POLITECNICO DI TORINO

DIMEAS - DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

Master's degree thesis

TESI DI LAUREA MAGISTRALE

SETUP OF INNOVATIVE METROLOGICAL SYSTEMS AND CHARACTERIZATION OF PRESSURE SENSORS FOR AERONAUTICAL APPLICATIONS

Academic Supervisors:

Prof.Vito Claudio Fernicola

INRIM Supervisors:

Dr. Andrea Merlone

Dr. Chiara Musacchio

Candidate:

Surendra
Rajkumar
Seelam-S251789

Academic Year 2020-2021

Acknowledgements

I would like to thank to Prof.Vito Claudio Fernicola, Senior researcher of INRIM supervisor of this thesis, for allowing me to carry out this project and supporting me with his suggestions and availability.

I would also like to express my great gratitude to Dr. Andrea Merlone, senior researcher of INRIM for his friendship, professionalism, and enormous patience demonstrated daily during this journey.

A big thank to Dr. Chiara Musacchio, INRIM researcher for the help and valuable suggestions during the thesis work.

A special thanks to my mother and family, who made so many sacrifices and allowed me to reach this goal. During the long course of the studies, they have always supported me and above all endured, making me grow and become the person I am today.

Thanks to all my bro's in Torino, with their constant support, but most of all with their gentleness and confidence in me, they continually urged me to always give my best by making this journey easier.

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Finally, but not least, I want to thank my "second family" ICT who made me feel at home all the time.

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Introduction

Wrong or inaccurate measurements can lead to wrong decisions, which can have serious consequences, costing money and even lives. The human and financial consequences of wrong decisions based on poor measurement being taken in matters as important as environmental change and pollution are almost incalculable. It is important therefore to have reliable and accurate measurements which are agreed and accepted by the relevant authorities worldwide. Metrologists are therefore continuously involved in the development of new measurement techniques, instrumentation, and procedures, to satisfy the ever-increasing demand for greater accuracy, increased reliability, and rapidity of measurements.

For individuals not directly involved in science to have confidence in the reliability and accuracy of the measurements made by scientists and Metrologists, it is essential that instruments used within any local or national measuring system are calibrated, and that the calibration may be traced to an internationally accepted system of standards or reference materials. For example, that the weighing scales in a local supermarket are calibrated against national standard weights and that these standards are themselves calibrated against an international standard of mass.

1.1 Metrology [1]

Metrology is the science of measurement. Metrology includes all theoretical and practical aspects of measurement.

Metrology is defined by the International Bureau of Weights and Measures (BIPM) as "*the science of measurement, embracing both experimental and theoretical determinations at any level of uncertainty in any field of science and technology*."

The ontology and international vocabulary of metrology (VIM) is maintained by the Joint Committee for Guides in Metrology (JCGM), a group made up of eight international organizations – BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML and ILAC.

Metrology is a very broad field and may be divided into three basic activities, though there is considerable overlap between the activities.

Definition of internationally accepted units of measurement. Realization of these units of measurement in practice. Application of chains of traceability linking measurements made in practice to reference standards.

1.1.1 SUB-FIELDS [1]

Metrology also has three basic subfields, all of which make use of the three basic activities, though in varying proportions: Scientific or fundamental metrology, Applied, technical or industrial metrology, and Legal metrology.

- Scientific metrology is concerned with the establishment of units of measurement, the development of new measurement methods, the realization of measurement standards, and the transfer of traceability from these standards to users in a society and strives for the highest degree of accuracy.

- Applied, technical or industrial metrology is concerned with the application of measurement to manufacturing and other processes and their use in society, ensuring the suitability of measurement instruments, their calibration and quality control
- Legal metrology "*concerns activities which result from statutory requirements and concern measurement, units of measurement, measuring instruments and methods of measurement and which are performed by competent bodies*". Legal metrology's primary focus is on measurements that directly affect consumers

However much scientific metrology and legal metrology may and can deal with very different levels of precision, they both deal with closely related problems. The potential consequences of inaccurate data related to commerce and medicine will affect us all, demonstrating that metrology is one of today's key sciences.

1.1.2 HISTORY OF METROLOGY [1]

Standardization of weights and measures has been a goal of social and economic advance since very early times, it was not until the 18th century that there was a unified system of measurement. The earliest systems of weights and measures were based on human morphology. The names of units often referred to parts of the body: the inch or pouce, the hand, the foot, and the yard or cubit corresponded to dimensions of the human body. Consequently, these units of measurement were not fixed; they varied from one town to another, from one occupation to another, and on the type of object to be measured.

This lack of a standardized system of measurements was a source of error and fraud in commercial and social transactions, putting a brake on international commerce and prevented the development of science as an international endeavour. With the expansion of industry and trade, there was an increasing need for harmonization of weights and measures between countries. Politicians and scientists resolved this situation by adopting a standard of measurement (distance or weight) by comparison with a standard (étalon) taken from Nature.

*One of the first such natural measures was the metre, which was defined in a decree of the French National Assembly (7 April 1795) as being equal to the ten millionth part of one quarter of the terrestrial meridian, but specified by measurements undertaken between Dunkerque and Barcelon*a. Such a unit was not arbitrary, being based on the size of the Earth. Once the base unit of length had been decided upon, it was possible to establish the resulting units of measure: the square metre (for area) and the cubic metre (for volume). The kilogram was originally defined as the weight of a certain volume of water, a convenient and readily purified liquid.

Such a system of simple multiples of base units lends itself naturally to extension. The decimal metric system was introduced in France on 7 April 1795 by the law "On weights and measures". This caused a major change in the everyday life of ordinary people, readily allowing the calculation of, for example, areas and volumes. Conversion from a sub-multiple to a multiple unit of length simply consists of moving the decimal marker – two or three places for area or volume, respectively.

The first standards (étalons) of the metre and the kilogram, against which all future copies were to be compared, were deposited in the Archives of the French Republic in 1799, dedicated to "all men and all times".

Because of its simplicity and universality, the decimal metric system spread rapidly outside France. The development of railways, the growth of industry and the increasing importance of social and economic exchange all required accurate and reliable units of measurement. Adopted at the start of the 19th century in several Italian provinces, the metric system became compulsory in the Netherlands from 1816 and was chosen by Spain in 1849. In France, the decimal metric system was exclusively adopted with the law of 4 July 1837

After 1860, the countries of Latin America took up the metre, and there was a steady increase in the adoption of the metric system by other nations during the latter half of the nineteenth century (for example, the United States of America, 1866, Canada, 1871, Germany, 1871). However, these countries were dependent for their national standards on copies of the original prototypes. This dependence, together with the lack of uniformity in making copies, limited the desired international standardization. To overcome these difficulties, the Bureau International des Poids et Mesures (BIPM) was founded by the terms of the diplomatic treaty known as the Metre Convention on 20 May 1875. To celebrate the signing of the Metre Convention, the date of 20 May is known as World Metrology Day.

Figure 1.1: BIPM Metre Convention

1.1.3 Traceability [1]

Metrology is of fundamental importance in industry and trade – not only from the point of view of the consumer but also for those involved in manufacturing. Both groups must have confidence in the accuracy and reliability of the measurements upon which they depend. Within the manufacturing process, to ensure the accuracy of measuring instruments, it is essential that they should be periodically calibrated against more accurate standards, which in turn should have their calibration traceable to even more accurate national measurement standards at the national level and, eventually, the international level. When these various levels of calibration have been documented, a **chain of traceable calibrations** is created.

Traceability means that the result of a measurement, no matter where it is made, can be related to a national or international measurement standard, and that this relationship is documented. In addition, the measuring instrument must be calibrated by a measurement standard that is itself traceable. *Traceability is thus defined as the property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international, through an unbroken chain of comparisons all having stated uncertainties. The concept of traceability is important because it makes possible the comparison of the accuracy of measurements worldwide according to a standardized procedure for estimating measurement uncertainty.*

At each stage in such a chain of traceability, one loses a certain degree of precision as shown in figure. Thus, the highest-level standards are the international standards, known with the greatest level of precision, and the lower level standards will have been determined to a lower level of precision. This lower level of precision will be one which is acceptable or appropriate for the use of that standard.

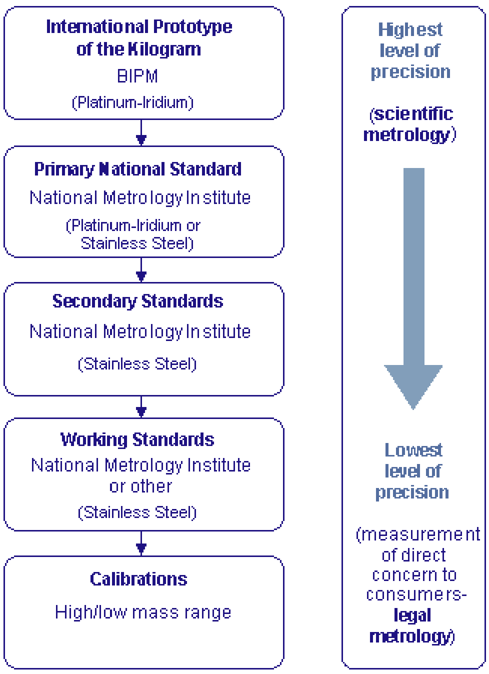


FIGURE 1.2: Schematic representation of the various types of standard that exist in a particular area of metrology, and how the level of precision will decrease along the chain of responsibility.

1.1.4 STANDARDS [1]

In measurement science, the word 'standard' is used with two different meanings: first, as a widely adopted specification, technical recommendation, or similar document; and, second, as a measurement standard. This note deals with measurement standards, which can be a physical measure, measuring instrument, reference material or measuring system intended to define, realize, conserve, or reproduce a unit or one or more values of a quantity to serve as a reference. For example, the unit of the quantity 'mass' is given its physical form by a cylindrical piece of metal of one kilogram, which represents the international standard, and gauge blocks represent certain values of the quantity 'length'.

A reference standard is a standard generally having the highest metrological quality available at a given location or in a given organization from which the measurements made at that location are derived. Calibration laboratories maintain reference standards for calibrating their working standards.

1.1.5 UNCERTAINITY [2]

The word "uncertainty" means doubt, and thus in its broadest sense "uncertainty of measurement" means doubt about the validity of the result of a measurement. Because of the lack of different words for this general concept of uncertainty and the specific quantities that provide quantitative measures of the concept.

for example, the standard deviation, it is necessary to use the word "uncertainty" in these two different senses.

The formal definition of the term "uncertainty of measurement" is parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand

Standard uncertainty is uncertainty of the result of a measurement expressed as a standard deviation

Type A evaluation (of uncertainty) is method of evaluation of uncertainty by the statistical analysis of series of observations

Type B evaluation (of uncertainty) is method of evaluation of uncertainty by means other than the statistical analysis of series of observations

Combined standard uncertainty is standard uncertainty of the result of a measurement when that result is obtained from the values of a number of other quantities, equal to the positive square root of a sum of terms, the terms being the variances or covariances of these other quantities weighted according to how the measurement result varies with changes
in these quantities

Expanded uncertainty is quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand

Coverage factor is numerical factor used as a multiplier of the combined standard uncertainty to obtain an expanded uncertainty

1.1.6 CALIBRATION [3]

An operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication.

1.1.7 FUTURE OF METROLOGY [1]

Measurements are made in a variety of places, for many different purposes.

- *From clinical tests in the medical laboratory to weighing scales in the supermarket.*
- *From electricity meters to process control instrumentation in the food industry.*
- *From frequency spectral analysis in telecommunications to pollution measurements in environmental protection.*
- *From the micrometer in the mechanical workshop to metallurgical analysis equipment in mining laboratories.*

The reason for the ever-increasing importance of metrology is the turbulence associated with globalization and global trade. The best route for any economy to prosper in the global marketplace is to improve the international competitiveness of its manufacturing industry. This certainly requires better products at lower prices, however, even that is not enough – the potential customer also needs to be convinced of the quality and compliance of the product, which must be proven by reliable test reports and conformity assessments.

