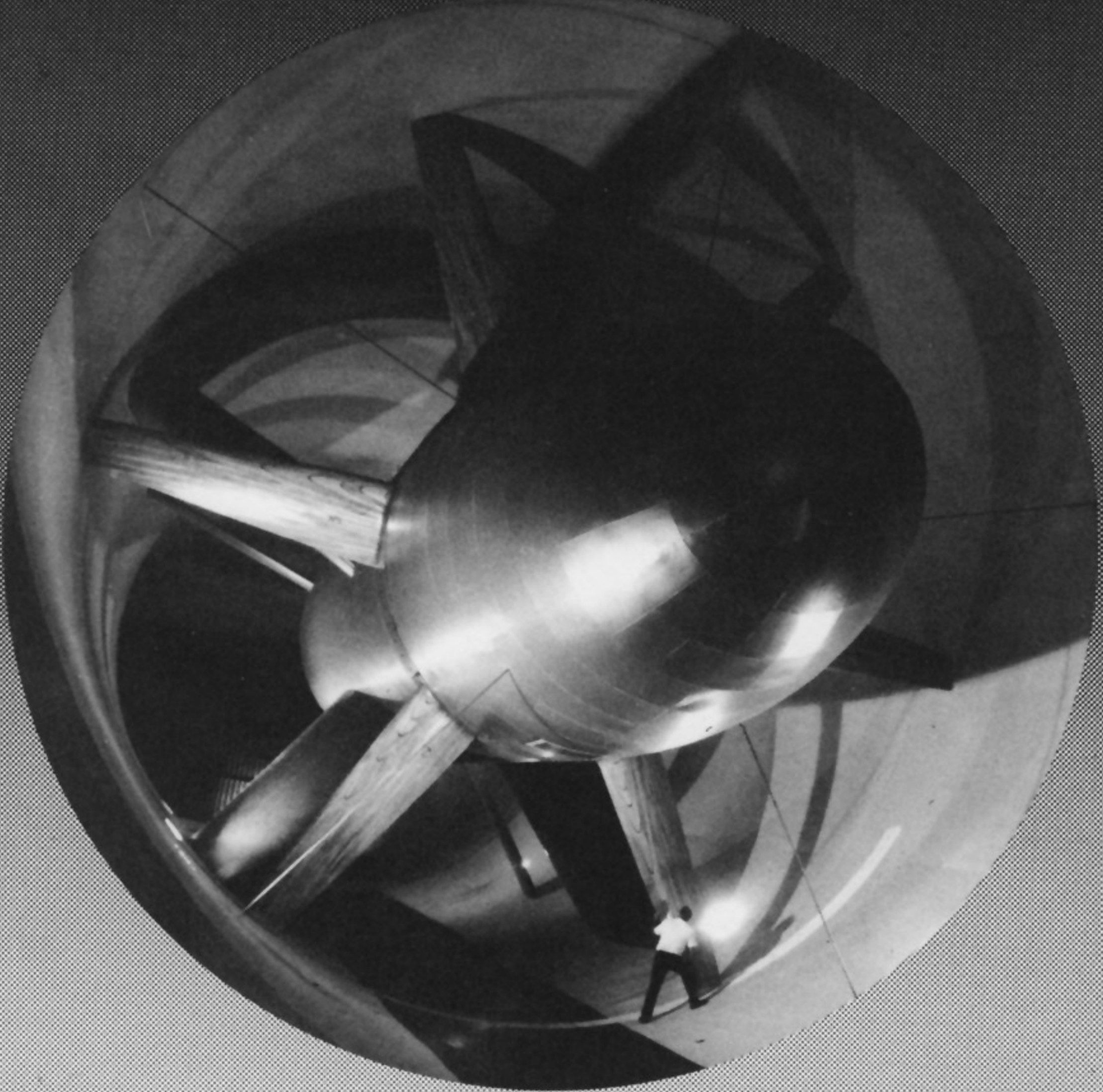
The General Motors Aerodynamics Laboratory



A Full-Scale Automotive WIND TUNNEL

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INTRODUCTION

The first full-scale automotive aerodynamics wind tunnel in North America is located at the General Motors Technical Center (Figure 1). Tunnel performance and flow quality specifications have been met through appropriate choices of design criteria, construction techniques, and inspection procedures. Test section size, two balances, and a boundary layer suction system provide a broad range of full-size and reduced-scale-model test capability. Test support, operational and engineering environments, and equipment have been specifically tailored for automotive aerodynamics requirements.

The concept for a new General Motors Wind Tunnel to develop and test all new vehicles from conceptual clay models to finished production vehicles was formulated in the early 1970's. In August 1980 GM completed the commissioning and calibration of a significant new engineering facility — the Aerodynamics Laboratory.

GM AERODYNAMICS HISTORY

In 1953 General Motors conducted a scale-model wind-tunnel test on the experimental Firebird I gas-turbine vehicle to determine its aerodynamic characteristics (Figure 2). This started the aerodynamics activity at General Motors, which led to the realization of the Aerodynamics Laboratory.

