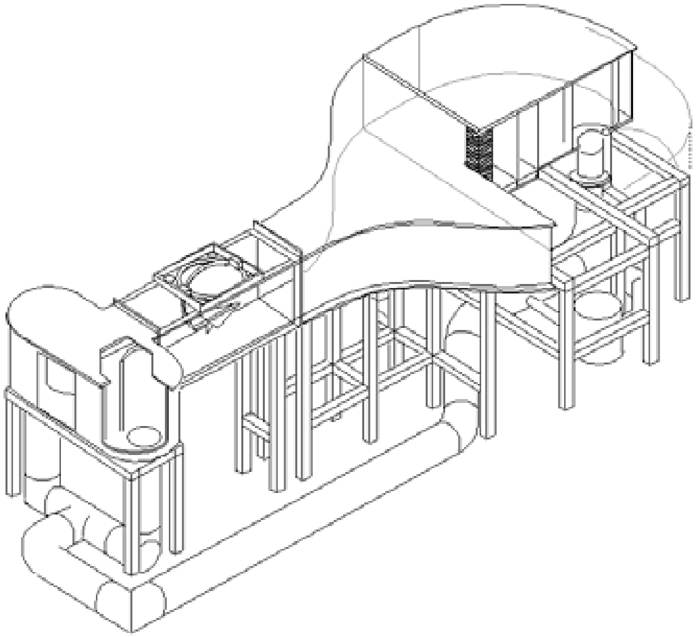
RESEARCH WATER TUNNELS

SPECIFICATIONS



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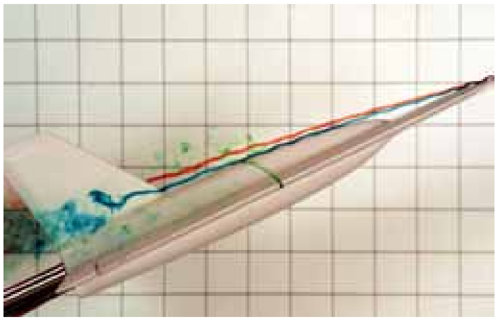
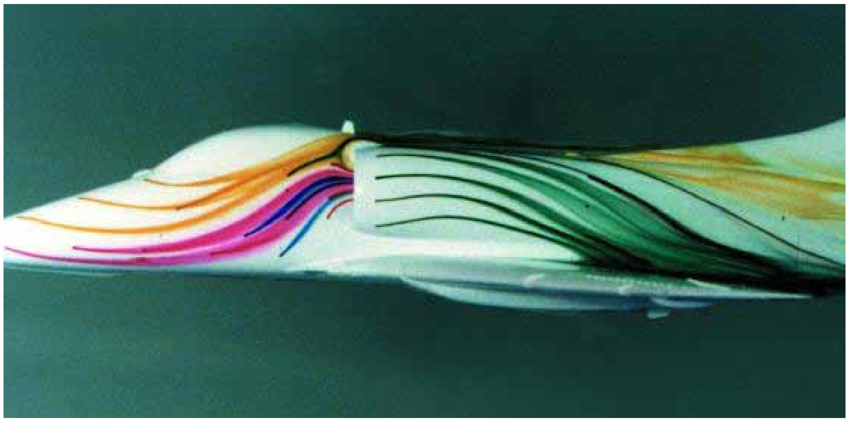
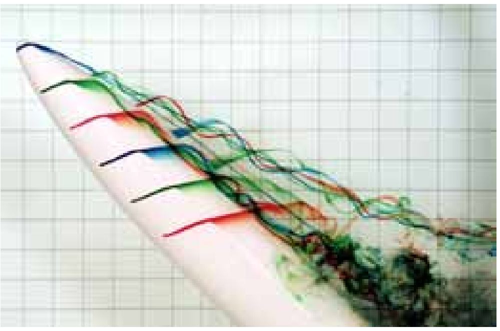
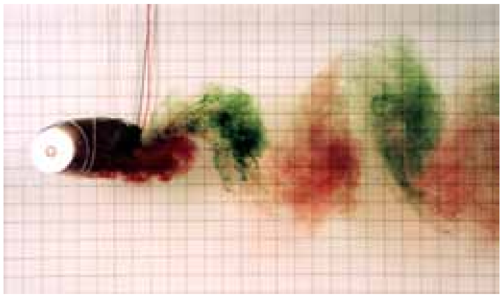
1 INTRODUCTION

Rolling Hills Research Corporation is an aeronautical technology company, founded in 2002. One of the company's key objectives is to develop technologies that aid in the understanding of aerodynamic phenomenon. The water tunnel is an excellent preliminary design and research tool for investigating the underlying flow physics that drive air-vehicle performance. This is primarily because of the extremely high quality of flow visualization that is possible in the water tunnel.









Although water tunnel testing was once regarded only as a qualitative tool used for visualizing the flow field around vehicles, RHRC has matured the technique to include quantitative measurements of forces and moments with a submersible strain-gage balance. In addition to static measurements, the water tunnel is an excellent tool for studying dynamic motions of aircraft, and the resulting differences in the flow field and corresponding forces and moments. In a sub-scale wind tunnel, dynamic experiments must be conducted at rates higher than full scale. In the water tunnel, the dynamically scaled rates are much lower than full-scale, so many of the difficulties normally found in dynamic experiments are greatly reduced. At these scaled rates, the inertial forces become extremely small, and the strength, stiffness, and size of the model support are greatly reduced. This allows many types of experiments to be conducted with a single, multi-axis, computer-controlled model support system. Section 5 discusses this.

RHRC offers two different models of research water tunnel, the Model 2436 and the Model 1520. The general layout of the two water tunnels is nearly identical, as shown in Figure 1, with the primary difference being the size of the test sections. Both tunnels utilize a "free-surface" test section, which allows for easy access to the test article during an experiment for model changes or motion control, without the necessity of draining the tunnel. The Model 2436 has a test section that is 24 inches wide, 36 inches deep, and 72 inches long, with an overall capacity of approximately 5000 gallons. The Model 2436 is sized so that a typical, low aspect ratio, 1/32nd scale aircraft model can be tested at high angles-of-attack (up to 90°), and remains free of excess blockage effects and wall interference. The Model 1520 has a test section that is 15 inches wide, 20 inches deep, and 60 inches long, with an overall capacity of approximately 1000 gallons. The Model 1520 is sized for use with typical 1/48th scale aircraft models. Both systems can be delivered, setup, calibrated and commissioned by an RHRC technician, and now both the Model 1520 *and 2436* are available in kit form. In the kit form, the water tunnel can be assembled by the customer using in-house labor to save money. The kit includes written instructions with photo illustrations.

