NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

THE LEWIS UNITARY PLAN WIND TUNNEL

LEWIS FLIGHT PROPULSION LABORATORY
Cleveland, Ohio

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THE LEWIS UNITARY PLAN WIND TUNNEL

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

GENERAL DESCRIPTION

A plan view of the Lewis Unitary Plan Wind Tunnel is shown in figure 1. The tunnel has a Mach number range of 2 to 3.5 and can be operated throughout the entire Mach number range on either an aerodynamic cycle at various air densities or on a propulsion cycle. On the aerodynamic cycle, the tunnel operates as a closed return-type tunnel, and on the propulsion cycle it operates as an open nonreturn-type tunnel. The main components are:

Air dryer building. - The purpose of the air dryer building is to dry the air used in the tunnel. It contains 1900 tons of absorbent known as type I grade D activated alumina in six beds 3 feet thick. The dryer is designed to pass 1838 pounds of air per second entering at 85° F with a dewpoint of 67° F and leaving with a dewpoint of -40° F for a 2-hour period. Reactivation of the activated alumina requires 4 hours heating and 4 hours cooling.

Valve 1. - Valve 1 is a 15-foot-diameter butterfly valve, which is used to control the air flow from the air dryer building when the tunnel is operated on the propulsion cycle.

Valve 2. - Valve 2 is a 4-foot-diameter butterfly valve, which is used as a shut-off valve for the bypass line around valve 1.

Valves 3 and 4. - Valves 3 and 4 are 14-inch- and 4-foot-diameter butterfly valves, respectively. They are used to control the air flow from the air dryer building when the tunnel is operated on the aerodynamic cycle at low air densities.

Valve 5. - Valve 5 is a $5\frac{1}{2}$-foot-diameter butterfly valve, used as an air-temperature control valve for the air entering compressor 2. It controls the air temperature by acting as a bypass for the air past cooler 2.

Cooler 2. - Cooler 2 is a finned-tube, water-coil-type heat exchanger, used to cool the air entering compressor 2. It is designed to cool 2670 pounds of air per second entering at 350° F and leaving at 120° F with a pressure drop of 10 inches of water.

Compressor 2. - Compressor 2 is a 10-stage axial-flow compressor, rated at a volume of 22,000 cubic feet of air per second at a pressure ratio of 2.4. It has 100,000 horsepower available to drive it, furnished by three wound rotor induction motors.

Valves 6 and 7. - Valves 6 and 7 are 6-foot- and $2\frac{1}{2}$-foot-diameter butterfly valves, respectively. They are used as compressor 2 bleed valves to match the compressor to the tunnel air-flow requirements.

Valve 8. - Valve 8 is a 15-foot-diameter butterfly valve used to bypass the air around compressor 2 when the compressor is not required.

Exhauster building. - The exhauster building houses two Cooper-Bessemer piston-type exhausters, giving a total exhauster capacity of 100,000 cubic feet of air per minute. The exhausters reduce the air density in the tunnel when the tunnel is operated on the aerodynamic cycle.

Valves 9 and 10. - Valves 9 and 10 are 4-foot- and 20-inch-diameter butterfly valves, respectively. They are used to control the amount of air that the exhausters can pump out of the tunnel.

Flexible-wall nozzle. - The flexible-wall nozzle produces supersonic flow through the test section; it consists of two flexible side walls of type 322 stainless steel 10 feet high, 76 feet long, and $1\frac{3}{8}$ inches thick actuated by hydraulically operated screwjacks; the top and bottom plates are fixed.

Test section. - The test section is 40 feet long, has a cross section of 10 by 10 feet at the entrance, and is 10 feet high by 10 feet 6.120 inches wide at the exit. All test-section plates are type 410 stainless steel $1\frac{3}{8}$ inches thick.

Second throat. - The second throat is another type nozzle used to save power by reducing the Mach number of the air leaving the test section before the normal shock wave. The two side walls are movable; each side wall consists of two hinged plates actuated by electrically driven screwjacks. The top and bottom plates are fixed.

Cooler 1. - Cooler 1 is a finned-tube, water-coil-type heat exchanger, used to cool the air entering compressor 1. It is designed to cool 1880 pounds of air per second entering at 650° F and leaving at 120° F with a pressure drop of 3 inches of water.

Compressor 1. - Compressor 1 is an 8-stage axial-flow compressor, rated at a volume of 78,000 cubic feet of air per second at a pressure ratio of 2.8. It has 150,000 horsepower available to drive it furnished by four wound rotor induction motors.

Valves 11 and 12. - Valves 11 and 12 are 8-foot- and 4-foot-diameter butterfly valves, respectively. They are used as compressor 1 bleed valves to match the compressor to tunnel air-flow requirements.

Valve 13. - Valve 13 is a 24-foot-diameter swinging-type valve, which is used to change the tunnel into either the aerodynamic or propulsion cycle of operation.

Exhaust muffler. - The exhaust muffler is used to quiet the discharge air of the tunnel when it is operated on the propulsion cycle.

Control room. - The control room is a sound-insulated, air-conditioned room from which the tunnel and model variables are controlled and monitored.

DAMPR room. - The DAMPR room is a sound-insulated, air-conditioned room adjacent to the control room in which the automatic pressure-recording equipment and the manometer boards for visual pressure indications are located.

10- BY 10-FOOT TEST SECTION

The test-section plan view, cross section, and elevation views are shown in figures 2(a), (b), and (c), respectively. The upstream cross section at the end of the flexible-wall nozzle plates is 10 by 10 feet. The $1\frac{3}{8}$-inch-thick type 410 stainless steel side walls diverge $0^\circ 22'$ each to a width of 10 feet 6.120 inches at the downstream end. Equally thick top and bottom plates are parallel. The location of the test rhombus is shown in figure 2(a).

The top and bottom plate openings for installation of model supports and auxiliary apparatus are identical. Either opening can be 20 feet long by 3 feet 6 inches wide maximum or some smaller increment depending upon the selection of insert plates. The tunnel insert plates cannot be altered; therefore, new inserts are required for passage or fastening of research apparatus to these plates. Model mountings as described under the section on MODEL SUPPORTS AND STINGS are mounted through these openings.

Personnel access doors 3 by 7 feet are located opposite each other at the downstream end of the test section on each side wall.

Two sets of upstream windows are located in the side walls. These 33-inch-diameter clear-opening windows are located $10\frac{1}{2}$ inches eccentric in 60-inch-diameter disks. The centers of the disks are 10 inches above the tunnel centerline. Rotating the 60-inch disks enables the 33-inch-diameter windows to cover any portion of a 54-inch-diameter circle about the 60-inch-diameter circle center. One set of 33-inch clear opening windows is in a fixed location downstream from the other windows and is mounted $20\frac{1}{2}$ inches above the tunnel centerline.

The whole floor of the test section is capable of being lowered to the first-floor level by means of four long screwjacks attached to each corner. Model installation is generally made through this 33-foot $4\frac{1}{8}$-inch by 10-foot clear opening by means of the special model dolly shown in figure 3. Two 25-ton traveling overhead cranes capable of running the length of the test-section housing building are available for model installation in special instances. These cranes also have 5-ton auxiliaries.

MODEL SUPPORTS AND STINGS

Sting Strut

The strut for sting-mounted models, as shown in figure 4, is mounted through the floor of the test section when supporting a model, and when not in use is completely retractable below the tunnel floor. The strut centerline may be located between 14 feet 5 inches and 23 feet 5 inches from the floor datum line in 6-inch increments. The strut has a chord length of 48 inches and is 8 inches thick.

The center of rotation of the strut is located $9\frac{1}{2}$ inches below the test-section floor, and the angle of attack can vary from -5° to 20°. The radius of rotation is a maximum of 6 feet 10 inches, while the minimum radius will depend on the interference of the strut socket with the floor of the tunnel. The position of the strut is remotely indicated in the tunnel control room.

A terminal panel is located in the top of the strut where all electrical and pressure connections from the model are made. This panel is easily accessible by removing the fairings from the sting socket.

The rear portion of the sting, which must fit the sting socket in the strut, must be made in strict accordance with the dimensions shown at the top of figure 4. Allowable sting loads are also indicated in this figure.

Suspended-Model Strut

A suspended-model strut with a typical model installed is shown in figure 5. The strut details will vary with each model, but the operating mechanism will be the same and will be furnished by the NACA. All struts must be designed to fit this operating mechanism. Any details not included in this brochure will be furnished on request.

Thickness of struts, which may vary from 3 to 10 inches, is limited by the travel of the bearing pads that support the strut in its housing.

The maximum permissible chord of the strut is 7 feet. However, in special cases, longer chord struts may be used, but these require special insert plates at one or both ends of the strut housing.

Angle of attack of the model is controlled by a screwjack mechanism which rotates the strut around a 3-inch-diameter pin located 7 inches above the inside surface of the tunnel top plate. The angle of attack can be adjusted through a total range of 20°. For example, if the screwjack mechanism is arranged to give a maximum negative angle of attack of -5°, the maximum positive angle will be 15°. However, it must be emphasized that it must be possible to adjust the model to 0° angle of attack in order to minimize starting loads.

The center of rotation of the strut may be positioned along the top of the tunnel in 6-inch increments between 11 feet 8 inches and 21 feet 8 inches from the tunnel joint datum line. This is without special insert plates.

The screwjack can be mounted on either end of the strut housing, depending on clearances to the tunnel structure.

In order to prevent leakage of air into the tunnel, the user must furnish a seal plate containing a seal groove for an inflatable seal which will be furnished by NACA Lewis laboratory.

Instrumentation and electrical leads from the strut will lead to a terminal panel on top of the test section as shown in figures 2(b) and (c). Pressure tubing is connected to this terminal panel through quick disconnect blocks, electrical leads through AN connectors, and thermocouples through special polarized plugs.

Auxiliary Strut

An auxiliary strut, shown in figure 6, is provided to hold a plug-actuating mechanism or tail rake, furnished by the user, when a suspended model is used. Equipment must be made to fit the flange on the end of the strut, as shown in figure 7. The strut is designed to rotate about the suspended-model strut center of rotation at a radius of 147 inches.

The leading edge of the strut may be located a minimum of 9 feet 5 inches and a maximum of 23 feet 11 inches from the test-section flexible-wall joint, with positioning in 6-inch increments. There are three more possible positions of the strut at 29 feet 5 inches, 29 feet 11 inches, and 30 feet 5 inches from the upstream tunnel joint.

All electrical cables and any instrumentation will lead to the same terminal panel on the top of the test section as used with the suspended-model strut.

MODEL INFORMATION

Delivery

The model shall be delivered to the Lewis laboratory 4 weeks previous to the scheduled starting date of the tests if only calibrating work is to be done on the model. If there is the possibility of necessary extensive instrumentation work, the model should be delivered 3 weeks earlier.

Model Size

Figure 8 shows the maximum estimated projected frontal area allowed for a model plus support, at each Mach number. Since the model size is also limited by the tunnel pressure ratio available for starting and other factors such as shock boundary layer interaction, figure 8 can be considered only a rough approximation. Therefore each model proposal must be evaluated independently and if starting appears to be marginal, a small-tunnel pilot investigation of the blockage and starting pressure ratio requirements will be required.

Model Strength

The maximum allowable stresses for the critical loading conditions shall not exceed 1/5 of the ultimate or 1/3 of the yield, whichever is least. In addition, for members loaded as columns, the Euler critical load shall be at least three times the applied load.

The starting loads shall be assumed to be a normal force resulting from the maximum steady-state dynamic pressure of 730 pounds per square foot absolute at the test-section Mach number. The model is to be assumed to be at its maximum critical angle of attack. A force equal to the normal force is to be assumed to be acting in a plus or minus yaw direction.

All auxiliary parts of the model that will be exposed to the air stream and are nominally at zero angle of attack shall be checked to at least 10° angle of attack.

The model shall be constructed of materials capable of withstanding the contemplated loads, pressures, and temperatures associated with the modes of testing as summarized under the section called Operating Characteristics.

Fuselage Specifications

The fuselage shall be constructed of steel, aluminum, magnesium, or plastic capable of withstanding contemplated forces and temperatures, yet be as light as feasible. The clearance between the fuselage and sting will depend upon the deflection characteristic of the balance and cannot be specified. An effort should be made to electrically indicate fouling between the sting and the model.

Sufficient access panels or cutouts shall be provided to facilitate maintenance of all working parts and instrumentation contained within the fuselage.

Wing and Control-Surface Specifications

Wing and tail surfaces shall be made of steel to minimize aeroelastic effects and shall be polished. Tail surfaces shall be made easily removable. Variable control surfaces which are to be deflected during testing should be provided, whenever possible, with remote actuation and position indication.

Pressure-Orifice and Tubing Specifications

All pressure orfices shall be flush and perpendicular with the external surfaces and shall be not less than 0.040-inch inside diameter. Tubing connected to such orfices shall be at least 1/16-inch outside diameter, and the 1/16-inch tubing run shall be short, increasing to 1/8-inch-outside-diameter tubing as soon as feasible. Whenever possible, 1/8-inch-outside-diameter tubing should be used throughout, especially if the pressure to be measured is less than 200 pounds per square foot absolute.

All instrumentation tubing shall conform to the following table of allowable sizes. It shall be type 347 fully annealed stainless steel whenever the size is smaller than 1/8-inch outside diameter or whenever it is used for rakes or serves any structural purpose. Otherwise, soft copper tubing may be used.

Tubing O.D., in.	Wall thickness, in.
0.0625	0.012
.090	.0145
.125	.018 to .032 Stainless steel
.125	.025 to .032 Soft copper
.188	.035 Soft copper

A maximum of 300 tubes may be used with each model strut. Tunnel users are expected to furnish the model with tubing of sufficient length to allow the attachment of quick-disconnect blocks, which will be furnished by NACA Lewis laboratory. These quick-disconnect blocks are to allow for quick installation of the model in the tunnel, since the pressure instrumentation may be prefabricated on special shop model stands that duplicate the model strut installation in the tunnel.

Special Considerations for Models for Inlet Investigation

Models designed for inlet investigation shall generally be constructed as described previously. The model body shall duplicate the full-scale configuration for sufficient distance to assure inlet and boundary-layer flows corresponding to the full-scale configuration. All canard surfaces and/or other appendages to the forebody shall be included. Ducts through the fuselage or nacelles shall be duplicated to the engine-inlet station. Mass flow shall be controlled by choking the duct exit with a parabolic-shaped plug. In scaling down the model, any boundary-layer bleeds shall be modified to correct for the difference in Reynolds Number. Provision shall be made for the installation of dynamic-pressure pickups on the model at locations such that indication of flow instability (buzz) can be obtained. The dynamic pickups will be furnished by NACA. Rakes shall be located in the model to determine pressure recovery and pressure distributions at suitable duct stations. These rakes shall have tubes that conform to the table of allowable sizes and shall be rigidly supported as well as have an airfoil-type chord section. Any soldering on the rakes shall be silver-soldering. Rake tubes should be so spaced that they measure equal areas of the duct in order to facilitate pressure integration. The mass-flow ratio will be determined by calculations based on the choked duct exit area and the static pressures measured upstream of the duct exit.

Model Mass-Flow Plug Design, Model Component Actuators, and Position Transducers

A typical plug that is used to control the air flow through a model is shown in figure 9. The design of a plug and actuator of this type requires that the plug itself shall have a parabolic contour so that the model exit area is directly proportional to the plug position. The plug drive shall be either an electrically driven screwjack or a hydraulic cylinder. When an electrically driven screwjack is used, it must be protected at both ends of its travel by limit switches so that it cannot damage itself or the model by traveling too far in either direction. When a hydraulic cylinder is used, it must be sized so that its stroke does not exceed the safe movement of the plug. It must be the cushioned type if it is to move rapidly, and must be free of external leaks during cycling or stand-by operation.

The plug or its operating mechanism shall have a position transducer connected to it so that the plug position is remotely indicated. This shall be either a selsyn geared to the plug drive so that it shall make at least 20 revolutions per inch of plug travel, or a 10-turn precision potentiometer geared to the plug drive so that full plug travel will turn the potentiometer at least eight turns. This potentiometer shall have a total resistance of approximately 1000 ohms and shall be linear within ±0.1 percent. In certain cases, linear slide wires may be used; these must also have a total resistance of approximately 1000 ohms and be linear within ±0.1 percent.

Items such as screwjacks, hydraulic cylinders, electric motors, selsyns, potentiometers, and slide wires must be capable of withstanding the tunnel test-section operating conditions.

The systems described for a typical plug drive and position indication should be used in all model component actuators. If others are to be used, they must meet with the approval of the NACA Lewis laboratory.

Electrical Considerations

Any wire or electrical device used in the tunnel test section must be capable of withstanding the test-section operating conditions. All models should be wired with stranded copper, silver-coated, teflon-insulated wire of a size that will conservatively carry the necessary current. Pressure transducers, strain gages, vibration pickups, and other low-voltage equipment that requires shielded wire should have each individual group of wires cabled inside a metal braided sheath. Each model device such as a motor, pressure transducer, solenoid, and so forth, shall have its wires terminate in an AN connector to match those existing on the appropriate strut terminal panel. Sufficient lead length should be allowed to reach the terminal panel easily and also allow for any angle-of-attack movement of the model strut. Power circuits (2 amps or more 28 volts D.C. or 5 amps or more 120 volts A.C.) shall terminate in plugs AN 3106-24-10P. Several circuits may be grouped in a single plug. Circuits requiring shielded wire should terminate in plugs AN 3106-14-6P with one connector and group of wires for each device. Wires for small motors, limit switches, selsyns, and so forth, should terminate in plugs AN 3106-16S-1P. Again, several circuits may be grouped in single plugs. The plugs listed will fit the AN connectors provided at the strut terminal panels. The NACA will provide all wiring from the terminal panels to the control room. A list of the permanent AN connectors as they exist on each strut terminal panel is shown in the following table. A column showing the type of cable from this terminal to the control room is also shown:

Quantity	AN Connector	Cable type	Wire length from model
Suspended-model strut terminal			
8	3100A-24-10s	6 conductor no. 9 wire	To be determined at time model position is decided
26	3100A-14s-6s	6 conductor no. 20 shielded wire	
20	3100A-16s-1s	6 conductor no. 16 wire	
Sting strut terminal			
5	3100A-24-10s	6 conductor no. 9 wire	Determined by sting length and connector position on terminal panel
16	3100A-14s-6s	6 conductor no. 20 shielded wire	
8	3100A-16s-1s	6 conductor no. 16 wire	

Wiring diagrams showing all electrical devices in the model and how they terminate on AN connectors should be submitted to the NACA at least 5 weeks before the scheduled date of the test.

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Thermocouples

All model thermocouples should be made with high-temperature glass-insulated thermocouple wire of as heavy a gage as practical. Consideration should be given to how much the wire might be abused by having to be moved or handled in the course of maintaining the model during testing. Leads from the model should be long enough to reach the appropriate strut terminal panel and should terminate in Thermo Electric Co. Type 2PSS plugs.

The suspended-model strut terminal panel contains wiring for 25 iron-constantan and 25 chromel-alumel thermocouples in five circuit Thermo Electric Co. Type JBW-5 panels.

The sting strut terminal panel contains wiring for 15 iron-constantan thermocouples in five circuit Thermo Electric Co. Type JBW-5 panels.

Miscellaneous

All removable parts shall have a minimum of fasteners and shall be doweled for accurate replacement. All screwheads on the surface of the model shall be filled with materials that will withstand the temperatures at which the tests will be conducted.

