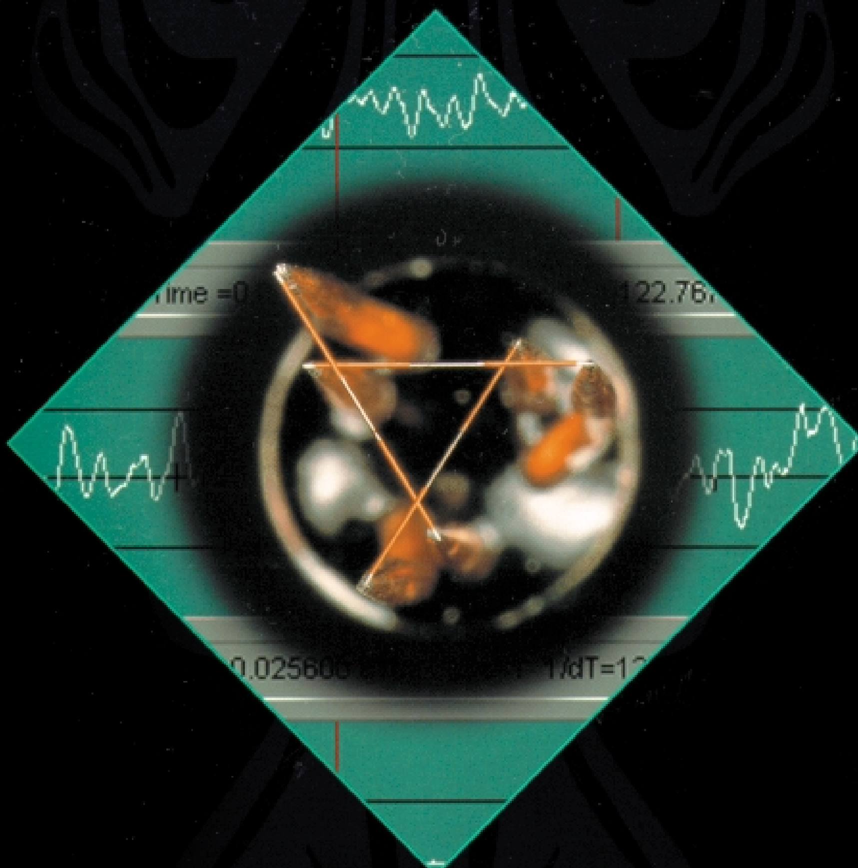
Innovation In Thermal Anemometry



A Complete Family of Thermal Anemometry Systems, Probes, and Accessories

TSI®

TSI—The first choice in fluid mechanics

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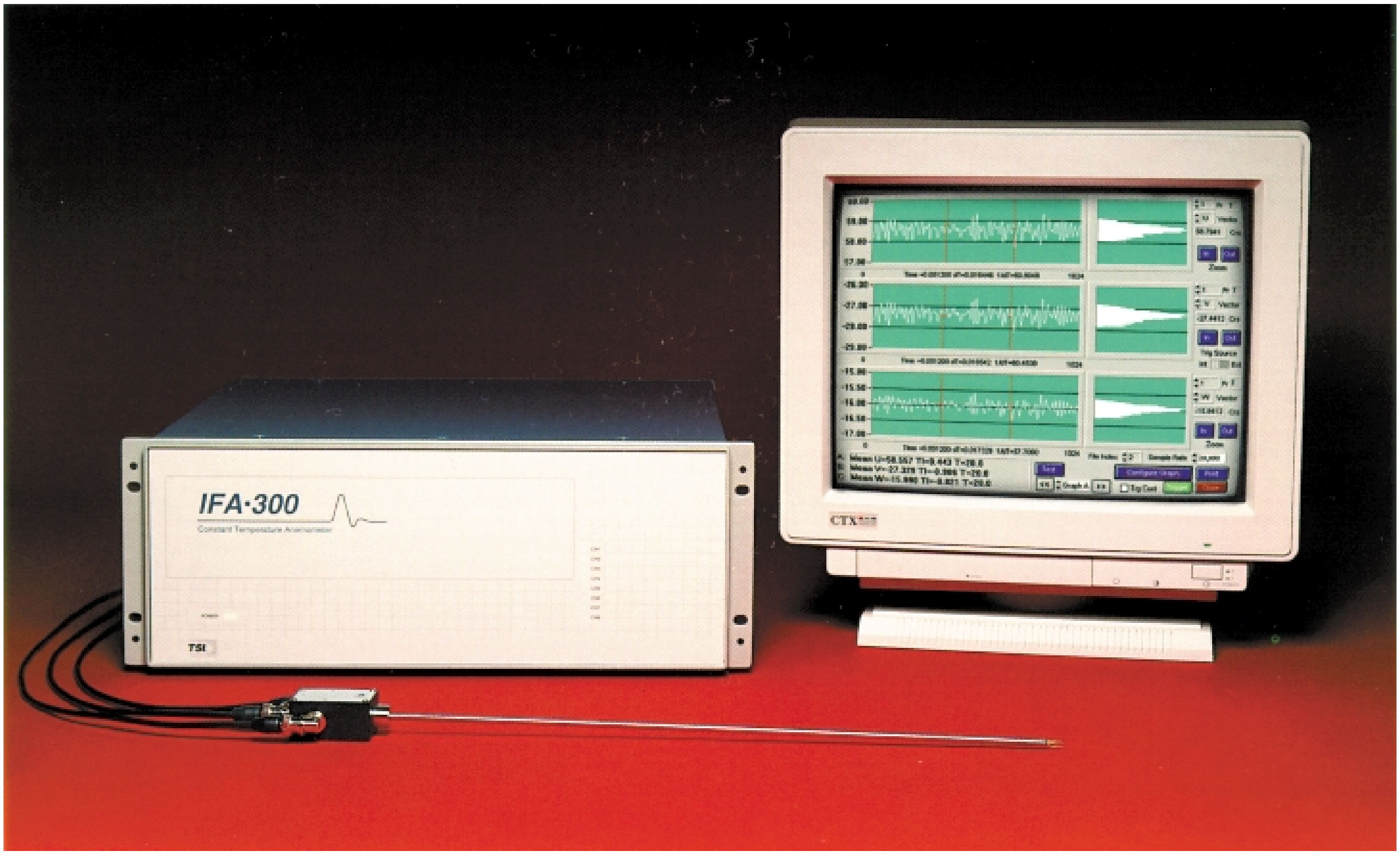
Introduction to Thermal Anemometry



Principles of Operation

Thermal anemometers measure fluid velocity by sensing the changes in heat transfer from a small, electrically-heated element exposed to the fluid. In the “constant temperature anemometer” the cooling effect produced by the flow passing over the element is balanced by the electrical current to the element, so that the element is held at a constant temperature. The change in current due to a change in flow velocity shows up as a voltage at the anemometer output. A modern anemometer will be linked to a personal computer, where the data is analyzed and presented to researchers in terms appropriate to their studies.

A key feature of the thermal anemometer is its ability to measure very rapid changes in velocity. This is accomplished by coupling a very fine sensing element (typically a wire four to six microns in diameter or a platinum thin-film deposited on a quartz substrate) with a fast feedback circuit which compensates for the drop in the natural response of the sensor. Time response to flow fluctuations as short as three microseconds can be achieved easily.

It is for this reason the thermal anemometer has become a standard tool for researchers examining the nature of turbulence. The small sensor size, normally only a millimeter in length, also makes this technique valuable in applications where access is difficult or where larger sensors obstruct the flow.

Since the actual measurement is of heat transfer between the sensor and its environment, the thermal anemometer will respond to changes in parameters other than velocity, such as temperature, pressure, and fluid composition. While this adds to versatility, it also means that when more than one parameter is changing, special techniques must be used. Modern systems generally include provisions for correcting the velocity reading automatically for temperature changes.

The limitations of the device are few. Accurate data analysis can become difficult in highly turbulent, non-isotropic, or reversing flows, and frequent sensor replacement may be necessary when working in liquid or particle laden flows. Even under these conditions, with care and regular sensor calibration, the instrument has proven itself as an excellent tool for fluid mechanics research.

Selecting A System

A modern thermal anemometer system gives the researcher complete results presented in fluid dynamics terms. Any such system includes five discrete elements: one or more probes and probe supports,anemometer electronics, analog-to-digital converter, data analysis software, and a calibration device. Some elements (probes, for example) offer the user many choices, while others offer only a few. These elements are all described here and then expanded later in the catalog. This section should be consulted when considering purchase of a complete system, to ensure that all key elements are selected.

Probes and Probe Supports

TSI offers a wide variety of probes. They vary in both the type of sensor used and the design of the probe which supports it. When selecting a probe, the user must choose between cylindrical and non-cylindrical sensors and/or between film and wire sensors. The choice is based on the fluid characteristics, the velocity range, the number of velocity components, contamination in the flow, and access to the flow.

TSI's probe supports are categorized into single- and dual-sensor probe supports and rigid and flexible types. Very often, a locking and protective shield is also used with a rigid probe support to provide added mechanical protection to the sensor and rigidity to the probe. Rigid probe supports are good for traversing across a test section while a flexible probe support is useful in a space-limited environment.

Film Sensors

The rigidity and strength of cylindrical film sensors, relative to wire sensors, make them the preferred choice in a wide range of thermal anemometry applications. Rigidity is especially important for multi-sensor measurements where the algorithms used for data reduction assume a straight sensor. Also, film sensors are less susceptible to damage or coating by particles in the flow than are wire sensors.

TSI hot film sensors are constructed of a high purity platinum film on a fused-quartz substrate. Platinum provides the most stable, anticorrosive film material available, while the quartz substrate provides high strength and low thermal conductivity. As a result, the "standard" 51 µm-diameter cylindrical hot film sensor has about the same spatial resolution (in three-dimensional flows, when length dominates) and conduction to the supports as a 4 µm-diameter tungsten wire. Film sensors with diameters of 25 µm and 152 µm are also available.

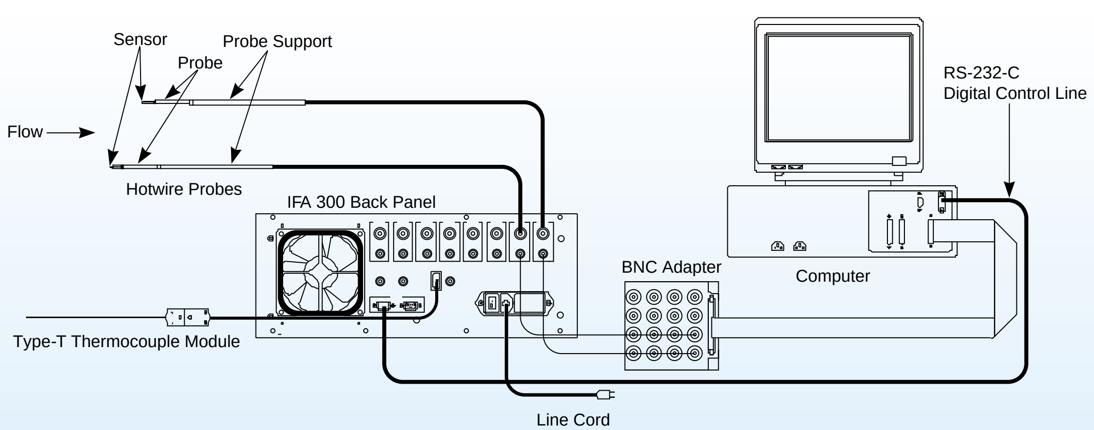
For applications in air, an alumina coating provides abrasion resistance, while for water and other conductive liquids a quartz coating provides electrical isolation from the fluid. Sensors with no coating can be provided (and are preferred) for truly non-conducting liquids. Gold plating on the ends isolates the sensor from the supports.

Non-cylindrical film sensors are particularly useful in water, in flows where substantial contamination cannot be avoided, or in situations where an exceptionally rugged sensor is required. Flush mounted film sensors for measuring wall shear, heat flux, or flow separation are also available.

Wire Sensors

The traditional sensor for research thermal anemometry has been a fine wire. For very low turbulence intensities, the wire sensor is still superior—and the smaller the wire, the better the results. For those applications that require a wire sensor, the 4 µm-diameter, platinum-coated tungsten wire is almost a standard for measurements at normal room temperatures and below. Tungsten is very strong and has a high temperature coefficient of resistance. It will, however, deteriorate at high temperatures in oxidizing atmospheres (such as air). Platinum wires, though weaker, can also be made very small and will withstand high temperatures in an oxidizing atmosphere. If more strength is needed at high temperatures, an alloy such as platinum-iridium should be used.

The standard 4 µm tungsten wires have the active portion of the sensor isolated from the supports with copper plating. The copper-plated portion is then soldered to the specially formed, low resistance support needles. Other techniques are also used, depending on the expected temperature of the fluid and the wire material. The design, construction, and mounting of the sensors listed in this catalog have



been optimized to satisfy nearly all requirements for flow measurements using wires.

Sensor Velocity Range

Physical limits to sensor performance on the high velocity end derive from two sources: contaminants in the flow striking the sensor and dynamic loading on the sensor from the fluid itself. For most applications with hot wires, contaminants are the major source of sensor breakage or sensor strain which causes calibration to change. Film sensors eliminate the strain problem and also require larger contaminants to cause breakage.

In reasonably clean flows, most wire sensors 4 µm in diameter or larger should survive at velocities below 300 m/s in room temperature air. An exception is platinum wires, where even fluid loading can be a problem, especially at high temperatures. Non-cylindrical sensors such as cones and wedges can survive very high velocities. To damage such a sensor, a contaminant would have to harm the point or edge of the sensor, changing the calibration.

Data interpretation in high velocity gases, especially transonic or supersonic flows, can be very difficult. Traditionally, compressibility effects have been assumed to start influencing data above 100 m/s in room temperature air. At the low velocity end, free convection impacts the ability to make accurate measurements. A typical value used as a minimum for air is 0.15 m/s. However, if the flow is vertical and always in the upward direction (same direction as the flow due to free convection), at a low sensor temperature (e.g. 40 °C) mean flow measurements down to 0.01 m/s can be made successfully. In water, the minimum velocity is about one-fifth the value in air and maximum water flow is up to 10 m/s.

Anemometer Electronics

Two main electronics packages are available from TSI. With either one, up to sixteen sensors can be operated simultaneously by selecting the appropriate number of anemometer channels and both anemometers come with integrated signal conditioning electronics.

The IFA 300 Research Constant Temperature Anemometer, is a general purpose anemometer which can be used for any flow measurement where thermal anemometry can be used. It features ultrahigh frequency response and low-noise circuits together with the revolutionary SmartTune™ bridge optimization technology which eliminates tuning, whether manual or done by computer mouse. Optional electronics can be used to operate a wire sensor as a high-frequency-resistance thermometer for temperature measurements and for correcting velocity data.

The FlowPoint™ Velocity Measuring System is the second package offered by TSI It offers ease of use and maximum value to the researcher who does not need to measure flow fluctuations above 10 kHz or more than two velocity components. Many industrial users and educational institutions find this product an ideal combination of economy and capability since it easily handles most applications up to velocities of 50 to 75 m/s.

Examples

The following examples demonstrate the process of selecting a system to meet specific application requirements.

Example 1. You require frequent measurements of three components in a flow of 50 m/s.

Component	TSI Recommended	Reason
Probe	1299-20-18	Three-sensor probe needed
Anemometer	Three channel IFA 300 (one IFA 300 and two 183150)	Three-component measurement capability at single location
Software	ThermalPro Software	Three-component analysis necessary
Calibration	Model 1128A or 1129 calibrator	Frequent measurements require convenience of field calibration
A/D Converter	ADCWIN-4	Includes sample and hold—four-channel capability sufficient

Example 2. Your application requires measuring of clean water flows ranging from 0.1 to 1 m/s and the flow direction is known.

Component	TSI Recommended	Reason
Probe	1210-20W, 1150, 1158	Good sensitivity, resistance to damage, easily repaired
Anemometer	FlowPoint (one 1500-2)	Low cost—frequency response requirements are low in liquid flows
Software	Included with FlowPoint	
Calibration	TSI water flow calibration	Necessary unless customer has a calibrated water flow facility
A/D Converter	Included with FlowPoint, without sample/hold	Sample and hold not needed for single channel

Analog-to-Digital Converters

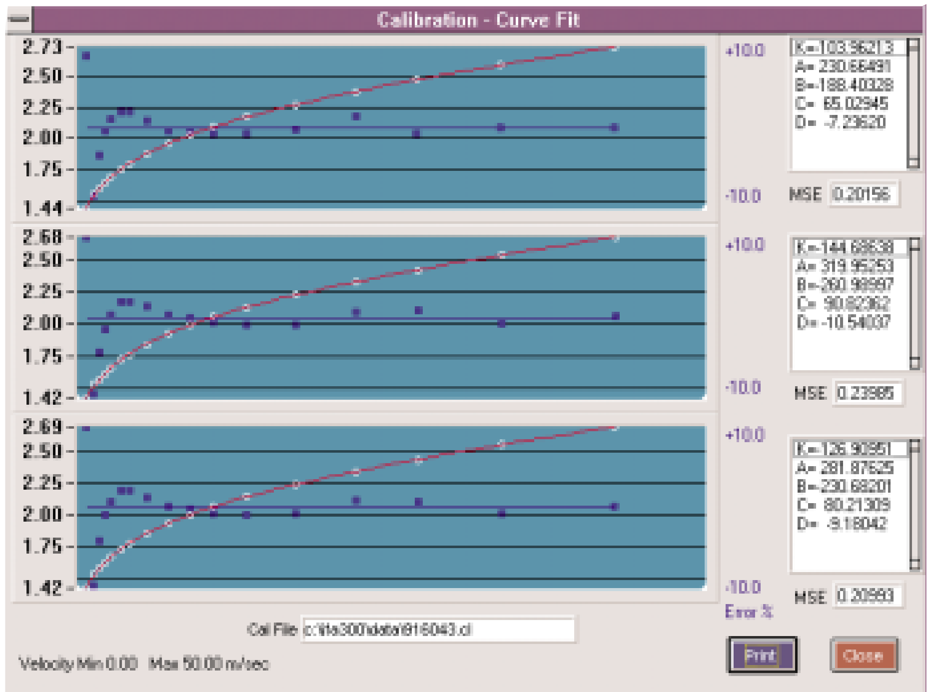
The interface which converts the analog voltage output of the anemometer to a digital form for use by a computer is essential to any modern anemometer. Several things must be considered when evaluating A/D converters for use with anemometers. These include making sure the digitizing rate is adequate to obtain the required frequency response (which may be as high as one megasample per second when used with the IFA 300) and ensuring that resolution is sufficient to resolve small changes in velocity. When used with the analog zero suppression and gain circuits found in the IFA 300 and FLOWPOINT, twelve bits is sufficient. In most cases, the ability to simultaneously sample multiple channels of analog input is also necessary when correlating two or more sensor inputs. TSI offers several A/D converters which meet these requirements, but due to the rapid change in technology in this area, it is wise to contact TSI directly to get the latest specifications.

Data Analysis Software

Once data is acquired by the computer, comprehensive, easy-to-use data analysis software is essential. TSI software is matched to the anemometer. The THERMALPRO™ software used with the IFA 300 is written using LabWindows CVI™ and runs under Windows™ 3.1 for 486 or Pentium computers. It offers complete experiment documentation, automated calibration, traverse control, and data acquisition and analysis for up to sixteen anemometer channels. Complete sensor calibration and detailed analysis and display of three-sensor data are also features of this package. Users of TSI's older IFA 100 anemometer can also upgrade their systems with this software, although some features are not accessible.

The second software package, included with the FLOWPOINT anemometer, is similar to the THERMALPRO package in configuration. The FLOWPOINT software runs under DOS, using LabWindows™. It allows up to sixteen channels of input with automated calibration, but data analysis is limited to one- and two-sensor probes.

Either of these packages can also be used with other anemometers, with some limitations. Contact TSI for further information.



Calibration

The final requirement for any anemometer system is calibration. The basic output of an anemometer is a voltage that varies non-linearly with velocity. For different sensors, this output will have a similar, but not identical, curve shape, necessitating individual sensor calibration. A sensor may also exhibit some output drift with time, especially when it is used in fluids with contaminants, which can collect on the sensor and change the heat transfer.

Calibration at or near actual experimental conditions is also important. For customers that do not have calibration facilities, TSI offers two solutions to calibration concerns. First, TSI maintains a complete calibration facility which can generate a wide range of velocities and is suitable for calibrating one-, two-, or three-sensor probes. This service can be performed in just a few days and is an economical way for users with occasional measurement requirements to have their probes calibrated. Water sensors can also be calibrated at TSI.