2 DEVICES

During the characteristic procedure, we have used facilities, equipment, and devices in INRIM to measure the pressure, temperature. They are as follows

2.1 Earth Dynamics Investigation Experiment 1 – EDIE1 [4]

In order to provide data with good accuracy, it is important to define a standard calibration procedure to be carried out in chambers that keep measured quantities both stable during the calibration period at each measuring point and uniform in the calibration volume around the sensors.

A new transportable calibration system, **Earth Dynamics Investigation Experiment 1 (EDIE1),** capable of simultaneous and independent control of pressure and temperature, was developed at the Italian Institute of Metrology (INRIM).This apparatus is also designed to allow the control in humidity, therefore completing the characterization of the whole AWS pressure–temperature–humidity modulus.

The most important feature, with respect to other systems, is that EDIE1 allows temperature calibrations in air, instead of in a bath, in order to simulate the real operational conditions and characterize the sensor response more accurately. A characteristic of this facility is its ability to cover a wide range of atmospheric variability with one medium. The temperature is controlled between −25 ^{0}C and +50 ^{0}C and the pressure between 50 kpa and 110 kPa. This temperature range together with adjustable pressure conditions in the chamber gives extensive simulation scenarios for instruments and other components which are exposed to weather changes during operation.

One of the biggest advantages of this apparatus is its reduced dimensions. The good compromise between the measuring inner chamber (inner diameter 220 mm and volume of about 15l) and the external total dimensions (350 × 650 mm) makes it transportable for *in situ* calibration campaigns.

2.1.1 Test chamber

The test chamber (Figure 2.1) is formed by two concentric steel cylinders; between them, there is an interspace in which a vacuum is created as the thermal insulator. The inner cylinder is the test zone; it contains a copper cylinder on which a cooling coil is present. The copper bottom and cover of this internal volume are to guarantee the best thermal uniformity with the walls. The thermostatic fluid flow is used for thermal control. A steel pipe, connecting the inner chamber with the outside, allows pressure control and is also used for permanent electrical wiring

FIGURE 2.1: Test Chamber without covers

The test chamber characteristics allow to perform calibrations by comparison against the reference standards with limited uncertainty contributions:

- axial chamber uniformity contribution to standard calibration uncertainty: 0.075 °C (maximum difference recorded in the calibration range)
- vertical chamber uniformity contribution to standard calibration uncertainty: 0.1 °C (maximum difference recorded in the calibration range)
- chamber stability contribution to standard calibration uncertainty: 0.01 °C (stability evaluated during a one-hour observation period).

2.2 Earth Dynamics Direct Investigation Experiment – EDDIE [5]

Mutual influences of pressure, temperature and wind on instruments is an important topic both for metrology and meteorology. From a metrological point of view, in order to evaluate the effect of these three quantities simultaneously, it is necessary to have an adequate experimental setup that allows to control the three parameters at the same time, with an adequate level of uncertainty and repeatability. For this reason, a facility here called **EDDIE – Earth Dynamics Direct Investigation Experiment** has been realized at INRIM within the framework of the EMRP ENV07 Project "MeteoMet".

The facility realized by INRIM consists in a closed tunnel that can generate the following environmental conditions: air pressure range from about 75 kPa to 110 kPa, air temperature range from about -40 °C to 40 °C and airspeed range from 0 m s^{-1} to about 30 m s^{-1}.

Although like a wind tunnel, the facility is not called as such since it is not designed and equipped like a facility for anemometers calibration or aeronautical research. One of the relevant characteristics of EDDIE consists in the test chamber, which is equipped with a device (called shield system) that will allow to evaluate the instrument behaviour in a specific condition of temperature and pressure both in absence and in presence of wind.

2.2.1 FACILITY SCHEME

EDDIE facility (where EDDIE means Earth Dynamics Direct Investigation Experiment) can be controlled in temperature, humidity, pressure, and air velocity in defined ranges. These multi controls have been built through the assembly of three different modules into a complete system. The first module (see figure 2.2) is composed by the air circuit for wind simulation at different climatic conditions. The second module consists in a dehumidification system for the dehumidification of the air contained in the test circuit (module1).

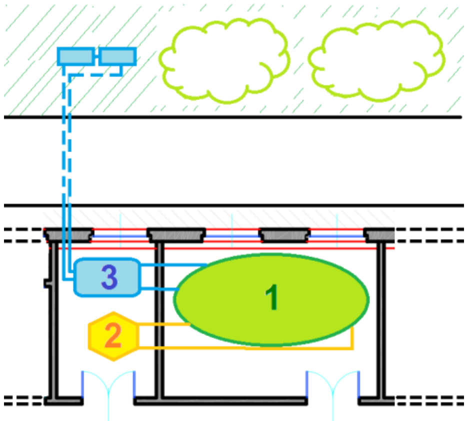


Figure 2.2: EDDIE scheme. 1.EDDIE circuit 2. dehumidification module 3. refrigerator module

Module 2 is necessary to reach extreme air temperature conditions, without damaging the motion part of the circuit and maintaining the optimal conditions for the refrigerator device operation avoiding condensation or ice formation on the exchanging parts. Module 2 has been planned to also set the ambient pressure inside the air circuit. The third module consists in a refrigerator system that allows the air temperature conditioning inside the circuit. Module 3 is a complex system that controls a chiller and a heating coil placed inside the air circuit. The system exchanges heat also with external ambient thanks to two axial fans placed outside the laboratory building. Module 2 and module 3 occupy a room next to the main laboratory and together with the electronic controls they compose the engine room of the EDDIE facility.
Module 1, 2 and 3 are going to be described separately and in detail in following sections. The multi-step management of EDDIE facility, the planned functioning tests and the expected capabilities of the facility will be treated as conclusion of this paper.

2.2.1.1 EDDIE MODULE n.1: the air circuit

The air circuit can be divided in three main sections: the whole circuit structure, the fan for the air movement and the test chamber. The whole circuit has been planned and equipped to be correctly interfaced to the control modules (the 2 and 3) and to satisfy the aerodynamic requirement of the project. The laboratory room sizes has been determinant in the circuit design and on its main characteristic that are surely not optimistic from an aerodynamic point of view. On the other hand, the flow quality (from a fluid dynamic point of view as turbulence intensity, vortices and so on) was not a critical parameter because the facility has not been conceived as an anemometer calibration one but as a multi generator of different climatic condition of pressure, temperature and humidity in presence or in absence of wind. Because of this aim, and because of size limits, typical structural characteristics of a wind tunnel are not present in EDDIE circuit design. In spite of these lacks, not allowing for an optimized aerodynamic operation, the circuit has been designed to reach an air flow that can be ranged between 0 m s^{-1} and about 30 m s^{-1}, as required by the project task taking into account to cover European weather conditions at a wide percent with sizes compatible with the most common automatic weather stations (AWS) nowadays on sale. Circuit design had also considered pressure requirements, in particular the necessity of work below ambient pressure, and the very restrictive temperature requirements because of the very low temperature to be reached (about -40 °C).

2.2.2 The Circuit Structure

The laboratory room that houses EDDIE is 7 m long and 5 m wide. The EDDIE circuit sizes are 4.8 m long and 2.4 m wide. 1 m to the side of the circuit are necessary for a correct circuit inspection and possibly maintenance actions. Figure 2.3 shows the definitive design of the facility.

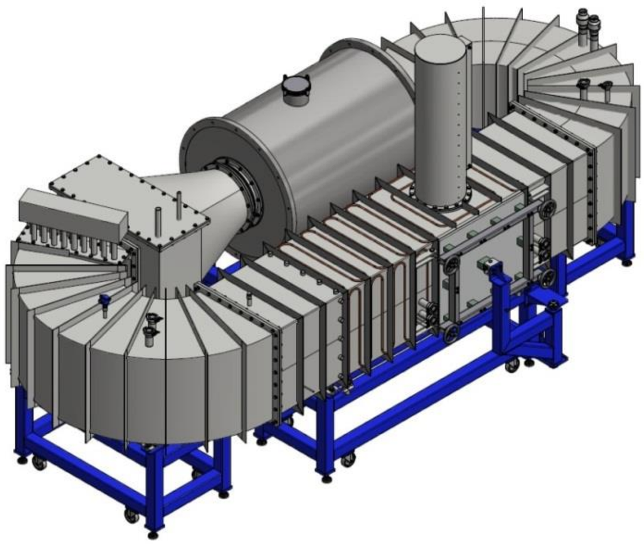


Figure 2.3: Air circuit definitive design

As figure 2.2 shows, the circuit is composed by a squared section test chamber with sizes 0.65x0.65x2.2 m^3. A first corner of 180° with converging section sizes (from 0.65x0.65 m^2 to 0.45x0.45 m^2) followed by a rapid convergent that connect the circuit with the fan inlet. The fan suction section is circular shaped with a diameter of 0.4 m. The centrifugal fan housing is 1.25 m long and it has a diameter of 0.95 m. After the centrifugal fan a divergent is placed, because of shape and sizes adaptation between the fan and the heat exchanger in the circuit. The divergent is 0.7 m long, it has a circular initial section connected to the delivery section of the fan with a diameter of 0.4 m and a final section of 0.65x0.65 m^2. The heater exchanger external sizes are

0.9x0.8x0.37 m^3. It is directly followed by the second corner of 180° with a squared section of 0.65x0.65 m^2 that is constant along the whole corner. Inside the second corner a heater coil is placed; in a way not to influence the circuit shape nor sizes. Finally, the end of the second corner is connected to a linear part 0.6 m long with a constant section of 0.65x0.65 m^2, that acts as connection with the inlet section of the test chamber.
The structure is made of 3 mm thick stainless steel (SS 304/304L). The test chamber and the two corners are stiffened by a series of supporting rids made of stainless steel and welded to the structure. This was done because the circuit structure would be loaded by a pressure of about 25 kPa both over and under the ambient pressure. The supporting rids are spaced 0.2 m apart along the linear surfaces whereas they are spaced 15° apart along the two corners. For safety reasons, the stiffness has been overestimated in order that the facility structure can hold about 50 kPa over/under the ambient pressure. In addition, more or less in the middle of the first corner (see Figure 2.3) two safety valves for the control of the maximum pressure inside the circuit are placed.
The test chamber is equipped with a stiffened rectangular door with an opening of 0.68x0.61 m^2 that allows the positioning of instruments under test and of all the equipment devices necessary for measurement activities. Its opening sizes are also adequate to the convergent placement and displacement used to reach the higher air velocities of 30 m s^{-1}. The test chamber top is equipped with a device for instruments shielding during measurement.
Several valves and open connection are placed along the circuit structure to connect instruments and modules like dehumidification system and refrigerator system. In particular, The air circuit is connected to the dehumidification system by two electro-valves placed upstream and downstream the test chamber; they allow the dehumidification operation and the pressure setting inside the air circuit according to the project requests Finally, next to the test chamber door, four connections closed with blank flanges for pressure tightness are placed to allow the connection of at least sixteen different instruments for measurement and monitoring inside the test chamber. The whole circuit structure will be coated by means of three different layers of insulation. The first layer, closer to the structure, will be obtained by the superimposition of two sheets of closed cell insulating material based on elastomeric foam with a reaction class C1 and a thickness of 25 mm. The second layer consists in a third sheet of the same insulating material but with a thickness of 19 mm. Finally, the finishing layer consists in an aluminium sheet 0.8 mm of thick. All the insulating connections will be adequately glued by insulating and anti-condensation tapes.

2.2.2.1 The Fan and the Convergent

The air circuit is designed to generate an air flow that can be controlled in velocity, temperature, pressure and humidity. A tubular centrifugal inline fan has been placed inside the circuit for airspeed generation and
control. The fan model is ECM 56-22 made by INOX AISI304 (see figure 2.4).

Figure 2.4: Cross section of a tubular centrifugal inline fan (left) and its position in the air circuit (right).

