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# NASA Glenn Icing Research Tunnel User Manual

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September 2003

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## Summary

This manual describes the Icing Research Tunnel at the NASA Glenn Research Center and provides information for users who wish to conduct experiments in this facility. The capabilities of the tunnel test section, main drive system, speed control system, and the spray bars are described. Tunnel nozzle performance maps of liquid water content as a function of median volume droplet size are presented for two types of spray nozzles at test-section velocities ranging from 100 to 300 knots (kn) (115 to 346 mph). The facility support systems, which include heated air systems, steam and service air systems, model supports at tunnel test section ceiling, model exhaust system, force balance system, wake survey system, and model electrical power system, are described. Also discussed are facility instrumentation capabilities for temperature and pressure measurements and model attitude simulation. In addition, photographic documentation and flow visualization techniques are explained, and pretest meeting formats and schedules are outlined. Tunnel user responsibilities, personnel safety requirements, and types of test agreements are explained. The Icing Research Tunnel is a closed-loop atmospheric tunnel with a test section that is 6 ft high, 9 ft wide, and 20 ft long. The test section is equipped to support testing at airspeeds from 50 to 300 kn (58 to 346 mph) in a temperature and water-droplet environment that simulates natural icing conditions.

## 1.0 Introduction

This manual describes the Icing Research Tunnel (IRT) at the NASA Glenn Research Center and provides information for users who wish to conduct experiments in this facility. The Research Testing Division (RTD) manages and operates the facility. The capabilities of the tunnel test section, main drive system, speed control system, and spray bars are described. Tunnel performance maps showing liquid water content (LWC) as a function of median volume droplet (MVD) size are presented for two types of spray nozzles at test section velocities ranging from 50 to 300 knots (kn) (58 to 346 mph). The goal of the IRT is to replicate the Federal Aviation Administration (FAA) aircraft icing certification standards contained in the Federal Aviation Regulation (FAR) Part 25, appendix C.

Facility support systems, which include heated air systems, steam and service air systems, an altitude exhaust system, a force-balance system, and a model electrical power system, are described. Facility instrumentation capabilities for measuring temperature and pressure and simulating model attitude are discussed. Photographic documentation and flow visualization techniques are also described. Pretest meeting formats and schedules are outlined. Responsibilities for users of the tunnel, personnel safety requirements, and types of test agreements are also explained.

The IRT is a closed-loop atmospheric tunnel that is equipped to support the low-speed testing of models. It has a rectangular cross section that is 6 ft high, 9 ft wide, and 20 ft long. The velocity of air in an empty test section can be controlled from 50 to 339 kn (58 to 390 mph).

NASA Glenn Research Center is located adjacent to Cleveland Hopkins International Airport in Cleveland, Ohio. A model can be delivered to the IRT by using air and motor freight. The customer can obtain the appropriate directions from the IRT facility manager. A schematic diagram of the tunnel, shop, and control room is given in figure 1. Those desiring to schedule test time in the facility should contact the IRT facility manager at least 1 yr in advance (see appendix A), to permit Glenn personnel time to review the proposed model design and test envelope and to draw up a schedule.

During a given test program, Glenn can provide complete security for proprietary or Government-sensitive information. Personnel access to the wind tunnel test chamber, test section, and control room can be tightly controlled. However, requirements for security must be discussed with the Glenn IRT facility manager at a meeting(s) held before the test. The topics to be discussed at this meeting are thoroughly covered in section 6.1.

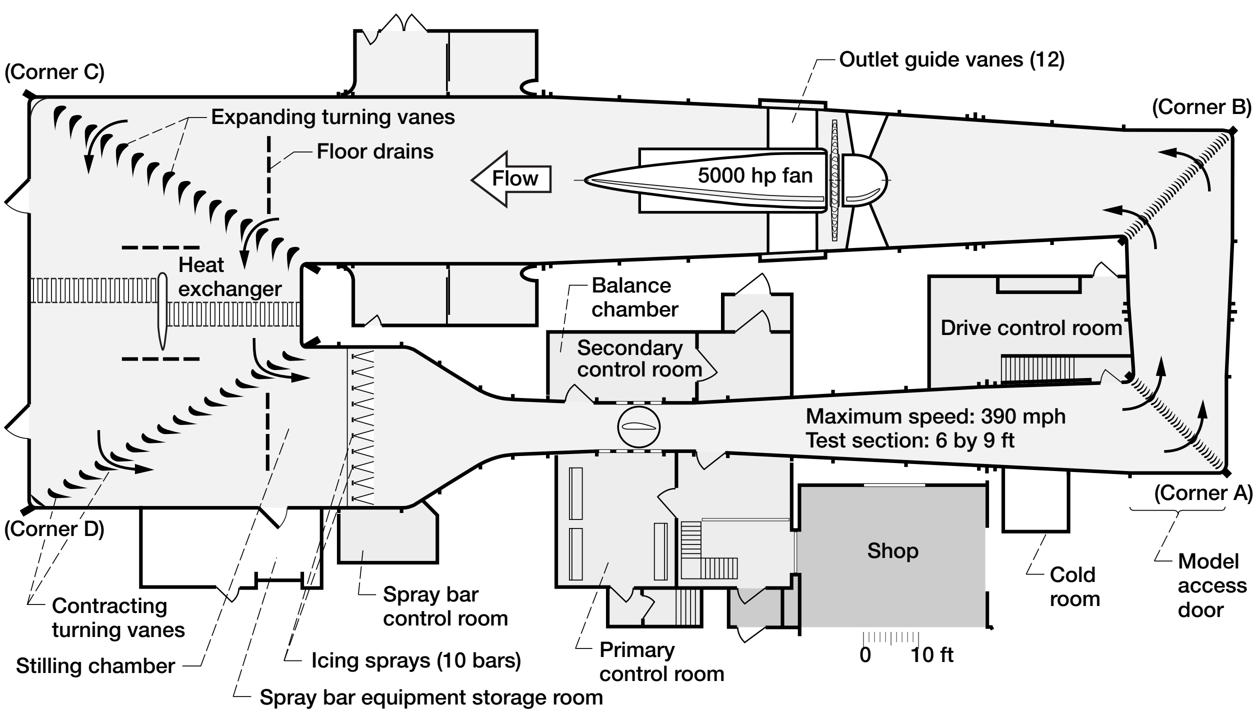



Figure 1.—Icing Research Tunnel (IRT), shop, and control room sections.

# 2.0 Description of the IRT Facility

## 2.1 General Description

The IRT is a closed-loop atmospheric tunnel with rectangular cross sections (see fig. 1). The test section is 6 ft high, 9 ft wide, and 20 ft long. The Glenn IRT service building is a two-story structure that is connected to a balance chamber enclosing the test section (fig. 2) by an airlock chamber and a model access door. The shop area on the first floor is available for model buildup. It has a 10.5-ft-wide by 10.67-ft-high model delivery access door located on the east side of the building (fig. 1). The balance chamber is a three-story structure whose first-floor layout is shown in figure 2. An access door on the east side of the balance chamber retracts upward to provide a 9.08-ft-wide by 8.25-ft-high opening through which models can be moved between the shop area and the balance chamber. On the second floor of the balance chamber are the tunnel test section, the tunnel access doorway, and the facility control rooms. A test section model access hatch and the test section altitude exhaust duct are located on the third floor. In some instances the model to be tested is too large to enter the test section through the balance chamber third floor access hatch, so the diffuser access hatch downstream of the test section is used to insert the model into the tunnel at corner A (see fig. 1). This access hatch is 8 ft high by 10 ft wide. The volume inside the entire tunnel is 234 272 $ft^3$. Figure 3 is a schematic of the IRT showing various tunnel sections, and table I gives the volume of each section.

The IRT can simulate the FAA icing envelope for the case of various LWCs and MVDs. The spray-bar system and the results of tests run in the IRT test section are discussed in section 2.6. The conditions are simulated via the refrigeration plant and a spray-bar system that generates a cloud of microscopic droplets of supercooled water. A sampling of models run in the IRT is shown in figure 4. For more information consult the reports on icing research and tunnel capabilities listed in references 1 to 12.

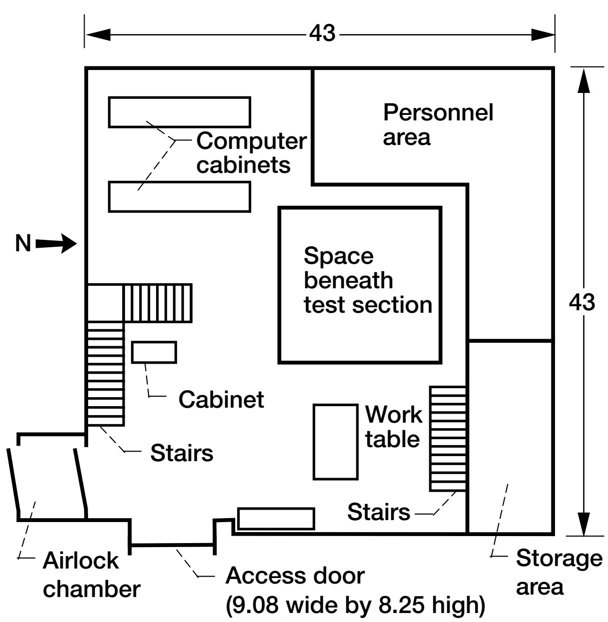



Figure 2.—First floor of IRT balance chamber. All dimensions are in feet.

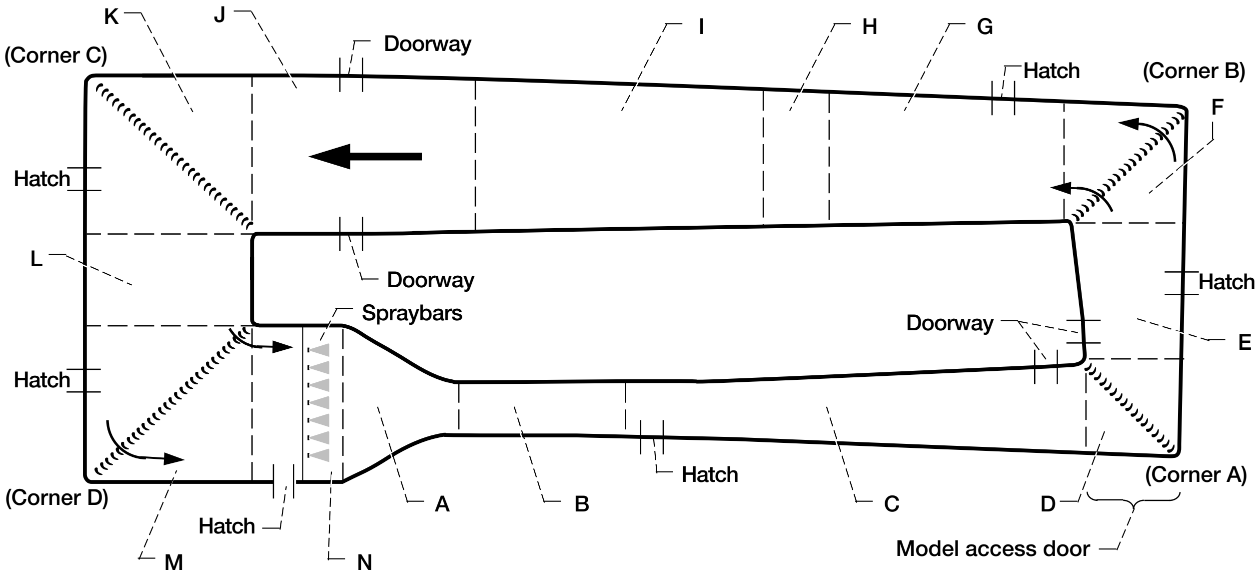
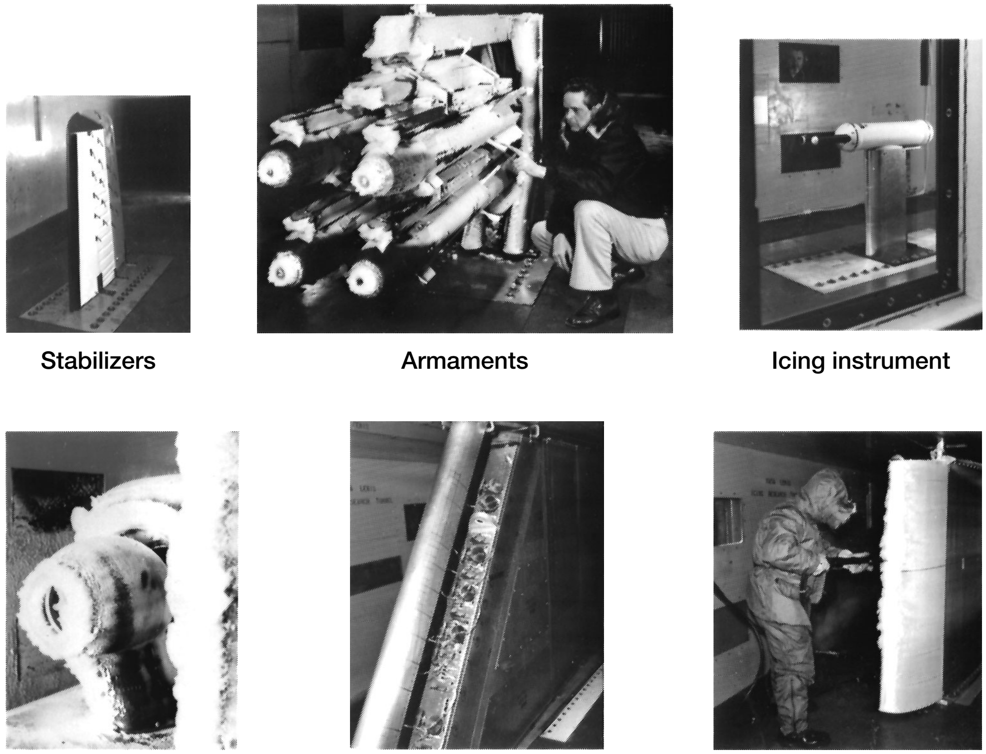



Figure 3.—IRT showing 14 distinct volume sections.

TABLE I.—ICING RESEARCH TUNNEL CIRCUIT DETAILS

| Tunnel volume section[a] | Description | Volume, $ft^3$ |
|---|---|---|
| A | Front leg convergence | 7 584 |
| B | Test section | 1 080 |
| C | Front leg diffuser | 11 387 |
| D | Corner A: hollow turning vanes steam heated | 4 197 |
| E | Cross leg diffuser | 6 907 |
| F | Corner B: hollow turning vanes, steam heated | 6 400 |
| G | Back leg fan inlet diffuser and guide vanes | 21 671 |
| H | Fan housing | 6 605 |
| I | Back leg fan outlet diffuser and guide vanes | 25 282 |
| J | Back leg vent tower | 32 444 |
| K | Corner C: hollow turning vanes, unheated | 39 612 |
| L | Cross leg heat exchanger duct | 19 147 |
| M | Corner D:  hollow turning vanes, unheated | 39 612 |
| N | Front leg spray bar duct | 12 344 |
| Total | | 234 272 |

[a]Sections correspond to those labeled in figure 3.



Stabilizers Armaments Icing instrument

Inlets Deicing systems Wings

Figure 4.—Aircraft models and experiments installed in IRT test section.

## 2.2 Wind Tunnel Performance and Capability

The maximum airspeed achievable in an empty IRT test section is 339 kn (390 mph). Estimates of the maximum airspeed in the IRT test section for various combinations of model blockage and overall drag coefficient with streamlined and squared-off afterbodies are presented in figures 5 and 6 and from “Estimates of Maximum Test Airspeeds in the NASA Glenn Icing Research Tunnel (IRT) Considering the Size and Shape of the Test Model” (D.A. Spera, 2002, NASA Glenn Research Center, Cleveland, OH, Preliminary Information Report #083), which can be obtained from the IRT project engineer.

The tunnel circuit operates at or below atmospheric pressure, and the test section total-temperature range for chilled air is controlled between –20 and +33 °F. The curve in figure 7 presents the difference in air total temperature in corner D of the tunnel and the air static temperature in the test section as a function of air velocity in the test section measured in knots and miles per hour. An uncertainty analysis for velocity measurement in the IRT test section for the case where the static temperature is –22 °F and the velocity is 300 kn (346 mph) is presented in “Uncertainty Analysis for Total Temperature, and Total and Differential Pressure Measurements in IRT Test Section.” (R.H. Soeder and P.Z. Blumenthal, 2002, NASA Glenn Research Center, Cleveland, OH, Preliminary Information Report #082). The analysis shows that the uncertainty in test section velocity is ±0.47 percent (±1.41 kn or 1.62 mph) for a velocity of 300 kn (346 mph). Appendix B describes the uncertainty analysis that is presented in this document, which can be obtained from the IRT project engineer.

Data presented in reference 13 were obtained using a 9-ft horizontal survey rake installed in the IRT test section (see fig. 8). The rake was installed at an axial position of 179.3 in., which was the axial station of the cross-sectional plane used during flow calibration tests in April 1997 and April 2000. In this position, the plane of the sensors passes through the axis of the model turntable.

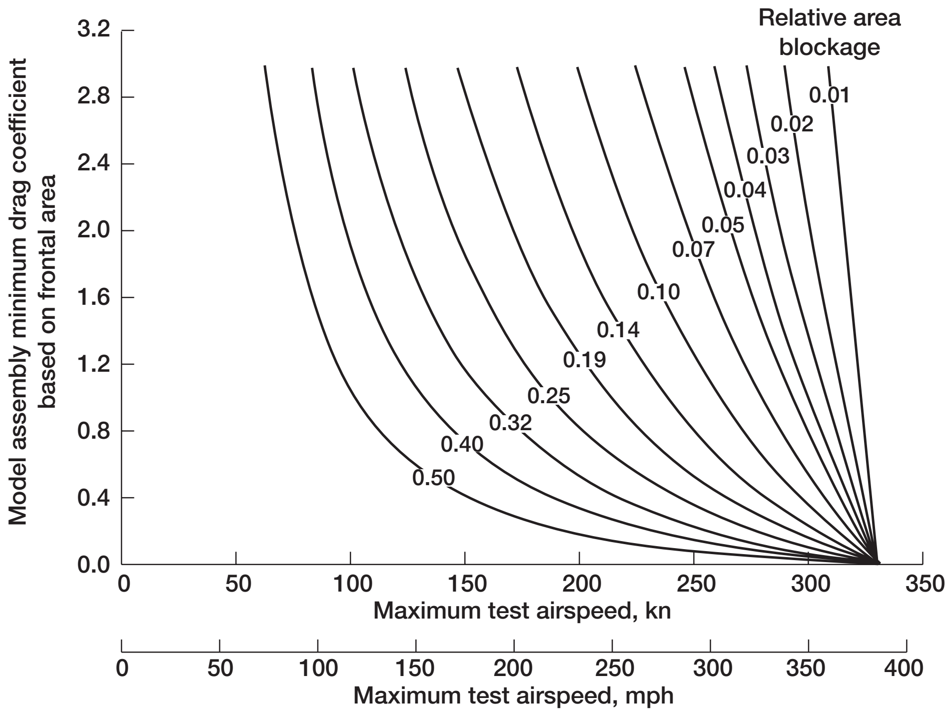



Figure 5.—Estimated maximum test airspeed in the IRT for test models with streamlined afterbodies, based on relative area blockage and assembly drag coefficient. Air density in stilling chamber, 0.00263 slug/ft$^3$. Stilling chamber is located in corner D of tunnel (see fig. 1).