INSTRUMENTATION AND DATA PROCESSING

Balances

Balances for the measurement of model forces will be supplied by the NACA Lewis laboratory. Three-component bearing-type strain-gage balances are available for sting-supported models. These balances are of the self-contained internal strain-gage type. Ball and roller bearings are used to isolate the components. Actual measurement of the forces is made by Baldwin SR-4 strain gages mounted on cantilever beams. The three components measured are axial force, front normal force, and rear normal force. The balances contain interchangeable links, so there is a wide selection of capacities available. Figures 10, 11, and 12 show the 4-inch-, 5-inch-, and 7-inch-diameter balances, respectively. The figures also give the mounting dimensions required for their use.

The following table gives the list of links available for each balance to give the required characteristics:

Axial force, lb	Front normal force, lb	Rear normal force, lb	Distance between front normal and rear normal links, in.
4-Inch balance			
±100	±100	±100	12
±200	±200	±200	
±300	±400	±400	
±500	±600	±600	
±800	±1,000	±1,000	
±1,200	±1,500	±1,500	
±1,800	±2,500	±2,500	
5-Inch balance			
±250	±1,000	±1,000	15
±500	±2,000	±2,000	
±750	±3,000	±3,000	
±1,000	±4,500	±4,500	
±1,500	±6,000	±6,000	
±2,250			
±3,000			
±4,000			
7-Inch balance			
±1,000	±2,000	±2,000	21
±1,500	±5,000	±5,000	
±3,000	±8,000	±8,000	
±5,000	±12,000	±12,000	
±7,500	±16,000	±16,000	
±10,000			

The links will take momentary overloads up to 200 percent of their capacity without damage. Continual overloads of this magnitude may rupture the SR-4 strain gages. The steel in the links will take 500 percent of the rated capacity before failure.

When it is necessary to maintain close alinement between the model and the sting at the rear of a large model, an external rear normal link is sometimes used in place of the one within the balance. This arrangement also increases the pitching-moment capacity of the balance system by increasing the distance between the front normal and rear normal links. The external link is usually identical to the links within the balance. Additional bearings are also required at the rear. Details of the mounting of the rear link and bearings are engineered for each model. The NACA Lewis laboratory will furnish the link.

If forces are to be measured on suspended strut models, a special balance is required. This type of balance is part of the suspension system within the strut. Forces are isolated by bearings or flexure plates, and measurement is made by SR-4 strain gages mounted on cantilever beams. Variations to adapt to particular models will be engineered as required.

Equipment is available in the shop area to check out and calibrate the balances. It is possible to apply any combination of loads to the balance. Loads are applied by motor- or hand-operated screwjacks. A strain-gage link is used for measuring the load applied. Equipment is also available for checking the calibrating strain-gage links against dead weights. After the balance is installed in the model, the same type of screwjack assembly is used for applying loads to the complete model both in the shop and in the tunnel. A heater, provided by NACA Lewis laboratory, is installed around the balance to maintain the balance at a constant temperature during the tunnel run to eliminate changes in calibration and zero shift due to temperature variations.

Attitude Indicator

A model attitude indicator system is available to show the true model angle of attack. This makes it possible to correct the strut position for sting and strain-gage balance deflections. The system consists of an angle-of-attack transmitter, shown in figure 13, which is placed in the model, and a receiver which is located in the control room. The over-all accuracy of the system is ±0.1°. Mounting the transmitter in the model as shown in the figure will allow it to monitor the model angle of attack from -5° to $+20^{\circ}$. For its proper operation, it requires four no. 20 wires connected to the terminals as shown in the figure.

Pressure Measurements

All pressure tubing from the model strut terminal panels leads to an interconnection panel in the DAMPR room. This interconnection panel allows tubes from the model to be connected to pressure-measuring equipment on the main manometer board, control-room manometer board, or the DAMPR system. The DAMPR system, completely described under the section on Data Recording and Computing, can accommodate 576 tubes for automatic recordings of pressures that will be used as final data.

The main manometer board consists of a bank of 156 tubes 96 inches long. The manometers are connected to wells in banks of 12 tubes, one tube of which is a reference tube (13 wells, 11 usable tubes each = 143 tubes), with a constant reference pressure kept on the well and reference tube. Depending upon the pressures being read, the type of fluid used, and the accuracies needed, one of four reference pressures can be used in any combination on the wells. These pressures can be set within the following limits with the indicated accuracies:

0 - 16.71 psf	±0.05 psf
418 - 696 psf	±2.0 psf
557 - 1393 psf	±4.0 psf
835 - 1950 psf	±6.0 psf

This main manometer uses either mercury or dibutyl phthalate only. It is used for visual reading only, that is, setting test conditions or determining when pressures are sufficiently stabilized to permit recording data.

The control-room manometer board consists of 48 tubes 45 inches long grouped as the main manometer but with its four wells referenced to atmospheric pressure.

Thermocouples

Thermocouple wiring exists from the strut terminal panels to an interconnection panel near the test section. At this point the alloy leads are connected to copper wires which run to the control room and to the automatic digital potentiometer (ADP). The ADP is described completely in the section on Data Recording and Computing. Each bank of ten thermocouples has an alloy pair for remote compensation at the model interconnection panel. The temperature scanner in the control room and the ADP automatically switch in the correct compensating thermocouple for the group of thermocouples each one is reading.

Control-Room Equipment

All data-recording equipment for the tunnel and model, including the schlieren image viewer, and the controls for the automatic pressure-recording equipment are located in the control room. In the control room, panel space is allocated for installing the controls and indicating equipment necessary to operate, control, and test the tunnel model. The panel is designed to use Radio and Television Manufacturers' Association standard 19-inch relay rack panel sections. All interchangeable or replaceable control-room panel sections conform to these standards. Figures 14 and 15 show the general arrangement of the east and west control panels, respectively. These panels are made of relay rack panel sections and contain all the data-recording equipment for the model under test. A résumé of the available equipment follows:

Visual aids. - Since the control room is located so far from the test section, closed-circuit television equipment has been installed. There are three television cameras complete with their power supplies and monitors. There are also four 24-inch television monitors and one 17-inch monitor installed in the control room. Any monitor is capable of being connected to any camera in any combination. Ordinarily, two television cameras are used as viewers for the two schlieren systems, and the third camera is used to view the model from some advantageous position while the model is in the tunnel for test.

Schlieren system. - The tunnel is equipped with two identical schlieren systems which may be used alternately or simultaneously. These systems are located at the forward and intermediate sets of test-section windows and are capable of showing the flow patterns in the test section regardless of the position of the 33-inch-diameter clear opening windows in the 60-inch-diameter disks. Figures 16(a) and (b) show the plan and elevation views, respectively. Schlieren images are viewed by means of the television equipment previously described. Photographs of the images are taken by a 70-mm Beattie Veritron automatic data-recording camera; 1/100-second steady-state pictures or 1-microsecond flash pictures may be taken. A total of 325 photographs $2\frac{1}{2}$ by $3\frac{3}{8}$ inches may be taken without reloading the camera magazine. In addition, a Fastax 16-mm high-speed motion-picture camera is capable of taking 100 to 4000-frame-per-second pictures of any image shown on the television camera. A lens turret containing three lenses allows magnification of any part of the standard image.

Temperature-measuring equipment. - Temperatures are indicated on two Gilmore Industries temperature scanners (see fig. 14). These are self-balancing strip-chart indicators and recorders. One is used for iron-constantan (I.C.) thermocouples and the other for chromel-alumel (C.A.) thermocouples. The I.C. recorder has a range of zero to 400° F. The C.A. recorder has a range of zero to 2500° F. If desirable or necessary, these ranges can be changed.

Each scanner is capable of scanning 100 thermocouples in banks of 10, making a total of 200 available temperature recordings. Any or all banks can be selectively controlled, and the scanner may be stopped on any particular thermocouple. While scanning, the instrument either indicates or prints while indicating, and may be stopped on any point for continuous indicating. A maximum time of 2 seconds is consumed for each individual thermocouple indication if the scanner traverses the full scale between successive readings.

On each bank a high- or low-temperature set point can be adjusted. If that point is reached during any scanning cycle, the scanner will stop and sound an alarm.

The same thermocouples that indicate on the scanner are also available to the ADP through a switching mechanism that is in operation during the time the automatic equipment is collecting data. During this time the scanner cannot be used.

Balance measurement. - The strain-gage balance outputs are measured and recorded by four Bristol automatic balancing potentiometers (see fig. 14). A strain-gage balance heater control is located in the same panel. A four-channel console on rollers is also available in the shop area to aid in check-out and calibration of the model balance. During data recording the strain-gage balance outputs are connected to the ADP.

Miscellaneous testing equipment. - Two Bristol two-pen XXY Recorders for plotting changing variables are available. These permit plotting two X variables against one Y variable. An example of such a plot would be that obtained by plotting two pressure-transducer output voltages generated by a model pressure against a plug position that was responsible for changing the pressure. Since the plug controls the mass flow through the model, it would be possible to plot pressure recovery against mass flow from the raw data.

Brush oscillograph recording equipment is available. This consists of one 6-channel strip-chart recorder and two 2-channel strip-chart recorders plus ten amplifiers, so that all recorders may be used at once. The recorders are suitable for electric or ink stylus, and the charts may be run at speeds of 5, 10, 25, 50, and 125 millimeters per second.

Photographic-type, multiple-channel oscillograph recording equipment is also available.

Data Recording and Computing

The 10- by 10-foot tunnel data-recording equipment is divided into two categories, the control-room equipment just described for the control and immediate visualization of the test conditions and the automatic recording equipment which collects information for a general-purpose electronic computer. The results of an experimental investigation often modify the course of a test. With this in mind, the automatic data system was designed to prepare computed results in a form that is suitable for rapid analysis while the test is in progress. A digital computer was chosen because it is capable of any desired degree of accuracy in the calculations. In order to prepare the data for the computer, it was necessary to develop equipment to convert pressures, voltages, and mechanical positions to digital form and to store and record them for the computer. The various components necessary to do this are described in the following pages. The automatic data-recording system and the computer, with output equipment located in the tunnel control room, will be used as an "on-the-line" data-reduction system. Selected computed data will be displayed in the control room starting 30 seconds after the data point is taken. Data required for later extended analysis are stored on punched cards for read-out at the analyst's convenience.

Automatic Recording Equipment

The Lewis laboratory has a system known as the Central Automatic Digital Data Encoder (CADDE) which is used by five of the laboratory's major test facilities to record digital readings from transducers of pressure, voltage, events per unit time, and mechanical position. A diagram of this system is shown in figure 17. The information is recorded on magnetic tape as four binary coded decimal digits with four additional characters for identification and computer instructions. The magnetic tape is the permanent record of the raw data. The computer will read-in and process the raw data simultaneously with its recording on magnetic tape. Computed results of immediate interest can be read out on paper tape which is typed out in the tunnel control room on either of two automatic typewriters. Converted raw data and intermediate results go to a high-speed card punch for tabulation by a line printer after the run is completed. Computed results typed out in the tunnel control room can also be sent to one of four automatic point plotters located near the typewriters.

Digital automatic multiple pressure recorder (DAMPR). - The DAMPR system pictured schematically in figure 17 consists of four tanks with 160 capsules mounted on each tank. The capsule, which is the primary sensing element of the pressure-measuring system, breaks an electric circuit when the pressures on either side of a diaphragm are equal within 0.01 inch of mercury. The tanks are evacuated to about 0.1 inch of mercury and then sealed off. When a reading is taken, pressurized air enters the tanks through a choked orifice. The time from the start of the pressure rise until the tank and model pressures are equal is measured by counting pulses generated by an oscillator in CADDE. When the tank pressure equals the model pressure the circuit between the oscillator and counter is opened by the capsule. The number in the counter is proportional to the time required for the tank and model pressure to be equalized. This number is stored in a 300-channel magnetic core memory for read-out to the magnetic tape handler and computer at the completion of the pressure scan.

The scan time (i.e., the time required for the pressure to rise to its maximum) is 10 seconds, and the repetition rate is once per minute. The oscillator generates approximately 1000 pulses per second, so that the resolution of the pressure-measuring system is equal to 0.0001 of the upper pressure limit for the tank. The four tanks have pressure limits of 2500, 5500, 12,000, and 20,000 pounds per square foot absolute.

The 300 copper pressure lines from the tunnel are terminated on an interconnection panel near the DAMPR tanks. The input to 576 capsules is also brought out on this panel so that any model tube can be jumpered to any capsule. The remaining 64 capsules are used to determine the slope and origin of the pressure-time line by applying known pressures to the capsules. Since the memory of CADDE is limited to 300 channels, a model requiring more than 300 channels would use a sequential scan of the four DAMPR tanks and would require 35 seconds for the complete scan.

Automatic digital potentiometer (ADP). - The ADP is a self-balancing multichannel millivolt meter with a digital read-out. It contains four separate balancing units with ranges of -3 to 17 mv, -2 to 38 mv, and 0 to 40 mv. The potentiometer indicates a voltage as a percent of the range. The four units balance sequentially, and the reading is transferred directly to the tape handler and computer without intermediate storage. The potentiometer balances and reads out at the rate of six channels per second during the scan time of the DAMPR tanks. Therefore, 60 voltages can be measured during this 10 seconds without slowing down the recording process. The instrument can read up to 200 voltages but will delay the transfer of the memory data to the tape handler and computer.

The input switch gear for the balancing units can switch thermocouple cold junctions (100° F) of I.C. or C.A. in series with the input voltage on any channel. A remote compensation thermocouple system, as described for the control-room temperature scanner, is used for thermocouple inputs.

Any type of voltage divider or strain-gage device having an impedance of less than 500 ohms can be measured with the ADP. A 40-mv power supply calibrated against the ADP standard cell is available for use with voltage divider networks such as the retransmitting slide wires on the Bristol potentiometers located in the control room.

Events per unit time (EPUT). - Any instrument which generates pulses at a rate proportional to the input signal can have these pulses counted in the CADDE memory. By feeding the pulses through a 10-second time gate, the number of events occurring in a known time interval can be recorded and sent to the computer. Output of a tachometer or fuel flowmeter could be measured in this way. The total number of counts cannot exceed 100,000, and the counting rate cannot be greater than 20,000 counts per second. When more than 100,000 counts are generated in 10 seconds, the length of time required to reach 100,000 counts is then recorded.

Automatic control-room monitor. - In order to provide a single log of test conditions, a monitor system has been provided to collect information automatically from the control-room instruments. The monitor accepts inputs from mechanical counters and voltage sources. Reading number, time, schlieren and manometer picture numbers, oscillograph trace numbers, tunnel wall Mach number setting, and shaft position settings are converted to digital form and typed out on the monitor typewriter in the tunnel control room. Analog to digital converters having a visual indication of the setting are available to indicate and record synchro shaft positions to an accuracy of 1 part in 10,000. Voltage inputs are converted to digits by an automatic digital potentiometer. Thermocouple voltages are measured by switching a 100° F reference junction in series with the thermocouple being sampled.

The monitor can accept 24 mechanical contact closure inputs and 25 voltage inputs. The monitor scans all of its inputs every time any control-room device is interrogated for an automatic read-out. It samples at the rate of 1.5 channels per second.

Contact closure devices. - There are 16 data bits to each binary coded decimal word recorded on tape and sent to the computer. A bit is present in a data word if there is a ground on the input to the shift register at the time it is loaded. The shift register is an electronic unit in which all numbers are assembled immediately prior to being recorded on a magnetic tape. A switching device located in the tunnel control room makes it possible to read up to 25 channels of information consisting of the presence or absence of a ground on any combination of the 16 data bits. The combinations need not be meaningful as a binary coded decimal digit, since the computer can translate the combinations of bits into any desired meaning.

Analog to digital converters are available to count shaft rotations of devices in the model or in the control room. These converters have 16 wires on which combinations of grounds appear to represent numbers up to 10,000 with an uncertainty of 1 part. These converters also have a 4-decimal visual indication of their position. They can be used with synchromotors to indicate positions of mechanical parts in the models.

Other contact closure devices, such as rotary switches, stepping switches, or toggle switches, can be used to put information into CADDE. This information can be data, calibration constants, or computer instructions.

The computer. - The information from the central data recorder is fed into an ERA 1103 (Engineering Research Associates) general-purpose electronic computer. The computer processes the data as it is received and reads out computed results while raw data are still being loaded into the machine. Computation instructions are contained in the machine for the test being run. The instructions for the preparation of the computer program must be received by the Lewis laboratory's Mechanized Computing and Analysis Branch at least 3 weeks before the test date if "on-the-line" computing is to be used.

FACILITIES PROVIDED FOR USERS

A total of 616 square feet of office space in two offices is provided for engineering personnel, and locker facilities are provided for all mechanical personnel.

Shop Model Stands

Four model stands are located in the shop area, which facilitate checking the model and making changes in the model or its components prior to its tunnel installation. Two stands are provided for sting-mounted models, one of which is shown in figure 18, and two stands are provided for suspended strut models, one of which is pictured in figure 19.

In the sting-mount model stand, the model is mounted exactly as it will be in the tunnel using the same sting. The sting is fastened at the rear of the stand, and the model overhangs the front of the stand where holes are located in the bed plate for mounting any instrumenting or testing equipment. The bed plate of the stand is 27 feet long, and the model centerline is located 48 inches or 60 inches above the bedplate depending on whether a spacer is used in the stand. A connector panel is available at each stand which is identical to the panel installed in the strut for connecting instrumentation. This panel makes it possible to check all instrumentation in the model before it goes into the tunnel and provides for quick installation.

In the suspended strut model stand, the model is suspended exactly as it will be in the tunnel using the same strut. The model is supported by its strut from an overhead pipe suspended between two columns 17 feet 10 inches apart. The pipe itself is 10 feet $9\frac{1}{4}$ inches above the floor with the model hanging 48 inches from the floor. The model can be positioned in three different places on the stand, each 60 inches apart.

Equipment

The wind tunnel shop contains an overhead 20-ton-capacity crane and a collection of machine tools including a lathe, milling machine, Do-All band saw and several drill presses and bench grinders. A 36-inch light gage roll, 60-inch light-gage bending brake, 48-inch light-gage shear, 24-inch throat Whitney-Jensen punch, and a Beverley throatless shear are available for sheet-metal work. Various sized surface plates are available for setup and layout work. There are several types of hand trucks and a 24- by 36-inch elevating table of 2000-pound capacity for handling model parts too big or heavy for easy hand lifting or carrying.

An acetylene gas, electric arc, and a heliarc welder, as well as a small spot welder, are available.

A tool crib located in the shop area has available a complete line of hand tools including some hand power tools.

A user supplying a model for testing in the tunnel will be assigned a model stand that duplicates the tunnel strut that will actually be used to test the model, and sufficient shop space with work benches and storage racks to work on his model. He will be issued a set of tool checks that will enable him to borrow any tool crib tools.

Power, Air, and Hydraulic Systems

At either the shop model stand or the tunnel test section the following types of electrical energy are available:

440-Volt, 60-cycle alternating current 3 phase
208-Volt, 60-cycle alternating current 3 phase
208-Volt, 60-cycle alternating current 1 phase
120-Volt, 60-cycle alternating current 1 phase
208-Volt, 400-cycle alternating current 3 phase
208-Volt, 400-cycle alternating current 1 phase
120-Volt, 400-cycle alternating current 1 phase
28-Volt, direct current

125-Pound service air and vacuum are also available at both the model stand and the tunnel test section.

When the model is installed in the tunnel test section the following services are available:

(1) 125 psig dry air, 2 lb/sec maximum continuous supply

(2) 40 to 150 psig dry air, 100 lb/sec; supply must be arranged for

(3) Hydraulic pumping unit for actuation, capable of pumping up to 10 gal/min at 3000 psig

Fuel Systems

<u>Gaseous system</u>. - The gaseous fuel system is designed to handle fuels that are in that state. It can deliver to the test section 1800 pounds of fuel per hour at a pressure of 200 pounds per square inch gage.

