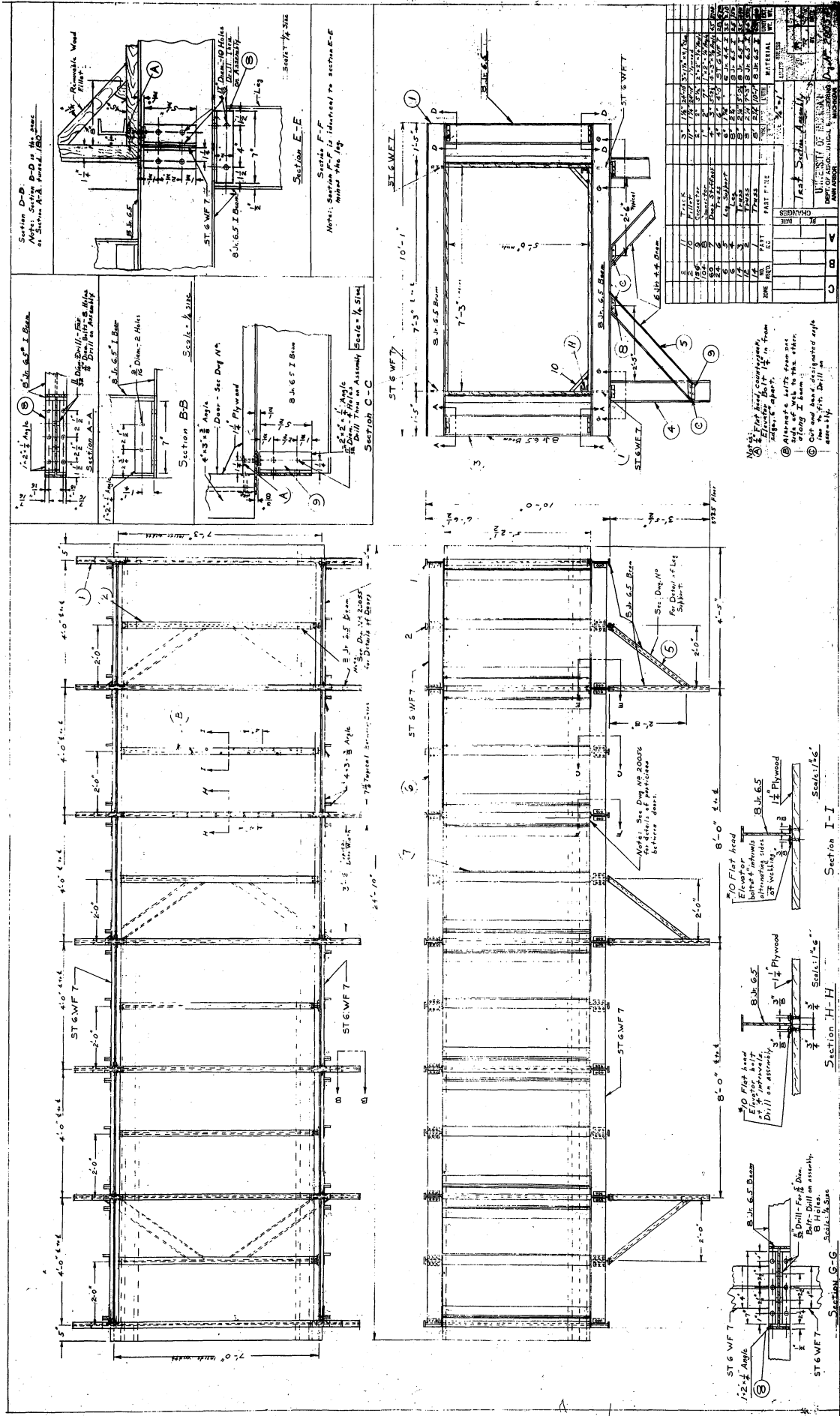
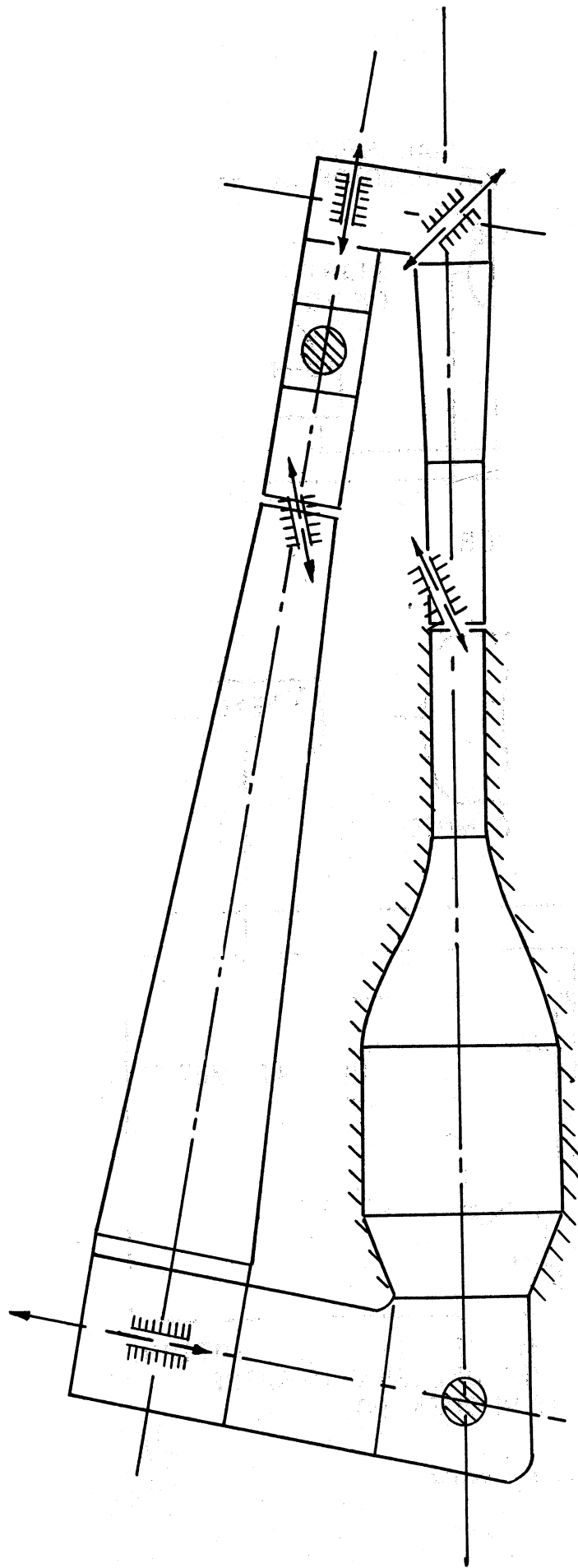