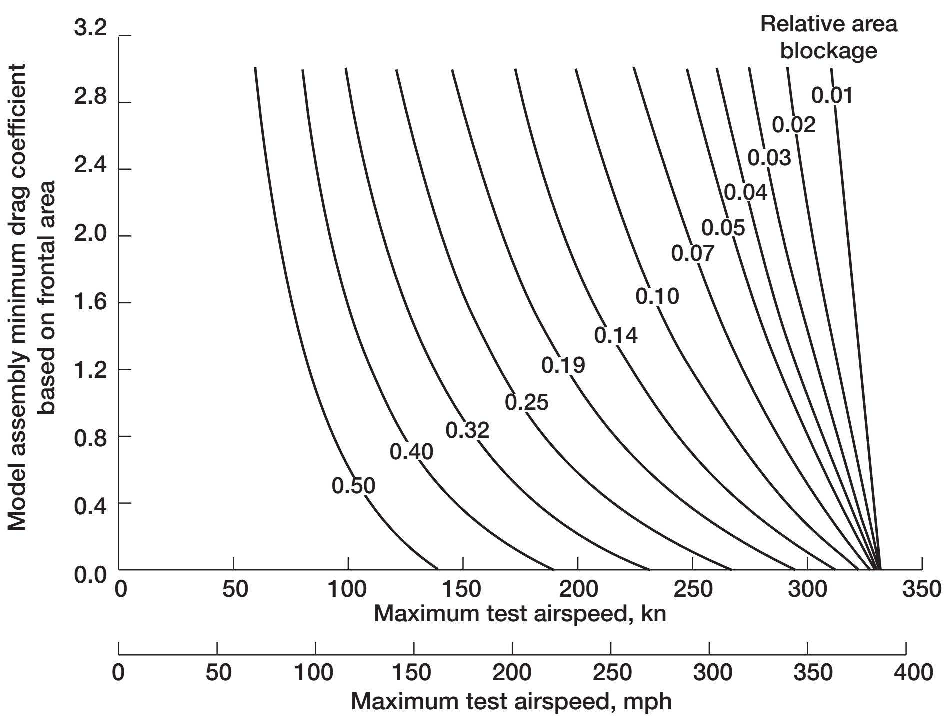



Figure 6.—Estimated maximum test airspeed in the IRT for test models with squared-off afterbodies, based on relative area blockage and assembly drag coefficient. Air density in stilling chamber, 0.00263 slug/ft$^3$. Stilling chamber is located in corner D of tunnel (see fig. 1).

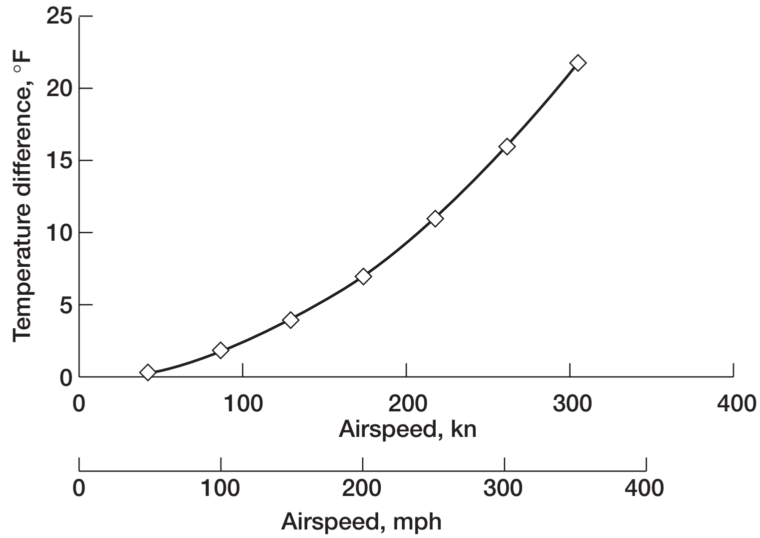



Figure 7.—Difference between total and static temperatures as a function of airspeed.

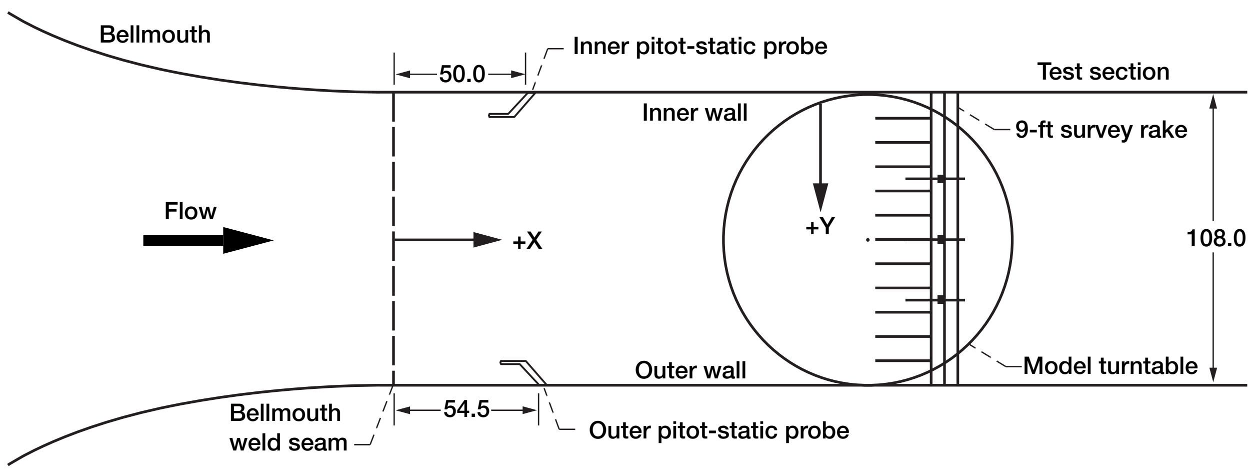



Figure 8.—IRT test section showing the 9-ft horizontal rake installed for both the April 1997 and April 2000 tests. All dimensions in inches unless otherwise noted.

The data from the year 2000 tests were acquired over a test section velocity range from 43 to 304 kn (50 to 350 mph). No icing conditions were tested, but the effects of air sprayed through the water-air nozzles were assessed. Detailed statistical information on total pressure, static pressure, Mach number, test section velocity, flow angle, and total temperature is discussed in reference 13. An examination of the data presented in reference 13 and recorded during the year 2000 tests shows that flow quality improvements were seen in pitch angle, yaw angle, and turbulence intensity over the year 1997 tests. Whereas the old folded heat exchanger was installed for the 1997 tests, the later tests were performed with the new heat exchanger installed, the C–D leg of the tunnel loop expanded, and new turning vanes in the C and D corners (see fig. 1).

Figure 9 is a summary plot that shows tunnel test section turbulence intensities for the years 1997 and 2000. The data in figure 9 were averaged over vertical distances above the test section floor ranging from 15 to 63 in. and test section velocities from 43 to 174 kn (50 to 200 mph). The year 2000 data included only hot-wire, multiple-probe data with no air spray, and the 1997 data included only

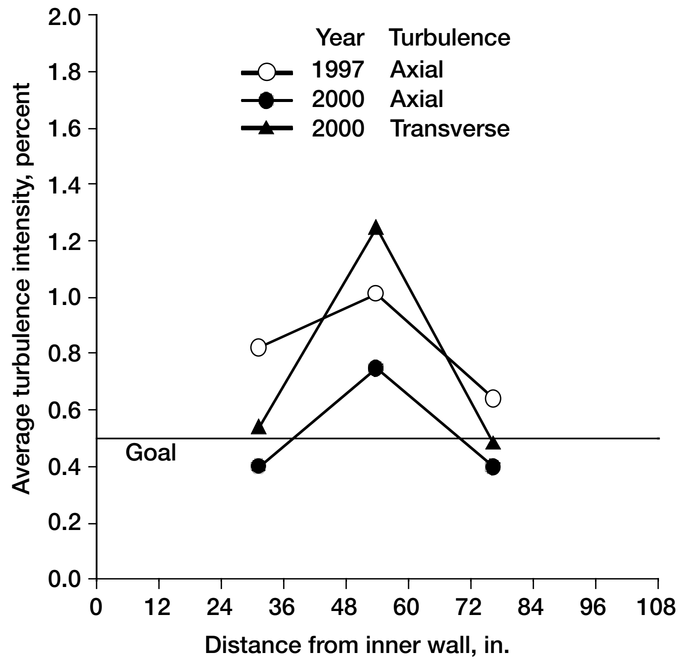



Figure 9.—Average axial and transverse turbulence intensity measured in IRT during years 1997 and 2000. Data averaged over vertical distances ranging from 15 to 63 in. above test section floor and test section velocities from 44 to 174 kn (50 to 200 mph).

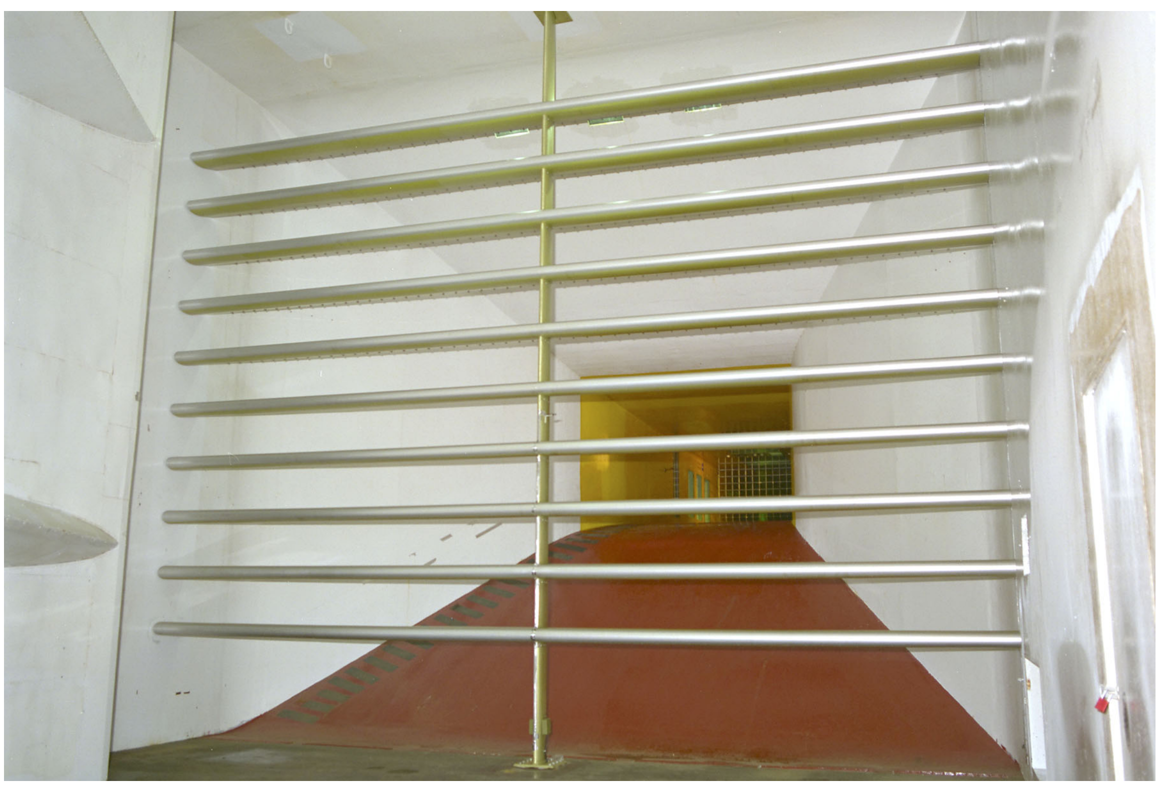


Figure 10.—Looking downstream through spray-bar section of IRT and into test section.

single-sensor, hot-wire data with no air spray. The data in figure 9 indicate that the axial turbulence intensity at the test section vertical centerline was reduced by about 0.25 to 0.75 percent in going from the 1997 IRT tunnel configuration to the 2000 IRT tunnel configuration. It can also be observed from figure 9 that the average axial turbulence intensities (year 2000 data) meet the 0.5-percent turbulence intensity goal beyond the test section centerline. The increase in turbulence intensity at the centerline of the tunnel is the result of turbulence generated by a vertical support beam that supports the spray-bar array at midspan (see fig. 10).

### 2.3 Test Section Details

The view of the inlet to the IRT test section looking downstream through the spray bars is shown in figure 10. The test section is 6 ft high, 9 ft wide, and 20 ft long. The tunnel area contraction ratio between the cross section at the spray bars and the cross section at the test section is 14.1 to 1.0.

The large balance chamber that surrounds the test section (fig. 1) is at approximately the same static pressure as the test section; therefore, no pressure bulkhead fittings or hermetically sealed connections are needed for the instrumentation leads and service air hoses entering the tunnel test section ceiling or floor. Personnel access to the test section from the balance chamber is through a 4.5-ft-wide by 5.25-ft-high door in the south tunnel wall. The south wall of the balance chamber also contains a 4- by 5-ft pressure-relief door that opens to the atmosphere if the altitude exhaust system controls should fail during tunnel operation. If the difference between atmospheric pressure and the balance chamber pressure reaches 360 lb/ft$^2$, a control-room alarm sounds, but if the pressure differential reaches 400 lb/ft$^2$, the pressure-relief door opens automatically and the fan drive system is immediately shut down. The balance chamber is designed for a pressure differential of 600 lb/ft$^2$.

The center of the 8.67-ft-diameter test section turntable is 106.5 in. from the inlet of the test section. The turntable can be rotated ±20° in the horizontal plane without hardware modifications. With minor hardware changes, the rotational range can be increased to meet test requirements. A plan view of the turntable and model mounting plate is shown in figure 11. Tunnel users must supply a mounting plate to attach the model to the turntable; it must adhere to the specifications shown in figure 12. The mounting plate must contain the mounting holes, as detailed in figure 12, for bolting the plate to the turntable but may contain other holes to accommodate the mounting of the model and routing of instrumentation leads. It is recommended that models be fastened to the turntable. A model that is less than the full height of the test section should be fastened to the turntable mounting plate (figs. 11 and 12) and, if required, can be attached to the test section ceiling (see sec. 3.3). Be advised that all forward-facing surfaces accrete ice; this factor should be considered in the design of the model and its attachments (see sec. 7.0).

The tunnel user must perform a detailed stress analysis on the model and support system and provide a copy of the stress analysis to the IRT facility manager and the IRT project engineer 8 weeks prior to the scheduled test (see sec. 7.0).

The test section ceiling has a hatch that is 4 ft wide by 12 ft long. Through this hatch, models and equipment may be moved into and out of the test section. A 2-ton electric crane located on the third floor of the balance chamber (fig. 2) is available to move models and equipment. Because of rigging constraints, the model profile in the vertical plane is restricted to 71.75 in. The model should have a hard lifting point(s) to reduce the amount of rigging required. Once the model has been properly positioned in the test section, the ceiling hatch cover is fitted into place. Openings in the hatch cover can be fitted with either steel plates or acrylic panels. The acrylic panels allow flow over the model to be monitored via flow visualization equipment (this topic is discussed in sec. 4.5). User-supplied panels of transparent material other than acrylic may be used if safety standards are met. Transparent panels that are to be inserted into the ceiling hatch cover of the test section must conform to the orientation and dimensions shown in figure 13. In addition the thickness of these panels should be 1 in. and have a 3/8-in. step (refer to sec. 3.3.3 for details).

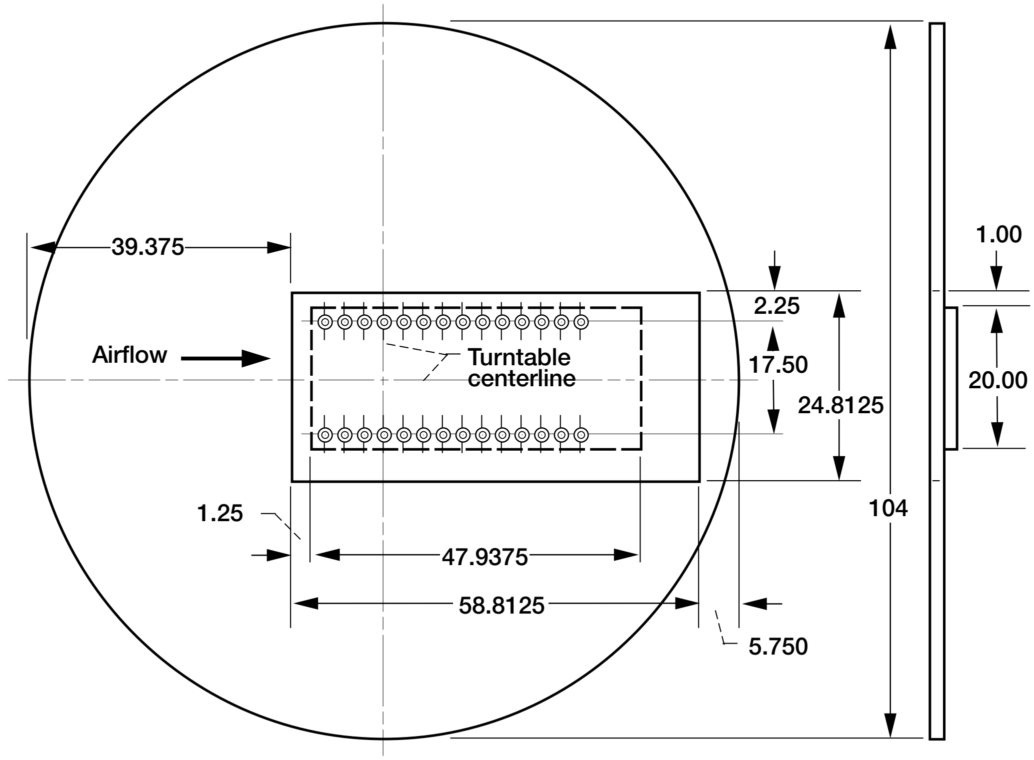



Figure 11.—Icing Research Tunnel turntable and model mounting plate. All dimensions are in inches.

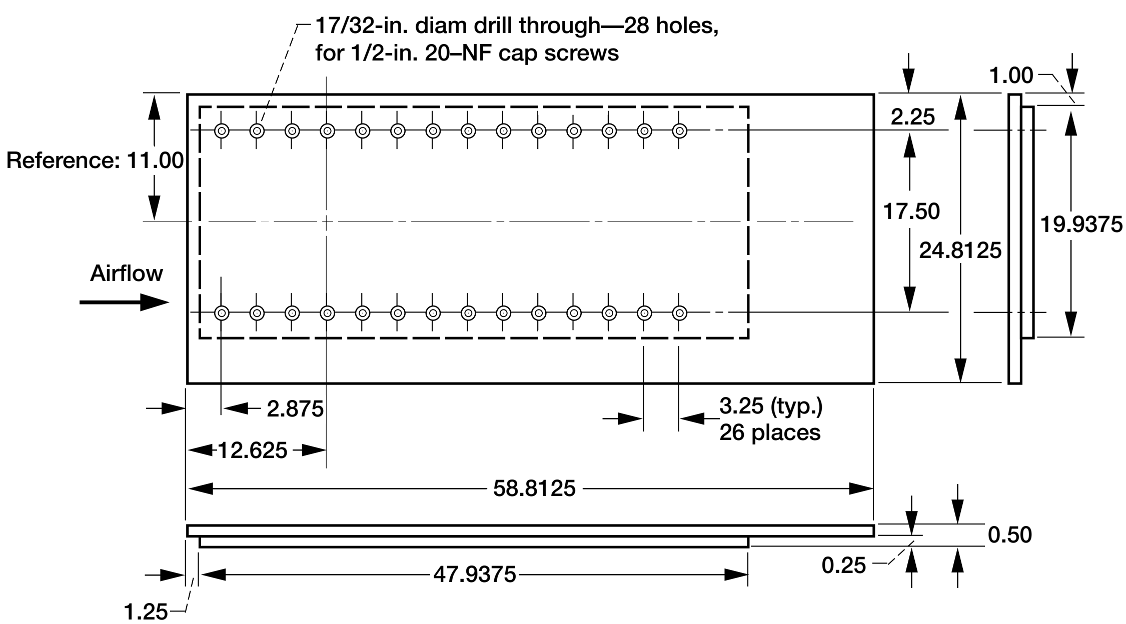



Figure 12.—IRT model mounting plate. Note: Tunnel is 6 ft high by 9 ft wide. If model extends beyond turntable, leave 1/2-in. clearance above top or below bottom of model. All dimensions are in inches; typ. is typical.