The system can be operated at reduced pressure with a corresponding decrease in the flow rate. Fuel is supplied to the system by large tank trailers in which the gas is stored under high pressure. Fuel flow is measured in orifice runs.

Liquid fuel system. - The liquid fuel available at the tunnel test section is furnished by two pumping systems. These are the pilot system, which can furnish zero to 5 gallons per minute at pressures up to 200 pounds per square inch, and the main high-pressure system, which can furnish zero to 228 gallons per minute at pressures up to 500 pounds per square inch. Since the main high-pressure system consists of three pumping units, two of 70-gallon-per-minute capacity and one of 88-gallon-per-minute capacity, it is possible to pump three different types of fuel simultaneously.

Fuel flow is measured in the fuel house with rotameters that have an accuracy of ±1 percent of scale. The fuel viscosity can also be measured with a Fisher and Porter viscosimeter, which has a range of 3 to 0.3 kinedynamic units.

The fuel is filtered so that all particles down to 0.0005 inch are removed before the fuel reaches the tunnel test section.

Remote-reading flowmeters are available for use in the control room.

Jet-Effects Model

For making jet studies, the model shown in figures 20 and 21 is available. The model is a body of revolution 12 inches in diameter with the inside divided into three separate concentric ducts by shrouds. These are called primary, secondary, and tertiary ducts, as shown in figure 21. These ducts are completely independent of each other, and each has its own air-measuring and control system located outside the tunnel as shown in figure 20. These ducts are sized so that the maximum air flows through them are the following percentages of the maximum total flow: primary, 70 percent; secondary, 20 percent; and tertiary, 10 percent. Maximum total flow for this model is 60 pounds per second at 40 pounds per square inch gage. This model can be operated with air at higher pressures, with a corresponding increase in the air flow; the air available to operate this model is indicated in the section entitled Power, Air, and Hydraulic Systems.

A 5-inch strain-gage balance is used in the model to measure forces on the external shell of the model plus the forces of any of the internal shrouds that are connected directly to the external shell. The internal shrouds can be connected to either the lower strut end or the external shell, depending upon whether or not the forces on it are to be measured.

In shroud connections, for any given shroud that is connected to the external shell, all of the shrouds larger than it must also be connected to the external shell; likewise, for any given shroud that is connected to the lower strut end, all shrouds smaller than it must also be connected to the lower strut end.

This model strut is mounted in the suspended-strut operating mechanism used for other suspended models. Details on design and possible location of this strut mechanism will be found in the section Suspended-Model Strut.

Modifications can be made to this model to accommodate different configurations. Joints are located in the strut, as shown in figure 21, and toward the rear of the model, as shown in figure 22, which enable the user to modify the entire model or just the rear portion. Details of the model and possible variations will be furnished at the request of the user.

OPERATING CHARACTERISTICS AND POWER COST ESTIMATING

Operating Characteristics

Complete estimated operating characteristics of the 10- by 10-foot Lewis Unitary Plan Wind Tunnel are shown in figure 22. These curves show the dynamic pressure, test-section altitude, Reynolds number, test-section total pressure, and test-section total temperature for the complete tunnel operating range on either the aerodynamic or propulsion cycle.

Operating Procedure

The tunnel is always started up or shut down on the aerodynamic cycle at low air densities to reduce the starting and stopping loads on the model. If a burning engine is being tested, the tunnel must be switched over to the propulsion cycle of operation after supersonic flow is established in the test section, before the engine can be started.

Propulsion-cycle testing operation. - Starting procedure (requires approx. 1 hr 25 min):

(1) Valves 1, 3, and 4 are closed. Valves 2, 8, 9, and 10 are open. Valve 13 is in the 13a position.

(2) The flexible-wall nozzle is set for Mach 2.5 or above, depending on the Mach number at which testing is to be done. Because of the throttling action of valve 1 at Mach numbers below 2.5, the pressure differential across valve 13 is too high for its operation. Thus, switching from the aerodynamic to the propulsion cycle or vice versa during tunnel operation must be done at Mach number 2.5 or above.

(3) The exhausters are started and the tunnel pressure is brought down to approximately 200 pounds per square foot absolute. This requires 20 minutes.

(4) Compressor 1 is started and brought up to operating speed. If the testing is to be done at Mach numbers above 2.5, compressor 2 is started and brought up to speed; then valve 8 is closed. This requires 15 or 30 minutes, depending upon the number of compressors required.

(5) With supersonic flow established in the test section, the tunnel pressure is brought up to atmospheric by allowing air to come in through valves 3 and 4 at a rate depending on the power rate of change, since the tunnel is limited to $7\frac{1}{2}$ megawatts per minute by the power company. This can require up to 25 minutes depending upon the tunnel Mach number.

(6) The exhausters are shut down; then valves 9 and 10 are closed.

(7) When the tunnel pressure reaches atmospheric, valve 1 is opened and valve 13 is put in the 13b position, thus changing tunnel operation from the aerodynamic cycle to the propulsion cycle. This requires 10 minutes.

(8) The flexible-wall nozzle can now be changed to any Mach number setting.

(9) The engine in the model can be started any time after step (7) is completed.

Shutdown procedure (requires approx. 1 hr):

(1) The flexible-wall nozzle must be set for Mach 2.5 or above.

(2) Valve 13 is moved to the 13a position; then valve 1 is closed. This requires 10 minutes.

(3) Valves 9 and 10 are opened, and the exhausters are started.

(4) Tunnel total pressure is reduced to approximately 200 pounds per square foot at a rate determined by the power rate of change. This requires up to 25 minutes.

(5) If compressor 2 is running, valve 8 is opened and compressor 2 is shut down. This requires 10 minutes.

(6) Compressor 1 is shut down. This requires 10 minutes.

(7) Exhausters are shut down, and valves 9 and 10 are closed.

(8) Tunnel pressure is brought up to atmospheric by bringing air in through valves 3 and 4. This requires 5 minutes.

Aerodynamic-cycle operation. - Starting procedure (requires approx. 2 hrs):

(1) Valves 1, 3, and 4 are closed. Valves 2, 8, 9, and 10 are open. Valve 13 is in the 13a position.

(2) The flexible-wall Mach number is set at the desired testing point.

(3) The tunnel is purged by starting the exhausters and bringing the tunnel pressure down to approximately 200 pounds per square foot absolute; then dry air from the dryer building is brought in through valves 3 and 4. This process is repeated twice; then tunnel pressure is brought down to 200 pounds per square foot and held there for starting purposes. This procedure requires about 1 hour.

(4) Compressor 1 is started and brought up to operating speed. If the testing is to be done at Mach number above 2.5, compressor 2 is started and brought up to speed; then valve 8 is closed. This requires 15 or 30 minutes, depending upon the number of compressors required.

(5) With supersonic flow established in the test section, the tunnel pressure can now be changed to the level at which the test is to be conducted. This can take up to 25 minutes, depending upon the power rate of change.

Shutdown procedure (requires approx. 50 min):

(1) The tunnel total pressure is brought down to approximately 200 pounds per square foot absolute. This can take up to 25 minutes, depending upon the power rate of change.

(2) If compressor 2 is running, valve 8 is opened and compressor 2 is shut down. This requires 10 minutes.

(3) Compressor 1 is shut down. This requires 10 minutes.

(4) Exhausters are shut down; then valves 9 and 10 are closed.

(5) Tunnel pressure is brought up to atmospheric by bringing air in through valves 3 and 4.

Power Cost Estimates

The data presented here are to be used in estimating electrical power costs for the operation of the Lewis Unitary Plan Wind Tunnel. The average rate per kilowatt hour is expected to be between 8 or 9 mils during the fiscal year of 1956, depending upon the monthly consumption at the Lewis laboratory.

With the tunnel operating on the propulsion cycle, the power consumed by the drive motors of compressor 1 over the Mach number range from 2 to 3.5 is approximately 120,000 kilowatts per hour. The tunnel can be operated between Mach number 2 and 2.5 with only compressor 1. At Mach number 2.5 compressors 1 and 2 can be operated together, depending upon desired tunnel conditions. At Mach number 2.6 to 3.5 both compressors 1 and 2 must be operated. The power required to drive compressor 2 varies from 50,000 kilowatts per hour at Mach number 2.5 to 80,000 kilowatts per hour at Mach 3.5.

The power required to operate the tunnel on the aerodynamic cycle is the same as the propulsion cycle or lower in proportion to the tunnel air density.

The drive systems and compressors may be operated slightly above or below the preceding power quotations to achieve particular test-section operating conditions.

In addition to these power figures, 900 kilowatts per hour for the compressor 1 drive and 750 kilowatts per hour for the compressor 2 drive must be added for the drive auxiliaries.

The cooling water system for the tunnel coolers requires 2000 kilowatts per hour.

Reactivation of the air dryer is necessary each day for propulsion-cycle operation but less often for aerodynamic-cycle operation, depending upon atmospheric conditions. Reactivation of the air dryer requires 9000 kilowatt hours of electrical energy.

Since the tunnel is always started or stopped on the aerodynamic cycle at low air densities, the exhausters are required for 20 to 30 minutes during tunnel starting and stopping when testing is done on the propulsion cycle. When testing is to be done on the aerodynamic cycle, the exhausters are required approximately 1 hour prior to tunnel operation for pumping down and purging the tunnel circuit and for most of the aerodynamic-cycle operation. The exhausters require a total of approximately 3000 kilowatts per hour during operation.

Operating Times and Length of Runs

The tunnel will operate some time between 10:00 p.m. and 7:00 a.m. five days per week under ordinary circumstances. The length of runs will be limited by either these times or by the dry-air requirements of the tunnel. When the tunnel operates on the propulsion cycle, the running time is limited by the air-dryer capacity; and it can be from 30 minutes in hot humid summer weather to over 9 hours in cold dry winter. When the tunnel operates on the aerodynamic cycle, running time is not limited by the air-dryer capacity.

From the preceding discussion, it seems obvious that all testing on the propulsion cycle should be scheduled during the winter months whenever possible.

INFORMATION TO BE SUPPLIED BY THE USER

The user shall furnish the following information as soon as possible after the tests have been requested:

I. Model Details and Stress Analysis

  A. Drawings of Model:

    1. Three-view suitable for inclusion in a report.

    2. One complete set of drawings or sketches providing the following data pertinent to the model:

      a. All configurations to be tested; configurations shall also be listed in tabular form and cross-referenced to drawings.

      b. Weight and center-of-gravity location for all configurations.

      c. Materials employed in fabrication.

      d. Heat treatments.

      e. Types of bolts, screws, and other fasteners.

      f. Weld dimensions.

      g. Special methods of adhesive bonding.

      h. Location of suitable reference stations for orientation of model in tunnel, including description of means of determining angular relation.

i. Location and identification of pressure rakes, probes, and orfices.

B. Drawings or Sketches of Model Installation: These drawings or sketches shall show the relation between the model, the balance, the sting, and the sting support for sting-mounted models, as well as the model's location in the tunnel test section. For suspended models, the drawings shall show the relation between the model, the supporting strut, and its location in the tunnel test section. All dimensions should be referenced to the datum line of the test section as shown in figure 2(a). References to all detailed drawings and subassemblies should be clearly shown.

C. Tabulated Data: The detailed information listed in table I of this manual shall be submitted. (Table I follows this section of the manual.)

D. Templates: The company shall provide templates of all critical surface contours such as body and duct lip contours. A surface shall be considered critical if deviations from the prescribed ordinates would influence the test results. The number of templates to be provided is not specified, but should be sufficient to establish the conformation of the surface with the desired ordinates.

E. Diagrams: These shall consist of elementary wiring diagrams of all electrical devices and thermocouples plus line diagrams and description of model fuel, air, oil, or control systems.

F. Stress Analysis: A stress analysis of the model and sting or model and strut based upon the maximum loads anticipated in the tests and on the information supplied in the preceding section on Model Strength, shall be submitted to the Lewis laboratory no less than 5 weeks prior to the scheduled starting date of testing.

Each section devoted to a detailed analysis shall contain a sketch showing the design forces and moments acting, the general equations for the stress distribution, and a concise statement of the assumptions and approximations involved.

G. Revisions: The Lewis laboratory should be notified immediately of any changes to the model or model support system which involve the structural integrity of the installation, the test procedure or results, or the instrumentation. Reasons for the revisions should be stated. Additional stress analysis should be submitted if there has been any structural change.

II. Test Program

A. The proposed test program should include the following items:

1. List of the data desired, for example, force data, duct-inlet pressure recoveries, mass-flow measurements, duct pressure distributions, temperature profiles, and so forth.

2. Tentative schedule of testing including model configurations, tunnel operating conditions, increments and ranges of the variable parameters, and the data to be taken at each condition.

III. Data Analysis Information

A. All areas and model dimensions required for computation factors; tabular form preferred.

B. Desired form of plotted results.

C. Required force and moment coefficient accuracies and estimated loads.

D. Required pressure-measurement accuracies and estimated extreme values relative to test-section dynamic pressure.

E. All calibration factors and calculative procedures of equipment necessary for data reduction.

F. Schedule of any special data required, such as balance calibration, probe calibrations, and so forth.

SHIPPING ADDRESS

Material shipped to the Lewis Unitary Plan Wind Tunnel to be used as a part of a model or test should be addressed as follows:

Lewis Unitary Plan Wind Tunnel
NACA Lewis Flight Propulsion Laboratory
21000 Brookpark Road
Cleveland 11, Ohio

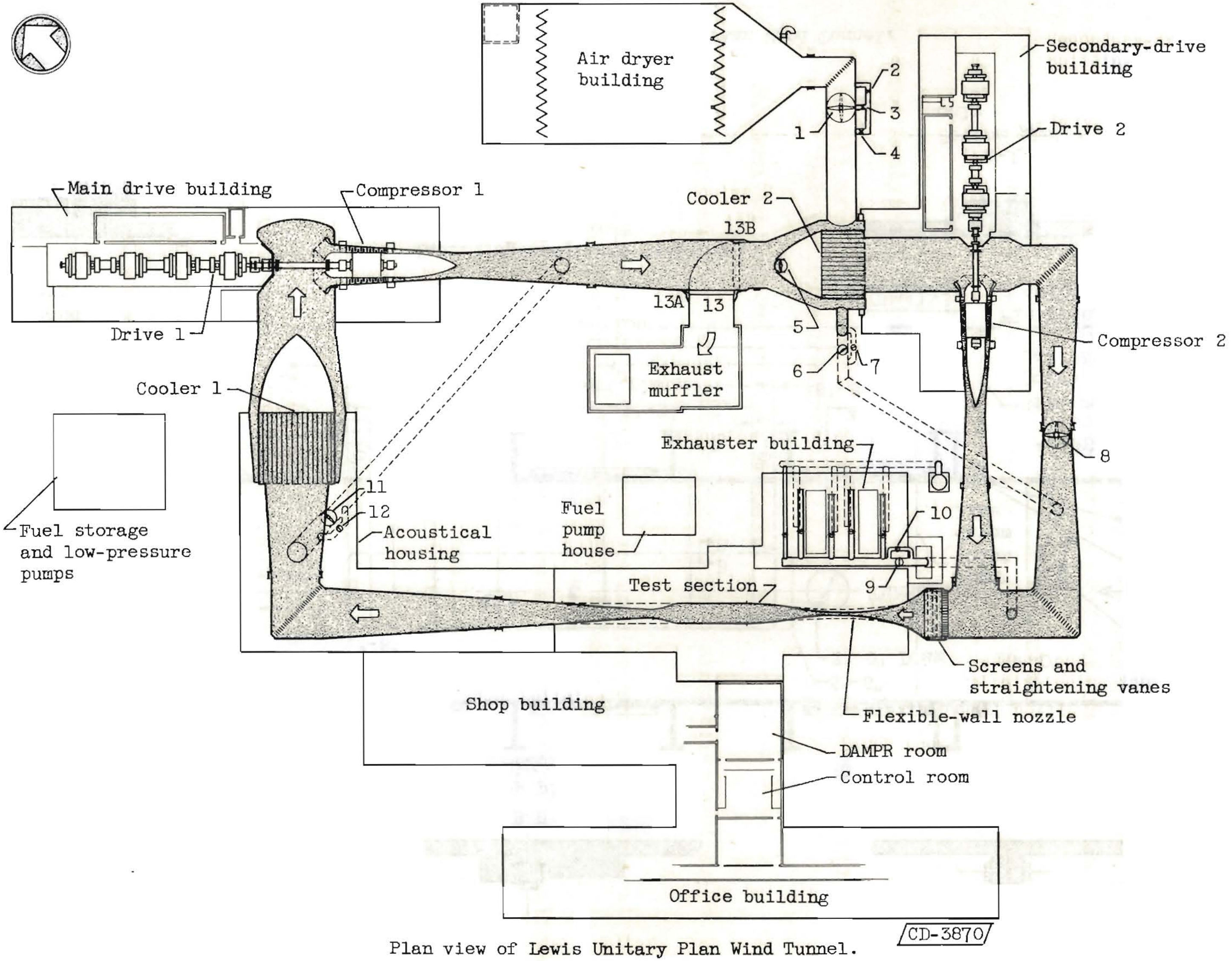
A return address and some type of model identification must be attached to the outside of the box.