The inline fans are characterized by aligned inlet and outlet sections and, in this case, also by an electric motor placed inside the cylindrical housing of the fan; these characteristics allow for the best placement of the fan inside the circuit; moreover, the cylindrical fan housing is an adequate choice for the additional pressure loads and the presence of the motor inside the housing improves the pressure tightness of the circuit; actually the circuit structure is not crossed by any rotating shaft. The significant technical characteristics of the fan are air flow of 16800 m^3h^{-1}, total lift 215 mmH_2O, maximum power absorption 26.5 kW. The fan has an inlet and an outlet section diameter of 0.4 m. The sizes of the holding are: 0.9 m in diameter and 1.2 m in length. The analyses for the fan choice mainly considered the pressure losses evaluated for the air circuit, the maximum generated flow and the sizes. No fan, able to generate an air flow that, according to the test chamber section sizes, would correspond to the project request of maximum air speed, had been found. For this reason, test chamber has been equipped with a convergent placed at the inlet of the chamber itself. The convergent has a very simple shape; it is a pyramidal frustum with a square inlet of 0.65x0.65 m^2 and a square outlet of 0.4x0.4 m^2. It has not been designed according common aerodynamic rules, i.e. Morelli equations (Pope 1999), because in the first place, it has been decided to put a more economic convergent with the possibility to change it later. For this reason, the convergent has been designed as two joined parts to be disassembled. Finally, it is equipped with three series of static pressure connections that can be used to measure a pressure reference value (ΔP_{ref}); this pressure reference will be necessary to evaluate the airspeed in the test chamber.

2.2.3 The Test Chamber

The test chamber is the part of the air circuit where the device under test (DUT) will be placed and where it will be invested by an air flow with defined values of speed, temperature, humidity and static pressure. The test chamber sizes are reported in the previous section. The main difference of EDDIE test chamber with respect to a typical wind tunnel test chamber is the presence of a particular device for the DUT shielding called “shield system”. The shield system consists in an external cylinder 1.1 m high with a diameter of 0.33 m. Inside this cylinder there is a second cylinder (the shield) that is piloted inside and outside the test chamber through a guide rail and a pneumatic piston. It is placed at about 0.5 m from the convergent outlet in reduce as much as possible the blockage effect and thus increasing the circuit pressure losses. The shield has been designed in order to test the DUT in presence or in absence of wind at every temperature value in the facility operating ranges. Indeed, the most difficult condition to simulate in this facility is the absence of wind, V=0 m s^{-1}, at a defined air temperature, because air has to be moved along the circuit in order to obtain a temperature value inside the test chamber. During temperature setting, when the air circulates inside the circuit, the shield can be lowered on the DUT, shielding it from the wind, but at the same time keeping it in the conditioned ambient. The shield can be moved also in presence of wind; therefore, it would be possible to perform analyses on the DUT output transients. The shield system can be disassembled from the test chamber top layer. In this case, the opening left by the shield system corresponds to a flanged hole with a diameter of 0.33 m that could be used for the placement of other devices.

2.2.3.1 EDDIE MODULE n.2: The Dryer and Pressure Control

In order to guarantee the functioning of the system to an operating temperature lower than the dew-point temperature of the laboratory being those the initial conditions of the air inside the circuit before starting, and avoiding condensation or freezing, it is necessary to dehumidify the air inside the circuit. To do this the EDDIE air circuit was connected in parallel with a dehumidification system (see figure 4).
During the drying procedure, humid air is sucked from the EDDIE circuit through the inlet of the rotary screw compressor (A). The compressor compresses the air in a 0.5 m^3 tank (B) at a pressure of 0.8 MPa performing the first step of the drying process. Then the compressed air enters the KA-MT-6 (C), a heatless adsorption dryer with integral activated carbon purifiers. The air flows into one of two chambers of the dryer both filled with molecular sieve, where the air is dried. During the drying process, the second chamber undergoes regeneration. At the start of the drying cycle, this chamber is open to atmosphere and a small portion of dried compressed air passes through the adsorption bed, transporting humidity out.

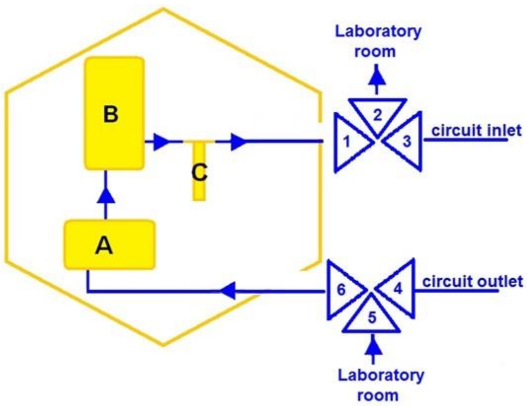


Figure 2.5: Schematics for the dehumidification system. A through C are itemized and described

When this procedure is complete, the chamber is re-pressurized in readiness to repeat the drying procedure. Dry compressed air then enters the integral activated carbon purifier stage, where oil-vapour is removed and finally the clean, dry air exits and enters the EDDIE circuit. Compressed air can be dried to a dewpoint of -40 °C, according to the needs of the experiment. Humidity of the air present in the circuit will be verified with a sensor positioned inside the test chamber. Using two precision three-way solenoid valves placed on the EDDIE air circuit at the entrance and exit of the dehumidification circuit, the system will be able to adjust the pressure inside the EDDIE circuit in order to set the pressure in a range between about 75 kPa and 110 kPa. During the normal cycle of dehumidification, valves number 2 and 5 remain closed, thus the same air continues to circulate during the operation. To increase the pressure inside the circuit, valves number 1, 3, 5 and 6 remain open while the others are closed. The compressor sucks air from the environment, while the compressed air increases the pressure in the chamber. To decrease the pressure, valves number 1, 2, 4 and 6 remain open. The compressor removes air from the circuit, reducing the pressure, while the excess air may be released into the environment through valve 2. To control and measure the working pressure a calibrated barometer is inserted in the test chamber.

2.2.3.2 EDDIE MODULE n.3: The Thermal Module

As stated, before in the introduction, the EDDIE facility can be controlled in temperature in a range between -40 °C, and 40 °C.

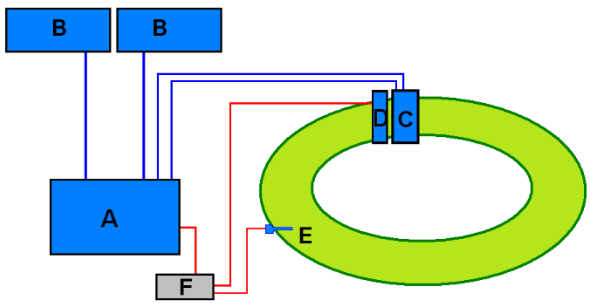


Figure 2.6: Schematics for the thermal module. The sub-modules A through F are itemized and described

The thermal module (called module 3 in Figure 2.6), which schematics are represented in figure 5, is composed by several sections: one refrigerating central unit (A), two external axial fan condensers (B), one heat exchanger (C), one electrical heater (D), one PT 100 thermometer (E) and one Programmable Logical Controller unit (F). Controlled by a Programmable Logical Controller (PLC), the 30 KW refrigerating central unit having sizes of 2.2x1.1x1.3 m^3, is directly linked to a heat exchanger which is responsible for the air refrigeration inside the EDDIE air circuit. The exchanger receives the R 404 A working fluid flowing from the refrigerating unit, exchanging heat with the moving air inside the circuit, and then back again into the unit: the heat is dissipated into the atmosphere by two 290 W axial fan condensers, located outside the building, each one capable of processing 7500 $m^3\ h^{-1}$. Two low-power fan condensers, instead of a larger, more powerful one, have been chosen in order to reduce noise and have the possibility to install the apparatus in proximity of offices. A cooling unit is not enough to set and maintain a specific temperature: for this reason, an electrical heater is required. Controlled by the PLC, the purpose of the electrical heater is twofold: when EDDIE works below room temperature, the cooling unit brings temperature down inside the circuit while the heater allows for a fine control; working above room temperature, the heater works alone in providing both the heating power and the fine regulation. The heater is composed by 9 armoured U-shaped smooth elements, 16 mm in diameter, made up of stainless steel. Each element has a nominal power of 889 W, adding up a total output power of 8 kW. Temperature control inside the main air circuit is made possible by a PT100, mounted at the second corner of the circuit. The PLC reads temperatures from the PT100, and makes use of this data to adjust the heater and the chiller operative behaviour in order to set and maintain the desired temperature, given also the wind speed, as set by the operator in the test chamber.

2.2.4 Planned Initial Tests and Facility Expected Capabilities

The planned tests are intended to investigate different aspects of the facility operation and capabilities: wind simulation, temperature, humidity, and pressure setting and control.
Wind simulation and temperature setting will be controlled simultaneously through a PLC whose interface to operators will be a touch screen, placed next to the test chamber door. On the touch screen it will be possible to set the quantities final values and its transients. Once the velocity and the temperature are set, the PLC will be able to control these parameters according to temperature values measured by the PT100 of the refrigerator system. The air velocity is not monitored as a feedback parameter control and initially its set values, used by the PLC control, will be only indicative since it is not possible to accurately know the airspeed inside the test volume without calibrating the air flow downstream the convergent. Therefore, the first tests that will be performed will deal with a complete mapping of the motion field inside the test chamber at different conditions of temperature and humidity.
The mapping of motion field consists in a sequence of measurements for the evaluation of the velocity mean values and, at last, of two components of it in every measurement point. Typically, these kinds of measurement are carried out with non-invasive anemometers such as Laser Doppler Anemometer or very small probes like hot wire anemometers.The evaluation of the velocity components allows to compute the turbulence intensity and to define the velocity direction inside the test chamber. Moreover, the different sections mapping along the test chamber axis allows to know the effective motion field, therefore the effective condition of wind, in which the DUT will be tested according to its positioning inside the test chamber.
The calibration of the air circuit follows the test chamber motion field mapping. If the motion field mapping underlines that the velocity filed is symmetrical, the calibration would be carried out in only one measurement point that generally corresponds to the centre of test chamber section. The circuit calibration in velocity follows a defined procedure that allows to extrapolate one or more calibration curves of velocity as a function a reference pressure measured at the convergent in the test chamber. The calibration curves obtained according this procedure can be used to evaluate the velocity at the centre of the test chamber without invasive probes in the test chamber. The calibration procedure must be performed for different calibration conditions of temperature, pressure, and humidity and in all the measurement points that will be used for future experiments.
Other tests that can be performed previously or simultaneously to the motion field analysis, regard the temperature and pressure stability inside the test chamber. These stabilities can be evaluated by means of very long monitoring of the quantities, operating, when necessary, on the PLC setting in order to improve the feedback control

of these parameters. It is not easy to predict the behaviour of these parameters before the facility start up because they depends on many aspect as the effective structure seal, its insulation, the fan engine heating, and so on. Therefore, no considerations on possible solutions or improvements are hereby reported.
Among the several opportunities offered by the EDDIE capabilities, some of the analyses that can be carried out on automatic weather stations and in particular on their signals/outputs are: the simultaneous effect of temperature, humidity, pressure and wind presence on the probes output and the transient behavior of instruments at given temperature, humidity and pressure during transition between absence of wind (0 m/s) and a defined airspeed.
The first kind of tests requires firstly the DUTs placement in test chamber close to the convergent outlet in order to take advantage of the potential core of the jet flow (Bradshaw 1970) under the ambient conditions set, secondly the monitoring of their output signals during an adequate sampling time (depending on the DUT). Finally, these results will have to be compared to same DUT output signals obtained without the four quantities simultaneous presence.
The second kind of tests requires the use of the shielding system. The shield, as written above, has been designed at 50 cm from the convergent outlet in order to decrease the blockage effect of this obstacle in front of the jet flow and therefore to reduce as much as possible the pressure losses caused by the shield presence. This implies that the DUT subject to these tests operates in a quite different motion field with respect to the tests previously described, because it will be placed far from the convergent outlet. At this distance from the convergent exit, the turbulence effects would be more significant and there would be presence of eddy structures. However, the preliminary motion field mapping described before, allows to well define the test conditions from an aerodynamic point of view. An evaluation of shield movement capabilities when subject to growing wind velocities will be necessary in order to establish the available velocity range for these kinds of tests. The results of these analyses could be useful, for example, to understand how the DUT output can be influenced by very variable weather, in presence of gusts of wind (ISO 17714: 2007).