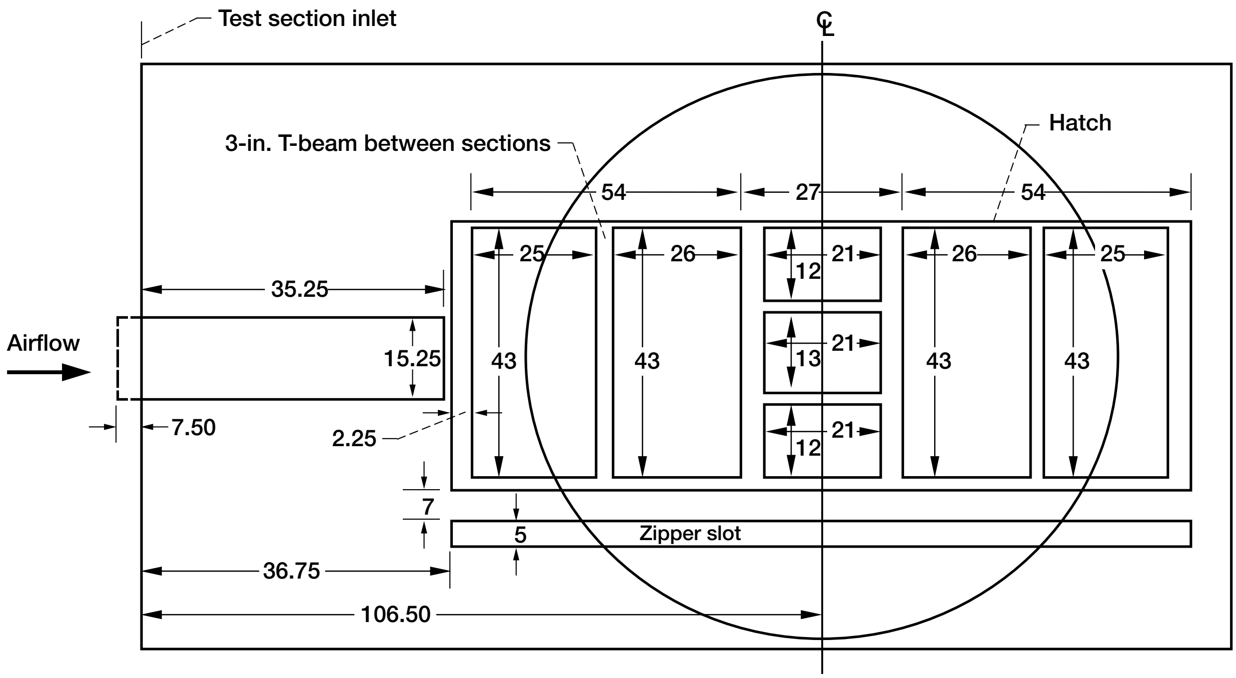



Figure 13.—Access to IRT test section from overhead hatch. Note: All support bars between hatch windows, except small windows across tunnel, can be removed and reset at 2-in. increments to make any size windows. Openings 54 by 43 in. can be subdivided into smaller sections in 2-in. increments. All dimensions are in inches.

An isometric view of the IRT north and south test section walls showing the visual access windows and the test section turntable is presented in figure 14. The test section wall adjacent to the south control room (see fig. 15(a)) contains four windows for observing the model during testing. Three windows are 29 in. wide by 44 in. high, and one window is 24 in. wide by 40 in. high. These four observation windows are electrically heated to prevent fogging. The test section vertical wall adjacent to the north side control room (fig. 15(b)) contains a doorway and three electrically heated windows through which the tunnel users may view the model during testing. All three windows are 24 in. wide by 40 in. high.

### 2.4 Main Drive System

The major components of the main drive system (fig. 16) are the motor, the fan blades, and the fan inlet and outlet guide vanes. The variable-speed motor, which is air cooled and rated at 5000 hp, is installed inside the faired nacelle. It is controlled from the operator's console in the control room. From this console the drive motor can be started and stopped, and the motor speed can be adjusted throughout a given tunnel experiment. The main drive motor is directly coupled to a fixed-pitch, 12-bladed fan fabricated from laminated Sitka spruce. The fan outer diameter is 25.17 ft, and the maximum rotational speed is 460 rpm.

### 2.5 Test Airspeed Control

Two electrically heated pitot-static probes positioned at the inlet to the tunnel test section are used to measure the total and static pressures required to compute the free-stream velocity in the test section. At the start of a test program, with the model installed in the test section, an aerodynamic checkout test is run to verify the structural integrity and the flutter regime of the model and also to establish a

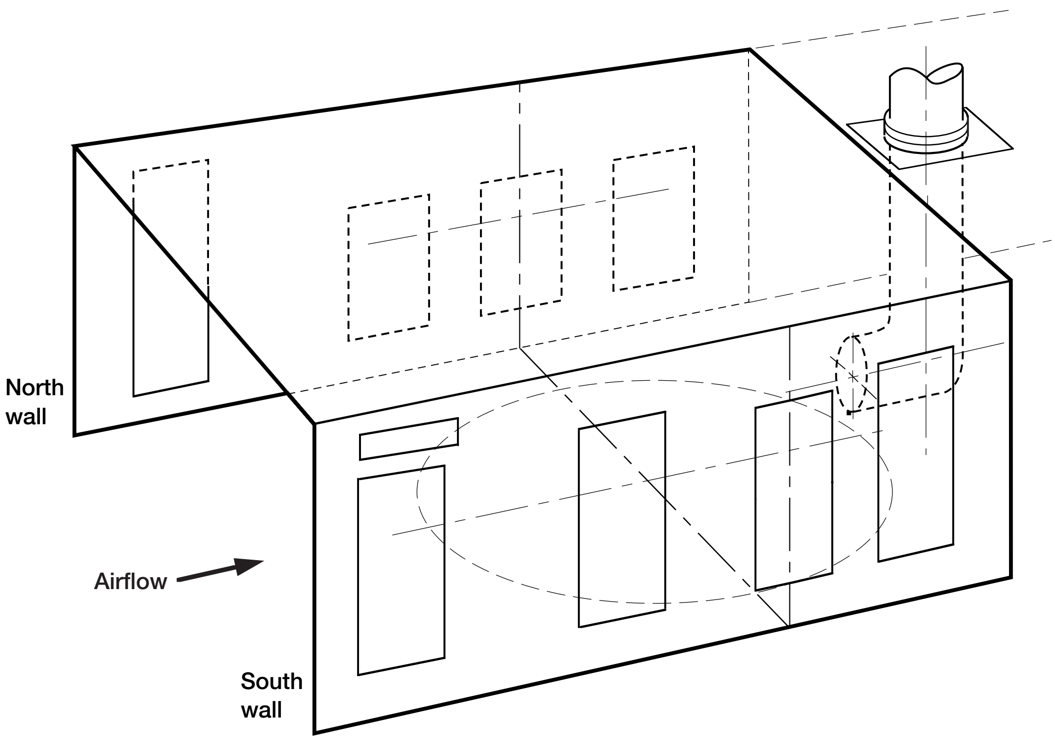


Figure 14.—IRT test section north and south walls showing visual access windows, turntable, and optional altitude exhaust piping.

relationship between test airspeed and fan speed in revolutions per minute. Data are recorded for conditions up to 110 percent of the desired airspeed or up to the maximum tunnel conditions. The tunnel operator uses this relationship to select a fan speed that will achieve the desired test airspeed. The fan speed can be accurately controlled to within ±1/2 rpm of the desired value and can be ramped between 50 and 460 rpm. The nominal ramp rate setting is 4 rpm/s, but it can be adjusted to values ranging from 1 to 10 rpm/s. This capability may be used to simulate a flight profile. Note, however, that this ramping capability is not a normal fan operating condition and must be prearranged and approved by the IRT project engineer.

## 2.6 Spray Bars

Air-assisted water spray nozzles are used to produce the proper-sized droplets in the icing cloud. Ten spray bars with a total availability of approximately 251 nozzles produce a uniform icing cloud in the test section. There are approximately 149 standard and 102 modified (mod-1) nozzles installed in the spray bars. A control-room software package selects the nozzle set to be used for a given test. A separate water supply system exists within each spray bar for the standard and the mod-1 nozzles. The only difference between nozzles is the diameter of the water tube. The standard nozzles are used to produce a higher LWC in the test section; the mod-1 nozzles are used to produce a lower LWC.

The goal of the IRT is to replicate the Federal Aviation Administration (FAA) aircraft icing certification standards contained in the Federal Aviation Regulation (FAR) Part 25, appendix C. These icing envelopes are presented in reference 14.

In figures 17 and 18 the IRT capabilities at airspeeds of 100 and 300 kn (115 and 346 mph) are compared to FAA icing certification criteria.

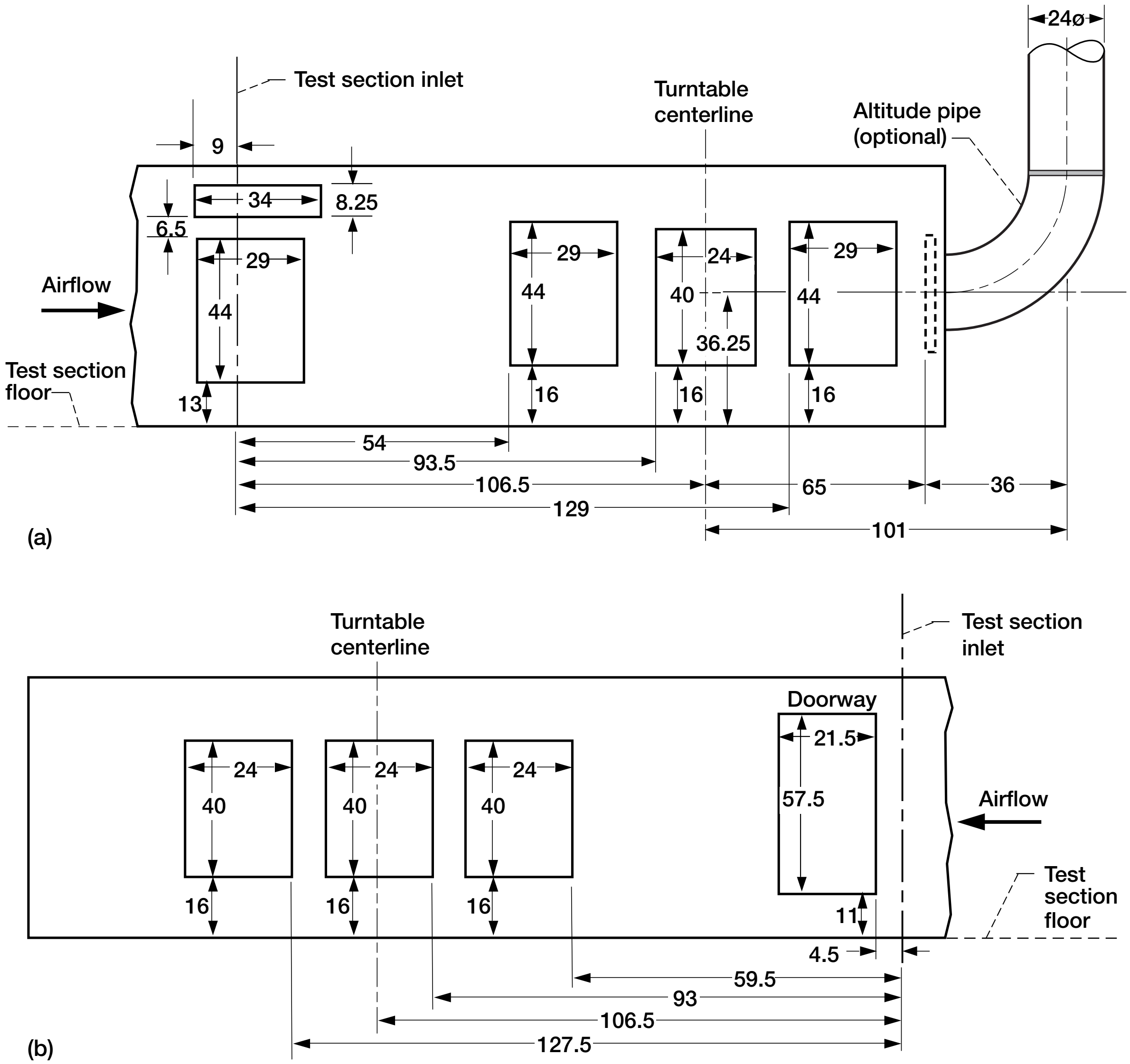



Figure 15.—IRT test section. (a) South wall showing four windows as viewed from primary control room (b) North wall showing three windows and doorway as viewed from secondary (customer) control room. All dimensions are in inches.

## 2.7 Control Rooms

There are two control rooms on the second floor of the balance chamber adjacent to the test section. A floor plan of the primary (tunnel-operation) control room, which is located on the south side of the facility test section, is presented in figure 19. Models can be viewed from the control room through the observation windows seen in the isometric diagram presented in figure 14. A floor plan of the secondary control room (for tunnel users), which is located on the north side of the test section, is presented in figure 20. At one of the pretest meetings, the IRT project engineer and the IRT electrical engineer will describe the facility equipment items and their locations in the control rooms. The control rooms, the balance chamber, and the facility test section are all at the same static pressure. The maximum tunnel velocity in an empty test section is 339 kn (390 mph).

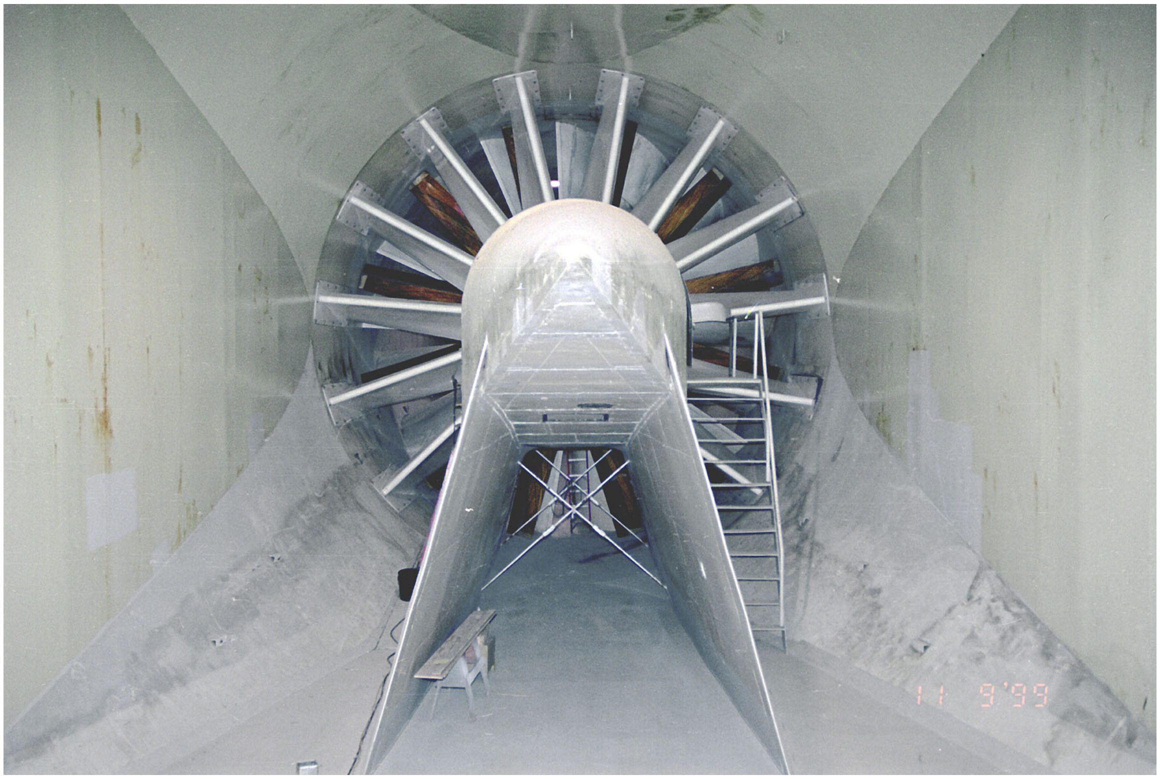



Figure 16.—IRT main drive system as viewed from corner C of tunnel (see fig. 1).

The tunnel is operated from an interactive, distributive control system known as the Westinghouse Distributed Processing Family (WDPF) (Emerson Process Management Power & Water Solutions, Pittsburgh, PA). Two operator consoles have color graphic displays for setting and monitoring the facility's operation. From these consoles, tunnel fan speed, spray-bar air and water pressures, spray duration, turntable position, and functions of other auxiliary systems are controlled. A third console contains instrumentation displays that are used to control tunnel lighting and emergency shutdown.

The control room also contains the Glenn Escort D data-acquisition system and the electronic scanning pressure (ESP) system for model instrumentation support. The Escort D system is interactive (push button) and can collect, process, display, and record data as accumulated during a test. Refer to Data Acquisition (sec. 5.1) for further details on the Escort D and ESP systems.

### 2.8 Cold Room

A cold room, which is 13 ft long by 11 ft wide by 9 ft high and can be temperature controlled down to –20 °F, is located on the outside wall of the tunnel upstream of the turning vanes in corner A (see fig. 1). A 36-in.-wide by 78-in.-high hatch provides direct access to the cold room from the tunnel so ice shapes can be analyzed in detail immediately after accretion without significant melting. This cold room contains a 6-ft-long by 31-in.-wide table that supports a 23.5-in.-diameter circular table that can translate and rotate in front of a laser scanner system. The scanner system contains a helium-neon 100-µW laser and a camera system that is used to measure ice accretions on a model segment placed on the turntable for scanning at the conclusion of a tunnel test.

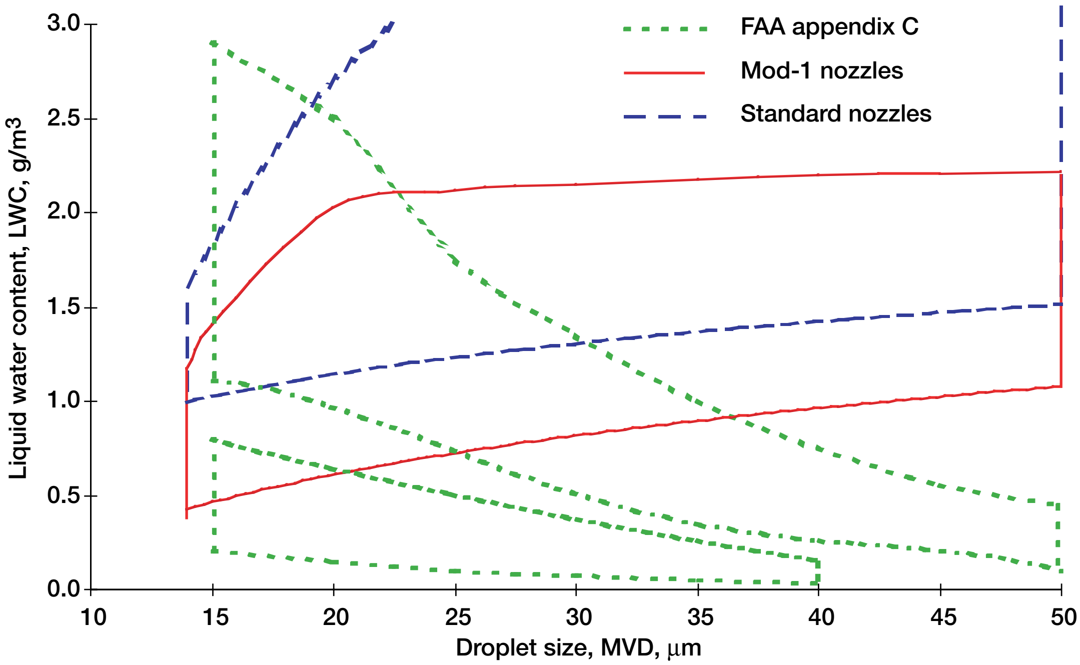



Figure 17.—Comparison of liquid water content (LWC) versus median volume droplet (MVD) size operating envelopes between IRT and FAA icing certification criteria for airspeed of 100 kn (115 mph).