2 FACILITY DESCRIPTION - MODEL 2436

The Rolling Hills Research Corporation Flow Visualization Water Tunnel is a closed circuit facility suitable for studying a wide range of aerodynamic and fluid dynamic phenomena. A drawing, which shows side and planform views and overall dimensions, is presented in Figure 2. The key design features of the tunnel are high flow quality and horizontal orientation. The horizontal configuration facilitates model access, enables models to be readily changed without draining the water from the tunnel, and provides for visualization of the flow axially from a downstream transverse window. The facility is operated as a continuous flow channel, i.e., the water level in the test section is not required to be at the top of the test section walls. Typically, the water level is adjusted to be approximately 2" below the top of the walls, negating the need for a sealed cover and providing simple access to the model while the tunnel is running. The entire circuit is constructed of non-corrosive materials supported by a painted structural steel framework. The primary components are constructed from molded polyurethane resin impregnated fiberglass. The interior surfaces are formed against a high gloss mold surface resulting in an exceptionally smooth finished surface. Exterior surfaces are composed of colored gel coat epoxy resin sprayed over fiberglass. The exterior is smooth to the touch and requires no paint.

The test section is nominally 24" wide, 36" high, and 72" long. It is constructed principally of tempered glass to permit maximum viewing of the model. The glass test section makes the water tunnel ideal for use with Particle Image Velocimetry (PIV) equipment. The test section and discharge plenum are configured to allow simultaneous viewing of a model from the top, bottom, both sides and from the rear. Viewing from the rear is especially advantageous when studying flow structures in the cross-flow plane. The centerline of the test section is 72" above the floor, resulting in 54" underneath the test section for convenient viewing and setup space for either direct or indirect (with a mirror) visual access for photography through the bottom of the test section. The tunnel centerline is near eye level for side and rear views. These heights were selected to provide eye-level viewing of the test section without the need for auxiliary platforms around the test section area. The area under the test section is completely clear since the return plumbing is routed to either side of the tunnel, or, if preferred by the customer, routed directly beneath the centerline of the tunnel below the floor level in a covered trench. Access underneath the test section is essential for obtaining photographs or for installation of video cameras. The test section flow velocity is variable from 0 up to 1.0 ft/sec. For most flow visualization testing using colored dye on the model surface, velocities in the range of 0.3 to 0.5 ft/sec are found to produce the best results. Higher speeds, approaching 1 ft/sec, are desirable for use with the submersible strain gage balance system because the larger dynamic pressure provides a better signal to noise ratio for the desired aerodynamic forces. The model support is mounted on top of the test section with the model inverted.

2.1 Circuit Component Descriptions

The following subsections describe the components of the basic tunnel circuit shown in Figure 2. The tunnel, with proper work area occupies a space approximately 40 ft. x 20 ft. The maximum height of the tunnel is approximately 8 ft. Ceiling height in the tunnel room should be 12 ft. minimum to permit installation/removal of the screens, models, etc. The facility will require a tap water supply and conventional drain system. The tunnel, when filled, contains approximately 5,000 gallons of water weighing approximately 40,000 lbs. The structure weight is about 8,000 lbs. The pump/motor is a 10 Hp, 2,800 gpm axial flow unit requiring a 230V, 3-phase, 60 Hz, 30-amp circuit. Other voltages can be accommodated for installations in other countries. Floor structure should accommodate a distributed load of 200 psf. All components prior to final assembly will pass through a 7 ft. x 4 ft. doorway.

2.1.1 Delivery Plenum/Flow Conditioners

Water is circulated at a flow rate up to 2,800 gallons/minute to provide up to 1.0 ft/sec flow rate in the test section. It enters the delivery plenum through a perforated cylinder arrangement located at the upstream end of the plenum. The perforated assembly absorbs sufficient energy to assure uniform delivery of water across the length of the cylinder. At the downstream end of the delivery plenum, there is a section with flow conditioning elements. The first is a perforated plate, which reduces the turbulence to a small scale, followed by two fiberglass screens that further reduce the turbulence level. The last is a honeycomb flow straightener. These flow conditioning elements can be easily rearranged or replaced to alter test conditions at the user's discretion.

2.1.2 Contraction Section

The contraction section has an area ratio of 6:1. The geometry has been selected to provide the minimum contraction length consistent with good velocity distribution, turbulence reduction, and avoidance of local separation and vorticity development.

2.1.3 Test Section

The test section internal dimensions are 24" wide, 36" high, and 72" long. The sidewalls diverge slightly to compensate for boundary layer growth and to maintain uniform flow velocity throughout. It is constructed of a painted steel frame with tempered glass on three sides. The tempered glass, 1/2" thick on the sidewalls and 3/4" thick on the bottom, is mounted with silicon rubber in the steel frame to assure a high safety factor in stress loads due to the weight and pressure of the water. Tempered glass was chosen over a Plexiglas or plastic based material primarily because of its superior resistance to scratches and because of its higher thermal conductivity, which allows it to more efficiently conduct heat away from nearby lamp sources used for lighting required for photography.

Laser velocimeter experiments can most successfully be conducted through tempered glass, where the thickness of the glass is constant and the surface is flat. Deflection of the surface will cause problems in keeping the laser beams focused on a preselected point if the laser beams are traversed to other locations in the test section.

The test section is constructed with a steel frame to provide a strong support platform for the model support hardware and provide a stable, low noise, environment for the 5-component strain gage balance. The model support base can be installed at alternate longitudinal positions on the frame, if desired, to maximize the available test section length either ahead of or behind the model. The frame also provides for the option of mounting other equipment on the section such as a 3-axis traversing system to be used for remote-controlled dye probes or hot film probes. The traversing system could also be used to mount and precisely position submersible LDV probes. RHRC has provided 3-axis traversing systems to be used in conjunction with the dynamic model support for previous customers. This optional equipment is available if the customer desires.