For users with more frequent measurement requirements, or those who cannot easily access the calibration services, the purchase of a portable calibrator is recommended. Both manual and automated calibrators are available from TSI. They can be used with virtually all TSI probe designs (for gas flow only).

Options

Although correct selection of the above components yields a complete velocity measurement system, TSI offers several optional components which let a user completely equip a flow facility from a single supplier. The most common of these are automated traverse packages, for moving the sensor probe to various locations in the flow, and computer systems for data analysis. TSI also offers user training and other forms of technical support.

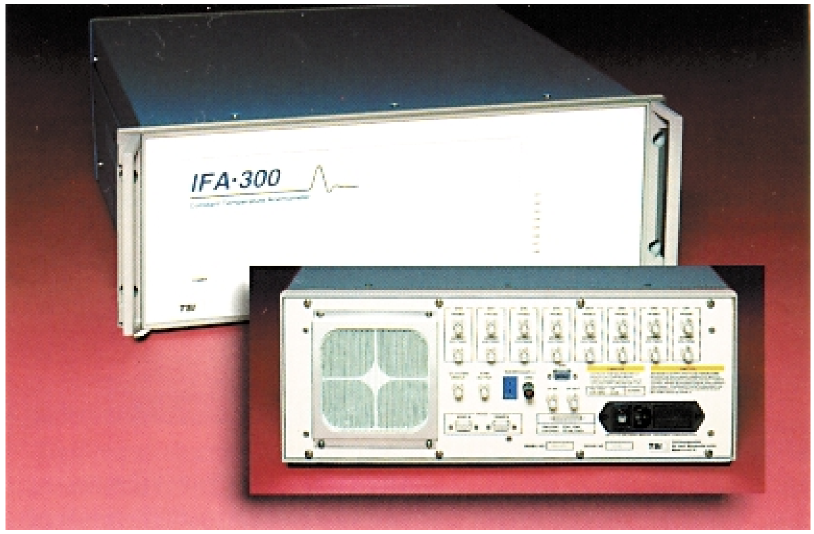
Research Constant Temperature Anemometer

Model IFA 300

A revolution in thermal anemometry

- SmartTune™ automatic bridge optimization technology
- High frequency response (with no tuning)
- Windows-based software
- Built-in signal conditioner and thermocouple circuit
- Optional constant current anemometer
- Fully computer controlled
- Ultra-low-noise circuits
- Optional integrated calibration system

The IFA 300 is a state-of-the-art research anemometer capable of meeting the most demanding measurement requirements. Whether your application involves measurement of high speed flows, measurement of very low turbulence intensities, fast temperature measurement, or the use of a high power bridge, the IFA 300 can do it all. It represents the depth of design capability and an understanding of the dynamics of constant temperature anemometry which TSI has developed over the past thirty years of building exceptional anemometry products. Examine the many features of this anemometer and we are sure you will agree that no other system can compare in performance or value.



SmartTune* Bridge Optimization

Research thermal anemometry has been an effective tool for fluid mechanics researchers for many years, but the requirement for precise manual frequency response tuning of the anemometer/sensor circuit has made accurate measurement an art form and has restricted some applications. With the effective implementation of TSI's SmartTune bridge optimization circuitry, the IFA 300 represents the greatest single advance in thermal anemometry technology in over thirty years.

SmartTune technology eliminates the controls normally used to optimize frequency response, while maintaining stability. This allows the anemometer to stay optimally tuned over its entire operating range. You only need tell the computer whether the sensor is a film or a wire and the rest is automatic. For the first time, turbulence measurements are possible with a thermal anemometer in applications where the mean velocity changes rapidly over a wide range, such as a blow-down wind tunnel, thanks to the self-optimizing SmartTune bridge circuit.

SmartTune technology eliminates the need for a special 1:1 bridge to achieve high frequency responses, with the IFA 300, the confusion over a multiplicity of inputs and settings is eliminated. You only need a single input jack to handle any sensor, under any conditions.

The System

The IFA 300 utilizes the latest in surface mount electronics to provide a reliable, compact system. From the rugged cabinet to the easily installed channel modules, the system is designed to provide many years of trouble-free operation. The signal conditioner and anemometer bridge functions are built on a single board, with up to eight channels available in a single 19-inch rack mount. Automated overheat ratio control and SmartTune bridge optimization further simplify the overall package by eliminating the numerous potentiometer adjustments previously required for each channel. A built-in thermocouple circuit in

*Patent applied for.

each cabinet simplifies temperature measurement. Control for the Model 1129 Automated Calibrator and signal conditioning for a pressure transducer are included in each cabinet. The overall result is an elegant, compact system—simple to use, very reliable, with superior specifications.

The Anemometer/Signal Conditioner

Each anemometer/signal conditioner in the IFA 300 is mounted on a single circuit board so installation and trouble shooting are quick and easy. Each board is fully electrically shielded, eliminating the possibility of interference. This integrated design, together with SMARTTUNE technology, allows high frequency response, a maximum probe current of 1.6 A, and equivalent amplifier input noise of only 1.7 $nV/\sqrt{Hz}$, specifications unmatched in the industry!

The signal conditioner section features a voltage offset of up to ten volts in 10 mV steps and up to 1000x gain. Both functions are fully computer-controlled and allow the user nearly infinite flexibility in managing the dynamics of the analog signal before digitizing. This can be critical when making measurements at very low turbulence intensities.

Data Acquisition and Analysis

The IFA 300 is designed for complete computer control. System operating functions, such as control of the overheat ratios and signal conditioner settings, are handled via an RS232 interface, while the high speed analog data from the anemometer output is managed with a high speed A/D converter mounted inside the computer.

Each system is supplied with a copy of TSI's THERMALPRO™ software. This software integrates all control and data acquisition functions, while providing complete data analysis.

Should you decide to use your own software for acquisition and analysis, you will find the IFA 300 straightforward to control using standard RS232 commands. This is a major advantage over other anemometer designs having specialized software controls with proprietary algorithms.

Options

While the basic IFA 300 system can handle up to eight anemometer channels in one cabinet, a total of sixteen anemometers can be monitored and controlled by THERMALPRO software with the addition of a second cabinet (and the appropriate digitizer). You can also operate this flexible package as two separate systems with the purchase of a second copy of THERMALPRO software and a second A/D converter.

In cases where there is a need for rapid-response temperature measurement, a fine hot wire sensor can be operated at a very low current, resulting in a high-frequency-response resistance thermometer. Frequency response from this circuit can easily exceed one kilohertz when a very small diameter sensor, such as our P.5 wire sensor, is used.

IFA 300 Specifications

Amplifier drift	0.3 µV/°C
Amplifier input noise	1.7 $nV/\sqrt{Hz}$ and 1.5 $pA/\sqrt{Hz}$
Frequency response	>250 kHz (without tuning)
Resistance measurement	0.1% ±0.01 ohms
Operating resistance	2 to 80 ohms
Maximum probe current	800 mA (1.6 A with high power setting)
Cable length	5 m or 30 m; RG-58 A/U (other lengths available on request)
Output	Bridge voltage to 11.5 volts
Size	17.8 cm × 48 cm × 41 cm (7 in. × 19 in. × 16 in.); standard 19-inch rack mount
Number of channels	Up to eight per cabinet; sixteen channels supported by standard software
Input power	100/120/220/240 VAC, 50-60 Hz, no switching required
Temperature measurement	Thermocouple circuit built-in for type-T thermocouple
Signal conditioning	
Offset	0 to 10 V in 10 mV steps, 0.15 % accuracy
Gain	1 to 1000 (1.0 MHz maximum bandwidth), 0.15 % accuracy
Low pass filters	Linear phase, 12 Hz to 1 MHz; 13 settings; -60 dB/decade
High pass filters	0.1, 1, 10 Hz; -60 dB/decade
Output (analog)	–5 to +5 V
Accessories included	One 5-meter probe cable per channel, one 2-meter output cable per channel (plus 2 extra per system), one Model 1340 thermocouple, one Model 1341 thermocouple cable, one BNC shorting cap (coaxial), one BNC "T" connector, power cable(s), one 4-meter (12 ft) RS232 cable, one shorting probe for single-sensor probe supports and one for dual-sensor probe supports, software, and instruction manual

To Order

All components for single channel operation, except the digitizer, are included in the basic IFA 300 package. Up to seven additional channels can be installed in the cabinet by TSI. Up to eight more channels can be added using a second cabinet. Constant current temperature modules can be substituted for the constant temperature anemometer modules.

Specify	**IFA 300**	**Single-channel Research CTA w/Data Analysis Software**—Includes cabinet for up to eight channels of anemometer/signal conditioner, one Model 183150 anemometer/signal conditioner module, one copy of THERMALPRO software and all necessary interface cables. **Note: the Multichannel Digitizer is not included. This must be purchased separately.**
	183150	**SMARTTUNE CTA Module w/Signal Conditioner**—Order one for each channel needed after the first (included in basic IFA 300). Maximum of eight per cabinet and sixteen per system.
	183102	**Cabinet**—Allows addition of eight channels to IFA 300, for a total of sixteen.

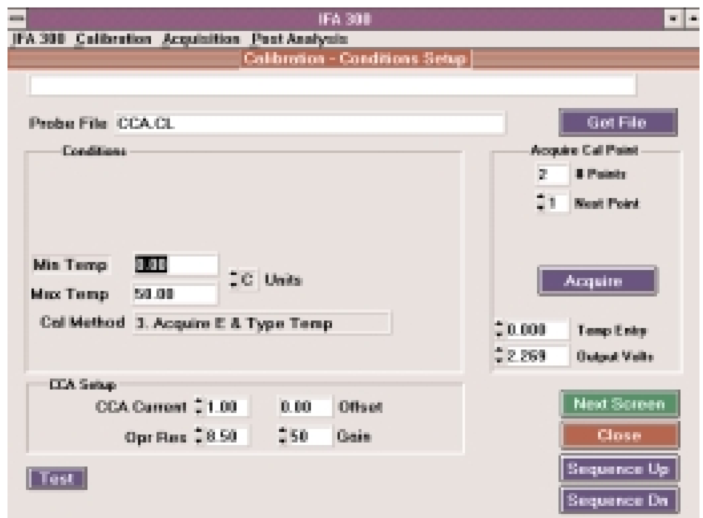
Example: To select a system with three anemometer channels and one temperature channel, order the following: (1) IFA 300, (2) 183150, and (1) 183145. **Note: digitizer and probes must be purchased separately**

Model 183145 Temperature Module

This circuit supplies the sensing current and signal conditioning needed to use a fine wire sensor as a resistance thermometer. While the built-in thermocouple circuit is adequate to compensate for normal variations in tunnel temperatures, if higher frequency temperature variations are present, a faster sensor is required. It is for such applications that the Model 183145 is used.

The frequency attainable depends directly on the diameter of the sensor selected. For example, the 3 dB point for a 4µm tungsten wire is about 700 Hz at 10 m/s. The maximum frequency increases with higher velocities or smaller diameter wires.

A wide range of computer-controlled current settings, low pass filters, gain settings, and offsets are provided to optimize the system for the sensor and the flow conditions. The temperature module plugs into a standard anemometer slot in the IFA 300.



Specifications

Low pass filters (Hz)	10, 20, 50, 100, 200, 500, 1K, 2K, 5K, 10K at -60dB per decade
High pass filters (Hz)	None, 0.1, 1, 10 at -60dB per decade
Offset	1 to 10 volts in 10 mv steps
Gain	1 to 1000
Output (analog)	–5 to +5 V

To Order

Specify	**183145**	**Temperature Module w/Signal Conditioner**—Used for fast response temperature measurement.

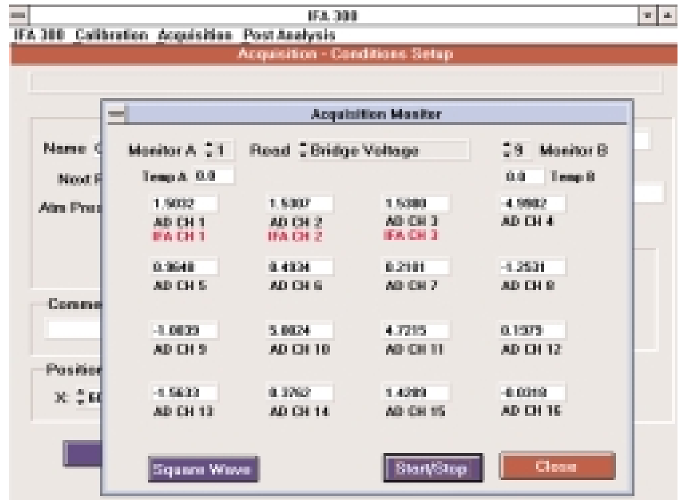
Analog-to-Digital Converters

Models ADCWIN-16 and ADCWIN-4

- High digitization rate
- Operates with 486 or higher computers
- True simultaneous sample and hold
- Integrated with THERMALPRO software
- Four- and sixteen-channel versions available

The ADCWIN-16 and ADCWIN-4 Analog to Digital (A/D) Converters match the capabilities of the IFA 300 anemometer, ensuring that information acquired by the anemometer is not lost in the digitization process. They are ideally suited for the specialized requirements of thermal anemometer signals. To make use of all the information in the analog anemometer output signal, they digitize the signal at a rate that ensures that no frequency information is lost or aliased. They also digitize the signal with sufficient resolution to detect small fluctuations in velocity and they simultaneously sample several anemometer signals in order to calculate valid crosscorrelation statistics.

ADCWIN-16



This digitizer offers the capability for simultaneous sampling of up to sixteen individual anemometer signals, the maximum number allowed in the IFA 300. The throughput rate of the card is one megasample per second for four or more channels (250 kilosamples per channel for four channels). One channel can be sampled at 714 kilosamples per second. Adding channels reduces the effective digitization rate for each channel. The card allows the user to select from a number of preset digitization rates. Large continuous data blocks can be written directly to high memory.

The ADCWIN-16 card features full 12-bit resolution, spanning a ten-volt input range. When used with the voltage offset and gain from the anemometer, this allows fluctuations in even the quietest flows to be measured accurately. The card is inserted into a 16-bit slot in your 486 or higher personal computer. Drivers for the card are included with THERMALPRO software and all digitization rate control is performed through the software.

ADCWIN-4

The ADCWIN-4 Analog-to-Digital Converter has the same operating characteristics and specifications as the ADCWIN-16 but offers only four input channels.

ADCTRIG

In addition to the BNC connections to the anemometer modules, the ADCTRIG also provides an input for an external switch to trigger data acquisition.

Specifications

Computer connection	Requires full-length 16-bit ISA (AT) slot
Number of input channels	16 (ADCWIN-16) or 4 (ADCWIN-4)
Resolution	12 bit, 1 in 4096
Input range	-5 to +5 V
Sample rates per channel	1 Hz to 200 kHz in a 1, 2, 5, 10 sequence; also 250, 294.1, 416.7, 500, 714.3 kHz
Data throughput rate	714.3 kHz (single channel); 833.4 kHz (2 channels); 882.3 kHz (3 channels); 1 MHz (4 or more channels)
Accessories included	One ribbon cable and adapter for BNC (coaxial) input board

To Order

Specify	**ADCWIN-16**	12 bit A/D, 1 MHz throughput, 16 channels
	ADCWIN-4	12 bit A/D, 1 MHz throughput, 4 channels
	ADCTRIG	BNC input board with external trigger

Note: A/D converters are not included with IFA 300 systems. They must be ordered separately.

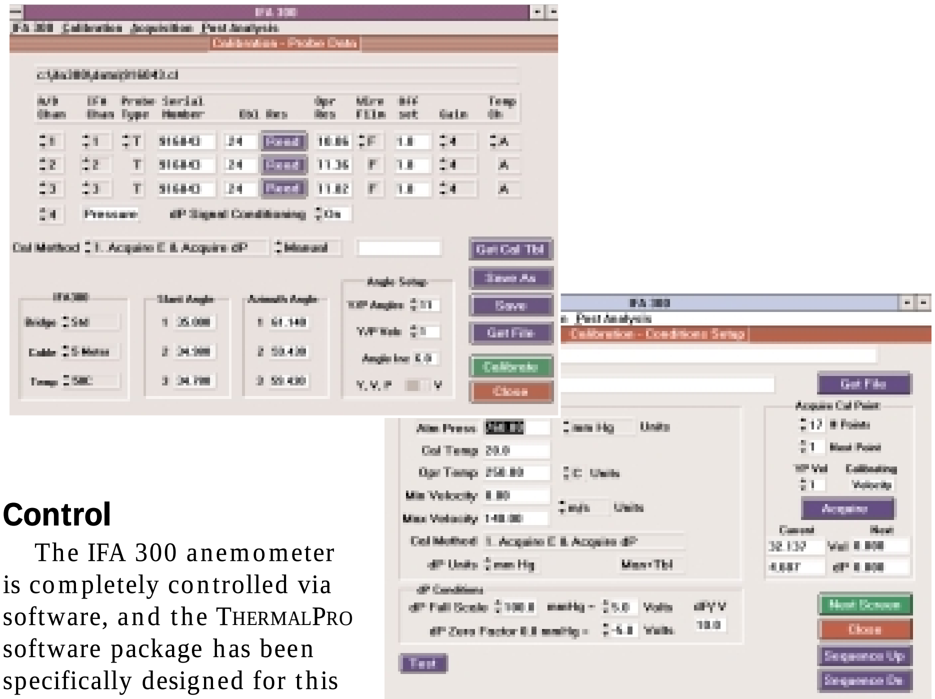
THERMALPRO™ Software

- Comprehensive data acquisition and analysis for thermal anemometry
- Operates under Windows™
- Gives results in fluid mechanics terms
- Analyzes data from one-, two-, or three-sensor probes
- Controls TSI's Automated Calibrator
- Controls TSI traverses

THERMALPRO software gives you complete control over the operation of your IFA 300 Research Constant Temperature Anemometer. It also offers the ability to acquire and analyze data from other analog sources, including TSI's earlier 1050 and IFA 100 series anemometers and anemometer systems from other manufacturers.

Almost any application requirements you could have for the IFA 300 have been anticipated and provided for. You can use a single integrated package to handle all of your needs. THERMALPRO software operates under Windows, using the familiar LabWindows CVI™ development language.

THERMALPRO software functions can be divided into four discrete sections: control, calibration, acquisition, and analysis. Each is discussed here.



Control

The IFA 300 anemometer is completely controlled via software, and the THERMALPRO software package has been specifically designed for this purpose. Utilizing a standard serial interface, THERMALPRO software and the IFA 300 communicate to set and monitor key operating parameters for up to sixteen anemometer channels. Easy-to-use set-up screens allow the user to set operating resistance, offset and gain, and high and low pass filters, and to choose film or wire sensors for each channel.

With the IFA 300's SMARTTUNE bridge optimization technology, bridge frequency response tuning using hardware or software is unnecessary. For other anemometers with less sophisticated controls, only limited parts of the control section are usable.

Calibration

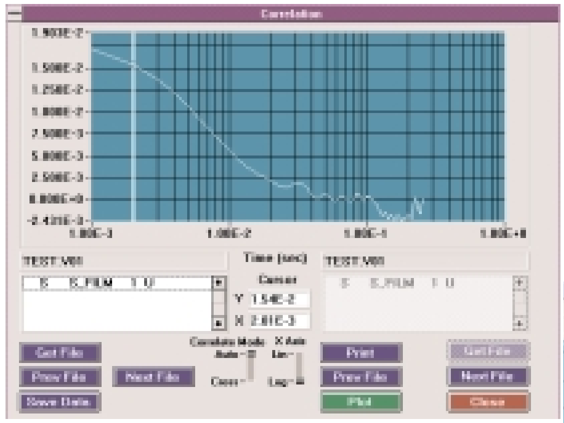
A major step in any thermal anemometry measurement involves calibrating the probe in the measurement environment over the velocity range of interest. This can be quite simple, as for single sensor probes used in air, or very complex, as when multiple sensor probes are used in a non-isotropic environment. Both manual and automated methods are used for sensor calibrations, which can be performed by TSI or on-site by the user. THERMALPRO software allows the user complete flexibility in choosing how to obtain and input calibration data.