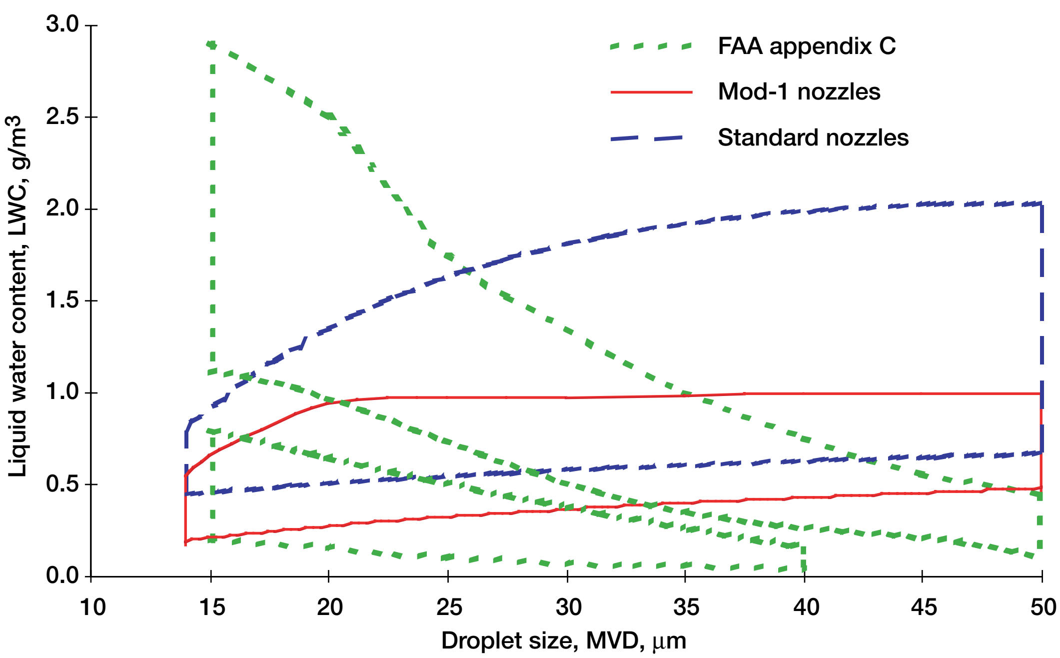



Figure 18.—Comparison of liquid water content (LWC) versus median volume droplet (MVD) size operating envelopes between IRT and FAA icing certification criteria for airspeed of 300 kn (346 mph).

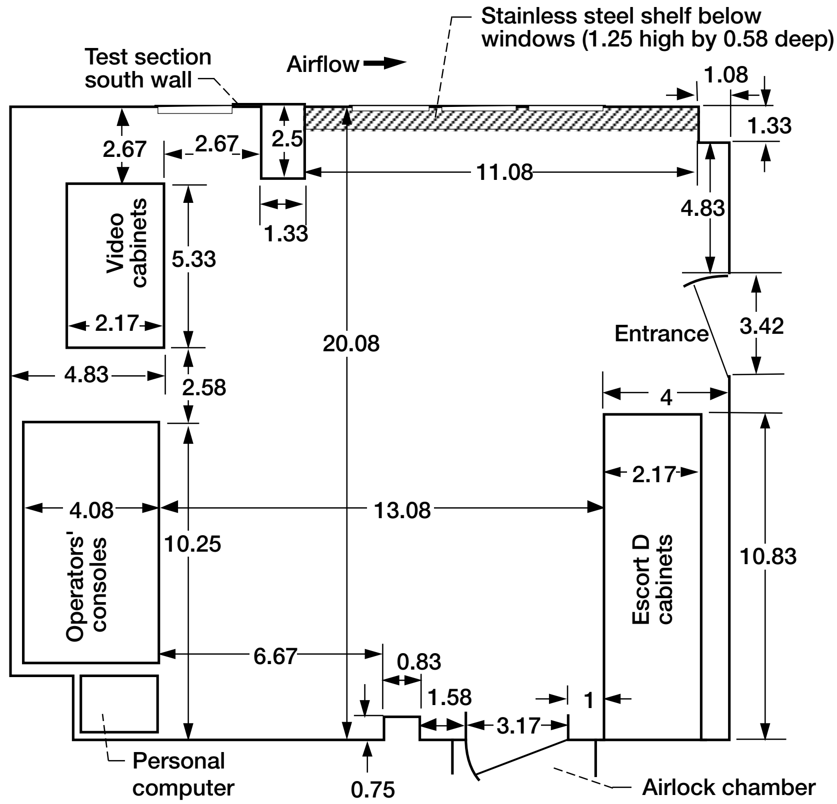



Figure 19.—Floor plan of IRT primary control room. All dimensions are in feet.

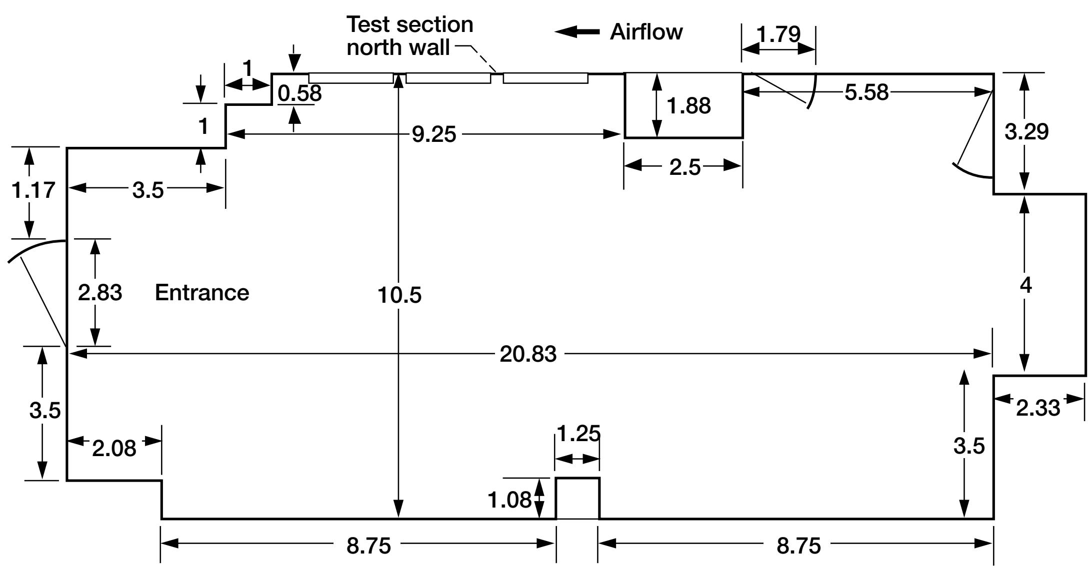



Figure 20.—Floor plan of IRT secondary (customer) control room. All dimensions are in feet.

The turntable can accommodate a model having up to a 24-in. span by a 21-in. chord airfoil or a detachable model leading edge segment up to a 36-in. span. The laser scanning system maps the surface of the ice shape and generates an (x,y,z) point cloud. This point cloud can be sliced to view multiple two-dimensional tracings or, with additional effort, the point cloud can be recreated by using a rapid prototyping machine. A three-dimensional ice shape has been successfully reproduced using polymer-coated metal beads. The IRT facility engineer is available to discuss details regarding this process with the customer.

# 3.0 Tunnel Support Service Systems

The following information is provided to acquaint the tunnel user with support services that are available at the test section.

## 3.1 Heated Air Systems

If the model requires heated air, there is a gas burner outside the tunnel for that purpose. Either 150-psig combustion air or 125-psig service air can be supplied to the burner. The particulars on the burner are presented in table II.

TABLE II.—BURNER DETAILS

| Operating condition | Combustion air | Service air |
|---|---|---|
| Pressure, psig | 150 | 125 |
| Flow rate, $lb_m$/s | 5 | 1 |
| Temperature, °F | 500 | 700 |

The heated air is transported to the model through a 4-in.-diameter line that can be downsized to meet model requirements. In addition, there is a 2-in. supply line that tees off the main 4-in. line and runs through a 45-kW, 440-V electric heater. The electric heater particulars are presented in table III.

TABLE III.—ELECTRIC HEATER DETAILS

| | |
|---|---|
| Flow Rate, $lb_m$/s | 0.5 |
| Temperature, °F | 900 |

The gas burner and the electric heater can be used independently. However, when the gas burner and the electric heater are used simultaneously, the gas burner acts as the preheater. The IRT facility engineer can discuss with the tunnel user the flow equations that are used to compute flow rate in the heated air system.

## 3.2 Steam and Service Air Systems

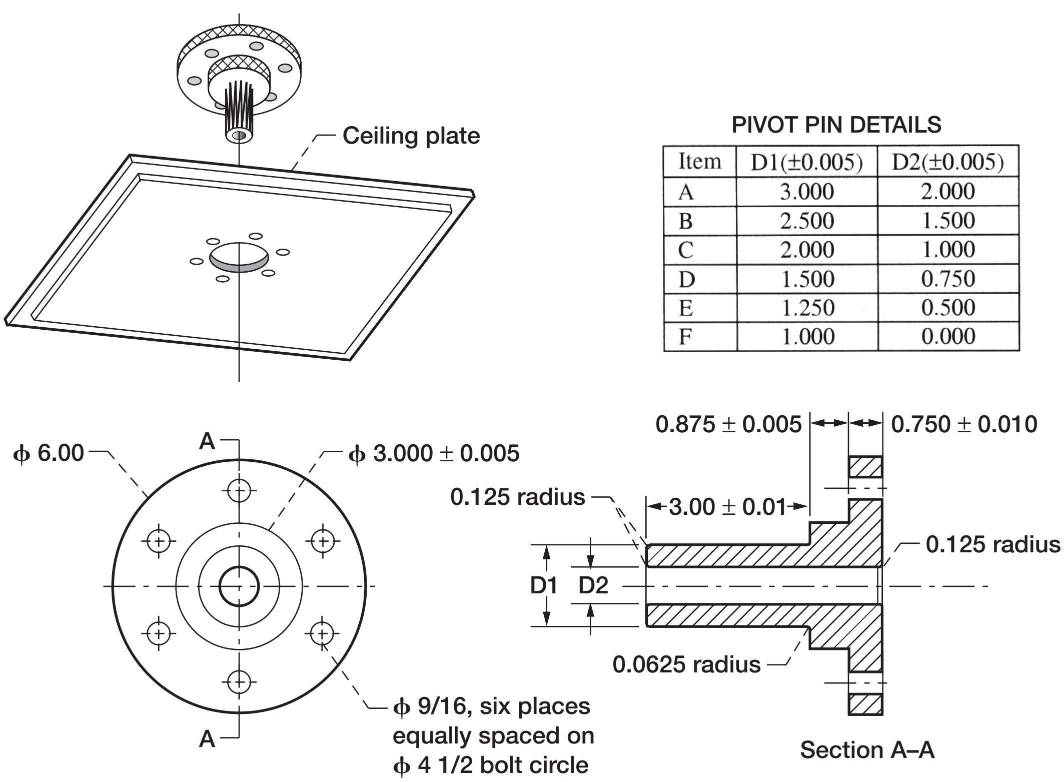
A 3/4-in.-diameter line provides 40-psig steam, which may be used for model and/or instrumentation deicing. Service or shop air, nominally at 125 psig, is available for pneumatic tools that may be needed to install the model in the test section.

## 3.3 Model Supports at Tunnel Ceiling

***3.3.1 Pivot pins***.—Six types of pivot pins are available to support models at the ceiling of the IRT test section. The outside diameters of these pins vary from 1.000 to 3.000 in. ± 0.005 in. (fig. 21). As shown in figure 21, the selected pin is inserted through an opening in a test section ceiling plate and into a customer-supplied bushing located at the top of the model. The pivot pin is then fastened to the test section ceiling plate (see sec. 3.3.3 below), which is located in the ceiling hatch. This arrangement adds stability to the model. The table in figure 21 lists the six types of pivot pins available for use at the IRT. The hollow core of the pivot pin can be used to bring instrumentation lines from the model through the IRT test section ceiling to facility recording equipment.

***3.3.2 Bushings***.—Seven types of bushings are available for model support at the ceiling of the IRT test section (fig. 22). The inside diameters of these bushings vary from 0.530 to 2.530 in. ± 0.005 in. (see the table in fig. 22 for details). The bushing selected is inserted through an IRT ceiling plate and onto a customer-supplied pin mounted at the top of the model. The bushing is then fastened to the ceiling plate. The addition of the bushing adds stability at the top of the model.

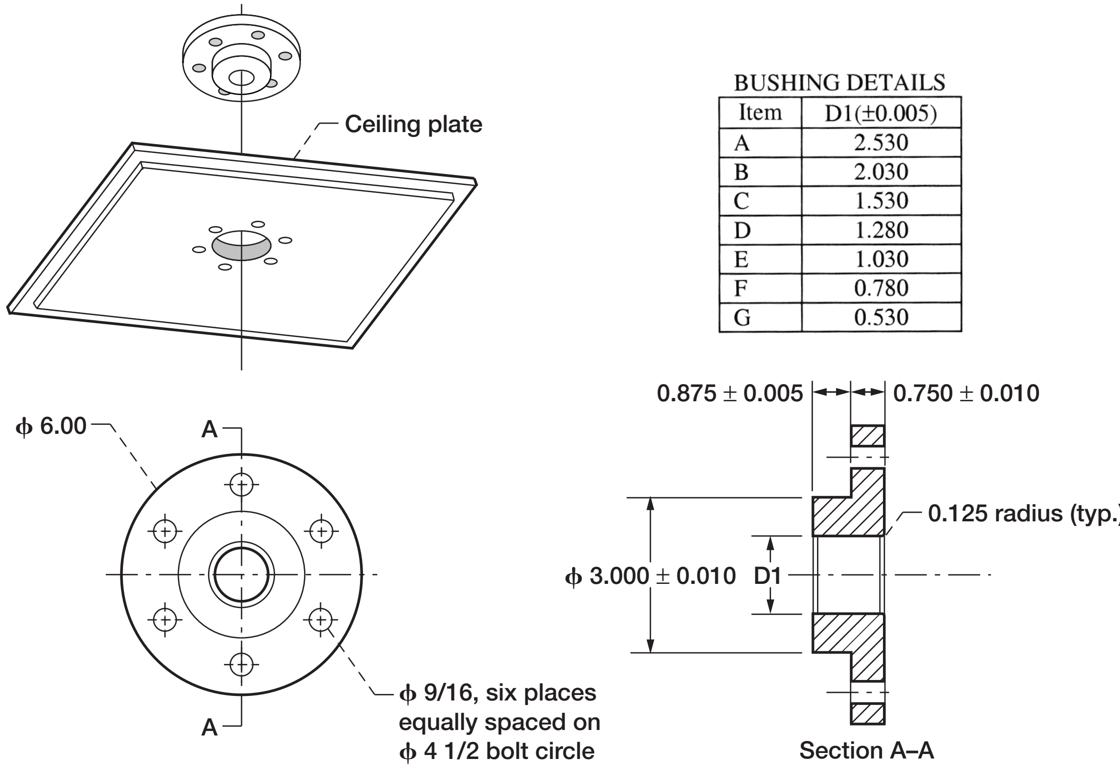
***3.3.3 Ceiling plate***.—The ceiling plate presented in figure 23 is used to retain a pivot pin or a bushing (see sec. 3.3.1 or 3.3.2). The ceiling plate is made of 6061–T6 aluminum and is inserted in the test section ceiling of the IRT. The ceiling plates are held in place by clamping devices.




PIVOT PIN DETAILS

| Item | D1(±0.005) | D2(±0.005) |
|---|---|---|
| A | 3.000 | 2.000 |
| B | 2.500 | 1.500 |
| C | 2.000 | 1.000 |
| D | 1.500 | 0.750 |
| E | 1.250 | 0.500 |
| F | 1.000 | 0.000 |

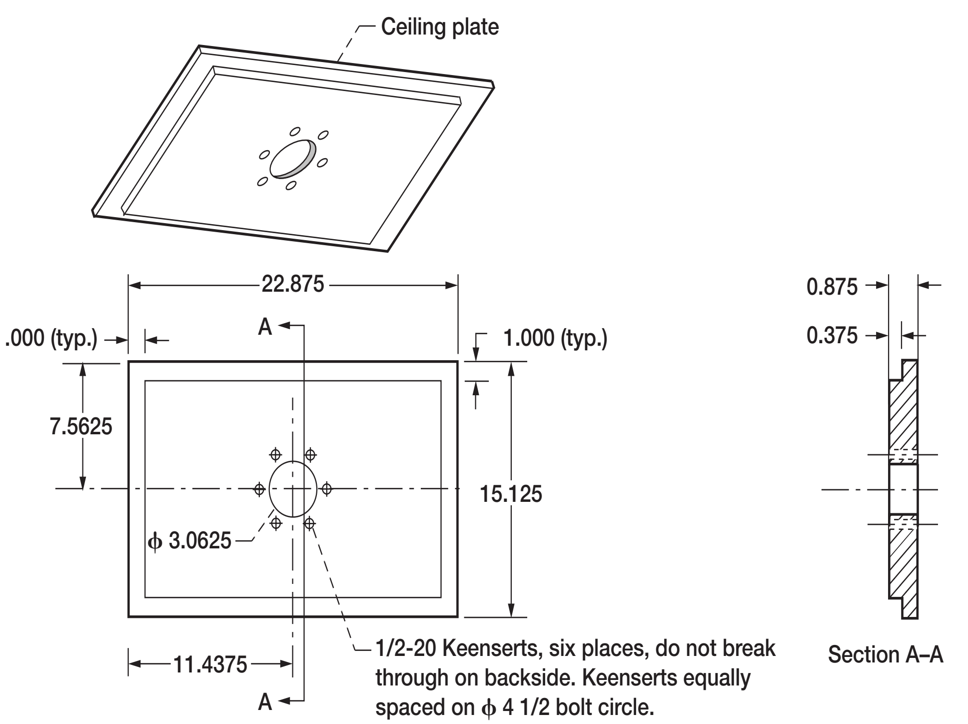
Figure 21.—Model support pivot pins on IRT ceiling. Pin material is 7075–T6 aluminum. All dimensions are in inches.




BUSHING DETAILS

| Item | D1(±0.005) |
|---|---|
| A | 2.530 |
| B | 2.030 |
| C | 1.530 |
| D | 1.280 |
| E | 1.030 |
| F | 0.780 |
| G | 0.530 |

Figure 22.—Model support pivot bushing in IRT ceiling. Bushing material is 7075–T6 aluminum. All dimensions are in inches; typ. is typical.




igure 23.—Ceiling plate for mounting model support pivot pins and bushings. Ceiling plate material is 6061–T6 aluminum. Standard tolerances are ± 0.010 in. All dimensions are in inches; typ. is typical.

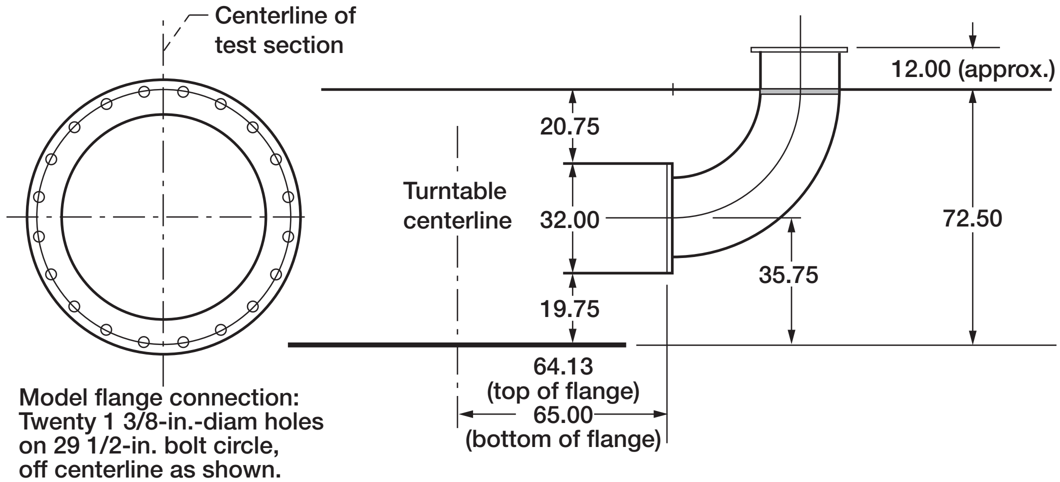



Figure 24.—IRT test section showing location of 24-in. standard steel flange and elbow for connecting inlet models to exhaust system. All dimensions are in inches.