The model support system attaches to the top of the test section and the model is tested in an inverted position. The model support has a removable panel to provide easy access to the model while the tunnel is running and to vary the background for photography.

The level of flow quality (measured outside the wall boundary layer and below the surface flow) up to 1 ft/sec flow velocity in the test section is:

Turbulence Intensity Level: <1.0% RMS

Velocity Uniformity: < ±2%

Mean Flow Angularity: $\leq \pm 1.0°$ in both pitch and yaw angle

A velocity sensor is installed in the tunnel plumbing circuit and is calibrated to provide a digital readout of the test section velocity on the tunnel control system panel. If the 5-component submersible balance system is to be used, it is very desirable to upgrade to the Speed and Temperature Measurement System, which very accurately measures the velocity and temperature in the test section. This information is used to accurately calculate the dynamic pressure that the model experiences, which is necessary for the calculation of aerodynamic coefficients.

2.1.4 Discharge Plenum

The configuration of the discharge plenum downstream of the test section is a unique feature of this water tunnel. The plenum incorporates a downstream viewing window to allow direct viewing of the model from the rear, eliminating the need for mirrors. The discharge plenum configuration has been designed to insure that no flow angularity or turbulence is developed which could propagate upstream into the test section. Capped stainless steel perforated cylinders similar to the delivery section perforated cylinder are installed in the discharge section exit holes to eliminate ingestion of air in the return circuit due to a large vortices entering the discharge pipes. These cylindrical screens also prevent any foreign objects from entering the return plumbing to the pump.

2.1.5 Return and Supply Piping

From the discharge plenum, the water flows downward through two vertical pipes into a collecting header. From the header, the water flows forward along the side of the tunnel through a supply pipe to the pump lying directly beneath the contraction plenum. The plumbing is taken to the side of the tunnel (either side, depending on customer choice) in order to keep the area under the test section completely free for observation and for placing video and photographic equipment. If the return plumbing can be submerged below the floor level, a centerline return is most desirable. Centerline return plumbing without being submerged makes it nearly impossible to work under the test section to obtain planform views of the model and to cross conveniently from one side of the test section to the other for alternate side views without walking around the end of the tunnel. This plumbing arrangement is not recommended. Vibration isolation joints are provided between the pump and supply/return piping. A fitting and valve is provided at the low point of the piping to permit draining the facility.

2.1.6 Pump/Motor

The water is circulated with a 2800 gpm capacity axial-flow pump driven by a variable-speed 7.5 HP electric motor. The pump housing is constructed of cast iron and is coated to prevent rust and corrosion. The impeller is made of bronze and is mounted on a stainless steel shaft. The test section flow velocity can be varied between 0 and 1.0 fps, irrespective of the changing head losses in the test section due to model size and attitude. Pump controls are mounted on a panel located near the test section area. Instrumentation to measure and display the test section velocity is provided.

2.1.7 Dye Supply System

A pressurized, six-color dye system using water-soluble food coloring is provided with individually routed lines from the dye canisters to the model support system. The system allows precise control of the rate of dye emission and provides a means of blowing air out of the dye lines going to the model. The dye canisters can be pressurized with a shop air system (or with an optional small compressor mounted on the tunnel) and the pressure level (20 psi maximum) is controlled by a pressure regulator. The quantity of dye is regulated for each canister by individual valves located on a panel near the test section.

2.1.8 Inlet Suction System (Optional)

For some experiments it is important to simulate the mass flow through the engine inlets for real aircraft models. A suction system consisting of a small pump and appropriate valves and flow meters is provided to vary the flow through separate engine inlets as desired to simulate zero to maximum inlet flow for a wide class of airplanes.

2.1.9 Jet Exhaust System (Optional)

A system to simulate the flow exiting from a jet exhaust can also be provided, if desired. A small pump similar to the inlet suction system pump and appropriate valves and a flow meter will be provided to simulate and regulate the flow.

2.1.10 Filtration System

Gradual discoloration of the water results from continued use of dye. The coloration can be removed periodically by adding a small amount of chlorine to the water. A filtration system is also provided for filtering and cleaning the water. This system utilizes a 3/4 Hp pump/motor with a strainer and a filter unit. The filtration system is normally operated when the tunnel is not in use, typically overnight. After extended operation, the water must be replaced. Tunnel drain and fill connections are provided for this purpose.

2.1.11 Tunnel Control

The tunnel speed control is a compact, all-digital, low-noise, inverter. Speed increments for speed selection (up or down) are adjustable by the user and speed (in user selected units) is displayed with a digital readout. The tunnel speed control integrates into the Computer Controlled Model Support System and 5-Component Balance System to provide computer control of the tunnel speed, and allow fully automated operation.

3 FACILITY DESCRIPTION - MODEL 1520

The Rolling Hills Research Corporation Model 1520 Water Tunnel is nearly identical to the Model 2436, but with a smaller test section. A drawing, which shows side and planform views and overall dimensions, is presented in Figure 3. The test section is nominally 15" wide, 20" high, and 60" long. The centerline of the test section is 66" above the floor, resulting in 56" underneath the test section for convenient viewing and setup space for either direct or indirect (with a mirror) visual access for photography through the bottom of the test section. The tempered glass, 3/8" thick on the sidewalls and 1/2" thick on the bottom, is mounted with silicon rubber, as with the Model 2436. The tunnel centerline is near eye level for side and rear views. These heights were selected to provide eye-level viewing of the test section without the need for auxiliary platforms around the test section area. The area under the test section is completely clear since the return plumbing is routed to either side of the tunnel, or, if preferred by the customer, routed directly beneath the centerline of the tunnel below the floor level in a covered trench. Access underneath the test section is essential for obtaining photographs or for installation of video cameras. The test section flow velocity is variable from 0 up to 1.0 ft/sec. For most flow visualization testing using colored dye on the model surface, velocities in the range of 0.3 to 0.5 ft/sec are found to produce the best results. Higher speeds, approaching 1 ft/sec, are desirable for use with the submersible strain gage balance system because the larger dynamic pressure provides a better signal to noise ratio for the desired aerodynamic forces. If flow quality is less of a concern, higher speed options are available for the Model 1520.