TABLE I

Date forwarded

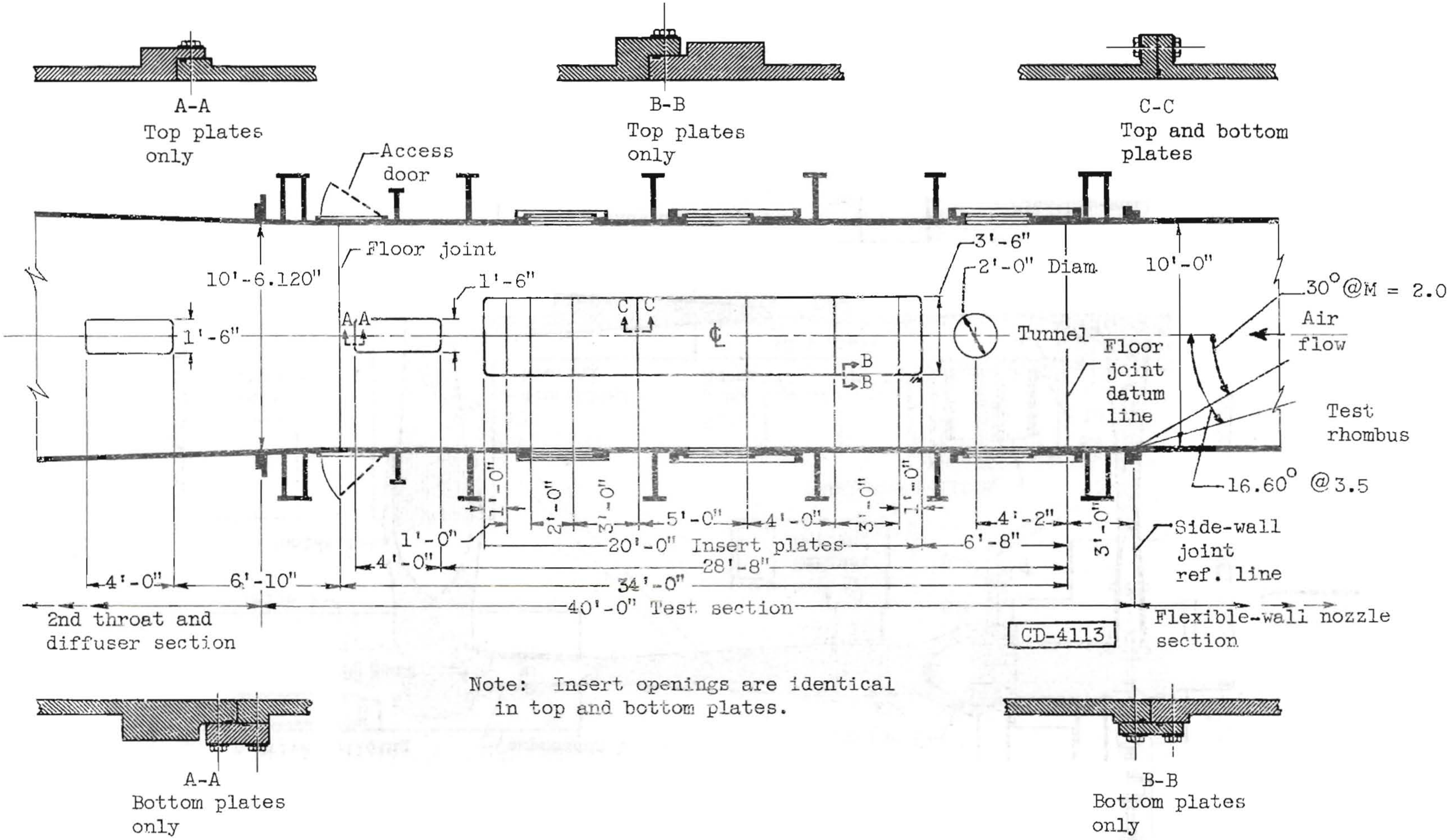
- Scale of model
- Center-of-gravity location
- Wing loading
- Wing area
    - Theoretical
    - Exposed
- Span
- Aspect ratio
- Taper ratio
- Sweepback
- Dihedral
- Incidence
- Geometric twist
- Airfoil section
    - Root
    - Tip
- Root chord
- Tip chord
- Root-chord location
    - Longitudinal
    - Vertical
- MAC
    - Length
    - Location

- Fuselage
  - Length
  - Width
  - Depth
  - Frontal area
  - Over-all fineness ratio
  - Forebody fineness ratio
  - Side area
  - Volume
  - Base area
- Wind-tunnel balance
  - Pitch beam center (to be placed as close as possible to model C.G.)
    - Location
    - Longitudinal
    - Vertical
    - Percent MAC
- Inlet models
  - Areas
    - Inlet
    - Physical lip details, boundary-layer bleeds, etc.
    - Plot of duct-area distribution with and without accessory housing
    - Typical cross sections
    - Compressor inlet
  - Engine-inlet air-flow matching characteristics



Plan view of Lewis Unitary Plan Wind Tunnel.

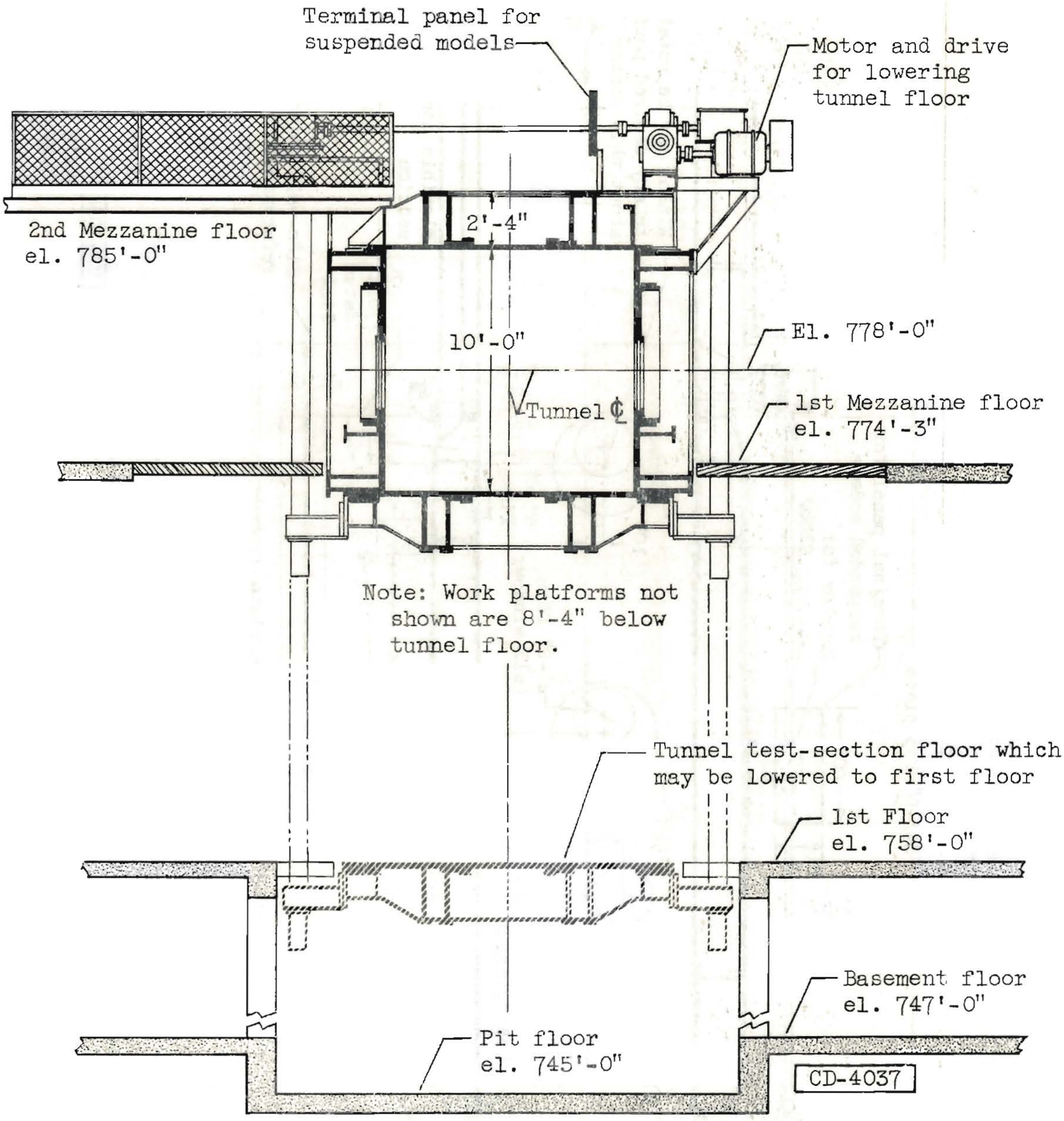
Figure 1.



(a) Plan view.

10- By 10-foot test section. Lewis Unitary Plan Wind Tunnel.

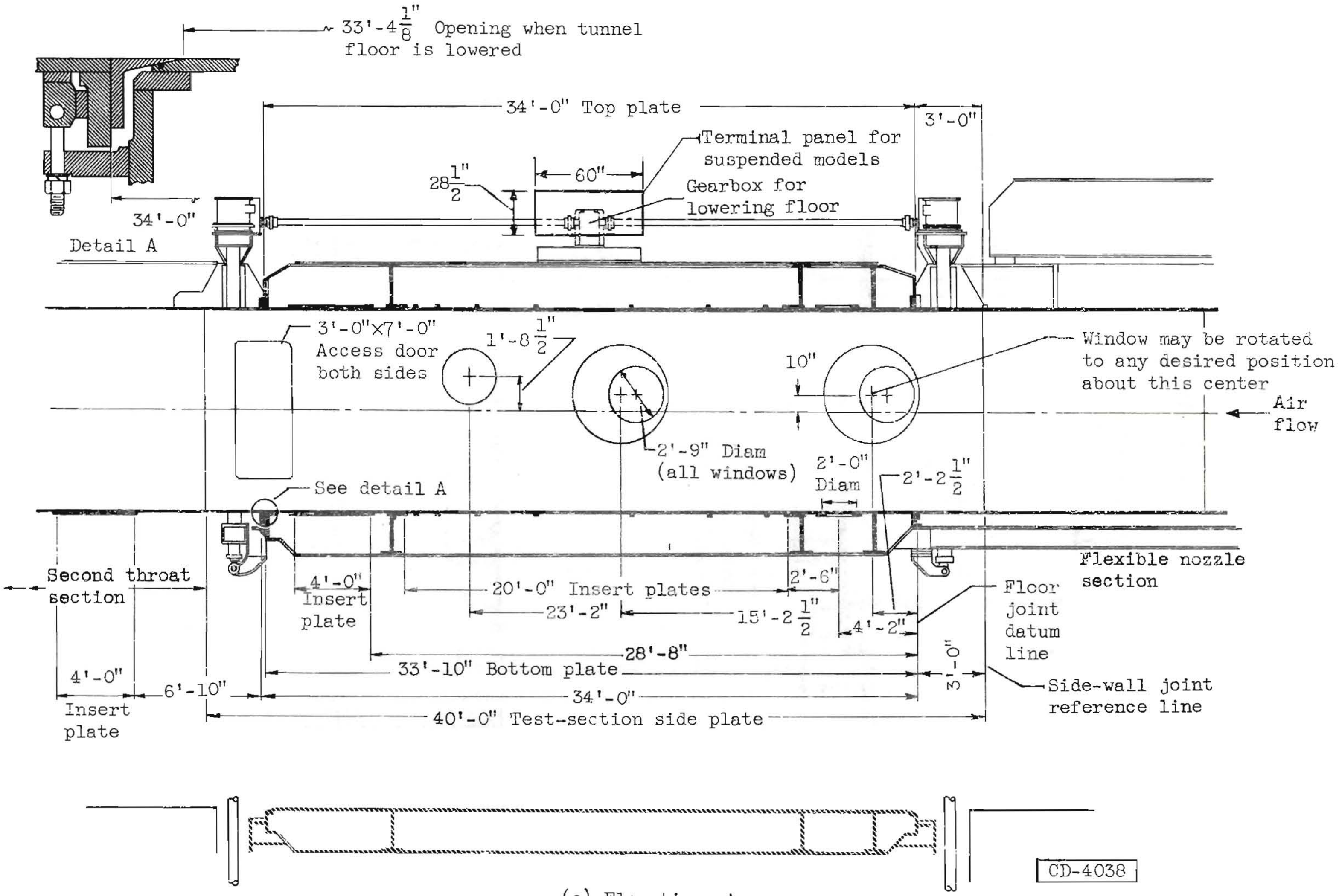
Figure 2a.



(b) Cross section.

10- By 10-foot test section. Lewis Unitary Plan Wind Tunnel.

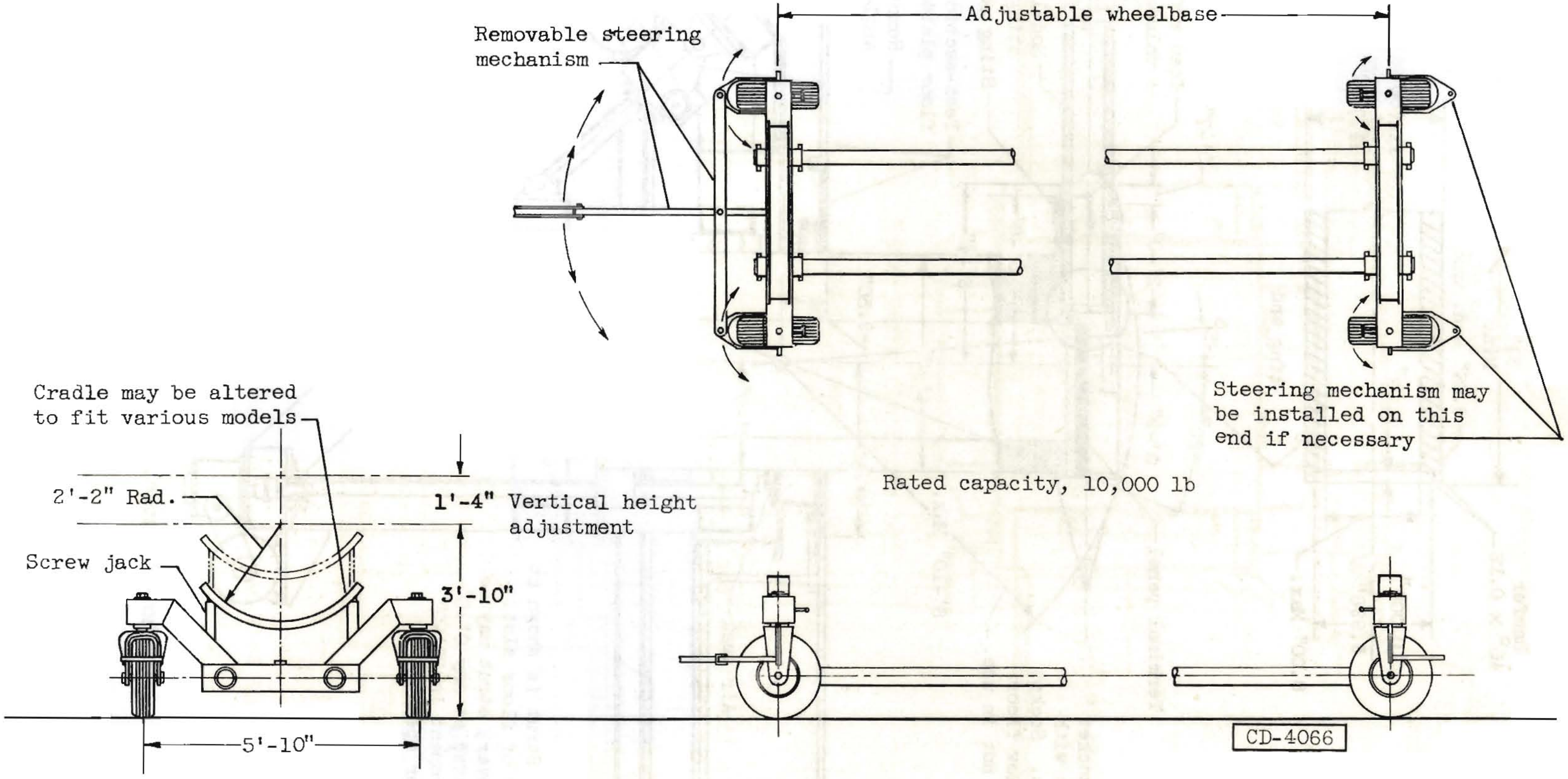
Figure 2b



(c) Elevation view.

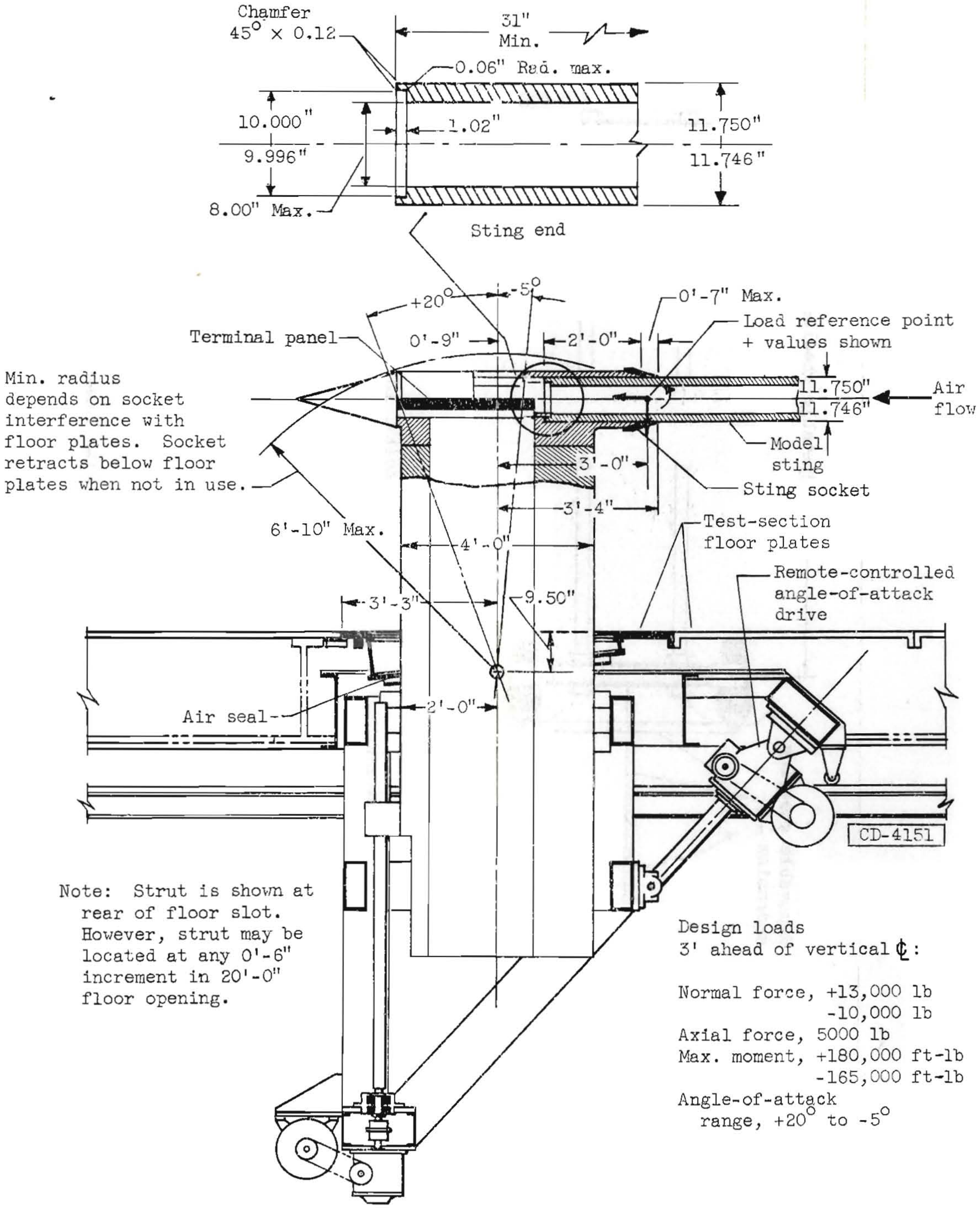
10- By 10-foot test section. Lewis Unitary Plan Wind Tunnel.

Figure 2c.



Model transport dolly. Lewis Unitary Plan Wind Tunnel.

Figure 3.