Fig. 8. Test section assembly.



Constrained in all directions

Constrained in one direction and free to move as shown by arrows.

Fixed point

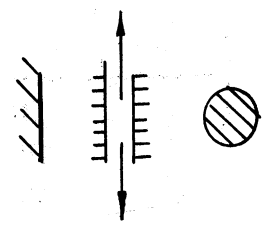


Fig. 9. Suggested restraint system for gust generator model.
(Drawing No. 20031)

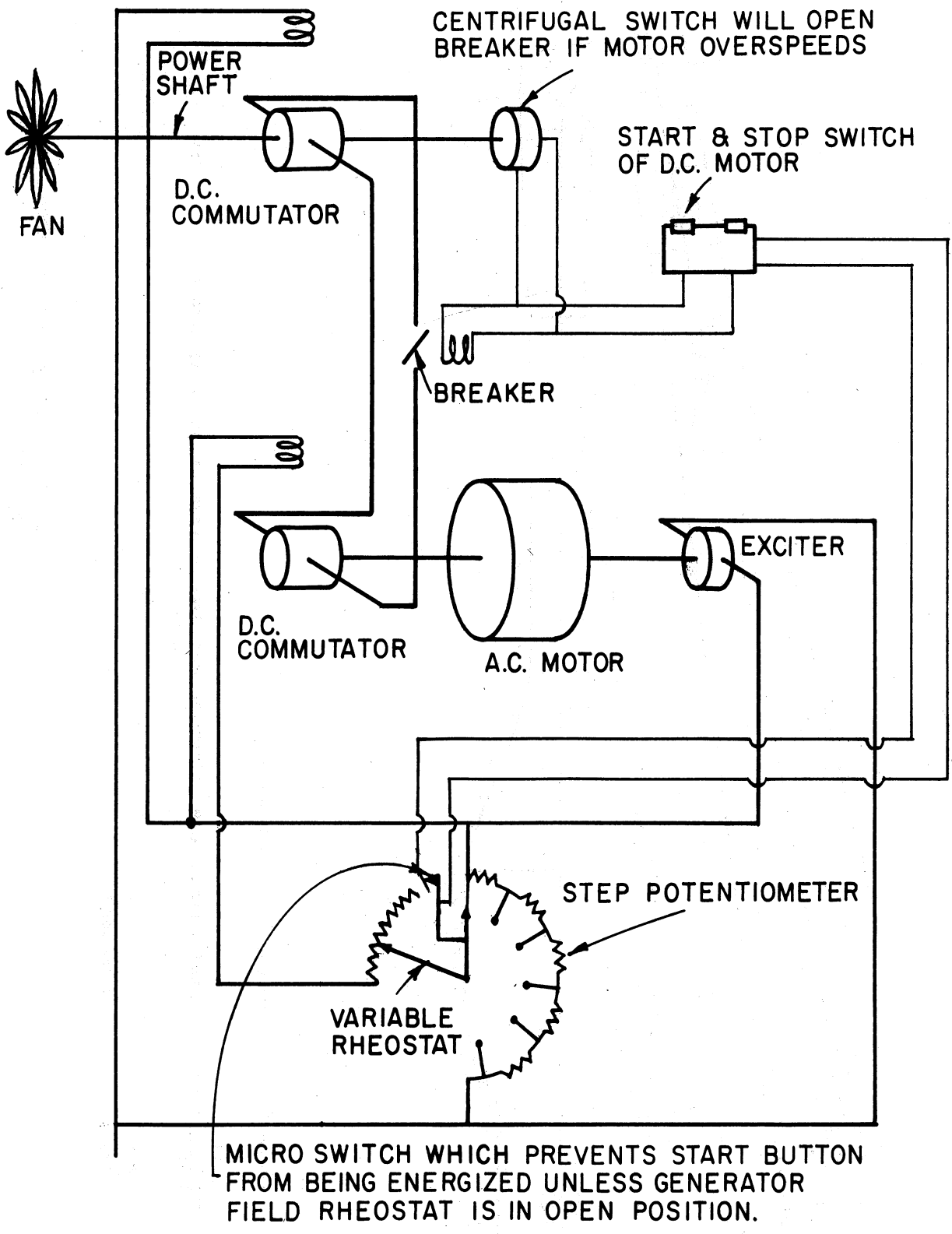


Fig. 10. Ward-Leonard control circuit.