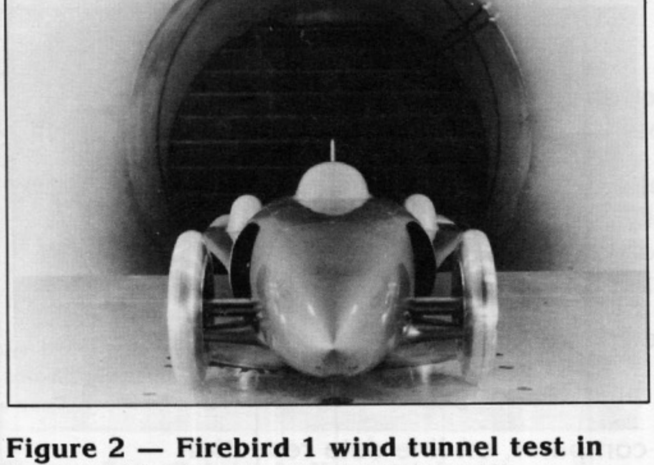

Figure 2 — Firebird 1 wind tunnel test in 1953 at the California Institute of Technology.

Figure 1 — Aerial view of GM Aerodynamics Laboratory.

Early work included scale-model testing in four U.S. aircraft wind tunnels to develop experience in automotive wind-tunnel testing techniques, and to explore land-vehicle aerodynamic characteristics.

In 1969 General Motors expanded its tunnel activity to include full-scale vehicle testing, and conducted the first full-scale automotive test in the Lockheed-Georgia Low Speed Wind Tunnel. General Motors' capability for scale-model testing was significantly increased with a new test facility at the Technical Center. When the General Motors Research Laboratories completed an aerodynamics conversion module for the Harrison Radiator Division environmental wind tunnel in 1972, aerodynamics became recognized as an important tool to improve vehicle fuel economy as the energy shortage and Federal legislation developed.

As aerodynamic requirements were established for each new vehicle line, the required test time increased dramatically. Effective wind-tunnel testing required test participation by many design disciplines, including aesthetics, body engineering, and engine cooling, as well as aerodynamics. Efficient use of tunnel time on new-product development required frequent inputs and design decisions to make the test output useful and realistic.

Testing at off-site rented facilities precluded test participation by all the required specialists, reducing the utility and progress of the event. Additionally, the required long-term scheduling of test time at rented tunnels made it difficult to respond to rapidly changing design schedules. To be effective in new product design, the wind tunnel should be used frequently throughout the design process, and should be available on a flexible, priority basis.

General Motors needed a captive, full-scale automotive wind tunnel to properly integrate aerodynamics into all new-vehicle designs. The tunnel had to be readily available to the Design Staff where body surface models are developed, and to engineering specialists whose requirements influence the test direction.

OBJECTIVES

GM's previous wind-tunnel experience and the future vehicle design needs produced the following objectives for a new wind tunnel.

- Rapid aerodynamic development capability of full-scale clay models and prototypes of all passenger-vehicle sizes and light-duty trucks.
- Evaluation of General Motors and competitive production passenger cars and light-duty trucks.
- Capability to develop improved aerodynamics of the large commercial vehicles such as trucks, buses, and trains, as well as reduced-scale multiple-vehicle testing to simulate the highway environment.
- Adequate performance and flexibility for future test requirements.
- Maximum accessibility to Design Staff's new-product clay models and to design-decision personnel.
- Provision for full product security in all facility operations.
- Immediate test data access by test-related personnel.

SPECIFICATIONS

In preliminary design the facility objectives were translated into the specifications shown in Table 1. A relatively long, closed test section was selected to accommodate large test vehicles with their forebody flow field and trailing wake system, and to provide for future multiple scale model, highway environment testing. Flow stability and adequate model yaw capability were also considerations. A closed-circuit single-return single-fan concrete air-path configuration was used based on flow uniformity considerations, external noise control, and variable Detroit weather conditions.

TABLE 1 — GM AERODYNAMICS LABORATORY SPECIFICATIONS

Test Section	17.72 ft. high, 34.12 ft. wide, 69.88 ft. long, closed with atmospheric vent
Airpath	Closed single-return with single fan
Maximum Speed	160 mph
Contraction Nozzle Ratio	5.0
Boundary Layer Control	Test section floor suction intake and return step slots
Balance Systems	Full-scale: 6 component, mechanical, external Reduced scale: 6 component, strain gauge, external
Drive System	Variable speed, 4000-HP DC electric motor
Temperature Control	Airpath heat exchanger, water to air
Data System	On-site computer, on-line data reduction

Maximum tunnel speed was targeted to provide essentially full-scale highway speed Reynolds Number flow conditions on typical 0.33 reduced-scale models. Test-section floor boundary-layer suction control was included to minimize boundary-layer influence, primarily on reduced-scale models.

Two separate balance systems were specified to accommodate the load range of full and reduced-scale models. Both balances are situated below the test section floor to simplify model support, and to minimize aerodynamic tare effects. Past wind tunnel design experience and accurate speed regulation dictated an electric-fan drive motor mounted within the airpath. The necessity to maintain airpath temperature limits for clay models required the use of an airpath heat exchanger. Uninterrupted rapid data acquisition and customer presentation for test direction structured the data system components.

An architectural engineering firm with aircraft wind tunnel design experience was given the primary responsibility of the total facility design. In addition, fluid dynamics consultants from General Motors Research Laboratories and universities were used extensively to develop, critique, and improve the detailed technical design. Each airpath component was selected by careful review of the estimated performance and cost of various alternatives. General Motors test engineers had considerable experience from extensive testing in a variety of rented aircraft tunnels. This provided useful inputs for the new design. A strong cooperative relationship with the Design Staff and familiarity with their design and model requirements provided valuable design inputs.

The laboratory was planned to be connected underground with the Design Staff (Figure 3). The significant size and cost of the new facility, plus the motivation to use the tunnel for product development with minimum delay for airpath tuning, encouraged the use of conservative and proven airpath elements. General Motors personnel and consultants maintained close contact and performed periodic reviews with the tunnel design firm. The successful commissioning and initial test operation of the tunnel supports the design and specification philosophy used.