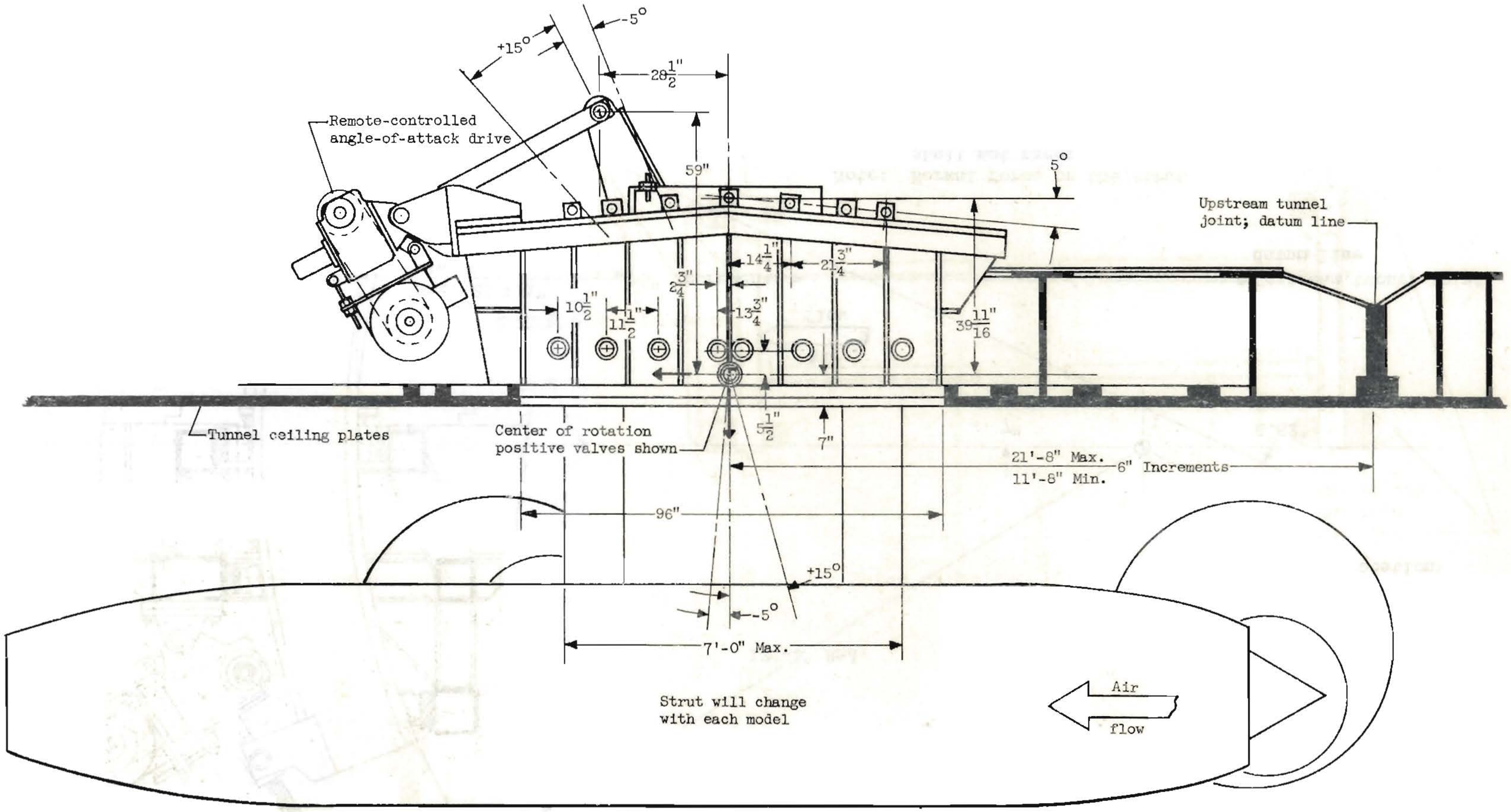
Note: Strut is shown at rear of floor slot. However, strut may be located at any 0'-6" increment in 20'-0" floor opening.

Design loads
3' ahead of vertical ℄:

Normal force, +13,000 lb
-10,000 lb
Axial force, 5000 lb
Max. moment, +180,000 ft-lb
-165,000 ft-lb
Angle-of-attack range, +20° to -5°

Sting-mounted-model strut. Lewis Unitary Plan Wind Tunnel.

Figure 4.



Allowable loads at center of rotation:

Normal force ± 50,000 lb
Axial force ± 50,000 lb
Pitching moment ± 175,000 ft-lb

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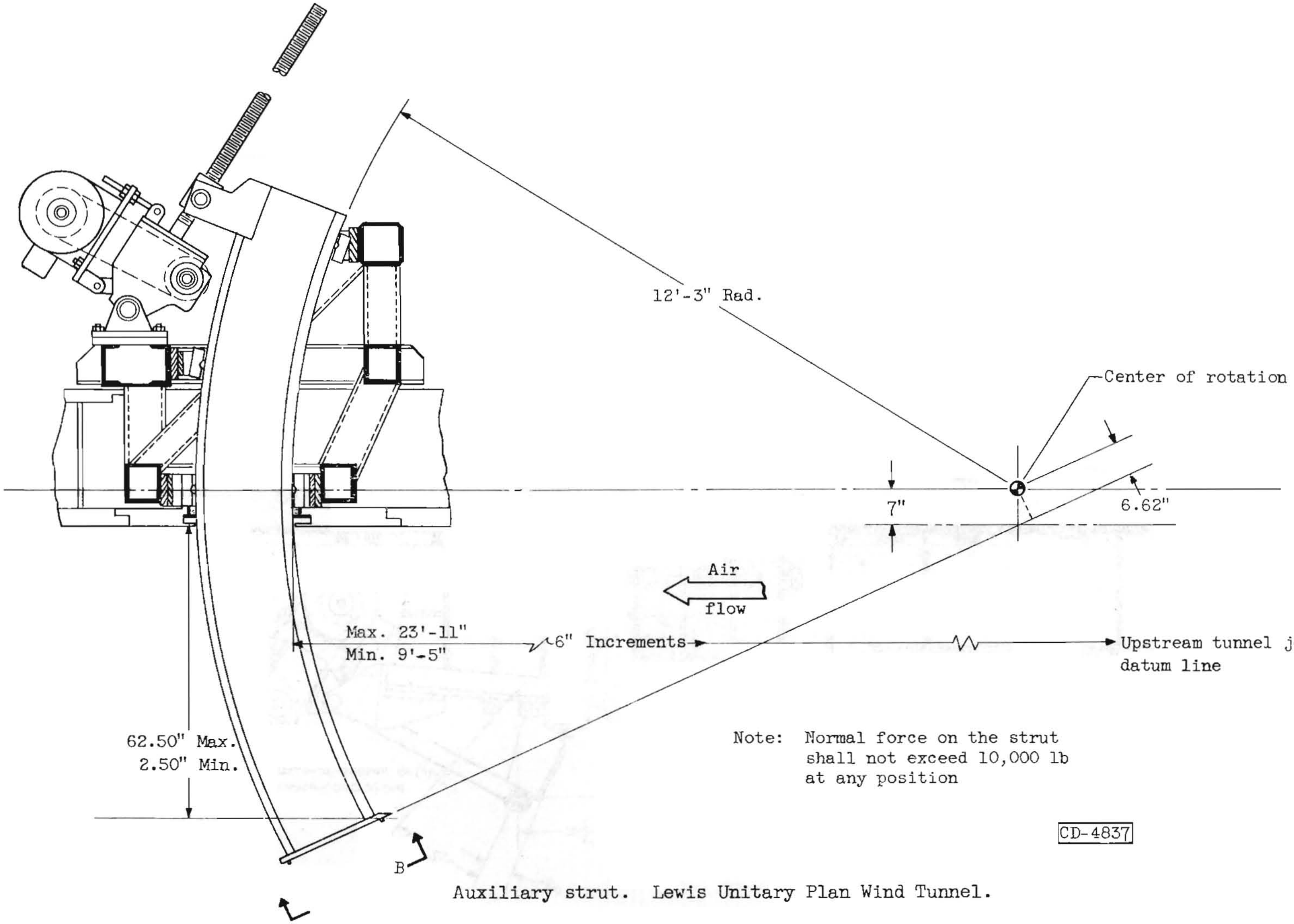
Suspended model strut. Lewis Unitary Plan Wind Tunnel.

Note:
$\text{Allowable load} = \dfrac{\text{Ultimate strength}}{\text{Safety factor}}$
Min. safety factor is 5.

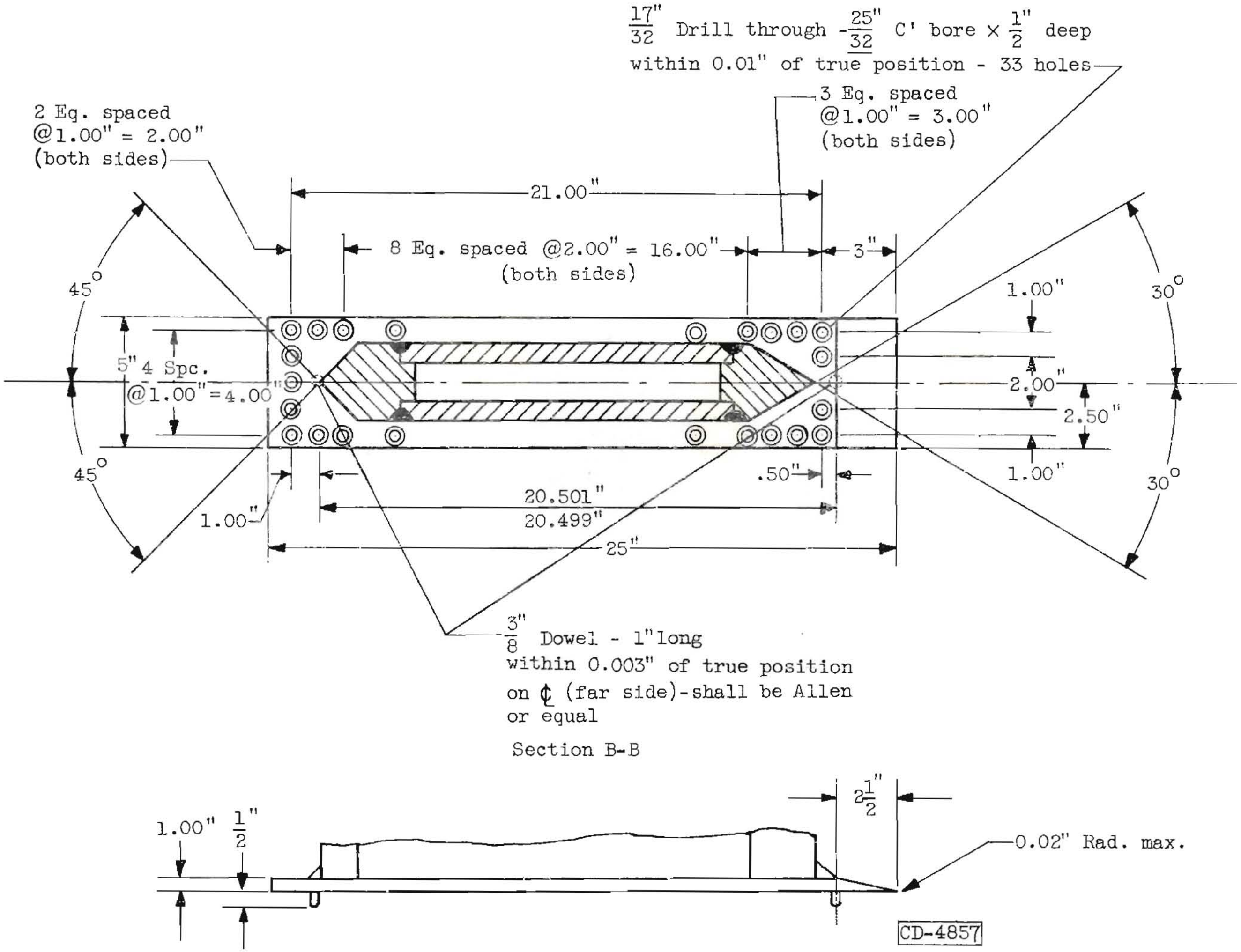
Figure 5.



Note: Normal force on the strut shall not exceed 10,000 lb at any position

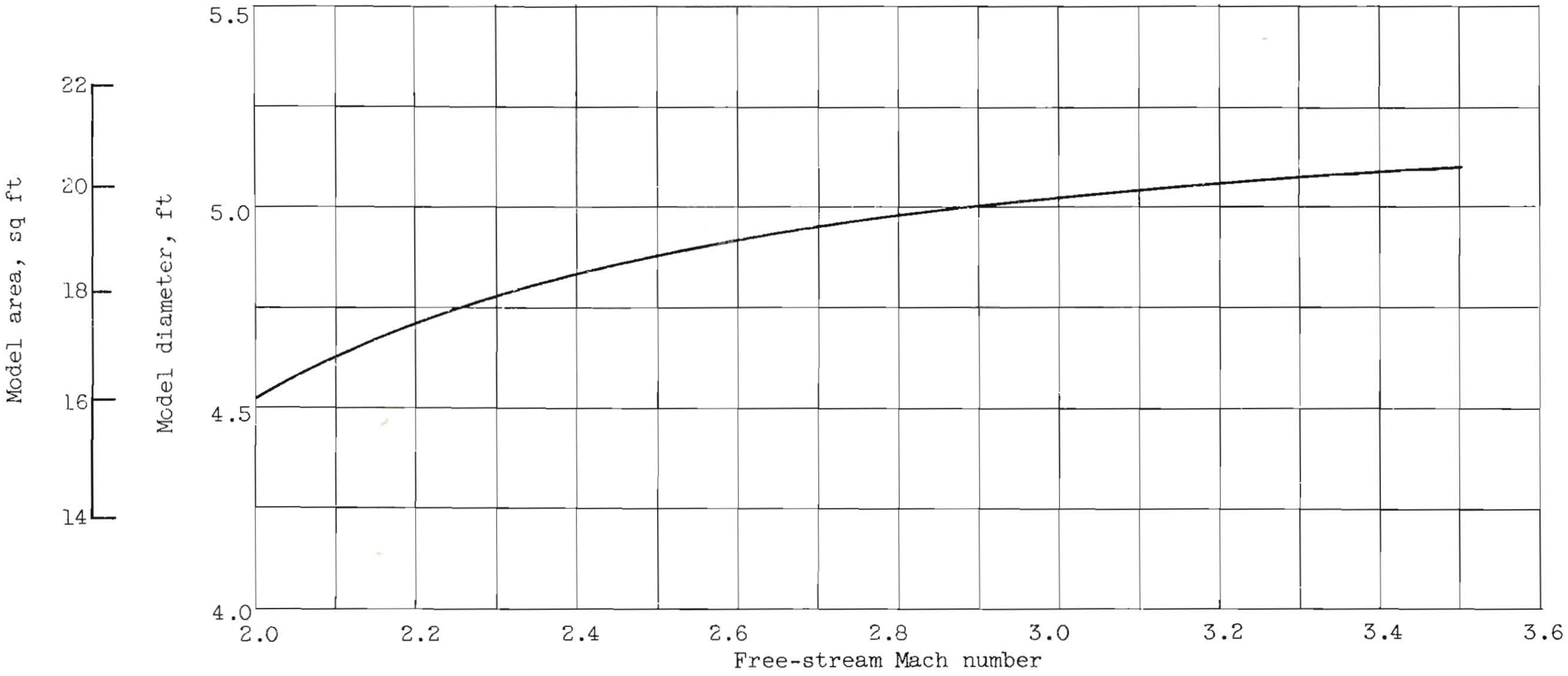
Auxiliary strut. Lewis Unitary Plan Wind Tunnel.

Figure 6.



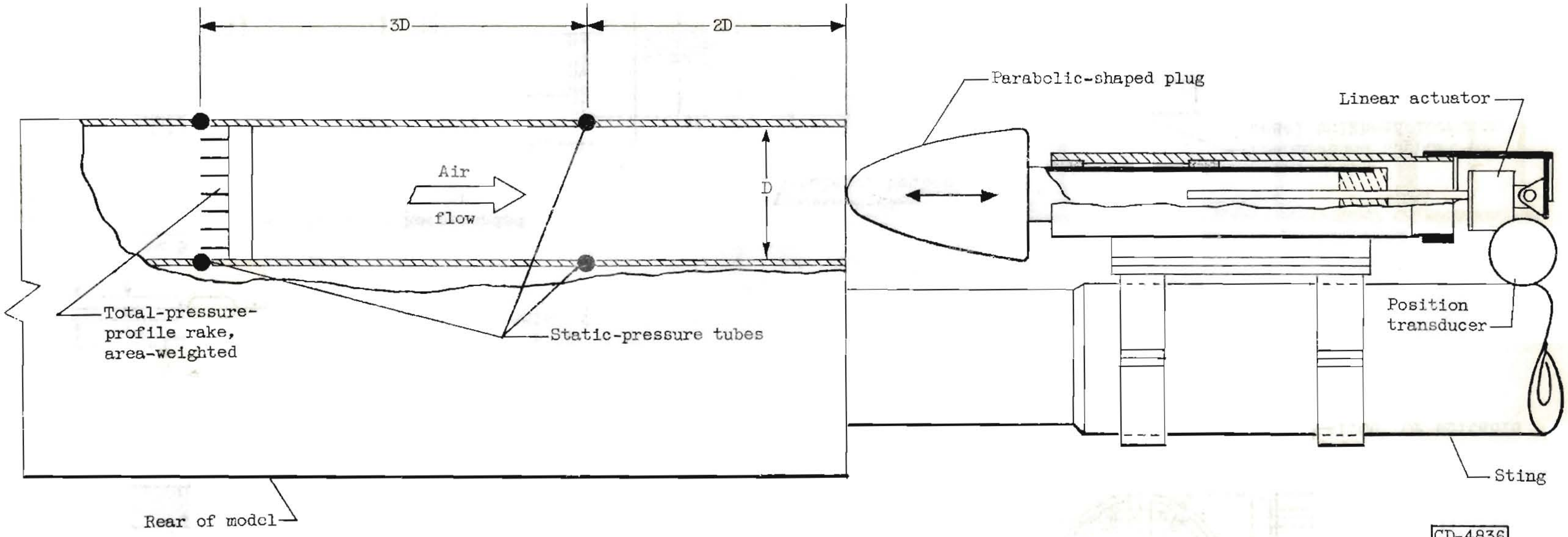
Auxiliary strut joint. Lewis Unitary Plan Wind Tunnel.

Figure 7.



Calculated allowable test-section blockage.
Lewis Unitary Plan Wind Tunnel.

Figure 8.