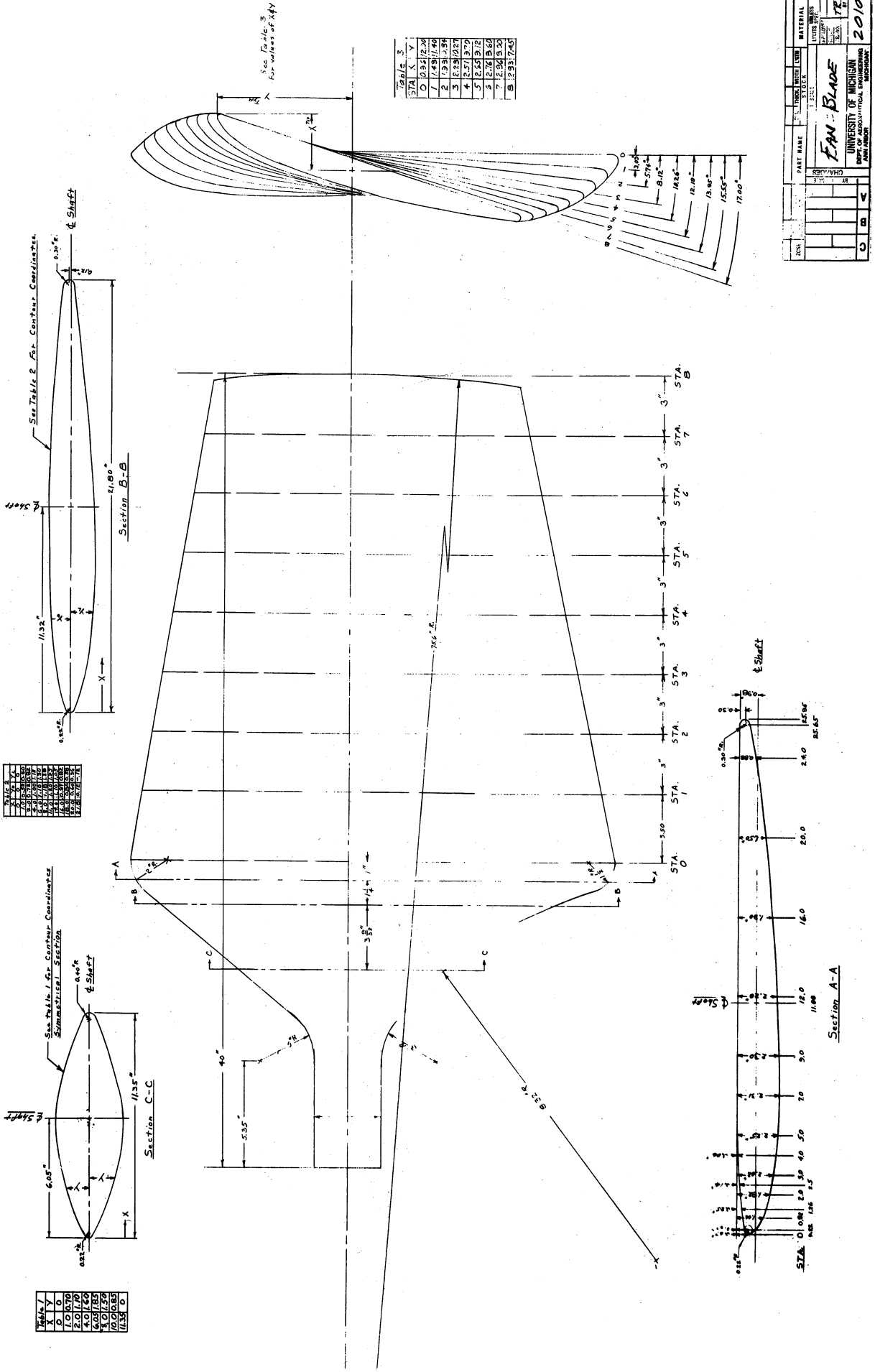
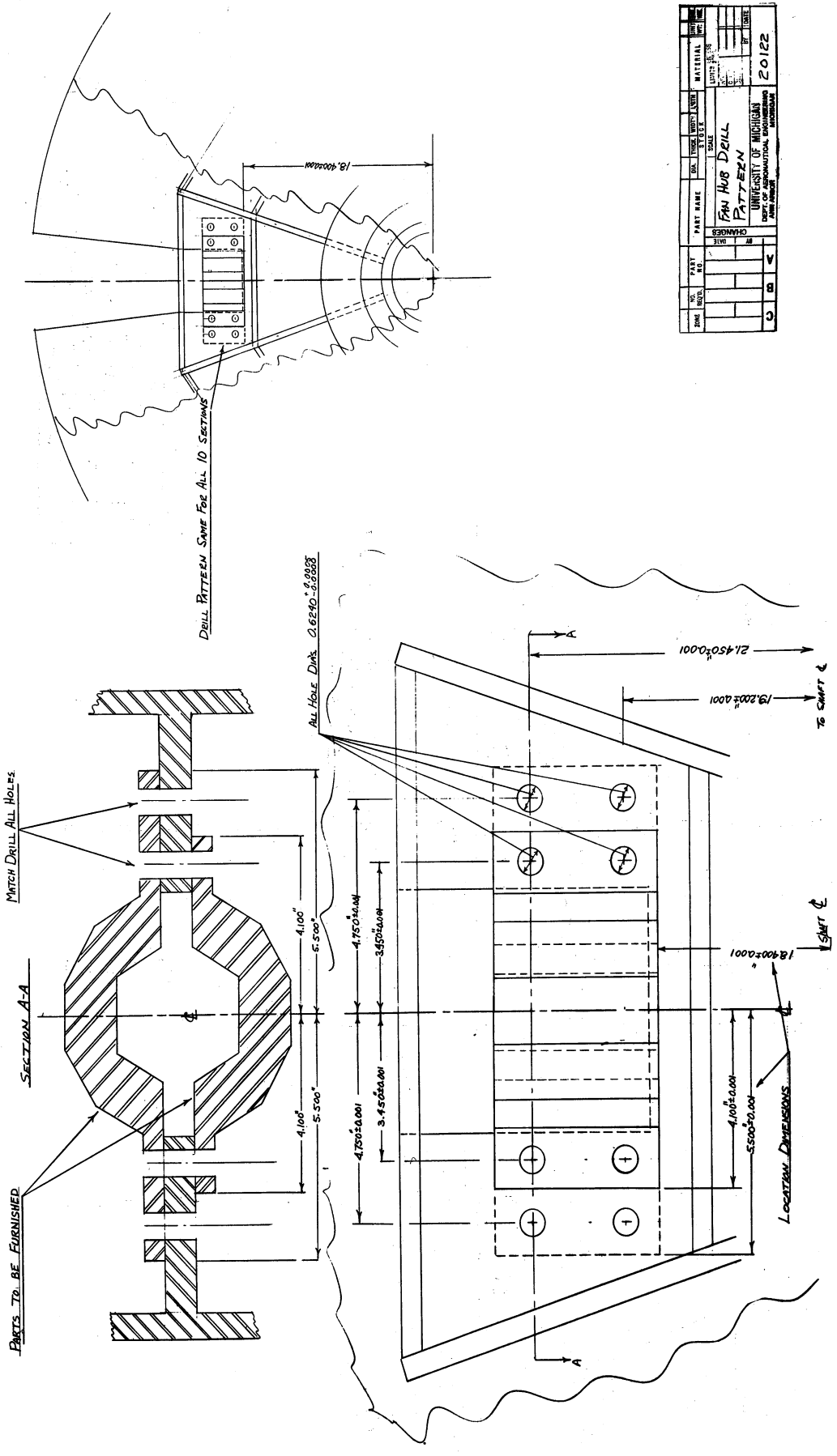