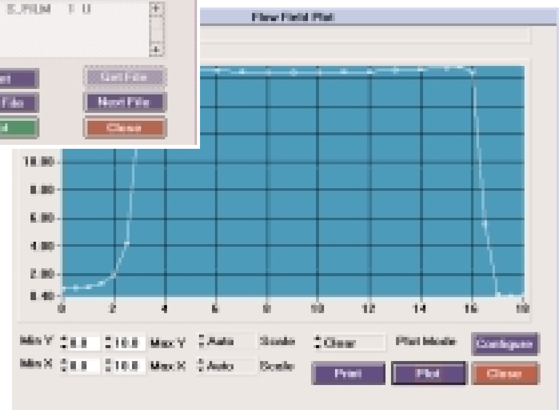
The preferred calibration method for many users is to calibrate their probes in the test environment immediately prior to the actual measurement. Traditionally, this has been difficult and time-consuming, especially with multiple-sensor probes. When THERMALPRO software is used with the IFA 300 and the Automated Calibrator, the entire process can be completed easily and quickly. Once instructed, the software automatically handles calibrator set-up, records velocity from the calibrator's pressure transducer, and changes the calibrator velocity. Even complex yaw and pitch calibrations for two- and three-component probes require minimal operator interaction. Provisions are also made for users to enter data manually or in a partially automated mode. If you have TSI perform the calibration, the calibration data is provided on a diskette, and easily integrated with the THERMALPRO software.

Data Acquisition

Acquisition of analog data from the IFA 300 is handled by an A/D converter, such as the ADCWIN-4 or ADCWIN-16, described earlier. THERMALPRO software gives you full control over the digitizing rate and other key operating parameters for these cards, and their drivers are integrated into the software.

Data acquisition also allows collecting supplementary data such as pressure, temperature, and location. Temperature and pressure transducers can be accommodated by acquiring data through the A/D converter and using the calibration function to interpret the data. Sensor position can be input manually or by using a TSI computer-controlled traverse, where THERMALPRO software directs probe movement according to a customer-created matrix. In either case, probe location, along with other key measurement parameters, are recorded in the file header for later use in plotting data.





Data Analysis

The section of greatest interest to most users is data analysis. The ability of the software to display the data in meaningful terms is of interest. But more important, it is here that interpretation of the input data takes place and key analysis algorithms are implemented. TSI has spent considerable effort to ensure that THERMALPRO software gives complete answers in fluid mechanics terms. All key flow parameters can be shown, in units of measure you select, with near real-time graphical displays of the velocity time-history and probability distribution. Mean velocity and turbulence intensity are also displayed immediately and all data can be saved for future analysis.

Post-processing gives complete statistics, including mean velocity, turbulence intensity, standard deviation, skewness, flatness, and normal stress for one-, two-, and three-component probes, and shear stress, correlation coefficient and flow direction angle for two- and three-component probes. In addition, power spectrum, autocorrelation, and crosscorrelation can be calculated and displayed.

The key algorithm used for three sensor probe analysis is based on work done by Fingerson* at TSI, with further refinement by Lekakis** and Walter.† These equations represent the latest refinements in deriving velocity from complex three-sensor probe geometries. Combined with the software data handling capabilities, even the most difficult analysis tasks become routine. All results can be stored in ASCII text files for easy additional analysis or plotting using third-party software.

Specifications

Functions controlled	All anemometer operating functions, data collection and analysis
Number of channels	Up to 16
Minimum computer requirements	PC-compatible 486 computer or higher with AT bus; 12 MB RAM; one serial port (in addition to mouse port); Microsoft™ mouse or equivalent; available 16-bit ISA (AT) slot (for A/D board); math co-processor; VGA graphics; DOS 6 or higher; MS Windows 3.1 or Windows for Workgroups 3.11
External signals	External analog signals such as pressure and temperature can be acquired and analyzed

To Order

Specify **THERMALPRO Software**	Thermal Anemometry Data Acquisition and Analysis Software for Windows

Note: One copy of THERMALPRO software is included with each IFA 300. Contact TSI for advice regarding use of THERMALPRO software with other anemometer systems.

*Fingerson LM (1968) Practical extensions of anemometer techniques. Advances in Hot-Wire Anemometry: 203-218
**Lekakis IC; Adrian RJ; Jones BJ (1989) Measurement of velocity vectors with orthogonal and nonorthogonal triple-sensor probes. Experiments in Fluids 7, 221-240
†Walter J (1995) Ph.D. Thesis, University of Iowa Hydraulics Laboratory

Air Velocity Calibrators

Models 1127, 1128, 1129

- Completely automates calibration acquisition
- Can be used with one-, two-, or three-sensor probes
- Probe mounts for yaw/pitch calibration
- Integrated with IFA 300 and THERMALPRO software

TSI's new Model 1129 Automated Calibrator for the first time gives users the ability to integrate the calibration process with software control of anemometer settings and data acquisition. This results in a seamless user interface which incorporates all operational requirements for anemometer measurements. Just attach the calibrator to a compressed air supply and to the IFA 300 cabinet. Then define a velocity range in the THERMALPRO software and attach a probe. The Automated Calibrator does the rest. It monitors the velocity through the output of a built-in pressure transducer, acquires sensor data, adjusts the flow rate to a new velocity, and repeats the process, until the entire velocity range is covered. The data is automatically integrated into the software calibration section.

While the calibrator's most obvious benefit is automated control, it has several other advanced design features. For one, its exclusive flow nozzle design exhibits a flat velocity profile over a broad dynamic range. For another, it sports a probe mounting system that can handle any type probe and probe support with great positioning flexibility, essential for yaw and pitch calibration of probes.

Though the Model 1129 Automated Calibrator is ideal for many applications, TSI also offers the Models 1127 and 1128, lower-cost, manual versions of the calibrator. They can be used in manual mode with any anemometer.

Specifications

Air velocity calibrators	
Turbulence intensity	0.3% typical
Velocity accuracy	0.5% typical
Fluid temperature range	Ambient
Nozzle sizes	10 mm and 14 mm
Weight	10.2 kg (22.5 lb) for calibrator; 5.8 kg (12.75 lb) for air filter system
Dimensions	43 cm wide × 25.4 cm deep × 79 cm tall (17 in. × 10 in. × 31 in.)
Air requirements	0.025 m^3/sec at 0.5 to 0.7 mPa (50 SCFM at 70 to 100 psi)
Pressure transducers	
Accuracy	0.15% of reading (includes effects of nonlinearity, hysteresis, and repeatability)
Resolution	0.01% full scale
Temperature sensitivity	Zero: 0.005% of full scale/°C Span: 0.02% of reading/°C

To Order

	Model	**Description**
Specify	1127	Manual velocity calibrator without pressure transducer
	1128A	Manual velocity calibrator with 0 to 10 mm Hg pressure transducer; velocity range 0.05 to 50 m/s
	1128B	Manual velocity calibrator with 0 to 100 mm Hg pressure transducer; velocity range 0.15 to 140 m/s
	1128C	Manual velocity calibrator with 0 to 1000 mm Hg pressure transducer; velocity range 0.5 m/s to Mach 1
	1129	Automatic velocity calibrator with 0 to 100 mm Hg pressure transducer; velocity range 0.15 to 140 m/s

Calibration Services

TSI provides calibration data, supplied on disk, for all probes it manufactures. When ordering, indicate the velocity range in air (0 to 5 m/s, 0 to 50 m/s, or 0 to 100 m/s) or water (0 to 1 m/s or 0 to 5 m/s).

To Order

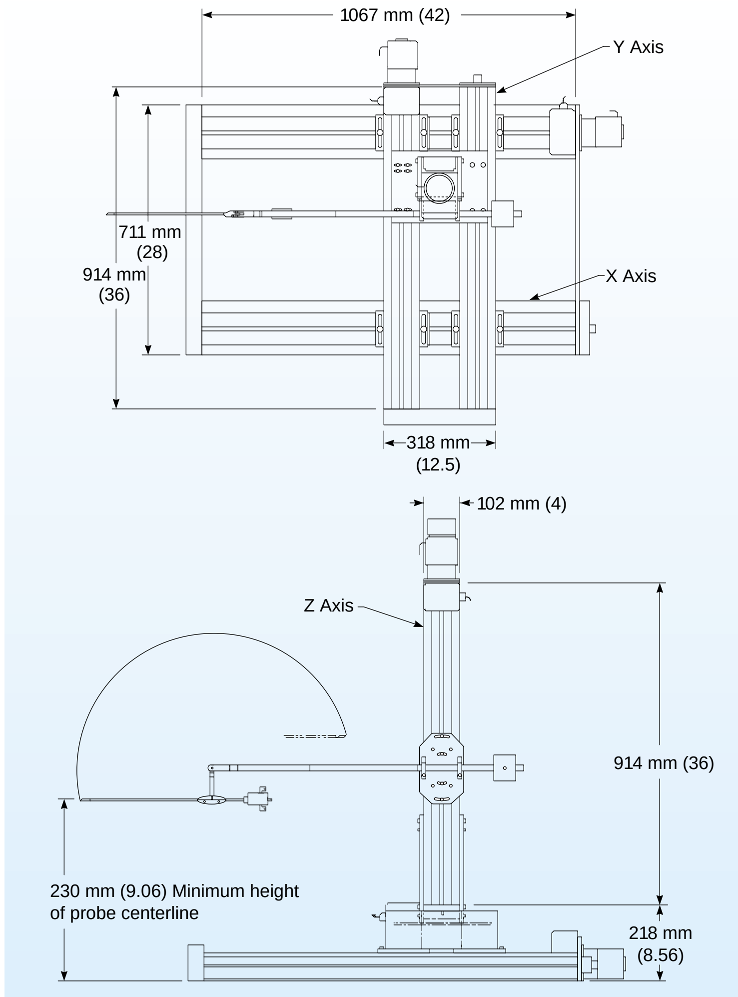
Specify	15222A	Air velocity calibration for TSI anemometers without software for 1, 2, or 3 sensors
	15231	Air velocity calibration for DAP software (IFA 100) for 1, 2, or 3 sensors
	15241	Air velocity calibration for FLOWPOINT anemometer for 1 or 2 sensors
	15251	Air velocity calibration for IFA 300 anemometer for 1, 2, or 3 sensors
	15223	Water velocity calibration (specify anemometer) for 1 or 2 sensors

Computer Controlled Traverse Systems

Models 1191, 1192, 1193

Three different computer-controlled traverses are offered by TSI, each able to precisely locate and move a probe. As part of an anemometer system, they enable automated measurement or remote operation. Typically, they are controlled using THERMALPRO software, where a customer-defined matrix identifies the measurement points. They also operate independently using front panel controls and displays on the power supply.

All traverses are built to ensure stable operation over the full translation range. They feature 600 mm travel with 10µm resolution, both absolute and relative homing capability, and a universal probe mount with tilt. The three models differ only in the number of axes of movement.



Specifications

Traverse	
Resolution	10 µm
Accuracy	±50 µm/ft
Repeatability	±20 µm
Traversing speed	10 mm/s
Backlash compensation	Yes
Limit switch settings	Adjustable
Stepper motor	200 steps/revolution
Stepper motor control	
Remote control	RS232
Front panel LED display	Position of each axis
Front panel control	Pushbutton; jog/slew from front panel
Power source	110 VAC ±10%, 60 Hz standard; 220 VAC ±10%, 50/60 Hz optional
Probe mount	Manual rotation and translation of probe

	Model 1191	**Model 1192**	**Model 1193**
Axes	Horizontal	Horizontal/vertical	Three-axis
Traversing length (mm)	600	600 × 600	600 × 600 × 600
Probe axis			
Minimum height	29 mm	138 mm	230 mm
Maximum height	629 mm	738 mm	830 mm
Weight (including mount)	29 kg	54 kg	104 kg
Dimensions (mm) excluding mount	1070 × 100 × 140	1240 × 1100 × 320	1330 × 1100 × 1250

To Order

Specify	1191	One-axis traverse with probe mount, 600 mm travel; 110V, 50/60 Hz
	1191E	Same as 1191 except 220V, 50/60 Hz
	1192	Two-axis traverse with probe mount, 600 mm travel in each axis; 110V, 50/60 Hz
	1192E	Same as 1192 except 220V, 50/60 Hz.
	1193	Three-axis traverse with probe mount, 600 mm travel in each axis; 110V, 50/60 Hz
	1193E	Same as 1193 except 220V, 50/60 Hz.

Note: THERMALPRO software is not included with traverses.

Probe Selection

TSI offers a wide range of thermal anemometry probes, each specially adapted for a particular application. The broadest probe classifications are based on the fluid measured (liquid or gas) and the number of velocity components. Within these classifications, a choice of probe configurations helps when selecting a probe to match the flow section geometry and accessibility.

TSI's probe family includes cylindrical and non-cylindrical hot film sensors and hot wire sensors. The choice between them is critical for most applications. Hot films consist of a thin film of platinum deposited on a quartz substrate, typically a cylinder which is attached to the sensor supports. Various cylinder diameters permit different spatial resolutions. If a more rugged sensor is required (typically in liquids), the film can be deposited on a cone or wedge-shaped substrate.

Hot wire sensors function similar to cylindrical hot-film sensors. They give better frequency response and lower noise but are more fragile and cannot be used in conductive liquids.

The probe section of this catalog describes a full line of standard probes mainly classified by the sensor type (cylindrical or non-cylindrical), the number of sensors, and the direction the mean flow moves relative to the probe body. They should handle the vast majority of applications. When standard probes are not adequate, TSI offers design services where a probe can be tailored to an application.

The section also includes probe supports, usually required since they contain the necessary cable connections, and probe shields, which help protect the delicate sensor. Probe supports can help when custom-tailoring a probe because of access restrictions. Shields are used as necessary.

Four Steps to Choosing A Probe

The four steps outlined below should be taken to determine the key measurement and environmental parameters that must be known in order to select the best probe and probe support for an application. The selection process then becomes relatively straightforward. You can move on to the "How To Use The Probe Catalog" section to help you locate a specific probe, or contact TSI for expert assistance. If no standard configuration meets your needs, contact TSI. We may be able to provide a custom design.

Step 1. Identify environmental conditions (determines the applicable sensors)

Clean gases near room temperature—This is the best and most common environment. Generally, cylindrical sensors, either wires or films, will be used. While non-cylindrical sensors can be used for mean velocity, it is difficult to interpret transient data resulting from high conduction losses to the supports.

High temperature gases—Sensors must normally be operated well above the environment temperature. Maximum operating temperature of film sensors is 425°C while for tungsten wires it is 300°C. Platinum wires can operate at much higher temperatures but are much weaker than tungsten. Platinum iridium is a compromise that is stronger than platinum but has a lower temperature coefficient (providing lower signal-to-noise ratio) The probe must also be selected for the appropriate temperature range.

Clean Liquids—Most liquids, such as water, are sufficiently conductive that the sensor element must be insulated. Thus, only coated film sensors ("W" designation) can be used. Standard construction techniques for probes used in conductive liquids limits the fluid temperature to approximately 30°C. In a truly insulating liquid (e.g. oil), a non-coated sensor should be used since it tends to collect less contamination. In liquids, boundary layer lag can substantially reduce the expected frequency response based on the standard electrical test (Leuck*).

Contaminated Liquids—Non-cylindrical sensors such as a cone or wedge are the proper choice. Non-cylindrical sensors can give good results, even for transients, in most liquids because the higher heat transfer rate tends to mask the effect of conductive losses to the supports. Standard non-cylindrical sensors measure only the component in the mean flow direction. Special sensors can be built for custom applications.

Step 2. Number of Velocity Components to be Measured (in all cases there are limits to the magnitude of the turbulence intensity that can be accurately measured - see technical section).

A single cylindrical sensor perpendicular to the flow will give a good measurement of the instantaneous velocity in the mean flow direction.

Two cylindrical sensors, properly oriented,will measure two components of velocity.

Three cylindrical sensors, properly oriented, will measure all three velocity components.

*Lueck RG (1979) Heated Anemometry and Thermometry in Water. Ph.D. Thesis, Department of Physics and Institute of Oceanography, University of British Columbia.

Step 3. **Hot wires versus cylindrical film sensors where either can be used.**

Hot wires will provide the best signal to noise and generally better frequency response than film sensors. For measurements with multiple sensors, they do not stay positioned as well (lengthen and bend when heated), causing errors in the velocity component calculations.

Cylindrical film sensors will generally not contaminate as easily (due to larger diameter) and will not shift resistance due to strain in a high velocity environment or due to particle impact.

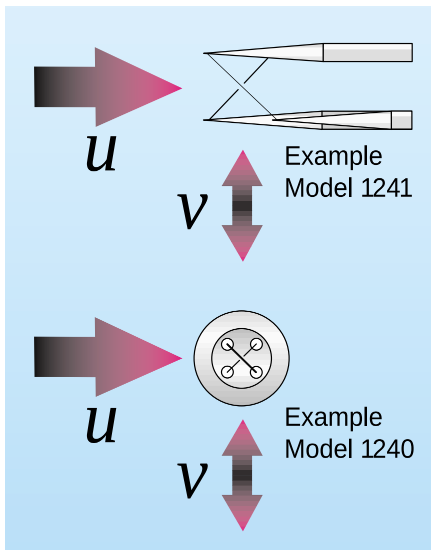
Step 4. **Probe and support selection**
Once the type and number of sensors on the probe is selected, further selections depend on the access to the flow and where the measurement is to be made. Right angle adapters, miniature probes, cross flow designs are all variations that help you get the sensor where it belongs with minimum flow field disturbance.

Special Designs

If you find that no standard probe meets your requirements, define your measurement needs according to the steps outlined above and contact TSI. We will respond quickly with a drawing and quote for a proposed solution. This is often an iterative process as we work with you to get the best possible approach, but it is one that has proved worthwhile to thousands of users around the world, each having a unique application.

X-Probe Selection

When selecting an X-probe, keep in mind that an X-probe measures two components of velocity (U and V) that are both in the plane formed by the two sensors. The U and V components will each be at 45 degrees to each sensor. It is assumed that the flow is two-dimensional, with the W component (normal to the plane formed by the two sensors) small in comparison to the total velocity vector. The X-probe should be aligned such that the major flow is in the U direction.



Using The Probe Section

Once you have completed the above steps, you are ready to examine the catalog to find the correct probe and support for your needs. As closely as possible, the catalog has been designed to lead you logically to the probe you need, or to let you determine quickly if you need to consider a special probe design.

The probe section of the catalog is organized according to the following characteristics:

- First, by broad sensor type (cylindrical or non-cylindrical)
- Second, by the number of sensors (one, two, or three) mounted on the probe
- Third, by the direction of the mean flow relative to the probe body (end flow, cross flow)
- Fourth, by the specific configuration of the probe (high-temperature, miniature, etc.).

Once you have located the type of probe best suited to your application, review the list of recommended sensors to determine if the specific sensor type (air or water, wire or film) which you need is available. See the sensor specification table on page 19 for a description of the sensor designations listed in the probe section and detailed specifications on each type of sensor.

When the probe type has been determined, the final step is to locate the best probe support and shield. A wide variety of supports and shields are listed after the probe section. Your choice will be largely based on access requirements. Remember that here, too, TSI supplies special designs to meet your application.

