

LABORATORY WORK №1

MAIN CHARACTERISTICS AND WORK PRINCIPLES OF THE PITOT TUBE

AIMS OF THE LABORATORY WORK:

- to be familiar with the theoretical material about pitot tube;
- to execute the procedure according to the following plan;
- to answer the questions after the work.

1 SHORT THEORETICAL MATERIAL

1.1

Definitions

Pitot tube— is a pressure measurement instrument used to measure fluid flow velocity.

Dynamic pressure —is the difference between the stagnation pressure and the static pressure.

Pitot pressure— is a measure of ram air pressure (the air pressure created by vehicle motion or the air ramming into the tube), which, under ideal conditions, is equal to stagnation pressure, also called total pressure.

1.2 Pitot Tube

Pitot tube was invented by the French engineer Henri Pitot in the early 18th century and was modified to its modern form in the mid-19th century by French scientist Henry Darcy. It is widely used to determine the airspeed of an aircraft, water speed of a boat, and to measure liquid, air and gas velocities in industrial applications. The pitot tube is used to measure the local velocity at a given point in the flow stream and not the average velocity in the pipe or conduit.

The basic pitot tube consists of a tube pointing directly into the fluid flow.



Picture 1.1 Pitot tube

As this tube contains fluid, a pressure can be measured; the moving fluid is brought to rest (stagnates) as there is no outlet to allow flow to continue. This pressure is the stagnation pressure of the fluid, also known as the total pressure or (particularly in aviation) the pitot pressure.

The measured stagnation pressure cannot itself be used to determine the fluid velocity (airspeed in aviation). However, *Bernoulli's equation states:*

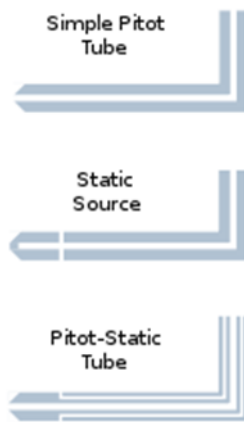
$$\textit{Stagnation pressure} = \textit{static pressure} + \textit{dynamic pressure}$$

Dynamic pressure is the difference between the stagnation pressure and the static pressure. The static pressure is generally measured using the static ports on the side of the fuselage. The dynamic pressure is then determined using a diaphragm inside an enclosed container. If the air on one side of the diaphragm is at the static pressure, and the other at the stagnation pressure, then the deflection of the diaphragm is proportional to the dynamic pressure, which can then be used to determine the indicated airspeed of the aircraft.

In industry, the velocities being measured are often those flowing in ducts and tubing where measurements by an anemometer would be difficult to obtain. In these kinds of measurements, the most practical instrument to use is the pitot tube. The pitot tube can be inserted through a small hole in the duct with the pitot connected to a U-tube water gauge or some other differential pressure gauge for

determining the velocity inside the ducted wind tunnel. One use of this technique is to determine the volume of air that is being delivered to a conditioned space.

Pitot-static pressure



Examples of pitot tube, static tube, and pitot-static tube.

The pitot-static system of instruments uses the principle of air pressure gradient. It works by measuring pressures or pressure differences and using these values to assess the speed and altitude. These pressures can be measured either from the static port (static pressure) or the pitot tube (pitot pressure). The static pressure is used in all measurements, while the pitot pressure is only used to determine airspeed.

Pitot pressure is obtained from the pitot tube. The pitot pressure is a measure of ram air pressure (the air pressure created by vehicle motion or the air ramming into the tube), which, under ideal conditions, is equal to stagnation pressure, also called total pressure. The pitot tube is most often located on the wing or front section of an aircraft, facing forward, where its opening is exposed to the relative wind. By situating the pitot tube in such a location, the ram air pressure is more accurately measured since it will be less distorted by the aircraft's structure. When airspeed increases, the ram air pressure is increased, which can be translated by the airspeed indicator.

Static pressure - is obtained through a static port. The static port is most often a flush-mounted hole on the fuselage of an aircraft, and is located where it can access the air flow in a relatively undisturbed area. Some aircraft may have a single static port, while others may have more than one. In situations where an aircraft has more than one static port, there is usually one located on each side of the fuselage. With this positioning, an average pressure can be taken, which allows for more accurate readings in specific flight situations. An alternative static port may be located inside the cabin of the aircraft as a backup for when the external static port(s) are blocked.