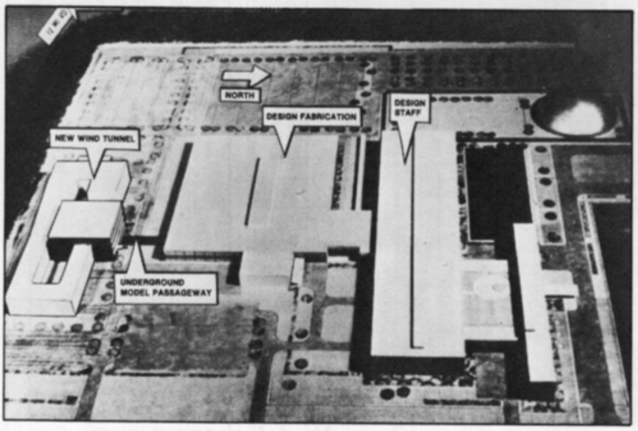

Figure 3 — Original site model with underground passageway to Design Staff.

CONSTRUCTION

Total facility-site construction duration was 34 months. Placement of this large structure within the General Motors Technical Center required special attention to the visual impact of the facility. The concrete airpath, selected on the basis of cost, external environmental noise control, and internal airpath temperature control, incorporated unique surface texture and color to be more aesthetically pleasing.

FEATURES

Many of the features to be discussed are identified in Figures 4, 5 and 13 for clarity.

LABORATORY BUILDING — The laboratory building provides four levels for the engineering and shop-support functions for wind-tunnel testing. The airpath is separate from the building except for the test section. The underground passageway to Design Staff provides a quick, secure route for test models to reach the laboratory. Test models are moved to the second-floor test section on a vehicle elevator. The basement houses mechanical shop facilities, test vehicle inspection and preparation areas, the mechanical balance foundation, and the primary-boundary-layer suction fan and ducting.

Engineering offices and design area plus an electronics laboratory are located on the first floor. The mechanical balance is situated on this floor directly beneath the test section. Since full security is maintained for each General Motors customer, all access to areas where testing or models may be seen is restricted by a door lock system.

The second floor contains the actual testing activity. The airpath passes through the building at this level, supported on its own foundation. The airpath segment, centrally contained on the second floor, is the test section. Adjacent to the test section is the model support area, which houses the personnel and equipment to make rapid configuration changes to the test model. This area is equipped with clay-handling equipment identical to that used in the Design Staff studios. Adjacent to the opposite wall of the test section is the tunnel control room and test-customer room. The third floor provides access to the test-section lights and windows of the test-section ceiling. Storage for facility calibration equipment and fixtures is also provided on this floor.

AIRPATH — The total airpath has a centerline length of 987 ft. It has a rectangular cross section except for the 100-ft.-long fan section and the transition sections before and after the fan section, which are 21 ft. and 188 ft. long, respectively. The