2.3 CRP101 High Accuracy Digital Pressure Gauge [6]

The CRP101 digital pressure gauge is designed to calibrate pressure instruments: pressure transducers, transmitters, pressure gauges and switches.

With the state-of-the art of microprocessor technology the CRP101 is the most advanced portable digital pressure gauge in term of accuracy. Fully compensated in the operating temperature range its polynomial characterization grants accurate measurements in every point of each pressure range.

- Pressure ranges from 200 mbar up to1000 bar
- Accuracy up to 0.02 % FS
- Fully temperature compensated (14…122 °F / -10 °C to 50 °C)
- Material: Stainless Steel

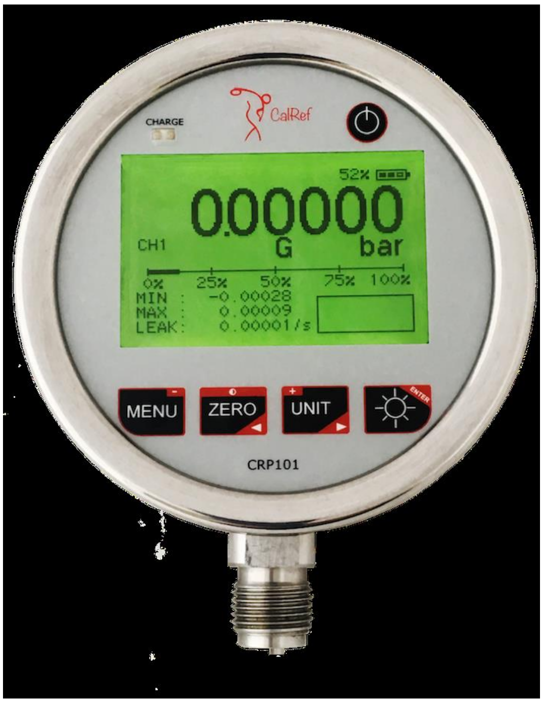


FIGURE 2.7: CRP101 High Accuracy Digital Pressure Gauge

2.4 Fluke 1586A Super-DAQ Precision Temperature Scanner [7]

The 1586A Super-DAQ collects time-stamped precision temperature and electrical measurements for data analysis by technicians, engineers, and quality control personnel to verify process control, analyze interactive systems, ensure conformance to quality standards, or to correlate related events for R&D or troubleshooting. Measurement data and statistics can be viewed in tabular format for all active channels

FIGURE 2.8: Fluke 1586A Super-DAQ Precision Temperature Scanner and Multiplexer

With the graphing feature, up to four channels can be plotted at the same time, making it easy to quickly assess test setup and results before analyzing the data on a PC.

The kit contains everything you need to connect a DAQ-STAQ multiplexer to your 1586A mainframe. The DAQ-STAQ is designed for high-accuracy measurements in secondary temperature calibration labs. Easily connect/disconnect thermocouples, PRTs and thermistors. There are twenty mini-jack thermocouple inputs and gold-plated PRT/thermistor connectors for up to 10 4-wire connections.

When configured with the DAQ-STAQ Multiplexer, the Super-DAQ has the accuracy of the best benchtop reference thermometer readouts for calibration of PRTs, RTDs, thermistors, or thermocouples. Lab efficiency can be increased when the Super-DAQ is connected to a Fluke Calibration drywell or bath and Automated Sensor Test routines are run.

The 1586 is ideal for several applications such as thermal mapping, temperature validation, process sensor calibration, and more. These applications are found in a various industries including pharmaceutical, biotechnology, food processing, aerospace, and automotive.

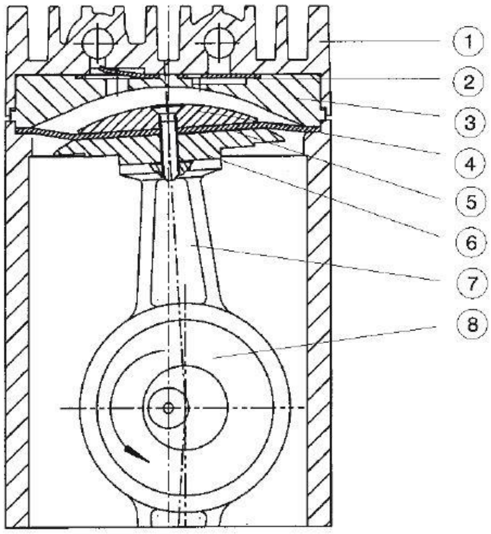
2.5 DIVAC 1.4 HV3 [8]

This range of vacuum pumps was developed especially for laboratory operations and as backing pumps for (wide range) turbomolecular pumps. It satisfies the highest expectations in terms of precision, reliability, and ease of use.

FIGURE 2.9: DIVAC 1.4 HV3

The DIVAC line of vacuum pumps is the logical continuation of diaphragm pump technology which has proven its quality in decades of service. Diaphragm vacuum pumps are single or multi-stage dry compressing vacuum pumps.

The circumference of a diaphragm is tensioned between a pump head and the casing wall (Fig. 2.10). It is moved in an oscillating way



(1) Casing lid
(2) Valves
(3) Lid
(4) Diaphragm disk
(5) Diaphragm
(6) Diaphragm support disk
(7) Connecting rod
(8) Eccentric disk

FIGURE 2.10: Schematic on the design of a diaphragm pump stage

By means of a connecting rod and an eccentric. The pumping or compression chamber, the volume of which increases and decreases periodically, effects the pumping action. The valves are arranged in such a way that during the phase where the volume of the pumping chamber increases it is open to the intake line. During compression, the pumping chamber is linked to the exhaust line.

The diaphragm provides a hermetic seal between the gear chamber and the pumping chamber so that it remains free of oil and lubricants(dry compressing vacuum pump).Diaphragm and valves are the only components in contact with the medium which is to be pumped. When coating the diaphragm with PTFE(Teflon) and when manufacturing the inlet and exhaust valves of a highly fluorinated elastomer as in the case of the DIVAC from LEYBOLD, it is then possible to pump aggressive vapors and gases.

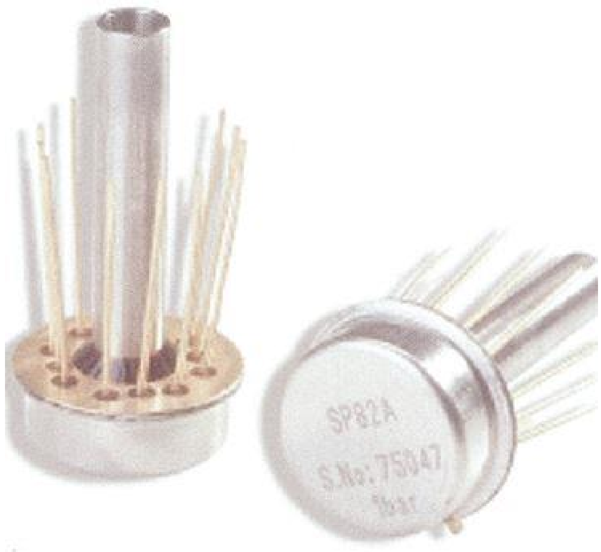
- Pumping speed: 1.3 m^3/h
- Ultimate pressure: $\leq$ 1.5 mbar
- Max. outlet back pressure: (absolute) 1500 mbar

Applications: Vacuum filtration, Vacuum distillation, Vacuum drying, Mass spectrometry, Medicine technology.

2.6 SP82 Pressure Sensors [9]

MEMSCAP high end sensor offers unique performance for your applications. The high proven quality and reliability of our sensors that match aerospace and defense standards offer unmatched results in a wide variety industry application ranging from meteorology, Sub- Sea, Instrumentation, Utilities, as well as R&D.The SP82 products are the result of an advanced silicon MEMS processing for extreme performances.

FIGURE 2.11: SP 82 Pressure Sensor



It features latest generation for pressure measurements, Piezoresistive silicon chip, available in Absolute, Relative (Gauge) & Differential configurations, Active chip temperature, simple and mature package fully hermetic TO-8 package. The benefits are excellent long-term stability (option L sensors) unmatched results for high reliability applications Small and cost-effective high accuracy, insensitive to humidity through unique passivation technique.

Applications

- Aerospace
- Defense
- Meteorology
- Sub-Sea
- Instrumentation
- Utilities
- Industry R&D

2.7 Model 745-Paroscientific Inc Pressure Instrumentation

The Model 745 Portable Transfer Standards provide the highest accuracy pressure measurements for laboratory and metrological applications. Digiquartz® Transducers cover 25 absolute and gauge pressure ranges up to 40,000 psi (276 MPa) with unsurpassed **accuracy**, **reliability** and **stability.**

The new, simple, intuitive front-panel user interface and versatile functionality with the rear panel RS-232 computer interface make the Model 745 the best choice for high performance pressure calibrations.

FIGURE 2.12: Model 745-Paroscientific Inc

Resolution:0.0001%FS
Accuracy: Better than 0.008%FS
Overpressure:1.2 times FS
Operating temperature range:0-40 °C
Power Requirement: +6 to +25 VDC
Adapter:110 V or 220 V AC
Typical Current Consumption:72 mA

2.8 T-CUBE DC SERVO MOTOR CONTROLLER

The T-Cube APTTM USB DC Driver (TDC001) is a very compact single channel DC servo controller/driver for easy manual and automatic control of DC Servo motors. This driver has been designed to operate with a variety of lower powered DC brushed motors (up to 15 V/2.5 W operation) equipped with encoder feedback. The TDC001 has been optimized for 'out of the box' operation with the Thorlabs range of Z8 series DC motor equipped opto-mechanical products.

FIGURE 2.13: T-CUBE DC Servo Motor Controller

Features

- Compact Footprint 60 mm x 60 mm x 47 mm (2.4" x 2.4" x1.8")
- Differential Encoder Feedback (QEP Inputs) for Closed
- Loop Positioning
- Auto-Configure Function for all Thorlabs Z8 Equipped
- Stages/Actuators
- Range of PSU Options Available Separately
- USB Plug-and-Play - Multi-axis Expansion
- Easy to Use Manual Controls with Velocity Slider and Jog Buttons
- Full Software Control Suite Supplied
- Extensive ActiveX® Programming Interfaces
- Fully Software Integrated with Other APT™ Family Controllers.

3 MIDAS [10]

SAT aircraft is a segment crucial for travelers in Europe because it is the only means of transportation that has those characteristics able to fill a gap that could not be done in another way. Short range flights, local communities' connections, door-to-door within 4 hours (one of the Flightpath 2050's targets) are only a few examples to stress the importance of the SAT segment in the European infrastructures.

A lot of researches are conducted in order to bring significant innovation into SAT aircraft with the main aim to increase performance and safety, to reduce fuel consumption and emissions

In this context, a joint research project was proposed and funded focused on, "a digital multifunction and fully integrated air data probe, capable of providing local measurements of Static Pressure, Total Pressure, Angle-of-Attack (AOA), Angle-of-Sideslip (AOS) and Total Air Temperature (TAT), to be used as part of a redundant Flight Control System architecture" for SAT applications.

Therefore, a critical mass of expertise in a wide range of skills is necessary. The Consortium has been drawn up in this spirit and this is why the Consortium gathers 3 partners. It includes

- One of the top 100 world universities for Mechanical and Aerospace engineering with more than 10-year of experience in design and development of innovative algorithms for air data system applications (POLITO),
- A major developer and supplier of avionic equipment, including electronics and software for aeronautical applications (SELT A&D), and a long-term expertise on ground segment support systems for maintainability and MROU.
- A National Metrology Institute, public research organization of international excellence highly experienced in calibration, performance testing, measurement uncertainty analysis, instrument design and development, equipped with special chambers and systems for sensor environmental tests (INRIM)

3.1 Modular and Integrated Digital Probe for SAT Aircraft Air Data System

The main objective of the MIDAS project is to design and manufacture a smart and fully integrated air data probe (ADP) for SAT applications, characterized by the following features:

- reduced size and weight
- reduced power consumption
- improved reliability
- fully integrated with the onboard communication bus.