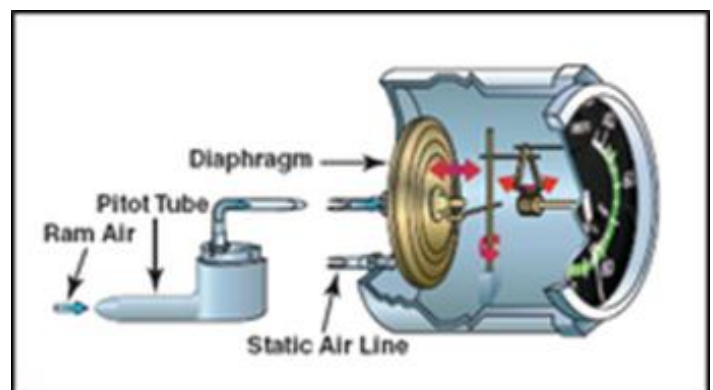
A pitot-static tube effectively integrates the static ports into the pitot probe. It incorporates a second coaxial tube (or tubes) with pressure sampling holes on the sides of the probe, outside the direct airflow, to measure the static pressure. When aircraft climbs, static pressure will decrease.

Some pitot-static systems incorporate single probes that contain **multiple pressure-transmitting ports** that allow for the sensing of air pressure, angle of attack, and angle of sideslip data. Depending on the design, such air data probes may be referred to as 5-hole or 7-hole air data probes. Differential pressure sensing techniques can be used to produce angle of attack and angle of sideslip indications.

Pitot-static instruments

Picture 1.2

Airspeed indicator diagram showing pressure sources from both the pitot tube and static port

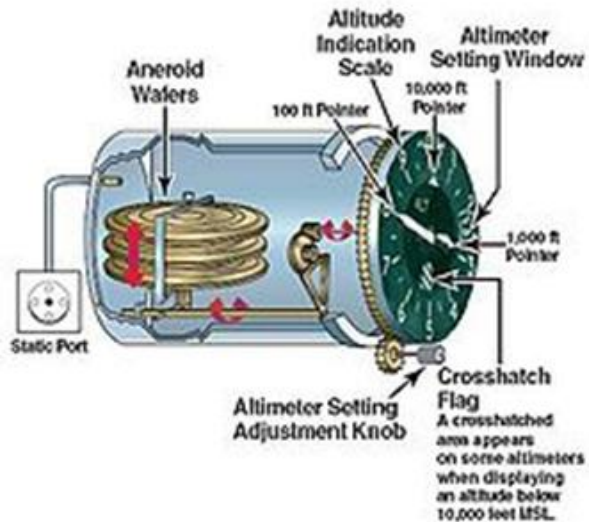


The pitot-static system obtains pressures for interpretation by the pitot-static instruments. While the explanations below explain traditional, mechanical instruments, many modern aircraft use an air data computer (ADC) to calculate airspeed, rate of climb, altitude and Mach number. In some aircraft, two ADCs receive total and static pressure from independent pitot tubes and static ports, and the aircraft's flight data computer compares the information from both computers and checks one against the other. There are also "standby instruments", which are back-up pneumatic instruments employed in the case of problems with the primary instruments.

1.3 Airspeed indicator

The airspeed indicator is connected to both the pitot and static pressure sources. The difference between the pitot pressure and the static pressure is called dynamic pressure. The greater the dynamic pressure, the higher the airspeed reported. A traditional mechanical airspeed indicator contains a pressure diaphragm that is

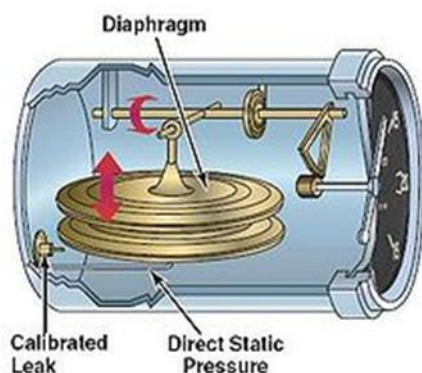
connected to the pitot tube. The case around the diaphragm is airtight and is vented to the static port. The higher the speed, the higher the ram pressure, the more pressure exerted on the diaphragm, and the larger the needle movement through the mechanical linkage.



*Picture 1.3
Diagram of an altimeter*

1.4 Machmeter

Aircraft designed to operate at transonic or supersonic speeds will incorporate a machmeter. The machmeter is used to show the ratio of true airspeed in relation to the speed of sound. Most supersonic aircraft are limited as to the maximum Mach number they can fly, which is known as the "Mach limit". The Mach number is displayed on a machmeter as a decimal fraction.



*Picture 1.4
A vertical airspeed indicator*

1.5 Pitot-static errors

There are several situations that can affect the accuracy of the pitot-static instruments. *Some of these involve failures of the pitot-static system itself—which may be classified as “system malfunctions”—while others are the result of faulty instrument placement or other environmental factors—which may be classified as “inherent errors”.*

1.5.1 System malfunctions

- **Blocked pitot tube**

Blocked pitot tube is a pitot-static problem that will only affect airspeed indicators. A blocked pitot tube will cause the airspeed indicator to register an increase in airspeed when the aircraft climbs, even though actual airspeed is constant.