Sensor Probe Selection

The chart below lists all the probes featured in this catalog and summarizes their key selection characteristics:

Model No.*	Page Number	Designation	Size	Temperature	Fluid	Sensor Type	Sensor Orientation	Sensor Position
Cylindrical Sensors								
1201	20	S	R	L	G	F	90	I
1210	20	S	R	L	G,L	W,F	90	I
1220	20	S	R	H	G	W,F	90	I
1260A	21	S	M	L	G,L	W,F	90	I
1276	21	S	SM	L	G,L	W,F	90	I
1214	21	S	R	L	G	W,F	90	I
1213	22	S	R	L	G,L	W,F	45	I
1263A	22	S	M	L	G	W,F	45	I
1211	23	S	R	L	G	W,F	0	I
1221	23	S	R	H	G	W,F	0	I
1212	24	S	R	L	G,L	W,F	90	U
1222	24	S	R	H	G	W,F	90	U
1262A	24	S	M	L	G,L	W,F	90	U
1279	25	S	SM	L	G	F	90	U
1277	25	S	SM	L	G	F	0	U
1218	26	BL,S	R	L	G,L	W,F	90	U
1261A	26	BL,S	M	L	G,L	W,F	90	U
1241	27	X	R	L	G,L	W,F	45	I
1248A	27	X	M	L	G,L	W,F	45	I
1240	27	X	R	L	G,L	W,F	90	I
1247A	28	X	M	L	G,L	W,F	90	I
1246	28	X	R	L	G,L	W,F	45	U
1245	28	X	R	L	G,L	W,F	90	U
1249A	29	X	M	L	G,L	W,F	45	U
1243	29	BL,X	R	L	G,L	W,F	45	U
1244	29	II	R	L	G,L	W,F	90	I
1288	30	SF	R	L	G,L	W,F	90	I
1287	30	BL,SF	R	L	G,L	F	90	I
1301	31	S	OP	L,TC	G,L	F	90	I
1302	31	X	OP	L,TC	G,L	F	45	I
1299	32	T	OP	L	G	F	54	I
1299A	32	T	OP	L	G	F	–	U
Non-Cylindrical Sensors								
1230	33	C	R	L	G,L	F	–	I
1231	33	C	R	L	G,L	F	–	U
1264A	33	C	M	L	G,L	F	–	U
1232	34	W	R	L	G,L	F	–	I
1232H	34	W	R	H	G	F	–	I
1233	34	W	R	L	G,L	F	–	U
1234H	35	SF,W	R	H	G	F	–	I
1269W	35	SF	R	L	L	F	–	I
1237	35	F	R	L	G,L	F	–	–
1268	36	F	M	L	G,L	F	–	–
1471	36	F	M	L	G	F	–	–
1472	36	F	SM	L	G	F	–	–

Sensor Designation

Cylindrical Sensors: **S**=Single; **II**=2 parallel sensors; **SF**=Split film; **X**="X" probe; **T**=Triple sensor; **BL**=Boundary layer

Non-cylindrical Sensors: **C**=Conical; **F**=Flush; **SF**=Side flow; **W**=Wedge

Sensor Size

(Diameter of probe body closest to sensor)

R=Regular (3.2 mm)
M=Miniature (1.5 mm)
SM=Subminiature (0.9 mm)
OP=One Piece (4.6 mm)

Temperature

(Maximum exposure temperature of probe body)**

L=150°C, (except 60°C for 1201)
H=300°C (except 250°C for 1232H, 1234H**)
TC = Probe with built-in thermocouple
Maximum temperature for water probes is approximately 30°C

Fluid

G=Gas
L=Liquid

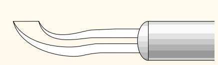
Sensor Type

W=Wire
F=Platinum film

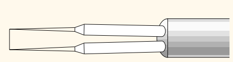
Sensor Orientation

(Relative to connector end of probe)

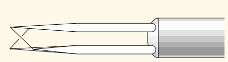
0=0°



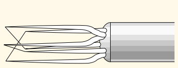
90=90°



45=45°



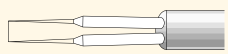
54=54.74°



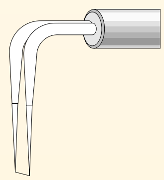
Sensor Position

(Relative to connector end of probe)

I=In-line



U=Upstream



***Probes are listed in numerical order in the index on page 48.**

Specifications

Hot Wire and Hot Film Sensors

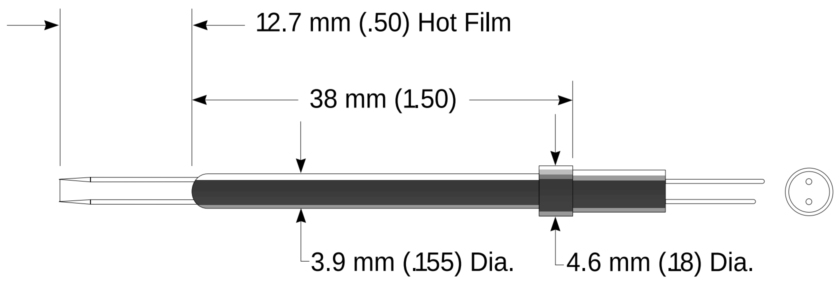
Type	Dash No. Designation Suffix in Probe No.	Diameter (D) of Sensing Area or Width in μm (in.)	Length (L) of Sensing Area in mm (in.)	Distance Between Supports in mm (in.)	Maximum Ambient Temperature (°C)	Maximum Sensor Operating Temperature	Temperature Coefficient of Resistance (/°C)
Hot Wire							
Tungsten Platinum Coated	-T1.5	3.8 (0.00015)	1.27 (0.05)	1.52 (0.06)	150	300	0.0042
Platinum	-P2	5.1 (0.0002)	1.27 (0.05)	1.27 (0.05)	750**	800	0.00385
Platinum Iridium (Alloy)	-PI2.5	6.3 (0.00025)	1.27 (0.05)	1.27 (0.05)	750**	800	0.0009
Platinum Iridium (Alloy)	-PI5	12.7 (0.0005)	1.27 (0.05)	1.27 (0.05)	750**	800	0.00094
Hot Film Gas							
Platinum	-10A	25.4 (0.001)	0.25 (0.01)	0.76 (0.03)	150/300	425	0.0024
Platinum	-10	25.4 (0.001)	0.51 (0.02)	1.27 (0.05)	150/300	425	0.0024
Platinum	-20	50.8 (0.002)	1.02 (0.04)	1.65 (0.065)	150/300	425	0.0024
Platinum	-60	152.4 (0.006)	2.03 (0.08)	3.05 (0.12)	150/300	425	0.0024
Platinum	Split Film	152.4 (0.006)	2.03 (0.08)	3.8 (0.15)	150/300	350	0.0024
Platinum	Non-Cylindrical	127 (0.005)	1.02 (0.04)	—	150/300	425	0.0024
Hot Film Liquid							
Platinum	-10AW	25.4 (0.001)	0.25 (0.01)	.76 (0.03)	30	67	0.0024
Platinum	-10W	25.4 (0.001)	0.51 (0.02)	1.27 (0.05)	30	67	0.0024
Platinum	-20W	50.8 (0.002)	1.02 (0.04)	1.65 (0.065)	30	67	0.0024
Platinum	-60W	152.4 (0.006)	2.03 (0.08)	3.05 (0.12)	30	67	0.0024
Platinum	Split Film	152.4 (0.006)	1.02 (0.04)	3.8 (0.15)	30	67	0.0024
Platinum	Non-Cylindrical	127 (0.005)	1.02 (0.04)	—	30	67	0.0024

****May require custom probe design**

Probes for Single Cylindrical Sensors

Probes for single cylindrical sensors are used for one-dimensional flow measurements. Within this category, the Model 1210 and its equivalent disposable probe, the Model 1201, are the most frequently used probe models.

Model 1201 Disposable Probe

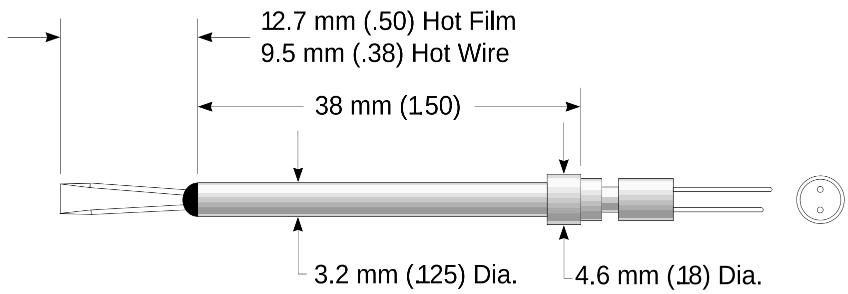


Recommended Sensors

For Gas Applications

1201-20
Max. Fluid Temp. = 60°C

Model 1210 General Purpose Probe



Recommended Sensors

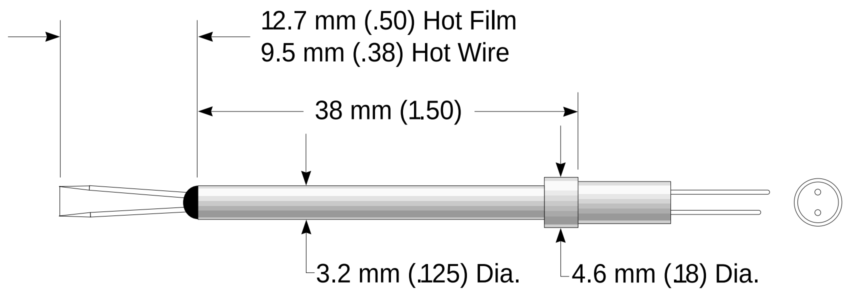
For Gas Applications

1210-T1.5
1210-20
1210-60
Max. Fluid Temp. = 150°C

For Liquid Applications

1210-20W
1210-60W

Model 1220 High Temperature Straight Probe



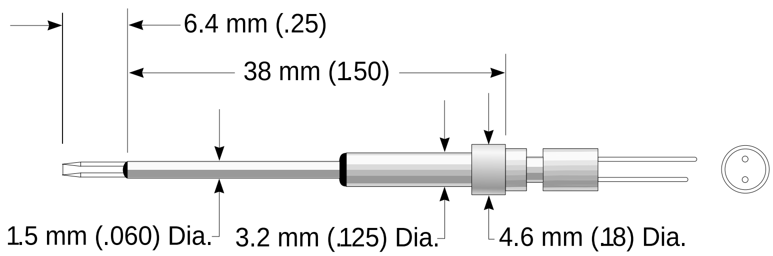
Recommended Sensors

For Gas Applications

1220-PI2.5
1220-20
1220-60
Max. Fluid Temp. = 300°C

Probes for Single Cylindrical Sensors

Model 1260A Miniature Straight Probe



Recommended Sensors

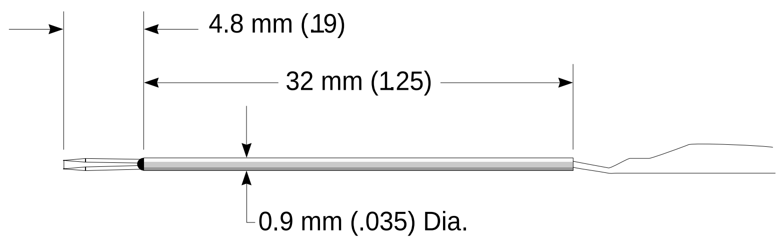
For Gas Applications

1260A-T1.5
1260A-10
Max. Fluid Temp. = 150°C

For Liquid Applications

1260A-10W

Model 1276 Subminiature Straight Probe



* Use for temperature measurement only with constant current bridge.

Recommended Sensors

For Gas Applications

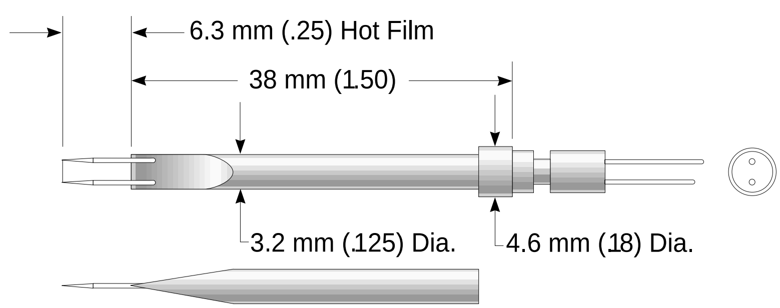
1276-P.5*
1276-10A
Max. Fluid Temp. = 150°C

For Liquid Applications

1276-10AW

Model 1214 Streamlined Probe

For high speed (e.g. supersonic) flows



Recommended Sensors

For Gas Applications

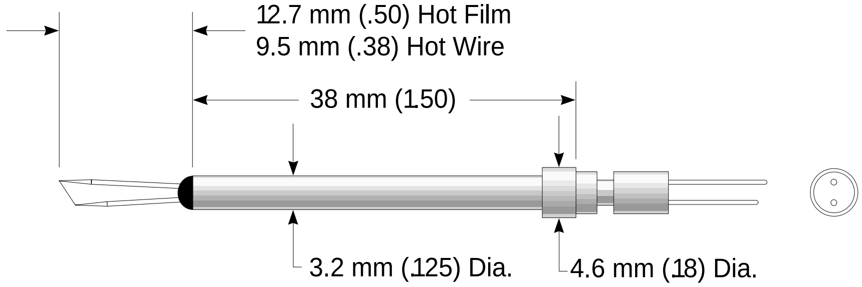
1214-T1.5
1214-20
Max. Fluid Temp. = 150°C

Dimensions in parentheses are in inches.

Probes for Single Cylindrical Sensors

Single sensors 45° to probe axis can be used in steady flows to measure turbulent shear stress or two components of velocity by rotating the probe about its axis.

Model 1213 Sensor 45° to Probe



Recommended Sensors

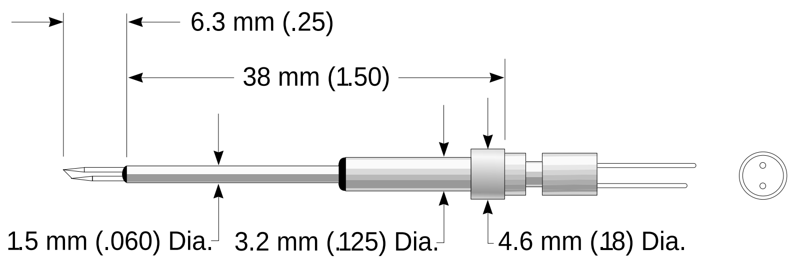
For Gas Applications

1213-T1.5
1213-20
1213-60
Max. Fluid Temp.= 150°C

For Liquid Applications

1213-60W

Model 1263A Miniature Sensor 45° to Probe



Recommended Sensors

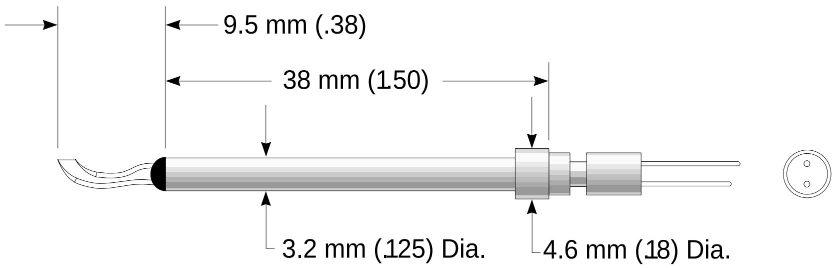
For Gas Applications

1263A-T1.5
1263A-10
Max. Fluid Temp.= 150°C

Probes for Single Cylindrical Sensors

In cross flow applications, probe interference is reduced by mounting the sensor parallel to the probe body.

Model 1211 Standard Probe

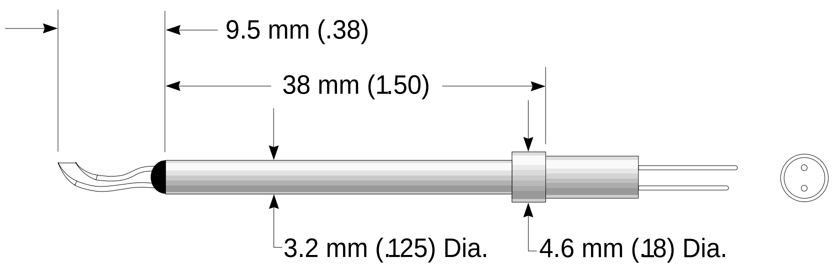


Recommended Sensors

For Gas Applications

1211-T1.5
1211-10
1211-20
Max. Fluid Temp.= 150°C

Model 1221 High Temperature Probe



Recommended Sensors

For Gas Applications

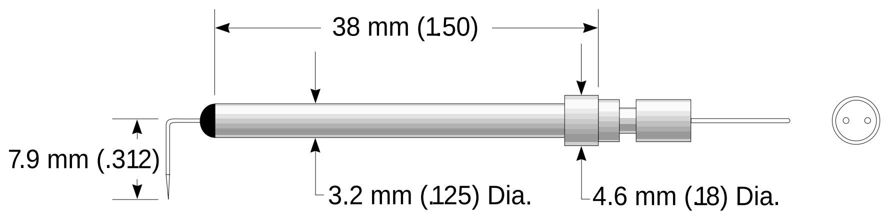
1221-PI2.5
1221-20
Max. Fluid Temp.= 300°C

Dimensions in parentheses are in inches.

Probes for Single Cylindrical Sensors

For minimum probe interference in cross flow applications,
the sensor needles are bent so the sensor is upstream of the probe.

Model 1212 Standard Single Sensor Probe



Recommended Sensors

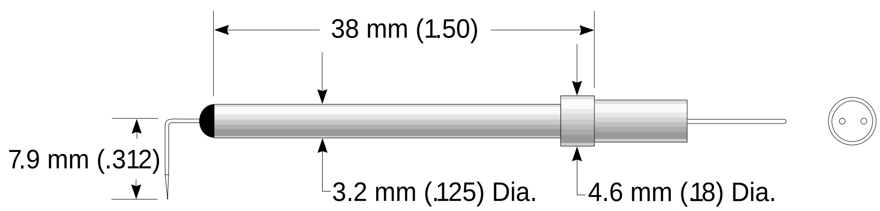
For Gas Applications

1212-T1.5
1212-20
1212-60
Max. Fluid Temp.= 150°C

For Liquid Applications

1212-20W
1212-60W

Model 1222 High Temperature Single Sensor Probe

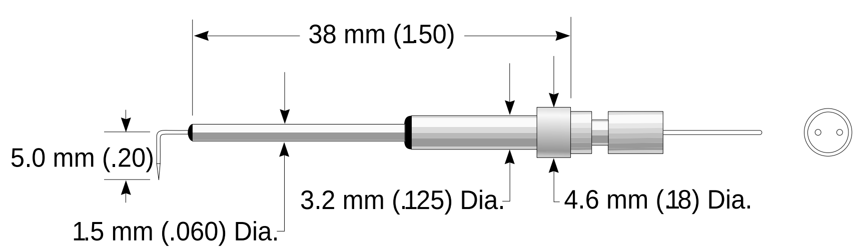


Recommended Sensors

For Gas Applications

1222-PI2.5
1222-20
Max. Fluid Temp.= 300°C

Model 1262A Miniature Probe



Recommended Sensors

For Gas Applications

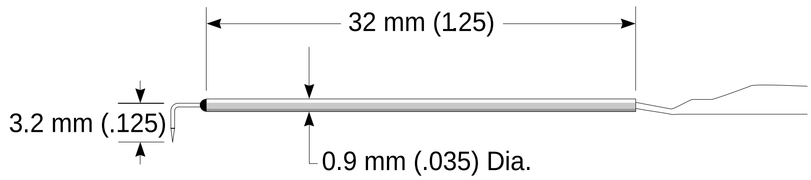
1262A-T1.5
1262A-10
Max. Fluid Temp.= 150°C

For Liquid Applications

1262A-10W

Probes for Single Cylindrical Sensors

Model 1279 Subminiature Probe



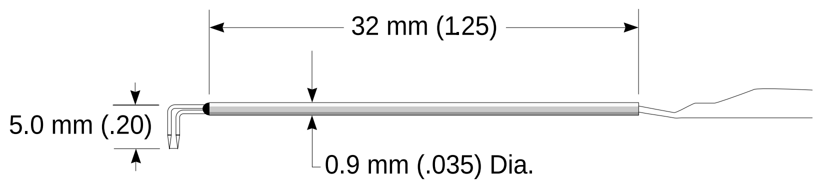
Recommended Sensors

For Gas Applications

1279-10A

Max. Fluid Temp.= 150°C

Model 1277 Subminiature Probe



Recommended Sensors

For Gas Applications

1277-10A

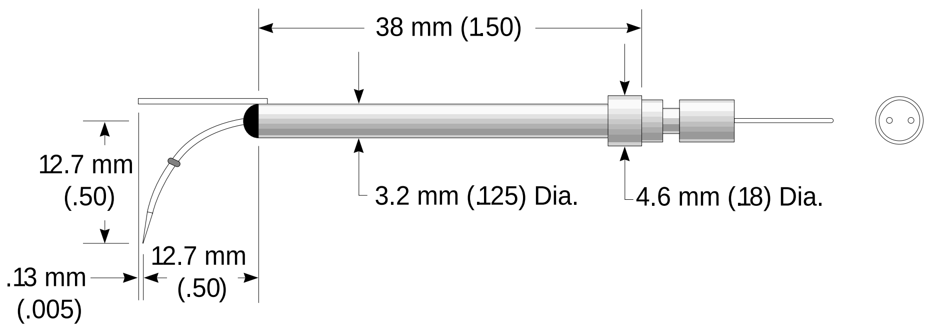
Max. Fluid Temp.= 150°C

Dimensions in parentheses are in inches.

Probes for Single Cylindrical Sensors

Boundary layer probes provide a protective pin to allow measurements very near the surface and a long radius bend to minimize disturbances.

