NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
LEWIS FLIGHT PROPULSION LABORATORY
CLEVELAND, OHIO

FOR P.M. PAPERS
May 22, 1956

LEWIS UNITARY PLAN WIND TUNNEL

FACT SHEET

Lewis Laboratory staff engineers made more than 100 design studies before selecting the configuration of the Lewis Unitary Plan Wind Tunnel. They built and tested a small scale model of the selected proposal before making final plans.

Design studies began in 1950, construction of equipment was started in early 1952, and ground was broken for the buildings July 31, 1952. The project was completed and the tunnel put into operation in May, 1956. NACA engineers supervised the construction job, which was carried out by more than 450 contractors, engineering firms, and suppliers. Total cost, including buildings, auxiliary equipment, instrumentation, utilities, roads, and the data-processing center, was $32,856,000.

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The continuous-flow wind tunnel has a Mach number range from 2.0 to 3.5, and is operational either in closed circuit for aerodynamic tests or on an open end cycle for combustion propulsion research. Tests may be run at simulated altitudes from 49,000 to 160,000 ft. in closed-circuit tests, and from 56,000 to 87,000 ft. in open-end runs.

Broad aims of the new wind tunnel include investigation of full-size and scale models of ramjet, turbojet, and other type engines and their components, for supersonic airplanes and missiles. Areas of interest include thermodynamic and aerodynamic performance, operating temperatures and stresses, combustion efficiency, and control systems.

The wind tunnel is maintained and operated by the NACA Lewis staff, for use by private industry, the armed forces, NACA and other Government agencies.

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The main tunnel buildings occupy a site 600 ft. square. Centerline length of the wind tunnel circuit is 1090 ft. through both compressors, 1180 ft. through primary compressor and bypass leg. Volume is 675,000 cu. ft.

Tunnel shells are constructed of firebox grade C steel 1 inch thick in all connecting ducts, and 1.5 inch thick at dished head near the main compressor. Tunnel steel was furnished and erected by Pittsburgh-Des Moines Steel Co.

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A 24-ft. diameter, 38-ton two-position valve closes in one position to direct tunnel air through the exhaust section into the open air, or in the other position to seal the exhaust section for closed-circuit operation. The tunnel contains two 15-ft. butterfly valves; one permits the flow to by-pass the secondary compressor, the other controls air flow from the air dryer into the tunnel circuit. Pittsburgh-Des Moines Steel Co. designed, manufactured and erected the 24-ft. valve. Salem-Brosius Co. supplied the two 15-ft. valves.

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Test models can be mounted on strut or sting supports in the test section. Bottom of the test section is an elevator platform, which can be lowered to shop floor level. Force data on models under test is measured by electrical resistance strain gages, and recorded by potentiometers and oscillographs. Air flow is observed and photographed through a schlieren optical system. Closed-circuit television provides test monitoring from the control room.

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More than 125 tons of stainless steel wire was used in the flexible wall nozzle and test section of the tunnel. The walls are plates $1\frac{3}{8}$ inches thick, 10 ft. wide and 78 ft. long -- probably the longest ever rolled. The flexibility of the walls permits adjusting the nozzle throat to change airspeed through the test section while the tunnel is operating. The throat width can be varied from 0.933 to 5.92 ft. Though the walls weigh 20 tons each, they can be positioned with an accuracy of .005 inch. Each wall moves 2.5 ft. maximum, forced by 27 large jack screws. Time to change from maximum to minimum opening: 25 minutes. The nozzle is 78 ft.,

$3\frac{5}{8}$ in. long while the test section measures 40 ft. Both are 10 ft. high.

The second throat, which is downstream from the test section, consists of two hinged sections with a total length of 61 ft.; material is ASTM firebox grade C steel, $1\frac{1}{4}$ inch thick. Each wall moves 2 ft. 3 in. at the throat. Air and internal surfaces are cooled by water injected through a row of orifices 4 inches apart in the sides, top and bottom of the throat.

A total of 722 tons of high grade steel went into the test section, second throat and nozzle, which were manufactured and erected by the American Bridge Company.

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The two compressors are axial flow, with a capacity of 80,000 cubic feet of air per second. The main compressor is used alone for air flow from Mach no. 2.0 to 2.5; both compressors for Mach numbers from 2.5 to 3.5.

The main compressor has eight stages, contains 1006 stainless steel blades ranging from 1.8 to 3.25 ft. long. Inlet diameter is 20 ft., weight is 225 tons. Main drive consists of four 37,500-hp, 6600 volt induction motors mounted in tandem on 108 ft. shaft. Total rotating length, with compressor, 183 ft., weight, 890,000 lbs.

The secondary compressor is 10-stage, contains 1395 stainless steel blades ranging from 1.05 to 1.55 ft. long, with inlet diameter of 15 ft., weighs 175 tons. Drive consists of three 33,334-hp motors similar to No. 1., mounted on 85 ft. shaft. Total rotating length 147 ft., weight, 680,000 lbs.

Drive motors designed, manufactured and installed by General Electric Co. Compressors manufactured by S. Morgan Smith Co. and erected on the site by Commercial Contracting Co. Compressor blades machined by the C. L. Gougler Machine Co. from forgings supplied by Steel Improvement and Forge Co.

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Heat generated by operation of the wind tunnel and by operation of test engines is dissipated through a cooling tower with capacity of 900,000,000 BTU per hour, maintaining constant tunnel temperature at 120 degrees F. Coolers are located upstream of the two compressors.

No. 1 cooler has capacity of 1880 lbs. of air per second at water flow of 32,000 gallons per minute; No. 2 cooler, 2670 lbs. of air per second. Ten-cell cooling tower, located across street from main tunnel structure, contains 480,000 gallons of water, which is supplied to tunnel coolers through 42-inch pipe. Capacity of the coolers is equal to 250,000 average household air conditioners.

Coolers manufactured by the A. O. Smith Co. and Griscom-Russell Co.

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The air dryer, a building 117 by 84 feet, 82 feet high, furnishes clean air to the wind tunnel, dried to a dew point of -40° F, regardless of outside air conditions. It contains 1890 tons of activated alumina drying agent, which takes up water at the rate of 1.5 tons, or 10 bathtubs full, every minute. The air dryer can be used as long as 2 hours on a humid summer day, up to 10 hours in winter. Drying capacity is equal to about 12,000 household clothes dryers.

When the alumina becomes saturated it is heated to 350 degrees for about four hours to remove moisture. Heating is accomplished by means of 32 natural gas burners producing 256,000,000 Btu and blown by eight large fans powered by 200 hp motors. Capacity of this heating system is enough to satisfy the winter-time needs of a city the size of Berea, nearby the laboratory.

Design of the building takes care of the relatively high rates of expansion and contraction in its use. The building is supported by 25 steel columns but only the center column is stationary. The walls are permitted to move -- as much as 1.5 in.

The air dryer was constructed by the George A. Rutherford Company, and the circulating fans by the Joy Manufacturing Company.

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Because of extreme changes of temperature inside the wind tunnel during operations, rubber and metal expansion joints as large as 26 feet diameter are necessary. These joints take as much as 13 inches of movement. The largest ones were manufactured by Solar Aircraft Company at

San Diego, California, and transported by ship through the Panama Canal, thence via Albany, New York, the Erie Canal and Lake Erie, to Cleveland.

Metal expansion joints were furnished by Piping Specialities Corp., and rubber joints by Moisson Packing and Rubber Co.

* * * * *

The name "Unitary" stems from legislation passed by Congress in 1949. The Unitary Plan Wind Tunnel Act evolved from studies of supersonic research facility needs by NACA, the armed services, and other Government bodies.

First estimates of the need for new facilities put the cost at several billion dollars, and made unified action by industry, Government and armed services imperative. Under the revised and coordinated plan, the Unitary tunnels are built primarily for development testing of aircraft, missiles, and propulsion systems.

NACA's Unitary tunnels are operated and staffed by NACA employees and are available for use by industry, the armed forces, NACA and other Government agencies interested in aeronautics. Business firms will pay full costs for use on proprietary projects.

The Act specified three NACA tunnels, one each at the Langley Aeronautical Laboratory, Langley Field, Virginia; the Ames Aeronautical Laboratory, Moffett Field, California; and the Lewis Flight Propulsion Laboratory, Cleveland, Ohio. Other Unitary facilities are being completed at the USAF Arnold Engineering Development Center, Tullahoma, Tennessee.

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Lines 2000 feet long carry 138,000 volts from the Cleveland Electric Illuminating Co. substation south of the laboratory gounds to the wind tunnel through an underground tunnel, 60 feet below the surface. Power connects to four 60,000-KVA transformers, which could supply power to light a city the size of Cleveland. Because of the electrical "load," the wind tunnel normally will be operated only at night. The power lines are routed underground to eliminate hazards to air traffic at the adjacent Cleveland-Hopkins Airport.