This is caused by the pressure in the pitot system remaining constant when the atmospheric pressure (and static pressure) are decreasing. In reverse, the airspeed indicator will show a decrease in airspeed when the aircraft descends. The pitot tube is susceptible to becoming clogged by ice, water, insects or some other obstruction. For this reason, aviation regulatory agencies such as the U.S. Federal Aviation Administration (FAA) recommend that the pitot tube be checked for obstructions prior to any flight. To prevent icing, many pitot tubes are equipped with a heating element. A heated pitot tube is required in all aircraft certificated for instrument flight except aircraft certificated as Experimental Amateur-Built.

- **Blocked static port**

Blocked static port is a more serious situation because it affects all pitot-static instruments. One of the most common causes of a blocked static port is airframe icing. A blocked static port will cause the altimeter to freeze at a constant value, the altitude at which the static port became blocked. The vertical speed indicator will become frozen at zero and will not change at all, even if vertical airspeed increases or decreases. The airspeed indicator will reverse the error that occurs with a clogged pitot tube and cause the airspeed be read less than it actually is as the aircraft climbs. When the aircraft is descending, the airspeed will be over-

reported. In most aircraft with unpressurized cabins, an alternative static source is available and can be toggled from within the cockpit of the airplane.

1.5.2 Inherent errors

Inherent errors may fall into several categories, each affecting different instruments. Density errors affect instruments metering airspeed and altitude. This type of error is caused by variations of pressure and temperature in the atmosphere. A compressibility error can arise because the impact pressure will cause the air to compress in the pitot tube. At standard sea level pressure altitude the calibration equation (see calibrated airspeed) correctly accounts for the compression so there is no compressibility error at sea level. At higher altitudes the compression is not correctly accounted for and will cause the instrument to read greater than equivalent airspeed. A correction may be obtained from a chart. *Compressibility error* becomes significant at altitudes above 10,000 feet (3,000 m) and at airspeeds greater than 200 knots (370 km/h). Hysteresis is an error that is caused by mechanical properties of the aneroid capsules located within the instruments. These capsules, used to determine pressure differences, have physical properties that resist change by retaining a given shape, even though the external forces may have changed. Reversal errors are caused by a false static pressure reading. This false reading may be caused by abnormally large changes in an aircraft's pitch. A large change in pitch will cause a momentary showing of movement in the opposite direction. Reversal errors primarily affect altimeters and vertical speed indicators.

1.5.3 Position error

Another class of inherent errors is that of *position error*. A position error is produced by the aircraft's static pressure being different from the air pressure remote from the aircraft. This error is caused by the air flowing past the static port at a speed different from the aircraft's true airspeed. Position errors may provide positive or negative errors, depending on one of several factors. These factors include airspeed, angle of attack, aircraft weight, acceleration, aircraft configuration, and in the case of helicopters, rotor downwash.

There are two categories of position errors, which are "*fixed errors*" and "*variable errors*". Fixed errors are defined as errors which are specific to a particular model of aircraft. Variable errors are caused by external factors such as deformed panels obstructing the flow of air, or particular situations which may overstress the aircraft.

1.6 Pitot-static system

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***. This equipment is used to measure the forces acting on a vehicle as a function of the temperature, density, pressure and viscosity of the fluid in which it is operating. Other instruments that might be connected are air data computers, flight data recorders, altitude encoders, cabin pressurization controllers, and various airspeed switches.

Errors in pitot-static system readings can be extremely dangerous as the information obtained from the pitot static system, such as altitude, is often critical to a successful flight. Several commercial airline disasters have been traced to a failure of the pitot-static system.