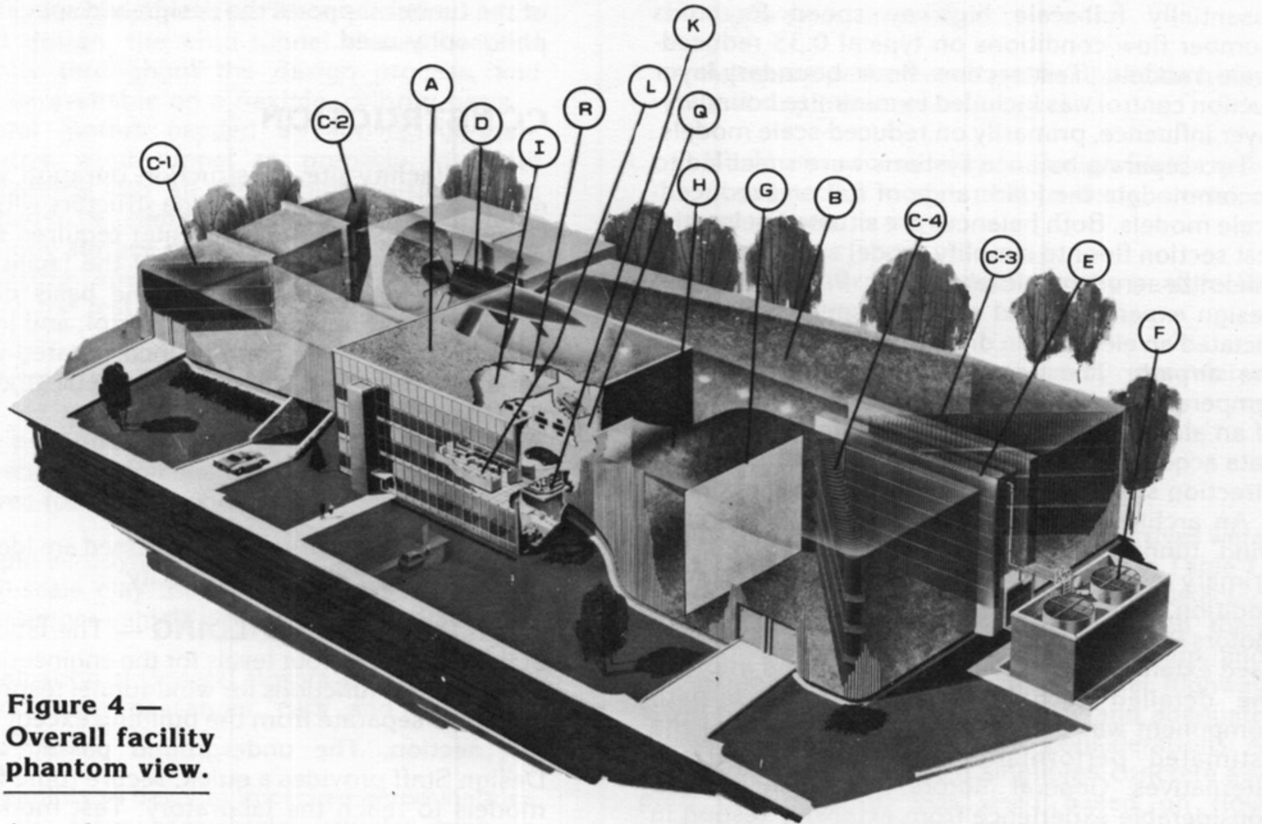

Figure 4 — Overall facility phantom view.

A — Laboratory building
B — Airpath
C — Corner turning vanes
D — Fan-drive system

E — Heat exchanger
F — Cooling tower
G — Flow screen
H — Contraction nozzle

I — Test section
K — Mechanical balance
L — Control room
Q — Model support area

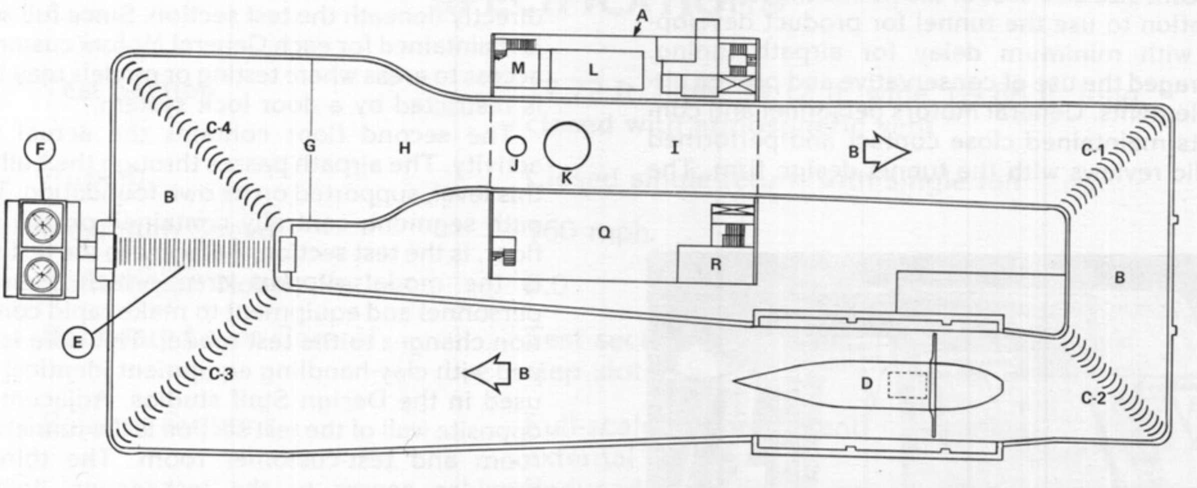

Figure 5 — Plan view of the second floor in the laboratory building.

A — Laboratory building
B — Airpath
C — Corner turning vanes
D — Fan-drive system
E — Heat exchanger

F — Cooling tower
G — Flow screen
H — Contraction nozzle
I — Test section
J — Scale-model balance

K — Main balance
L — Control room
M — Customer room
Q — Model support area
R — Vehicle elevator

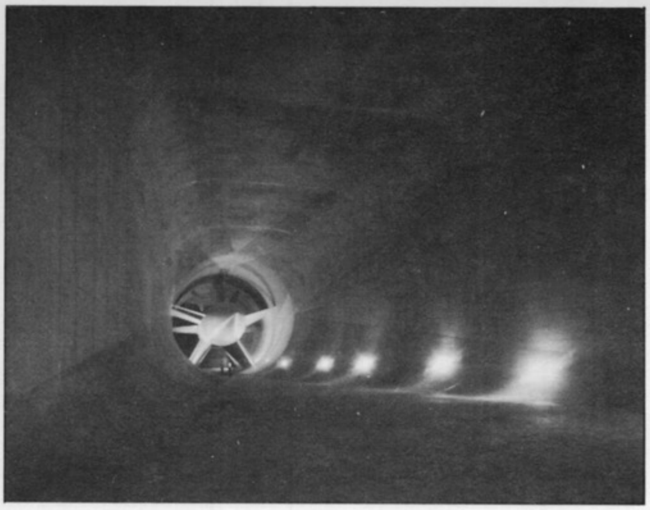

Figure 6 — View of airpath, looking upstream to the fan from corner 3.

four airpath corners are identified 1 through 4 in Figures 4 and 5. The inside airswept surface is poured-in-place concrete except for the circular fan section, which is welded steel-plate construction. The basic concrete structure encloses the fan section steel to maintain environmental, acoustical, and aesthetic integrity.

CORNER TURNING VANES — Banks of steel, single-plate turning vanes are used diagonally across each of the four airpath corners to uniformly turn the air. Figure 7 shows the turning vanes at corner 3.

FAN AND DRIVE SYSTEM — A six-blade fixed-pitch fan is driven by a variable speed, 4000-HP DC electric motor. A stationary nose cone, piloted on the motor shaft, guides the flow into the fan (Figure 8). The motor is mounted directly behind the fan in a large centrally mounted motor nacelle.