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The high-speed, electronic digital computer accepts the raw data in the form of punched paper tape or magnetic tape from CADDE and other sources. It performs the appropriate calibrations and calculates from these data, the end results of the test. Selected output is immediately typed in the control room, and detailed output is stored on punched paper tape to be typed at a later time. The computer, which occupies an area 16 by 56 feet, has a storage capacity of 17,408 ten-digit decimal numbers; these are manipulated at the rate of 10,000 additions per second. It was purchased from the Remington Rand Division of the Sperry Rand Corporation and is called the ERA 1103.

END

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ELECTRONIC BRAINS SPEED WORK OF ENGINE LABORATORY

Answers to complex problems involving great volumes of measurements -- the raw data of aeronautical engine research -- are now ready almost immediately, with the aid of new electronic equipment at the NACA Lewis Flight Propulsion Laboratory, Cleveland Airport. The elaborate "electronic brains" do their computing work in a fraction of the many weeks required by manual methods.

The Central Automatic Digital Data Encoder, or CADDE, located in the Lewis Unitary Plan Wind Tunnel office building, is the only centralized system of its type. It is part of a data processing center connected directly to the tunnel and four other major research installations on the laboratory grounds. One of these is 3/4 miles away.

Equipment of the center includes data recording and translating devices, control room monitors, devices for rejecting errors, and a general purpose electronic computer -- all automatic.

The automatic data processing center slashes the delay between a test run and the return of computed data to the engineer. This laboratory work involves blocks of data, now totaling as many as 80,000 separate measurements in a single day. The data are concerned with calculations of speed, thrust, fuel flow, temperature, and other propulsion parameters.

With CADDE, research measurements are recorded permanently on magnetic tape, and are then read and processed by the computer. Tunnel operators can read completed results of immediate interest on paper tape printed in the tunnel control room on automatic typewriters; this data may then convert to a graphical form by automatic plotters if desired. Since results of an experiment sometimes modify the course of a test, the automatic data system is designed to prepare computed results in graphic form for rapid analysis while the test is under way. The computations are available in the control room within 30 seconds after the data is taken in the test section.

Older methods of processing such research data employ banks of manometers, which are photographed; the film must then be developed and the information transferred to IBM cards for processing. The lag between completion of a test and reduction of the data to useable form usually requires three weeks or more. The human element not only delays the process, but frequently introduces errors.

The Lewis laboratory data-handling system was evolved by members of the staff of the Physics Division. NACA scientists plan to connect the system to other test facilities to increase its use.

END

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NEW WIND TUNNEL TESTS FULL-SCALE ENGINES AT SUPERSONIC SPEEDS

CLEVELAND, OHIO, May 22, 1956 - - Engine operating conditions at supersonic speeds and altitudes of 30 miles can be duplicated on the ground in a new wind tunnel at the NACA Lewis Flight Propulsion Laboratory, Cleveland Airport.

This was exhibited today in the first public inspection of the new facility, now in full operation. The tunnel's 250,000 horsepower electric-motor drive is the most powerful of its kind in the world. Air speeds range between Mach number 2.0 and 3.5, or between 1200 and 1800 miles an hour at high altitudes.

The 10- by 10-foot Lewis Unitary Plan Supersonic Wind Tunnel, built for development testing of engines and components for high-performance aircraft, is used in cooperation with industry and the armed forces by the National Advisory Committee for Aeronautics. The NACA is the government's prime agency engaged in research for the aircraft and engines of tomorrow.

According to Dr. Edward R. Sharp, director of the laboratory, the new tunnel is valuable especially for work on problems of turbojet and ramjet engines. Dr. Sharp said engines and components as large as 5 feet in diameter may be studied in the 10-foot-square test section.

The tunnel may be operated either in closed circuit for aerodynamic tests, or in open-end propulsion circuit, with engines running under combustion test. Its main purpose is investigation of such problems as engine-inlet and -outlet geometry, engine matching and interference effects, and over-all drag. Though many tests will be conducted with scale models, the test section can accommodate full-size engines and components.

"There is ample evidence," Dr. Sharp said, "that the rate of development of modern engines is influenced very strongly by the facilities available for testing them at full scale."

The Unitary Plan Supersonic Wind Tunnel supplements the Lewis 8- by 6-foot Supersonic Wind Tunnel, which has a Mach number range of 1.4 to 2.0. Experience with that research tool produced large performance gains for the current "century series" fighters, such as the F-102 and F-104. As a result of the significant gains obtained with this tunnel, the larger and higher speed new facility was built.

Main features of the Unitary Supersonic Wind Tunnel:

Two compressors that handle approximately a ton of air per second;

Seven electric motors in two banks, developing a normal total of 250,000 horsepower, with 300,000 horsepower available for limited periods;

A stainless steel flexible-wall nozzle, which controls air flow and permits change of air speed during operation;

An air dryer that can remove 15,000 gallons of water, or enough to fill a community size swimming pool;

An adjustable second throat, which saves operating power at high Mach numbers;

A noise reducing exhaust muffler;

A complete 138-KVA electrical substation connected to the power source through underground conduit;

A data-reduction center able to compute scientific data in a small fraction of the time required by manual methods;

Large, completely equipped shop and office buildings;

A closed-circuit television for monitoring tests.

In operation, the tunnel draws air through the dryer and the flexible wall nozzle into the test section, where the engine or airplane model is mounted. For speeds above Mach 2.5, the two compressors are operated together. For lower speeds, the secondary compressor is shut down and the air flow is valved around it through a bypass circuit.

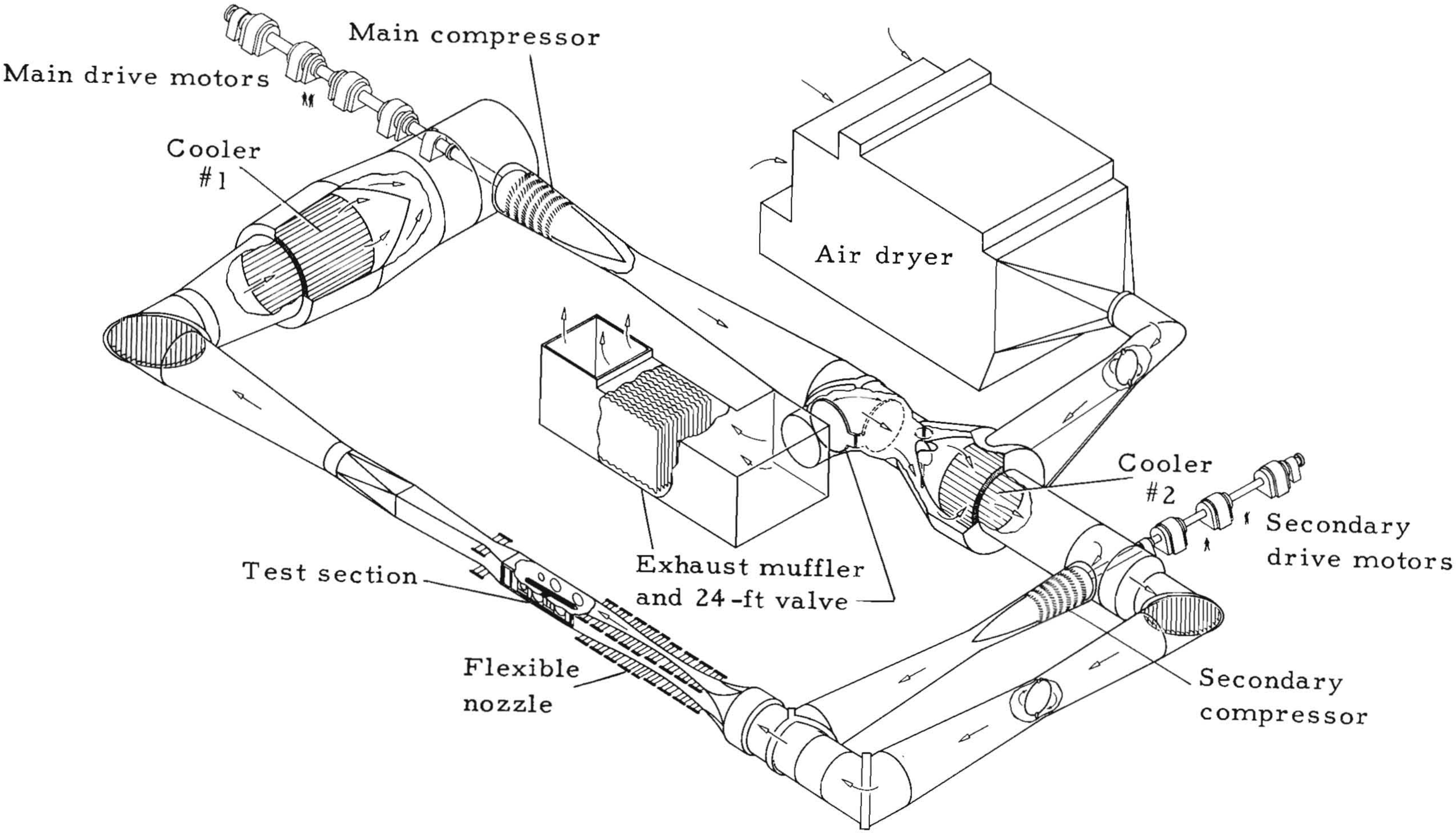
The altitude simulated in the test section where the model is located is regulated by means of exhausters located near the flexible nozzle. Air temperature is controlled by a water cooling tower separated from the main tunnel structure. Elaborate systems for safety and for remote control of all elements of this huge research tool are included, and soundproofing reduces external noise to acceptable levels. For the propulsion cycle, duration of a single test is limited by capacity of the air dryer to less than an hour on a humid summer day and to about 10 hours in the winter. Operation of the facility on the closed-circuit aerodynamic cycle, however, is not time limited.