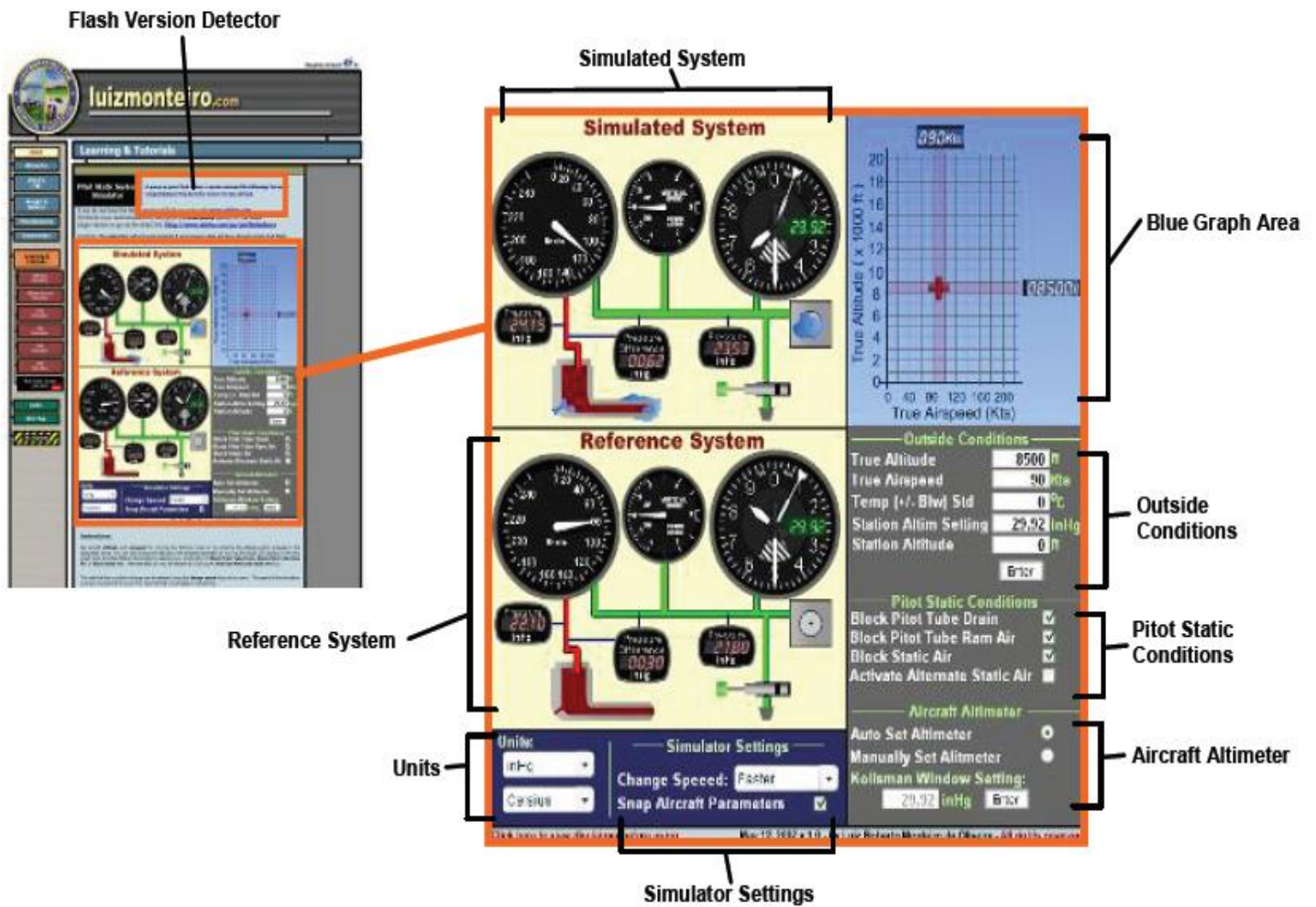
- **To determine the main characteristics of the Pitot-static system, we used Pitot-Static System Simulator which we can browse on the web page www.luizmonteiro.com**

DESCRIPTION OF THE PITOT STATIC SIMULATOR SYSTEM

Luizmonteiro Pitot Static Simulator System was designed to help you understand how to use the simulator. Note that the results are only approximations and should never be used in real flight. Before you begin using the simulator, please make sure that your browser has the Adobe Flash version 8 or higher. **If you do not have this you may go to the Adobe website at:**