### 3.4 Engine Inlet Model Exhaust System

Vacuum pumps that provide an exhaust flow for engine inlet models in the IRT are located in the central altitude exhaust facilities at Glenn and thus are a shared resource that must be scheduled weekly. Requests for services are submitted on the Thursday prior to the test week.

The IRT exhaust system is used to simulate internal flows for inlet models. It consists of a series of duct expansions and contractions that vary in diameter from 24 to 36 in. The geometrical relationship between the test section turntable and the altitude exhaust piping is presented in figure 24. The flow rate of the system is measured by a venturi installed in the facility ducting. Three venturi diameters are available: one is calibrated for 0.1- to 3-$lb_m$/s flow rates; the second is calibrated for 3- to 20-$lb_m$/s flow rates; and the third is calibrated for 15- to 85-$lb_m$/s flow rates. The smallest diameter venturi is installed in a 12-in.-diameter pipeline that runs off and is parallel to a 36-in.-diameter pipeline. Either of the other two venturis can be installed directly in the 36-in.-diameter line.

The IRT project engineer can discuss with the tunnel user the flow equations that are used to compute exhaust system flow rates. The flow is regulated by a pneumatic butterfly valve that is controlled by the facility computer. In each system the butterfly valve is placed in the pipeline between the model and the venturi. The exhaust pipe flange is skewed in the vertical plane (see fig. 24), and will require a flexible connection between the model exhaust and the inlet to the steel elbow.

### 3.5 Force-Balance System

The IRT houses an external force-balance system that can be installed upon request to measure aerodynamic loads acting in a horizontal plane on the test model. The model must be attached to the turntable in the floor of the test section. The model may also be attached to a support in the ceiling if additional strength and/or rigidity are required. The balance components mounted under the turntable form the lower platform balance, and those in the ceiling structure make up the upper bearing balance. Loads transmitted to the floor and ceiling attachments are measured and recorded independently; this

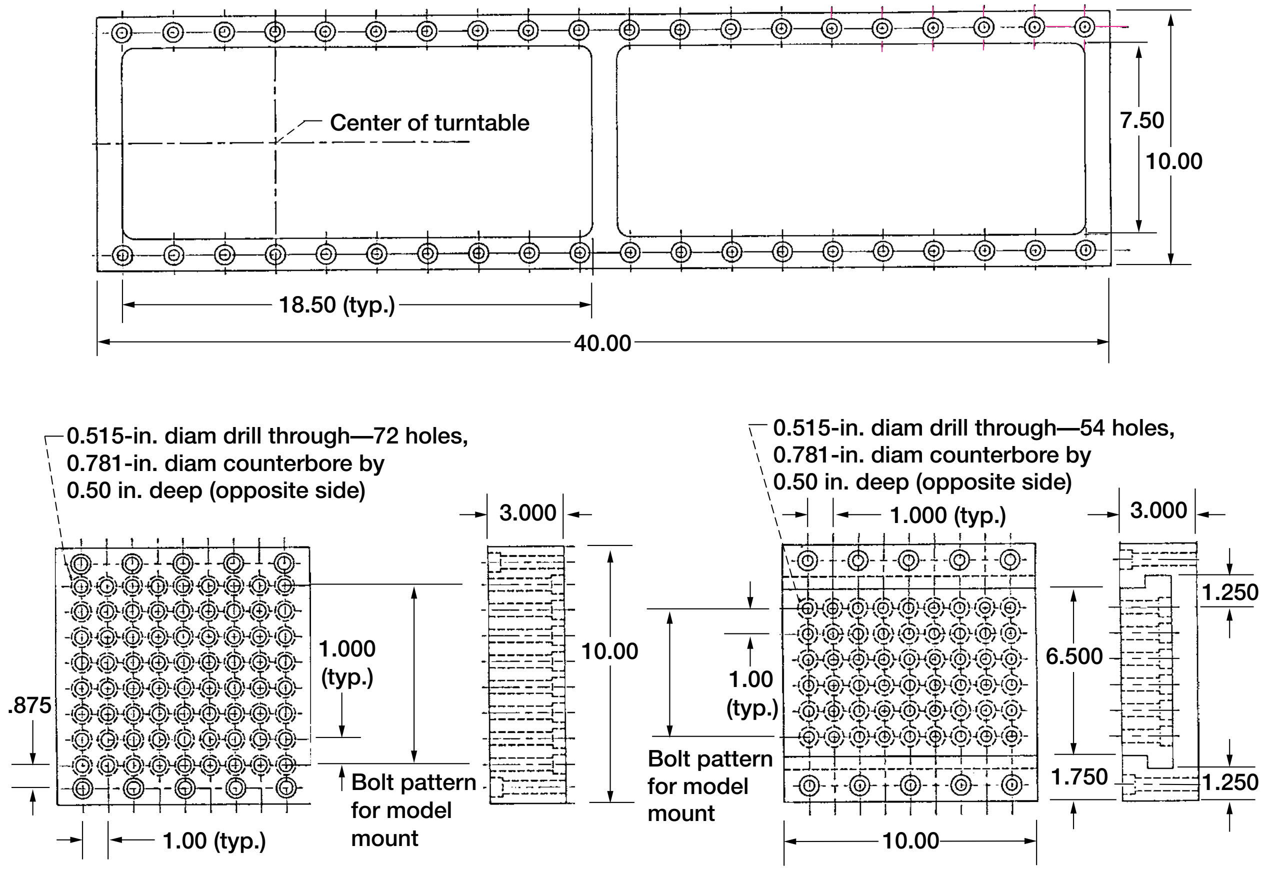



Figure 25.—IRT force-balance lower model mount. All dimensions are in inches; typ. is typical.

allows users to analyze load reactions separately when a model is supported at both its upper and lower ends. Figures 25 to 27 provide details of the upper and lower attachment pads used to secure the model.

Five load reactions can be measured with the IRT force-balance system. The lower platform balance can measure two force components on the floor mount, which are parallel to and normal to the horizontal centerline of the turntable, as well as one moment on the floor mount about the vertical centerline of the turntable. The upper bearing balance can measure two force components on the upper mount, which are parallel to and normal to the direction the horizontal centerline of the turntable. Since the model is free to rotate about the vertical centerline of the turntable in the upper bearing balance, there is no moment reaction at the upper mount. As the turntable is rotated to produce different angles of attack on the model, the directions of the measured loads also rotate, remaining parallel to and normal to the turntable centerline.

For example, if an airfoil model is mounted in the test section with its span vertical and its chord parallel to the test section longitudinal centerline, the balance system can measure not only the normal and chordwise reaction forces independently at the lower and upper ends of the airfoil but also the pitch moment on the airfoil at its lower end. Table IV lists the load capacities in the normal, chordwise, and pitching moment directions for the lower and upper mounts in the force balance.

The full-scale ranges of individual load cells within the balance system can be selected to provide the required sensitivity to the user's expected loads, within the total capacities listed in table IV. All load-cell output signals are collected through the Escort D data system for online and/or postprocessing analysis. The IRT facility engineer is available to answer any questions that the tunnel user may have regarding

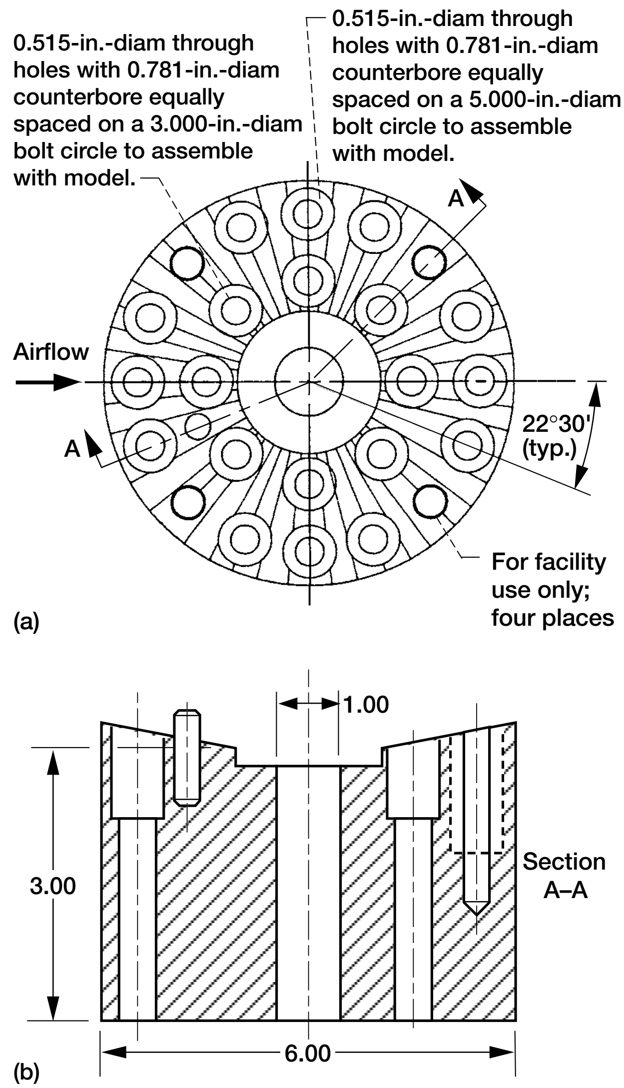



Figure 26.—IRT force-balance upper model mount. (a) Top view. (b) Side view. All dimensions are in inches; typ. is typical.

installation of the model and the force balance. It should be noted that measurement accuracy on lift and drag forces and on pitching moment depends on wall effects, model size, model gaps between floor and ceiling, and aspect ratio of the model.

### 3.6 Wake Survey System

The function of the wake survey system is to sample the total- and static-pressure profiles directly downstream of the test section model. This assembly consists of a pitot-static pressure probe attached to a low profile drive system that traverses across the tunnel floor. The pitot-static probe is positioned on the tunnel centerline, 36 in. above the tunnel floor. The probe has a total sweep of approximately 86 in. as measured from the IRT test section south wall towards the test section north wall. The drive system extends the full width of the IRT test section (108 in.) and consists of a Thomson ball screw unit, a 15:1 gearbox, and a brushless servomotor. The survey assembly can be used to monitor pressure levels across the tunnel and has the capability to be programmed for stepped-position or constant-velocity sweeps.

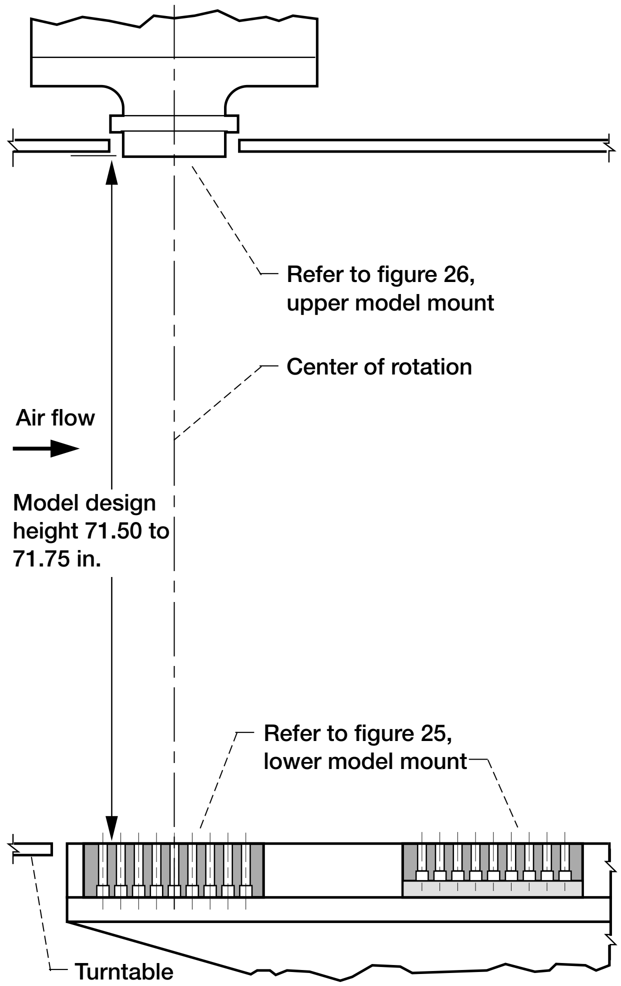



Figure 27.—IRT force-balance mounting pads (side view).

TABLE IV.—CAPACITIES OF THE IRT FORCE-BALANCE SYSTEM FOR TWO MODEL-MOUNTING METHODS

| Load component | Capacity of mounting method | |
|---|---|---|
| | Lower mount | Upper mount[a] |
| | Force, $lb_f$ | |
| Normal (lift) | ±10 000 or ±20 000 | ±10 000, ±2000, or ±1000 |
| Chordwise (drag) | ±1000 | ±1000, ±500, or ±90 |
| | Moment, ft-$lb_f$ | |
| Pitch moment | ±25 000 or ±50 000 | 0 (bearing) |

[a]Three combinations of load cells are available at the upper mount to measure normal (lift) and chordwise (drag) forces. These combinations are as follows: (±10 000 and ±1000) $lb_f$, (±2000 and ±500) $lb_f$, or (±1000 and ±90) $lb_f$.

TABLE V.—MAXIMUM CAPACITIES OF FACILITY AND PORTABLE POWER SYSTEMS

| Voltage, V | Phase | Frequency, Hz | Current, A |
|---|---|---|---|
| Facility | | | |
| 440 | Three | 60 | [a]1000 |
| [b]208 | Three | 60 | 225 |
| 115 | Single | 60 | 250 |
| Portable | | | |
| 120/208 | Three | [c]400 | [d]175/60 |
| 115 | Single | 400 | 30 |
| 0 to 40 | ---- | ---- | 100 |
| [e]0 to 80 dc | ---- | ---- | 250 |
| [f]0 to 312 ac/dc | Three | 0 to 5000 | 19 |
| [e]400 ac variable | Single | 60 | 180 |

[a]Amperage depends on other auxiliary systems that may be in use. This 440-V system supports the four electrically heated test section windows in the south control room and the three electrically heated windows in the north control room (sec. 2.3) at 15 A each; the electric air heater (sec. 3.1) at 100 A; a 28-V dc inverter at 30 A; and a 115-V, 400-Hz converter at 130 A.

[b]Can be used as single-phase, 208-V system or single-phase, 110-V system.

[c]System is 400 V, 60 Hz converted to 208 V, 400 Hz; 15-kW capacity on motor generator.

[d]If generator used at another Research Testing Division facility is available, then 175 A can be provided for IRT test.

[e]440-V, 60-Hz to 28-V dc inverter.

[f]Elgar programmable power supply.

### 3.7 Model Electrical Power

The descriptions and maximum capacities of the power systems available to the tunnel user are listed in table V.

## 4.0 Instrumentation

Instrumentation in the IRT may be categorized as (1) facility instrumentation or (2) model instrumentation. The facility instrumentation data necessary to operate the tunnel are normally displayed on the WDPF graphic pages. Data such as tunnel velocity, motor revolutions per minute, average tunnel temperature, model angle of attack, spray-bar control parameters, and other auxiliary systems information are primarily monitored by the tunnel operators. Hard copies of display pages showing the values of these parameters are available on request. In addition, most of the facility instrumentation signals are duplicated and available at the patchboard of the Escort D data-acquisition system. These parameters can be included in the scan pattern of specific data software modules and, thus, be recorded as part of the overall test plan.

Model instrumentation is handled by the Escort D data-acquisition system, which has a capability of 192 analog input channels. In the standard software module, 92 channels are reserved for facility instrumentation, thereby leaving 100 user-defined channels for the model. If all 92 channels are not needed, the remainder can be repatched and used for model data. Any combination of thermocouples, pressure transducers, or any other analog voltage signal devices (10-V dc maximum) are compatible with the Escort D system and can be assigned to these channels. Twenty signal conditioners are readily accessible if needed for any of the Escort D inputs.

Special model pressures that must be read numerous times and/or must be highly accurate are measured with the ESP system. This system can read 224 model pressures (with 215 data channels, 7 check pressure channels, and 2 channels dedicated to a pitot-static probe that is used to measure pressures that are used to calculate model pressure coefficient curves (see section 4.2)), and it can be tied into the Escort D data system. These channels are in addition to the 192 analog input channels previously noted.

All data going to the Escort D system can be permanently recorded on a data collector for further offline processing. An option to preserve data on magnetic tape for future reduction by the tunnel user can be exercised at the completion of the test. Specific details of the Escort D and ESP systems are given in section 5.1, Data Acquisition.

### 4.1 Temperature Measurements

Facility air temperatures are measured at corners C and D of the tunnel (see fig. 2) by means of total-temperature probes mounted on the leading edges of the turning vanes. Corner D of the tunnel has an array of 24 type T thermocouples whose readings are mathematically averaged to represent the total temperature of air in the test section. Readings from a duplicate array of thermocouples are available to users through the Escort D system. Each spray bar is also instrumented with thermocouples to measure both air and water temperatures. These facility temperatures are displayed on the WDPF system. The thermocouple measurements have an uncertainty limit of ±0.41 percent for total temperature equal to –0.7 °F in corner D. The uncertainty calculations are discussed in appendix B and “Uncertainty Analysis for Total Temperature, and Total and Differential Pressure Measurements in IRT Test Section.” (R.H. Soeder and P.Z. Blumenthal, 2002, NASA Glenn Research Center, Cleveland, OH, Preliminary Information Report #082). Model temperatures are measured by using type T thermocouples that reside in existing interconnect boxes. The interconnects can be accessed from the top hatch of the test section or through the floor of the test section underneath the turntable. Full-size, three-prong male connectors are needed to fit into the interconnects. An additional 96 thermocouples can be accommodated by two 48-channel, 150 °F reference ovens. These ovens can be accessed only from the bottom of the test section. Oven inputs require no connectors and handle type K, T, J, or E thermocouples.

### 4.2 Pressure Measurements

The two facility pitot-static probes measure total pressure with a 0- to 20-psia transducer and measure the difference between the total and static pressures with a 0- to 3.0-psi differential-pressure transducer. These pressure measurements are input to the WDPF and Escort D systems and, together with the test section temperature, are used to calculate the tunnel test section velocity. The uncertainty limit of the total-pressure transducers is ±0.10 percent of full scale and the uncertainty limit of the differential-pressure transducers is ±0.16 percent of full scale. The uncertainty calculations in total and differential pressure, the equation used to compute the test section velocity, and the uncertainty in that measurement are also discussed in Preliminary Information Report #082 and in appendix B. A third facility pitot-static probe is mounted in the test section, and the pressure measurements are recorded by an ESP module and are sent to the Escort D system. These pressure data are used to compute model pressure coefficients.

The facility spray-bar air pressure and the difference between water and air pressures are displayed on the WDPF and the Escort D systems. The air pressures are held to within ±0.1 psig, and the pressure differences are held to within ±2 percent or ±2 psid (whichever is greater) of their respective setpoint values in the steady-state spray mode. There are a total of seven 32-port ESP modules that can be used to measure research pressures. Port 1 of each module is reserved for a check pressure to verify proper operation of the system. Ports 2 and 3 of module 1 are reserved for a third facility pitot-static probe which leaves 215 ports (i.e., channels) available for research measurements. Five of the seven 32-port ESP modules have a ±5 psid transducer for each port (channel). There are 153 channels for research measurements, 5 channels for check pressures, and 2 channels for facility pressures with an accuracy specified as ±0.1 percent of full scale. The transducer typical operating range is from 0 psid (the transducer reference pressure is atmospheric) to –5 psid. Two of the seven 32-port ESP modules can be used for measuring model pressures or can be used to measure pressures associated with the heated air system (see sec. 3.1) and the engine inlet model exhaust system (see sec. 3.4). Port 1 of each module is reserved for a check pressure, which leaves 62 channels available for use with either model pressures or the above noted support service systems. Each module port (channel) has its own ±30 psid transducer, with an accuracy specified as ±0.1 percent of full scale.