Complete test information is recorded automatically by electronic devices for immediate processing or for later computing in a unique central data handling system. This center, located in the tunnel offices, handles not only the data produced in the Unitary tunnel but that of four other major research facilities on the laboratory grounds.

The new Lewis tunnel is the highest powered of three designed and built by the National Advisory Committee for Aeronautics under the Unitary Plan Legislation passed by Congress in 1949. Its cost was $32,856,000. The other two tunnels are located at the Langley and Ames laboratories. The $75,000,000 Unitary project is the largest single wind tunnel construction program undertaken by NACA in its 41-year history.

END

NACA
C-42074


Main compressor
Main drive motors
Cooler #1
Air dryer
Cooler #2
Secondary drive motors
Exhaust muffler and 24-ft valve
Test section
Flexible nozzle
Secondary compressor

National Advisory Committee for Aeronautics
Lewis Flight Propulsion Laboratory, Cleveland, Ohio

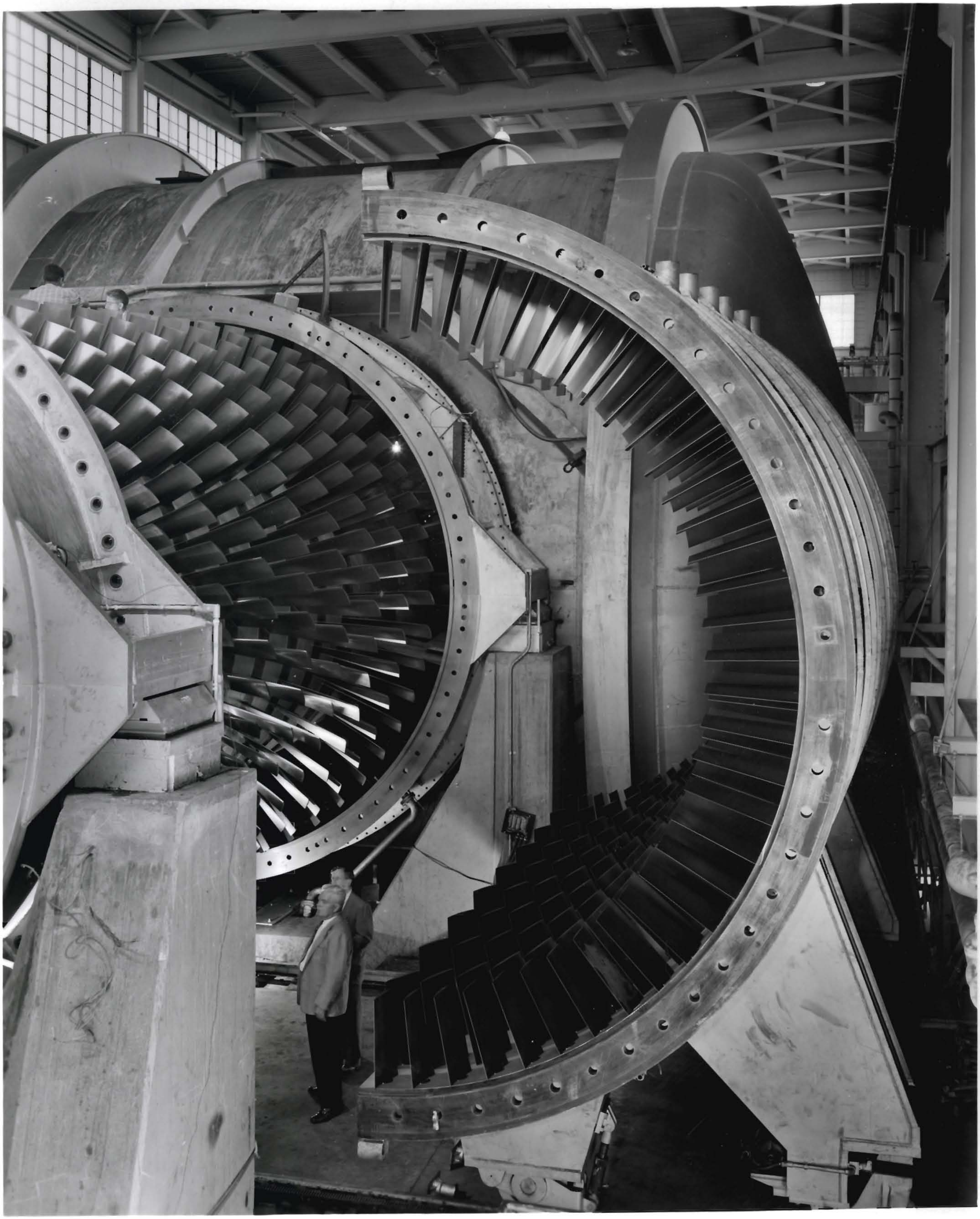
C-42074 Schematic diagram of main elements of the Lewis Unitary Plan Wind Tunnel. The facility will permit altitude testing of full-scale scale jet engines and aircraft models, at air speeds up to 3 1/2 times the speed of sound. The flexible nozzle permits changing air speed during a run.

NACA
C-39724

National Advisory Committee for Aeronautics
Lewis Flight Propulsion Laboratory, Cleveland, Ohio

C-39724 Blades of main drive compressor that drives air through the Lewis Unitary Plan Wind Tunnel. Stator blades (left) form rows that redirect the air from stage to stage as it is propelled by the rotor blades (right); compressor delivers 2000 pounds of air per second at a pressure ratio of 2.8.

NACA
C-39726



National Advisory Committee for Aeronautics
Lewis Flight Propulsion Laboratory, Cleveland, Ohio

C-39726 Inspection of the fully-bladed 8-stage main drive compressor, driven by 150,000 h.p. electric motors, prior to assembly of the stator halves. This compressor, with a pressure ratio of 2.8, is one of two that provide Mach 3.5 air speeds in the 10- by 10-foot test section of NACA's Lewis Unitary Plan Wind Tunnel.

C-39731

National Advisory Committee for Aeronautics
Lewis Flight Propulsion Laboratory, Cleveland, Ohio

C-39731 Blades of compressor 1 of the Lewis Unitary Plan Wind Tunnel. During operation, the rotor blades (upper right and left) sweep past the stator blades (center) at about 600 miles per hour, forcing the air through the tunnel throat at supersonic speeds.

NACA
C-39782

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Lewis Flight Propulsion Laboratory, Cleveland, Ohio

C-39782 Electronic digital computer of the Lewis Unitary Plan Wind Tunnel, which receives decimal numbers from CADDE (C-42021). The computer processes these readings and signals automatic typewriters in the control room, (C-40247) where computed values of selected parameters are typed 30 seconds after the data signal is sensed. Values of nonselected parameters are recorded on punched tape for later analysis.