<http://www.adobe.com>

Pitot Static System Simulator Application Parts



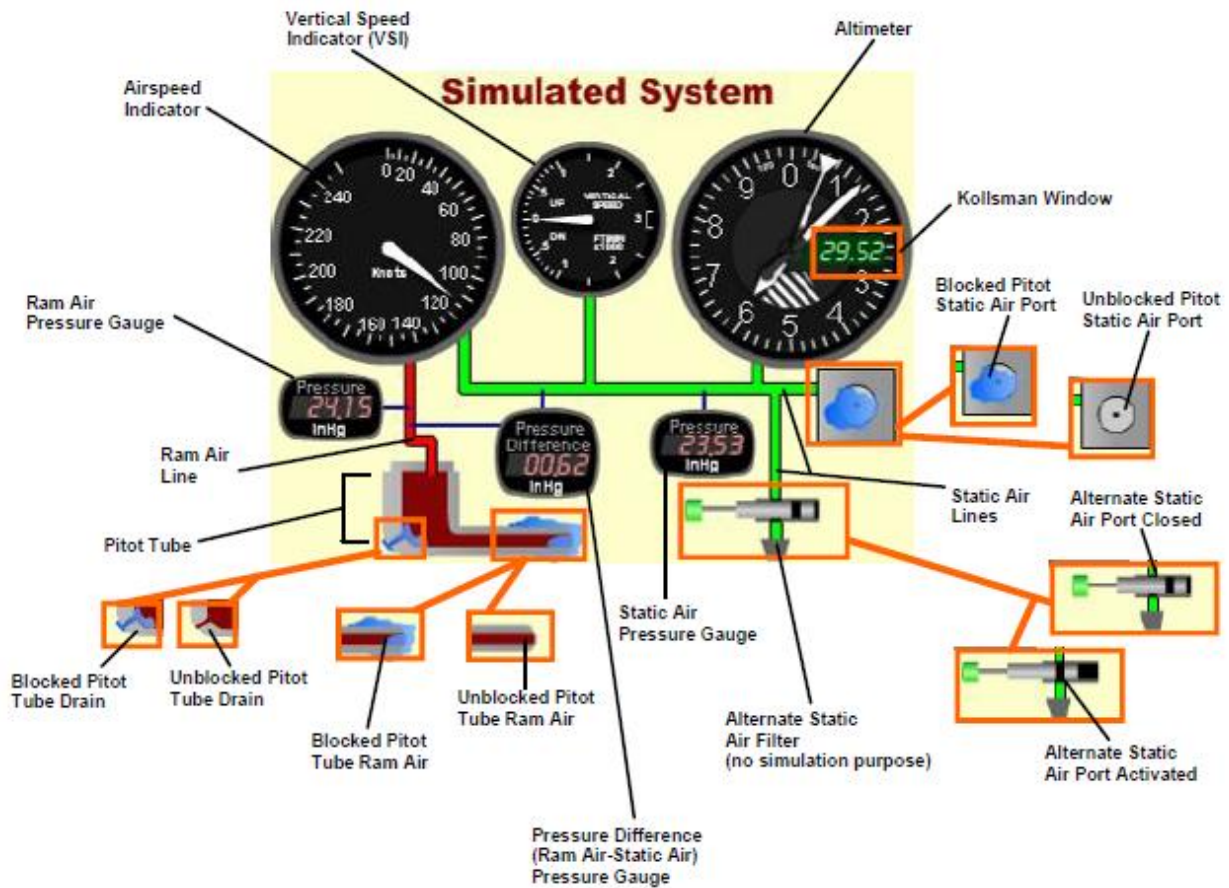
• [1]— picture depicted from Simulated Luizmonteiro Pitot Static System

✓ For further laboratory work performance you have to familiarise yourself with main applications parts of the Pitot Static Simulator System.

Main components of the Luizmonteiro Simulator System

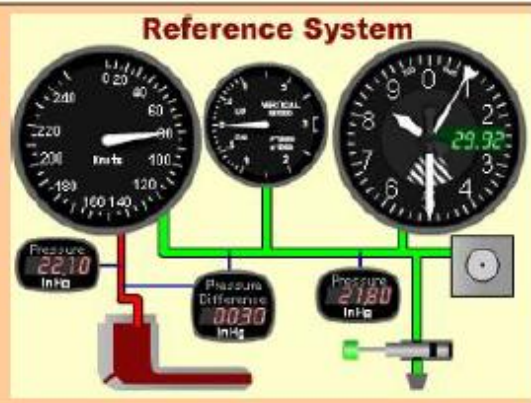
Picture № 1.6

Pitot Static System Simulator Application Parts (cont.)



Note that the Reference System has the same parts as the Simulated System except that you cannot block the Ram Air, Drain Hole or Static Air Port. Also the Kollsman Window is always set to the Station Altimeter Setting even if the Aircraft Altimeter Setting (Kollsman Window in the Simulated System) is manually set to a different setting. In addition to the Alternate Static Air Port does not engage in the Reference System.

The reason for this is that the Reference System is used to compare the readings with the Simulated System when these variables are introduced.



Pitot Static System Simulator Application Parts (cont.)

Simulated System

This is the Pitot Static System that applies blockages and the manually set altimeter setting.



Reference System

This is the Pitot Static System that can be used as a reference to compare results from the Simulated System. The Reference System always has the correct Altimeter Setting and is not affected by blockages selected by the user.



Outside Conditions

True Altitude

The actual altitude that the aircraft, and therefore the Pitot Static System is placed.

True Airspeed

The actual airspeed that the aircraft, and therefore the Pitot Static System is moving in the air.

Temp (+/- Blw) Std

The variation in temperature above or below the temperature in standard atmosphere.