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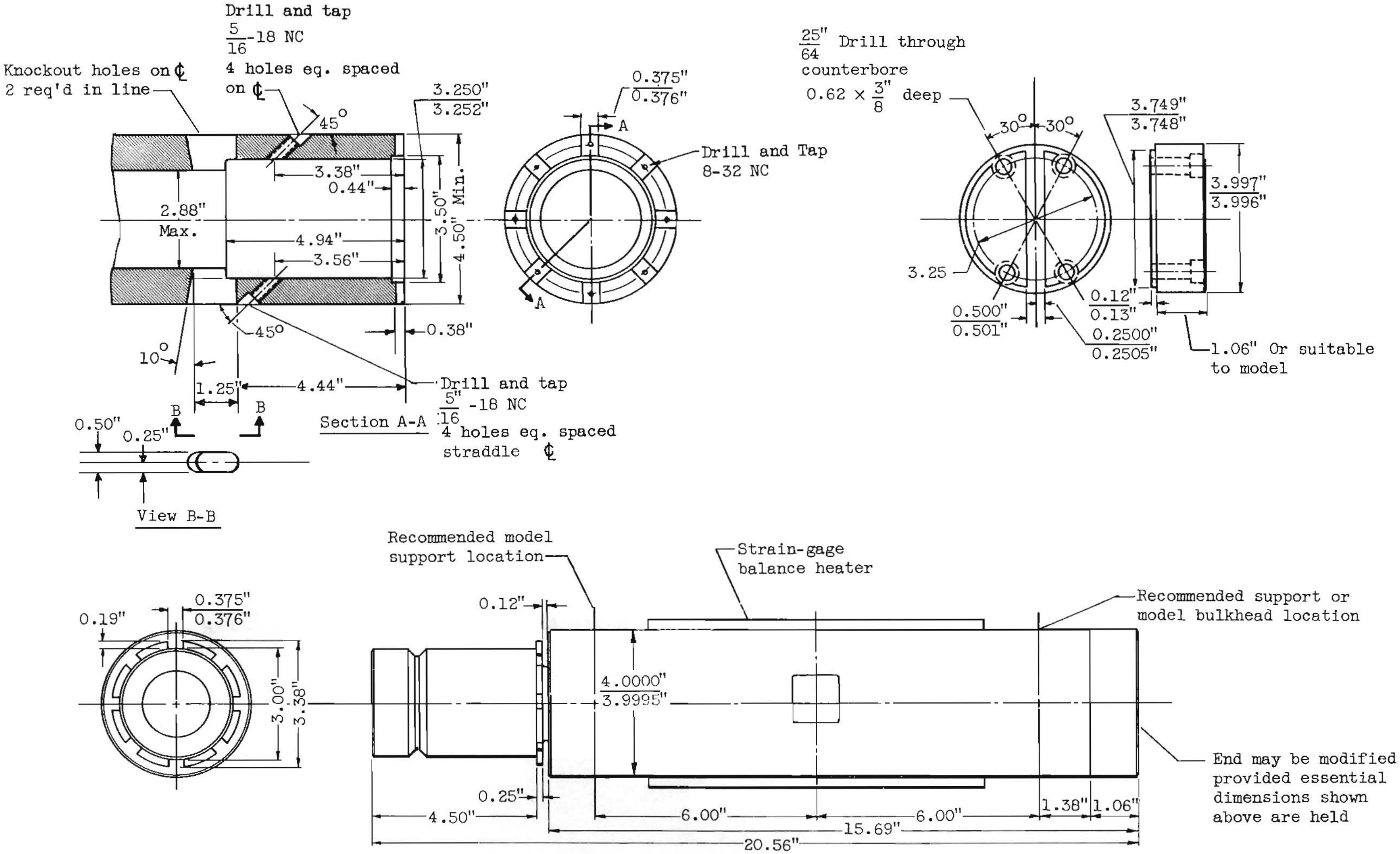
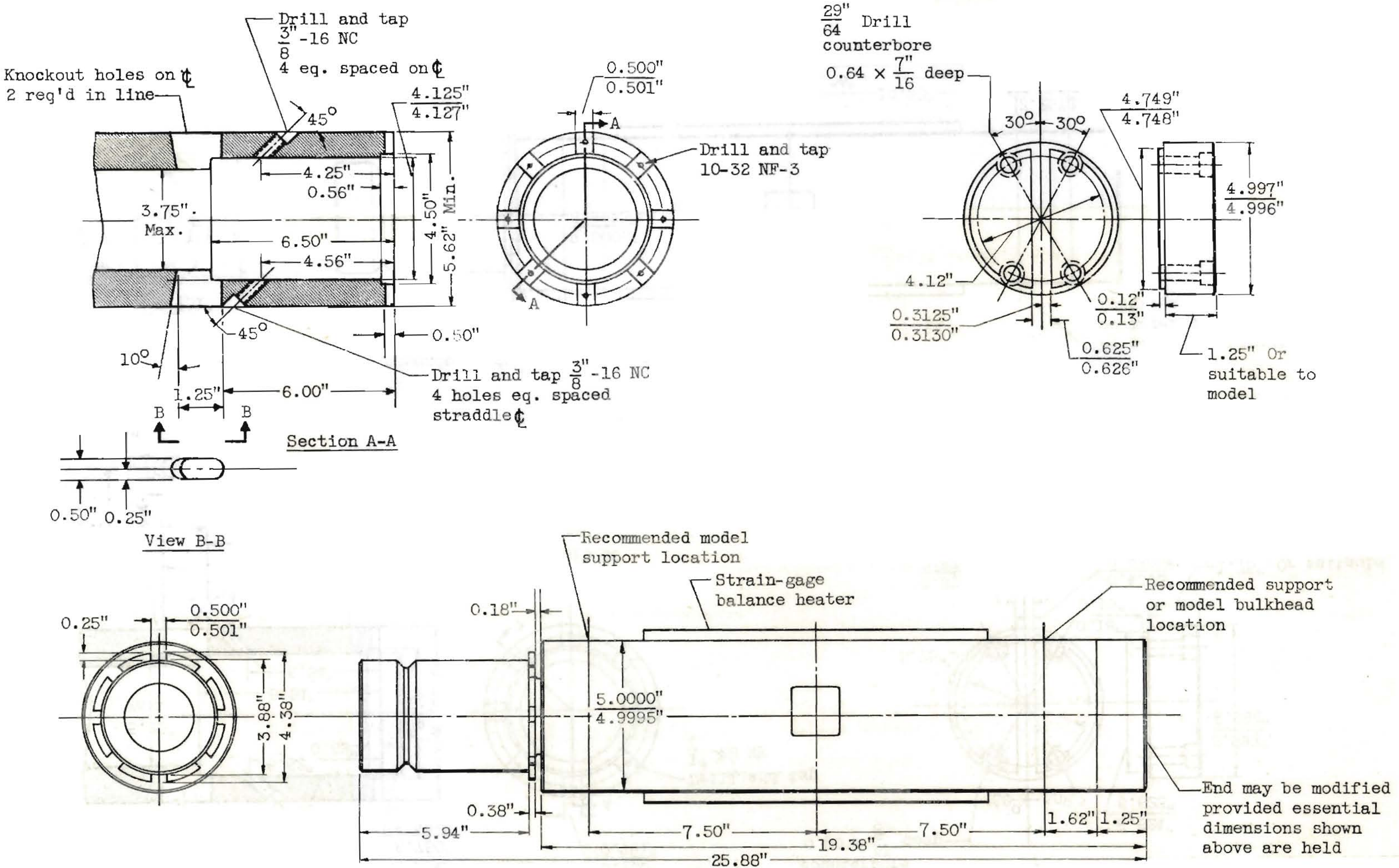
Typical plug mechanism for sting-mounted model. Lewis Unitary Plan Wind Tunnel.

Figure 9.



4-Inch strain-gage balance. Lewis Unitary Plan Wind Tunnel.

Figure 10.



5-Inch strain-gage balance. Lewis Unitary Plan Wind Tunnel.

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Figure 11.

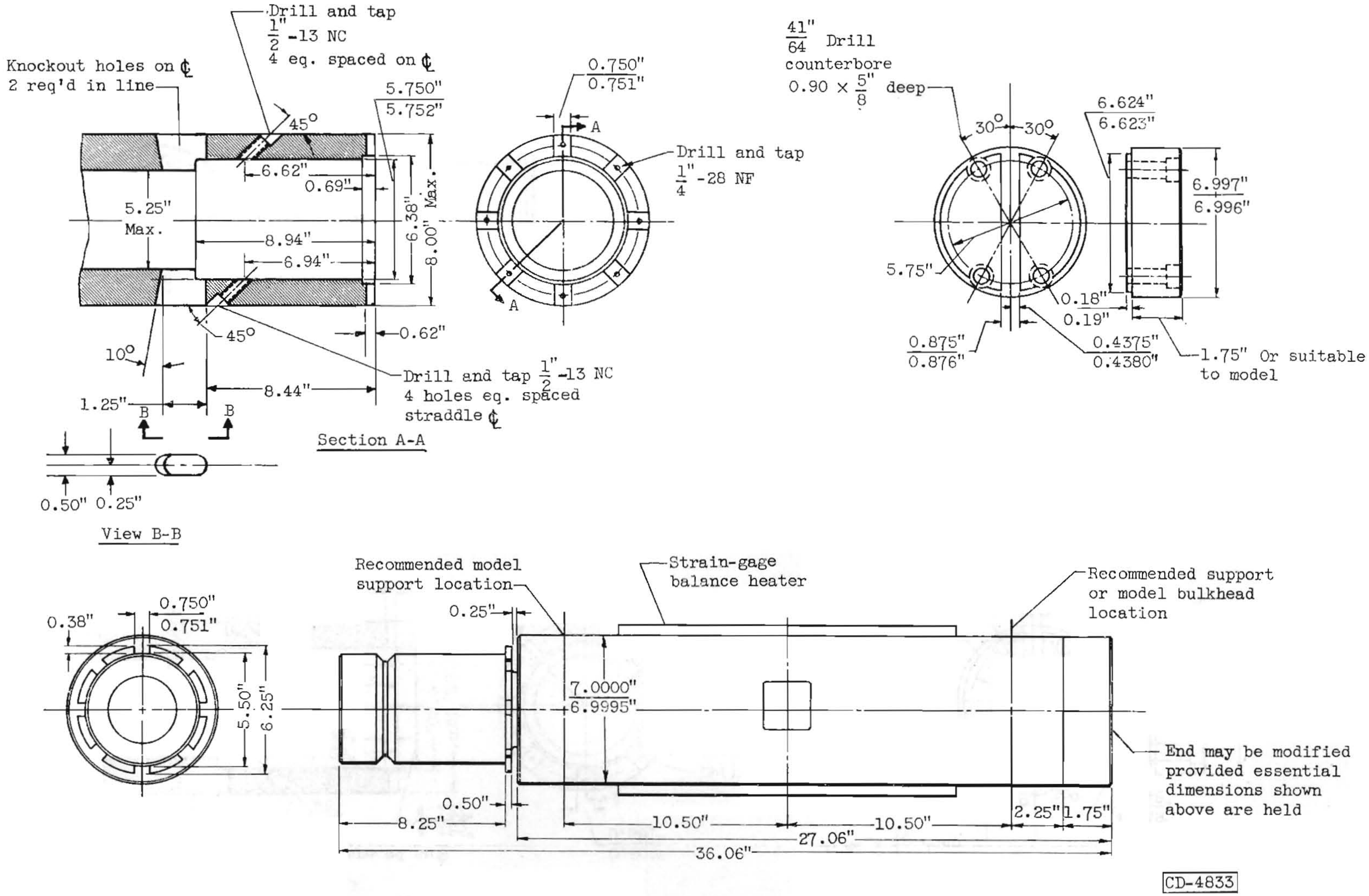
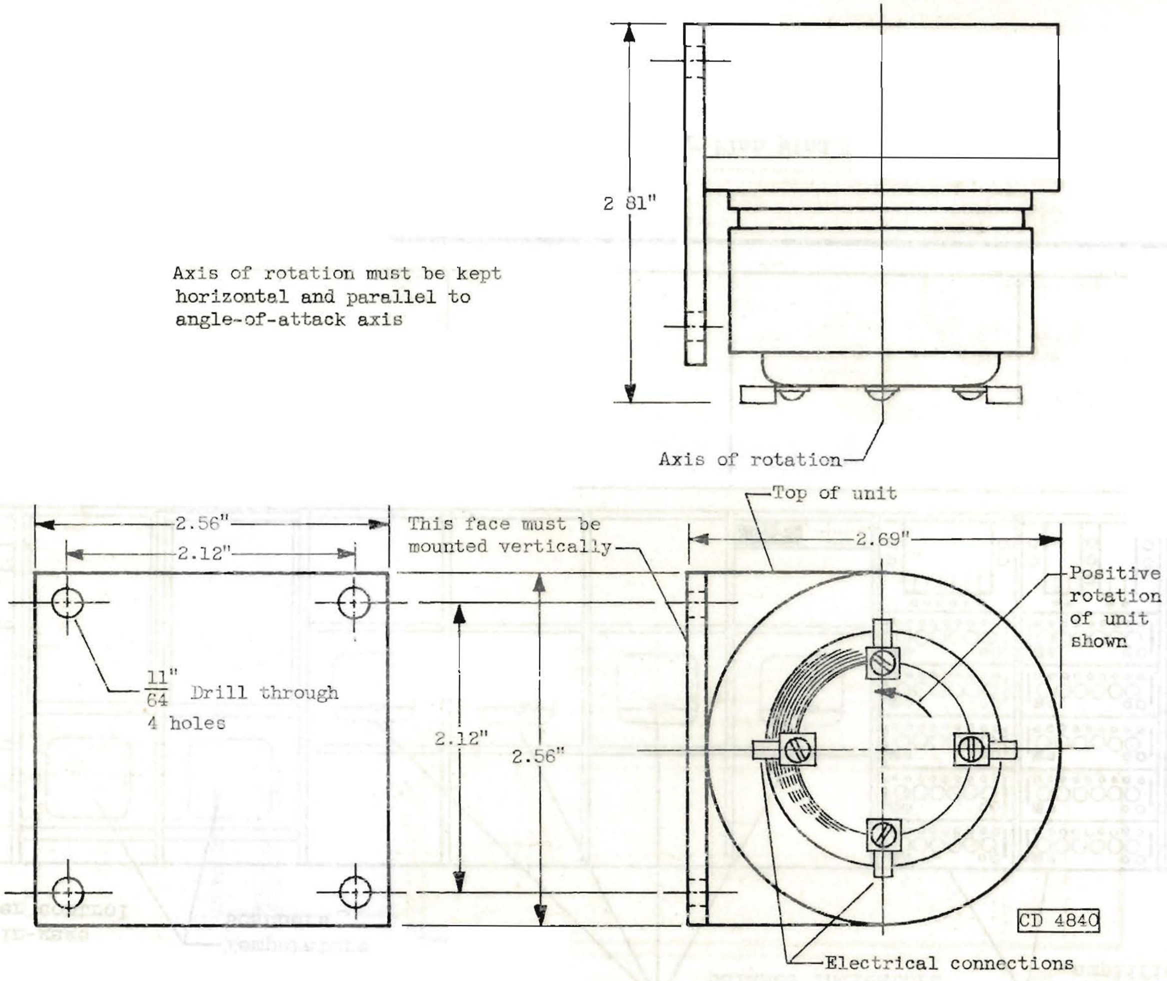
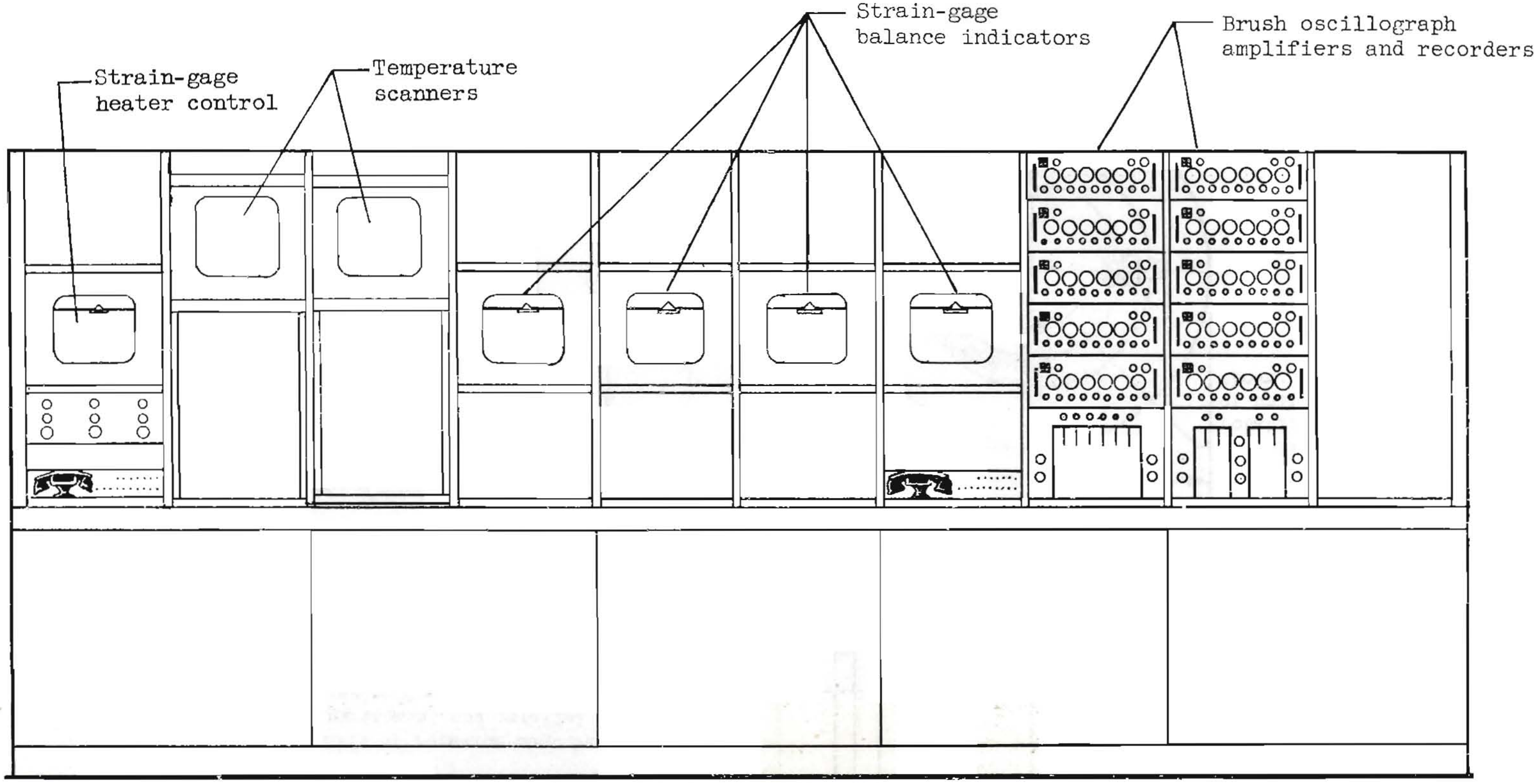


Figure 12. 7-Inch strain-gage balance. Lewis Unitary Plan Wind Tunnel.



Attitude indicator transmitter. Lewis Unitary Plan Wind Tunnel.

Figure 13.