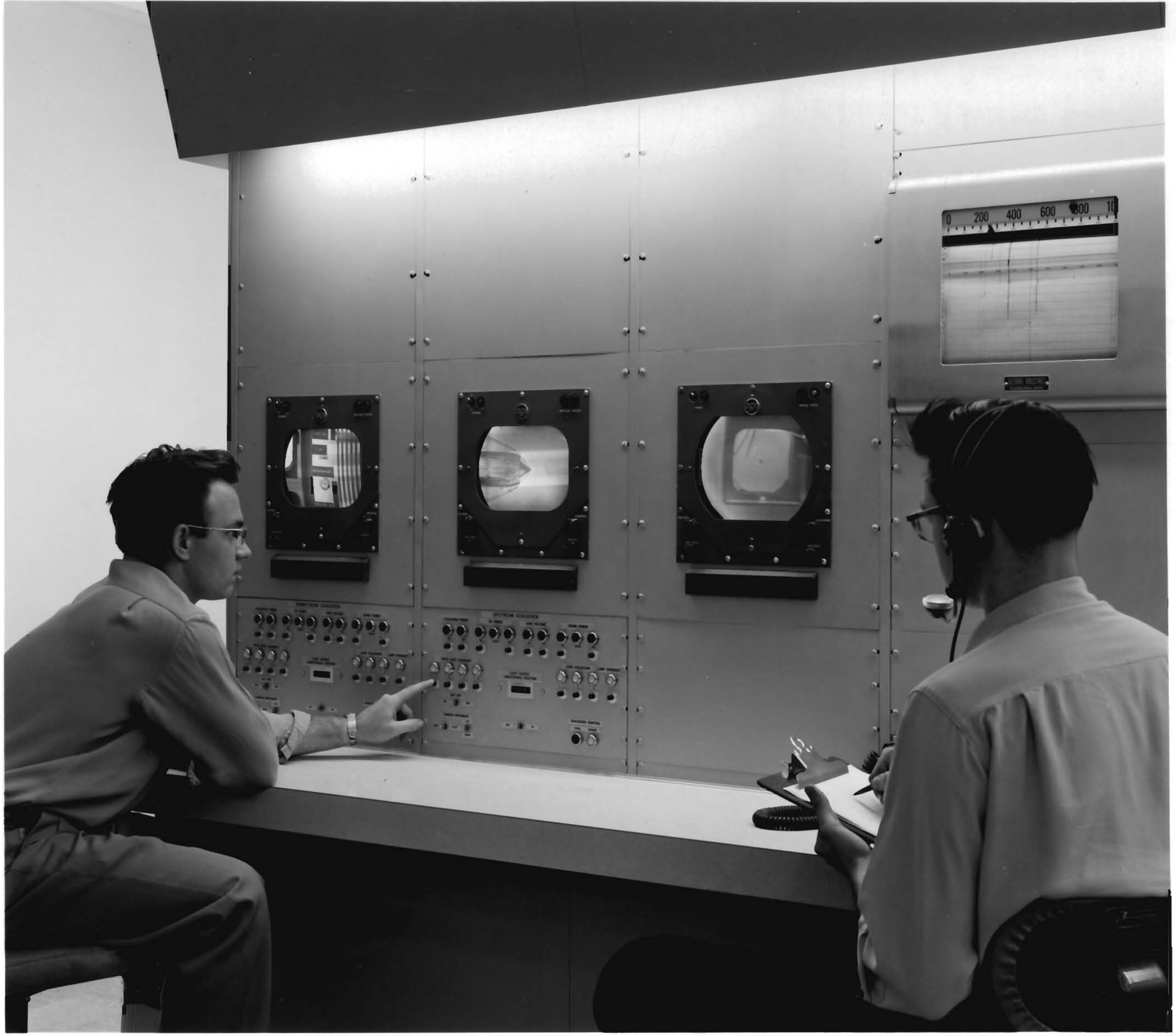
NACA
C-40247

National Advisory Committee for Aeronautics
Lewis Flight Propulsion Laboratory, Cleveland, Ohio

C-40247

Control room of the Lewis Unitary Plan Wind Tunnel, viewed from the adjacent observation-conference room. The tunnel diagram (top, center) provides a pictorial indication of the position of each of the major valves that control tunnel operation. Each of the 24-inch television monitors (near ceiling) can be connected to any of the three TV cameras that survey the tunnel.

NACA
C-40249



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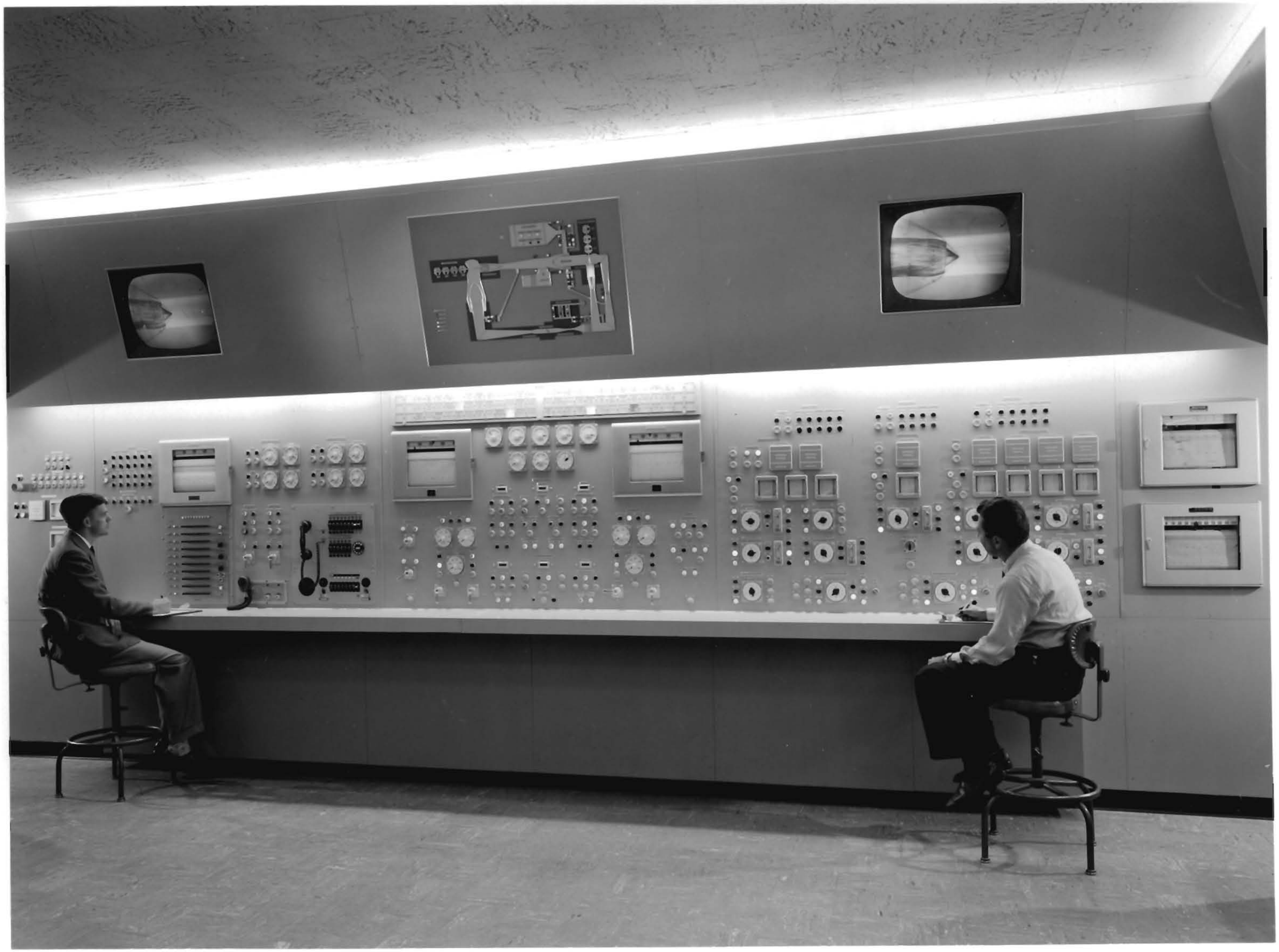
Lewis Flight Propulsion Laboratory, Cleveland, Ohio

C-40249 Operators of the Lewis Unitary Plan Wind Tunnel operate Schlieren controls (left) and observe the resulting Schlieren pattern on TV closed-circuit monitors. Instrument at upper right is an XY recorder, which plots computed values of any two selected parameters, as they are measured.

NACA
C-40250



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C-40250 One of three control panels in control room of the Lewis Unitary Plan Wind Tunnel. The tunnel model (top center) shows position of the valves that control the operating cycle of the tunnel. The TV monitor screens can be connected to any of 3 closed-circuit TV cameras used to monitor tunnel components.

NACA
C-40304

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C-40304 Aerial view of the Lewis Unitary Plan Wind Tunnel. The facility permits altitude testing of full-scale jet engines and aircraft models at air speeds up to 3 1/2 times the speed of sound.