Station Altim Setting

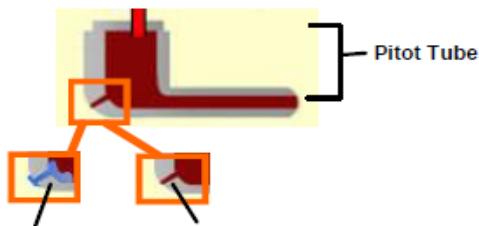
The Altimeter Setting for a particular airport or station. This is the same Altimeter Setting that would be obtained on the ATIS (Airport Terminal Information Service). Note that unless **Auto Set Altimeter** is selected, the Kollsman window (i.e. the altimeter in the aircraft) will not be adjusted automatically in the **Simulated System**, simulating either the pilot forgetting to set the altimeter or the altimeter setting not being available. The Kollsman window in the **Reference System** will be set to the station altimeter setting regardless if **Auto Set Altimeter** is selected or not.

Station Altitude - The altitude of the airport or station where the Altimeter Setting was obtained.

Pitot Static Conditions

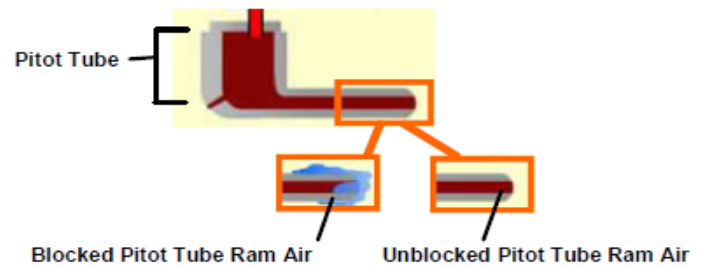
Block Pitot Tube Drain

Simulates the blockage of the Pitot Tube Drain.



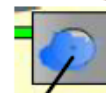
Block Pitot Tube Ram Air

Simulates the blockage of the Pitot Tube Ram Air.

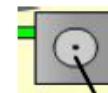


Block Static Air

Simulates the blockage of the Static Air Port.



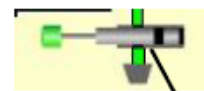
Blocked Pitot Static Air Port



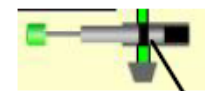
Unblocked Pitot Static Air Port

Activate Alternate Static Air

Simulates the activation of the Alternate Static Air Port. Typically as the aircraft increases in speed the static pressure using the Alternate Static Ports is typically slightly less than that of the actual Static Port outside the aircraft for non-pressurized aircraft.



Alternate Static Air Port Closed



Alternate Static Air Port Activated

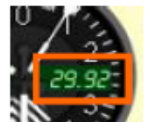
Aircraft Altimeter

Auto Set Altimeter/Manually Set Altimeter

Determines whether the Kollsman Window Setting is automatically adjusted if a different station altimeter setting is entered.

Kollsman Window Setting

This setting is made by the pilot on the aircraft's altimeter.



Units

This section allows the user to change pressure units from inHg (inches of mercury) to hPa (Hecto Pascal) or temperature from Celsius to Fahrenheit.

Change Speed

The rate that the conditions change can be selected using the change speed drop down menu.

Snapped Aircraft Parameters

If the Snapped Aircraft Parameters check box is selected, then altitude will be rounded to the nearest 500 feet and airspeed will be rounded to the next 5 knots. If this is not selected then altitude will be rounded to the nearest 100 feet and airspeed will be rounded to the nearest 1 knot. This happens regardless if the altitude and airspeed were entered manually or by dragging them using the cross in the blue graph.

2.1 Explore Pitot Static Simulator Tutorial with experimental standart data without errors(ideal state) in the Simulated Reference Window of the Luizmonteiro Program.

2.2 Investigate Pitot Static Simulator Tutorial with experimental standart data with errors in the Simulated Reference Window of the Luizmonteiro Program and compare indicated data from Simulated Window with the Refernce Window of the programe.

TASKS FOR THE LABORATORY WORK

2.1 System simulating with ideal state of device's work

1. Open the file with Swiff Player and download *Pitot Static Simulator Tutorial*. Define the main work characteristics of the Simulator System.
2. Set aircraft altitude and airspeed by moving the blinking cross or by entering the altitude and/airspeed in designated boxes. You can also change value of the data separately by moving the digital LCD displays in blue graph area. (*Picture№ 2. 1*)
3. Chose the propose data at the table below according your variant and fulfill the designated boxes into the *Pitot Static Simulator Tutorial*. Put the initial data to the graph Outside Conditions of Tutorial Simulator

(Look for example at the Picture№ 2. 2).