The tunnel, with proper work area occupies a space approximately 30 ft. x 15 ft. The maximum height of the tunnel is approximately 6.5 ft. Ceiling height in the tunnel room should be 9 ft. minimum to permit installation/removal of the screens, models, etc. The facility will require a tap water supply and conventional drain system. The tunnel, when filled, contains approximately 1,000 gallons of water weighing approximately 7,500 lbs. The structure weight is about 2,000 lbs. The pump/motor is a 5.0 HP, 900-gpm axial flow unit requiring a 230V, 3-phase, 60 Hz, 20-amp circuit. Other voltages can be accommodated. Floor structure should accommodate a distributed load of 100 psf. All components prior to final assembly will pass through a 7 ft. x 6 ft. doorway.

4 MODEL 1520 OR 2436 KIT OPTION

The Model 1520 and 2436 Flow Visualization Water Tunnels can be provided as a turnkey installation as described in detail in Sections 2 & 3. The basic turnkey tunnel configuration has a variable-speed drive motor and controller and axial-flow pump to provide for continuous tunnel speed variation from 0 to 1 ft/sec. The Kit Option is now being offered in order to reduce the cost of acquiring the tunnel by allowing the customer to perform many of the component assembly and installation tasks, reducing the labor content required by RHRC.

The basic tunnel kit is offered with a variable speed axial flow pump with continuous speed control capability between 0 and 1 ft/sec, identical to the turnkey tunnel. A complete set of instructions including a written manual with photographs is to be supplied with the tunnel components to assist the customer in the on-site assembly and installation.

The kit version does not include the dedicated air compressor for the dye delivery system for customers who do not have shop air (20 psi is maximum required), and the inlet and jet exhaust systems, which are, specialized options for aircraft configurations. All of these are options, as well as the computer controlled model support system and 5-component balance system, are available for an additional charge, if desired.

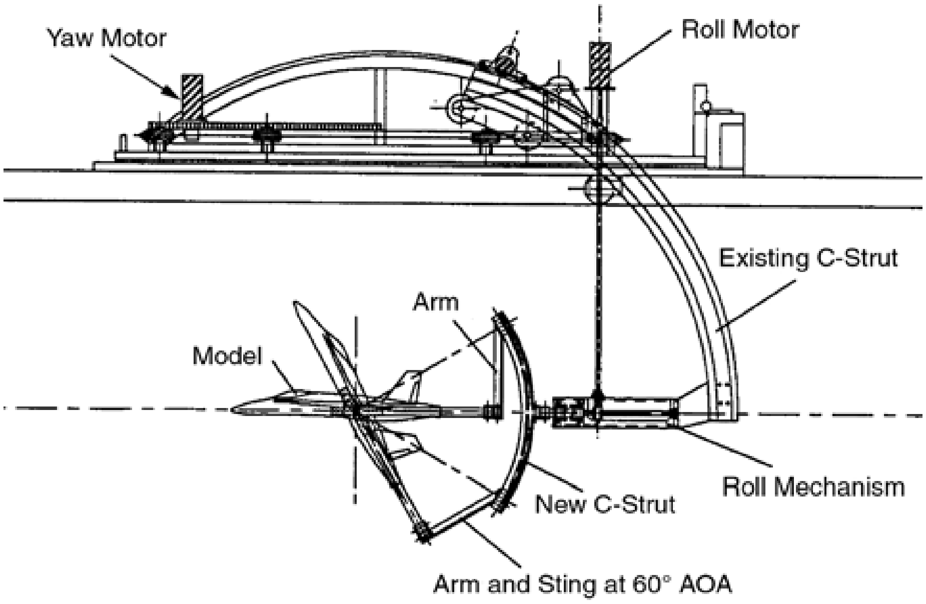
Regardless of whether the tunnel is purchased as a kit or turnkey installation, the entire tunnel is assembled, tested, and calibrated in the RHRC laboratory, and then disassembled and shipped to the customer.

Currently, the only major option available for the Model 1520 is for a higher top speed:

OPTION B – Provides an increased top speed in the test section of approximately 3 ft/sec. To achieve this top speed, the main pump and motor are increased to the size normally used in the Model 2436, the speed controller size is increased, the return plumbing is enlarged from 8” diameter to 10”, and the fiberglass inlet and exit fittings are enlarged, as are the inlet and exit flow baffles.

5 DYNAMIC MODEL SUPPORT SYSTEM

Rolling Hills Research Corporation is a leading supplier of water tunnels for industry and research, with the "Eidetics" brand being produced since 1985. Because RHRC also conducts research in its own water tunnel, the facility has been continuously enhanced. The latest enhancement is a computer controlled model support system that is designed to provide very smooth, accurate motions. When used in combination with RHRC'S submersible 5-component semi-conductor strain gage balance, the system is capable of performing experiments that previously could only be performed in expensive, specialized wind tunnels. Now, experiments such as forced oscillations and rotary balance motions can be performed in the water tunnel with the extra benefit of excellent flow visualization of complex flows.



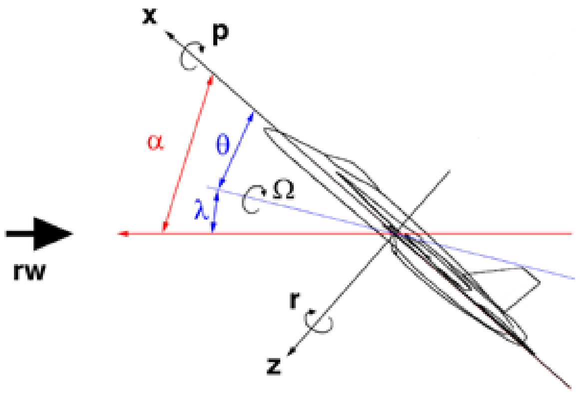
Historically, dynamic experiments, such as forced oscillation and rotary balance, have been performed very late in an aircraft design program, if at all. By the time this type of test is conducted, it is normally financially and politically unacceptable to drastically alter a configuration. However, if the dynamics of a configuration are examined early in a program, changes can be made with minimum impact, and potential problem areas can be avoided. The low cost of water tunnel models and experiments make them excellent options for a first look at a configuration.