## 4.3 Model Attitude

A model mounted on the test section turntable can be rotated ±20° about the test section vertical centerline. Angular data can be recorded on the WDPF and the Escort D systems; the accuracy of this measurement is ±0.1°. Turntable rotation in excess of ±20° can be accommodated with minor hardware changes to meet the user's requirements. This point should be discussed with the IRT project engineer.

## 4.4 Photographic Documentation

Video and still photographic equipment may be used to record visual data and to document instrumentation. The cameras available for use in the IRT are discussed in reference 15. Photographic equipment may be mounted in or on the tunnel ceiling hatch panels or in the control-room windows (see fig. 13 for arrangement of panels in the hatch cover). Photographic equipment may also be carried into the test section between runs. If necessary, the acrylic windows can be replaced with other materials (see sec. 2.3). Alterations to the hatch cover need to be discussed with the facility engineer as far in advance of the test as is possible.

The Glenn Imaging Technology Center has the expertise, equipment, and experience to meet the imaging needs of tunnel users. Professional photographers and videographers can provide details of available hardware, installation, or other aspects of the test. Scientific imaging specialists use a variety of imaging technologies as problem-solving tools for data acquisition and analysis.

The Imaging Technology Center recommends that imaging requirements be discussed early in the project planning process to ensure the availability of expertise and equipment. The following paragraphs provide an overview of still imaging, video imaging, high-speed imaging, digital still imaging, and image archiving.

***4.4.1 Still imaging***.—The IRT facility has both Nikon F3 and F4 cameras (Nikon Corporation, Tokyo, Japan) available with standard databack (a feature that allows exposures to be labeled with the time, date, or other information) or, if necessary, a 250-exposure magazine. Both cameras are available with flash equipment. The exposure time of the Nikon F4 can be as fast as 1/8000 s, and the continuous motor drive rate is 5 frames per second.

Depending on the needs of the test, the ambient lighting in the tunnel may be supplied by quartz halogen lamps with a color temperature of 3200 K or HMI lighting (hydrargyrum medium-arc-length iodide lamps) with a color temperature of approximately 5500 K (daylight). In most circumstances, flash is recommended.

The focal lengths of available Nikon lenses range from 35 to 400 mm. The 60-mm macrolens has been the most popular both for general overall shots and for closeups of icing details. A 17- to 35-mm zoom lens for extreme wide angle shots when using a film-based camera is also available.

***4.4.2 Video imaging***.—A variety of black and white and color video cameras are available to IRT customers. Most of the cameras operate at 30 frames per second and utilize C-mount lenses. Cameras can be outfitted with a variety of different lenses including macro, zoom, wide-angle, and telephoto focal lengths. Standard Nikon lenses for 35-mm, single-lens reflex cameras can also be used with available adapters.

Remote control units are installed in rack-mounted cabinets in the IRT control room and include pan and tilt controls, videotape recorders, and monitors. Status monitors can display signals from up to eight video cameras. Six VHS/S–VHS VCRs are available to record signals from any of the video cameras installed. In addition, a Betacam SP (Maxell Corporation of America, Fair Lawn, NJ) video tape recorder is available for tunnel users who desire maximum image quality.

All video camera signals can have time-code information SMPTE (Society of Motion Picture and Television Engineers) and IRIG–B (Inter-Range Instrumentation Group standard time distribution signal) recorded onto the tape. This is useful when comparing different views or tapes of the same event. A character generator is also available for inserting text onto the video image to title different views, name test runs, or to note test conditions. IRT parameters such as airspeed, angle of attack, and temperature can also be superimposed on the recorded video image.

A video camera mounted in the well above the test section is used to monitor the model for safety. However, tunnel users can also have this signal routed to one of the VCRs for use as data. In addition, small black and white cameras (depending on lighting conditions) can be gated down to an effective shutter speed of 1/10 000 s. Wiring in the facility makes it possible to locate black and white and color cameras in any existing test section window.

High-resolution CCD (charged coupled device) video cameras are also available and are especially suited to recording high-magnification closeup images. In previous tests, this equipment has been used to document the accretion of ice in a very small area.

Finally, a Xybion camera (Xybion Corporation, Cedar Knolls, NJ) is available, which has both extremely short-duration gating capabilities (10 ns) and low-light sensitivity. Additional information on these cameras can be found in reference 15.

A high-definition video system is also available. The high resolution of this system enables tunnel users to view tests, models, and ice accretion in stunning detail, rivaling the images in 35-mm motion picture film. The resolution of the CCD imager is 1920 horizontal lines by 1720 vertical lines. This system will record images at variable frame rates from 4 to 60 frames per second in a progressive scan format. The images are recorded in 16:9 aspect ratio (rectangular) as opposed to the 4:3 aspect ratio of current analog video cameras. The high-definition video system also features extreme low-light sensitivity, and the film has an equivalent ISO/ASA (International Organization for Standardization/ American Standards Association) speed of 1000. Camera setup parameters can be modified and stored in the camera memory, enabling the user to customize the camera output to the needs of a particular test. The parameters can be recalled easily from memory, ensuring consistency in the camera setup throughout the duration of the test.

Tunnel users can frame-grab individual images during the test or posttest (high-definition resolutions) and convert them to any popular image file format such as TIFF (Tagged Image File Format bitmap), PICT (MAC Picture Image file), or JPEG (Joint Picture Experts Group), etc.

In addition, tunnel users can review the videotapes with a high-definition videocassette recorder available in the IRT, transfer the images to VHS/S–VHS, and have them encoded to a DVD disc.

***4.4.3 High-speed imaging systems***.—Several systems are available to meet the high-speed imaging requirements of tests conducted in the IRT. A Kodak Ektapro Motion Analysis system (Eastman Kodak Corporation, Rochester, NY) employing an image intensifier can capture black and white images at speeds up to 1000 frames per second, with interframe times down to 10 μs. Total recording duration is 4.9 s when the camera is being operated at 1000 frames per second. The images are stored in electronic memory and can be downloaded to a VCR, or the images can be stored for posttest analysis. However, the resolution of this system is lower than that of conventional video cameras. A Kodak HG–2000 high-speed imaging system is capable of capturing high-speed black-and-white images at rates up to 200 frames per second. The images are stored as individual TIFF files and can also be converted to video or to digital movie files such as QuickTime (Apple Computers, Inc.), AVI (Microsoft (Microsoft Corporation, Redmond, WA) audio video interleaved file format for a windows movie), MPEG–1 (Motion Picture Experts Group) or MPEG–2 (the file format used for DVD).

Other high-speed imaging systems are available upon request, including 16-mm color film (at frame rates up to 100,000 frames per second).

***4.4.4 Digital camera***.—A Kodak professional DCS 620 digital camera is available to facility customers during IRT experiments. The camera is an integration of Nikon and Kodak technologies.

The digital images produced by the Kodak DCS 620 have a resolution of 2 million pixels with an aspect ratio of 2 to 3. The camera can utilize film with an ISO rating of 200 to 1600, image quality can be enhanced through the use of an anti-aliasing filter to minimize color aliasing or an infrared filter to improve image quality. A large, wide, cross array with a five-area autofocus sensor can cover a wide horizontal and vertical array. An ac battery charger/adapter is included with the system.

The Kodak DCS 620 system can capture images at 0.5 frames per second continuous frame rate with a 3.5 frames per second burst for 12 images. The camera also contains a GPS (Global Positioning System) option which determines the latitude and longitude of the camera.

Camera image management permits storage on personal computer (PC) cards and JPEG file processing allows the user to finish files on the camera. The camera has the ability to recover deleted images. Users can transfer images from the camera to a host computer by connecting it to a Macintosh (Apple Computers, Inc., Cupertino, CA) or a computer that supports Microsoft Windows. Additional camera features include a camera top status LCD panel which includes shutter speed, aperture setting, exposure compensation information, and autofocus mode. Also, there is a camera image LCD panel where the user can perform functions such as setting the date and time, formatting a PC card, deleting images, displaying a histogram and specifying camera properties. A camera back status LCD panel displays camera and digital information. Section 4.4.1 stated that a 17- to 35-mm zoom lens is available for still camera use. It should be noted that the use of this lens on the DCS 620 digital still camera is constrained by the chip size in the camera body. The lens is effectively only a 28 mm equivalent on the DCS 620 camera.

***4.4.5 Image archiving***.—The Imaging Technology Center has a variety of tools to assist users in cataloguing and archiving their image data. Images can be made available on 8- by 10-in. photographic prints; catalogued on CDs; or converted to QuickTime, AVI, or other digital media files. In addition, images and data can be recorded onto DVD and made available as DVD-video, DVD–ROM, or a Hybrid DVD. The IRT project engineer can arrange a meeting between the tunnel user and the Imaging Technology Center staff to discuss these issues.

### 4.5 Standard Flow Visualization Techniques

Common techniques to facilitate flow visualization, such as coating the model with fluids or chemicals or employing optical methods, may be used in the IRT. Coating the model with a viscous fluid or paste, or spraying the model with a fluorescent oil before a test run is permitted; however, such model coatings must be applied by the tunnel user.

Any chemicals used to produce a visual effect in the tunnel must be nontoxic to personnel and must be noncorrosive to the facility. Documentation attesting to the benign nature of the chemical is required. Optical devices for flow visualization may be mounted in the test section hatch cover, but these must be supplied by the tunnel user. All chemical use must be approved by the Glenn Environmental Management Office. Some chemical use may require a safety permit, which can take up to 2 months for approval.

### 4.6 Laser Sheet Flow Visualization

The laser sheets used in the IRT facility are produced by a 15-W, argon-ion laser. The laser and an attached optical box are placed on a laser table located on the third floor of the IRT balance chamber. Since the balance chamber may experience drops in pressure of up to 2 psi, the laser is housed in an environmentally controlled box that keeps the laser tube at a constant pressure. The optical box attached to the laser is made of dyed acrylic sheet, which allows the observers to see the optical components inside the box. The laser beams, which operate in the 460- to 540-nm wavelength, cannot be seen. Fiber-optic cables from the optics box extend to a laser-sheet-generating optical head located on a traverse mechanism mounted to the overhead hatch of the IRT test section. The lenses in the optical head produce a vertical sheet of light that can be positioned along the longitudinal centerline of the test section in order to study the flow at various longitudinal locations of the model.

The flow field can be viewed by using three video cameras. One camera, located on the hatch (which is on the third floor of the facility balance chamber), provides an overhead view of the laser sheet. A second video camera, located in the auxiliary control room, permits a side view of the laser sheet. A third video camera, placed upstream of the model, provides a frontal view. Questions about the positioning of the video cameras can be discussed with the IRT project engineer and the facility electrical engineer.

During testing, the windows in the primary control room are covered with a dyed acrylic sheet that absorbs the energy of the laser beam and protects the tunnel operators and tunnel users from the laser light. These windows make wearing safety goggles in the primary control room unnecessary; therefore control-room operations, including observation of the model, can continue as usual. Safety laser goggles are required to be worn by observers in the secondary control room or overhead above the ceiling hatch.

### 4.7 Infrared Thermography System

The IRT has an AGEMA infrared system (FLIR Systems, Inc., Boston, MA) for tunnel users who require thermal measurements and analyses. The infrared system has three different lenses, with fields of 10°, 20°, and 40°. The lens used for a test is coupled to a scanner module with two built-in temperature references (microblackbodies). The scanner accuracy is ±1.8 °F, and the sensitivity is 0.18 °F at 86 °F. Optical stability is achieved through precision, diamond-turned optics, and mechanical stability is achieved by housing all optical components in a single structural element.

The signal is digitized in the system scanner prior to being delivered to the system controller. This feature eliminates the risk of data corruption normally associated with analog systems. The 12-bit data acquisition and storage ensures that all information required for full-image analysis is obtained and retained, regardless of the system settings at the time that measurements are taken. The system scanner is coupled to the system monitor, keyboard, and mouse. The monitor, in turn, is coupled to the system controller and video printer.

Data acquired by the system scanner are transferred to the system controller, which contains a built-in local area network (LAN) interface through which the images can be transferred to a PC or other workstation for further analysis or archiving.

The lens and scanner are portable and may be placed at various locations throughout the test section of the tunnel. The system is remotely controlled from the north (secondary) control room. Tunnel users should indicate the need for this equipment as early as possible because it is occasionally lent out to other facilities.

Examples of the system's use include measuring the temperature change associated with the impingement, runback, and freezing of water on an airfoil; monitoring deicing heater zone warming; and detecting the transition between laminar and turbulent air flow.

# 5.0 Data Processing

## 5.1 Data Acquisition Hardware

Escort D, which is supported by the Glenn Information Services Division (ISD), is the current facility data-acquisition and display system. This system is flexible enough to accommodate changes in the experiment. It can also be a node in either a large, distributed network system or a stand-alone computer data system. It offers high resolution and fast update rates for cathode ray tube displays. Escort D is a minicomputer-based, real-time, data-acquisition and display system. It is generally applicable to steady-state tests and (in some cases,) slow transient tests with periods of 1 s or more. The Escort D system contains a superplex data-acquisition feature that permits sampling of a subset of data channels at a faster rate than the basic update rate. The subset of data channels is sampled repeatedly at specified time intervals, all within one scan of the data. This repeated scan (the subset) is referred to as the "fast scan;" the nonrepeated part of the entire scan is called the "regular scan." Typically, the superplex data-acquisition feature is applied with moving-probe data. The moving probe is typically placed downstream of the model to sample the flow field across the test section (see section 3.6, Wake Survey System).

Analog data from an experiment are digitized and then acquired by a minicomputer located in the IRT control room. These data are then transmitted through a network link (for unclassified projects) to a data collector in the Research Analysis Center (RAC). Data from sensitive projects are stored on the control-room minicomputer. Real-time processing tasks include scheduling a data-acquisition cycle, converting raw counts to engineering units, performing online calculations, updating the facility display lists, and formatting the data for archival recording on a data collector. The minicomputer also distributes the processed data to the various displays and output devices in the control room. Figure 28 shows the flow of information schematically. Communication takes place over an Ethernet data link. Update time for a standard-length program display is 1 s. Data can be acquired and processed with a standard data software module or software specifically designed for a particular task.

Tunnel users have the option of furnishing their own data-acquisition and data-processing equipment or providing model instrumentation compatible with the Escort D system. Data-acquisition needs should be specified during a pretest meeting between the tunnel user, the IRT facility manager, the IRT project engineer, and the IRT electrical engineer.

***5.1.1 Types of instrumentation***.—Thermocouples, pressure transducers, or any other analog voltage signal devices (10 V dc maximum) are compatible with the Escort D system. Turbine-type flowmeters with frequency outputs are handled by using frequency-to-direct current converters.

***5.1.2 Electronically scanned pressure (ESP) system***.—Steady-state model pressures that must be highly accurate and/or must be read repeatedly are usually measured with the ESP system. This system uses plug-in modules, each containing 32 individual pressure transducers that can be addressed and scanned at a rate of 10 000 ports per second. A unique feature of the ESP system is its ability to apply a three-point pressure calibration to each port transducer. The three calibration pressures are measured with precision digital quartz transducers. The standard calibration interval of all ESP transducers is every 7200 cycles (approx. every 2 h), but the time interval can be varied if required. The

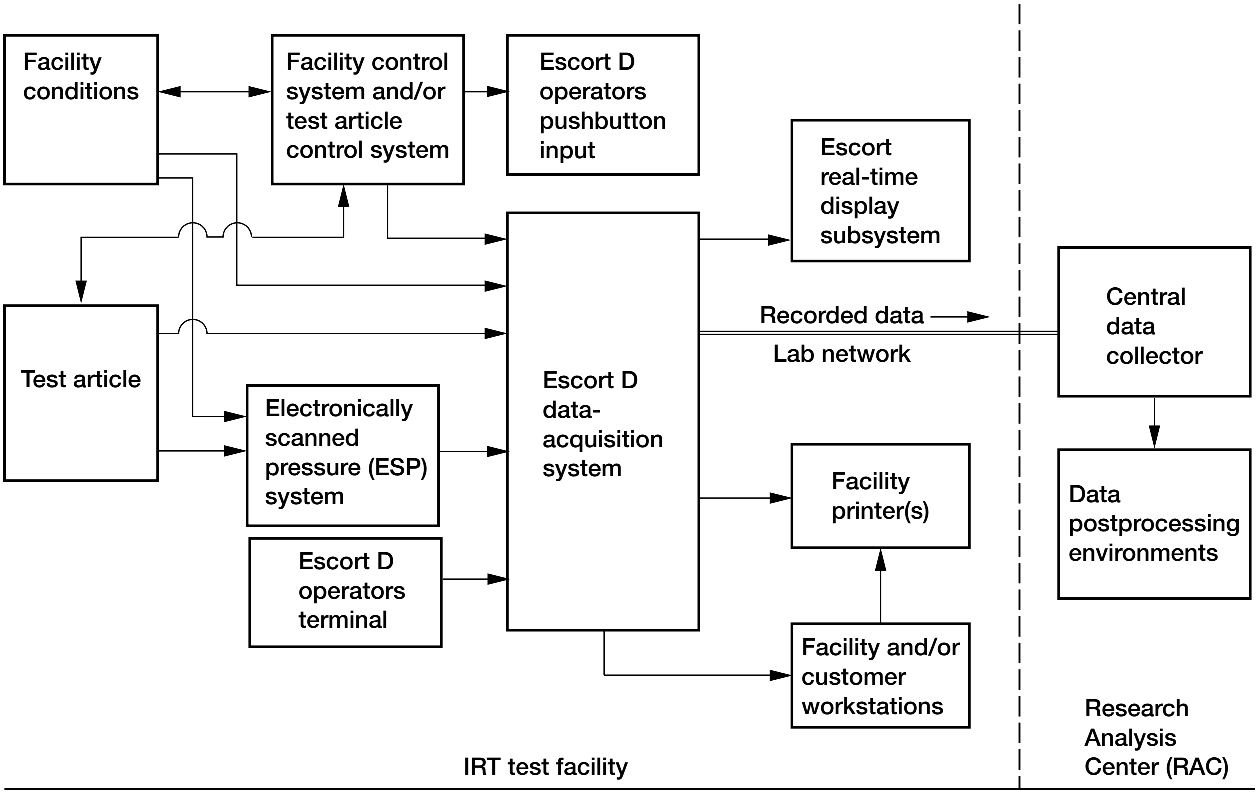



Figure 28.—Flow chart of IRT data system.

online calibration of all port transducers ensures that errors are not greater than ±0.10 percent of full scale.

The IRT has five 32-port (±5 psid) ESP modules, for a total of 160 pressure channels. One port per module is used for a check pressure, which leaves 31 channels per module or a total of 155 channels for test data. An online graphic display of each channel is programmed into a PC. Each cycle of pressure readings can also be digitally displayed when a prompt appears on the screen. A continuous cyclic update can be digitally displayed by linking the ESP system to the Escort D data system.

***5.1.3 Real-time displays***.—The standard general-purpose Escort D program uses 256 channels, which can be displayed in real time as pages on monitors in the control room. Page 1 of the output is an overall display directory. Pages 2 to 10 are dedicated to tunnel operating conditions and auxiliary systems, such as tunnel flow conditions, wake survey probe, force-balance system, altitude exhaust and heated air systems, and spray bar system. Pages 11 to 199 are available for user displays. The format for user displays is 25 lines with 80 characters per line. Line 1 is reserved for the standard Escort D header. Users laying out values horizontally on one line should allow three spaces between parameters for flags that may appear when a numeric value is out of range. Modifications and additional displays can be created in the control room with the aid of the IRT electronic engineer. Each display is updated every 1 s.

Another feature of the IRT data system is online real-time plotting. The plots requested most by customers are measured $C_P$ (pressure coefficient) versus x/c (airfoil thickness/chord length) superimposed on a plot of theoretical $C_P$ versus x/c. The theoretical data are supplied by the user preferably in a Microsoft Excel spreadsheet format. Other variables such as temperatures can also be plotted versus time. Plotting routines can also be modified or newly created in the control room with the assistance of the IRT electronic engineer. Pages 501 to 749 are available for user plots as per Escort D software.