NACA
C-40871

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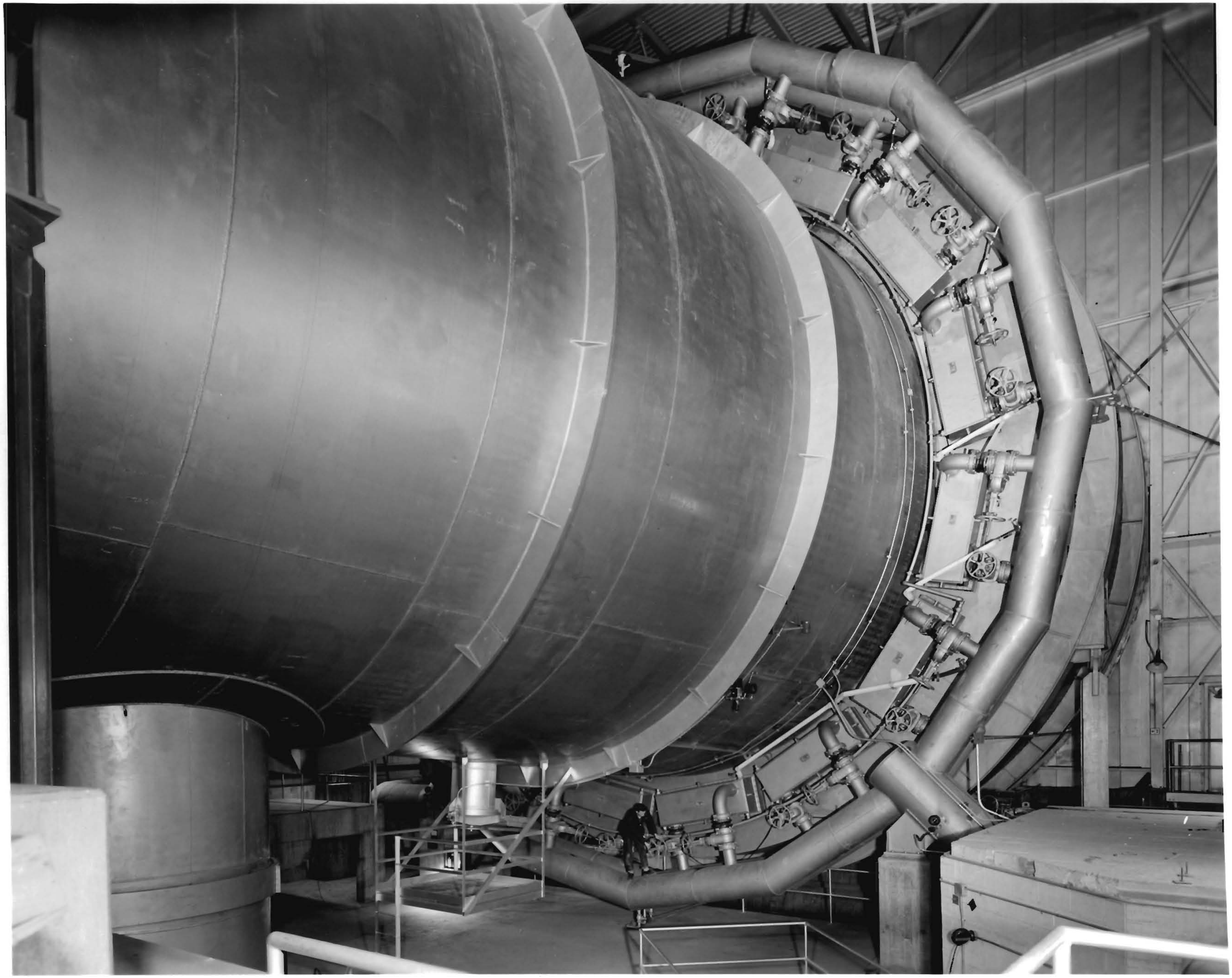
Lewis Flight Propulsion Laboratory, Cleveland, Ohio

C-40871 Screened inlet of secondary compressor of the Lewis Unitary Plan Wind Tunnel, driven by the 36-inch shaft at left which spans a 25-foot portion of the tunnel. This compressor is used, in addition to the main compressor, when the tunnel is operated between Mach 2.5 and Mach 3.5.

NACA
C-40928



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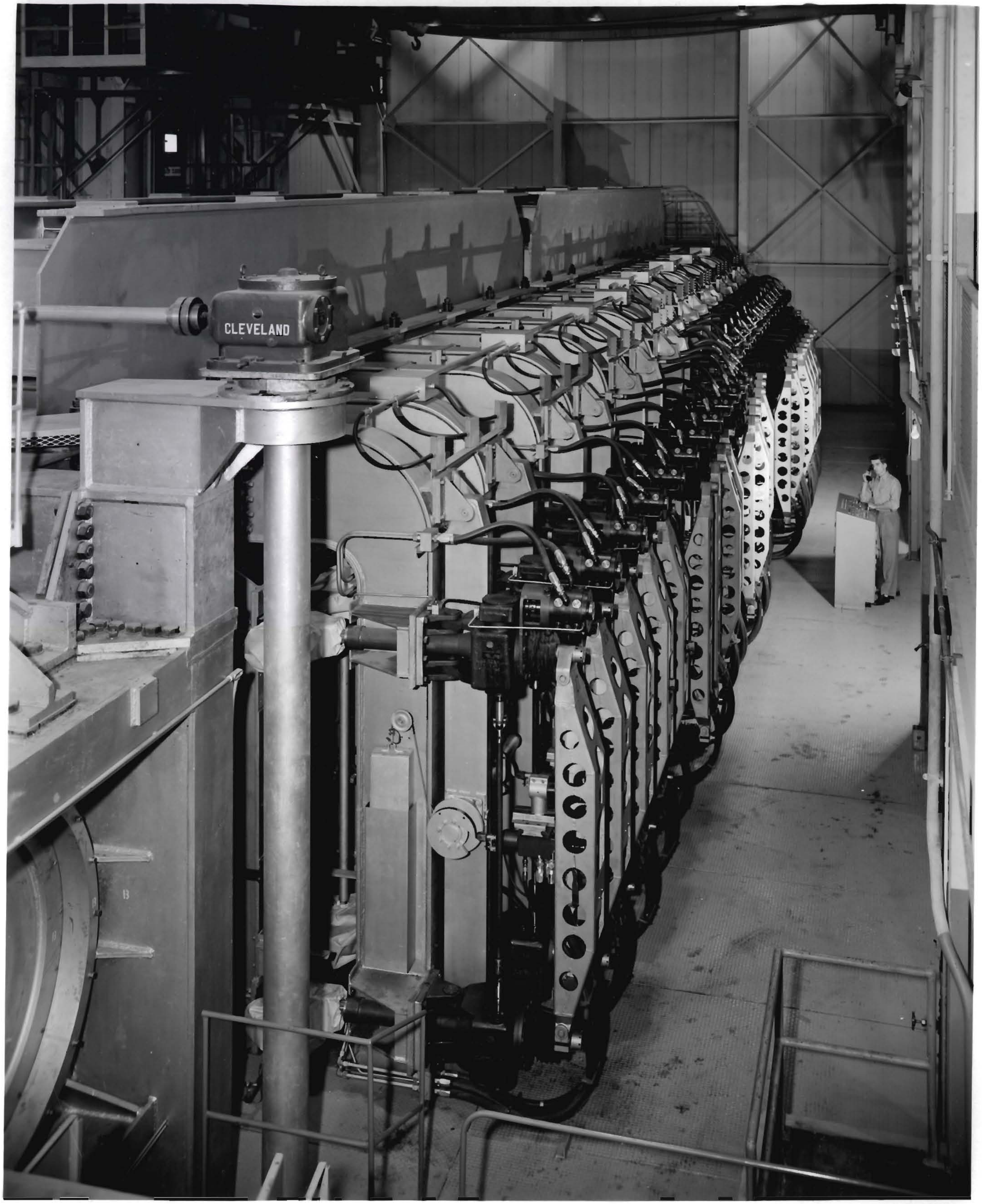
C-40928 External view of cooler #1 of the Lewis Unitary Plan Wind Tunnel. During operation of the tunnel on the aerodynamic cycle, air is recirculated and must be cooled to prevent continuous temperature rise. Water is supplied to heat exchangers through the large pipe that encircles the tunnel. (Internal view, C-41950.)