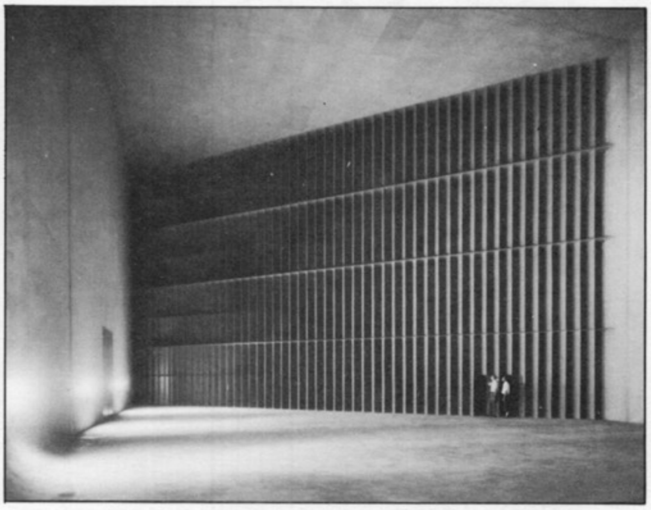

Figure 7 — Corner 3 turning vanes.

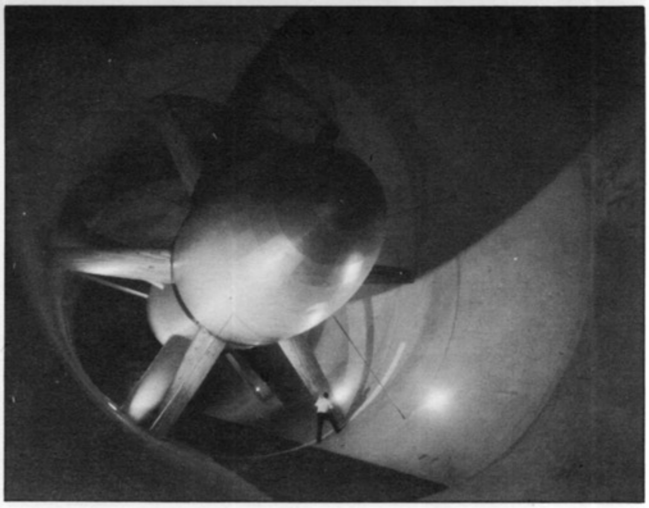

Figure 8 — Nose cone and fan.

The nacelle is supported from the airpath wall by five hollow fan stator blades of airfoil section, plus five symmetrical airfoil sections at the trailing end (Figure 9). The fan hub is mounted directly on the motor shaft extension.

The fan blades are laminated sitka spruce wood. The blade surface is varnished and has fiber glass and high-strength tape for leading-edge protection. The tip of each blade is contoured balsa wood splined to the blade. This soft wood provides an expendable tip that can be repaired or replaced if any debris reaches and impacts the fan tip.

DC power is provided by silicon-controlled rectifier modules and controlled motor supply. Forced-air cooling, electrical supply, and other motor services pass through the hollow stator struts to the motor. Motor-fan speed control and motor temperature and lubrication monitors are located in the tunnel control room. Automatic motor shut down occurs when pre-set motor problem status levels are reached.

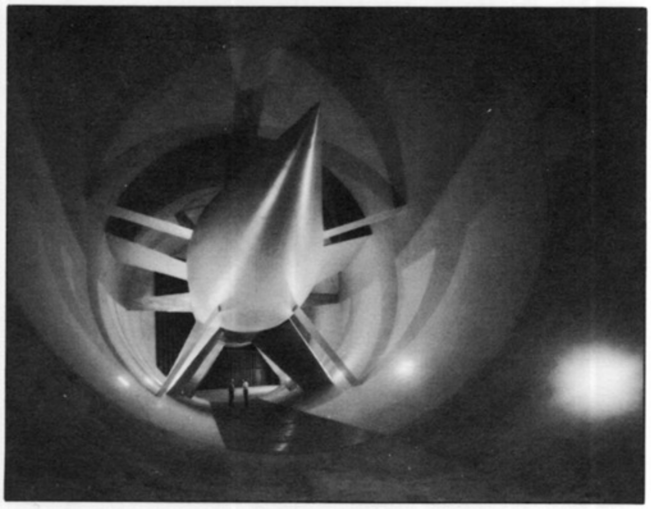

Figure 9 — Fan and tail cone of the motor nacelle.

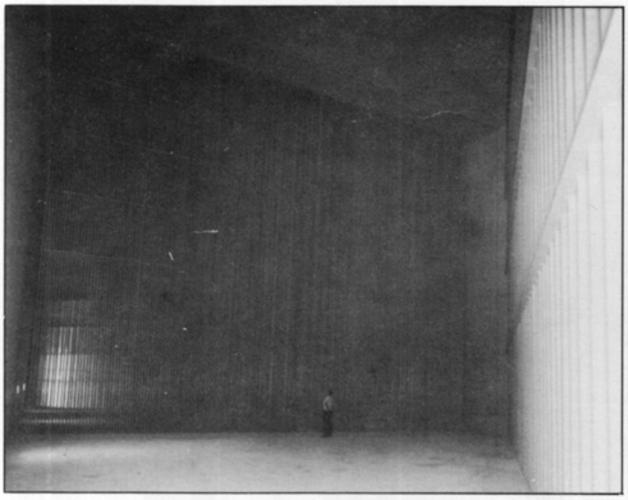

Figure 10 — View of heat exchanger from corner 3.