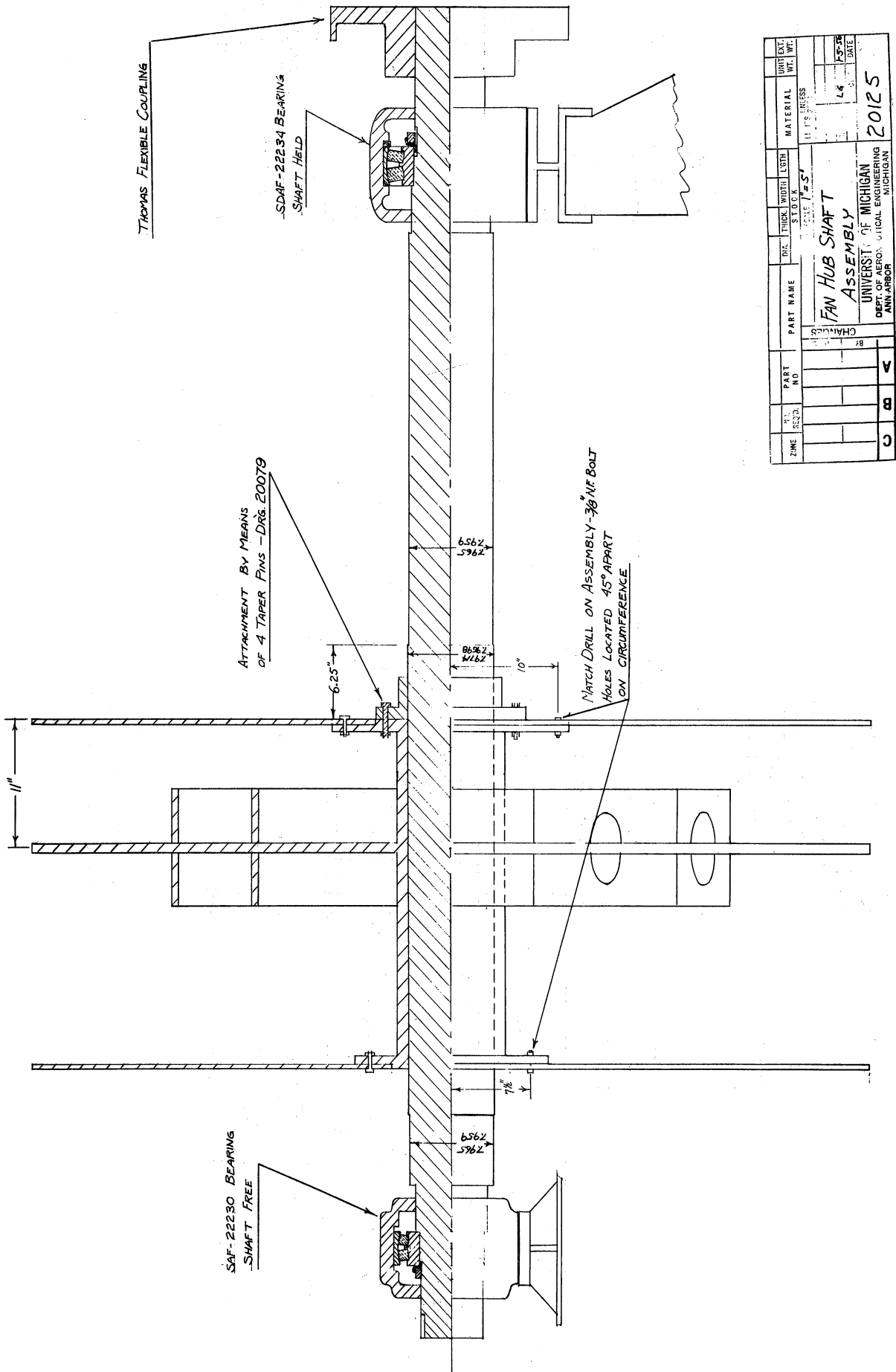