Table№ 2.1.1

VARIANT №1

VARIANT№2

True Altitude	3500ft	True Altitude	6200ft
True Airspeed	95Kts	True Airspeed	100Kts
Temp(+/-)	5,0 C°	Temp(+/-)	0 C°
Station Alt. Settings	28,92 InHg	Station Alt. Settings	30,1 InHg
Station Altitude	1500ft	Station Altitude	2000ft

Example of the data changing and establishment in the Tutorial Simulator

Picture № 2. 1.1

The screenshot displays the simulator's main interface. On the left, there are two sets of gauges: 'Simulated System' and 'Reference System'. The 'Simulated System' gauges show values like 2810, 100, and 29.92. The 'Reference System' gauges show 240, 100, and 29.92. In the center, there is a graph with 'True Altitude (x 1000 ft)' on the y-axis (0 to 20) and 'True Airspeed (Kts)' on the x-axis (0 to 200). A red crosshair is positioned at approximately 5 on the y-axis and 100 on the x-axis. To the right of the graph is an 'Outside Conditions' panel with fields for True Altitude (5000 ft), True Airspeed (100 Kts), Temp (+/- Blw) Std (0.0 °C), Station Altim Setting (29.92 inHg), and Station Altitude (0 ft). Below this is a 'Pilot Static Conditions' section with checkboxes for Block Pitot Tube Drain, Block Pitot Tube Ram Air, Block Static Air, and Activate Alternate Static Air. At the bottom left, there are 'Units' (inHg, Celsius) and 'Simulator Settings' (Change Speed: Faster, Snap Aircraft Parameters checked). A 'True Airspeed Digital LCD Display' shows '085Kts' and an 'Altitude Digital LCD Display' shows '05000ft'. A 'Blinking Cross' is shown in a separate inset.

True Airspeed Digital LCD Display

Altitude Digital LCD Display

Blinking Cross

True Altitude and True Airspeed can be entered here as well. Values remain in blue color and are only effective once you click <Enter>. Once entered the values turn black

Outside Conditions

True Altitude 5000 ft

True Airspeed 100 Kts

Temp (+/- Blw) Std 0.0 °C

Station Altim Setting 29.92 inHg

Station Altitude 0 ft

Enter

Units: inHg Celsius

Simulator Settings

Change Speed: Faster

Snap Aircraft Parameters

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If the **Snap Aircraft Parameters** check box is selected, then altitude will be rounded to the nearest 500 feet and airspeed will be rounded to the next 5 knots. If this is not selected then altitude will be rounded to the nearest 100 feet and airspeed will be rounded to the nearest 1 knot. This happens regardless if the altitude and airspeed were entered manually or by dragging them using the cross in the blue graph.

The rate that the conditions change can be selected using the **Change Speed** drop down menu. The speed of the simulation is always one second for every four seconds that would elapse in actual time.

The diagram shows the graph from the simulator with a red crosshair at the center (5000 ft, 100 Kts). Dashed arrows point in various directions from the crosshair, each with a label describing the resulting flight profile:

- Level with decreasing or increasing speed (Drag Airspeed LCD left or right)
- Constant speed climb (Drag Blinking Cross in this direction)
- Climb with increasing speed (Drag Blinking Cross in this direction)
- Level with increasing speed (Drag Blinking Cross in this direction)
- Climb with decaying speed (Drag Blinking Cross in this direction)
- Level with decreasing speed (Drag Blinking Cross in this direction)
- Descent with decreasing speed (Drag Blinking Cross in this direction)
- Constant speed descent (Drag Blinking Cross in this direction)
- Constant speed climb or descent (Drag Altitude LCD in up or down)
- Descent with increasing speed (Drag Blinking Cross in this direction)

The graph axes are labeled 'True Altitude (x 1000 ft)' and 'True Airspeed (Kts)'. A digital display at the top shows '085Kts' and another at the right shows '05000ft'.

Setting data procedure

Picture№ 2.1.2

Simulated System

Reference System

Units:
 inHg
 Celsius

Simulator Settings
 Change Speed: Faster
 Snap Aircraft Parameters

Outside Conditions

True Altitude	3000 ft
True Airspeed	95 kts
Temp (+/- Blw) Std	-5.0 °C
Station Altimeter Setting	28.92 inHg
Station Altitude	1500 ft

Pitot Static Conditions

- Block Pitot Tube Drain
- Block Pitot Tube Ram Air
- Block Static Air
- Activate Alternate Static Air

Aircraft Altimeter

- Auto Set Altimeter
- Manually Set Altimeter
- Kollsman Window Setting: 28.92 inHg Enter

True Altitude (x 1000 ft)
 True Airspeed (Kts)

1) Enter 3000 ft here
 2) Enter 95 ft here
 3) Enter -5 °C ft here
 4) Enter 28.92 InHg here
 5) Enter 1500 ft here
 6) Click the <Enter> button

Note that if Auto Set Altimeter is selected the aircraft's altimeter Kollsman window will be set automatically with the Station's Altimeter Setting

Kollsman window will be set automatically with the Station's Altimeter Setting

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4. Investigate Simulated and Reference Systems and fulfill following table with the indicated measurements.