HEAT EXCHANGER — The airpath heat exchanger is located between corners 3 and 4 in the largest cross sectional area of the tunnel (Figure 10). It consists of 175 vertical one-piece, extruded-aluminum hollow airfoils. Water from an evaporative spray cooling tower immediately outside the airpath is circulated through these airfoils to maintain airpath temperatures between 60°F and 85°F. Maintenance of this temperature range protects clay models from surface thermal damage and provides reasonable personnel conditions. During the warmer period of the year, the cooling tower operates in its normal mode, cooling the water with flow up to 6,000 gallons per minute. In cold weather, steam heat is supplied to the water basin, which has floating plastic insulation.

FLOW SCREEN — The flow screen is a typical wind tunnel device to improve the test section velocity uniformity (Figure 11). There are significant air loads on the screen at high speeds since it constitutes 25 percent of the total loss of the airpath. Six cables, aligned with the flow, transfer the screen load to the corner 4 turning-vane structure.

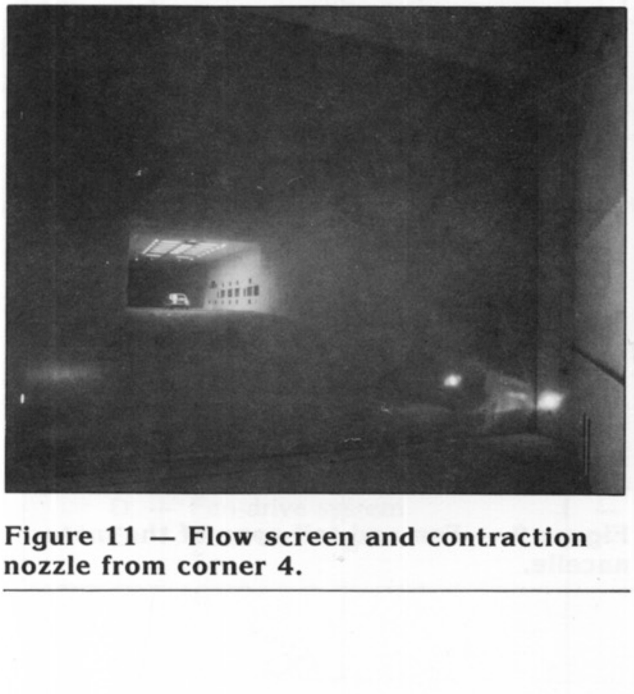

Figure 11 — Flow screen and contraction nozzle from corner 4.

Figure 12 — Front view of test section, showing the floor boundary layer primary-intake-suction slot.

TEST SECTION — The test section (Figures 12 and 13) has a constant height of 18 ft. and a total length of 70 ft. The side walls have slight divergence, 0.24 of a degree per side, to maintain constant static pressure with anticipated boundary

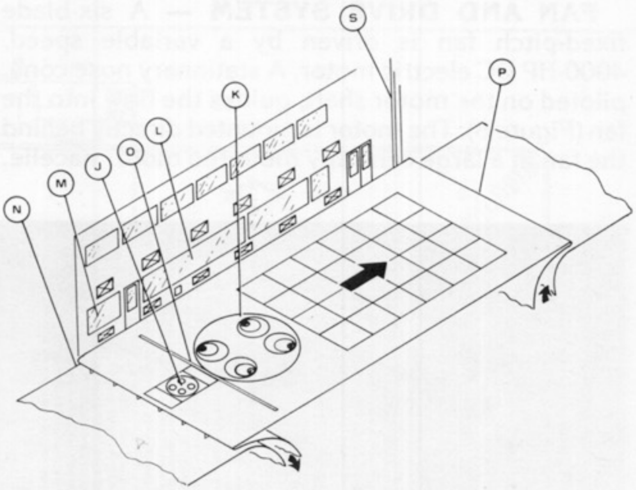

Figure 13 — Schematic view of test-section features.

J — Scale-model turntable
K — Mechanical balance turntable
L — Control room
M — Customer room
N — Primary boundary layer intake
O — Secondary boundary layer intake
P — Boundary layer system return
S — Test section

layer growth. The initial width of the test section is 34 ft. Variable lighting and generous use of laminated observation windows provide for good vision and photography. The entire test section is surfaced with plastic laminate clad plywood to provide a combination of flexibility and point-load damage resistance, and the surfaces are coated with self-extinguishing epoxy paint. The test section is vented to the atmosphere by two vertical floor-to-ceiling slot vents at the end of the test section.

The mechanical balance turntable (Figure 14) is a rotating top cap of the balance structure. Test model access to this turntable is through a top-hinged door in the test section wall.

To minimize floor boundary layer thickness, primarily for scale-model testing, a suction system is employed. A portion of the boundary layer approaching the test section is drawn into a vertical primary duct inlet, across the full width of the test section floor (Figure 12). A duct system below the floor moves the air to the trailing edge of the test section where it is returned through a rearward-facing step to the first diffuser (Figure 15). A secondary intake slot, flush with the floor immediately forward of the mechanical balance turntable, can be opened for use with scale models on the mechanical balance. The primary suction system is normally run with full-scale testing to reduce boundary layer thickness at the model. The system is also run as required during non-testing hours to provide low velocity through the heat exchanger to maintain airpath temperatures.

MECHANICAL BALANCE — A virtual center, pyramidal, weigh-beam mechanical balance (Figure 16) was selected based on desired accuracy, repeatability, projected use, and past tunnel experience. The balance is mounted on a massive concrete foundation totally isolated from the building. All full-scale test vehicles are tested on this balance. It is also used to test reduced-scale models of the larger vehicles -- such as trucks, buses, and trains -- with measurement accuracy compatible with the reduced aerodynamic loads. The resolving center of this balance is on its vertical rotational axis at the center of the turntable on the test section floor.