## 5.2 Data Collection

When the standard data software module is installed in the Escort D system and the “Data Record” button is activated, all data channels are scanned once, saved on the data collector, and assigned a unique reading number. Data can be processed offline by using the Center’s mainframe computer to provide the desired output. In addition to the “Data Record” button, which records a snapshot of all the data for that instant of time, there is a “Cyclic Record” button, which continuously records all data at predefined time intervals. The default time interval is 1 s. There are two buttons that can be programmed to increase the recorded time interval. For example the first button can be programmed for a 3-s interval. When this button is pressed, a message on a control-room monitor indicates that the recording interval is 3 s. Whenever the “Cyclic Record” button is pressed, the recording of all data will then occur every 3 s. In addition a second button can be programmed for another time interval, such as 5 s. Because of the large amount of cyclic data being collected, a limit of 600 cycles is imposed on this type of recording. To stop and save the cyclic data before the 600 cycle limit is reached, the user presses the regular “Data Record” button. An “Abort” button is available if the data being recorded are in question and do not have to be saved. Once the user becomes familiar with the recording procedure, the entire operation is easily accomplished.

## 5.3 Data Output

The customer may require only specific output parameters from all the data channels in the scan pattern that are automatically recorded. A customized output file can be generated to meet the user’s needs. The output is an ASCII (American Standard Code for Information Interchange) text file arranged in a spreadsheet format and stored on the Escort D system. The file contains a user-defined header with user-defined names and engineering units followed by the values of recorded data. The first few columns show the unique reading number, the scan cycle, the run number, the date, and the time of day followed by the user’s requirements. Appendix C presents a sample of a customized Escort D output file and a symbol list of parameters that are listed in the table.

Usually the output file is generated at the end of each test period and the FTP (File Transfer Protocol) is then transferred to the facility workstation, where the customer can review the data. From the workstation all data can be written to a CD or floppy disc, depending on the size of the file. If the users prefer to use their own computer, provisions can be made to accomplish the data transfer. The user’s computer should be equipped with an Ethernet network interface and accompanying TCP/IP (Transmission Control Protocol/ Internet Protocol) software.

## 5.4 User Workstation

The IRT south control room (see fig. 1) contains a PC currently running with the Windows 2000 operating system. The workstation is generally used by facility customers for postprocessing test data that have been transferred from the Escort D system. To access this workstation, users need to obtain a guest ID from the facility electronic engineer, who will set up a guest account with access limited to the user’s data, including digital photographs. The workstation consists of a monitor, chassis, keyboard, mouse, and power and monitor cables. The PC has a rewritable CD drive (compact disc, read and write) as well as Microsoft Excel and Word application programs. Other software may be added when needed, as determined by NASA research engineers. The workstation shares a black and white postscript printer with the Escort D system during facility testing. The printer can also be shared with any customer's PC.

The workstation in the south control room can be used in conjunction with a still imaging Nikon F4 camera that has a 17- to 35-mm macrolens. A detailed description of this camera and other lenses available from the Imaging Technology Center is presented in section 4.4.1. It should be noted that Glenn does not provide film for this camera. A Kodak DCS 620 digital camera can also be used in conjunction with the workstation. This camera has a 17- to 35-mm lens. A detailed description of this digital camera and the lens is presented in section 4.4.4.

### 5.5 Facility Image Recording Equipment

Tunnel users have access to six Panasonic industrial S–VHS video tape recorders (VTRs) for use with the photographic equipment described in section 4.4. These VTRs provide over 400 lines of horizontal resolution in the S–VHS mode because of the increased bandwidth of the format's luminance channel (1.6 MHz). The IRT project engineer can also direct tunnel users to a member of the Imaging Technology Center at Glenn to obtain more detailed information on this equipment.

## 6.0 Pretest Requirements

Glenn schedules the IRT for continuous testing throughout the year. A summary of the procedure to obtain tunnel test time is contained in appendix D. Users are advised to contact the IRT facility manager (see appendix A) at least 1 yr in advance of the desired tunnel test time. Early notification will allow the facility manager and appropriate IRT personnel to review the proposed model design and to ensure compatibility with the tunnel test section. Non-NASA users should send a formal letter of request for tunnel use to the IRT facility manager at Glenn. The following pertinent information is required in the request: (1) a brief description and purpose of the test, (2) the Glenn point of contact, if any, and (3) a request for test time, including the approximate dates and duration.

On receipt of a formal request for tunnel test time, the IRT facility manager will review the proposed project. If the project is accepted, a test agreement will be prepared and sent to the requester to be signed and returned (non-NASA requesters only). The test agreement outlines the legal responsibilities of both Glenn and the tunnel user during the time the project is active at the Center, from model arrival to model return.

The four types of IRT test agreements are as follows:

(1) NASA test program
(2) NASA-industry cooperative program (nonreimbursable Space Act Agreement)
(3) Other U.S. Government agency agreement programs (reimbursable or nonreimbursable interagency agreement)
(4) Industry proprietary or noncooperative program (reimbursable Space Act Agreement)

The requester fills out the pretest survey and sends it electronically to the IRT facility manager. The internet address for obtaining a pretest survey form is as follows: http://www.grc.nasa.gov/WWW/IRT/Testing/PreTestSurvey.html. The tunnel user is also requested to prepare an IRT model systems report for the IRT project engineer prior to the first pretest meeting held at Glenn. The IRT project engineer will specify the content of the IRT model systems report. A general description of the contents of this document is presented in section 7.1.

## 6.1 Pretest Meetings

A series of pretest meetings are held at Glenn to discuss the test plan, instrumentation, tunnel hardware, data requirements, power requirements, and other miscellaneous services described in the following paragraphs. The number of pretest meetings required is a function of the complexity of the test. The attendees at these meetings are the requester personnel (e.g., the lead engineer plus key test personnel), the IRT facility manager, the IRT project engineer, IRT electrical engineer, and key IRT personnel.

***6.1.1 Test objectives and run schedule***.—The requester should provide a statement indicating the test objectives and goals. The statement should thoroughly explain any special test requirements. A prioritized run schedule compatible with the available test window should also be provided.

***6.1.2 Instrumentation***.—The tunnel user should provide the IRT project engineer with a list of requested instrumentation. If the Escort D system is to be used, the tunnel user's instrumentation must be adapted to the IRT data system (see secs. 4.0 and 5.0). If the tunnel user's data system is to be used, this should be discussed with the IRT project engineer and the IRT electrical engineer at the first pretest meeting.

***6.1.3 Hardware***.—The tunnel user is required to submit drawings of the model and support hardware as installed in the test section. The tunnel user must provide the mounting plate to attach the model to the test section turntable (see sec. 2.3) and any hardware necessary to fasten the model to the tunnel, other than that shown in figures 21 to 27, and provide guidelines to handle hardware security.

***6.1.4 Data acquisition and reduction***.—Data-reduction information, consisting of data inputs, data outputs, and equations in engineering language, must be provided if Glenn personnel are to reduce the data for the tunnel user. The IRT project engineer will contact the appropriate personnel in ISD and set up any necessary meetings between tunnel users and ISD personnel to establish computing requirements, including any computing encryption. Final computing instructions are due from the tunnel user to ISD personnel 8 weeks before the start of testing.

Tunnel users may choose to bring a self-contained computer system onsite for data processing. Such arrangements can be discussed with the IRT project engineer and the IRT electrical engineer.

***6.1.5 Power requirements***.—The power requirements for the model should be stated by the tunnel user at the pretest meeting. The power available is discussed in section 3.7.

***6.1.6 Services required***.—At the pretest meeting, tunnel users should specify which facility services will be required for their tests. The services available are heated air systems (sec. 3.1), engine inlet model exhaust system (sec. 3.4), and model attitude (turntable positioning) system (sec. 4.3).

## 6.2 Pretest Documentation

The tunnel user must supply the IRT project engineer with the following information at least 8 weeks before the scheduled tunnel test:

(1) Test matrix for the model
(2) Model system drawings (see sec. 7.1.1)
(3) IRT model systems report (the IRT project engineer establishes the content of this report; the outline of this report is presented in sec. 7.1).
(4) All calibration information required of the tunnel user
(5) A list of all tunnel-user-supplied equipment, with block diagrams and wiring schematics of the equipment
(6) Model assembly and installation procedures (see sec. 7.4)

(7) Data acquisition and reduction instructions (see sec. 6.1.4)

If a model is identical or very similar to a previously installed model and if the test conditions do not exceed those of previous tests, the requirement to submit load and stress reports may be waived because of the similarity. If the tunnel user and Glenn agree to a cooperative publication of the data, the tunnel user may be asked to supply selected model drawings and/or photographs for reproduction in NASA technical papers.

### 6.3 Model and Equipment Delivery

All models, instrumentation, and support hardware should be delivered to Glenn to the attention of the IRT project engineer (the IRT facility manager will supply the name of this engineer to the tunnel user). To reduce installation delays (see sec. 7.2), all model parts, model internal instrumentation, and tunnel-user support hardware should be assembled prior to shipment to Glenn. Large shipping crates must have skids so they can be handled by forklift trucks. The maximum weight of the model plus the shipping crate should not exceed 3000 lb. The delivery date of equipment and models prior to testing will vary according to the complexity of the model installation and the amount of instrumentation to be hooked up to the data system. The tunnel user and the IRT project engineer should agree to an appropriate delivery time.

When shipments leave the customer's plant, the IRT project engineer should be notified of the scheduled arrival date and identifying shipping numbers. Deliveries are normally accepted at Glenn from 8:00 a.m. to 4:30 p.m. eastern standard time, Monday through Friday, excluding Federal Government holidays. Off-hour delivery can usually be accommodated by prior arrangement with the IRT facility manager or the IRT project engineer.

## 7.0 Risk Assessment of Wind Tunnel Model and Test Hardware

The following sections discuss permissible model design criteria pertaining to loads and allowable stresses, which are presented in the IRT model systems report, and model fabrication and quality assurance requirements.

### 7.1 Model Systems Report

An IRT model systems report prepared by the tunnel user is required for all model systems to be tested at Glenn. The IRT model systems report is to be a complete, comprehensive stand-alone document. The user must submit this report to the IRT project engineer at least 8 weeks prior to tunnel entry, but the IRT project engineer may request an earlier delivery date for the report. The IRT project engineer establishes the content of the IRT model systems report from the information outlined in sections 7.1.1 to 7.1.7.

***7.1.1 Model system drawings***.—The model system drawings should include the as-built drawings of the model system configuration to be tested and (where applicable) assembly drawings, installation drawings, electrical sketches, and wiring diagrams. Detailed drawings of the cross-sectional area distribution of the model should also be provided to assist in checking blockage and air load calculations.

***7.1.2 Model design loads***.—The model design load calculations must take into account model specifications and requirements. Derived loads must consider aerodynamic, mechanical, and thermal effects. Life-cycle requirements must also be addressed.

***7.1.3 Model stress analysis***.—The models tested in the IRT are usually flight-type hardware, so the allowable stresses must be adjusted to reflect this fact. First, the aeronautical category of the model to be tested must be determined (i.e., military, normal, transport, rotorcraft, utility, commuter, etc.). Then the Federal Aviation Regulations (FAR) for the model category should be consulted to determine the allowable stresses (i.e., factor of safety, strength, and deformation). The stress analysis that is given to the IRT project engineer should cite the specific FAR manual used to determine the allowable stresses on the model.

Thermal stresses that could occur in the model because of the IRT experiments should be subtracted from the ultimate tensile strength and the tensile yield strength before safety factors for the allowable stresses are applied. The material properties used in calculations should be the expected minimum values.

The stress analysis should include (1) dynamic factors that may result from flow separation, (2) thermal stresses due to cold-air experiments, (3) stress concentration factors, and (4) cyclic thermal loads. The calculations should show that the worst-case load does not exceed the allowable stresses.

For each section of the model analyzed, there should be a sketch showing the forces and moments acting on that section. The analysis of each section should list approximations, assumptions, model section properties, and the heat-treatment conditions of the material. All general equations should be listed before the numerical values are substituted. The number of axial stations selected should be based on an axial cross-sectional model change of at least +5 percent. Detailed shear and moment diagrams for the model should be presented along with the stress analysis for a worst-case loads scenario.

The model stress analysis must summarize all safety factors that are used in model design calculations. General equation sets, terms, and computer programs must be referenced. Any assumptions that are used in equation set development must be properly noted. The model stress analysis should also specify material data for all components that comprise the model system as well as for fasteners that are used to secure model components together. The material data should include standard and minimum properties within the complete range of environments to which the model will be exposed (i.e., pressure, temperature, or other environmental effects).

A structural analysis for the model system components must be performed if applicable. This analysis considers bolted, welded, brazed, and bonded joints. A model system component analysis must be performed for pressurized systems, hydrostatic systems, and specialized model systems that are subjected to fatigue and thermal effects.

***7.1.4 Model stability requirements***.—The IRT model systems report should have a section dedicated to model stability. The information presented should show that the model, mounting points, and restraints are statically and dynamically stable (i.e., there is at least a 15-percent margin between the natural frequencies of the model and its restraints and the model and model restraint frequencies that occur due to the test conditions) within the model test matrix. It should also discuss the effects of Reynolds number, Mach number, surface conditions, and so forth in the development of equations noted in the analysis. Also the range of such parameters as mass and inertia and the stiffness coefficients used in the dynamic analysis should be noted.

***7.1.5 Inspection report***.—The user may be required to supply the IRT project engineer with an inspection report. The IRT project engineer initiates this request and specifies the content of the inspection report. The inspection report may contain information on fabrication planning, material information, or nonconforming hardware control information. If this is a requirement, the IRT project engineer can supply the customer with the Glenn Research Center procedure document, GRC–P4.4 "Control of Nonconforming Product" (latest revision), and/or quality assurance information.

***7.1.6 Structural test report***.—The IRT project engineer initiates the request for a structural test report if required. This test report may include material properties, model load information, static and dynamic balancing, and model runup tests.

***7.1.7 Hazard analysis***.—A hazard analysis may have to be developed for some tests in the IRT test section. The decision to develop this analysis should be made at the first pretest meeting of the user, the

IRT facility manager, and the IRT project engineer (at least 1 yr before the actual tunnel test time). The IRT project engineer will decide if such an analysis is required and what the hazard report should contain. The hazard report can discuss possible damage to the model and the facility if a model failure occurs due to stress, thermal effects, fatigue, instrumentation malfunction, facility power loss, chemicals, or some other factor. This report is the joint effort of the IRT project engineer and the user. It is included as part of the IRT model systems report.

## 7.2 Design Criteria for Model and Support Structures

The following sections discuss model and support structure material selection, structural joints, pressure systems, pressure piping, and electrical equipment components.

***7.2.1 Material selection***.—Materials for the model and support structures are to be selected and sized on the basis of the applicable physical and mechanical properties listed in one or more of the following standards:

(1) American Society for Testing Materials (ASTM)
(2) American Society of Mechanical Engineers (ASME)
(3) Society of Automotive Engineers (SAE)
(4) The Aerospace Structural Metals Handbook from the Department of Defense (DOD)

All material properties used in the model structural and hazard analyses shall be the minimum values for the complete range of environments to which the model will be exposed.

***7.2.2 Structural joints***.—All counterbores, spot faces, and countersinks in the model, mounting plate (sec. 2.3), and other support structures must be aligned so as to keep the fasteners from bending due to torquing.

Screws and/or threaded connectors used to join a model to a support structure should be able to withstand torquing at loads greater than the maximum separating forces expected. Joint separation criteria are addressed in reference 16. Information on the design of bolted joints and gaskets are presented in references 17 and 18. All structural bolted or screwed connections must have positive mechanical locks such as locking inserts, self-locking nuts, cotter pins, or safety wiring.

All welded joints should be designed and fabricated in compliance with the code of the American Welding Society (AWS).

***7.2.3 Pressure systems***.—Model systems and test equipment using hydraulic, pneumatic, or other systems with operating pressures above 15 psig shall be designed, fabricated, inspected, tested, and installed in accordance with FAR. The FAR manual used should be applicable to the model or support system category defined by the tunnel user. Hydraulic and pneumatic support systems are discussed in the Miscellaneous Equipment section in the FAR manuals.

Pressure-relief devices may be required in a hydraulic or pneumatic system but not necessarily in the model. These devices should be able to relieve the overpressure by discharging a sufficient flow from the pressure source under the conditions causing a malfunction.

The IRT facility manager and the IRT project engineer should be given the following information about all components of a pressure system: volume capacity, temperature range, working pressure, and proof pressure. Note that all components of a pressure system should be stored in clean, dry, and sealed conditions after proof testing and before delivery to the IRT.

***7.2.4 Pressure piping***.—All piping shall be designed, fabricated, inspected, tested, and installed in compliance with the FAR or the American National Standards Institute (ANSI) Piping Code. Powered models that have internal piping and acceptable pressure levels are discussed in Hydraulic Systems in the Miscellaneous Equipment section in the FAR code. To obtain the appropriate FAR manual, the model's category must be determined. Pressure vessels constructed from standard pipe, standard pipe fittings, and standard flanges are also considered pressure piping. For these, acceptable pressure levels are specified in the Hydraulic Systems section in the FAR code.

Allowances for thinning of the pipe wall due to bending and/or threading of the pipe should be in accordance with the ANSI Piping Code. Threaded joints, seal welding of threaded joints, and flange joints must also comply with this ANSI code.

***7.2.5 Electrical equipment components***.—Because of the harsh environment in the IRT test section, the hardware, equipment, and material to be used must conform to the National Electrical Code. Each set of wires on all pressure transducers, strain gauges, vibration pickups, and other low-voltage devices must be shielded. Details regarding user-supplied control panels and/or control boxes and the associated wiring to the facility control room should be discussed with the IRT electrical engineer at one of the pretest meetings. The format for user-supplied electrical schematics, wiring diagrams, and connectors to interfaces at control panels, control boxes, and/or the model should be also discussed with the IRT electrical engineer.

### 7.3 Model Fabrication Requirements

Models should be completely assembled at the manufacturer's plant, and any discrepancies should be corrected at that time. All model parts must be inspected to ensure proper fit and must be certified for the loads and deflections to be encountered during testing. In addition, all remotely controlled model functions must be checked out, and all position indicators should be calibrated before shipment to Glenn.

All electrical leads and pressure lines from the model should be clearly identified. The pressure lines must be clean and free of oil and debris and must have been checked for leaks at operating pressures.

### 7.4 Model Installation Procedures

Written procedures for model assembly, installation, and configuration changes in the IRT are required for quality assurance. They should be submitted to the IRT project engineer at least 8 weeks before the scheduled test. These procedures should list sequentially the steps to be taken to mount the model in the tunnel test section. They should also indicate the model's alignment in the test section and the bolt torquing values for fastening the model to the mounting plate. The assembly, installation, and checkout of user-supplied hardware should also be addressed. The model installation procedures should be supplemented with the necessary drawings and/or sketches.

## 8.0 General Information

The following information is provided to familiarize the tunnel user with the services available and the standard operating procedures of the IRT.

### 8.1 Logistical Support

***8.1.1 Model buildup***.—In most instances the designs of the models tested in the IRT vary from simple to moderately complex, and the degree of difficulty of installation in the tunnel varies accordingly. The lead time by which the model must arrive at the IRT before testing should be agreed upon with the IRT project engineer.

***8.1.2 Space assignment***.—The primary control room (fig. 19) is used for tunnel operations and space in it for tunnel users is limited. Most of the space in the secondary control room is generally available for tunnel users. Figure 20 shows details of the space available in this control room.

***8.1.3 User personnel responsibilities***.—The tunnel user's own mechanics and technicians must install the model in the tunnel. The user's personnel must also set up any custom data systems, along with the required instrumentation. All tools, spare parts, special equipment, and supplies necessary to work on the model and its ancillary systems must be provided by the tunnel user. A tunnel-user aerodynamist familiar with the model and the test objectives must be present during testing.

***8.1.4 Operation of Government equipment***.—Tunnel-user personnel may not operate Government-furnished equipment or make connections to this equipment without the approval of a Glenn representative.