Fig. 11. Fan blade profile.



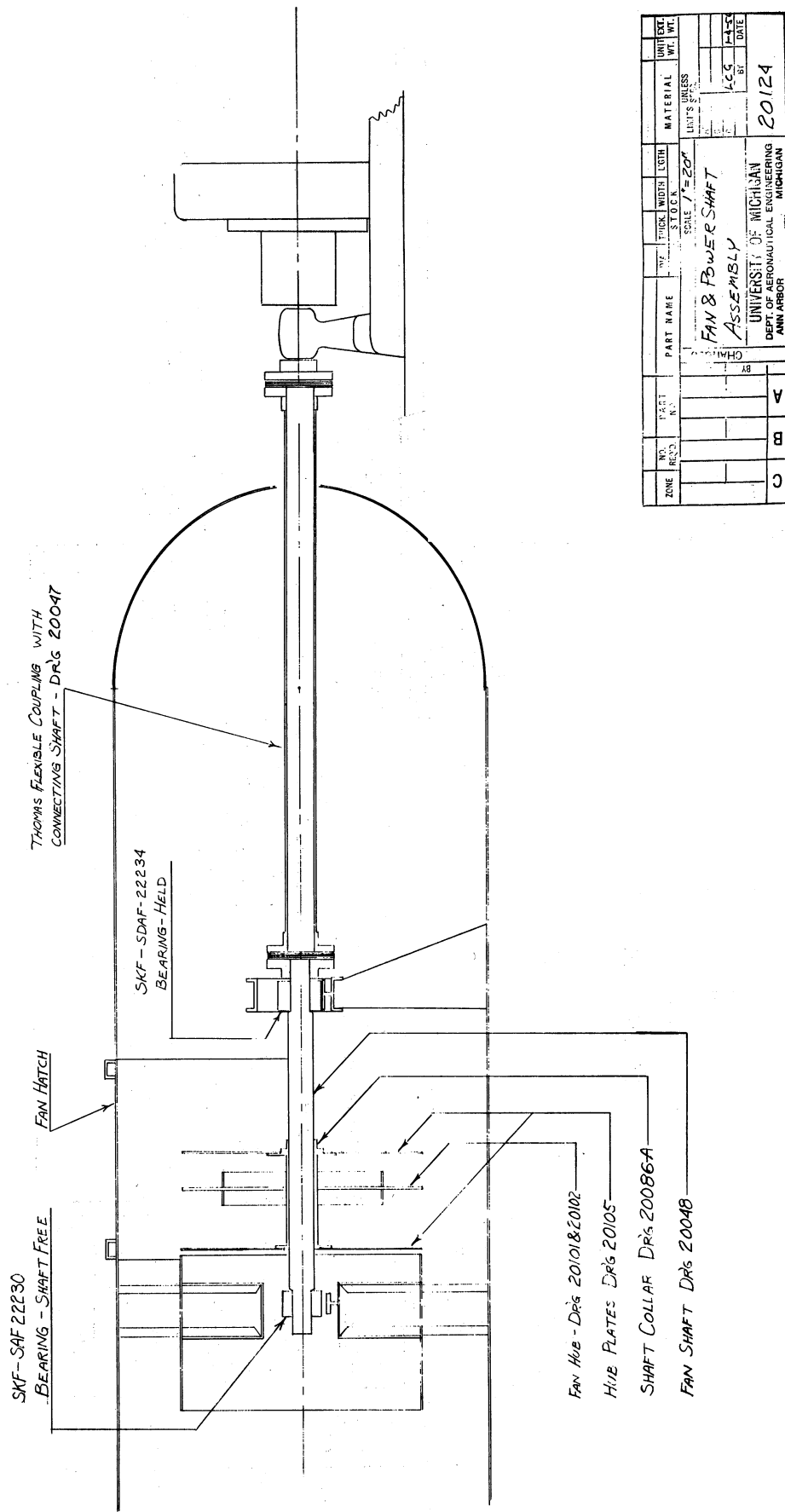
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Fig. 12B. Fan blade clamping blocks attached to fan hub (rough shape of blocks before machining).



PART NO.	PART NAME	QTY.	UNIT EXT.	DATE
A	FAN HUB SHAFT			2015
B	ASSEMBLY			
C	UNIVERSITY OF MICHIGAN DEPT. OF AEROSPACE ENGINEERING ANN ARBOR, MICHIGAN			

Fig. 13A. Fan hub shaft assembly.



ZONE	NO. REC'D	PART N.O.	PART NAME	THICK. STOCK	WIDTH	LETH	MATERIAL	UNITE
C								
B								
A								
SCALE 1"=20" FAN & BLOWER SHAFT ASSEMBLY UNIVERSITY OF MICHIGAN DEPT. OF AERONAUTICAL ENGINEERING ANN ARBOR MICHIGAN							UNITS UNLESS OTHERWISE SPECIFIED LCC BY DATE 2012	

Fig. 13B. Fan power shaft assembly.