The test-vehicle wheels are supported on top of the balance on four adjustable risers, one in each quadrant of the balance turntable. Various size top plates are used on the risers to accommodate different tire foot prints. Matching these plates to the tire contact patch minimizes unrealistic aerodynamic loads on the wheel support surfaces. A system of three eccentric circles surrounds each tire mounting plate to provide adjustment for various tread and wheelbase dimensions (Figure 17). The balance mechanically resolves the aerodynamic load on the test vehicle by linkages and levers into the six components: drag, lift, and

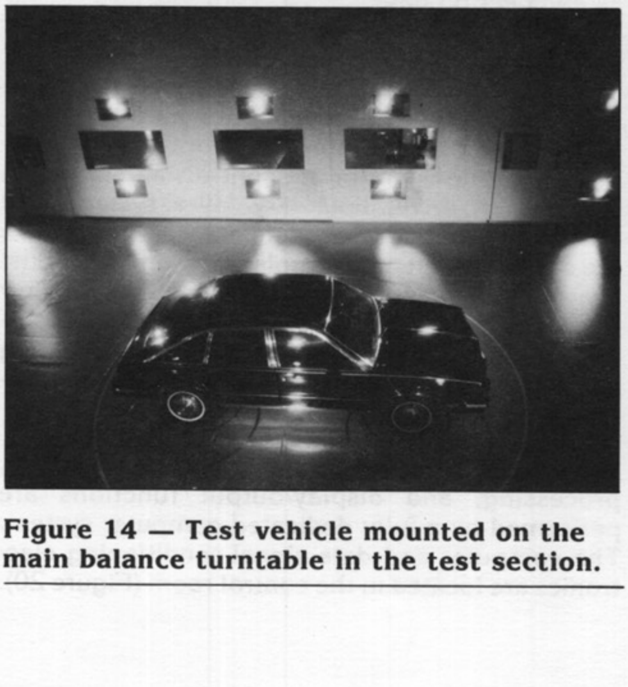

Figure 14 — Test vehicle mounted on the main balance turntable in the test section.

Figure 15 — View of the test section from corner 1.

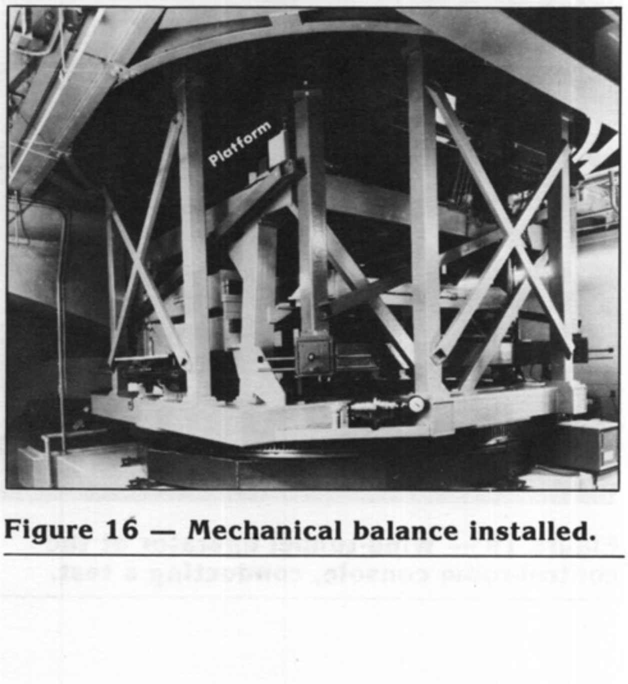

Figure 16 — Mechanical balance installed.

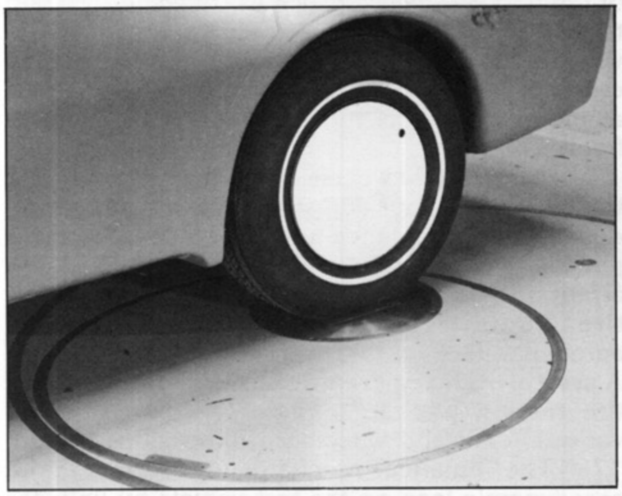

Figure 17 — Mechanical-balance wheel-contact plate with adjusting circles.

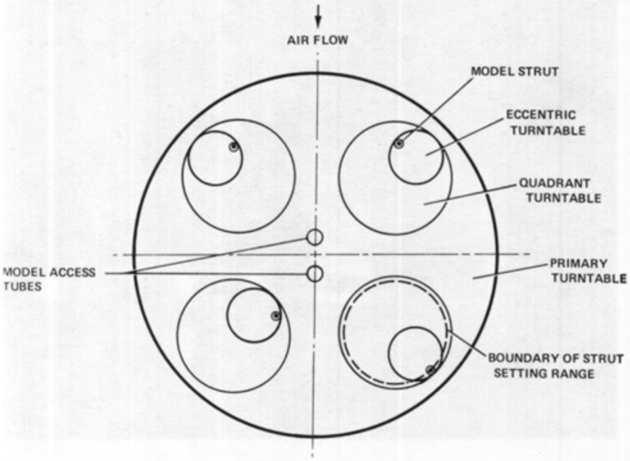

Figure 18 — Plan view of the scale-model balance turntable with model-mounting strut adjusting circles.