FIGURE 3.0 : MIDAS Probe Courtesy of SELT and Politecnico di Torino

3.2 Pitot-static probe

A pitot-static system is a system of pressure-sensitive instruments that is most often used in aviation to determine an aircraft's airspeed, Mach number, altitude, and altitude trend. A pitot-static system generally consists of a pitot tube, a static port, and the pitot-static instruments

A pitot tube can be used to measure fluid flow velocity by converting the kinetic energy in a fluid flow to potential energy.
The principle is based on the Bernoulli Equation where each term of the equation can be interpreted as pressure

$$p + 1/2\ \rho\ v^2 + \rho\ g\ h$$
$$= p + 1/2\ \rho\ v^2 + \gamma = \text{constant along a streamline} \ldots\ldots\ldots\ldots\ldots (1)$$

where
p = static pressure (relative to the moving fluid) (Pa)
ρ = density of fluid (kg/m^3)
v = flow velocity (m/s)
$\gamma = \rho\ g$ = specific weight (N/m^3)
g = acceleration of gravity (m/s^2)
h = elevation height (m)
Each term of the equation has the dimension force per unit area N/m^2 (Pa) - or in imperial units lb/ft^2 (psi).

Static Pressure
The first term - p - is the static pressure. It is static relative to the moving fluid and can be measured through a flat opening in parallel to the flow.

Dynamic Pressure
The second term - $1/2\ \rho\ v^2$ - is called the dynamic pressure.

Hydrostatic Pressure

The third term - γh - is called the hydrostatic pressure. It represents the pressure due to change in elevation.

Stagnation Pressure

The Bernoulli Equation states that the energy along a streamline is constant - and can be modified to

$$p_1 + 1/2 \rho v_1^2 + \gamma h_1$$
$$= p_2 + 1/2 \rho v_2^2 + \gamma h_2 = \text{constant along the streamline} \ldots\ldots (2)$$

where

suffix$_1$ is a point in the free flow upstream

suffix$_2$ is the stagnation point where the velocity in the flow is zero

Flow Velocity

In a measuring point we regard the hydrostatic pressure as a constant where $h_1 = h_2$ - and this part can be eliminated. Since v_2 is zero, (2) can be modified to

$$p_1 + 1/2 \rho v_1^2 = p_2 \ldots\ldots (3)$$

or

$$v_1 = [2 (p_2 - p_1) / \rho]^{1/2}$$
$$= [2 \Delta p / \rho]^{½} \ldots\ldots (4)$$

where

$\Delta p = p_2 - p_1$ (differential pressure)

With (4) it's possible to calculate the flow velocity in point 1 - the free flow upstream - if we know the differential pressure difference $\Delta p = p_2 - p_1$ and the density of the fluid.

The Pitot Static Probe is a qualified module, commercially available from external supplier. The proposed pitot static probe embeds a de-ice and heating system; the maximum rated power for de- icing is 55W.

3.3 Total Air Temperature Probe

In aviation, stagnation temperature is known as total air temperature and is measured by a temperature probe mounted on the surface of the aircraft. The probe is designed to bring the air to rest relative to the aircraft. As the air is brought to rest, kinetic energy is converted to internal energy. The air is compressed and experiences an adiabatic increase in temperature. Therefore, total air temperature is higher than the static (or ambient) air temperature. Total air temperature is an essential input to an air data computer to enable computation of static air temperature and hence true airspeed

The TAT probe is a qualified module commercially available from external supplier. The proposed TAT probe embeds a de-ice and heating system; the maximum rated power for de-icing is 55W.

3.4 MIDAS Test Reader

With the help of test reader, the readings are displayed in the computer using MIDAS test reader application by SELT aerospace and defense. The test box consists of SP82 pressure sensors where static and dynamic pressure tubes are connected from pitot tube.

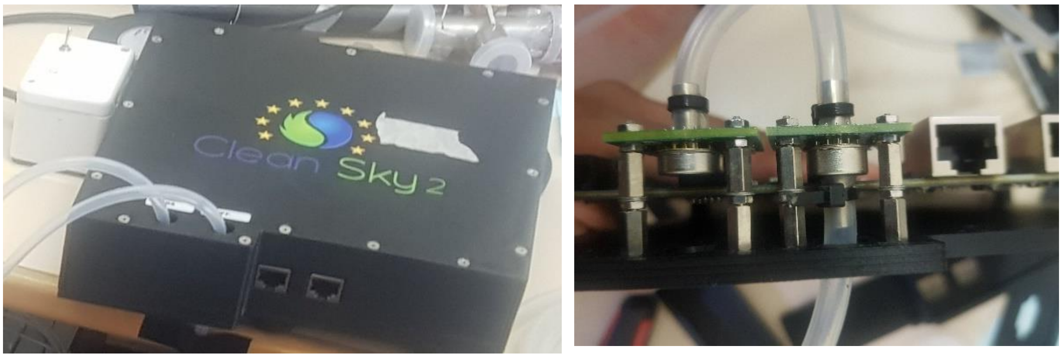


FIGURE 3.1: MIDAS test reader and SP82 Pressure sensors in MIDAS test reader Courtesy of SELT and Politecnico di Torino

3.5 Probe Characterization

ADP pressure and temperature sensors test, and calibration will be performed at INRIM to investigate the effect of pressure, temperature, humidity and effect of wind on the readings.

Laboratory special equipment such as the Earth Dynamics Direct Investigation Experiment-EDDIE chamber which will be used to characterize the developed sensors in terms of evaluating the effect of wind and of pressure on atmospheric contact thermometers. This facility can generate wind up to 30 m/s and temperature ranging from -40°C to 50°C and with pressures from atmospheric ground level to 50 kpa.

To understand the effect of condensation and convection on sensing elements a test is performed in climate chamber Earth Dynamics Direct Investigation Experiment 1-EDDIE1 chamber. Ice is considered as one of the parameter affecting the measurement quality. When equipped with a special barometric pressure-controlled vessel, the system allows investigations from -40 °C to 70 °C and from 110 kpa to 1 kpa.

4 Characterization

Sensor characterization is an important test process to yield the behavior and accuracy across various operating conditions. Publishing sensors' characterized information enables users to deploy sensors most effectively in their applications.

4.1 MIDAS test reader Characterization

The characterization of MIDAS test reader is done using the EDDIE-1, diaphragm valves, CRP101 High Accuracy Digital Pressure Gauge, DIVAC 1.4HV3, clamping collar, centering rings, flexible tubes.

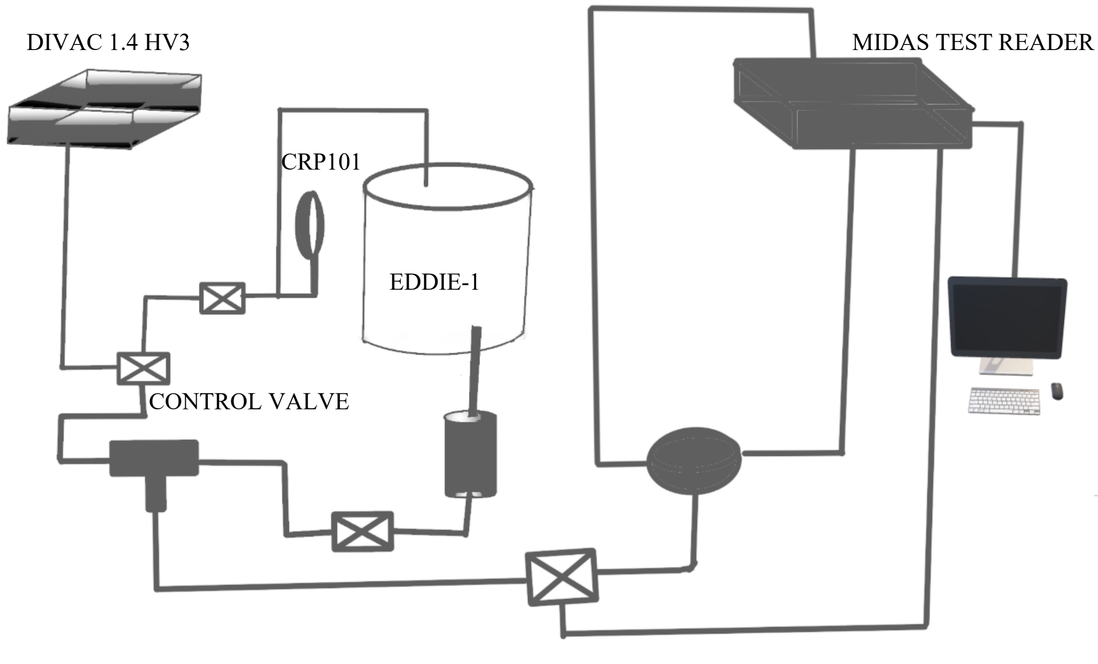
4.1.1 Procedure

Midas test reader consists of two ports for static pressure, dynamic pressure. At room temperature and pressure, the same pressure is sent through both static and dynamic pressure ports the differential pressure in the reader is not zero a value exists. One end of tube is connected to EDDIE-1 and another end is connected to MIDAS test reader.

The EDDIE-1 chamber relates to diaphragm valves, DIVAC 1.4HV3, CRP101 high accuracy digital pressure gauge using clamping collar, centering rings as shown in schematic diagram 4.0 The pressure was controlled using DIVAC 1. 4HV.CRP101 high accuracy digital pressure gauge acts as reference pressure reading and compared with respect to MIDAS pressure test readings.

The MIDAS test reader is connected to computer and digital readings are noted using the application provided by SELT aerospace and defense. The experiment was repeated thrice for the verification of differential pressure readings with increasing pressure once and decreasing pressure twice. The readings are attached in annex A