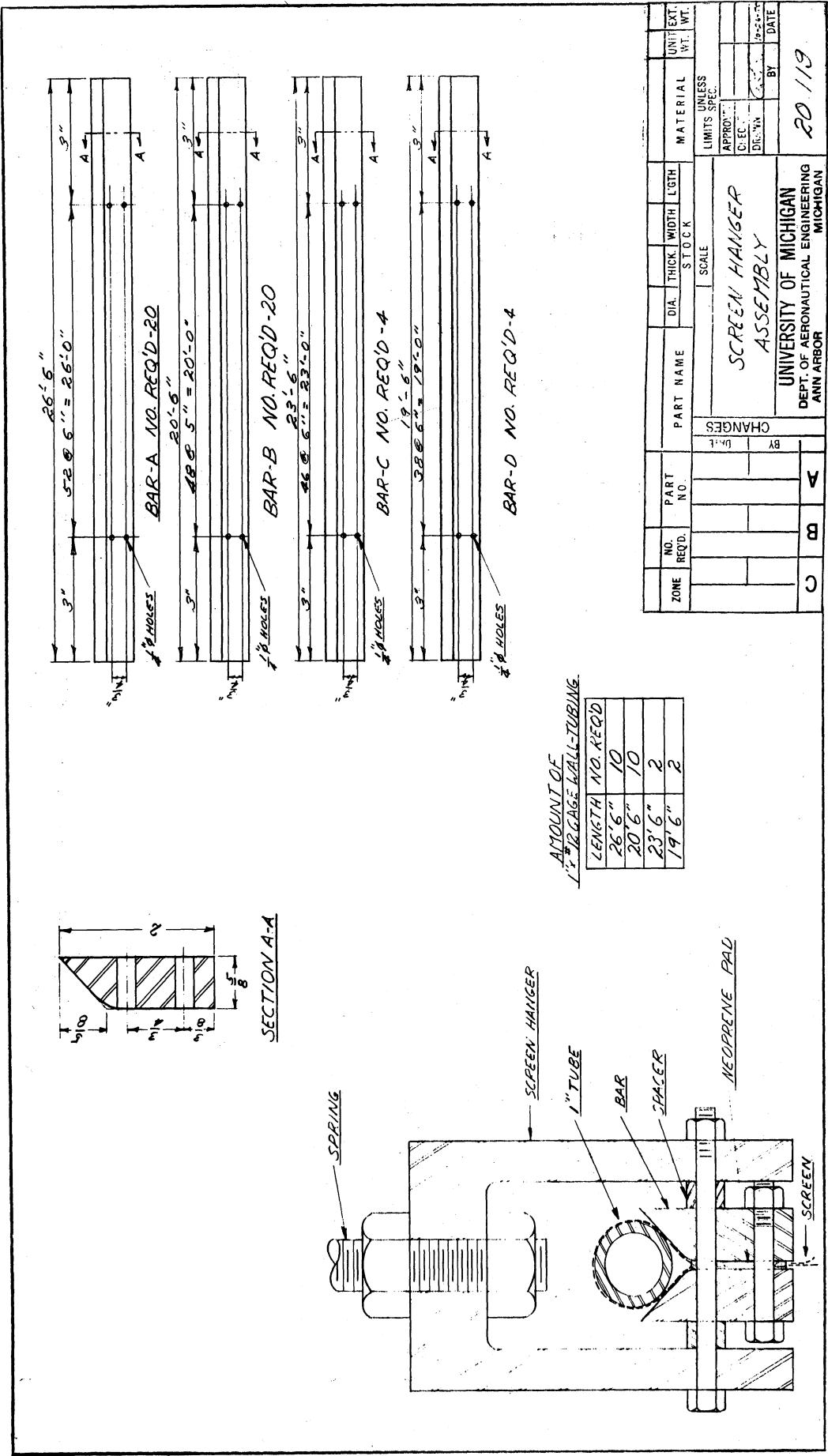


Fig. 14. Hanger assembly for screens.