NACA
C-40937



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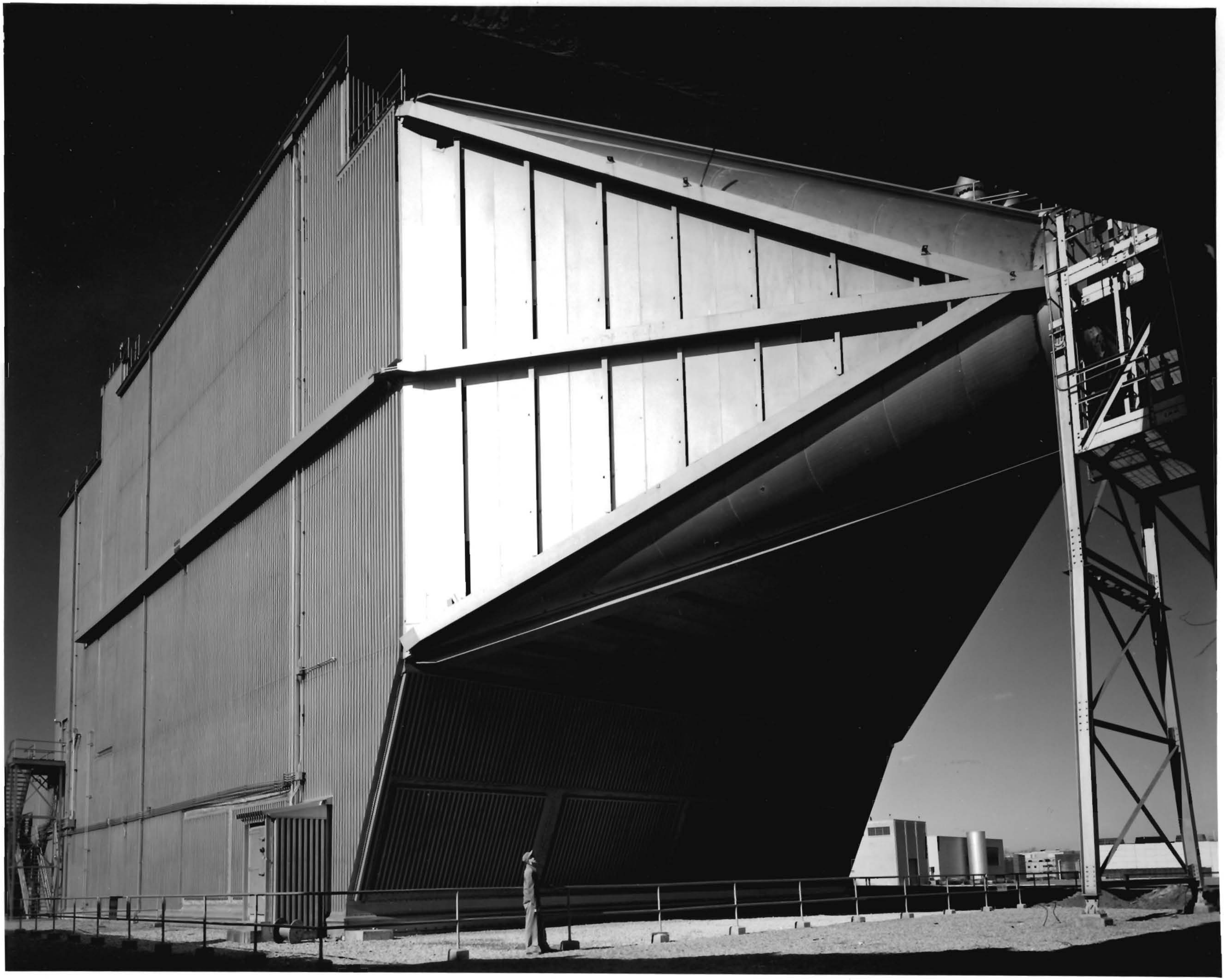
C-40937

Hydraulic jacks that flex the side walls of the nozzle of the Lewis Unitary Plan Wind Tunnel. Size of the nozzle opening controls velocity of the air through the test section. Each of the side walls is a plate of stainless steel, 10 feet high, 76 feet long, and 1 3/8 inches thick; they are flexed in and out a maximum of 26 inches each.

NACA
C-41250



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C-41250 Air dryer building of the Lewis Unitary Plan Wind Tunnel. Air enters the building from the left and passes over 1900 tons of activated alumina, which can remove 15,000 gallons of water before it must be reactivated by heating the alumina. Air enters the tunnel through the converging duct shown at upper right.

NACA
C-41730

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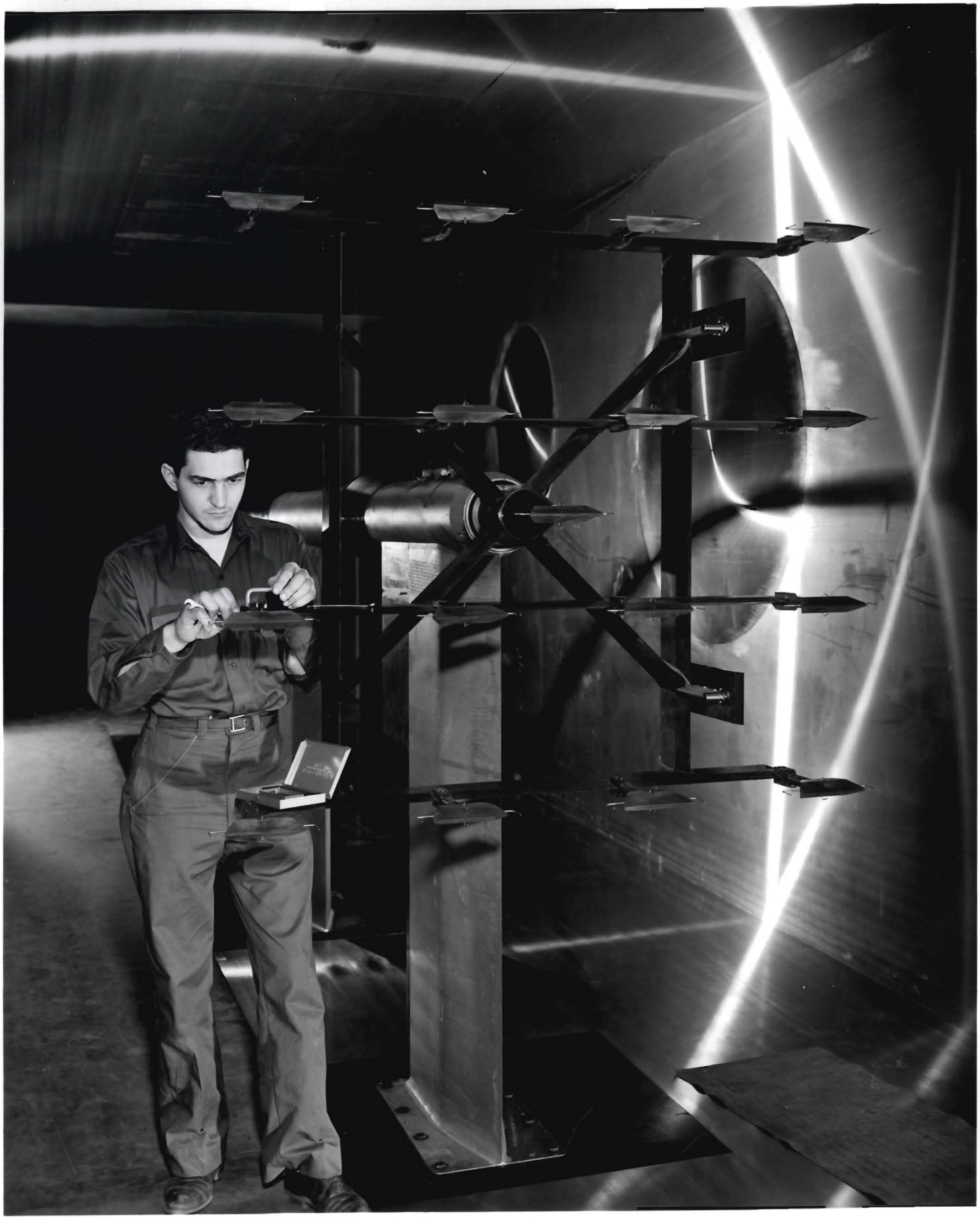
C-41730 Model preparation in the shop of the Lewis Unitary Plan Wind Tunnel. Four model stands and access to hand tools, power tools, welding and sheet-metal equipment provide opportunity for tunnel users to make final or in-test changes to models.

NACA
C-41794



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C-41794 Installation of a calibration rake in the 10 by 10-foot test section of the Lewis Unitary Plan Wind Tunnel. Precise determination of actual flow patterns in the tunnel increases the accuracy with which test-data can be interpreted.