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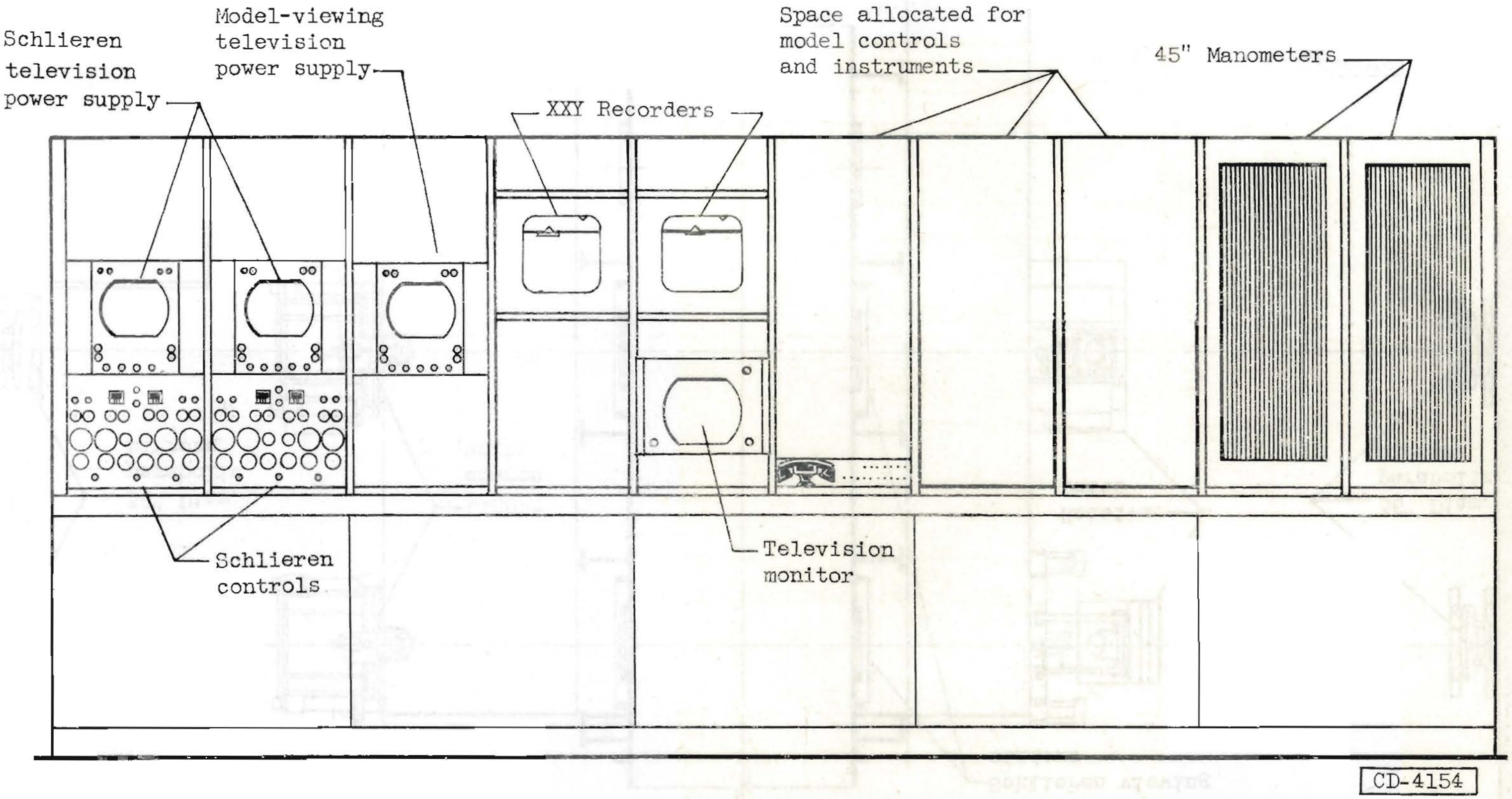
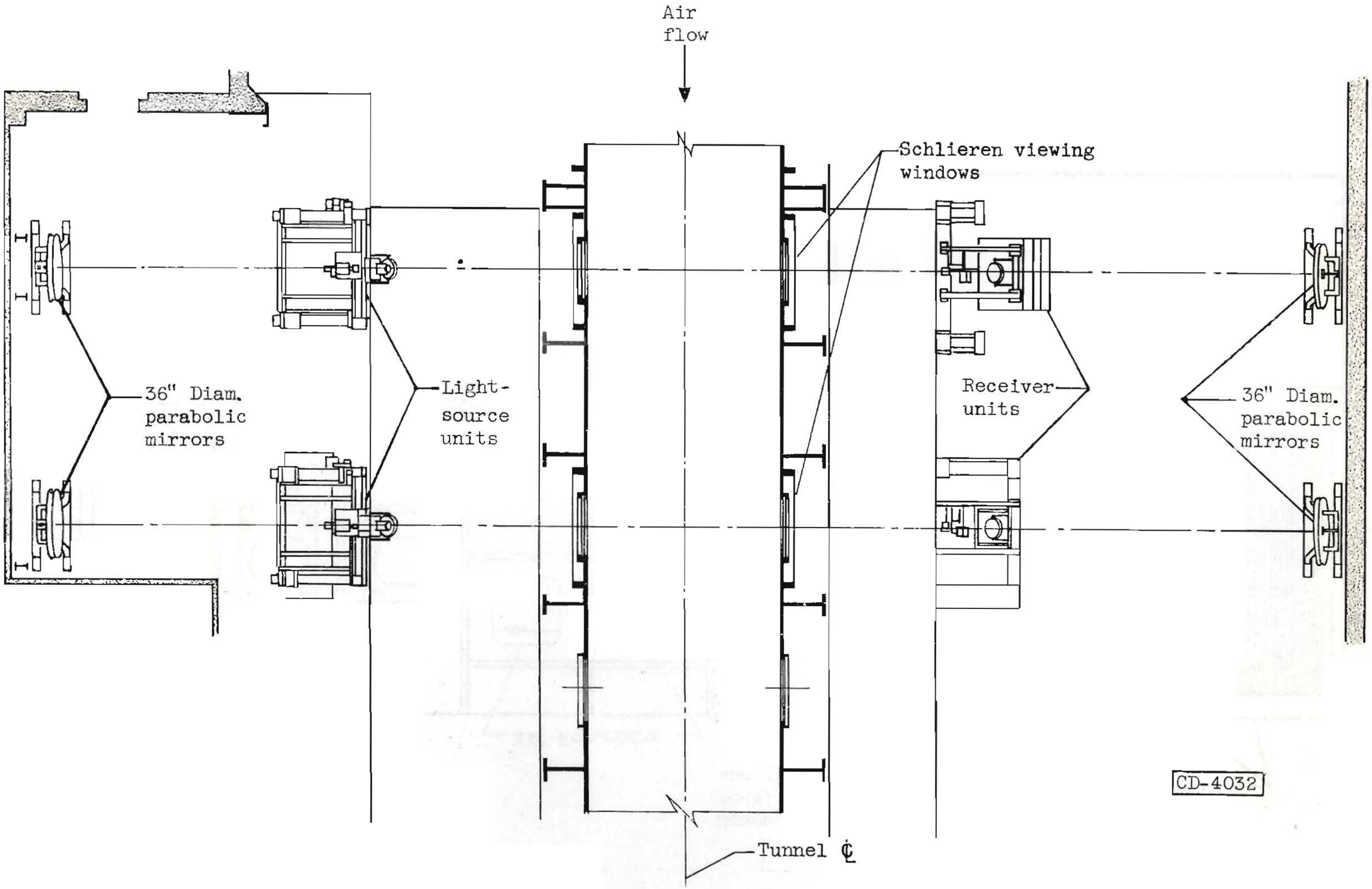
East control panel. Lewis Unitary Plan Wind Tunnel.

Figure 14.



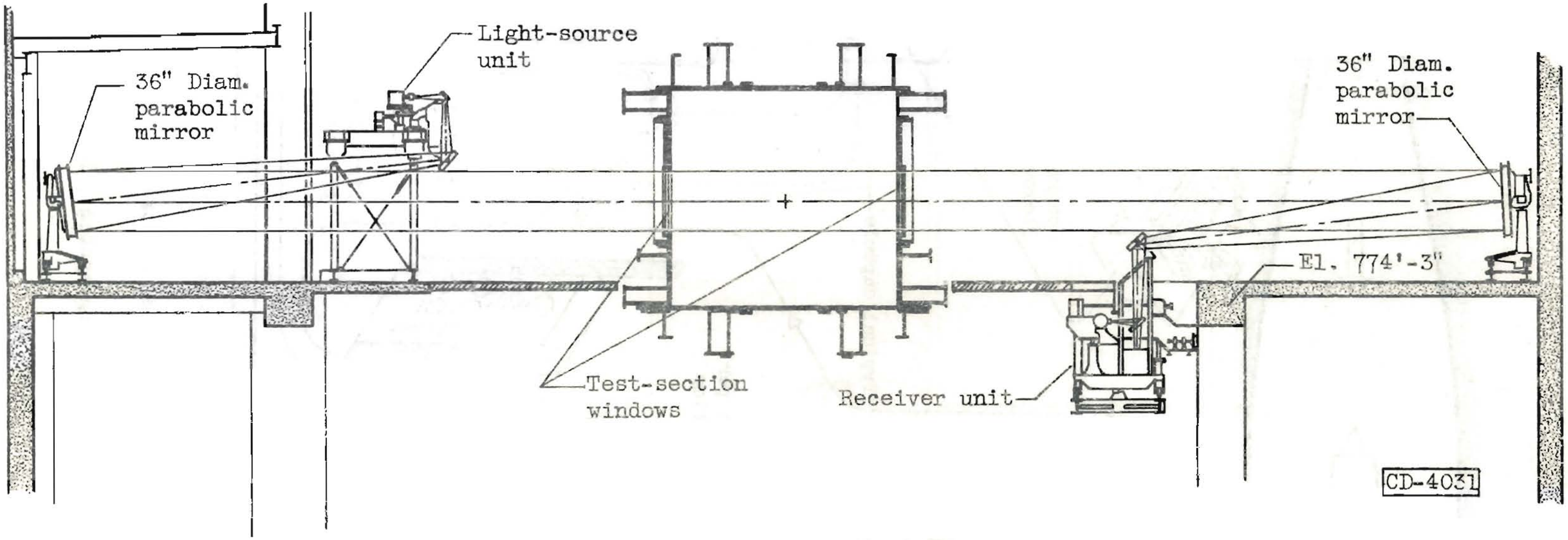
West control panel. Lewis Unitary Plan Wind Tunnel.

Figure 15.



(a) Plan view.

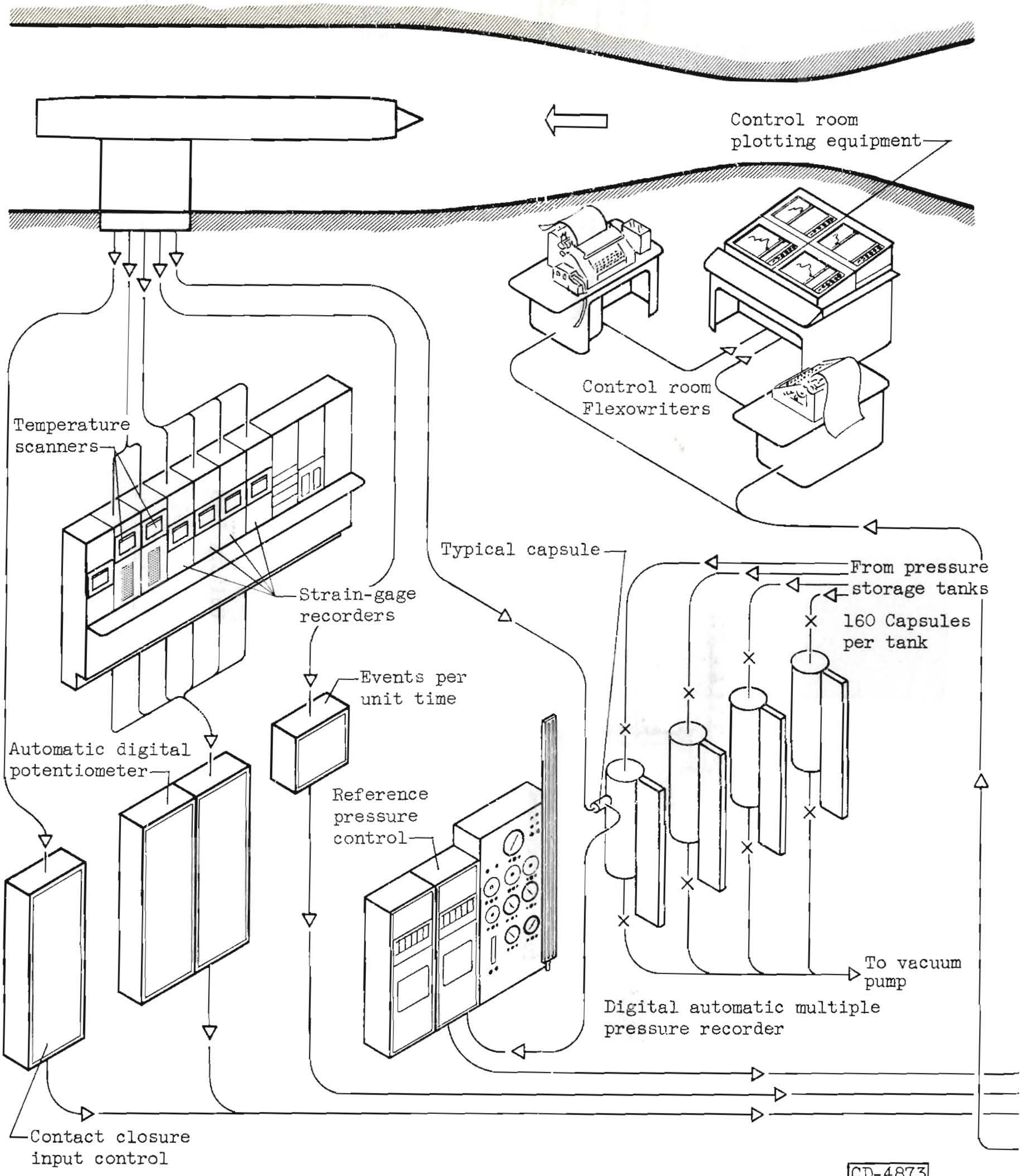
Figure 16. Schlieren system. Lewis Unitary Plan Wind Tunnel.



(b) Elevation view looking upstream.

Schlieren system. Lewis Unitary Plan Wind Tunnel.

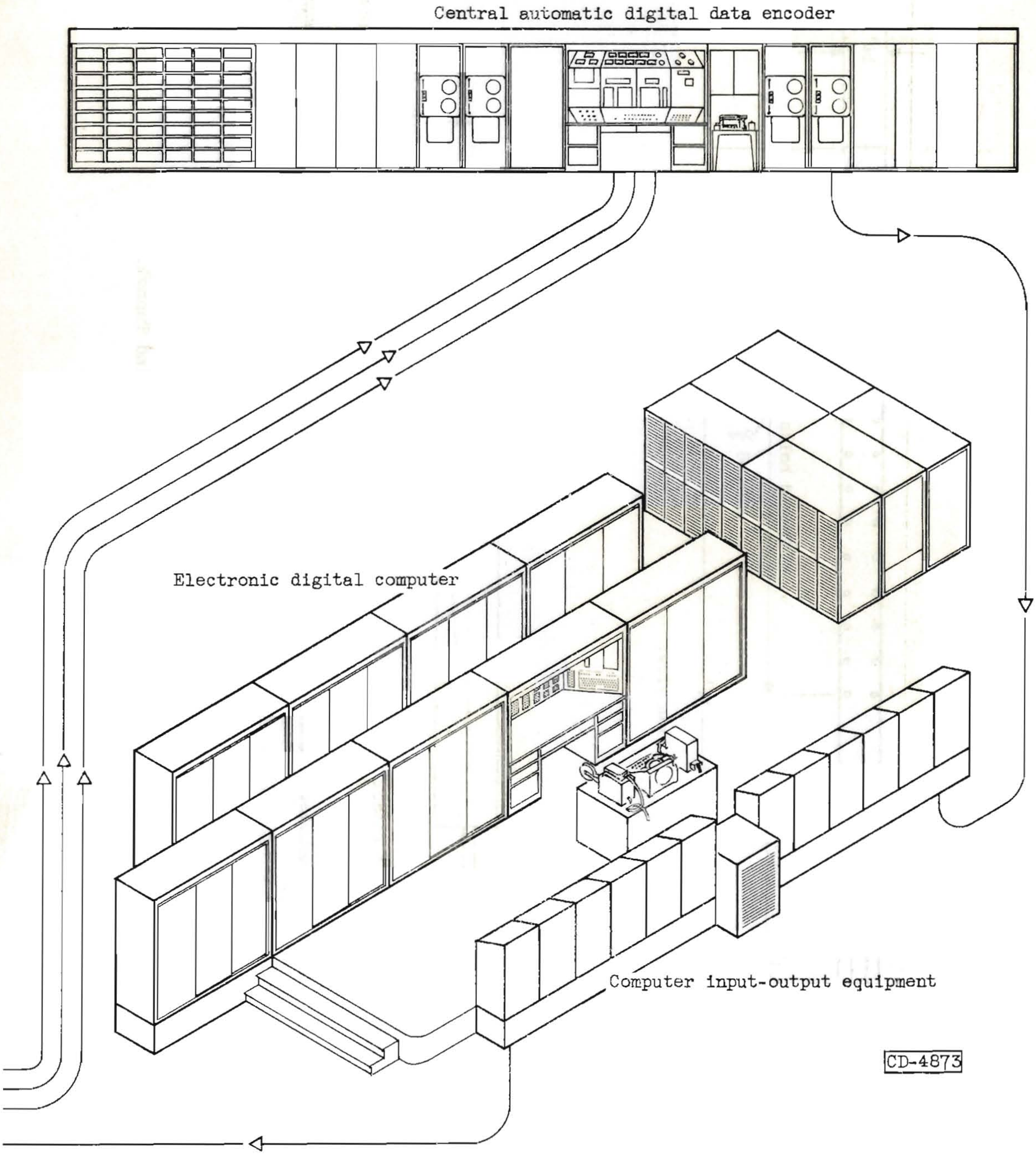
Figure 16 Concluded.



(a) Wind tunnel equipment.

Automatic data recording and processing system. Lewis Unitary Plan Wind Tunnel.

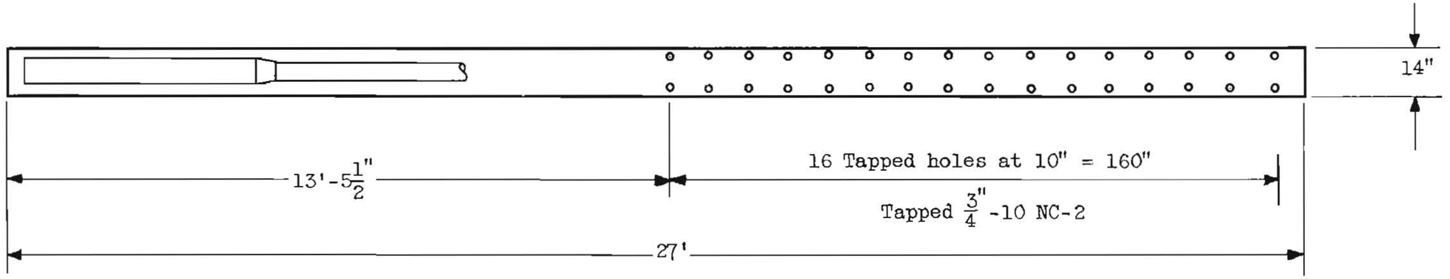
Figure 17.



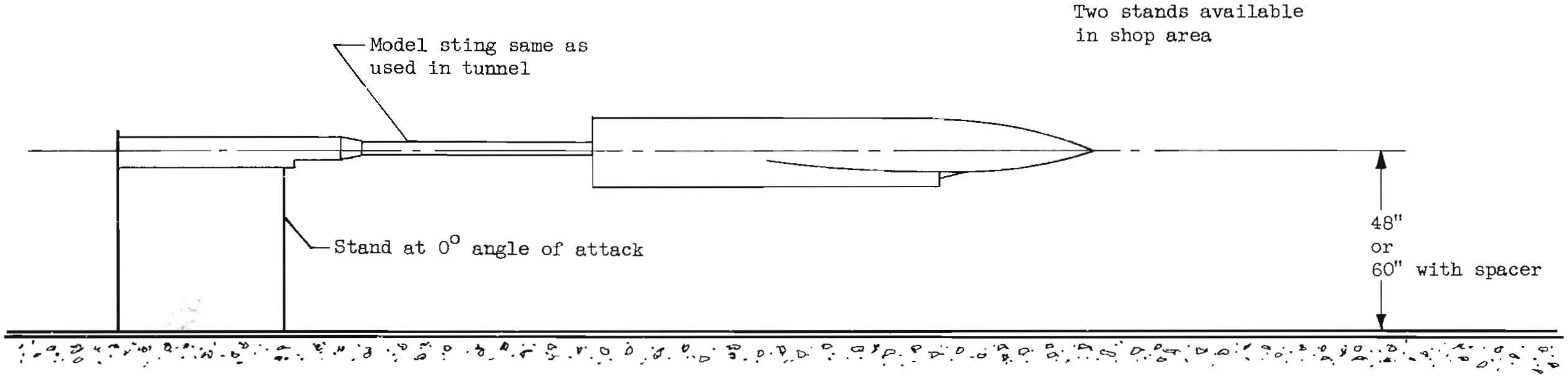
(b) Central computing equipment.

Automatic data recording and processing system. Lewis Unitary Plan Wind Tunnel.

Figure 17 Concluded.