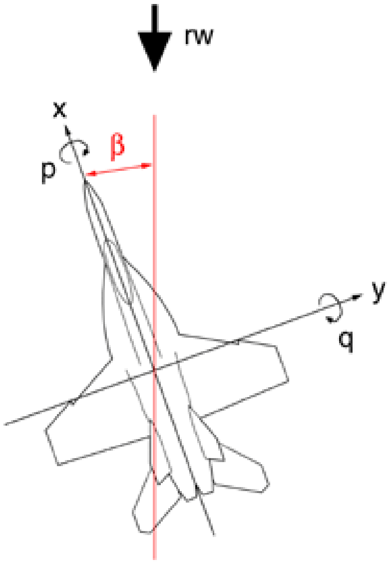
Current accepted wind tunnel techniques for measuring vehicle dynamics are typically conducted at very low tunnel velocities. This is primarily because the aircraft rotational motions scale with the tunnel speed. Even at these low speeds, the loads on a wind tunnel support system can be very large, effectively limiting the model rotation rates. In conjunction with this, the inertial loads from the model can be much larger than the aerodynamics that the researcher is trying to measure.

Free surface water tunnels are normally run at speeds of less than 1 ft/s, in order to provide high quality flow visualization and low turbulence. At these tunnel speeds, the reduced frequencies generated by a full-scale maneuver produce a slow-scaled response, so the rotational inertial loads are negligible. This means that many of the difficulties normally encountered in dynamic testing are not present in the water tunnel. The model support for a water tunnel does not have to be nearly as strong and cumbersome, and the only tare that needs to be removed is the gravity tare. These factors create a test environment where high quality data can be obtained relatively inexpensively.

5.1 Model Support Components

5.1.1 Basic Angle Definitions





5.1.2 Standard Yaw and Pitch Sector

The yaw axis is driven by a high torque servomotor, providing an inertially fixed yaw motion (y). An optical encoder is used to provide position and speed feedback. The yaw axis is supported on a large circular anodized aluminum sector, with the center of the arc defining the model rotation center. When configured for the Model 2436 tunnel, the yaw angle can be varied from ±22°, while in the Model 1520, angles of ±10° are achievable. A large C-strut is mounted on the yaw table, in the vertical plane, to provide motion in the pitch direction (q). The pitch angle can be varied from 0° to 45°. A C-strut extension is available that adds an additional 10° of pitch motion, while the small C-strut included with the Rotary Balance Rig adds an additional 60° of pitch angle.

5.1.3 Roll Axis and Rotary Balance

The roll motor is contained in a waterproof housing that is attached to the end of the large C-strut. The motor housing is equipped with a moisture sensor that alerts the user to any potential leaks. The roll motor uses a planetary gear head with backlash of less than ½°. The rotary balance provides a small C-Strut that is mounted between the model and the roll motor housing. The rotary balance C-strut uses a series of screw holes to provide angle settings at every 1°. At first glance, the small C-strut seems to provide a redundant pitch axis. In fact, when the large C-strut is set to 0°, the small C-strut can be used to set q from 0° to 60°. When the small C-strut is set to 0°, the roll motor can be used to provide body-axis roll motions. When the large C-strut is set to 0°, the small C-strut can be set to provide q, but now the roll motor will produce a rolling motion about the velocity vector. This motion is referred to as coning or rotary balance motion. This type of motion was formerly used to investigate the spin characteristics of aircraft, but more recently it has been used to study the agility of modern fighter aircraft. If a rotary balance motion is performed with the large C-strut at a non-zero angle, the resulting motion is referred to as inclined axis coning. The resulting motion provides coning with a once-per-revolution oscillation in both angle-of-attack and sideslip, which are 90° out of phase with each other.

5.1.4 PID Control System

The RHRC model support system uses the National Instruments FlexMotion system to provide the basic proportional-integral-differential feedback and control system. The system consists of a servo motor power supply and amplifier and a PCI based computer board that reads and processes the optical encoder signals. Electrical limit switches are integrated into the system to provide protection for the model support hardware in the event of an unintended command. When a limit switch is triggered, the power to the servomotor is immediately disconnected.

5.1.5 Experiment Control Software

RHRC provides an extensive software package for experiment control, data acquisition, and data processing. The software is written using National Instruments LabVIEW API, and provides a user-friendly, graphical, interface. The software provides integration between the dynamic model support system, the 5-component submersible balance, and the water tunnel controls. The system is capable of running in an autonomous mode where weight tares, up-zeroes, tunnel speed control, model motion, and data down-zeroes can be performed for a series of runs. Experiments can always be run in a manual, interactive, mode as well.

5.2 Available Experiments

The chart in Figure 4 shows a graphical summary of the experiments that are available with the computer controlled model support. These tests can be run in either manually, or in a completely automated fashion. In the manual mode, the researcher must record a weight tare and a wind-off zero before setting the tunnel velocity and moving the model through the desired motion. In the automated mode, the research specifies a run schedule of various desired experiments. The system first checks that the inputs are legitimate and can be produced, it then automatically records the required weight tares and zeroes and then starts the tunnel and records the aerodynamic forces and moments on the model. After the run, the balance calibration is applied and the data is reduced to traditional body-axis coefficients.

5.2.1 Static Aerodynamics

Static aerodynamics may be measured in several ways. The model may be manually commanded to a desired point and the balance output recorded, or several automated modes may be used. The typical automated static test would run a series of angles-of-attack at specified sideslip angles and tunnel speeds. The system is set up to wait until the balance signal reaches a steady state value before proceeding to the next data point.

5.2.2 Single Axis Ramp-and-Hold

This type of motion is useful for investigating phenomenon such as dynamic lift overshoot. The data is recorded as a function of time so the enhanced lift can be observed to decay.

5.2.3 Single Axis Sine-Wave Forced Oscillation

The sine-wave motion is used in classical wind tunnel forced oscillation experiments. The motion is defined by a frequency and amplitude about a center point. Typically these motions are produced about one of the three body axes: roll, pitch, or yaw.

5.2.4 Single Axis Constant Rate Forced Oscillation

RHRC has developed a slightly different forced oscillation technique where a constant rate is held across as much of the motion amplitude as possible. This kind of forced oscillation is useful for extracting steady state derivatives as a function of rate. These motions are also typically produced about one of the three body axes: roll, pitch, or yaw.

5.2.5 Multi-Axis Forced Oscillation

In addition to forced oscillations about a single axis, motions may be specified that combine rates in all three axes simultaneously. This is a very unique feature to this facility, and it has been put to good use by RHRC in investigating the validity of mathematical superposition applied to the aerodynamics generated by dynamic motions.