NACA
C-41827

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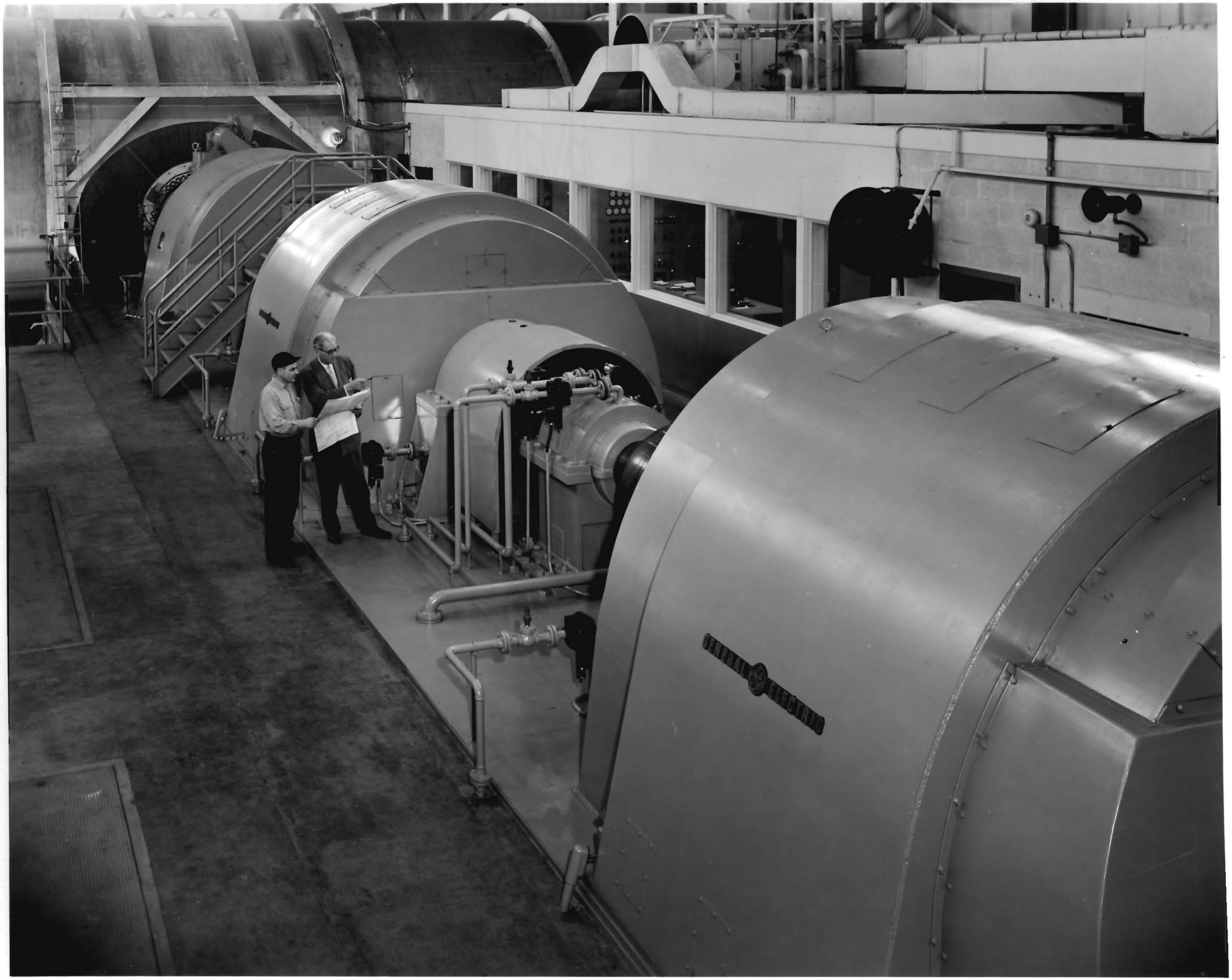
C-41827 Four wound-rotor induction motors in tandem, totalling 150,000 HP, drive the main compressor of the Lewis Unitary Plan Wind Tunnel, which can deliver 76,000 cubic feet of air per second at a pressure ratio of 2.8 (See C-39724 and C-41951).

NACA
C-41904



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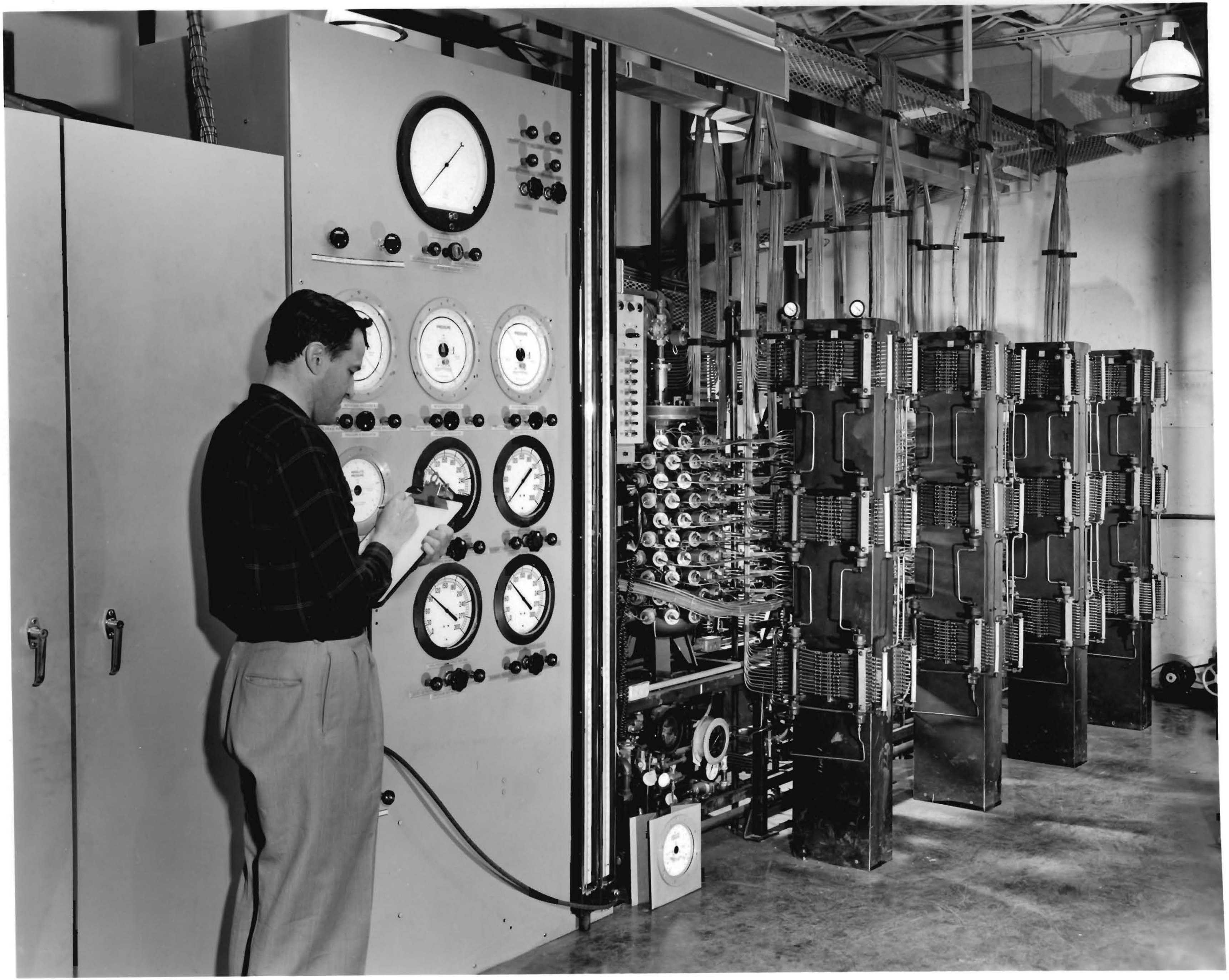
Lewis Flight Propulsion Laboratory, Cleveland, Ohio

C-41904 Three wound-rotor induction motors in tandem, totalling 100,000 HP, drive the ten-stage secondary compressor of the Lewis Unitary Plan Wind Tunnel. (Drive shaft shown in C-40871.)

NACA
C-41912



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C-41912 Copper tubing conducts pressures from sensors in the Lewis Unitary Plan Wind Tunnel to capsules mounted on a pressure tank (center.) Electronic counting of the time required for the test pressure to balance a diaphragm in the capsule against gradually increasing tank pressure transmits the pressure data to the recording system. (See C-42021.)

NACA
C-41950

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C-41950 Diffuser cone (bright object) of cooler #1 of the Lewis Unitary Plan Wind Tunnel. All air flowing through the tunnel goes through the cooler and is discharged around the periphery of the cone. When the tunnel is being operated on the aerodynamic cycle (no combustion in the test model) the air is continually recirculated through the tunnel and must be cooled to prevent continual temperature rise.

NACA
C-41951

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C-41951 40-Inch drive shaft and screened inlet of the 8-stage main compressor of the Lewis Unitary Plan Wind Tunnel. At full power, the shaft transmits a torque of almost a million foot-pounds from the 150,000 HP drive motors. (See C-39724 and C-41827). The structure in right foreground provides bearing support for the long drive shaft.