Table 2.1.2

VARIANT №1

VARIANT№2

Indicated data on :	Simulated Window	Reference Window	Simulated Window	Reference Window
Ram Air Pressure				
Pressure Difference				
Static Air Pressure Gauge				
Kollsman Window				
Vertical Speed Indicator (VSI)				
Airspeed Indicator				
Altimeter				

5. Compare obtained data from different indicators and make conclusions about work performance of the Luizmonteiro Simulator and indications which are obtained without errors.

2.2 System simulating with different errors types and difficult, hazardous weather conditions

2.2.1

Put on Pitot Static Conditions window
ERROR 1: Blocked Static Air Port

1. Set aircraft altitude and airspeed by moving the blinking cross or by entering the altitude and/airspeed in designated boxes. You can also change value of the data separately by moving the digital LCD displays in blue graph area.
2. Chose the propose data at the table below according your variant and fulfill the designated boxes into the *Pitot Static Simulator Tutorial*.

VARIANT №1**VARIANT№2**

True Altitude	4500ft	True Altitude	7200ft
True Airspeed	105Kts	True Airspeed	120Kts
Temp(+/-)	3,0 C°	Temp(+/-)	-9 C°
Station Alt. Settings	28,92 InHg	Station Alt. Settings	35,1 InHg
Station Altitude	1200ft	Station Altitude	1500ft

3. Investigate Simulated and Reference Systems and fulfill following table with the indicated measurements.

Table 2.2.2

VARIANT №1**VARIANT№2**

Indicated data on :	Simulated Window	Reference Window	Simulated Window	Reference Window
Ram Air Pressure				
Pressure Difference				
Static Air Pressure Gauge				
Kollsman Window				
Vertical Speed Indicator (VSI)				
Airspeed Indicator				
Altimeter				

4. **Put on Pitot Static Conditions window** :“Activation of the Alternate static Air “

Then compare obtained data from different indicators and make conclusions about work performance of the Luizmonteiro Simulator and indications which are obtained with error caused by blocked Static Air Port. Define main ways to solve it.

2.2.2

Put on Pitot Static Conditions window

ERRORS 2: Blocked Pitot Tube Drain**
Blocked Static Air Port

1. Chose the propose data at the table below according your variant and fulfill the designated boxes into the *Pitot Static Simulator Tutorial*.

Table№ 2.2.2.1

VARIANT №1

VARIANT№2

True Altitude	6500ft	True Altitude	8800ft
True Airspeed	155Kts	True Airspeed	160Kts
Temp(+/-)	-18,0 C°	Temp(+/-)	-29 C°
Station Alt. Settings	28,92 InHg	Station Alt. Settings	35,1 InHg
Station Altitude	1200ft	Station Altitude	1500ft

2. Investigate Simulated and Reference Systems and fulfill folowing table with the indicated measurements.

Indicated data on :	Simulated Window	Reference Window	Simulated Window	Reference Window
Ram Air Pressure				
Pressure Difference				
Static Air Pressure Gauge				
Kollsman Window				
Vertical Speed Indicator (VSI)				
Airspeed Indicator				
Altimeter				

3. Put on Pitot Static Conditions window :” Aircraft descends 200ft “

Then compare obtained data from different indicators and make conclusions about work performance of the Luizmonteiro Simulator and indications wich are obtained with errors caused by blocked Static Air Port. Define main ways to solve it.

3 Perform final report, which must include:

1. aims of laboratory work;
2. short theoretical information;
3. work procedures according your variants;
4. general conclusions.

Also you have to prepare picture to perform each step of execution experiments with input data at the Pitot Static Simulator Program.

- See for more information which helps you to work with Pitot Static Simulator Tutorial Program on web page www.luizmonteiro.com
- Or open text file *Pitot_Static_Simulator_Tutorial.pdf*

CONTROL QUESTIONS

1. Pitot tube is ...?
2. Why do we use the pitot tube?
3. What equation describes the work of pitot tube?
4. Dynamic pressure is ...?
5. Pitot-static system of instruments uses the principle of ... Why?
6. The **pitot pressure** is ...?
7. The **static pressure** is ...?
8. The **multiple pressure** is ...?
9. Airspeed indicator is ...?
10. Machmeter is ...?
11. Pitot-static errors are ...?
12. Name all errors, give them definitions and explain them.