5.2.6 Rotary Balance – Coning Motion

The rotary balance produces a motion that resembles a cone. This motion occurs when an aircraft is at a constant angle-of-attack, and commands a roll around the velocity vector. This type of motion is common for fighter aircraft at higher angles-of-attack when they are performing tracking maneuvers. At AOAs approaching 90°, the coning motion resembles a flat spin and is also of great interest for general aviation vehicles.

5.2.7 Inclined Axis Coning

Inclined coning is identical to the rotary balance motion, except that the rotational motion is about an axis that is skewed from the velocity vector. This motion results in an oscillating angle-of-attack and sideslip at the frequency of the coning, and with magnitudes that are equal to the angle that the rotation is skewed from the velocity vector.

5.2.8 Coning Motion with Superimposed Forced Oscillations

This rather unique experiment was first specified by Dr. Murray Tobak and Dr. Lewis Schiff of NASA Ames. While it is similar to the inclined coning motion described above, it has the distinct advantage of separating the frequency of coning from the frequency and magnitude of the forced oscillation.

5.2.9 Arbitrary Motions

The system is able to accept a time history of a desired motion, and recreate it in the water tunnel.

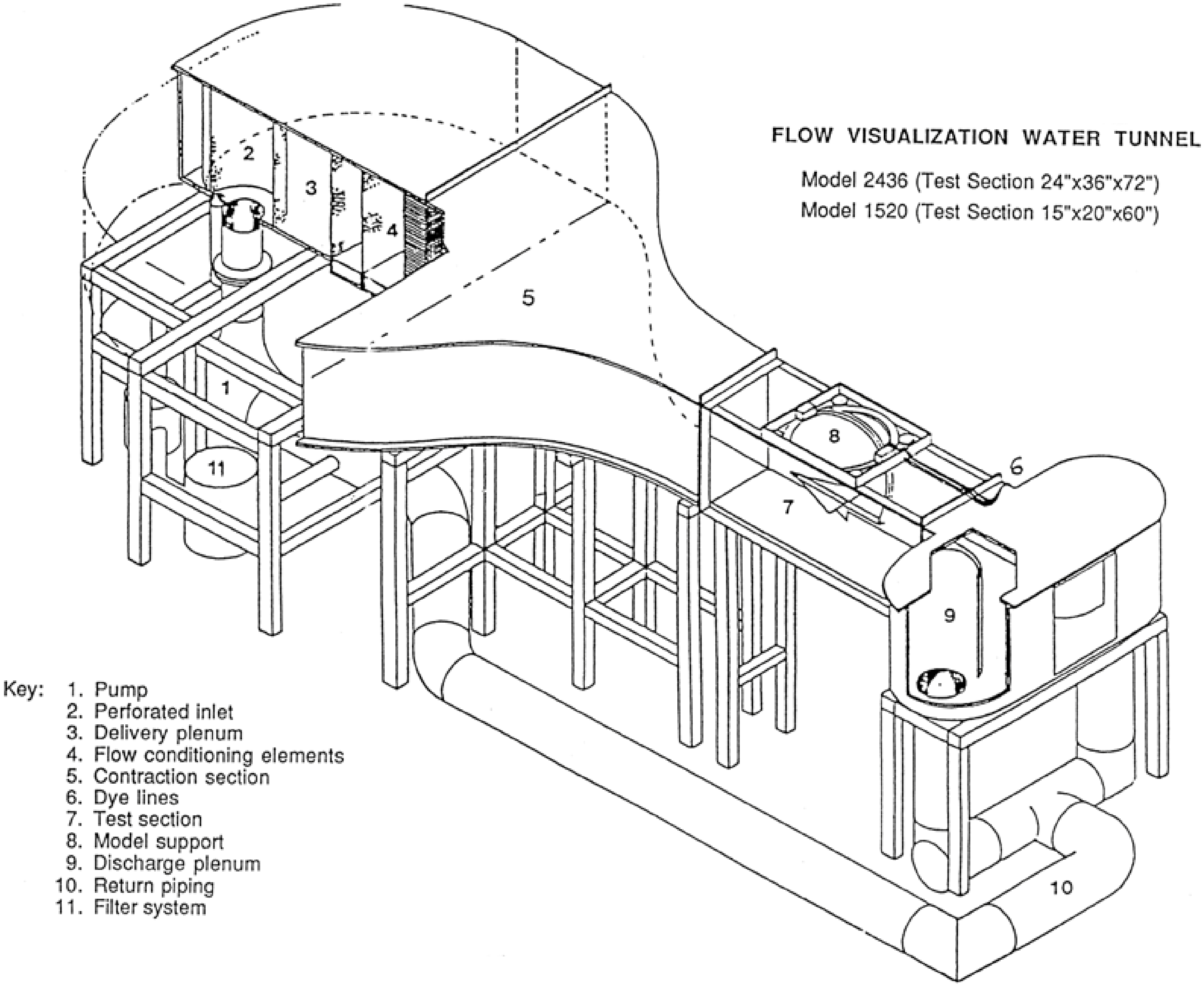
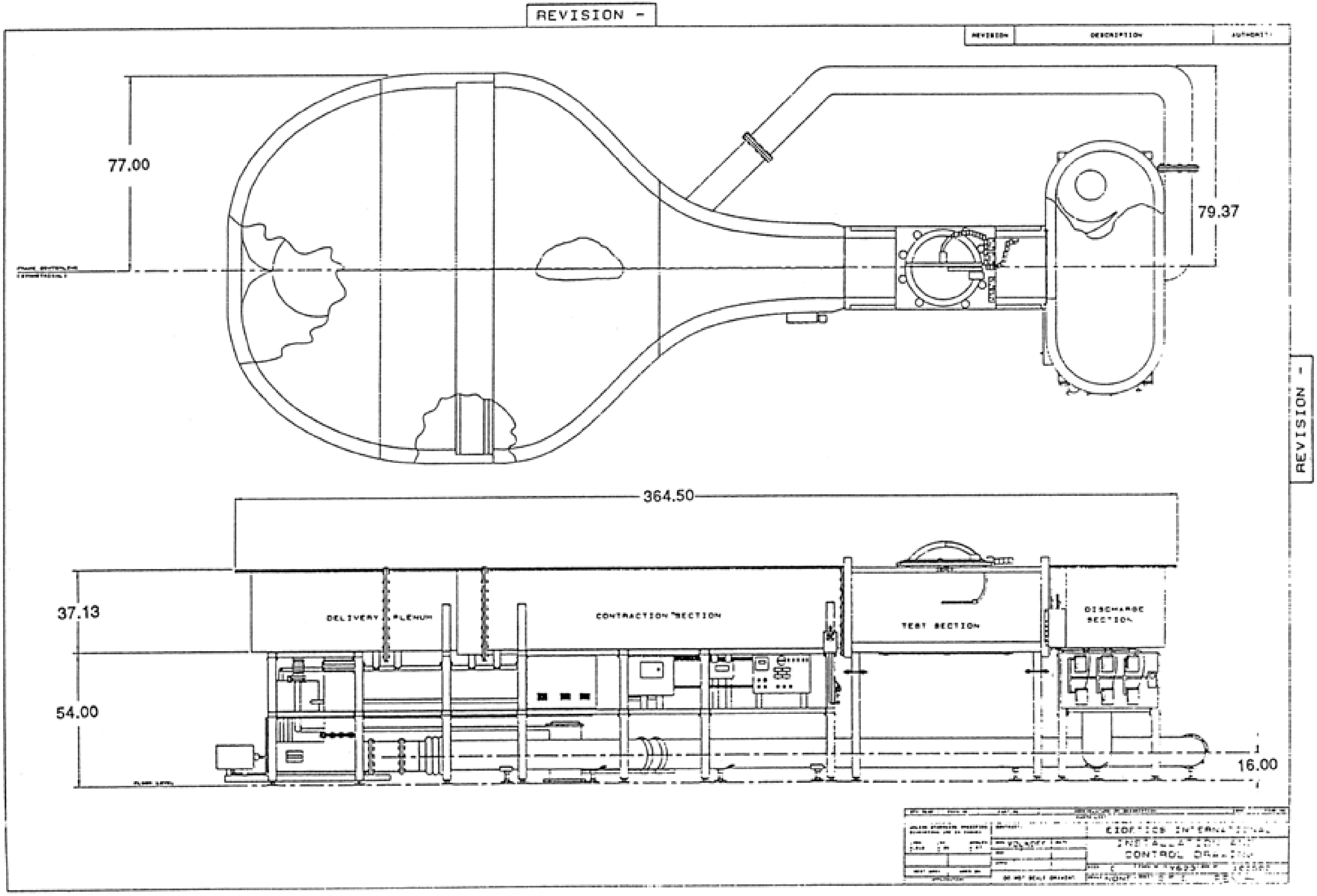