Model 1218 Standard Boundary Layer Probe



Recommended Sensors

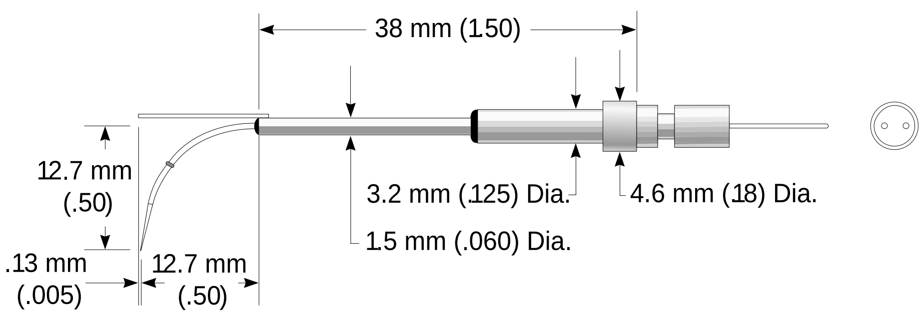
For Gas Applications

1218-T1.5
1218-10
1218-20
Max. Fluid Temp.= 150°C

For Liquid Applications

1218-20W
1218-60W

Model 1261A Miniature Boundary Layer Probe



Recommended Sensors

For Gas Applications

1261A-T1.5
1261A-10
Max. Fluid Temp.= 150°C

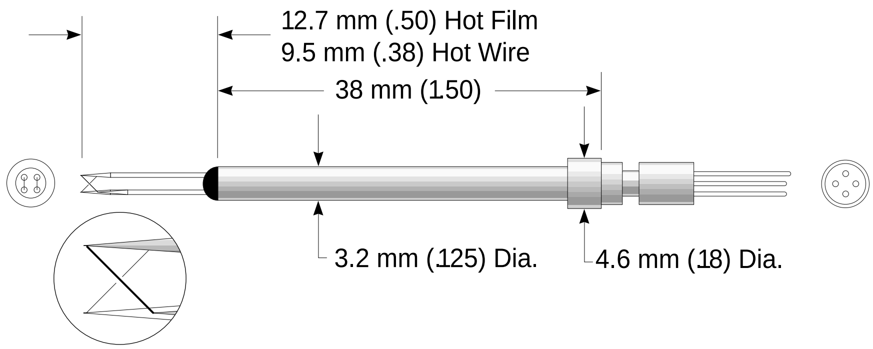
For Liquid Applications

1261A-10W

Probes for Dual Cylindrical Sensors

Dual sensor probes position two sensors in close proximity, generally in an "X" configuration, for measuring two components of flow and the correlation between them. For accurate measurements, the maximum turbulence intensity is limited by the sensitivity to the flow perpendicular to the measured components.

Model 1241 End Flow "X" Probe



Recommended Sensors

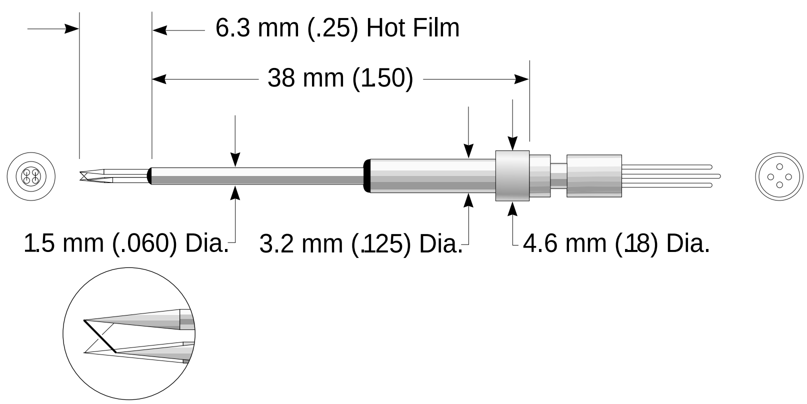
For Gas Applications

1241-T1.5
1241-20
Max. Fluid Temp.= 150°C

For Liquid Applications

1241-20W
1241-60W

Model 1248A Miniature End Flow "X" Probe



Recommended Sensors

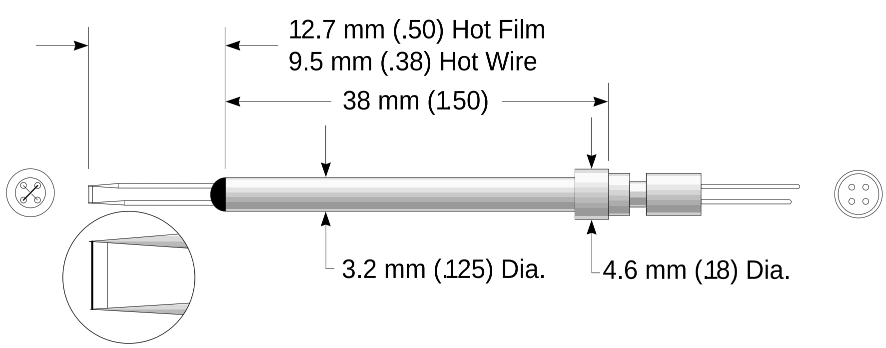
For Gas Applications

1248A-T1.5
1248A-10
Max. Fluid Temp.= 150°C

For Liquid Applications

1248A-10W

Model 1240 Standard Cross Flow "X" Probe



Recommended Sensors

For Gas Applications

1240-T1.5
1240-20
Max. Fluid Temp.= 150°C

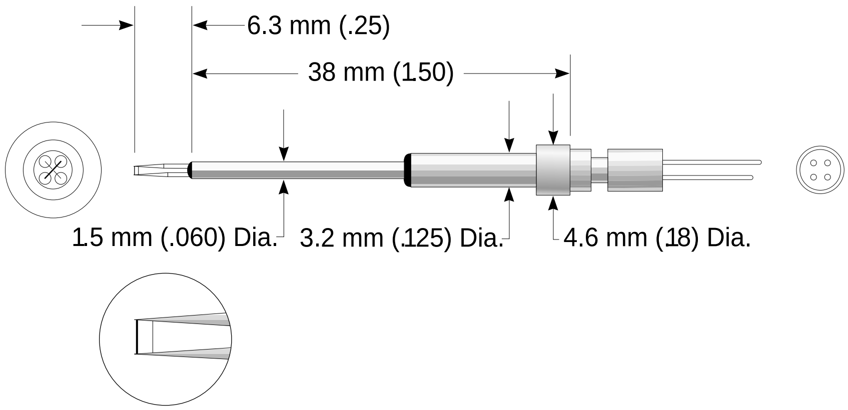
For Liquid Applications

1240-20W
1240-60W

Dimensions in parentheses are in inches.

Probes for Dual Cylindrical Sensors

Model 1247A Miniature Cross Flow "X" Probe



Recommended Sensors

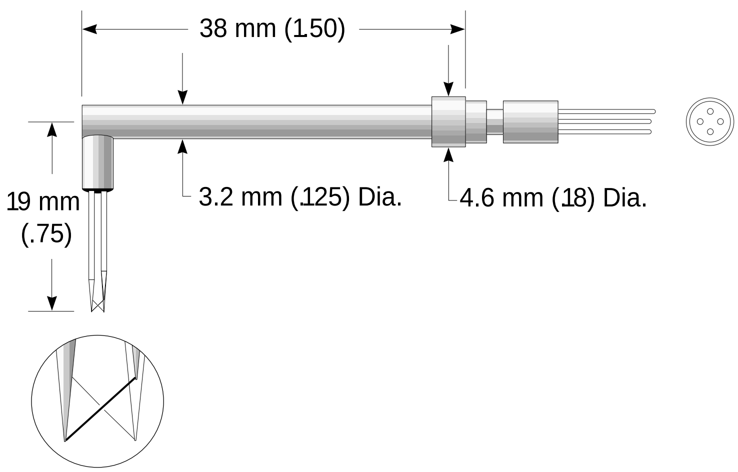
For Gas Applications

1247A-T1.5
1247A-10
Max. Fluid Temp.= 150°C

For Liquid Applications

1247A-10W

Model 1246 Cross Flow "X" Probe, Sensors Upstream



Recommended Sensors

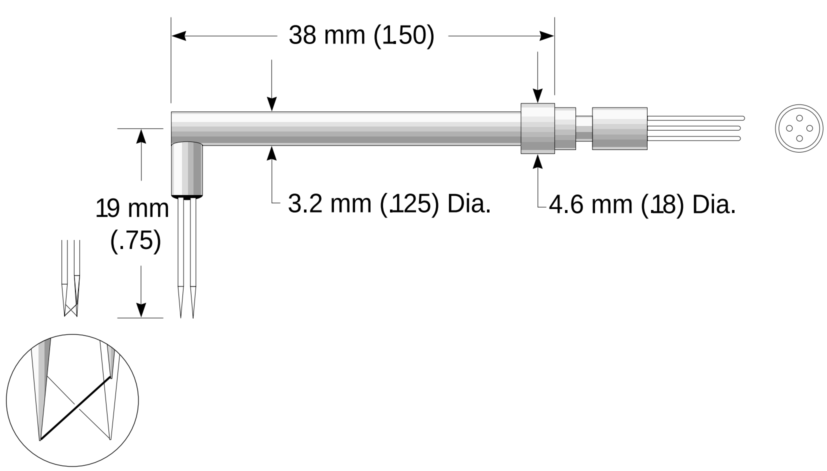
For Gas Applications

1246-T1.5
1246-20
Max. Fluid Temp.= 150°C

For Liquid Applications

1246-20W
1246-60W

Model 1245 Cross Flow "X" Probe, Sensors Upstream



Recommended Sensors

For Gas Applications

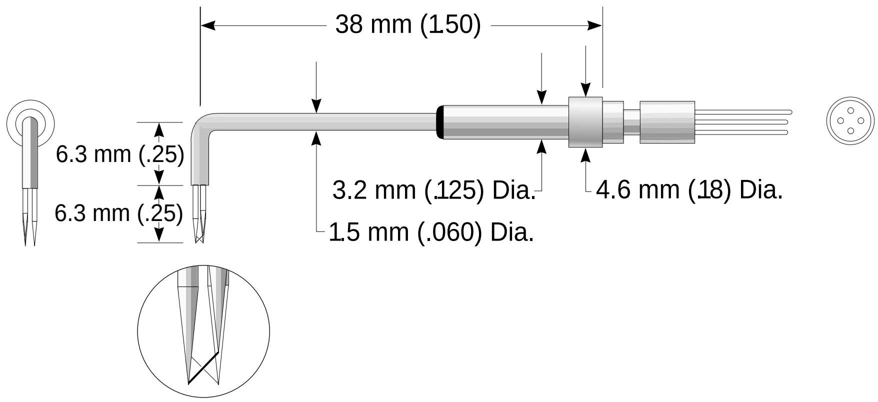
1245-T1.5
1245-20
Max. Fluid Temp.= 150°C

For Liquid Applications

1245-20W
1245-60W

Probes for Dual Cylindrical Sensors

Model 1249A Miniature Cross Flow "X" Probe, Sensors Upstream



Recommended Sensors

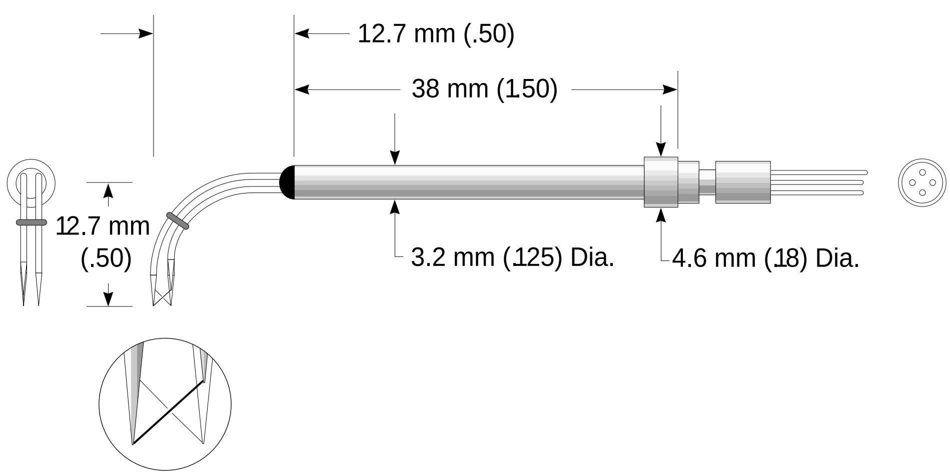
For Gas Applications

1249A-T1.5
1249A-10
Max. Fluid Temp.= 150°C

For Liquid Applications

1249A-10W

Model 1243 Boundary Layer Cross Flow "X" Probe, Sensors Upstream



Recommended Sensors

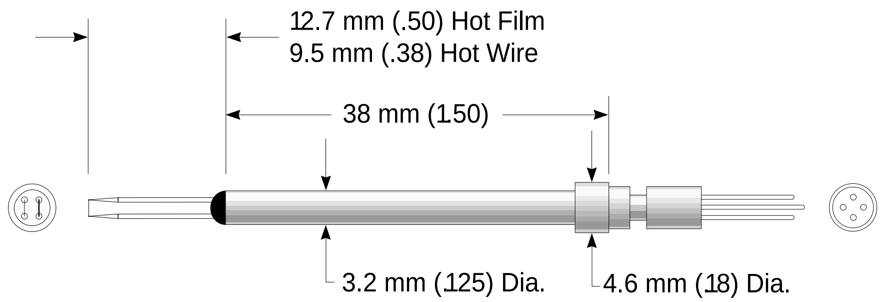
For Gas Applications

1243-T1.5
1243-20
Max. Fluid Temp.= 150°C

For Liquid Applications

1243-20W
1243-60W

Model 1244 End Flow Parallel Sensor Probe



Recommended Sensors

For Gas Applications

1244-T1.5
1244-20
Max. Fluid Temp.= 150°C

For Liquid Applications

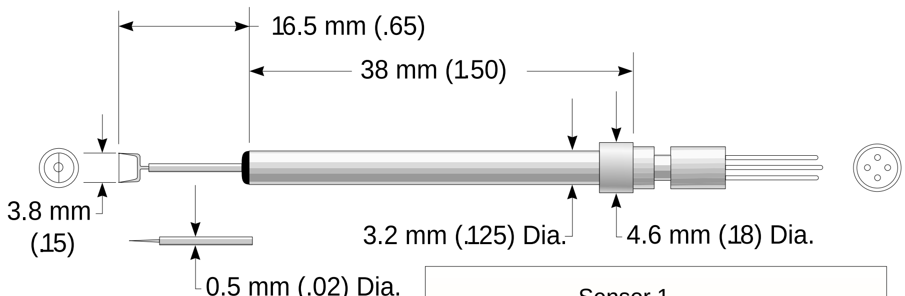
1244-20W
1244-60W

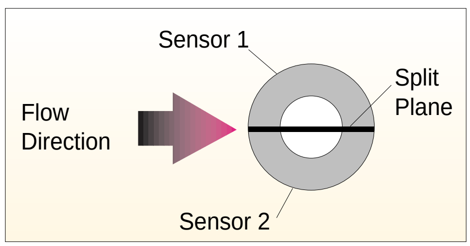
Dimensions in parentheses are in inches.

Probes for Dual Cylindrical Sensors

Split film sensors are 152µm film sensors that are separated along the length into two independently-controlled sensors. With one sensor oriented upstream and the other downstream, they can sense flow reversal as well as measure flow. With the sensors oriented with the split facing upstream, they can make two-component measurements similar to “X” probes. They are effective at higher turbulence intensities because of less sensitivity to flow perpendicular to the measured components.

Model 1288 End Flow Split Film Probe





Sensor Cross-section

Recommended Sensors

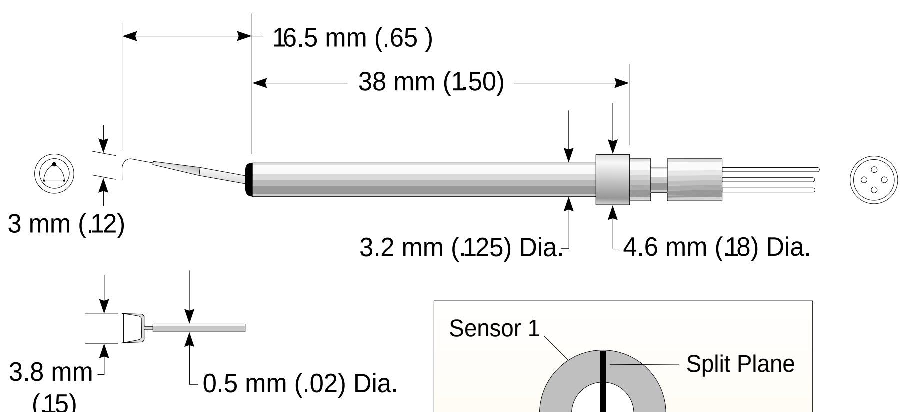
For Gas Applications

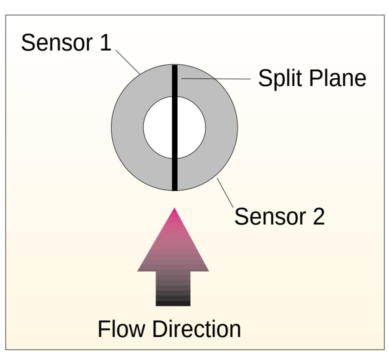
1288
Max. Fluid
Temp.= 150°C

For Liquid Applications

1288W

Model 1287 Cross Flow Split Film Boundary Layer Probe





Sensor Cross-section

Recommended Sensors

For Gas Applications

1287
Max. Fluid Temp.= 150°C

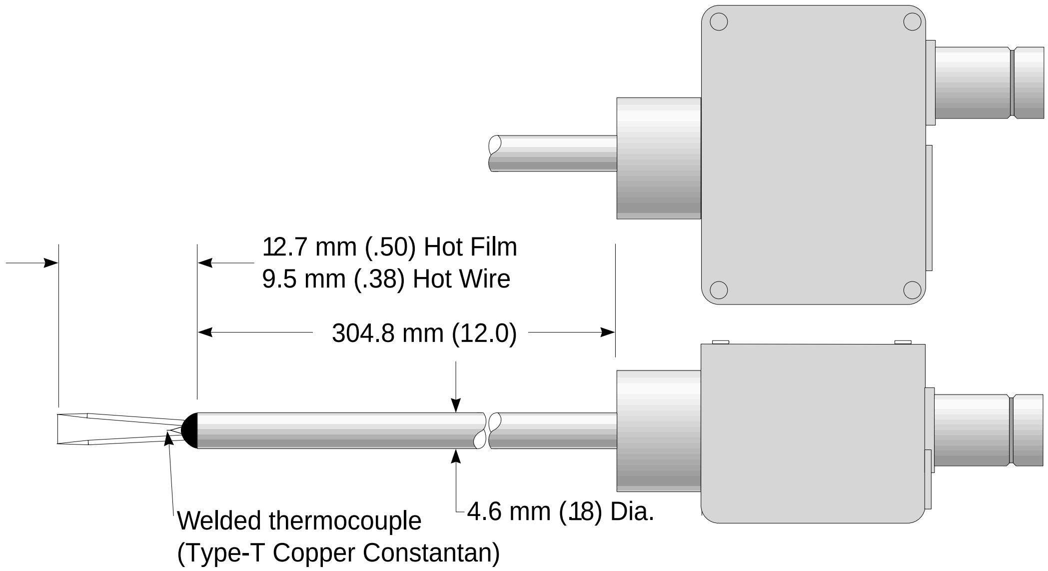
For Liquid Applications

1287W

Probes With Thermocouples Built In

For convenience, these probes have built-in thermocouples so the temperature measurement is always close to the velocity measurement, even when traversing the probe.