FIGURE 4.0: Schematic diagram for MIDAS test reader



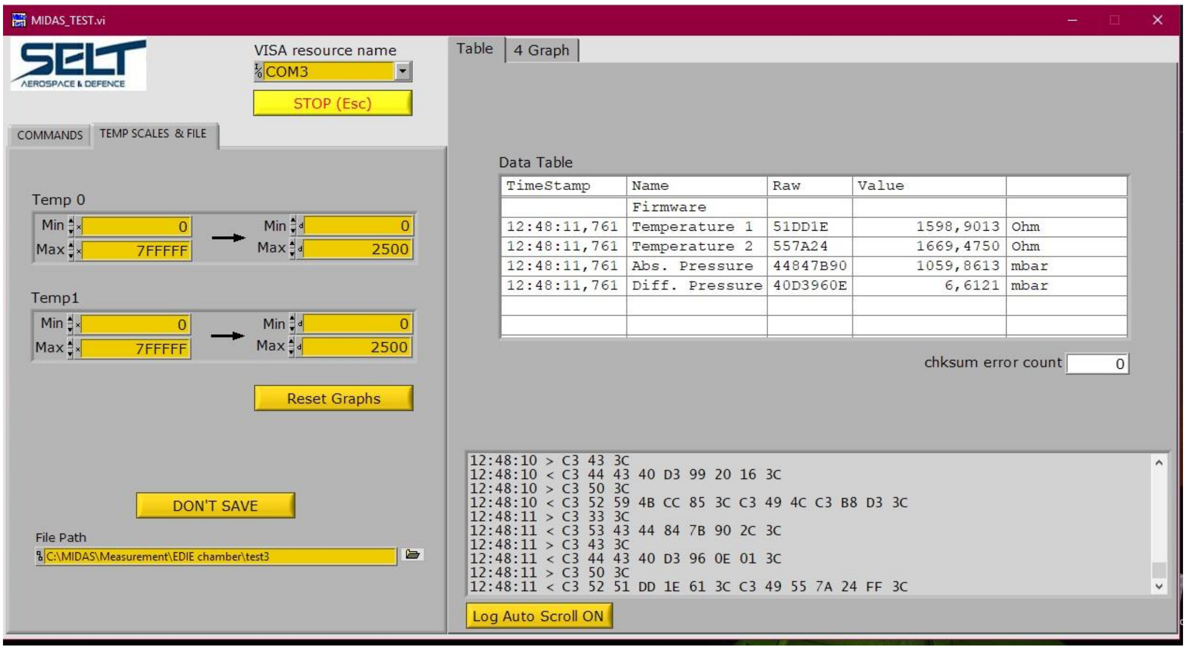


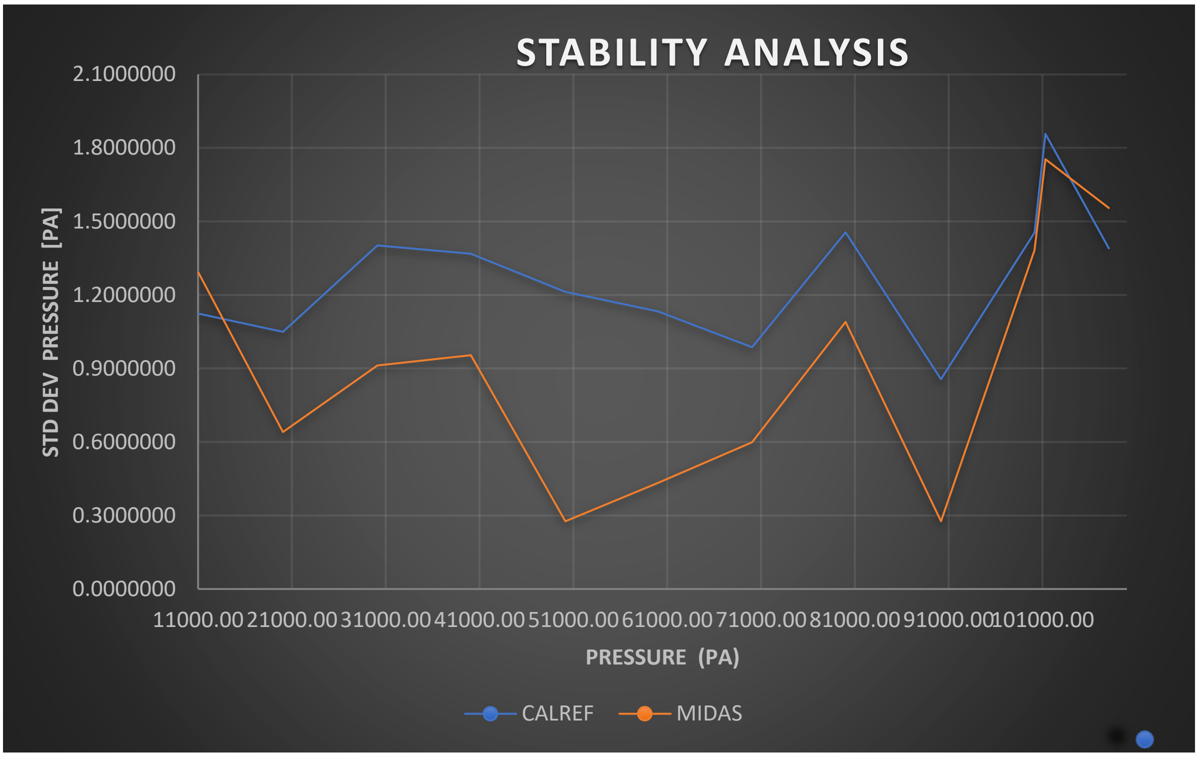
FIGURE 4.1: MIDAS test reader application in computer Courtesy of SELT and Politecnico di Torino

4.1.2 STABILITY CHART

We can see the stability of measurement in this graph. It is plotted by taking large samples of experimental values. As the first step mean was taken and standard deviation and difference was calculated within the range of pressure from **11000 Pa to 108000 Pa**

TABLE 1: Stability readings of MIDAS test reader and P Calref

Characterization of MIDAS Reader		
PRESSURE (PA)	**STD DEV (P calref)**	**STD DEV (ABSOLUTE PRESSURE MIDAS)**
11042.00	1.2909944	1.1233887
20030.92	0.6400955	1.0496269
30097.00	0.9128709	1.4020667
40063.42	0.9537936	1.3681341
50141.08	0.2763854	1.2133379
59995.33	0.4330127	1.1336225
70046.58	0.5994789	0.9865565
80029.25	1.0897247	1.4557556
90173.08	0.2763854	0.8562403
100162.92	1.3819270	1.4548310
101324.92	1.7539638	1.8575796
108076.50	1.5545632	1.389882



GRAPH 1: Stability of MIDAS test reader and P Calref

4.2 Uncertainty

We have calculated uncertainty by following the guidelines in **JCGM 100:2008** GUM 1995

4.2.1 Standard uncertainty

Type A In the first step we have calculated the mean for each temperature by taking at minimum 5 to 12 readings respectively and pool standard deviation For the standard uncertainty we have taken the ratio standard deviation of mean to square root of the number of replicates

Type B In the second step we have got the values of the uncertainty due to the diaphragm valves, CRP101 High Accuracy Digital Pressure Gauge, DIVAC 1.4HV3 , chamber instability and gradient uncertainty by considering the normal distribution value and rectangular distribution for the Pressure gauge and DIVAC 1.4 HV3

Characterisation of MIDAS Reader				
s.no	**PCalref (PA)**	**Absolute Pressure (PA)**	**Differential Pressure (PA)**	**STD DEV DELTA (MIDAS)**
1	11042.00	11050.12	665.65	0.3968697
2	20030.92	20031.77	669.26	0.4279213
3	30097.00	30096.85	669.44	0.5387176
4	40063.42	40064.56	668.77	0.4252867

5	50141.08	50140.80	669.57	0.6275277
6	59995.33	59995.86	669.67	0.4294853
7	70046.58	70051.06	672.82	0.4710707
8	80029.25	80033.43	669.14	0.5720449
9	90173.08	90175.28	666.52	0.4728783
10	100162.92	100158.84	664.42	0.5017386
11	101324.92	101323.05	663.90	0.5379507
12	108076.50	108070.68	662.99	0.8697972
		Mean Differential Pressure	**668.20**	
			TYPE A UNCERTAINITY	**0.036**

Table 2: Type A Uncertainty

	from manufacturer	Experiment
CRP101 High Accuracy Digital Pressure Gauge,	0.1	0.05
DIVAC 1.4HV3	0.1	0.05
the diaphragm valves	0.02	0.01
MIDAS Test Reader		0.036
	TYPE B UNCERTAINITY	**0.072**

TABLE 3: Type B Uncertainty

4.2.2 Combined uncertainty

In third step we have combined the uncertainty values from Type A and Type B by doing the square root of squares of the numbers

4.2.3 Expanded uncertainty

In the final step the combined uncertainty is multiplied by 2 as we are considering the confidence level of 95%The uncertainty values are as follows

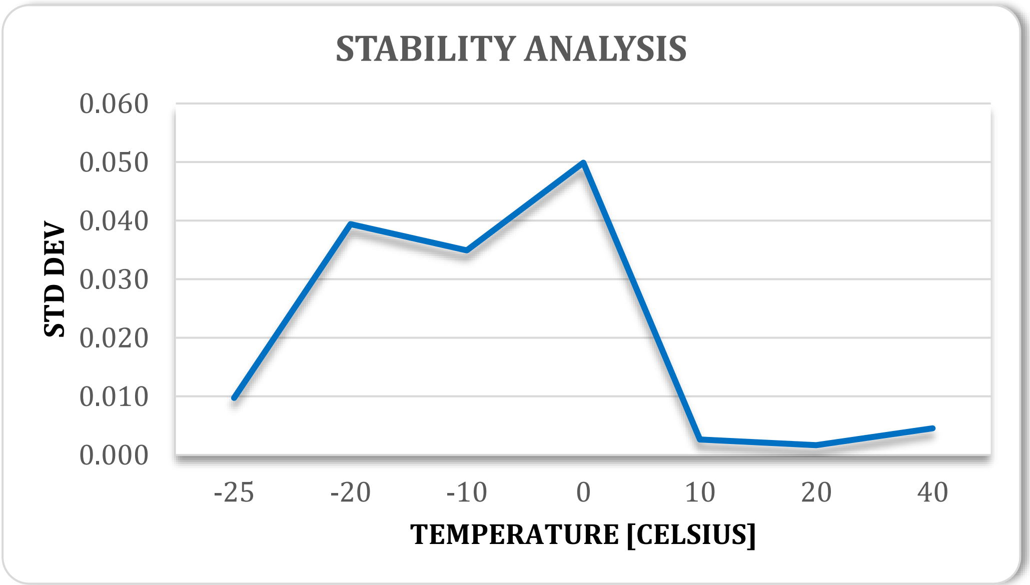
Combined uncertainty	0.08
Expanded uncertainty (C. L=95%)	0.16

4.3 TAT Characterisation

The characterization of MIDAS test reader is done using the EDDIE-1, DIVAC 1.4HV3, Fluke 1586A Super DAQ, two PRT100 thermometers in the the range of -25 ºC to 40 ºC.

4.3.1 Procedure

Connect all the required wiring cables to the EDIE-1 by using wiring hub in order to keep it airtight to maintain vacuum inside the chamber and place the PRT probe in the EDIE-1 chamber in close proximity to one another (20 cm distance) and the thermostat is also connected to regulate the temperature and a pump to create vacuum inside the chamber. the leads are connected to the Fluke 1586A Super DAQ with 4-wire connection. The vacuum pump is turned on and readings are taken in the range of -25 ºC to 40 ºC to know the stability inside the chamber. The PRT probe readings and values of the temperature in the thermostat and the corresponding resistance readings of TAT are taken from Fluke 1586A Super DAQ



GRAPH 2 : STABILITY ANALYSIS OF TAT

The readings from Fluke 1586A Super DAQ are compared with respect to values of PRT 100 thermometers. All the readings are attached in ANNEX B.

4.3.2 CALIBRATION CURVE

We have taken the **Callendar–Van Dusen equation** as it explains the relationship between resistance (R) and temperature (T) of platinum resistance thermometers (RTD).

$$R(T)=R(0)\ [1+A*T+B*T^2+(T-100)C*T^3]$$

$$R(T)=R(0)\ [1+A*T+B*T^2]$$

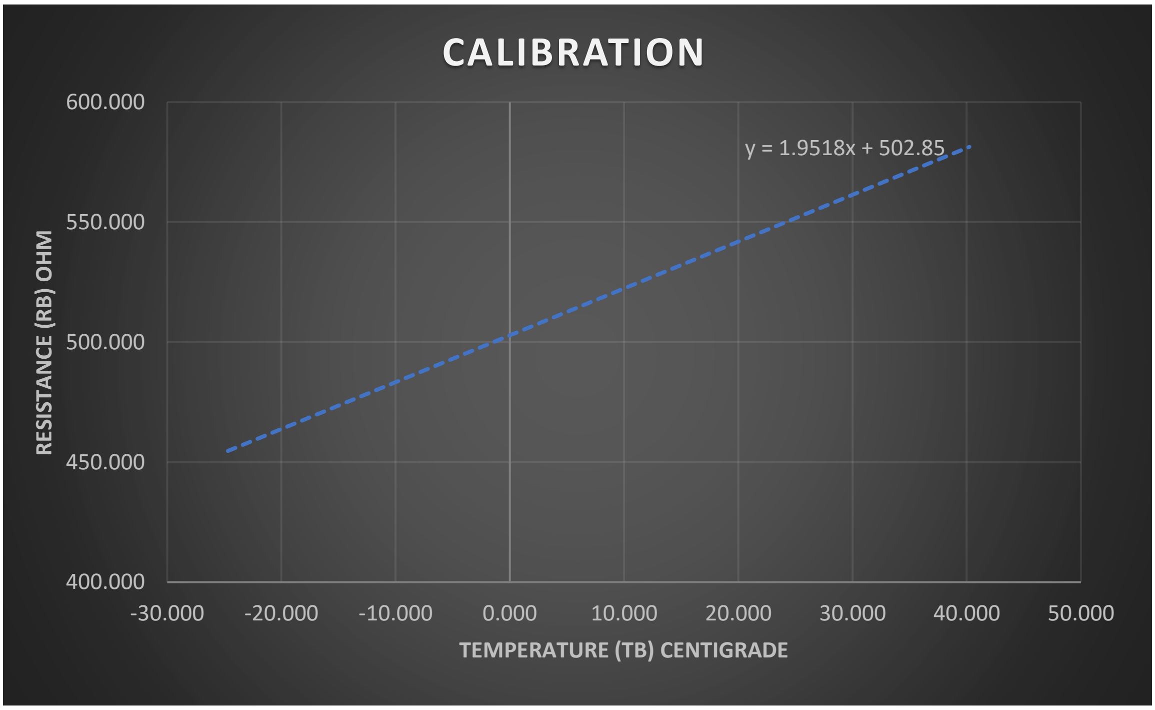
The above

equation is generally valid only over the range between 0 °C to 661 °C

We have taken the thermometer b readings because it is near to the sensor. As per the