Figure 1: General RHRC Water Tunnel Layout



Model 2436 Water Tunnel

Figure 2: RHRC Model 2436 Water Tunnel

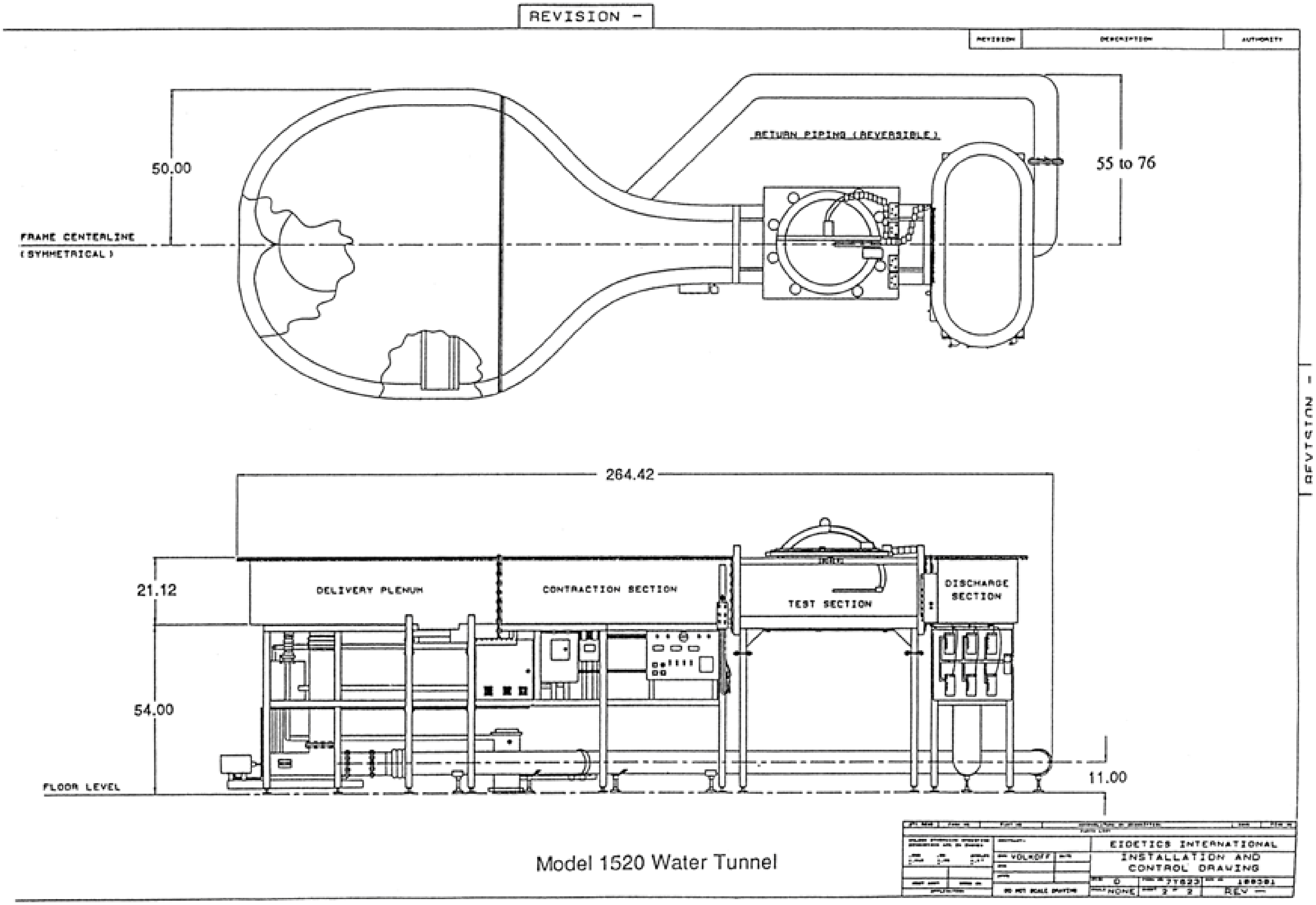
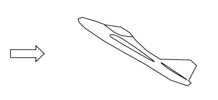
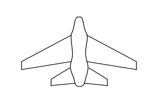
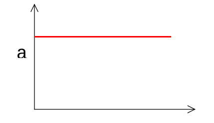
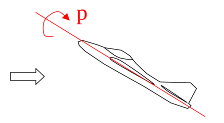
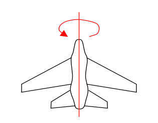
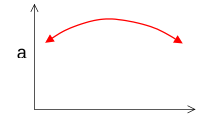
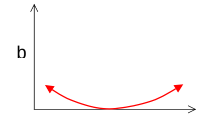
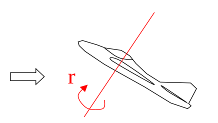
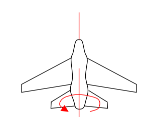
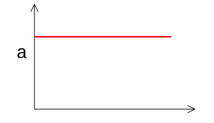
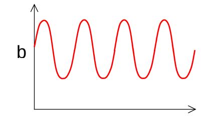
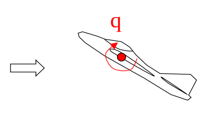
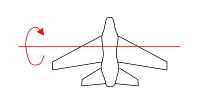
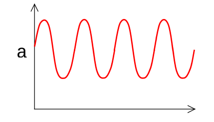
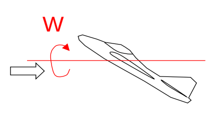
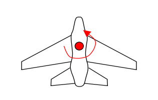
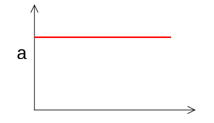
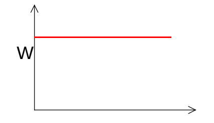
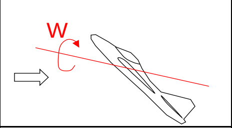
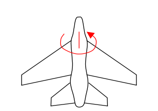
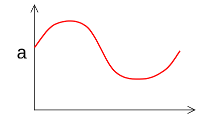
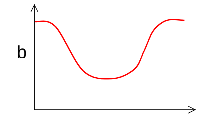
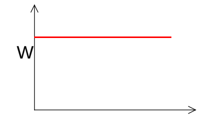
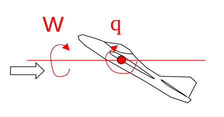
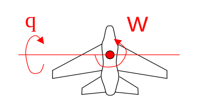
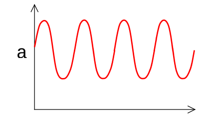
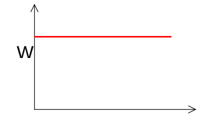
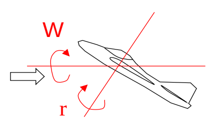
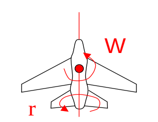
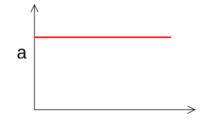
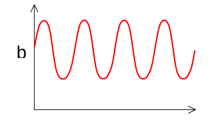
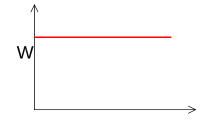