Figure 19 — Wind-tunnel operator at the control-room console, conducting a test.

side forces; pitch, yaw, and roll moments. The test vehicle and the entire balance including its supporting frame are yawed in unison by a DC electric drive and gear box.

SCALE-MODEL BALANCE — Reduced-scale models of passenger vehicles are tested on a platform type six-component strain-gauge balance. In this case the model is mounted on four model struts passing into the model wheels. Adjustment of the strut locations is made by rotation of eccentric-circle plates in the floor similar to the mechanical balance (Figure 18).

Normal location for the scale-model balance is just downstream of the primary-boundary-layer suction intake slot (Figure 13). The scale-model balance turntable was sized for optional mounting in any of the largest eccentric circles in the four mechanical balance turntable quadrants. This permits two scale models to be tested simultaneously, one mounted on the scale-model balance and one mounted on the mechanical balance. In addition, the scale-model balance assembly can be used in any of the 24 modular floor panels in the test section for special testing (Figure 13).

CONTROL ROOM — Design priorities in the control room layout included maximum visibility of the test model by seated personnel, location of controls and readouts on the console based on use priority, and proper isolation of tunnel operating personnel from distracting activity.

A custom, low-profile control console ensures good visibility and control locations (Figure 19). In addition, two closed-circuit TV monitors are employed to provide the operator with viewing ability from the far side of the test section. Both video cameras have remote pan-tilt-zoom control, and can be moved to various pre-wired positions at test-section windows for special requirements. This TV system also provides effective flow-visualization visibility and the video signals can be tape recorded as engineering data.

At the extreme right end of the console, a CRT console displays requested test-run conditions, actual tunnel status, plus raw and reduced balance data. A communication panel provides voice contact with various laboratory locations. Immediately in front of the operator are controls and monitors for the fan drive, boundary layer system, and mechanical and scale-model balances. Located to the operator's left are controls and monitors for the heat exchanger system, the test-model radiator flow measurement, and a pictorial status of all airpath-door security. A video control panel and lighting controls for all airpath, test section, and control-room illumination complete the console.

DATA SYSTEM — Wind-tunnel data acquisition, processing, and display/output functions are performed by a fully dedicated computer system. The computer and data signal-conditioning electronics are located in the control room (Figure 20).

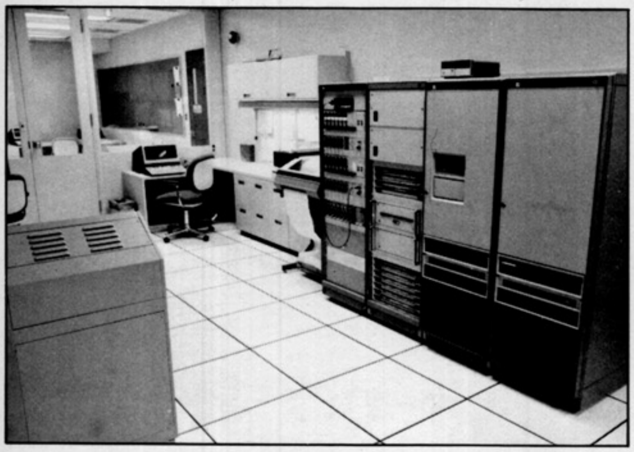

Figure 20 — Data acquisition system and the data engineer's position in the control room.

This system is configured with 32 channels of analog, 14 channels of digital, and 10 channels of pulse data input.

Computer system analog inputs include test-section dynamic pressure and air temperature, scale-model balance loads, and model-surface pressures. Radiator airflow anemometer speed signals are transmitted to the system as pulse data. Mechanical and scale-model balance yaw angle and mechanical-balance loading are input as BCD information. After these inputs are processed into engineering units, the results are output to several CRT's, printers, and a pen plotter.

ORGANIZATION AND USE

The Aerodynamics Laboratory is operated by GM Current Product Engineering. It provides wind-tunnel test capability and assistance to all GM staffs and divisions, and is a self-supported resource with engineering management, aerodynamic test engineers, electronic and mechanical technicians, and maintenance and clerical personnel, all on-site. Test engineers assigned to a specific test provide pretest consultation, actual test management and coordination, and data reporting and consultation as required by the GM unit customer.

A typical full-scale clay model is moved through the underground passageway from the Design Staff into the laboratory basement for test preparation. Specific measurements are made, interchangeable model-configuration parts are checked against the test plan, and special wind-tunnel instrumentation is installed, such as radiator airflow anemometers. After preparation, the model is moved to the second floor and mounted on the mechanical balance.

Judgments can be made effectively as the test proceeds to combine the aesthetic and aerodynamic requirements of a new-vehicle program. This concept permits frequent testing throughout the design process, which is essential to meeting aerodynamic targets.

SUMMARY

General Motors has in full operation the first full-scale automotive aerodynamics wind tunnel in North America at the GM Technical Center in Warren, Michigan. The configuration, equipment, and performance were determined by automotive test requirements. By conservative fluid-dynamic design and careful fabrication and inspection, the facility has met its flow-quality and performance objectives. Contracted wind-tunnel design talent plus fluid-dynamics consultant expertise, combined with General Motors' past wind-tunnel experience, has produced a successful engineering tool.