Model 1301 General Purpose Probe With Thermocouple

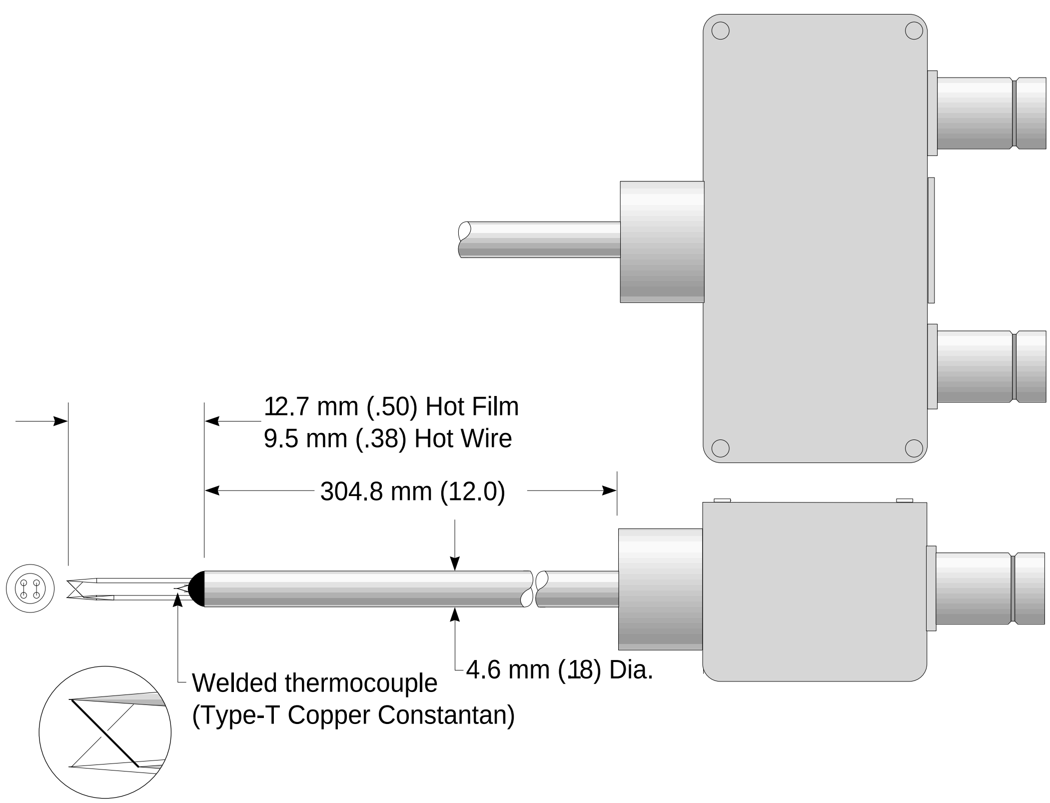


Recommended Sensors

For Gas Applications

1301-T1.5
1301-20
1301-60
Max. Fluid
Temp.= 150°C

Model 1302 End Flow "X" Probe With Thermocouple



Recommended Sensors

For Gas Applications

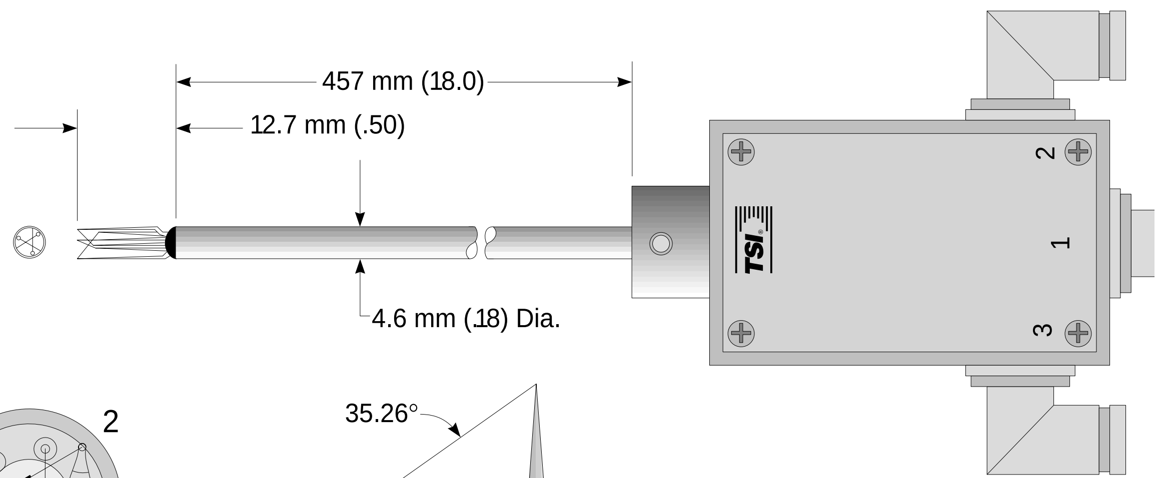
1302-T1.5
1302-20
1302-60
Max. Fluid
Temp.= 150°C

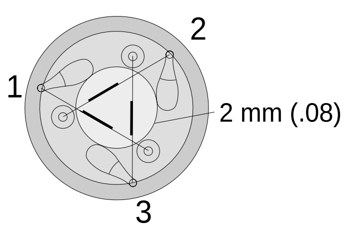
Dimensions in parentheses are in inches.

Probes for Three Cylindrical Sensors

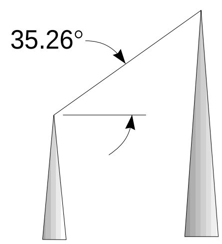
Three-sensor probes are used to locate three sensors in close proximity. They are generally used to measure all three velocity components. Good measurements require that the flow vector stays within the one octant defined by the three sensors. The sensors are located optimally for maximum spatial resolution and minimum probe interference.

Model 1299 End Flow 3-D Probe





Enlarged End View

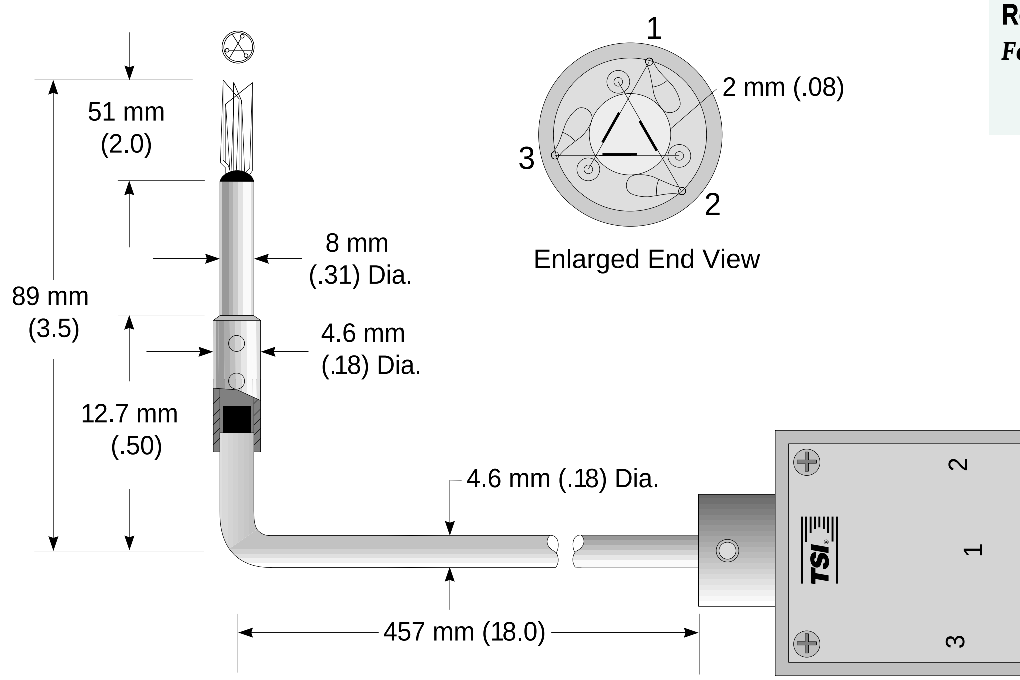


Sensor Angles

Recommended Sensors
For Gas Applications
1299-18-20
Max. Fluid Temp.= 150°C

Model 1299A Cross Flow 3-D Probe

Recommended Sensors
For Gas Applications
1299A-18-20
Max. Fluid Temp.= 150°C

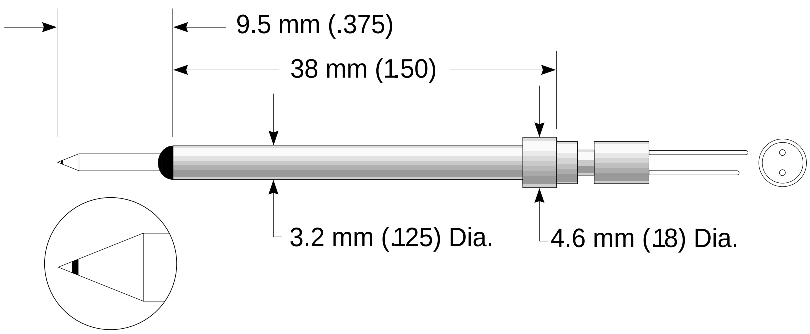


Non-Cylindrical Probes

Non-cylindrical probes tend to be more contamination resistant than cylindrical sensors, more rugged, and have essentially no limit on maximum flow velocity. In gases, higher frequencies are attenuated, compared with a steady state calibration, due to conduction losses to the surrounding material.

Cone-shaped sensors are contamination resistant and especially suited to liquid applications or highly contaminated gases.

Model 1230 End Flow Conical Probe



Recommended Sensors

For Gas Applications

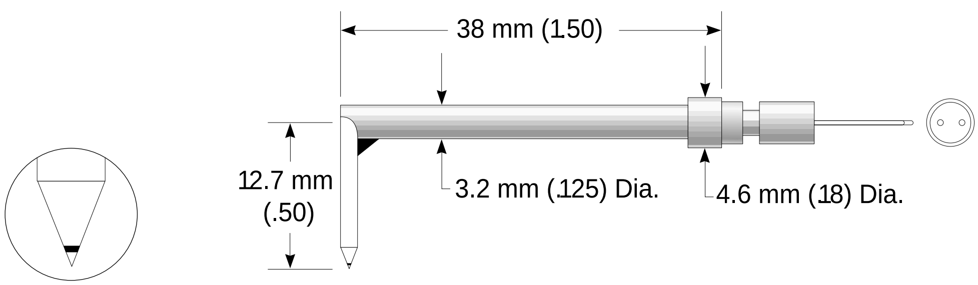
1230

Max. Fluid Temp.= 150°C

For Liquid Applications

1230W

Model 1231 90° Cross Flow Conical Probe, Sensor Upstream



Recommended Sensors

For Gas Applications

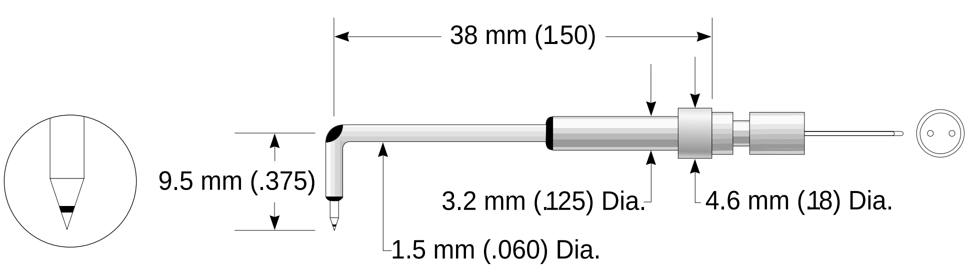
1231

Max. Fluid Temp.= 150°C

For Liquid Applications

1231W

Model 1264A Cross Flow Miniature Conical Probe, Sensor Upstream



Recommended Sensors

For Gas Applications

1264A

Max. Fluid Temp.= 150°C

For Liquid Applications

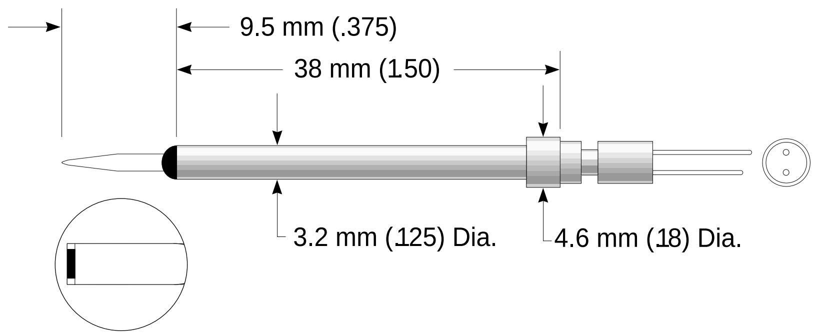
1264AW

Dimensions in parentheses are in inches.

Non-Cylindrical Probes

Wedge-shaped sensors have a cosine response similar to cylindrical sensors but are somewhat less contamination resistant compared to cone-shaped sensors.

Model 1232 End Flow Wedge Probe



Recommended Sensors

For Gas Applications

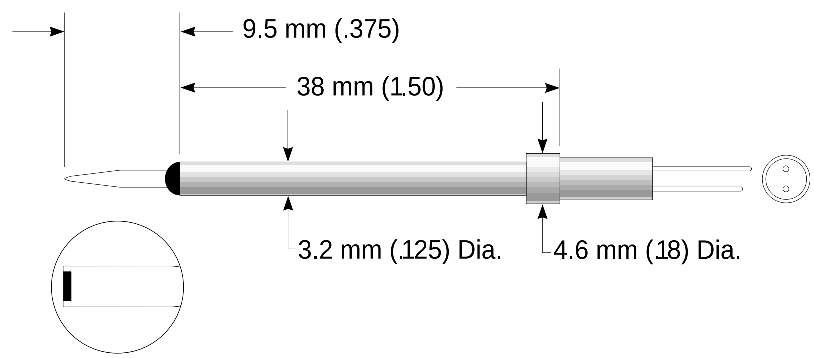
1232

Max. Fluid Temp.= 150°C

For Liquid Applications

1232W

Model 1232H High Temperature End Flow Wedge Probe



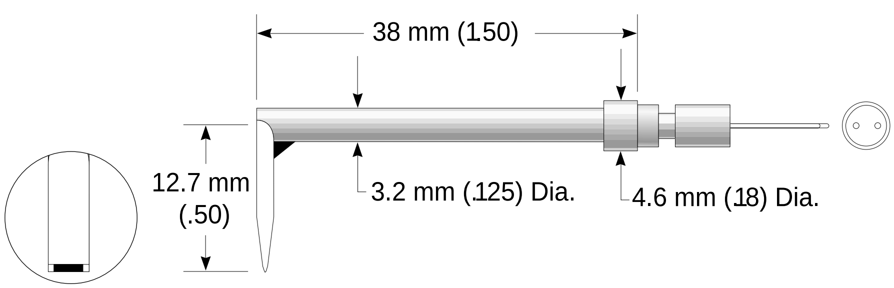
Recommended Sensors

For Gas Applications

1232H

Max. Fluid Temp.= 300°C

Model 1233 90° Cross Flow Wedge Probe, Sensor Upstream



Recommended Sensors

For Gas Applications

1233

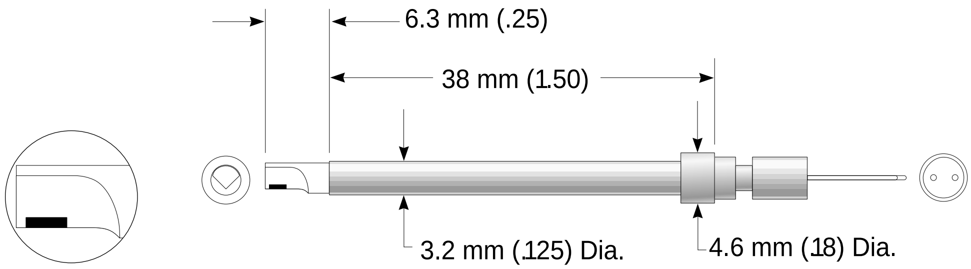
Max. Fluid Temp.= 150°C

For Liquid Applications

1233W

Non-Cylindrical Probes

Model 1234H High Temperature Cross Flow Wedge Probe



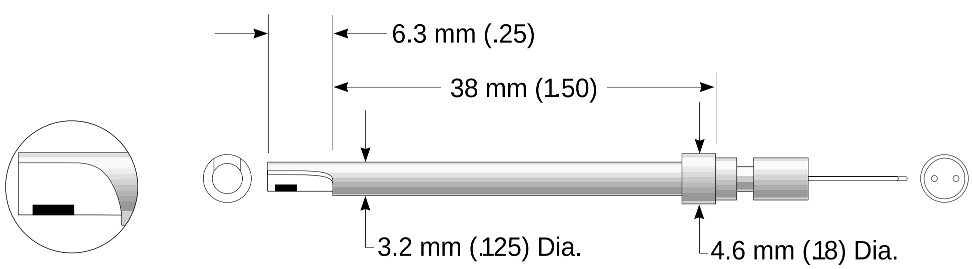
Recommended Sensors

For Gas Applications

1234H
Max. Fluid Temp.= 300°C

The rugged sensor is designed specifically for field applications or other conditions where the tips on cones or wedges are likely to become damaged.

Model 1269W Ruggedized Cross Flow Probe



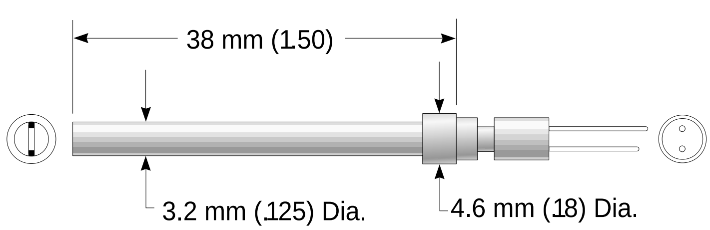
Recommended Sensors

For Liquid Applications

1269W

Flush mount sensors are designed to be mounted flush with a wall surface for boundary layer studies or simply as a monitor.

Model 1237 Standard Flush Mount Sensor



Recommended Sensors

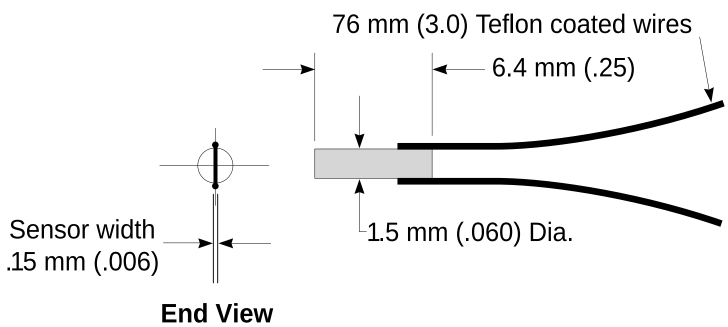
For Gas Applications

1237
Max. Fluid Temp.= 150°C

Dimensions in parentheses are in inches.

Non-Cylindrical Probes

Model 1268 Miniature Flush Mount Sensor



Recommended Sensors

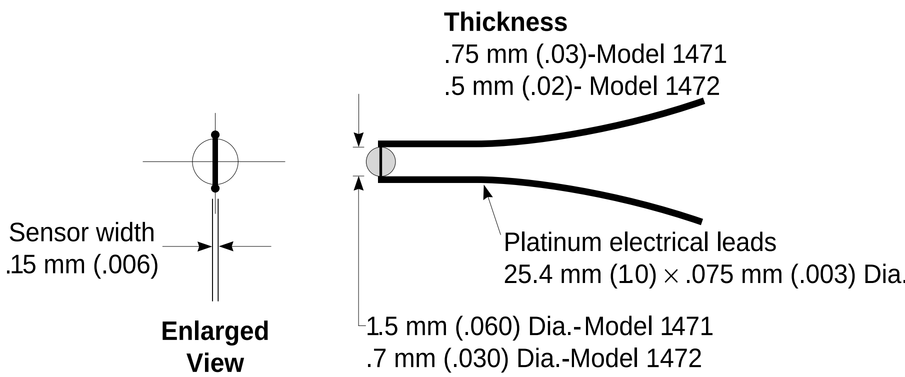
For Gas Applications

1268
Max. Fluid Temp.= 150°C

For Liquid Applications

1268W
(Note: Use Model 1108 Adapter)

Model 1471 Miniature Flush Mount Sensor
Model 1472 Subminiature Flush Mount Sensor



Recommended Sensors

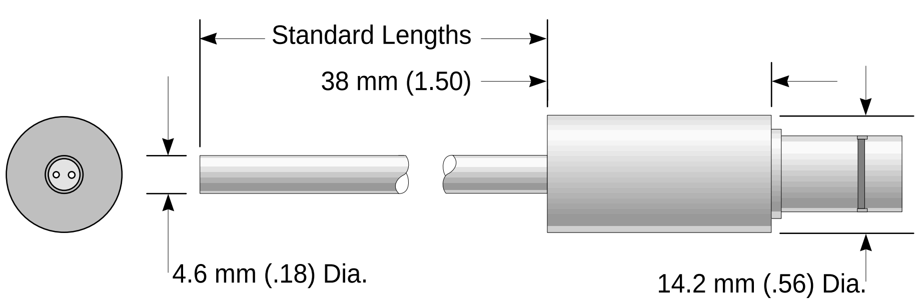
For Gas Applications

1471
Max. Fluid Temp.= 150°C

1472
Max. Fluid Temp.= 150°C

Single Sensor Probe Supports

Model 1150 Standard Probe Support
Model 1160 High Temperature Probe Support



Designed for most standard TSI single sensor plug-in probes.