C-42021

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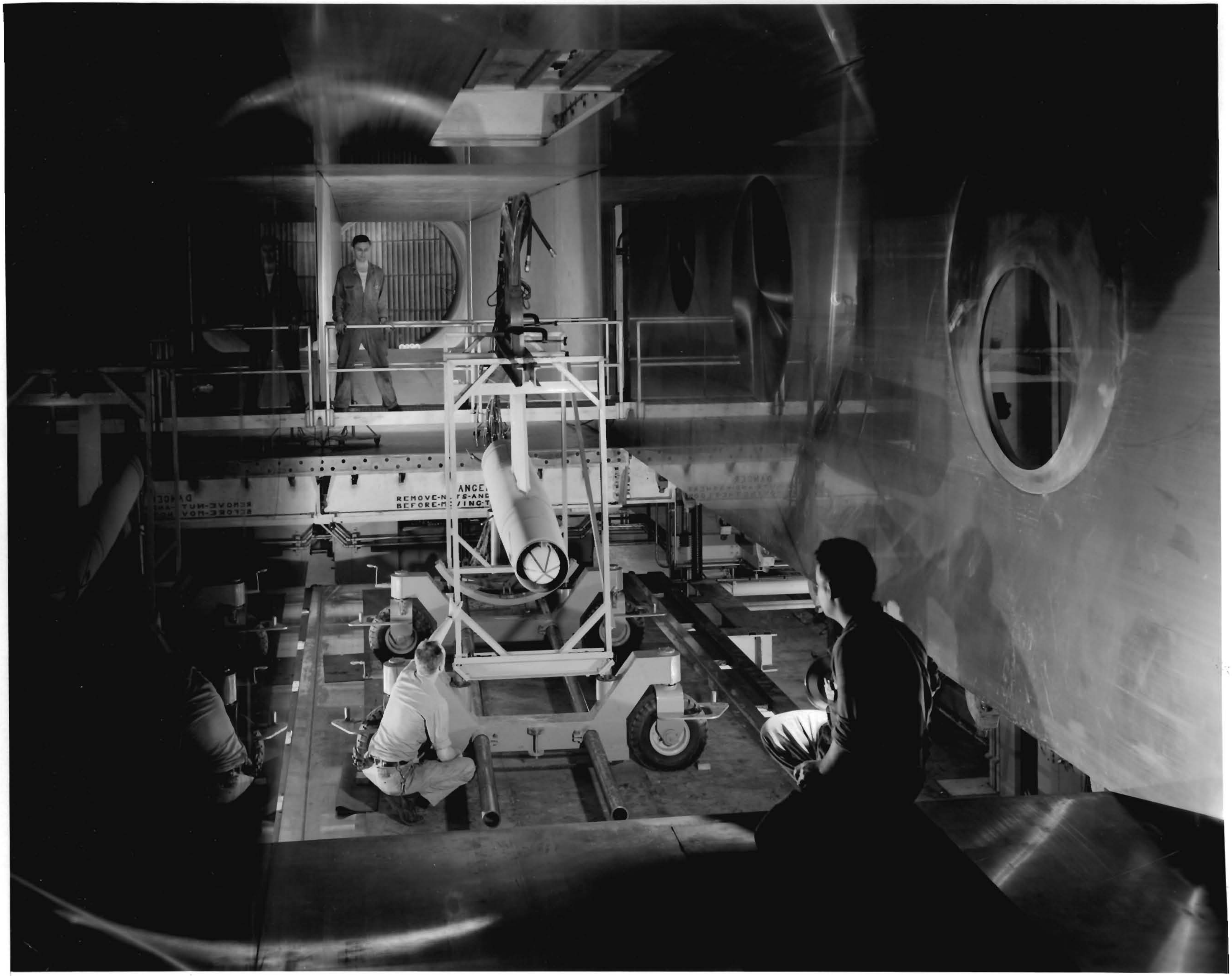
Lewis Flight Propulsion Laboratory, Cleveland, Ohio

Central automatic digital data encoded (CADDE) located at the Lewis Unitary Plan Wind Tunnel. CADDE translates the data signals it receives from the tunnel into binary-coded decimal numbers, which are recorded on magnetic tape, and may then be fed into an electronic computer for immediate reduction to usable form and transmitted to the control rooms for study by test engineers.

C-42021

NACA
C-42030



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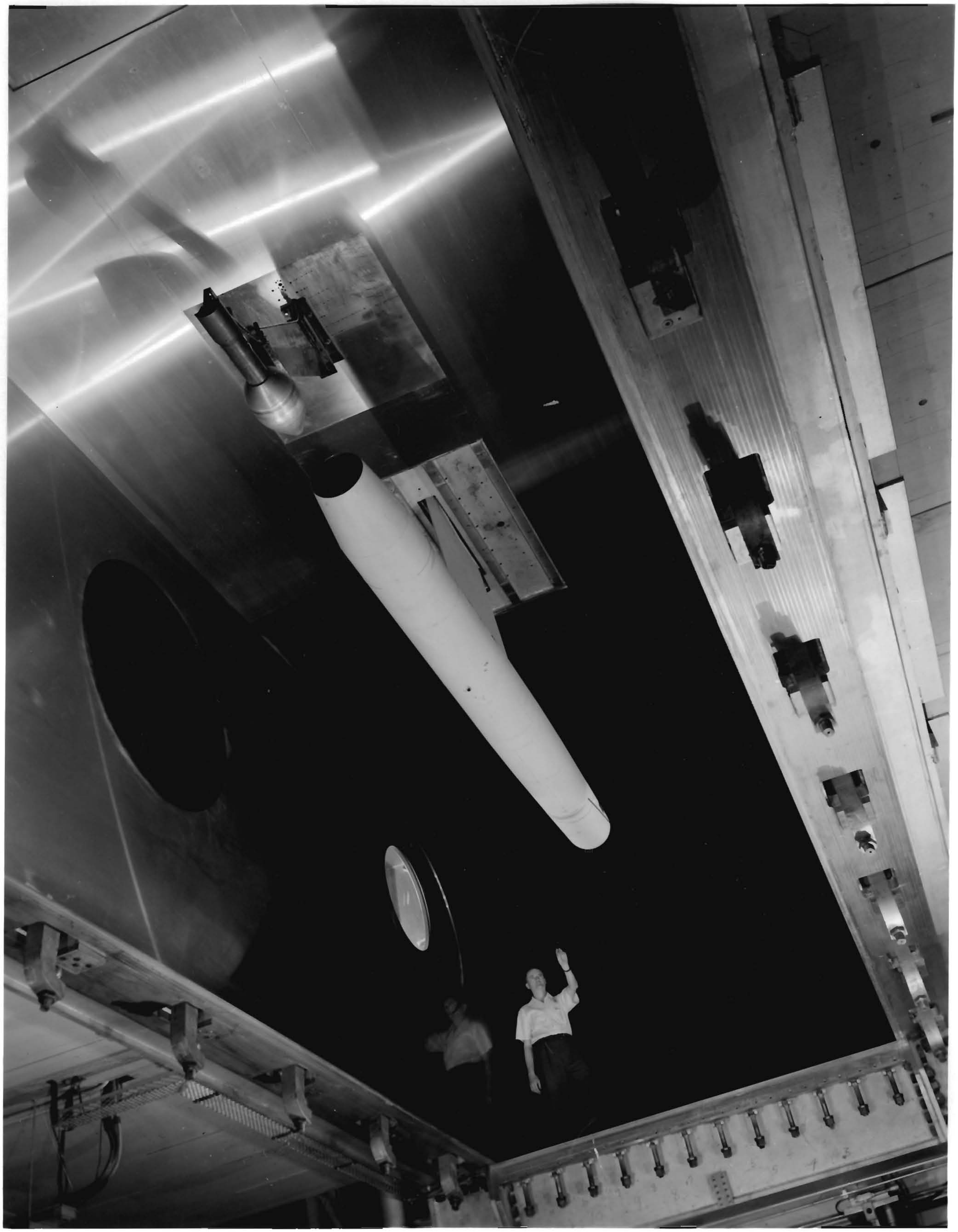
C-42030 Downstream view from the nozzle of the Lewis Unitary Plan Wind Tunnel, showing a ramjet model being raised into test position by the elevator-floor. The model will be suspended from the tunnel ceiling, and its attitude can be varied during the test by means of a pivot mount.

NACA
C-42032



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C-42032 Aft view of a 16-inch ramjet in test position, seen through the floor opening of the Lewis Unitary Plan Wind Tunnel. The body of revolution downstream of the ramjet nozzle is a movable

NACA
C-42068

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Lewis Flight Propulsion Laboratory, Cleveland, Ohio

C-42068 The 24-foot-diameter swinging valve shown is one of the key control elements of the Lewis Unitary Plan Wind Tunnel. In one position, it seals off the tunnel exhaust, making the tunnel a closed circuit, which is used for aerodynamic testing of models. In its other position, the valve acts as a seal across the tunnel and leaves the tunnel exhaust open. This arrangement, used when combustion is to take place in an engine model, makes the tunnel a nonreturn type: all air going through the tunnel is taken from the atmosphere, and returned to the atmosphere after one pass through the tunnel.