Ra (ohm)	Rb (ohm)	Mean Ta (°C)	Mean Tb (°C)	Mean Difference (°C)	STD DEV A	STD DEV B	STD DEV Difference
453.317	454.441	-25.075	-24.682	-0.393	0.017	0.010	0.008
461.856	462.984	-20.608	-20.400	-0.208	0.058	0.039	0.018
482.949	484.078	-9.936	-9.730	-0.206	0.038	0.035	0.003
500.875	502.007	-0.607	-0.440	-0.168	0.057	0.050	0.007
522.134	523.274	10.348	10.398	-0.050	0.002	0.003	0.000
541.239	542.380	20.203	20.204	-0.001	0.001	0.002	-0.001
580.042	581.177	40.223	40.233	-0.010	0.004	0.005	-0.001

TABLE 4: TAT Calibration reading



GRAPH 3: TAT CALIBRATION CURVE

We took the resistance readings with respect to the temperature from the fluke model 1586A Super DAQ, mean temperature of thermometer and standard deviation was calculated. A graph is plotted between the resistance and temperature which we say it "Calibration Curve"

If go for quadratic fit or CVD you can get the resistance value using the temperature value easily but if we go vice versa we will get roots for the temperature which does not give accurate results

Equation is as follows:

Resistance (ohm) =1.9526*(Temperature Reading (°C)) +502.81

4.3.3 Uncertainty

We are considering of thermometer b as it is close to sensor

We have calculated uncertainty by following the guidelines in **JCGM 100:2008** GUM 1995

Standard uncertainty

Type A

In the first step we have calculated the mean for each temperature by taking at minimum 40 to 100 readings respectively and pool standard deviation

For the standard uncertainty we have taken the ratio standard deviation of mean to square root of the number of replicates

TABLE 5: TYPE A Uncertainty

Reading (°C)	**Mean Ta** (°C)	**Mean Tb** (°C)	**STD DEV A**	**STD DEV B**
-25	-25.075	-24.682	0.017	0.010
-20	-20.608	-20.400	0.058	0.039
-10	-9.765	-9.571	0.121	0.107
0	-0.607	-0.440	0.057	0.050
10	10.348	10.398	0.002	0.003
20	20.203	20.204	0.001	0.002
40	40.223	40.233	0.004	0.005
		With sensor	**0.016**	**0.014**

By following the similar procedure of MIDAS test reader uncertainty, the results are

Combined uncertainty	0.0214(approx. 0.02)
Expanded uncertainty (C. L=95%)	0.0428(approx. 0.043)

4.4 Pitot Tube Characterization

The characterization of Pitot tube in MIDAS test reader is done using the EDDIE, Model 745-Paroscientific Inc Pressure Instrumentation, T-Cube DC Servo Motor Controller, CRP101 High Accuracy Digital Pressure Gauge and connectors in the range of speed 0 m/s to 30 m/s and temperature -20 ºC to 20 ºC.

4.4.1 Procedure

Pitot tube is placed in the EDDIE, the static pressure port is connected to CRP101 High Accuracy Digital Pressure Gauge and both static pressure and total pressure ports are connected to MIDAS test reader respectively with the help of connectors and tubes. To read the pressure inside the EDDIE Model 745-Paroscientific Inc Pressure Instrumentation is used and acts as reference pressure reading.

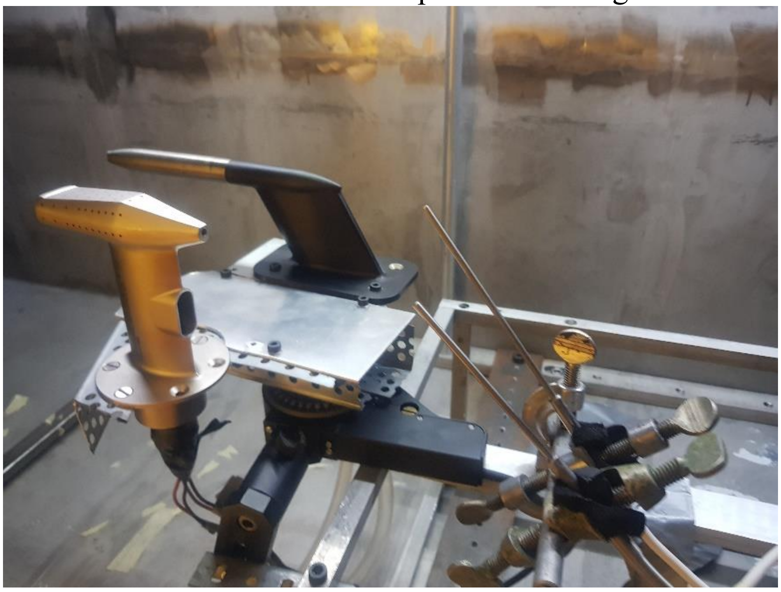


FIGURE 4.0: MIDAS Probe in Wind Tunnel Courtesy of SELT and Politecnico di Torino

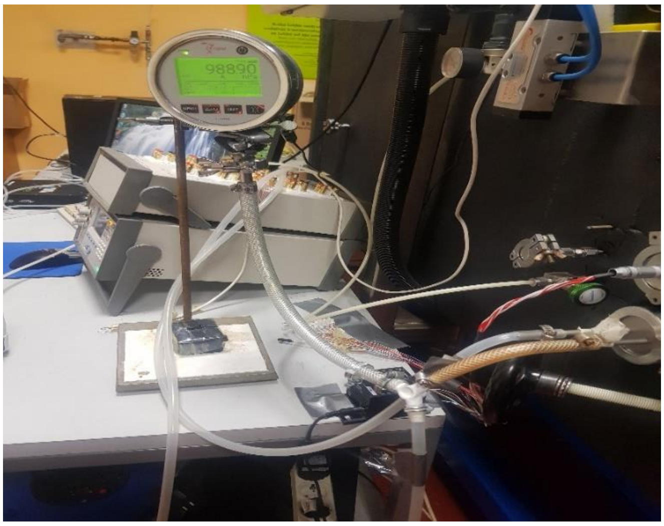


FIGURE 4.1: PRESSURE PORTS connected to external devices

The test was done at different pressures and temperatures as shown in the table 6

Static pressure [Pa]	**Temperature [°C]**
108000	11.5
101325	15
74682	-1.25
50505	-20.75
98878	8.02

TABLE 6: Test plan of PITOT tube

The readings are taken in controlled atmosphere at speeds in the range of 5 m/s to 30 m/s.The pressure readings from pitot tube are compared with respect to reference pressure reader and attached in ANNEX C.

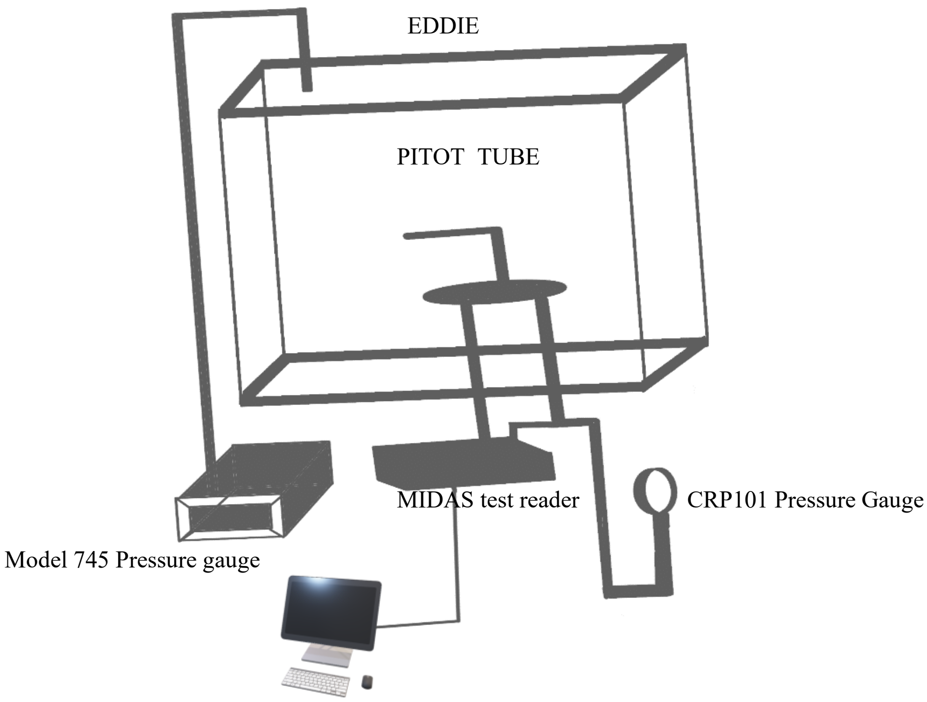
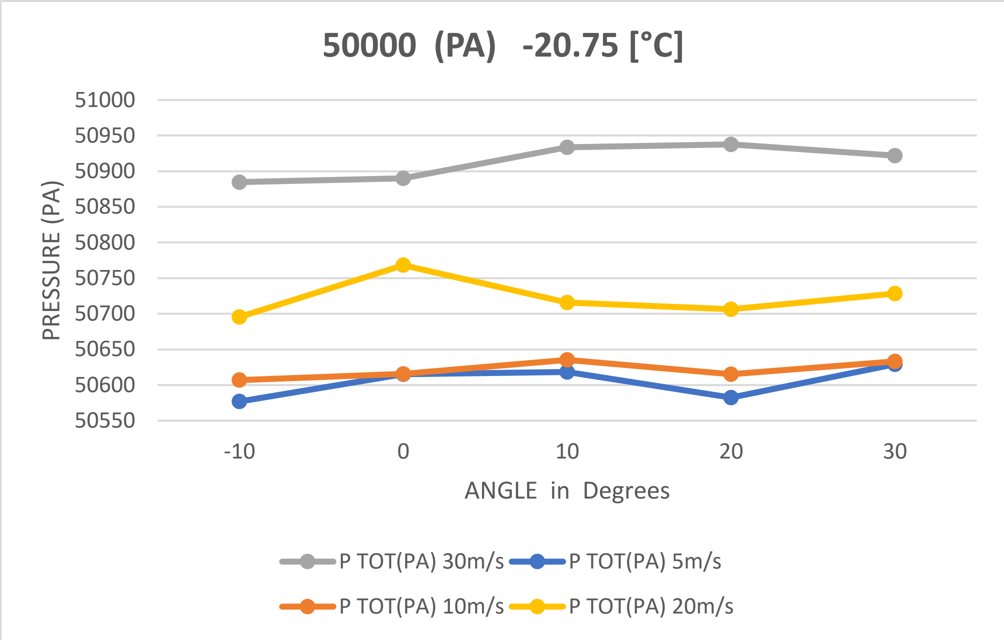
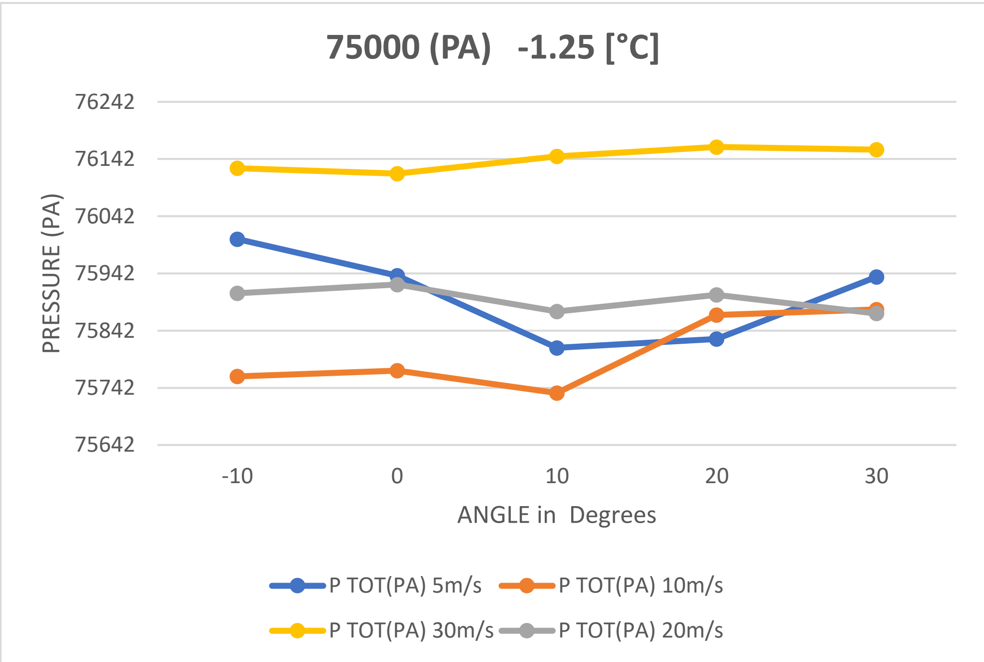


FIGURE 4.2: Pitot tube Characterization Schematic diagram

The pitot tube is characterized with respect to pressure, angles and change in speeds. The results are depicted in graphs. At lower temperature and pressure, the change takes place in positive angles.