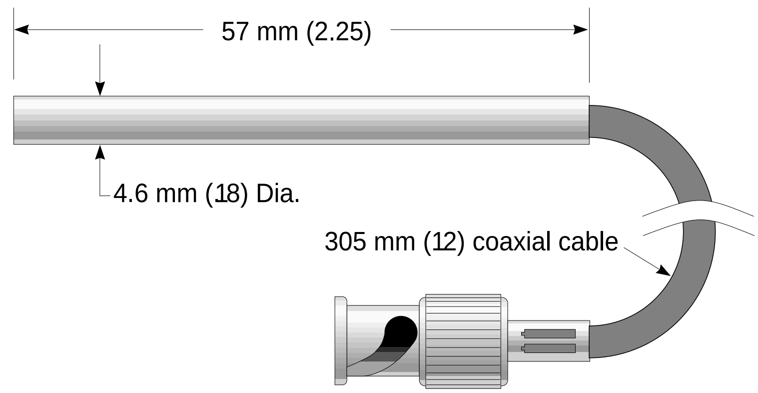
Specify

1150-6 for 152 mm (6 in.) length
1150-18 for 457 mm (18 in.) length
1150-36 for 915 mm (36 in.) length
Max. Fluid Temp.= 150°C

1160-6 for 152 mm (6 in.) length
1160-18 for 457 mm (18 in.) length
Max. Fluid Temp.= 300°C

Single Sensor Probe Supports

Model 1151 Probe Support

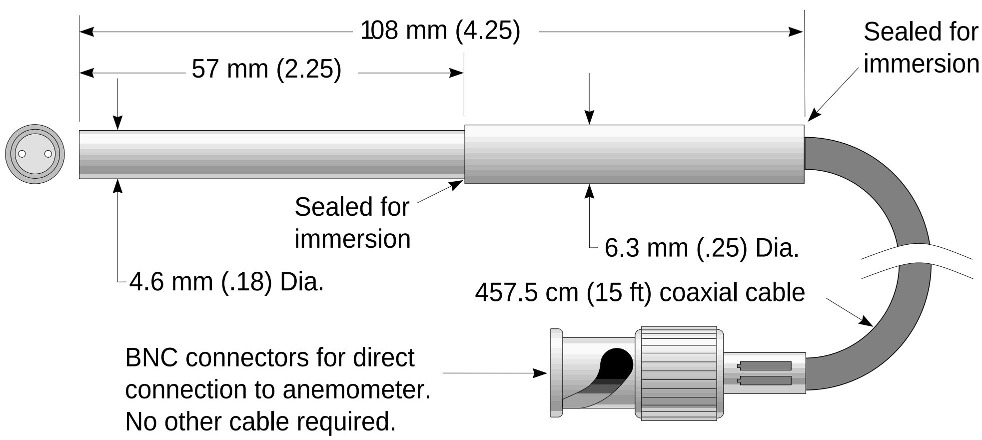


Convenient probe support for small spaces.

Specify

1151-1
Max. Fluid Temp.= 150°C

Model 1159 Immersible Probe Support

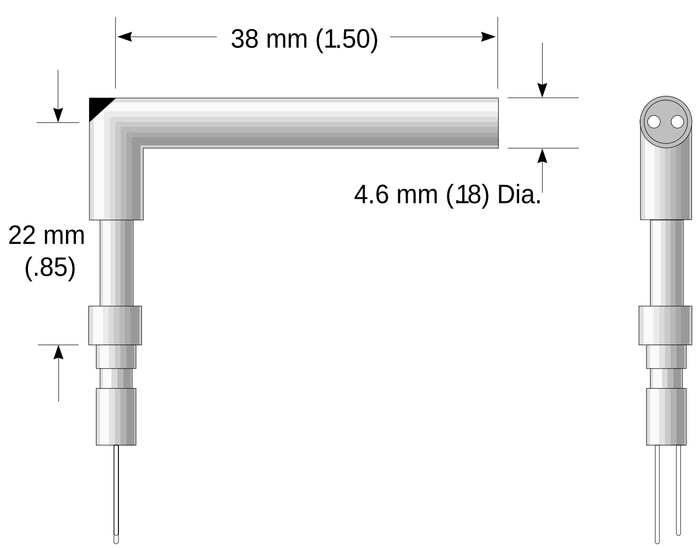


Small probe can be immersed entirely for liquid flow applications.

Specify

1159-15

Model 1152 90° Angle Adapter



Right angle bend provides access to upstream points with straight probes.

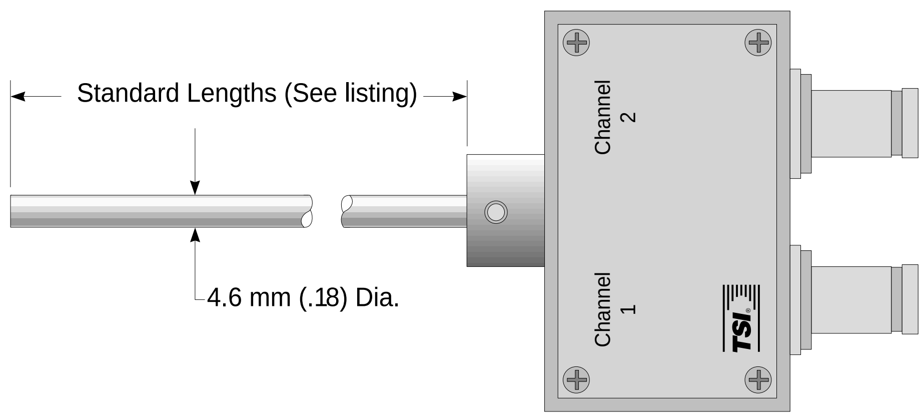
Specify

1152

Dimensions in parentheses are in inches.

Dual Sensor Probe Supports

Model 1155 Standard Probe Support
Model 1165 High Temperature Probe Support



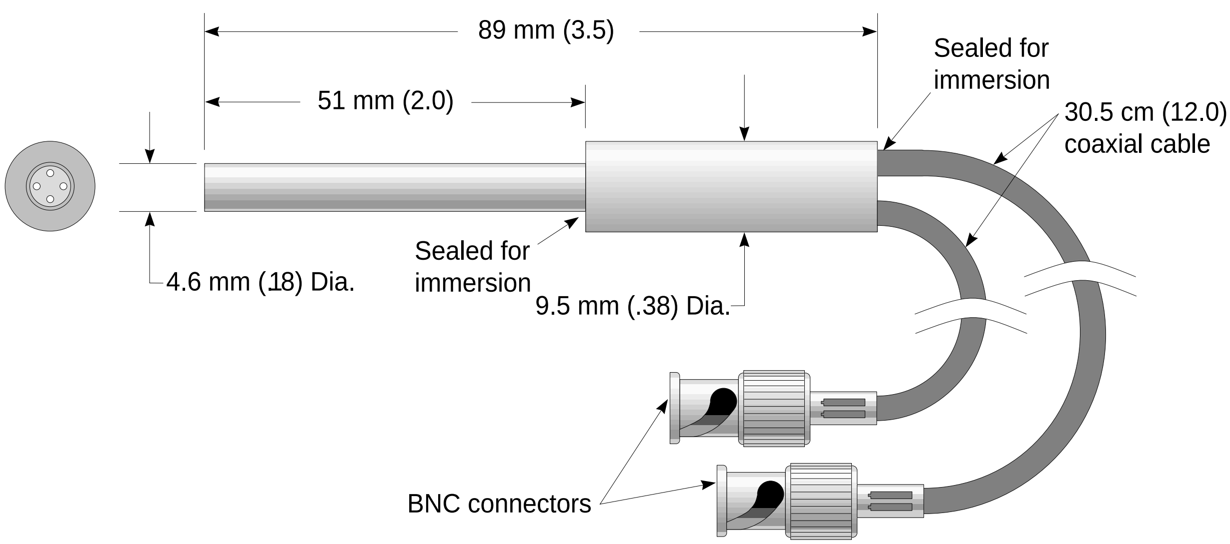
Designed for most standard TSI dual sensor plug-in probes.

Specify

1155-6 for 152 mm (6 in.) length
1155-18 for 457 mm (18 in.) length
1155-36 for 915 mm (36 in.) length
Max. Fluid Temp.= 150°C

1165-6 for 152 mm (6 in.) length
1165-18 for 457 mm (18 in.) length
Max. Fluid Temp.= 300°C

Model 1156-1 Probe Support



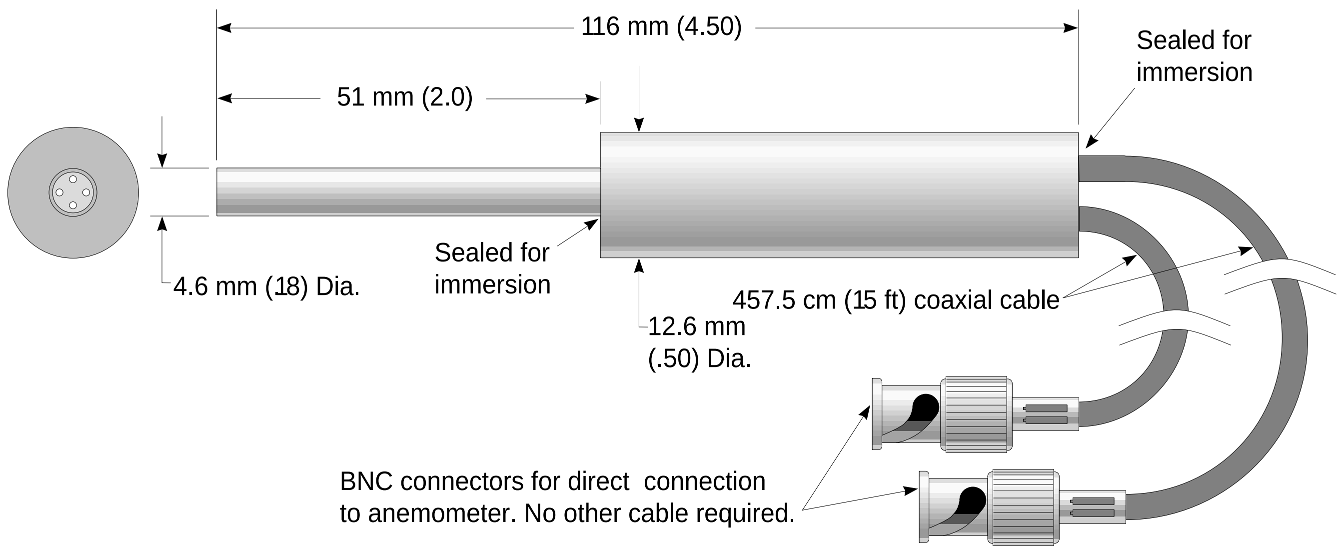
Convenient probe support for small spaces.

Specify

1156-1
Max. Fluid Temp.= 150°C

Dual Sensor Probe Supports

Model 1154-15 Dual Sensor Probe Support for Liquids

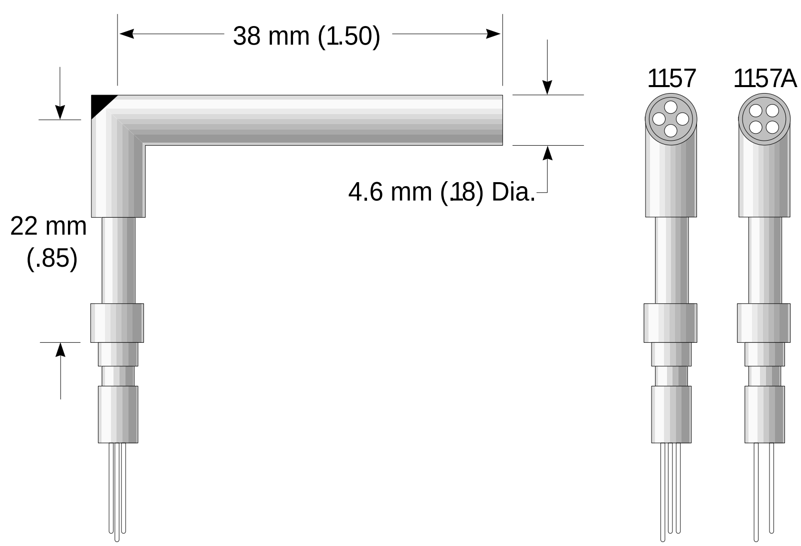


Small probe can be immersed for liquid flow applications.

Specify

1154-15

Model 1157 90° Angle Adapter



Right angle bend provides access to upstream points with straight probes.

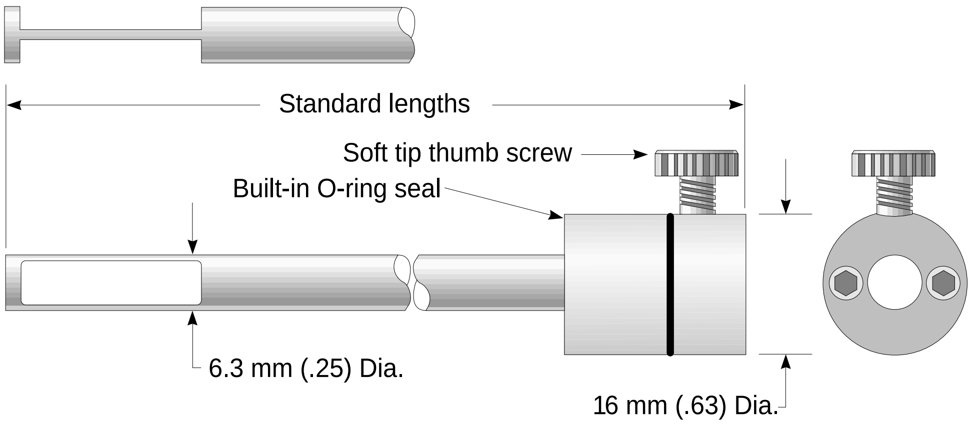
Specify

1157
1157A (for use with Models 1240 and 1247A probes only)

Dimensions in parentheses are in inches.

Probe Accessories

Model 1139 Shield With Window

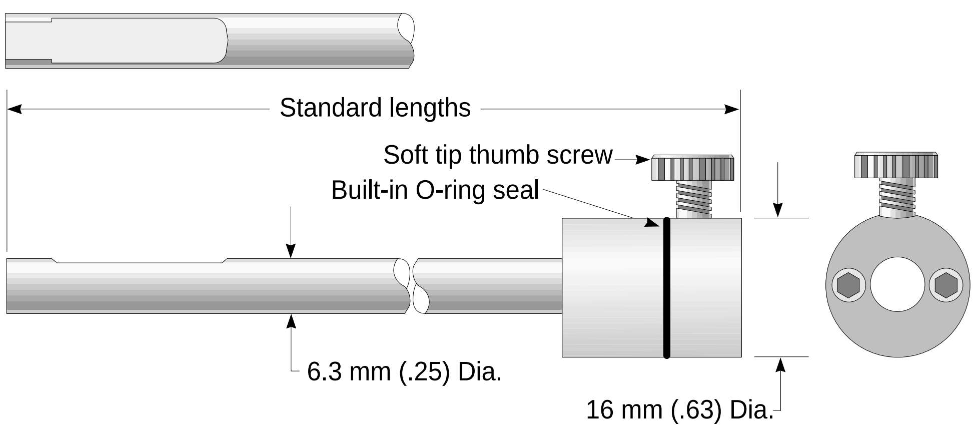


Completely protects sensor while providing opening for cross-flow measurements. Probe can be extended beyond end for unobstructed measurements. Fits Model 1150 Probe Supports.

Specify

1139-6 for 152 mm (6 in.) length
1139-18 for 457 mm (18 in.) length
1139-36 for 915 mm (36 in.) length

Model 1158 Locking Protective Shield

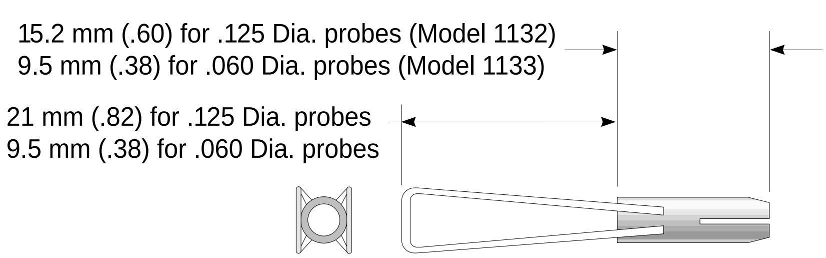


Protects probe when used as a shield, locks probe into socket when extended. Provides sturdy support for probe. Fits Model 1150 Probe Supports and most standard probes.

Specify

1158-6 for 152 mm (6 in.) length
1158-18 for 457 mm (18 in.) length
1158-36 for 915 mm (36 in.) length

Model 1132 Wire Shield
Model 1133 Miniature Wire Shield



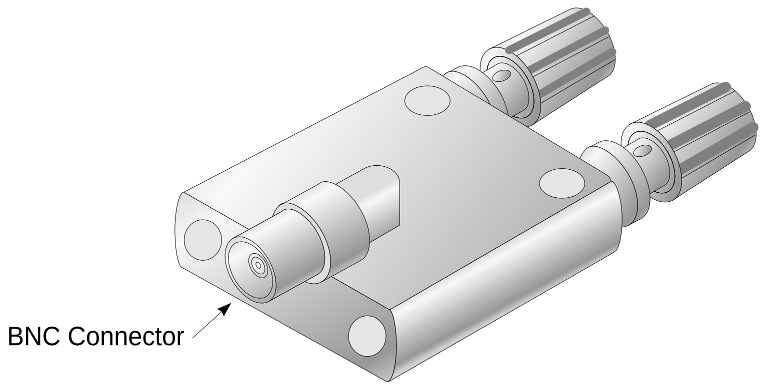
Protects probe from breakage while in use. Can be installed and removed as required using friction fit.

Specify

1132 for 3.18 mm (1/8 in.) diameter probes
1133 for 1.5 mm (.060 in.) diameter probes

Probe Accessories

Model 1108 BNC Subminiature Probe Adapter

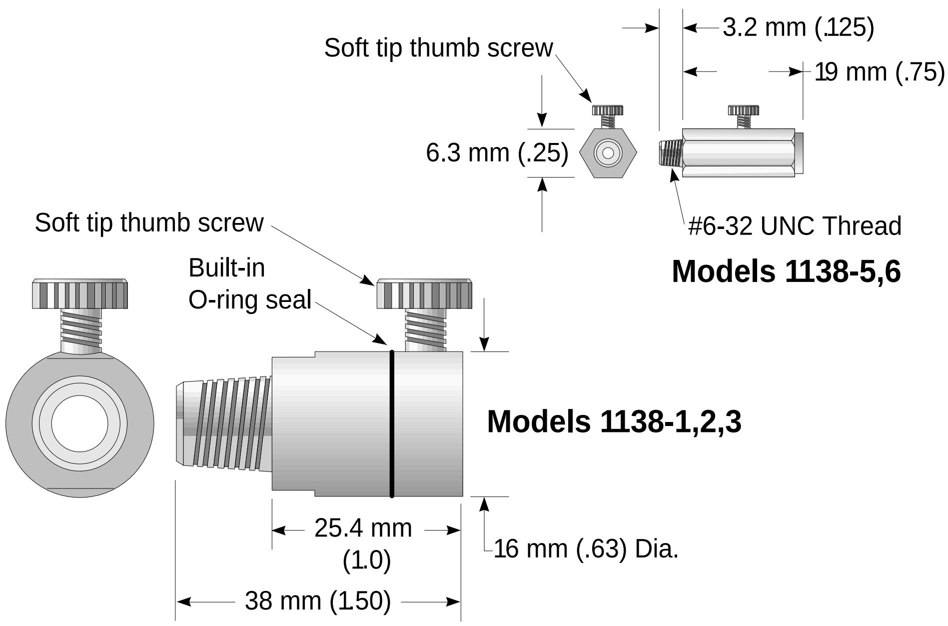


Adapts from probe wires to BNC connector for subminiature probes with wire leads.

Specify

1108

Model 1138 Mounting Blocks

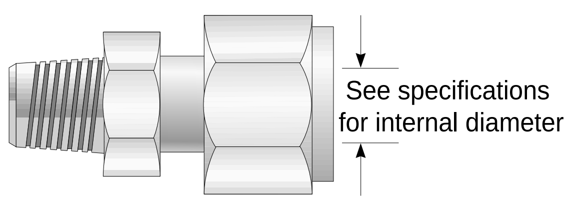


A sealing fitting for probe traversing and for mounting probe supports to the wall of a test section.

Specify

- 1138-1 for .250 in. Prot. Sleeve-1/4 NPT
- 1138-2 for .180 in. Probe Support-1/4 NPT
- 1138-3 for .125 in. Standard Probe-1/8 NPT
- 1138-5 for .060 in. Miniature Probe-6-32
- 1138-6 for .035 in. Submin. Probe-6-32

Model 1137 Mounting Block



Sealing fittings for probe traversing and for mounting probe supports to the wall of a test section. Has nylon ferrules for higher pressure applications.

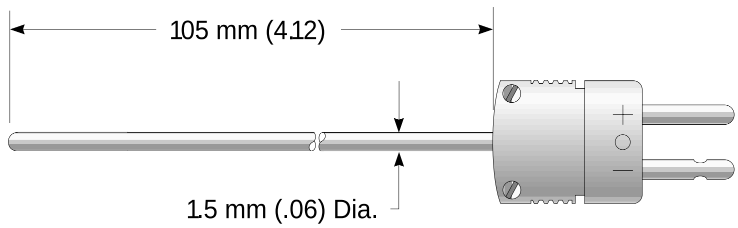
Specify

- 1137-1 for .250 diameter, 1/4-18 NPT
- 1137-2 for .180 diameter, 1/4-18 NPT
- 1137-3 for .125 diameter, 1/8-27 NPT
- 1137-4 for .060 diameter, 1/8-27 NPT

Dimensions in parentheses are in inches.