Plan view



Elevation view

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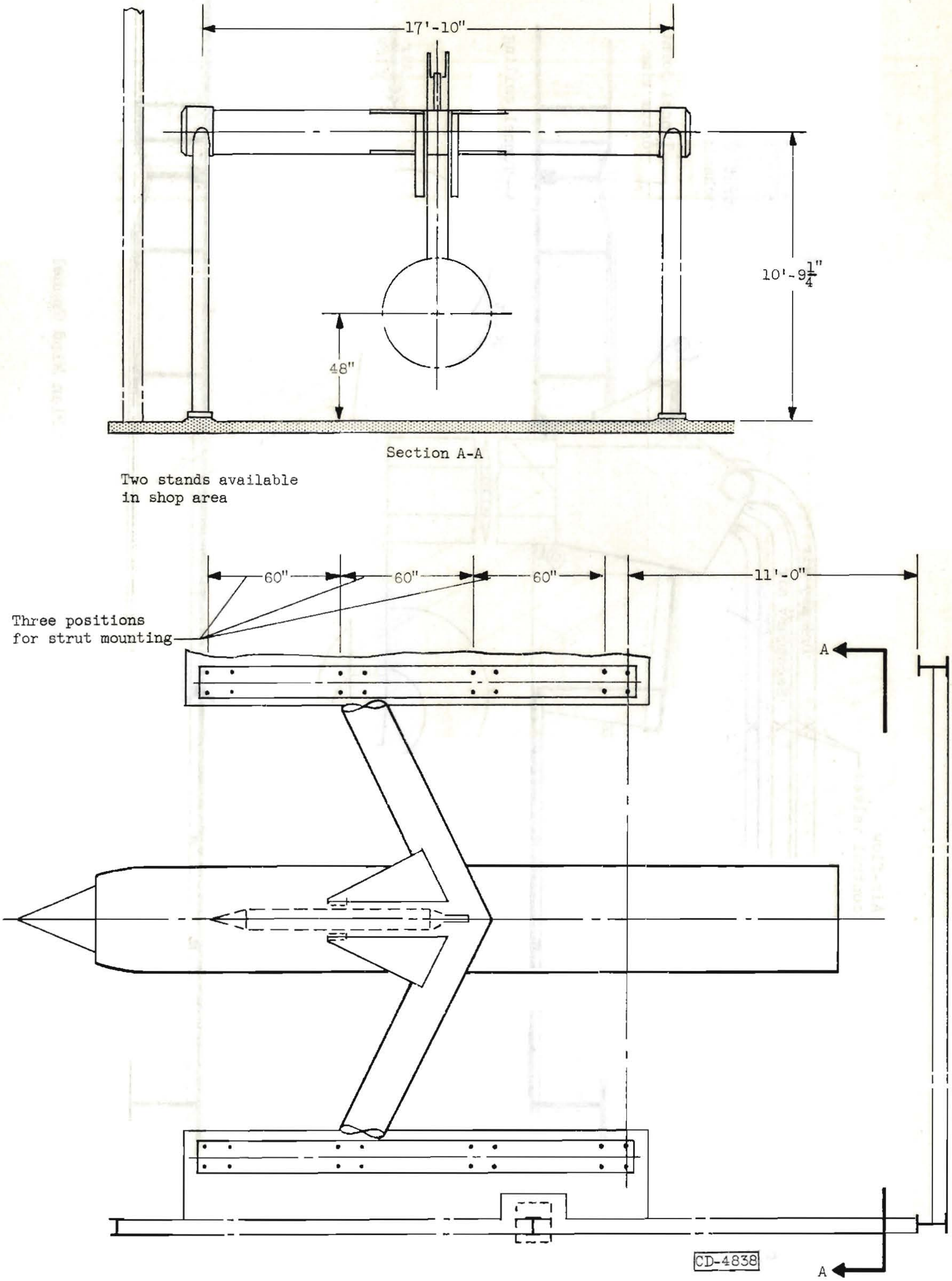
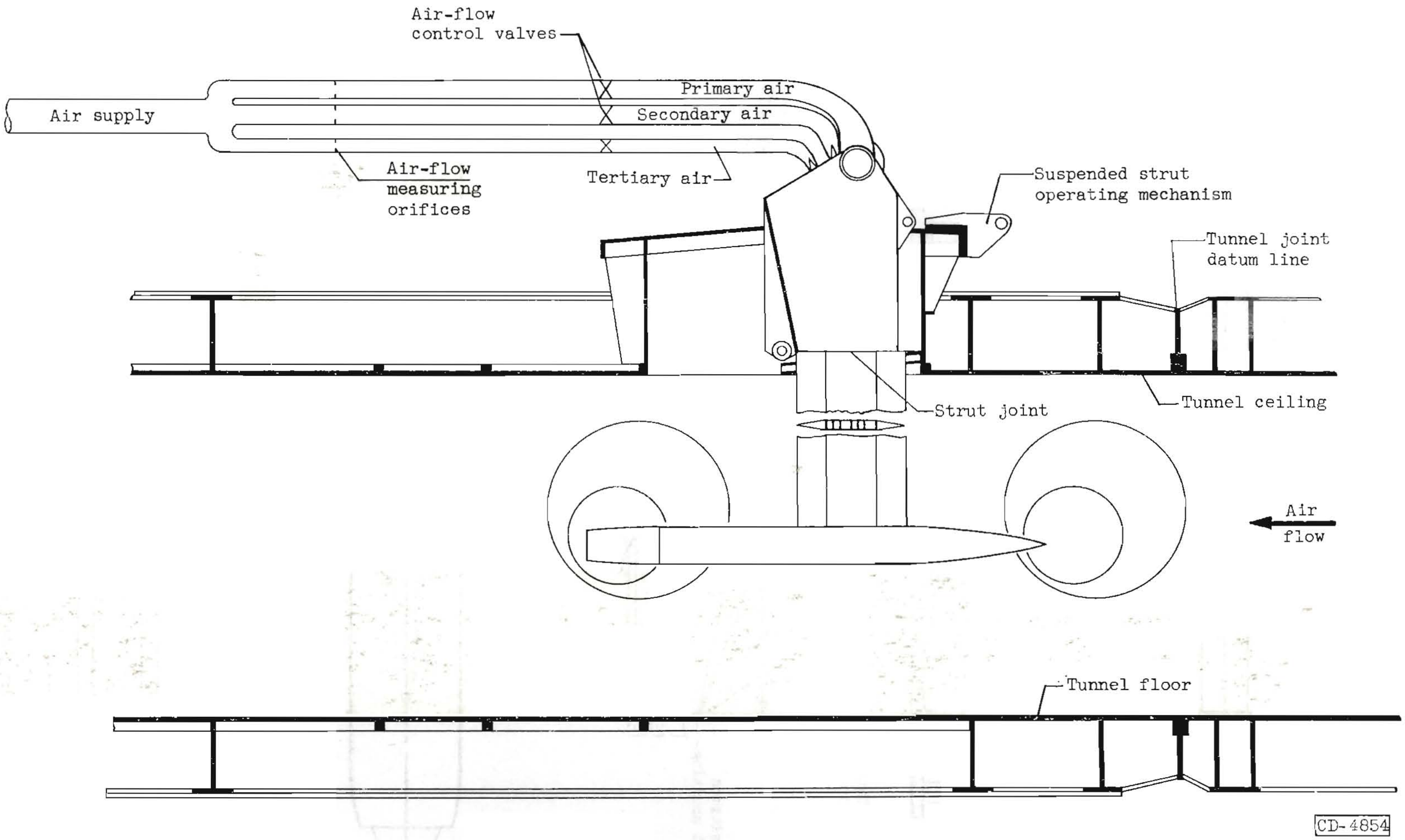
Shop stand for sting-mounted models. Lewis Unitary Plan Wind Tunnel.

Figure 18.



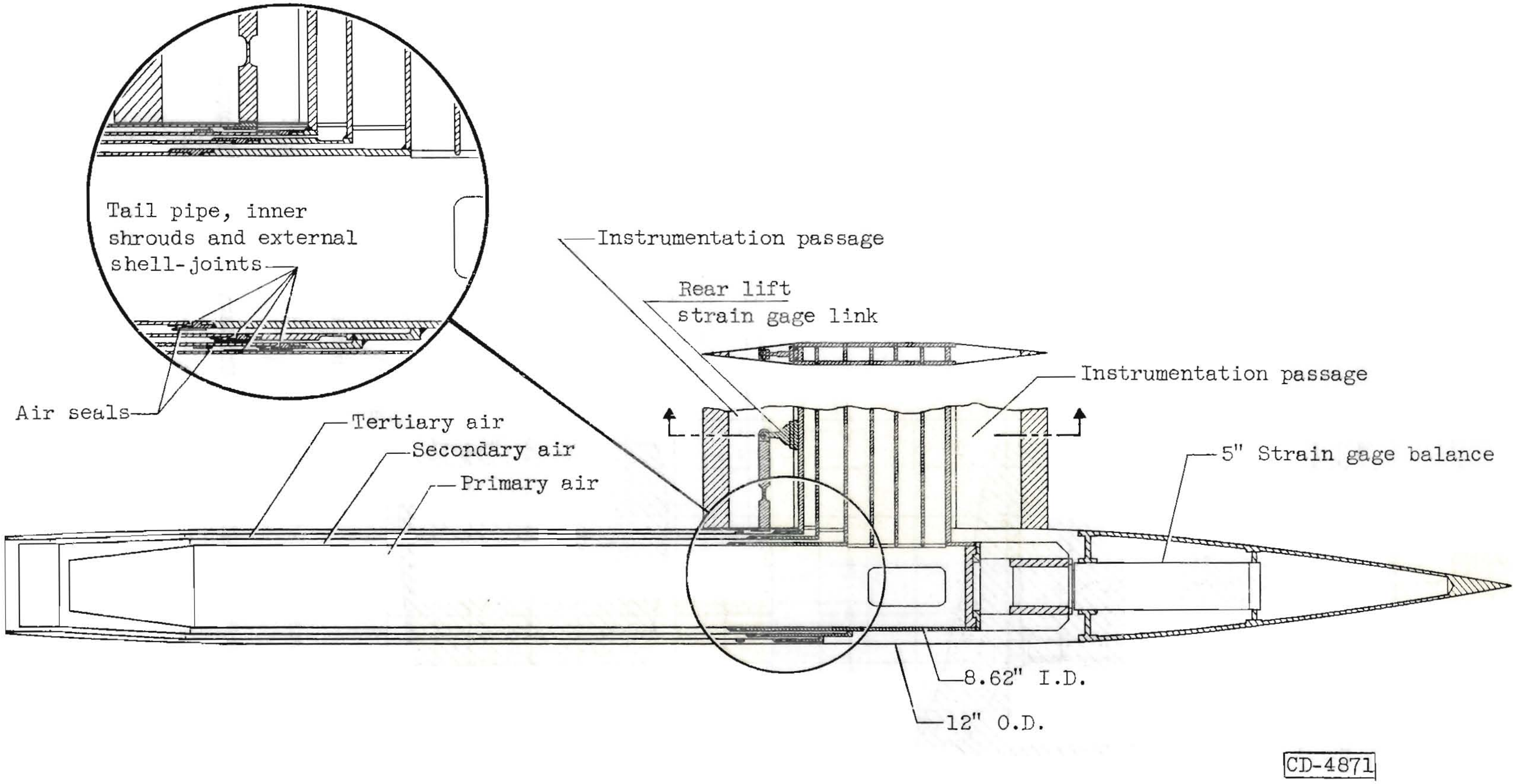
Shop stand for suspended models. Lewis Unitary Plan Wind Tunnel.

Figure 19.



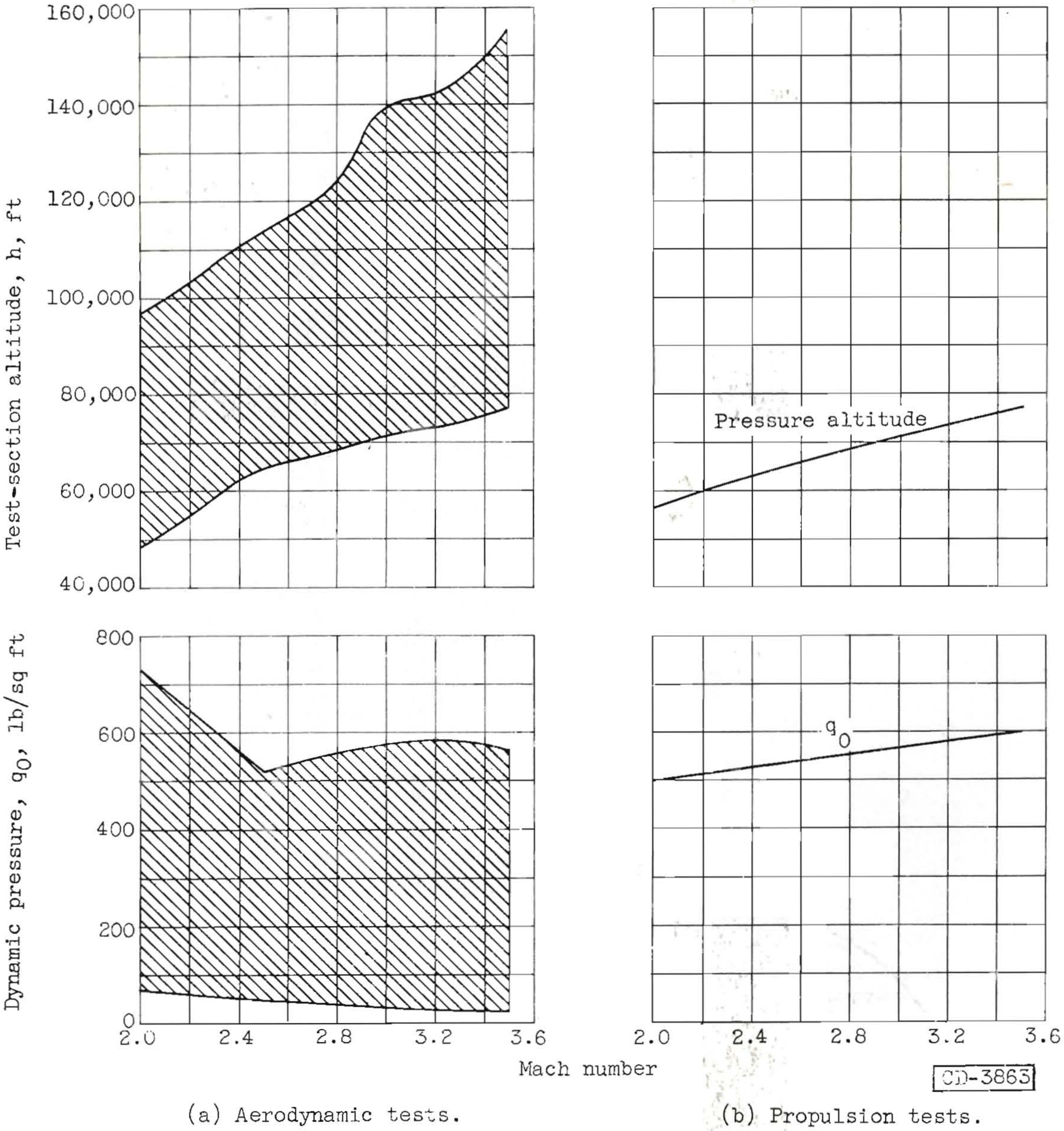
Jet-effects model installation. Lewis Unitary Plan Wind Tunnel.

Figure 20.



Jet-effects model. Lewis Unitary Plan Wind Tunnel.

Figure 21.

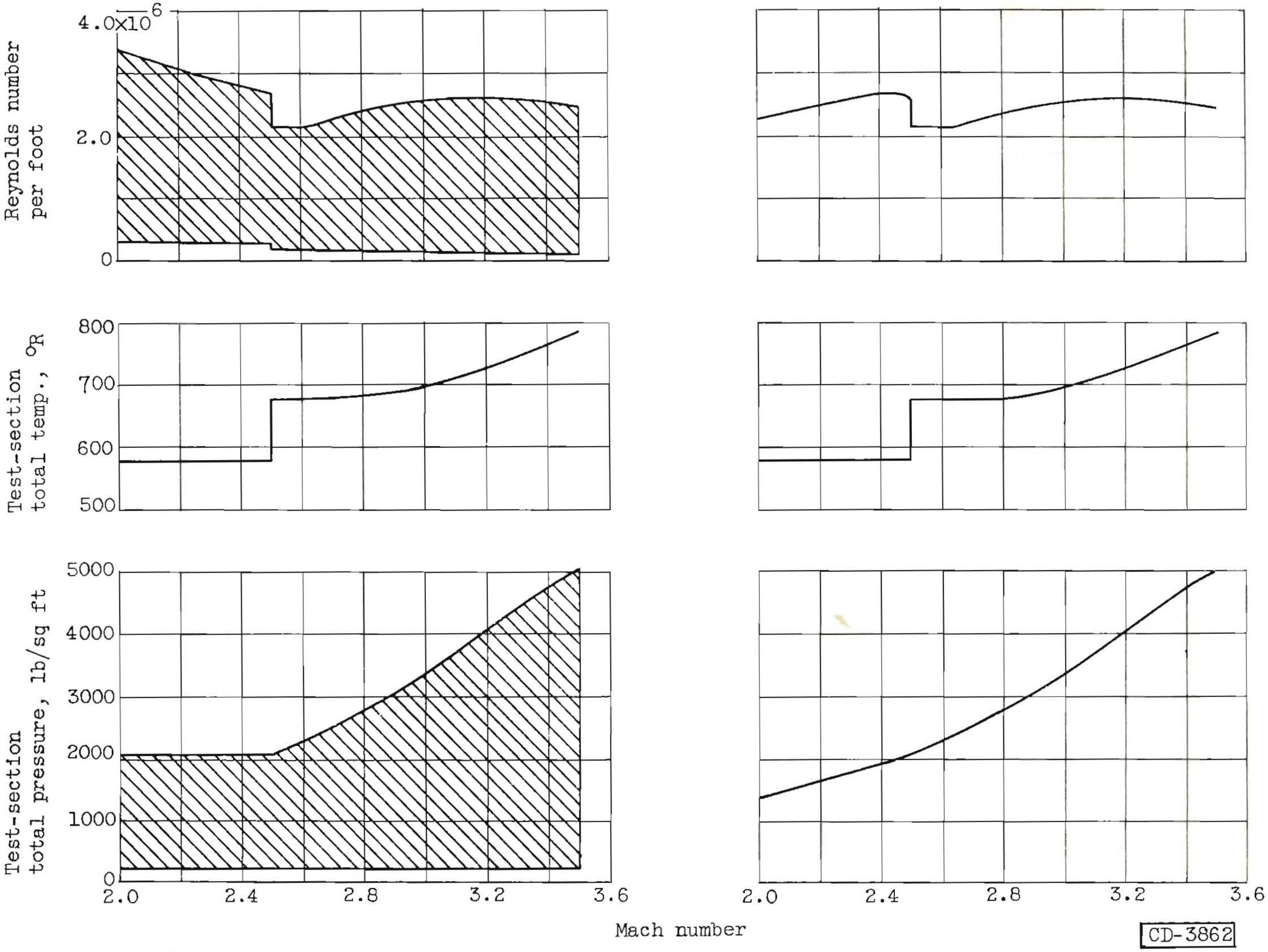


(a) Aerodynamic tests.

(b) Propulsion tests.

Estimated performance. Lewis Unitary Plan Wind Tunnel.

Figure 22.



(a) Concluded. Aerodynamic tests.

(b) Concluded. Propulsion tests.

Figure 22 Concluded. Estimated performance. Lewis Unitary Plan Wind Tunnel.