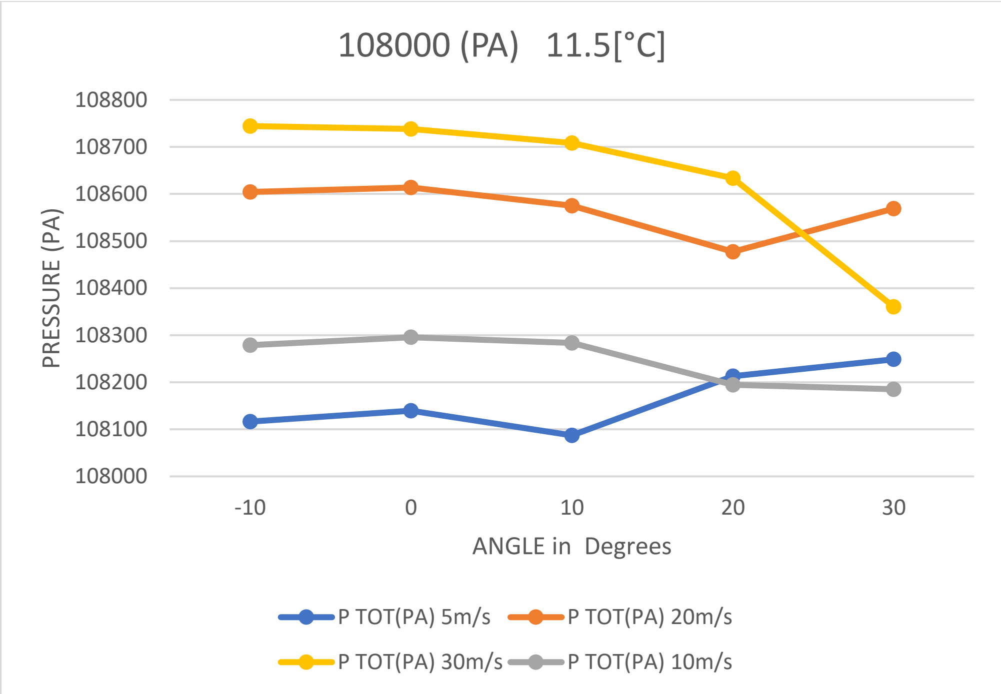


Graph 4: Characteristic of Pitot Tube at 50000 PA



Graph 5: Characteristic of Pitot Tube at 75000 PA

At higher pressure and positive temperature, the pressure is decreasing gradually at higher speeds and angles from 10^0



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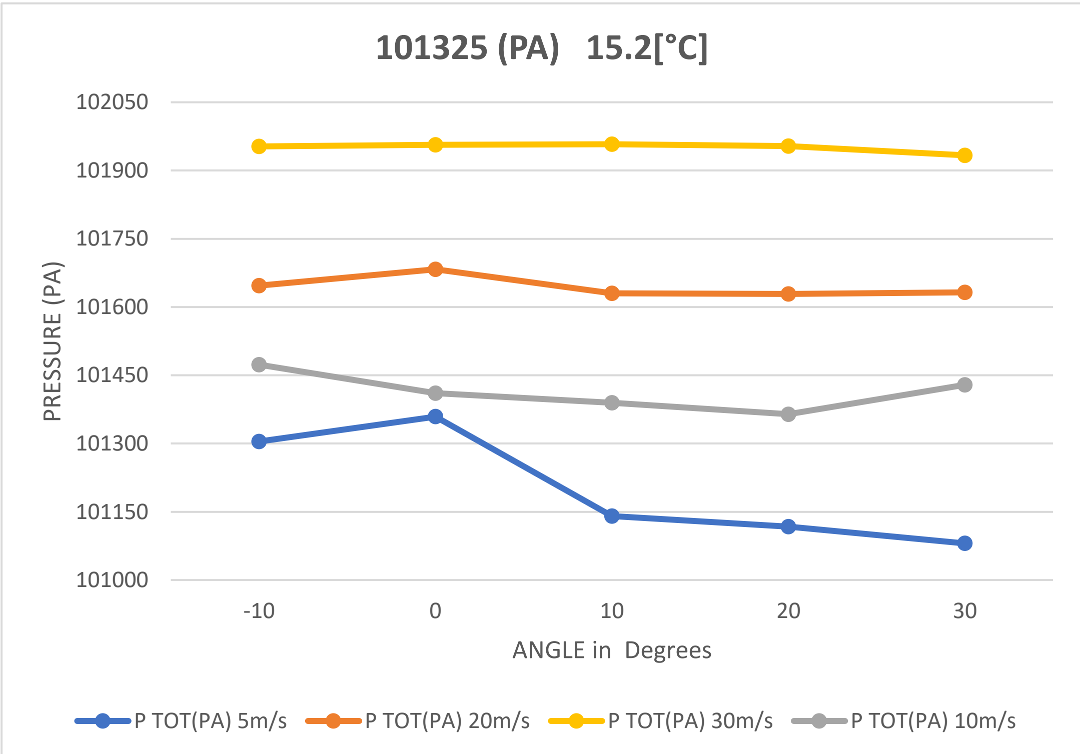
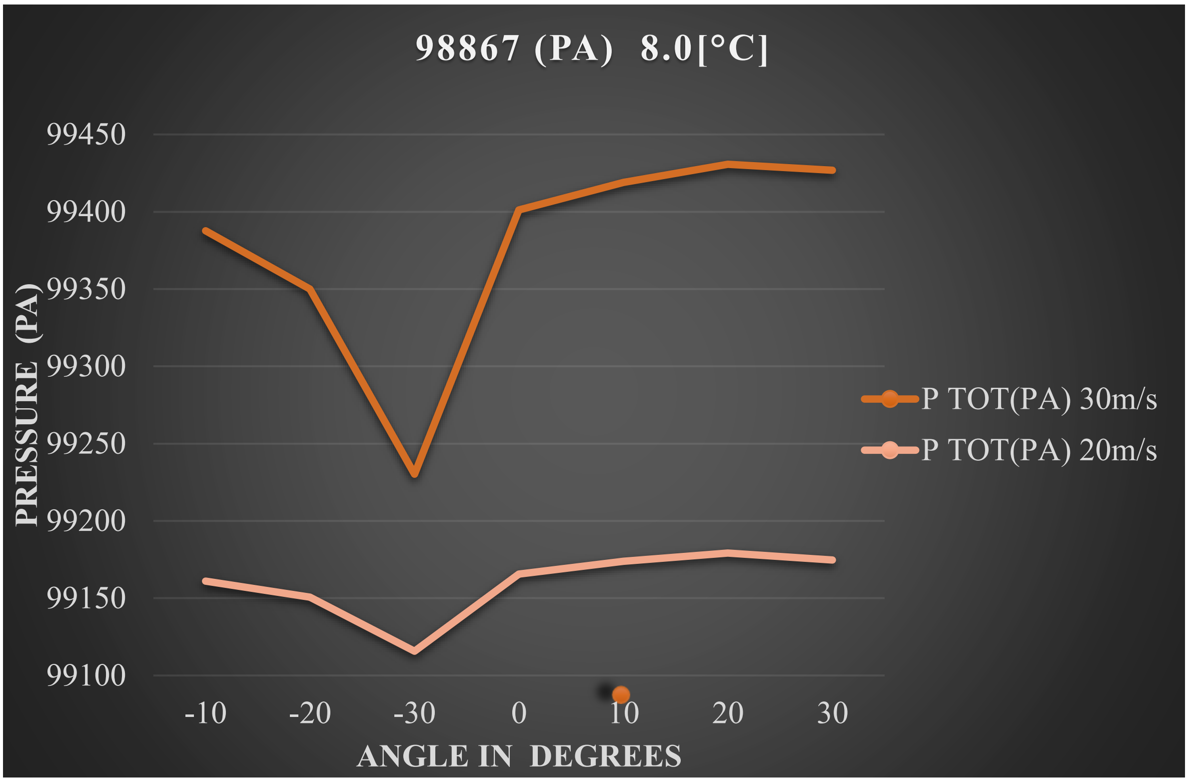
Graph 6: Characteristic of Pitot Tube at 108000 PA

We consider standard atmospheric pressure and temperature; the pressure change is very low from 10^0.



Graph 7: Characteristic of Pitot Tube at 101325 PA

At pressure 98867 PA which is atmosphere pressure on the day of test, the change takes place at -30^0 and at rest of the angles there is a steady change.



Graph 8: Characteristic of Pitot Tube at 98867 PA

5 Conclusion

In this thesis work, the characteristic of MIDAS test reader, MIDAS probe (consists of Pitot tube and TAT) is made for short range flights, local communities' connections, door to door within 4 hours.

During the characterization of TAT, Pitot tube and MIDAS test reader process we faced a lot of challenges. In the experiment process of TAT soldering the 18 wires to smallest pins of connector is one of it. The characterization equation of TAT is verified using EDDIE-1 and MIDAS test reader.

In the experiment process of MIDAS test reader, initially the pressure difference readings of the pitot tube initially were wrong, we have repeated the experiment with different methods in EDDIE-1. We dismantle the MIDAS test reader and tighten the ports using zip tags.

We shifted the test reader to EDDIE (barometric chamber), repeated the experiment three times in both increasing and decreasing pressure order. With respect to observed readings, MIDAS test reader was showing the pressure difference if the pressure flow is same and other factors are working great.

In the experiment process of PITOT tube, rotating at different angles is difficult in EDDIE-1 (WIND TUNNEL). To Connect the servo motor controller to power source we tried using a large variety of cables which were available in market, but it did not yield any result, so we broke the connectors and soldered the pins which was successful. The testing was done in both controlled and uncontrolled atmosphere more than thrice for the accuracy. We can observe from the graphs at low temperature and at extreme angles the pressure change is less and vice versa.

Considering the future of MIDAS probe and MIDAS test reader the readings were taken more than thrice and verified, as they are crucial for safety of aircraft and the characterizations are done by considering all the factors that affect them in real environment.

Engineers design modern machines, they employ various sensors to measure important process variables, such as flow, level, pressure, and temperature. These measurements are used to help the process controlling system and adjust other factors in order to maintain the proper values of these quantities and ensure safe operation.

Metrology is the future in characterizing the sensors which can ensure the safety and quality of any machine in modern era.

6 ANNEXS

- Click here ANNEX OF MIDAS PROBE
- Scan here

FIGURE 6.0: QR CODE OF ANNEX

7 References

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