Probe Accessories

Model 1341 Thermocouple Probe

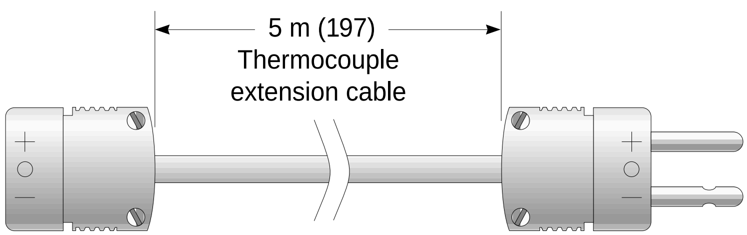


Measures temperature of measurement environment. Type-T copper-constantan.

Specify

1341

Model 1340 Thermocouple Extension Cable

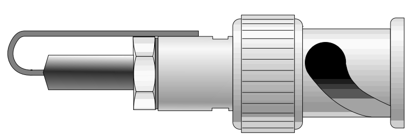


Cable 5 m long connects Model 1340 Thermocouple to anemometer. Type-T copper-constantan.

Specify

1340

Model 1304 Control Resistor
Model 1305 Control Resistor



BNC Connector for direct connection to 1050 anemometer or 1750 anemometer

Model 1304 control resistors are used with bridges that have a 5 to 1 ratio, such as 1750 and 1050/1053/1054 anemometers. The Model 1305 control resistors are used with bridges that have a 1 to 1 bridge ratio such as the 1:1 bridge used for high frequency applications of the IFA 100 and 1050.

Specify

1304-XX

1305-XX

where XX is the resistance to the nearest 1 ohm. To determine the correct resistance, refer to equation 2 on page 44.

Probe Accessories

Model 10120 Hot Wire/Film Sensor Repair Kit

Includes equipment needed to attach hot wire or cylindrical film sensors designed for gas applications to needle supports. Kit includes soldering iron with spare tips, single-edge razor blades, soldering stand with clip, jeweler's broach, soft solder (400°F melting point), distilled water, brush, acid flux, and a file. A microscope or magnifier of about 10X to 20X is also recommended.

Specify
10120 for 110VAC, 60 Hz
10120-1 for 220VAC, 50 Hz

Model 10121 Hot Film Replacement Sensors

These are high-quality, alumina-coated hot film sensors (cylindrical elements for air only) for field replacement use. They are furnished in quantities of 10 with mounting instructions.

Specify
10121-10 for 0.025 mm (0.0015 in.) dia. with 0.5 mm (0.020 in.) sensor length
10122-20 for 0.05 mm (0.002 in.) dia. with 1.0 mm (0.040 in.) sensor length
10122-60 for 0.15 mm (0.006 in.) dia. with 2 mm (0.080 in.) sensor length

---

Model 10122 Hot Wire Replacement Sensors

These are high-quality, platinum-coated tungsten hot wire sensors for field replacement use, furnished in quantities of 12 on a card. Each sensor is strung across a slot for ease in positioning and mounting. The ends of the wires are plated to isolate the active sensor region.

Specify
10122-T1.5 for 0.0038mm (0.00015 in.)dia. with 1.25 mm (0.050 in.) sensor length
10122-T2 for 0.005mm (0.0002 in.) dia. with 1.25 mm (0.050 in.) sensor length

---

Model 10123 Wire for Hot Wire Sensors

This is the same high-quality, platinum-coated tungsten wire used in the Model 10122 but furnished on a spool in a 2-meter length.

Specify
10123-T1.5 for 0.0038 mm (0.00015 in.) dia. with 2-meter length of wire
10123-T2 for 0.005 mm (0.0002 in.) dia. with 2-meter length of wire

Dimensions in parentheses are in inches.

Determining Operating Resistance of a Sensor

Each TSI probe is furnished with complete sensor data showing the recommended operating resistance (R_{op}) of the sensor.

Fragile Sensors
To be opened only by user

TSI

Probe Model ____ **Serial** ____ **TSI Ref. No.** ____

Sensor No.	Probe RES at 0°C R_0, Ω	R_{100}-R_0 Ω	Recommended Oper. RES R_{0p}, Ω	Recommended Oper. Temp. T_{0p}, °C	Internal Probe RES R_{int}, Ω
1					
2					
3					

Notes: 1. Control RES (If required) = (R_{0p} + R cable) × 5 on 5:1 BRIDGE
2. R_0 = R sensor + R_{int}

Call 1-800-874-2811 for service. Made in U.S.A.

Example of Sensor Data Label

The operating resistance of the sensor determines the temperature at which the sensor will be operated. Operating resistances are calculated from sensor resistance data taken at 0°C (R_O) and 100°C (R_{100}-R_O) and include the internal probe resistance (R_{int}). The operating resistance listed with each probe corresponds to the recommended operating temperature of the sensor (T_{op}) which is also included with the probe. Sensors for use in air or other gases are usually run at temperatures of 250°C, while water sensors are run at 67°C. These sensor temperatures have been selected to optimize sensitivity and signal-to-noise ratio, and provide maximum sensor life. If a different sensor temperature is desired, it can be calculated from:

Equation 1

$$R_{op} = \frac{T_s\left(R_{100} - R_O\right)}{100°C} + R_O$$

where:
R_{op} = Operating resistance of the sensor (ohms)
T_s = Desired sensor temperature (°C)
R_{100}-R_O = Sensor resistance change between 0°C and 100°C (ohms)
R_O = Sensor resistance at 0°C (ohms)

The operating resistance of the sensor can be set with a variable resistance decade or with a fixed control resistor. The required control resistor value can be determined by:

Equation 2

$$R_{CR} = \left(R_{op} + R_c\right) \times 5$$

(for 5:1 bridge ratio)

where:
R_{CR} = Control resistor value (ohms)
R_c = Probe cable resistance, including probe support (ohms)

For TSI 1050 Anemometers with resistance decades, or for IFA 100, IFA 300, and FLOWPOINT Anemometers, the operating resistance can be set directly if the probe cable resistance is properly accounted for.

Probe Calibration

The probe current versus velocity curves* on page 45 show the sensitivity of various types of sensors. Velocity sensitivity is taken directly from the slope of the curve as amps per units of velocity. To convert from current sensitivity to bridge voltage sensitivity, use the following equation:

Equation 3

$$\frac{\Delta E_B}{\Delta V} = \frac{\Delta I_s}{\Delta V}\left(R_{op} + R_B\right)$$

where:
$\frac{\Delta E_B}{\Delta V}$ = The slope of the calibration curve at the velocity of interest, proportional to the ratio of change in sensor current (ΔI_S) for a small change in velocity (ΔV) past the sensor.
E_B = Bridge voltage
V = Velocity
R_{op} = Sensor operating resistance
R_B = Bridge resistor in series with the sensor (10 ohms for IFA 300 STD Bridge)

The curves can also be used to determine the electrical power dissipated in the sensor or to estimate the approximate bridge voltage at a given velocity:

Equation 4

$$E_B = I_s\left(R_{op} + R_B\right)$$

where:
E_B = Bridge voltage
I_s = Sensor current
R_{op} = Sensor operating resistance
R_B = Bridge resistor

The sensor curves shown are valid only for the sensor resistance listed. For a different resistance sensor, correct the sensor current by:

Equation 5

$$I_{s_2} = I_{s_1}\sqrt{\frac{R_{op_1}}{R_{op_2}}}$$

where:
I_{S_2} = New sensor current
I_{S_1} = Sensor current from curve
R_{op_1} = Sensor resistance listed on curve
R_{op_2} = Actual sensor resistance

Sensitivity to Resistance Change

Often in anemometry, questions may arise regarding: 1) Effect of cable length on calibration; 2) "Noise" from slip rings and other types of "contact problems;" 3) Effects of resistance shifts of the sensor; 4) Stability requirements of other resistors in the bridge. These questions all relate to the effect of resistance changes on the output voltage. This can be expressed as:

*Curves are for typical sensors. Actual sensors will vary.

Equation 6

$$\frac{\Delta E_B}{\Delta R_{op}} = -\frac{I_s}{2}\,\frac{\left(R_{op}/R_B\right)\left(2R_{op}/R_e - 1\right)+1}{\left(R_{op}/R_e\right)-1}$$

For example, if R_{op} = 9 ohms, R_e = 6 ohms, and R_B = 10 ohms, then:

$$\frac{\Delta E_B}{\Delta R_{op}} = -2.8\,I_s\left(volts/ohm\right)$$

From the sensor current curves at the right and equation (3), a resistance change can be related to velocity sensitivity.

Effects of Amplifier Drift

The following relationship gives the ratio of bridge voltage (output) change to a change in amplifier input voltage.

Equation 7

$$\frac{\Delta E_B}{e_b} = -\frac{1}{2}\left[1+\frac{R_B}{R_{op}}\right]\frac{\left(R_{op}/R_B\right)\left(2R_{op}/R_B - 1\right)+1}{\left(R_{op}/R_e\right)-1}$$

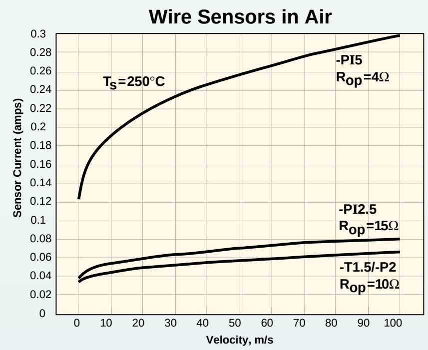
Using the above example:

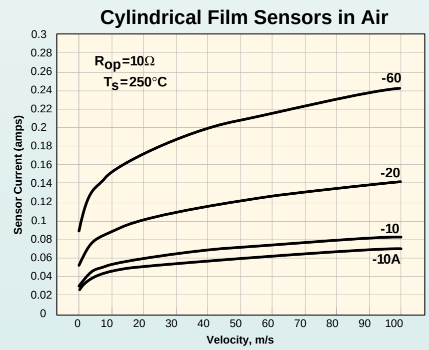
$$\frac{\Delta R_B}{e_B} = -3.63$$

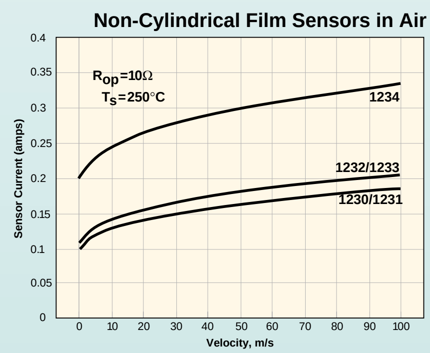
Therefore, a change of 10 microvolts at the amplifier input (equivalent input drift for example) gives only 36.3 microvolts at the anemometer output for the assumed conditions. A constant temperature anemometer is inherently a very stable instrument.

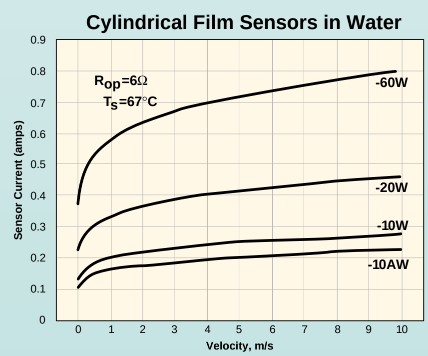
Conduction Loss to Supports

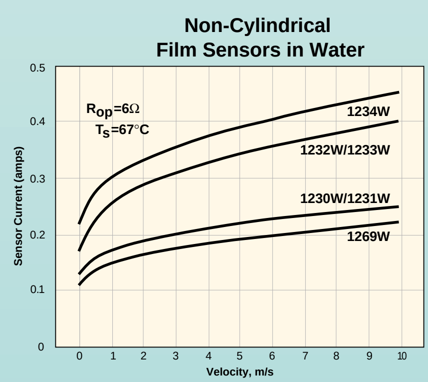
The steady-state effects of conduction losses to supports have little influence on the mean velocity accuracy if the sensor is properly calibrated. Only when attempts are made to predict the calibration heat transfer equations will the steady state conduction to supports become a factor. In noncylindrical film sensors, the dynamic effects of nonsteady state heat conduction to the supporting structure can be significant, particularly in gases. For example, the high frequency (compensated) sensitivity can be less than half of that predicted by a steady-state calibration curve.** The actual attenuation depends on many factors including the size and shape of the sensor and its environment. In general, the high heat transfer rates in water reduce this error to acceptable levels, while in gases a dynamic calibration is required for optimum results. It should be emphasized that this effect is usually negligible in both hot wires and cylindrical film sensors. This is because the conduction loss to the supports is small and the supports are a sufficiently large heat sink so their temperature change is small.



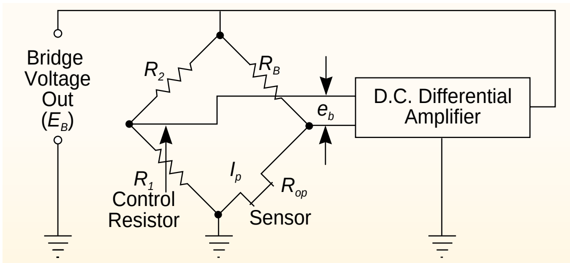








**For additional technical information, request TSI Quarterly reprint Q22, January-March 1983, "Dynamic Response of Conical and Wedge Type Hot Films Comparison of Experimental and Theoretical Results," E. Nelson and J.A. Borgos.



Schematic of Constant Temperature Anemometer

Calibration Adjustments

Calibrations are made by plotting Bridge Voltage, E_B, as a function of Velocity and then fitting the data with a polynomial or exponential curve fit. If the calibration must be adjusted for use with a different bridge resistance, R_B, or cable resistance, R_c, it is useful to assume that the sensor current is constant (for a given velocity and sensor temperature). For convenience, internal probe resistance is included in sensor resistance data, but probe support resistance can be measured or nulled out and should be included with cable resistance, R_c. Then we can calculate a new bridge voltage for each velocity.

Equation 8

$$I_s = \frac{E_B}{\left(R_B + R_c + R_{op}\right)}$$

and so:

$$E'_B = E_B \frac{\left(R'_B + R'_c + R_{op}\right)}{\left(R_B + R_c + R_{op}\right)}$$

Temperature Sensitivity

Bridge Voltage is corrected for ambient temperature changes as follows. A reasonable assumption is that

$$\frac{E_B^2}{\left(T_s - T\right)}$$

is constant for a given velocity as temperature changes. Therefore, we can predict a bridge voltage E_B' for a new temperature, T', as follows.

Equation 9

$$E_{B'} = E_B \left[\frac{T_s - T'}{T_s - T}\right]^{1/2}$$

Directional Sensitivity of Cylindrical Sensors

The following provides a very brief introduction to techniques for measurements with cylindrical thermal sensors. To simplify this presentation, it is assumed that the sensor is sufficiently long so that the following approximation can be used:

Equation 10

$$V_{eff} = V \cos \alpha$$

In other words, the effective cooling velocity past the sensor varies as the cosine of the angle between the sensor axis and the velocity vector. At 90°, $V_{eff} = V$ and at 0° $V_{eff} = 0$. It should be noted that in the ideal case, the sensitivity remains constant as the velocity vector moves around the sensor at a constant angle, α, to the sensor axis.

Single Sensor Oriented Perpendicular to the Mean Flow

Let the mean flow be represented by $\overline{V_1}$ and the fluctuations represented by v_1, v_2, and v_3 where v_2 represents the fluctuations in the direction parallel to the sensor and v_3 represents the fluctuations in a direction perpendicular to v_1 and v_2. The effective velocity measured will be:

Equation 11

$$V_{eff} = \sqrt{\left(\overline{V_1} + v_1\right)^2 + v_3^2}$$

If we neglect v_3, then:

$$\overline{V_1} = \overline{V} = \overline{V_{eff}}$$

and

$$\sqrt{\overline{v_1^2}} = \sqrt{\overline{v_1^2}}$$

The value of V_1 is the average value while

$$\sqrt{\overline{v_1^2}}$$

is the rms value.

When

$$\sqrt{\overline{v^2}} \big/ \overline{V} = 0.2$$

(= 20% turbulence intensity), the error due to ignoring v_3 is about 2% for isotropic, normally distributed, and normally correlated turbulence.† The mean velocity error is also about 2%.

X Probe (Two cylindrical sensors oriented at 90° to each other)

The X probe is used to measure two velocity components. Writing the equations for the effective velocity for the two sensors "A" and "B" with the mean velocity in the plane of the two sensors $\overline{V_3} = 0$ and α_1 = the angle between V_1 and sensor B gives:

Equation 12

$$V_{A,eff}^2 = \left(V_1 \cos \alpha_1 - V_2 \sin \alpha_1\right)^2 + v_3^2$$

$$V_{B,eff}^2 = \left(V_1 \sin \alpha_1 + V_2 \cos \alpha_1\right)^2 + v_3^2$$

If the sensors are further aligned so $\alpha_1 = 45°$ and v_3^2 is assumed negligible, then rearranging the above equations gives:

Equation 13

$$V_1 = 2^{-1/2}\left(V_{A,eff} + V_{B,eff}\right)$$

Finally, if the sensors are aligned so that $\overline{V_2} = 0$ and $\overline{V_1} = \overline{V}$, then:

Equation 14

$$\overline{V} = 2^{-1/2}\overline{\left(V_{A,eff} + V_{B,eff}\right)}$$

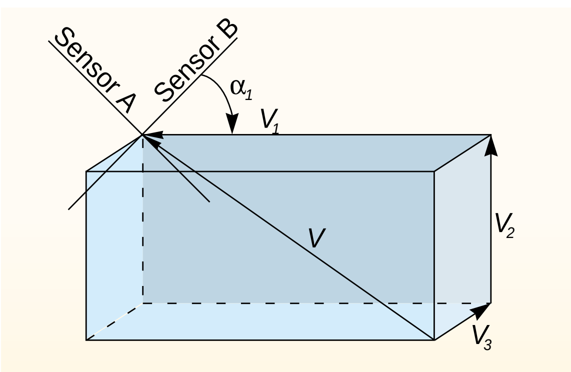
$$\overline{v_1^2} = 2^{-1}\overline{\left(v_{A,eff} + v_{B,eff}\right)^2}$$

$$\overline{v_2^2} = 2^{-1}\overline{\left(v_{A,eff} - v_{B,eff}\right)^2}$$

$$\overline{v_1 v_2} = 2^{-1}\overline{\left(v_{A,eff} + v_{B,eff}\right)\left(v_{A,eff} - v_{B,eff}\right)}$$

Neglecting v_3 gives an error of about 8% when the turbulence intensity is 20%, with the same flow field as discussed for the single wire.†

The above is given here to provide some insight into how single sensors and X probes are used and the limitations at high turbulence intensities. Refinements of the equations as well as other considerations are contained in the extensive literature on thermal sensors contained in the Freymuth bibliography.



Configuration of X-probe.

Nomenclature

E_B = bridge voltage output
ΔE_B = small change in bridge voltage output
e_b = small voltage change at amplifier input
f = frequency, (Hz)
I_s = current through sensor (amps)
ΔI_s = small change in sensor current
R_c = probe cable resistance (includes probe support resistance, but not internal probe resistance)
R_{CR} = control resistor value
R_e = resistance of sensor at ambient (environment) fluid temperature (ohms)
R_o = sensor resistance at 0°C
R_{op} = resistance of sensor at operating temperature
ΔR_{op} = small change in sensor resistance
R_B = bridge resistor in series with the sensor, 10 ohms for FLOWPOINT, IFA 100, IFA 300 except 2 ohms for IFA 100, IFA 300 Hi Power Bridge; 40 ohms for Model 1053B, 1054A, 1054B, and #1 Bridge on Model 1050; 10 ohms for #2 Bridge on Model 1050 and 2 ohms on #3 Bridge on Model 1050; 20 ohms for Model 1750.
T = fluid temperature
T_s = sensor operating temperature (°C)
V = fluid velocity past sensor
ΔV = small change in fluid velocity past sensor
V_1, V_2, V_3 = orthogonal components of V relative to flow facility
V_{eff} = effective cooling velocity past sensor (equivalent value of V_N)
$V_{A,eff}$ = effective velocity as seen by sensors (and similarly for sensor B)
v = small fluctuations in velocity V
α_1 = angle between velocity vector and sensor axis

†S.P. Parthasarathy and D.J. Tritton, "Impossibility of Linearizing Hot-Wire Anemometer for Turbulent Flows," AIAA J., vol. 1, pp. 210-1211, 1963.

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