***8.1.5 Tunnel safety***.—Tunnel users may enter the tunnel test section only after they are given permission by the IRT project engineer or a qualified IRT tunnel operator. Care must be taken while examining the model in the test section to preclude injury from sharp edges on the model due to ice accretion or from instrumentation probes and/or rakes that may be positioned in the tunnel test section (see sec. 9.1). The test section floor is slippery after a run, so caution must be exercised when entering the test section (see sec. 9.1). All persons entering the tunnel for an extended period of time after a test run must wear the proper protective cold-weather clothing (see sec. 9.2).

***8.1.6 Aerodynamic test for model checkout***.—The IRT project engineer will direct IRT personnel in the steps that are outlined in the IRT Model Qualifications Procedures for the Aerodynamic Test Record sheet. Step V on the aforementioned sheet discusses the procedure to increase tunnel speed in 10 percent increments to 110 percent of the maximum test velocity. A copy of the Model Qualification Procedures sheet is available to IRT personnel from the IRT project engineer.

***8.1.7 Support during tests***.—All tunnel-user requests for worker assistance and shop or facility services should be submitted by the tunnel user to the IRT project engineer.

***8.1.8 Personnel safety briefings***.—Prior to the start of the test program the IRT project engineer will call a meeting that is to be attended by user and IRT facility personnel to discuss potential hazards and the methods of operations during the test.

## 8.2 Operations

***8.2.1 Normal operating days and shift hours***.—The facility is staffed Monday through Friday for a two-shift operation. The first shift (0800 to 1600 h) is reserved for model work and facility checkout. During the second shift (1600 to 2400 h), tests are run between 1630 and 2300 h, after which the icing capabilities at the tunnel are shutoff, and the fan is turned off at 2330 h. This test window can be expanded for an ambitious test schedule by requesting an early start. Tunnel users should discuss extending the test time with the IRT facility manager and the IRT project engineer as early in the pretest planning as possible.

***8.2.2 Off-shift access***.—Access to the IRT at times other than operating shifts must be with the permission of the IRT project engineer.

## 8.3 Planning

***8.3.1 Safety permit request***.—The IRT project engineer will prepare a Safety Permit request package for each model. This package describes the safety aspects of the tests as well as the test objectives, run schedule, instrumentation, and hardware. The Safety Permit Request package is sent to the Glenn Safety Office where this information is logged into the Safety Permit System and is then disseminated to the appropriate Safety Permit groups for their review and approval. The Safety Permit Request should be completed and available for review at least 12 weeks prior to the start of testing.

The following is a list of conditions that would require special action by the IRT Facility Safety Committee:

(1) Use of radioactive materials or gases
(2) Use of high-speed rotating model parts without suitable shrouds
(3) Ejection into the tunnel circuit of material or gases that may cause an explosion
(4) Use of toxic materials

At one of the pretest meetings, the IRT project engineer can advise the tunnel user about the acceptability of toxic model materials. A Material Safety Data Sheet is required for all toxic materials.

***8.3.2 Test time***.—The tunnel test time charged to a non-NASA user will include the total time the facility is available to the user, that is, time for model and instrumentation installation and removal, experiment time, and time for returning the tunnel and associated areas to their pretest condition. The time required to uncrate the user's model and equipment and to crate them for shipment must also be included. Extensions to a test window may be granted. Extensions are negotiable between the tunnel user's lead engineer and the IRT facility manager. Discussions with Glenn personnel who have experience with the facility should enable the tunnel user to make a fairly accurate estimation of the time required to complete the test program.

***8.3.3 NASA debriefing***.—Prior to completion of the test program, the tunnel user's lead engineer shall meet with the IRT facility manager to evaluate the test support received by the tunnel user during the test program. The IRT facility manager will make arrangements for the meeting.

## 8.4 Security Notification Requirements

The amount of advanced notice required to obtain access to the IRT at the NASA Glenn Research Center depends on the classification of the test program and characterization of the non-NASA visitor.

***8.4.1 Nonclassified test by U.S. citizen***.—For nonclassified test programs, the IRT project engineer will notify the Glenn Visitor Control Center at least 3 days prior to the arrival of a non-NASA visitor who is a U.S. citizen. The following visitor information is required: (1) the name of the visitor, (2) the visitor's place of employment, (3) the purpose of the visit and the associated dates, and (4) the Glenn contact person and escort.

***8.4.2 Nonclassified test by non-U.S. citizen***.—All non-U.S. citizens, as well as U.S. citizens employed by foreign-owned companies, must be sponsored and may require a National Agency Check. The sponsor (the Glenn research engineer) of the test is responsible to obtain all necessary approvals for these individuals. The approval process is initiated with the completion of NASA form C–216 (Non-U.S. Citizen Access Request), which is found on the Web at http://forms.grc.nasa.gov. Upon completion of this form, it is submitted to the International Visitor Coordinator (IVC) of the Security Management and Safeguards Office (SMSO) at Glenn at least 8 weeks prior to the visit. The name of the IVC can be found by going to the SMSO home page http://smo.grc.nasa.gov. Selecting the Foreign Visitor Access Procedures link opens the International Visitors Program (IVP) home page, and the name of the IVC is listed on the bottom of the first page. Specific security plans for the facility, technology control plans, and computer system security plans should be submitted as soon as possible to the SMSO after submission of the C–216 form. An outline of the Security and Export Control Plan (incorporating plans for facility security and technology control) may be obtained from the IVC or by selecting the IVC Security Plan link on the IVP home page. Computer system security plans should be coordinated with the Glenn Information Technology (IT) Security Manager, who resides in the Computer Services Division.

All (computer) system requirements should be validated with the Glenn IT Security Manager. The IVC can provide the name of this manager to the research engineer.

***8.4.3 Sensitive test by U.S. citizen***.—A sensitive test program at Glenn may be conducted only by a U.S. citizen. For such tests the proper security clearance must be in place prior to the arrival at Glenn of a non-NASA U.S. citizen. The Glenn Security Office must receive a visit notification letter from the visitor's place of employment. This letter is to include the following information for each visitor:

(1) Social Security number
(2) Full name
(3) Date and place of birth
(4) Security clearance level
(5) Date clearance was granted
(6) Who granted the clearance
(7) Date and duration of visit
(8) NASA contact

Visit notification letters are to be sent to the following address:

NASA Glenn Research Center
ATTN: Security Management and Safeguards Office
Mail Stop 105–2
21000 Brookpark Road
Cleveland, OH 44135
Phone: 216–433–8976
FAX: 216–433–6664

The IRT project engineer will notify the Glenn Security Management and Safeguards Office and the Visitor Control Center 3 days prior to the arrival of non-NASA visitors who are participating in a sensitive test program at the Center.

# 9.0 Personnel Safety

The following information is provided to acquaint the tunnel user with tunnel test section and facility control-room safety requirements. However, tunnel users are responsible for understanding all the potential hazards associated with the operation of the IRT and protecting all user personnel from injury. User personnel are also responsible for any actions that may endanger Glenn personnel.

## 9.1 Hazards

All first-time tunnel users and/or visitors must take the mandatory safety briefing given by the IRT project engineer or the IRT crew chief. Additional hazards associated with a particular test will be discussed with tunnel users by the IRT facility manager and the IRT project engineer at one of the pretest meetings.

Tunnel-user personnel should be aware of the following hazards:

(1) The facility control rooms are located within the facility balance chamber (see fig. 2). Since the noise levels in the balance chamber may be high during tunnel testing, there may be noise problems in the control rooms. In such cases, hearing protectors (provided by Glenn) may be required.

(2) Models installed in the tunnel test section may have sharp edges due to their design and fabrication and/or the accretion of ice during testing. The tunnel users and the IRT project engineer should discuss tunnel test section safety associated with the model at one of the pretest meetings.

(3) The test section floor is often wet and slippery as a result of using the spray bars during a tunnel test or from melting ice and/or condensation. Tunnel users should not enter the test section to examine the model after a test run until they have the permission of the IRT project engineer or a qualified tunnel operator. Tunnel users entering the test section after a test run must wear appropriate shoes and be careful of their footing.

(4) Barometric pressures in the balance chamber may be as low as 3.3 psi below atmospheric under extreme conditions, which is equivalent to an altitude of approximately 7200 ft. Abrupt airspeed changes during normal and emergency tunnel operation will cause the pressure in the balance chamber and in both control rooms to change quickly and may cause some discomfort to personnel.

(5) The tunnel user’s senior engineer is responsible for ensuring that all members of the user team are accounted for prior to closing the access hatch to the tunnel test section.

(6) Freon 134a (E.I. du Pont de Nemours and Company, Wilmington, DE) is the coolant in the IRT refrigeration system and can be toxic. Freon detectors operate continuously in the tunnel and emergency breathing apparatus is readily available to all personnel in the unlikely event of a Freon leak.

All first-time tunnel users and/or visitors must take the mandatory safety briefing given by the IRT project engineer or the IRT crew. Additional hazards associated with a particular test will be discussed with tunnel users by the IRT facility manager and the IRT project engineer at one of the pretest meetings.

## 9.2 Protective Equipment

Tunnel users must observe the guidelines regarding the use of protective equipment and clothing during a test program. Users may require protective hearing equipment while working in the balance chamber when the tunnel is operating. When the model is being examined between runs, users should wear cold-weather clothing and gloves (both supplied by Glenn).

## 9.3 Emergency Procedures

The IRT facility has specific operating procedures to protect tunnel personnel, the facility, and computing equipment in case of emergency. The IRT project engineer will discuss these procedures with tunnel users at the pretest meeting.

## 9.4 Working Alone

Inside the tunnel, users should always work in groups of at least two people. Working alone is not permitted unless specific, limited approval is obtained in advance from the IRT project engineer. Working alone is defined as working out of audio or visual contact with a coworker for more than 5 min.

# Appendix A
# IRT Contact Person

The following individual is the key contact person at the IRT facility. Mail correspondence can be addressed as follows:

NASA Glenn Research Center
ATTN.: (Name of IRT facility manager)
Mail Stop 6–8
21000 Brookpark Road
Cleveland, OH 44135

The name of the IRT facility manager can be obtained on the Web from http://facilities.grc.nasa.gov. On this home page under Test Information in the left hand column, click on the Contact Information link. The names and the phone numbers of the facility managers are listed on this page. The above-noted URL is valid for customers that are either offsite or onsite. In the absence of a computer, call 216–433–4000 (Glenn switchboard operator), and ask the operator to supply the name of the facility manager. The telephone numbers at the facility are 216–433–2051 and 2052. Tunnel user models and equipment can be shipped to the following address:

NASA Glenn Research Center
ATTN.: (Name of the IRT project engineer)[1]
Mail Stop 11–1
21000 Brookpark Road
Cleveland, OH 44135

[1]The name of the IRT project engineer can be obtained from the IRT facility manager.

# Appendix B
# Uncertainty Analysis for Total-Temperature and Total- and Differential-Pressure Measurements in IRT Test Section

An array of 24 copper-constantan thermocouples is used to measure the air total temperature in corner D of the IRT tunnel loop. The average of these 24 total-temperature measurements is used as the total temperature in the IRT test section. The uncertainty of these thermocouple measurements is computed using an uncertainty module for a copper-constantan thermocouple and is presented in "Uncertainty Analysis for Total Temperature, and Total and Differential Pressure Measurements in IRT Test Section." (R.H. Soeder and P.Z. Blumenthal, 2002, NASA Glenn Research Center, Cleveland, OH, Preliminary Information Report #082). The copper-constantan thermocouple uncertainty limit is ±0.41 percent (±1.86 °R) for a total temperature of 458.9 °R (–0.7 °F) in the test section.

Two pitot-static probes, one mounted on the IRT test section vertical north wall and the other on the vertical south wall, are used to measure total and differential pressure. The total pressure is measured using a 0- to 20-psia Setra Model 270 transducer (Setra Systems, Inc., Boxborough, MA), and the differential pressure is measured using a 0- to 3-psid Setra Model 239 transducer. The uncertainty modules used to compute the total and differential pressure are described in Preliminary Information Report #082. The total-pressure uncertainty calculated is ±0.10 percent (±0.0205 psia) of full scale and the differential-pressure uncertainty calculated is ±0.16 percent (±0.0018 psid) of full scale.

Differential calculus calculations are performed using the uncertainty values noted above for total temperature and total and differential pressure. It is assumed that the test section conditions are a static temperature of –22 °F and a velocity of 300 kn (346 mph). Calculations presented in Preliminary Information Report #082 show that the uncertainty in velocity measurement with current instrumentation is ±0.47 percent (±1.41 kn or 1.62 mph) of the full scale measurement.

# Appendix C
# Example of Customized Escort D Output File

Shown below is an example of an Escort D system output data file from a test run. Readings 10095 to 10097 are single data record snapshot formats where the reading number is incremented with each push of the record button while the scan cycle remains a constant 1 s. Reading 10098 is a cyclic data record format of 11 cycles recorded every second. Reading 10099, also cyclic, is eight cycles recorded every 3 s. In both cyclic examples, the scan cycle is updated in unison with the selected time interval while the reading number remains constant. Each output file is limited to 256 columns with a limit of 10 files per user.

| RDG | SCAN | RUNID | DATE | TOD | TSTAVG deg | TTOTAVG deg | PTOTN psia | PTOTS psia | PTAVG psia | DPNAVG psid | DPSAVG psid | DPAVG psid |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10095 | 1 | 5 | 11-Mar-02 | 16:40:35 | 61.84 | 62.12 | 14.395 | 14.402 | 14.399 | 0.027 | 0.027 | 0.027 |
| 10096 | 1 | 5 | 11-Mar-02 | 16:48:10 | 44.53 | 46.98 | 14.388 | 14.390 | 14.389 | 0.241 | 0.244 | 0.242 |
| 10097 | 1 | 5 | 11-Mar-02 | 16:56:08 | 14.05 | 21.49 | 14.382 | 14.376 | 14.379 | 0.760 | 0.766 | 0.763 |
| 10098 | 1 | 5 | 11-Mar-02 | 16:56:54 | 13.78 | 21.32 | 14.379 | 14.370 | 14.375 | 0.771 | 0.775 | 0.773 |
| 10098 | 2 | 5 | 11-Mar-02 | 16:56:55 | 13.71 | 21.26 | 14.379 | 14.371 | 14.375 | 0.771 | 0.776 | 0.774 |
| 10098 | 3 | 5 | 11-Mar-02 | 16:56:56 | 13.65 | 21.20 | 14.380 | 14.371 | 14.376 | 0.773 | 0.777 | 0.775 |
| 10098 | 4 | 5 | 11-Mar-02 | 16:56:57 | 13.70 | 21.26 | 14.379 | 14.373 | 14.376 | 0.773 | 0.779 | 0.776 |
| 10098 | 5 | 5 | 11-Mar-02 | 16:56:58 | 13.69 | 21.25 | 14.380 | 14.371 | 14.376 | 0.773 | 0.778 | 0.775 |
| 10098 | 6 | 5 | 11-Mar-02 | 16:56:59 | 13.66 | 21.23 | 14.379 | 14.372 | 14.376 | 0.774 | 0.779 | 0.776 |
| 10098 | 7 | 5 | 11-Mar-02 | 16:57:00 | 13.69 | 21.24 | 14.379 | 14.371 | 14.375 | 0.773 | 0.777 | 0.775 |
| 10098 | 8 | 5 | 11-Mar-02 | 16:57:01 | 13.71 | 21.25 | 14.378 | 14.372 | 14.375 | 0.771 | 0.776 | 0.774 |
| 10098 | 9 | 5 | 11-Mar-02 | 16:57:02 | 13.64 | 21.18 | 14.378 | 14.370 | 14.374 | 0.771 | 0.776 | 0.773 |
| 10098 | 10 | 5 | 11-Mar-02 | 16:57:03 | 13.64 | 21.19 | 14.376 | 14.371 | 14.374 | 0.772 | 0.777 | 0.774 |
| 10098 | 11 | 5 | 11-Mar-02 | 16:57:04 | 13.68 | 21.24 | 14.378 | 14.370 | 14.374 | 0.772 | 0.777 | 0.775 |
| 10099 | 1 | 5 | 11-Mar-02 | 16:57:29 | 13.64 | 21.22 | 14.378 | 14.369 | 14.373 | 0.774 | 0.780 | 0.777 |
| 10099 | 2 | 5 | 11-Mar-02 | 16:57:32 | 13.65 | 21.23 | 14.377 | 14.372 | 14.375 | 0.775 | 0.780 | 0.777 |
| 10099 | 3 | 5 | 11-Mar-02 | 16:57:35 | 13.65 | 21.20 | 14.378 | 14.375 | 14.376 | 0.773 | 0.777 | 0.775 |
| 10099 | 4 | 5 | 11-Mar-02 | 16:57:38 | 13.63 | 21.21 | 14.379 | 14.374 | 14.376 | 0.774 | 0.780 | 0.777 |
| 10099 | 5 | 5 | 11-Mar-02 | 16:57:41 | 13.62 | 21.16 | 14.377 | 14.377 | 14.377 | 0.772 | 0.777 | 0.774 |
| 10099 | 6 | 5 | 11-Mar-02 | 16:57:44 | 13.60 | 21.15 | 14.377 | 14.374 | 14.376 | 0.772 | 0.778 | 0.775 |
| 10099 | 7 | 5 | 11-Mar-02 | 16:57:47 | 13.63 | 21.17 | 14.376 | 14.371 | 14.374 | 0.771 | 0.776 | 0.774 |
| 10099 | 8 | 5 | 11-Mar-02 | 16:57:50 | 13.64 | 21.20 | 14.378 | 14.371 | 14.375 | 0.773 | 0.778 | 0.775 |

The following abbreviations are for the parameters listed in the above table:

| | |
|---|---|
| DATE | day of the year |
| DPAVG | overall average differential pressure from north and south IRT test section pitot-static probes, psid |
| DPNAVG | average differential pressure at north pitot-static probe in the IRT test section, psid |
| DPSAVG | average differential pressure at south pitot-static probe in the IRT test section, psid |
| PTAVG | overall average total pressure from north and south IRT test section pitot-static probes, psia |
| PTOTN | total-pressure value measured at north pitot-static probe in the IRT test section, psia |
| PTOTS | total-pressure value measured at south pitot-static probe in the IRT test section, psia |
| RDG | data reading number |
| RUNID | test run identification number |
| SCAN | data scan number |
| TOD | time of day |
| TSTAVG | calculated average static temperature in the test section, °F |
| TTOTAVG | average total temperature measured in corner D, °F |

# Appendix D
# Procedure for Obtaining Tunnel Test Time

The following is a summary of the process for obtaining tunnel test time:

(1) At least 1 yr before the test, the tunnel user contacts the IRT facility manager and submits the overall test requirements.
(2) The IRT facility manager and the appropriate RTD personnel review the request.
(3) The tunnel user submits a formal letter of request to the IRT facility manager at NASA Glenn (non-NASA requesters only).
(4) If the project is accepted, a test agreement is prepared and signed by the requester (applies to non-NASA requesters only).
(5) Pretest meetings are held to discuss the test plan, instrumentation, tunnel hardware, and data requirements. Attendees are the requester and key tunnel-user personnel, the IRT facility manager, appropriate RTD branch chiefs, key RTD personnel, and the IRT project engineer.

The tunnel user must supply the IRT project engineer with the information that is presented in section 6.2.

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This manual describes the Icing Research Tunnel at the NASA Glenn Research Center and provides information for users who wish to conduct experiments in this facility. The capabilities of the tunnel test section, main drive system, speed control system, and the spray bars are described. Tunnel nozzle performance maps of liquid water content as a function of median volume droplet size are presented for two types of spray nozzles at test-section velocities ranging from 100 to 300 knots (kn) (115 to 346 mph). The facility support systems, which include heated air systems, steam and service air systems, model supports at tunnel test section ceiling, model exhaust system, force balance system, wake survey system, and model electrical power system, are described. Also discussed are facility instrumentation capabilities for temperature and pressure measurements and model attitude simulation. In addition, photographic documentation and flow visualization techniques are explained, and pretest meeting formats and schedules are outlined. Tunnel user responsibilities, personnel safety requirements, and types of test agreements are explained. The Icing Research Tunnel is a closed-loop atmospheric tunnel with a test section that is 6 ft high, 9 ft wide, and 20 ft long. The test section is equipped to support testing at airspeeds from 50 to 300 kn (58 to 346 mph) in a temperature and water-droplet environment that simulates natural icing conditions.

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