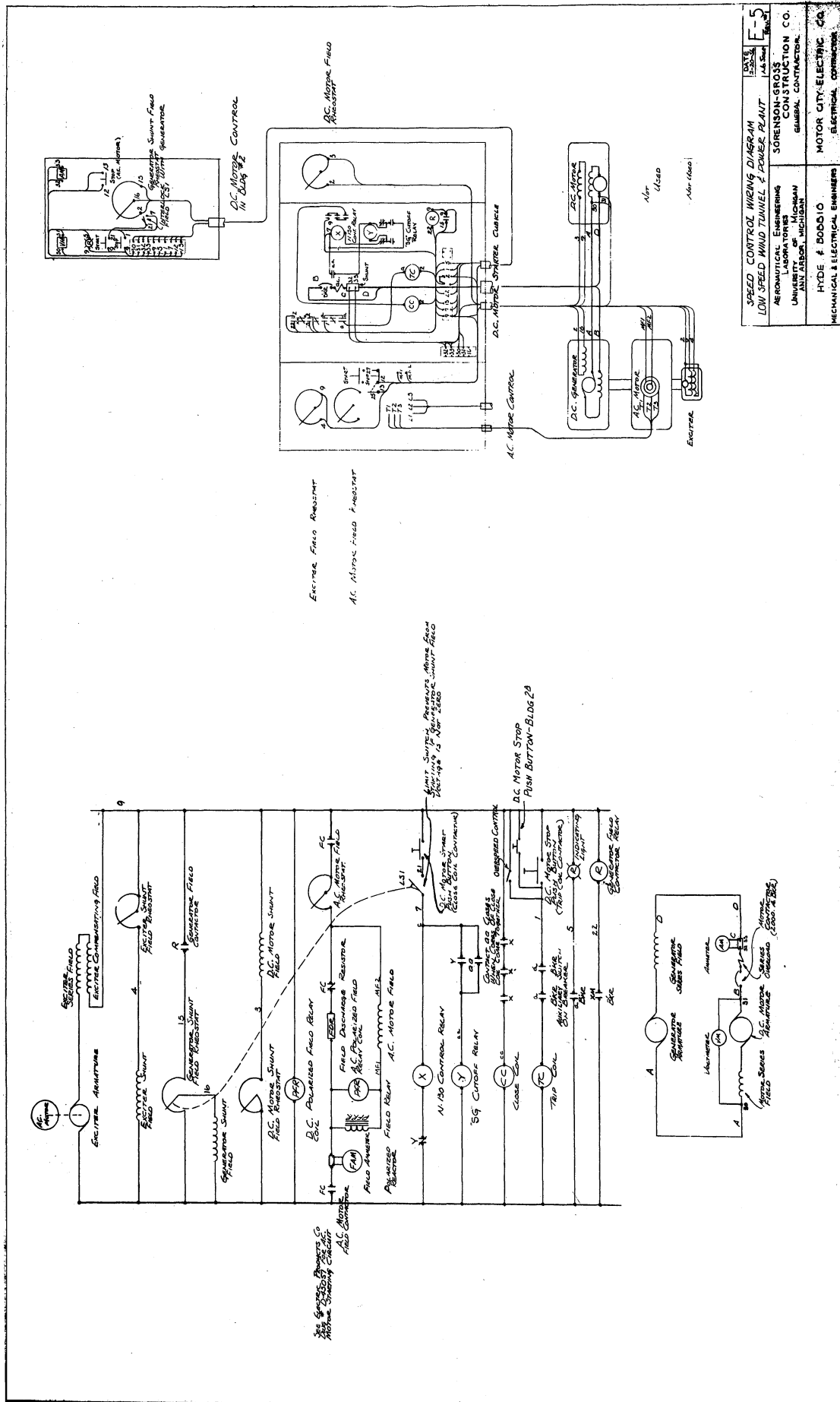
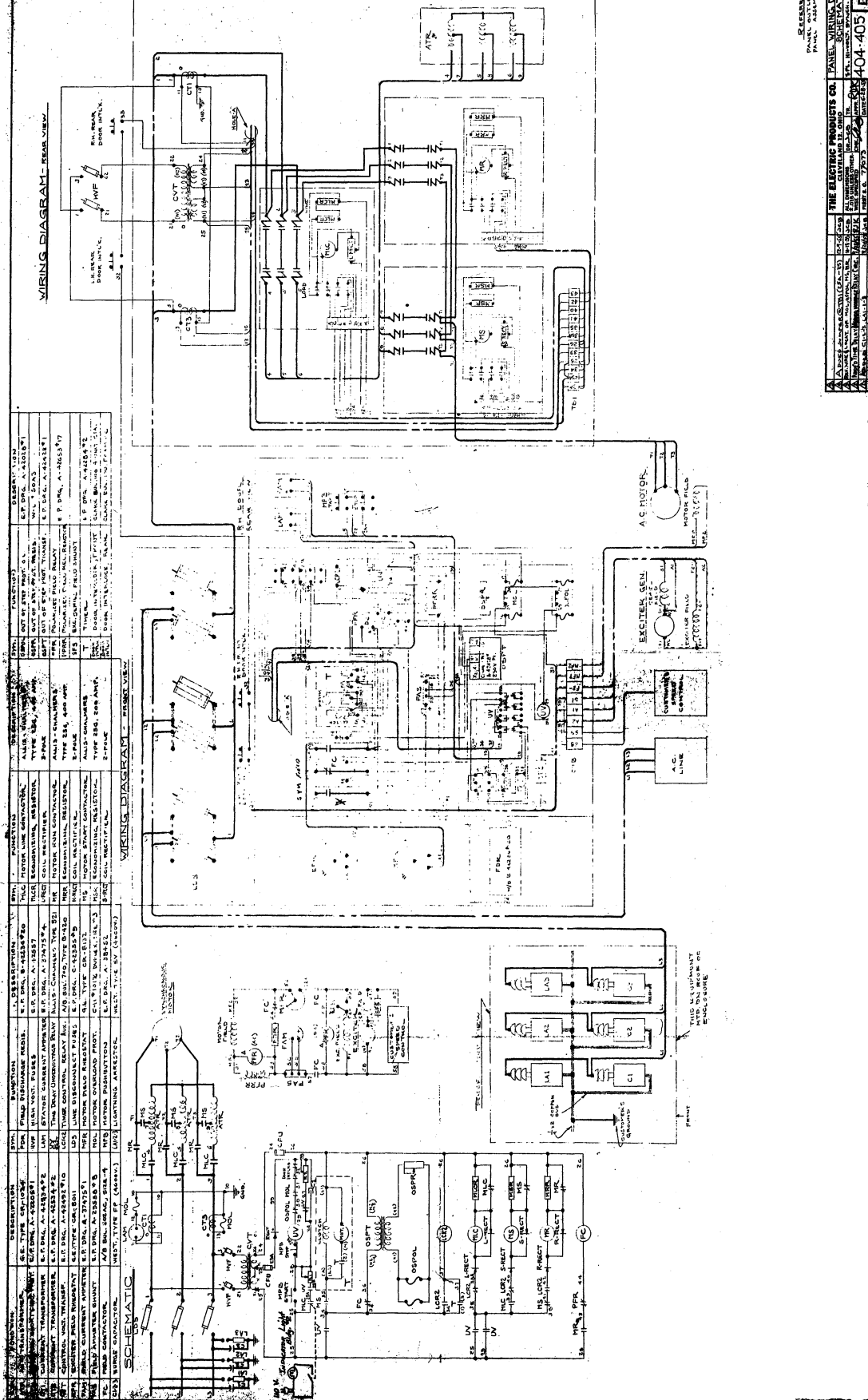


Fig. 15. Speed control wiring diagram for low speed wind tunnel.

D-43037



THE ELECTRIC PRODUCTS CO. PANEL WIRING DIAGRAM
 404-403 D-430
 THE ELECTRIC PRODUCTS CO. PANEL WIRING DIAGRAM
 404-403 D-430

Fig. 16. Starting cubicle wiring diagram.