Figure 3: RHRC Model 1520 Water Tunnel

Experiment	Side View	Front View	a History	b History	WHistory
Static					
Body Axis Roll					
Body Axis Yaw					
Body Axis Pitch					
Velocity Vector Roll					
Inclined Axis					
Tobak-Schiff Pitch*					
Tobak-Schiff Yaw*					

- requires 10° c-strut extension

Figure 4: Experiment Capability of RHRC Computer-Controlled Model Support System

RHRC RESEARCH WATER TUNNEL INSTALLATIONS

Customer/Location	Model No.	Date
Military University of Technology, Warsaw, Poland	2436	2012
University of Nebraska, Lincoln, Nebraska	2436-Long	2012
University of Washington, Friday Harbor Labs	1520H	2012
University of Massachusetts, Amherst, Massachusetts	1520HK	2011
Missouri University of Science and Technology, Rolla, Missouri	1520HK	2011
Wrocław University of Technology, Wrocław, Poland	2436	2009
Old Dominion University, Norfolk, Virginia	1520K	2009
University of Virginia, Charlottesville, Virginia	1520HK	2009
Carleton University, Ottawa, Canada	2436	2008
University of Alabama, Tuscaloosa, Alabama	1520EXT	2006
University of Rhode Island, Kingston, Rhode Island	1520H	2005
Tuskegee University, Tuskegee, Alabama	1520K	2004
Universidad Autonoma de San Luis Potosi, SLP, Mexico	1520K	2003
Centre National de la Recherche Scientifique, Marseille, France	1520HK	2003
University of Bath, Bath, United Kingdom	1520	1999
Agency for Defence Development, Taejon, Korea	2436	1998
University of Akron, Akron, OH	1520HK	1997
University of Texas at Austin, Austin, TX	1520K	1997
Saab Military Aircraft, Linkoping, Sweden	1520K	1995
Berkley Outdoor Recreation, Spirit Lake, IA	1520HK	1995
Institute of Aerospace Research, National Research Council Ottawa, Ontario, Canada	1520K	1995
Western Michigan University, Kalamazoo, MI	1520K	1994
Cornell University, Ithaca, NY	1520K	1994
Notre Dame University, Notre Dame, IN	1520K	1993
Rockwell International, El Segundo, CA	2436	1990
Parks College, St. Louis, MO	1520	1989
RHRC Laboratory, El Segundo, CA	2436	1989
McDonnell Aircraft Co., St. Louis, MO	1520P	1989
Texas A&M University, College Station, TX	2436H	1989
Singapore Aerospace, Singapore	2436	1989
Aeronautical Research Lab, Melbourne, Australia	1520H	1989
U.S. Air Force Academy, Colorado Springs, CO	1520	1989
AerMacchi, S.P.A., Varese, Italy	2436	1989
Naval Postgraduate School, Monterey, CA	1520	1988